Sixteenth Marcel Grossmann Meeting

Monday 05 July 2021 - Saturday 10 July 2021

Book of Abstracts

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New results from testing relativistic gravity with radio pulsars

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We experience a golden era in testing and exploring relativistic gravity. Whether it is results from gravitational wave detectors, satellite or lab experiments, radio astronomy plays an important complementary role. Here one can mention the cosmic microwave background, black hole imaging and, obviously, binary pulsars. This talk will concentrate on the latter and new results from studies of strongly self-gravitating bodies with unrivalled precision. I compare the results to other methods, discuss implications for other areas of relativistic astrophysics and will give an outlook of what we can expect from new instruments in the near future.

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Black Holes in the 21cm signal of HI from cosmic dawn

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A deep absorption in the 21-cm line of atomic hydrogen (HI), redshifted to the epoch of cosmic dawn (z ~ 20), was reported by the EDGES experiment. To explain that absorption trough it has been proposed that either an additional exotic cooling mechanism, or a brighter radio background emission previously unaccounted for is needed. Here we discuss the possibility that the required cosmic radio background could be produced by non-thermal emission from a prolific population of black holes formed at cosmic dawn. We conclude that unless black holes formed at that epoch are radically different from those observed in the local Universe, the radio emission is orders of magnitude below the required levels.

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SRG Orbital Observatory: X-Ray map of the Universe with a million accreting supermassive black holes

Author: Rashid Sunyaev[None]

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SRG with German (eRosita) and Russian (ART-XC) X-Ray telescopes was launched by RosKosmos on July 13th of 2019 from Baikonur. During the flight to the L2 point of the Sun-Earth system, SRG performed calibrations and long duration Performance Verification (PV) observations of a dozen of targets and deep fields. Starting in the middle of December 2019, the SRG scanned the whole sky three times. During these scans, SRG discovered two and a half million point X-Ray sources: mainly AGNs and QSOs, stars with hot and bright coronae, and 40 thousand clusters of galaxies. There is a competition and synergy with the search for clusters of galaxies by Atacama Cosmology and the South Pole Telescopes sensitive in the microwave spectral band. We see X-Rays from hundreds of stars accompanied by exoplanets. SRG provided the X-Ray map of the whole sky in hard and soft bands, the last is now the best among existing. It reveals a lot of information about the distribution of absorbing cold gas in the Milky Way and provides a beautiful image of the North Polar Spur and similar bright emitting eRosita Bubble on the Southern side from the Central Part of the Galaxy. I will describe the Observatory plans for the future and demonstrate several results from the PV phase observations. The huge samples of the X-ray selected quasars at the redshifts up to z=6.2 and clusters of galaxies will be used for well-known cosmological tests and detailed study of the growth of the large scale structure of the Universe during and after reionization. SRG/eRosita is discovering every day several extragalactic objects which increased or decreased their brightness more than 10 times during half of the year after the previous scan of the same strip on the sky. A significant part of these objects has observational properties similar to the Tidal Disruption Events. ART-XC discovered a lot of bright galactic and extragalactic transients.

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A 21-solar mass black hole in the X-ray binary system Cygnus X-1

Author: James Miller-Jones[1]

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The fate of massive stars is influenced by the mass lost to stellar winds over their lifetimes, which limit the masses of the stellar remnants that they eventually produce. In this talk I will discuss our recent redetermination of the black hole mass in the X-ray binary system Cygnus X-1. At 21 solar masses, our measurement makes this the most massive dynamically-confirmed stellar-mass black hole yet detected without the use of gravitational wave facilities. With the system having been formed in an environment with close to solar metallicity, this measurement challenges existing estimates of wind mass loss rates from massive stars. I will present the new astrometric measurements that resolved the discrepancy between radio and optical parallax values, and outline how this enabled us to refine the measured black hole mass. Finally, I will briefly discuss the implications of this result for massive star evolution.

Monday Plenary Session / 54

Singularity theorems in spinning black holes

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There are three regions in the Kerr spinning black hole metric, separated by the two event horizons. The outer two are probably good approximations to the corresponding regions as a real black hole

forms, but the inner Kerr is not. It has to have something to generate the gravitational field outside, and that can only be a singularity since it is by definition matter free. However, even after 58 years there is no proof that singularities form inside real collapsing bodies. I believe this is because they are singularity free!

Monday Plenary Session / 196

The Development of General Relativity

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The development of the Einstein Field Equations is traced and it is argued that Einstein probably had included the cosmological constant in his field equations but then dropped it at first and later re-inserted it when he needed it for a static cosmological solution of his field equations. His initial derivation would have been geometrical, rather than field theoretic. The significance of this fact for the interpretation of the cosmological constant and its role as "dark energy" is discussed.

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Ulugh Beg's Scientific School in Samarkand

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Ulugh Beg was the grandson of Tamerlane who conquered a vast area in Transoxania and Iran around 1400. Mohammad Taraghay, best known as Ulugh Beg (lit. "Grand prince") was born in 1394 in Sultaniya (Zanjan, Iran). In 1409, he became the ruler of Samarkand where he founded a school in 1420 which is still well preserved there. Astronomy was the major subject taught in the school and Ulugh Beg gathered a group of astronomers there. He also founded an observatory in 1424 which was designed by the Iranian scholar Jamshid Kashani (al-Kashi) who upon Ulugh Beg's request, supervised the construction and operation of the observations made there. After Ulugh Beg's tragic murder arranged by his son in 1449, the observatory was destroyed and forgotten. Its remnants were rediscovered in 1908 near Samarkand. The main part of the observatory was a huge stone sextant more than 40 meters long. It measured the meridian transit of celestial bodies from which the declination of the ecliptic, the equinoxes and the geographical latitude of the locality could be determined accurately. The results of the observations were composed in a Persian treatise called Zij Ulugh Beg. Zijis a Persian word used for a collection of astronomical tables with explanations for using them in astronomical calculations. Several commentaries are written on this work5and selections of it are translated into Arabic, English, French, Russian and Turkish. Ulugh Beg also devised a method for finding the sine of one degree for which he solved a cubic equation by an iterative method.

Tuesday Plenary Session

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The strong cosmic censorship in general relativity

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I will review recent progress on our understanding of the issue of strong cosmic censorship in general relativity, including very recent developments in the case of non-zero cosmological constant.

Tuesday Plenary Session / 159

The black hole entropies

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One of the surprising properties of black holes is that they can be assigned an entropy proportional to the area of the horizon. With this assignment, black holes obey the laws of thermodynamics. Over the last decade, a new type of black hole entropy entropy formula was developed which is believed to give the von Neumann or fine grained entropy of the black hole. It is also a formula involving an area, the area of a certain minimal surface, which can be in the black hole interior. We will review this formula, as well as its quantum corrections. We will briefly mention an application to black hole evaporation, a topic which will be covered more extensively in Ahmed Almheiri's talk.

Tuesday Plenary Session / 184

Quantum Field Theory with Boundary Conditions at the Horizons

Author: Gerard 't Hooft[None]

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In using QFT to study black holes, coordinate transformations are needed with boundary conditions at the horizons. To avoid quantum copies it is imperative that the mapping must be one-to-one. It is explained why this turns the horizons into projective spheres instead of regular spheres. Also what is needed is the concept of antivacuum', a state on which all creation operators vanish. This procedure describes a black hole that only contains pure quantum states, and evolves with a unitary

evolution operator, agreeing with standard QFT outside the horizons. It is explained how information is preserved and firewalls are transformed away. What used to be regarded as theinterior' of a black hole is now relocated to regions beyond the infinite future and before the infinite past, hence of no direct physical relevance.

Tuesday Plenary Session / 197

Probing singularities of GR with Quantum Fields

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Singularity theorems of Penrose and Hawking are based on geodesic incompleteness. Physically, this criterion refers to the fate of classical test particles. What if one uses quantum fields instead? They would be more fundamental probes. For technical simplicity, I will restrict myself to cosmological singularities and show that one can unambiguously evolve quantum
fields across them in a rigorous sense. Already for test quantum
fields, classical singularities are not absolute boundaries where physics breaks down. I will also discuss the behavior of expectation values of renormalized products of
fields. The overall conclusion
is that singularities of classical GR are tamer when seen from a quantum perspective, and the quantum considerations provide more refined tools to probe their structure. This work is based on joint work with Tommaso De Lorenzo and Marc Schneider, and supported by the NSF grant PHY-1806356 and the Eberly Chair funds of Penn State.

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Entropy of the Hawking radiation

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Hawking showed that the von Neumann or fine-grained entropy of the radiation emanating from an evaporating black hole monotonically increases throughout the black hole's lifetime. This suggests that black hole formation and evaporation can evolve a pure quantum state of a collapsing star into a mixed quantum state of the Hawking radiation. This is in direct conflict with the unitarily of time evolution in quantum mechanics, which requires that the radiation entropy vanishes once the black hole has completely evaporated. I will review some recent progress on this issue and discuss a new formula for computing the von Neumann entropy of the radiation that more carefully accounts for the gravitational nature of the theory. It predicts that the entropy of the radiation far away from the black hole can receive contributions from the black hole interior, including a term coming from the area of a surface near the event horizon. I will show how this formula produces an entropy that is consistent with unitary black hole evaporation and gives the so-called "Page curve" of an entropy that initially rises but then ultimately diminishes down to zero.

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Nonlinear stability of Kerr for small angular momentum

Author: Sergiu Klainerman[1]

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I will talk about my very recent result in collaboration with Jeremie Szeftel in which we provide a complete proof of the nonlinear stability of the family of Kerr spacetimes Kerr(a, m) with small a/m. The proof, which builds on our previous work " Global non-linear stability of Schwarzschild space under polarized perturbations'' , introduces various new geometric and analytic ideas to dispense on any symmetry assumptions.

Wednesday Plenary Session

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Testing LCDM on small scales with cluster lenses

Author: Priya Natarajan[1]

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The key elusive cosmic constituents - dark matter, dark energy and black holes - play a fundamental role in shaping the visible universe. In this talk, I will discuss the current status of our understanding of the distribution of dark matter on small-scales in LCDM and the key open questions. Gravitational lensing by clusters of galaxies offers a powerful way to map dark matter and the high quality of current data permits detailed comparison with simulations of structure formation. Deep Hubble Space Telescope data in combination with ground-based follow-up spectroscopy permit the construction of high-resolution lensing derived maps of dark matter that can be used to stress-test the LCDM model. I present results from recent work that reveal tensions between the predictions of the standard cold dark matter theory and observations of cluster lenses.

Wednesday Plenary Session / 145

Planck and the H0 tension

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The Planck mission found excellent agreement with a spatially flat Universe and fluctuations consistent with simple models of inflationary cosmology. The Planck data are well described by a six parameter model that has become known at the LCDM cosmology. Nevertheless, there have been claims of deviations (or tensions) with the LCDM cosmology both internally to the Planck data and with other astrophysical data. I will discuss an extensive reanalysis of Planck that makes use of more sky. The fit to the LCDM model is improved and there is no evidence for any internal inconsistencies within the Planck dataset. These results are consistent with the new results from ground based polarization experiments. I will then describe some aspects of the so called 'Hubble tension', i.e. the discrepancy between the LCDM value of H0 and the value inferred from the Cepheid distance ladder. I will point out three puzzling aspects of the distance ladder measurement.

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New Determination of the Hubble Constant with Gaia EDR3, Further Evidence of Excess Expansion

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The Hubble constant remains one of the most important parameters in the cosmological model, setting the size and age scales of the Universe. Present uncertainties in the cosmological model including the nature of dark energy, the properties of neutrinos and the scale of departures from flat geometry can be constrained by measurements of the Hubble constant made to higher precision than was possible with the first generations of Hubble Telescope instruments. A streamlined distance ladder constructed from infrared observations of Cepheids and type Ia supernovae with ruthless attention paid to systematic now provide <2% precision and offer the means to do much better. By steadily improving the precision and accuracy of the Hubble constant, we now see evidence for significant deviations from the standard model, referred to as Lambda CDM, and thus the exciting chance, if true, of discovering new fundamental physics such as exotic dark energy, a new relativistic particle, or a small curvature to name a few possibilities. I will review recent and expected progress, most recently based on measurements from Gaia EDR3 released in December, 2020.

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The unreasonable effectiveness of LCDM

Author: Licia Verde[1]

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The standard cosmological model (the LCDM model) has been established and its parameters are now measured with unprecedented precision. However, there is a big difference between modelling and understanding and precision is not enough: accuracy is also crucial. The "unreasonable effectiveness" of the LCDM model offers challenges and opportunities. In particular, as statistical errors in some key cosmological parameters have shrunk significantly very recently, some tensions have emerged, the most famous one being the 'Hubble tension'. This has motivated the exploration of extensions to the standard cosmological model in which higher values of H0 can be obtained from CMB measurements and galaxy surveys. The trouble, however, goes beyond H0; such modifications affect other quantities too, such as cosmic times, age of the Universe and the matter density. Any Hubble trouble has implications well beyond H0 itself. I will recap some recent results, trying to look at cosmological tensions in both a model-dependent and model independent way and speculate what we can learn about the LCDM model and its effectiveness.

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The Hubble constant tension

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An important and unresolved question in cosmology today is whether there is new physics that is missing from our current standard Lambda Cold Dark Matter (LCDM) model. A current discrepancy in the measurement of the Hubble constant, Ho, could be signaling a new physical property of the universe or, more mundanely, unrecognized measurement uncertainties. I will discuss two of our most precise methods for measuring distances in the local universe: Cepheids and the Tip of the Red Giant Branch (TRGB). I will present new results from the Carnegie-Chicago Hubble Program (CCHP. Using the Hubble Space Telescope Advanced Camera for Surveys, we are using the TRGB to calibrate Type Ia supernovae out into the Hubble flow to provide an independent measurement

of Ho. I will address the uncertainties, discuss the current tension in Ho, and whether there is need for additional physics beyond the standard LCDM model.

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The Hubble tension

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In recent years, a determination of the Hubble constant from supernovae has become increasingly discrepant with that inferred from the cosmic microwave background. This "Hubble tension" is not easily attributable to any known systematic artifacts in either measurement and may thus be indicating some new physics beyond that in the standard cosmological model. Easy fixes based on late-time modifications to the expansion rate are elusive as they require violations of the strong energy principle and even then introduce new discrepancies. One possible explanation involves a modification to the early-time expansion history of the Universe. I will discuss the Hubble tension, the difficulties with late-time solutions, these new "early dark energy" models, and their current status.

Thursday Plenary Session

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Frame-Dragging And ITS Tests With LASER Relativity And Geodesy Satellites

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Dragging of inertial frames, or frame-dragging, is an intriguing and fascinating phenomenon of Einstein's theory of General Relativity (GR) with relevant astrophysical implications. Some theories of gravitation, alternative to GR but in agreement with its post-Newtonian tests, predict a different result from GR for frame-dragging. However, frame-dragging tests, in agreement with GR, have been obtained with LARES (LAser RElativity Satellite), of the Italian Space Agency (ASI), successfully launched in February 2012, and with data from the LAGEOS (Laser Geodynamics Satellite), LAGEOS 2 and GRACE (Gravity Recovery and Climate Experiment) satellites. The accuracy of these tests reached a few parts in a hundred. The forthcoming ASI LARES 2 satellite, to be launched in 2021, together with data from the LAGEOS and GRACE Follow-On satellites, is aimed at frame-dragging tests with an accuracy of a few parts in a thousand.

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Einstein confirmed: New high precision tests of General Relativity

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General Relativity (GR) is a consequence of the Einstein Equivalence Principle. Accordingly, tests of GR are either test of its foundation or test of consequences of GR. In general, tests of the foundations are zero tests. Test of predictions of GR rely on certain notions like standard clocks or non-rotating frames which can be defined within GR and which are basic in the prediction of certain numerical values for particular effects. We outline the structure of these tests and report on recent high precision laboratory tests of foundations and of consequences of GR. At the end the importance of quantum tests of GR emphasized and the importance of fundamental tests for practical applications is outlined.

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Cosmology and Multi-Messenger Astrophysics with Gamma-Ray Bursts

Author: Lorenzo Amati[1]

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Since their discovery in the late ‘60s, Gamma-Ray Bursts constitute one of the most fascinating and mysterious phenomena for modern science, with strong implications for several fields of astrophysics and fundamental physics. In this review, I will focus on the perspective key-role of GRBs for cosmology and multi-messenger astrophysics. Indeed, the huge luminosity, the redshift distribution extending at least up to z~10 and the association with the explosive death of very massive stars make long GRBs (i.e., those lasting up to a few minutes) potentially extremely powerful cosmological probes (early Universe, geometry and expansion rate of space-time, “dark energy” evolution). At the same time, short GRBs (lasting no more than ~1-2s) are the most prominent electromagnetic signature of gravitational-wave sources like NS-NS and NS-BH merging events, and both long/short GRBs are expected to be associated with neutrino emission. I will also report on the status of the THESEUS space mission project, aiming at fully exploiting these unique potentialities of the GRB phenomenon.

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The irreducible mass of the Christodoulou - Ruffini - Hawking Mass formula

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We reveal three new discoveries in black hole physics previously unexplored in the Hawking era. These results are based on the remarkable 1971 discovery of the irreducible mass of the black hole by Christodoulou and Ruffini,
1. The Horizon Mass Theorem states that the mass at the event horizon of any black hole: neutral, charged, or rotating, is always twice its irreducible mass observed at infinity.
2. The External Energy Theorem asserts that the rotational energy of a Kerr black hole exists completely outside the horizon. This is due to the fact that the irreducible mass does not contain rotational energy
3. The Moment of Inertia Theorem shows that every black hole has a moment of inertia. When the rotation stops, the irreducible mass of a Kerr black hole becomes the moment of inertia of a Schwarzschild black hole. This is recognized as the rotational equivalent of the rest mass of a moving body in relativity.
Thus after 50 years, the irreducible mass has gained a new and profound significance. No longer is it a limiting value in rotation, it determines black hole dynamics and structure. What is believed to be a black hole is a mechanical body with an extended structure. Astrophysical black holes are likely to be massive compact objects from which light cannot escape.

Thursday Plenary Session / 50

Laser interferometry in space

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In the last decade, laser interferometry in space has advanced from planning on ground to an established technique for gravitational physics, both for the detection of gravitational waves (LISA project) as well as for global observation of the Earth gravity field (GRACE Follow-On). I will summarize the past and planned missions including LISA Pathfinder, GRACE Follow-On, Pathfinder missions in China and LISA.

Thursday Plenary Session / 59

The Transient Sky viewed through the Five-hundred-meter Aperture Spherical radio Telescope (FAST)

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Inspired by the visionary efforts of building Arecibo, the Five-hundred-meter Aperture Spherical radio Telescope (FAST) was formally established in 2007; its construction commenced in 2011; achieved first light in 2016; started normal operation in 2020. The first internationally open call-for-proposal was released in March 2021. I report here a few science highlights so far, particularly from the Commensal Radio Astronomy FAST Survey (CRAFTS), which is an unprecedented large-scale commensal radio survey enabled by a several novel techniques. CRAFTS simultaneously records pulsar, Galactic HI, extra-galactic HI, and transient data streams. CRAFTS has discovered more than 150 new pulsars, including more than 40 MSPs, more than 20 binaries, and at least one DNS system. We have imaged about 5% of the full sky in HI, including the Lockman hole, the Orion region, etc. CRAFTS has also resulted in 6 new FRBs, including one high DM repeater that has since been localized and is shown to be the FRB with the largest fraction of local host DM. Other dedicated programs have provided the stringiest limit on the radio flux of the Galactic FRB source, the first evidence of 3D alignment between a pulsar's spin axis and spatial velocity, the most radio faint pulsar through a search of unassociated Fermi sources, etc.

Thursday Plenary Session / 60

The Latest Progress of PandaX – a deep underground liquid xenon observatory

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The dark matter and neutrinos are keys to the formation and evolution of the universe. Yet we do not know what is dark matter, and we do not fully understand the fundamental properties of neutrinos. PandaX is an underground xenon-based observatory located in the world deepest China Jinping Underground Laboratory in Sichuan, China. The current phase of PandaX consists of a 4-tonne scale dual-phase xenon time-project-chamber detector, and we plan to carry out a wide range of studies in dark matter searches, Majorana neutrinos, astrophysical neutrinos, etc. In this talk, I will present the latest progress of PandaX, and give an outlook of its future.

Thursday Plenary Session / 143

Gravitational coupling between millimetre-sized masses: prospects for a quantum Cavendish experiment

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Earth-based experiments have been continuously increasing their sensitivity to gravity phenomena at laboratory scales. A yet unexplored frontier is the regime of microscopic source masses, which enables studies of fundamental interactions and provides a path towards exploring the quantum nature of gravity. We have recently demonstrated gravitational coupling between a test mass and a 90mg gold sphere, the smallest source mass to date in table-top gravity experiments. The miniaturized torsion balance measurement achieves a systematic accuracy of 3e-11 m/s2 and a statistical precision of 3e-12 m/s2. We expect that further improvements will enable the isolation of gravity as a coupling force for objects well below the Planck mass. This is a practical prerequisite for future "quantum Cavendish" experiments that aim to probe probe gravitational phenomena originating from quantum superposition states of a source-mass configuration.

Friday Plenary Session

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Dragging of inertial frames by matter and waves

Authors: Jiri Bicak[1]; Tomáš Ledvinka[2]

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We shall analyze three specific general-relativistic problems in which gravitomagnetism plays the important role: the dragging of magnetic fields around rotating black holes, dragging inside a collapsing slowly rotating spherical shell of dust, compared with the dragging by rotating gravitational waves (CQG 34, 205006 (2017), Phys. Rev. D 85 124003, (2012) etc). We shall also briefly show how „instantaneous Machian gauges" can be useful in the cosmological perturbation theory (Phys. Rev. D 76, 063501 (2007)). Finally, we shall mention the „Quantum Detection of Inertial Frame Dragging" (Phys. Rev. D 103, 024027 (2021)).

Friday Plenary Session / 58

Evolution of close binary stars and their role in the most powerful stellar explosions

Author: Norbert Langer[1]

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The majority of massive stars is born in close binary stars, and their evolution is strongly altered by their companion star. We discuss the main mechanisms of close binary interaction, and their relevance for understanding the diversity of core collapse supernovae. Binary interaction also affects, and sometimes enables, extreme events, like hypernovae, long-duration gamma-ray bursts, super luminous supernovae, and compact object merger. We will explore the capabilities and problems of binary evolution models in predicting these events and their discrete progenitor states, and the consequences thereof.

Friday Plenary Session / 53

Observations of Fast Radio Bursts

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Fast Radio Bursts (FRBs) are few-millisecond bursts of radio waves coming from far outside the Milky Way. Some repeat. Their origin is presently unknown as is whether they represent a single class of object or multiple classes. Recently there has been tremendous observational progress on understanding FRBs thanks to a variety of new instruments designed for their study. In this talk I review what is known about FRB observational properties, including population property distributions of both repeaters and apparent non-repeaters, as well as what is known about their host galaxies and environments.

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Numerical Relativity and the Interpretation of Gravitational Wave Observations

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Numerical relativity simulations of compact-object binary coalescences have played an important role in the detection of gravitational wave observations and the characterization of the sources. As current detectors increase their sensitivity and future detectors join the effort, the role of numerical relativity will become more prevalent. I will provide an overview of the current status of compact-object binary simulations and discuss the challenges that numerical relativity will face in the near future imposed by gravitational wave observations.

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The Physical Mechanisms of Fast Radio Bursts

Author: Bing Zhang[1]

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Fast radio bursts (FRBs) are cosmological millisecond-duration bursts in the radio band. The recent detection of the Galactic FRB 200428 suggests that magnetars can produce FRBs. In this talk, I will review the current understanding of the physical mechanisms of FRBs in reference of two related astrophysical phenomena, namely, radio pulsars and gamma-ray bursts. I will discuss the observational evidence in favor of FRB emission involving a neutron star magnetosphere. Some ideas and issues of various radiation mechanisms for FRBs and the associated X-ray bursts within the magnetar framework will be critically discussed. Several open questions in the field regarding repeaters vs. non-repeaters and whether there are engines other than magnetars will be presented.

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The story of GW 170817 - GRB 170817A: from gravitational waves to heavy elements

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The detection of gravitational waves from the binary neutron star merger, GW 170817, and subsequent short GRB as well as a kilonova signature and late afterglow confirmed a standing predictions and opened new fields of research. In this talk I will review early predictions, observations and interpretation as well as lessons that have been learnt. I will also review the exciting new line of studies that has emerged from this discovery and expectations for future events.

Massive Binary Stars in the Era of Gravitational Wave Astrophysics

Author: Selma de Mink[1]

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The direct detection of gravitational waves has triggered excitement from physicist, astrophysicists and general public alike. The first event and many that followed originated from surprisingly heavy systems, with typical masses of 30-45 solar masses, well in excess of the masses of black holes known in X-ray binary systems. How did heavy pairs of Black holes form? What do these measurements tell us about the massive stars that were their progenitors? In this talk I will try to give a taste of the excitement and rapidly developing ideas and new questions about the formation of Gravitational Wave sources and the stars they originate from and what we hope to learn in the near future with next generation detectors.

Friday Plenary Session / 420

Recent advances in the observation of high energy cosmic rays

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The study of High Energy (HE) and Ultra-High Energy (UHE) cosmic rays is currently being driven by new and very interesting data from both space-borne and ground-based experiments. The talk will be devoted to a review of recent observations of electrons/positrons, protons/antiprotons, and nuclei, at energies above hundreds of GeV. New techniques and mission concepts will also be briefly discussed.

Friday Plenary Session / 48

Probes of the Progenitors, Engines and Physics behind Stellar Collapse

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Understanding the nature of the stellar collapse plays an important role in a wide range of astrophysics. Stellar collapse produce the compact remnants (neutron stars and black holes) that make up a menagerie of exotic astrophysics objects from pulsars and X-ray binaries to the merging compact objects detected in gravitational waves. Stellar collapse plays an important role in most gamma-ray burst engines and their supernovae disseminate many of the heavy elements into the universe. But, to understand the true impact of stellar collapse on these phenomena, we must understand the engine driving supernova explosions. Despite recent successes supporting the convection-enhanced, neutrino-driven engine driving these explosions, we are far from a complete picture of these explosions. For example, uncertainties in stellar evolution prior to collapse and the engine itself make quantitative predictions from stellar collapse. Here we review our current understanding of stellar collapse (both the engine and its progenitor stars) and the observations (both current and proposed) to help us improve this understanding.

Saturday Plenary Session

Saturday Plenary Session / 66

Highlights of Insight-HXMT and perspectives of eXTP

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Insight-HXMT is China's first X-ray astronomy satellite and was successfully launched on June 15th, 2017. It carries three sets of collimated X-ray instruments with large effective areas in 1-250 keV. In addition, it can also serve as a nearly all-sky monitor for high energy sources between 0.2 to 3 MeV, such as bright pulsars and gamma-ray bursts. I will review some highlights of the scientific results of Insight-HXMT. I will also briefly introduce the enhanced X-ray Timing and Polarimetry (eXTP) mission, a large China-Europe collaboration, currently in Phase B and planned for launch in around 2027.eXTP will open a new era in exploring the extreme universe.

Saturday Plenary Session / 51

The Southern Wide-field Gamma-ray Observatory

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The Southern Wide-field Gamma-ray Observatory (SWGO), is a new project for gamma-ray astrophysics in the energy range from a few hundred GeV up to a PeV. SWGO will be a steradian field of view, 100% duty-cycle detector, surveying the southern sky and monitoring for transient phenomena, as such it complements very well the planned flagship facility the Cherenkov Telescope Array. As the first instrument of this type in the Southern Hemisphere, SWGO will ideally suited to map out the diffuse emission of the inner galaxy, the Fermi bubbles, and search for WIMP annihilation in the halo of the Milky Way. In this talk I will present the status of SWGO detector design and site search is well as give an overview of the scientific prospects.

Saturday Plenary Session / 63

Exploring the dynamic X-ray universe with the Einstein Probe mission

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Time-domain astrophysics has been revolutionized by the advent of the multi-wavelength and multi-messenger era. The Einstein Probe (EP) is a space mission designed to discover and characterize high-energy transients and to monitor source variability in the X-ray band. Its large field-of-view telescope equipped with the micro-pore optic will carry out high-cadence all-sky monitoring survey with unprecedented sensitivity in the previously poorly monitored soft X-ray band. It has also the capability of quick and deep onboard follow-up observations and good source localization in X-ray. Currently in the development phase, EP is a project of the Chinese Academy of Science (CAS) with the participation of European Space Agency and Max Planck Institute for extraterrestrial Physics. In this talk I will introduce the Einstein Probe mission, and discuss its main science goals in the field of cosmic high-energy transients.

Saturday Plenary Session / 73

The X-Ray Imaging and Spectroscopy Mission (XRISM)

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The X-Ray Imaging and Spectroscopy Mission (XRISM) is a JAXA/NASA X-ray observatory with collaboration from ESA and several institutes and academic institutions worldwide. It is proposed to fulfill the promise of high-resolution X-ray spectroscopy with imaging once realized but unexpectedly terminated by a mishap of ASTRO-H/Hitomi. XRISM carries two sets of X-ray Mirror Assemblies and is equipped on the focal plane with a 6 x 6 pixelized X-ray micro-calorimeter array and an aligned X-ray CCD camera. With the combination of high-resolution spectroscopy imaging and the broader field of view, XIRSM is expected to pioneer a new horizon of the Universe in X-ray astrophysics. Aiming to launch the satellite in Japanese Fiscal Year 2022, we are proceeding production of components and integration of the satellite. I will report the development status, reviewing the science objectives and the operation plan.

Saturday Plenary Session / 141

Exploring the transient sky with the SVOM mission

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I will present the SVOM mission that the Chinese National Space Agency and the French Space Agency havedecided to jointly implement for a launch in autumn 2022.In the line of Swift, SVOM has been designed to detect, characterize and quickly localize gamma-raybursts (GRBs) and other types of high-energy transients. For this task, the spacecraft will carry two widefieldhigh-energy instruments: ECLAIRs, a hard X-ray imager, and the Gamma-Ray Monitor, a broadbandspectrometer. Upon localizing a transient, SVOM will quickly slew towards the source and start deep follow-upobservations with two narrow-field telescopes: the Micro-channel X-ray Telescope in X-rays and the Visible Telescope in the visible.The originality of SVOM is to have a set of instruments deployed on the ground to complete the measurements made in space.i.e.a Wide Angle Camera and two dedicated ground robotic telescopes.The nearly anti-solar pointing of SVOM combined with the fast

transmission of GRBpositions to the ground thanks to a VHF antenna network will facilitate the observations of SVOM transients by the largestground based telescopes.All this together makes SVOM a powerful time domain machine.

Saturday Plenary Session / 399

First result of LHAASO: Implication for extreme particle accelerators

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The Large High Altitude Air Shower Observatory is a new-generation multi-component instrument for TeV-PeV gamma rays and TeV-EeV cosmic rays. Recently, LHAASO has published its first result on the discovery of 12 ultrahigh-energy (E>100TeV) gamma-ray sources at more than 7 sigma confidence level. Among them, there are famous sources like the Crab Nebula, the Cygnus Cocoon, as well as new sources without TeV counterpart. The discovery indicates the prevalence of PeV particle accelerators in our Galaxy.

Saturday Plenary Session / 419

The enhanced X-ray Timing and Polarimetry mission eXTP: a future X-ray mission to study the state of matter under extreme conditions

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The eXTP (enhanced X-ray Timing and Polarimetry) mission is a major project of the Chinese Academy of Sciences (CAS), with a large involvement of Europe and expected ESA support. It is designed to study the state of matter under extreme conditions of density, gravity and magnetism, as for instance what is happening on the vicinity of black holes or what is the state of matter inside neutron stars. Its predicted launch is in 2027. eXTP will carry a unique suite of instruments, enabling for the first time ever the simultaneous spectral-timing-polarimetry studies of cosmic sources in the energy range from 0.5 to 30 keV. The eXTP scientific payload includes four instruments: SFA (Spectroscopy Focusing Array), PFA (Polarimetry Focusing Array), LAD (Large Area Detector) and WFM(Wide Field Monitor). They offer an unprecedented simultaneous wide-band X-ray timing and polarimetry sensitivity. A large European consortium is contributing to the eXTP study, both for the science and the instrumentation, providing two of the four instruments: LAD and WFM. The WFM for eXTP will be a wide field X-ray monitor instrument in the 2-50 keV energy range. Its unprecedented combination of large field of view and imaging down to 2 keV will allow eXTP to make important discoveries of the variable and transient X-ray sky, outstanding contributions to multi-messenger astronomy.

Saturday Plenary Session / 77

The Gamow Explorer

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Gamma Ray Bursts (GRBs) are bright backlights that can be used to probe the high redshift universe (z>6) when the first stars were born, galaxies formed and Hydrogen was reionized. Since the afterglow is bright only for a few days, speed is of the essence. Gamow Explorer is optimized to quickly identify high redshift events to trigger follow-up spectroscopic observations with JWST and >8m class ground-based telescopes. A wide field of view Lobster Eye X-ray Telescope will find GRBs and locate them with arc minute precision. A rapidly slewing spacecraft will point a 5 photometric channel Photo-z Infra-Red Telescope to identify high redshift (z > 6) GRBs using the Lyman-drop out. The Gamow Explorer will also rapid identify X-ray and IR counterparts associated with GW events. The mission will be proposed to the 2021 NASA MIDEX call and if approved launched in 2028.

Saturday Plenary Session / 299

A 40-Year Journey

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More than one hundred years ago, Albert Einstein published his Theory of General Relativity (GR). One year later, Karl Schwarzschild solved the GR equations for a non-rotating, spherical mass distribution; if this mass is sufficiently compact, even light cannot escape from within the so-called event horizon, and there is a mass singularity at the center. The theoretical concept of a 'black hole' was born, and was refined in the next decades by work of Penrose, Wheeler, Kerr, Hawking and many others. First indirect evidence for the existence of such black holes in our Universe came from observations of compact X-ray binaries and distant luminous quasars. I will discuss the forty year journey, which my colleagues and I have been undertaking to study the mass distribution in the Center of our Milky Way from ever more precise, long term studies of the motions of gas and stars as test particles of the space time. These studies show the existence of a four million solar mass object, which must be a single massive black hole, beyond any reasonable doubt.

Parallel Sessions

Accretion Discs and Jets

Accretion Discs and Jets / **567**

Accretion of the relativistic Vlasov gas onto a moving Schwarzschild black hole

Author: Patryk Mach[1]

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I will discuss recent analytic results on the stationary accretion of the relativistic collisionless Vlasov gas onto a moving Schwarzschild black hole. The model assumes that the gas obeys the Maxwell-Juttner distribution at infinity. The Vlasov equation is solved formally in terms of suitable action-angle variables in the framework proposed originally by Rioseco and Sarbach. Depending on the asymptotic temperature, the results interpolate between two regimes: In the limit of infinite asymptotic temperature of the gas, we recover the qualitative picture known form the relativistic Bondi-Hoyle-Lyttleton accretion of the perfect gas with the ultra-hard equation of state, in which the mass accretion rate is proportional to the Lorentz factor associated with the black hole velocity. For low asymptotic temperatures, the mass accretion rate is not a monotonic function of the velocity of the black hole. The model can be applied in situations where the gas is not likely to be in thermal equilibrium in the vicinity of the black hole, for instance in the context of dark matter accretion. The talk is based on two papers written jointly with Andrzej Odrzywolek: Phys. Rev. Lett. 126, 101104 (2021) and Phys. Rev. D 103, 024044 (2021).

Accretion Discs and Jets / **542**

Limiting effects in tori clusters

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We consider agglomerates of misaligned tori orbiting a supermassive black hole. The aggregate of tilted tori is modelled as a single orbiting configuration by introducing a leading function governing the distribution of toroids (and maximum pressure points inside the disks) around the black hole attractor. The orbiting clusters are composed by geometrically thick, pressure supported, perfect fluid tori.
This analysis places constraints on the existence and properties of tilted tori and more general aggregates of orbiting disks.
We study the constraints on the tori collision emergence and the instability of the agglomerates of tori with general relative inclination angles, the possible effects of the tori geometrical thickness and on the oscillatory phenomena.
Some notes are discussed on the orbiting ringed structure in dependence of the dimensionless parameter ξ representing
the (total) BH rotational energy extractable versus the mass of the BH, associating ξ to the characteristics of the accretion processes.

Accretion Discs and Jets / 740

Time-dependent Kerr discs and tidal disruption events

Author: Steven Balbus[None]

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Whilst the classical Novikov and Thorne solutions for steady state black hole accretion discs have been known for nearly half a century, the development of time-dependent relativistic disc theory is relatively new. I will review the formal theory of time-dependent thin discs in Kerr geometry, and argue that analysis of tidal disruption events (the tidal destruction of a star by a supermassive galactic black hole and the subsequent accretion of the debris) is an ideal venue for its application. Late time X-ray observations probe the disc regions near the innermost stable circular orbit, whilst the simultaneous UV emission arises from farther out. The observed steeply falling X-ray light curves together with a simultaneous flat UV plateau are, we shall show, strong support for the basic disc emission model. Nonthermal x-ray emission, conditions of strong variability, and limitations of the thin disc model will be discussed as time permits.

Accretion Discs and Jets / 33

Multifrequency Behaviour of High Mass X-ray Binary Systems

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In thus talk I will present the zoo of the High Mass X-ray Binary Systems (HMXBs). Among these I will discuss the X-ray/Be systems and in particular A0535 + 26/HDE245770. Through the multifrequency experimental data obtained in long observation campaigns it was possible to develop a particular model for the aforementioned system and then a general one that explains the delay between the flares in the X-band compared to those in the optical. This general model has been successfully applied to different binary systems for which the delay is known experimentally. This model can also be successfully extended to extragalactic systems in which a star is engulfed by tidal effects from the central black hole. Some examples will be shown.

Accretion Discs and Jets / 743

Electromagnetic fields in polish doughnut models

Authors: Eva Hackmann[1]; Audrey Trova[2]; Kris Schroven[None]; Vladimír Karas[None]; Jiri Kovar[None]; Petr Slany[None]; Claus Laemmerzahl[3]

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Analytical models of accretion disks have been an important tool to understand the basic underlying principles of accretion. Classically, these models are constructed using an isolated Kerr black hole. However, astrophysical black holes are usually surrounded by electromagnetic fields. We consider here the presence of electromagnetic test fields that are weak in the sense that they do not influence the spacetime geometry. The origin of these fields could be internal, like a tiny electric charge of the black hole, or external, like the galactic magnetic field. We show a general method to construct polish doughnuts in such settings and discuss some particular examples.

Accretion Discs and Jets / 999

Simulations of black hole accretion and jets

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In this talk I will review the recent insights into the physics of black hole accretion and jets enabled by the advances in general relativistic numerical simulations. In particular, I will discuss how the jets form, collimate, accelerate, and interact with the ambient medium.

Accretion Discs and Jets / 392

Measurement of Black Hole Spin with the Event Horizon Telescope: Theory of Radiative Echoes and VLBI Observations

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Observational measurement of the black-hole spacetime is one of the essential topics in modern physics and astrophysics, since it will lead to a critical test of the theory of general relativity. In general relativity, the spacetime around is uniquely determined by its mass and spin parameter. The mass can be accurately measured by observing orbits of stars or gas dynamics inside the sphere of its gravitational influence. On the other hand, it is not easy to extract the spin information, which depends on the complexity of accretion flow properties and spacetime effects in the vicinity of the black hole.

In this presentation, we simulate Event Horizon Telescope (EHT) observations for a gas cloud intermittently falling onto a black hole and construct a method for spin measurement based on its relativistic flux variation. We investigate the spin's signature by calculating an infalling gas cloud's motion and photon trajectories in the Kerr spacetime by the general relativistic ray-tracing method. The light curve of the infalling gas cloud is composed of peaks formed by photons that directly reach a distant observer and by secondary ones reaching the observer after more than one rotation around the black hole. The time interval between the peaks is determined by a period of photon rotation near the photon circular orbit, which uniquely depends on the spin.

To optimize our new spin measurement method, we perform synthetic EHT observations for the supermassive black hole at the Galactic center (Sgr A*) under a more realistic situation by performing three-dimensional general relativistic magnetohydrodynamics simulations. Even for the realistic situation, the black hole spin's signature is detectable in correlated flux densities, which are accurately calibrated by baselines between sites with redundant stations. The synthetic observations indicate that our methodology can be applied to EHT observations of Sgr A* from April 2017-2022.*

Accretion Discs and Jets / 808

Magnetized accretion disk structure in the background of an accelerating black hole

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An accelerating black hole can be described by a solution of Einstein's vacuum field equation. This talk will explain the analytical magnetized tori around this black hole and states its properties. The astrophysical motivation for choosing such fields is the possibility to constitute the simplest reasonable model for a real situation occurring in these objects' vicinity in this situation.

Accretion Discs and Jets / 776

Relativistic Jets from Spinning Black Holes

Author: Ramesh Narayan[1]

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Many accreting black holes in Nature are observed to have relativistic jets, and it has been suggested that the jets receive much of their power from the spin energy of the central black hole. There is considerable evidence in support of this idea from computer simulations of accretion flows. The talk will review some recent progress in this field.

Accretion Discs and Jets / 646

Advective accretion onto a non-spherical accretor in white dwarf and neutron star binaries: a new scenario of shock formation

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Numerous studies on hydrodynamics of the Keplerian as well as the sub-Keplerian accretion disc around a compact object (e.g., white dwarf (WD), neutron star (NS), or a black hole (BH)) attempted to explain the observed UV, soft and hard X-ray spectra. Although, when the compact object (e.g., a WD or an NS) has a finite surface, its rapid rotation, the stellar magnetic field could cause deformation of the spherical symmetry. Earlier studies for Keplerian disc showed that a deviation from the spherical symmetry of the compact object could affect the observed light curve and spectra at high frequencies. Here, we have explored the effect of the non-spherical nature of a compact object on the hydrodynamics of an optically thin, geometrically thick sub-Keplerian advective flow. We find that

due to non-spherical shape of the central accretor, there is a possibility to trigger Rankine-Hugoniot shock in the sub-Keplerian advective flow close to the accretor without considering any general relativistic effect or presence of the hard surface of the star. Our results are more relevant for accretion onto WD as hardly any general relativistic effect will come in the picture. We propose that some observational features e.g., high significance of fitting the spectra with multi-temperature plasma models rather than single temperature models, and variable efficiency of X-ray emission (X-ray luminosity in comparison with optical and UV luminosity of the disk) in nonmagnetic cataclysmic variables can be explained by the presence of shock in the sub-Keplerian advective flow.

Accretion Discs and Jets / 209

The Nature of the X-ray Emission and Innermost Accretion Regions of Typical Radio-Loud Quasars

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Radio-loud quasars (RLQs) are typically more X-ray luminous, by a factor of 2-20, than matched radio-quiet quasars (RQQs). This excess X-ray emission has generally been attributed to small-scale jets. To determine the nature of this excess X-ray emission, we have constructed a large, uniform sample of 729 optically selected RLQs with high fractions of X-ray detections and radio-slope measurements. We investigate correlations between their X-ray, optical/UV, and radio luminosities, as well as their X-ray spectral and variability properties. Strikingly, we find that steep-spectrum RLQs (SSRQs) follow a quantitatively similar relation between X-ray vs. optical luminosities as RQQs, suggesting a common accretion-disk corona origin for the X-ray emission of both classes. Formal statistical model selection supports these conclusions, as does consideration of analogies with black-hole X-ray binaries. However, the relation's intercept for SSRQs is larger than that for RQQs and increases with radio loudness, suggesting a connection between the radio jets and the accretion-flow configuration. Flat-spectrum RLQs also generally appear to have corona-dominated X-ray emission, though in some cases jets make large contributions. Our spectral measurements of X-ray continuum shapes and (average) reflection signatures confirm these conclusions, as do our inter-observation measurements of X-ray variability on timescales of weeks-years. Our results indicate the corona-jet, disk-corona, and disk-jet connections of RLQs are likely driven by independent physical processes. Moreover, the observed corona-jet connection implies that small-scale processes in the vicinity of black holes, probably associated with the magnetic flux/topology instead of black-hole spin, are controlling quasar radio loudness.

Accretion Discs and Jets / 801

Properties of accretion disk models with quadrupole

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There is an alternative generalization of the q-metric Weyl's procedure describes a deformed compact object in the presence of an external distribution of matter via exercising quadrupole moments. This metric may associate the observable effects to these parameters as dynamical degrees of freedom in

the system. The talk will describe this metric and exploring the properties of analytical accretion disk models in this background.

Accretion Discs and Jets / 778

Ionized accretion disks orbiting magnetized black holes

Author: Zdeněk Stuchlík[None]

We give summary of some astrophysically important new phenomena related to ionized Keplerian or toroidal disks orbiting around a Kerr black hole immersed in a large-scale external magnetic field.

1. Under appropriately chosen conditions the electrons can be treated in "force-free" approximation, while ions in "dielectric approximation". Then off-equatorial "dielectric clouds" could be formed and represent an obstacle for the Blandford-Znajek process.
2. Keplerian disks ionized near the ISCO could be important in creation of ultra-high energy cosmic rays. Due to the magnetic Penrose process realized in a proper way, protons or ions could be accelerated up to energy overcoming `10^22` eV in conditions quite realistic from astrophysical point of view.
3. Slightly charged hot-spots orbiting near the ISCO could give rise to high-frequency quasi-periodic oscillations (HFQPOs) in X-rays observed around supermassive black hole in Active Galactic Nuclei, with predicted frequencies in agreement with observed frequencies, if the so called epicyclic geodesic model of HFQPOs is applied with modification given by the interaction of the large-scale magnetic field with charge of the hot-spot.
4. The new radiative Penrose process has been recently discovered, being related to the negative energy photons created due to the back-reaction of the charged particles moving in the ergosphere of the magnetized black holes. This kind of Penrose process can both increase by one order energy of the radiating particle, or can lead to "floating orbits" crossing repeatedly the ergosphere boundary.

Accretion Discs and Jets / 679

Hydrodynamical instability with noise in the Keplerian accretion disks: modified Landau equation

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Abstract:
The origin of hydrodynamical instability and turbulence in the Keplerian accretion disk is a long-standing puzzle. The flow therein is linearly stable. Here we explore the evolution of perturbation in this flow in the presence of an additional force. Such a force, which is expected to be stochastic in nature hence behaving as noise, could result from thermal fluctuations (however small be), Brownian ratchet, grain−fluid interactions, feedback from outflows in astrophysical disks, etc. We essentially establish the evolution of nonlinear perturbation in the presence of Coriolis and external forces, which is the modified Landau equation. We obtain that even in the linear regime, under suitable forcing and Reynolds number, the otherwise least stable perturbation evolves to a very large

saturated amplitude, leading to nonlinearity and plausible turbulence. Hence, forcing essentially leads a linear stable mode to unstable. We further show that nonlinear perturbation diverges at a shorter time-scale in the presence of force, leading to a fast transition to turbulence. Interestingly, the emergence of nonlinearity depends only on the force but not on the initial amplitude of perturbation, unlike the original Landau equation-based solution.

Reference:
Ghosh, S., Mukhopadhyay, B., 2020, MNRAS, 496, 4191

Binary-Driven Hypernovae of Type 1, 2 and 3

Binary-Driven Hypernovae of Type 1, 2 and 3 / 958

GRB-SN association and Inferences of GRB 190114C for the Crab pulsar and the supernova remnant

Authors: Rahim Moradi[1]; Jorge Armando Rueda Hernandez[2]; Remo Ruffini[2]; Carlo Luciano Bianco[2]; Christian Cherubini[3]; Simonetta Filippi[4]; Narek Sahakyan[5]; Y. Wang[2]; Liang Li[6]

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We assume that the progenitor of the Crab nebula and of the Crab pulsar, like GRB 190114C is a binary-driven hyper-novae of type I (BdHNe I). In BdHN I the explosion of the supernova as well as of the role of the hypercritical accretion of the SN ejecta onto the binary companion neutron star (NS) and onto the newbornNS (νNS) have central role. The synchrotron emission powered by the νNS-pulsar emission and the accreted SN ejecta onto the νNS, gives origin to the X-ray afterglows. We evidence that the X-ray afterglow luminosity of GRB 190114C, selected as a prototype, extrapolated to 1000 yr, coincides with the currently observed emission of the Crab Nebula. We model the νNS through the equilibrium sequence of Maclaurin spheroid. By requiring that the νNS period extrapolated to 1000 yr coincides with the one of PSR B0531+21 (the Crab pulsar) , we study the evolution of the spin of the νNS with the initial P = 0.9 ms.

Binary-Driven Hypernovae of Type 1, 2 and 3 / 946

General Relativistic Turbulence in spherically symmetric Core-Collapse Supernovae simulations

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It is generally believed that General Relativity (GR) is of secondary importance in the explosion of core-collapse supernovae (CCSN). However, as 3D simulations are becoming more and more detailed, GR effects can be strong enough to change the hydrodynamics of the supernova and affect the explosion. Since a 3D simulation in full GR is computationally extremely challenging, it is valuable to modify simulations in a spherically symmetric spacetime to incorporate 3D effects. This permits exploration of the parameter dependence of CCSN with a minimum of computational resources. In this talk I will report on the formulation and implementation of general relativistic neutrino-driven turbulent convection in the spherically symmetric code GR1D. This is based upon STIR, the recently proposed Newtonian model based on mixing length theory of Couch et al. (2020). When the parameters of this model are calibrated to 3D simulations, we find that our GR formulation significantly alters the correspondence between progenitor mass and explosion vs. black-hole formation. We therefore believe that, going forward, simulating CCSN in full GR is of primary importance.

Binary-Driven Hypernovae of Type 1, 2 and 3 / 598

Neutrino and gamma-ray production from proton-proton interactions in binary-driven hypernovae

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We estimate the neutrino emission from the decay chain of the π-meson and μ-lepton, produced by proton-proton inelastic scattering in energetic ($E_{\rm iso} \geq 10^{52}$ erg) long gamma-ray bursts (GRBs), within the type I binary-driven hypernova (BdHN) model. The BdHN I progenitor is a binary system composed of a carbon-oxygen star ($\mathrm{CO_{core}}$) and a neutron star (NS) companion. The $\mathrm{CO_{core}}$ explosion as supernova (SN) triggers a massive accretion process onto the NS. For short orbital periods of few minutes, the NS reaches the critical mass, hence forming a black hole (BH). Recent numerical simulations of the above scenario show that the SN ejecta becomes highly asymmetric, creating a \textit{cavity} around the newborn BH site, due to the NS accretion and gravitational collapse. Therefore, the electron-positron ($e^{\pm}$) plasma created in the BH formation, during its isotropic and self-accelerating expansion, engulfs different amounts of ejecta baryons along different directions, leading to a direction-dependent Lorentz factor. The protons engulfed inside the high-density ($\sim 10^{23}$ particle/cm^3) ejecta reach energies in the range $1.24 \leq E_p \leq 6.14$~GeV and interact with the unshocked protons in the ejecta. The protons engulfed from the low density region around the BH reach energies ~ 1~TeV and interact with the low-density (~ 1 particle/cm^3) protons of the interstellar medium (ISM). The above interactions give rise, respectively, to neutrino energies $E_\nu \leq 2$ GeV and $10 \leq E_\nu \leq 10^3$ GeV, and for both cases we calculate the spectra and luminosity.

Black Hole Thermodynamics

Black Hole Thermodynamics / 833

Linear growth of the two-point function for the Unruh state in 1+1 dimensional black holes

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The two-point function for a massless minimally coupled scalar field in the Unruh state is computed for various examples of 1+1 dimensional black holes. It is found that for spacelike separations of the points the two-point function grows linearly in terms of a time coordinate that is well-defined on the future black hole horizon, and for Schwarzschild-de Sitter black holes is also well-defined on the future cosmological horizon. The two-point function for a massive scalar field in Schwarzschild-de Sitter spacetime is also discussed.

Black Hole Thermodynamics / 746

Rindler trajectories and Rindler horizons in the Schwarzschild spacetime

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We investigate radial Rindler trajectories in a Schwarzschild spacetime. We assume the trajectory to remain linearly uniformly accelerated (LUA) throughout its motion, in the sense of the curved spacetime generalisation of the Letaw-Frenet equations. For the Schwarzschild spacetime, we arrive at a bound on the magnitude of the acceleration $|a|$ for radially inward moving trajectories, in terms of the mass M of the black hole given by $|a| \leq 1/(\sqrt{27}M)$ for a particular choice of asymptotic initial data h, such that, for acceleration $|a|$ greater than the bound value, the linearly uniformly accelerated trajectory always falls into the black hole. For $|a|$ satisfying the bound, there is a minimum radius or the distance of closest approach for the radial LUA trajectory to escape back to infinity. However, this distance of closest approach is found to approach its lowest value of $r_b = 3M$, greater than the Schwarzschild radius of the black hole, when the bound, $|a| = 1/(\sqrt{27}M)$ is saturated. We further show that a finite bound on the value of acceleration, $|a| \leq \mathcal{B}(M,h)$ and a corresponding distance of closest approach $r_b > 2M$ always exists, for all finite asymptotic initial data h. We

further investigate the past and future Rindler horizons for these radial Rindler trajectories. The analytical solution for the radial LUA trajectories along with its past and future intercepts $calC$ with the past null infinity $calJ^{-}$ and future null infinity $calJ^{+}$ are presented. The Rindler horizons, in the presence of the black hole, are found to depend on both the magnitude of acceleration $|a|$ and the asymptotic initial data h, unlike in the flat Rindler spacetime case wherein they are only a function of the global translational shift h. The implications for the corresponding Unruh effect are discussed.

Black Hole Thermodynamics / 410

Black Hole Thermodynamics from Entanglement Mechanics

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Since its inception, the Bekenstein-Hawking area relation for black-hole entropy has been the primary testing ground for various theories of quantum gravity. However, a key challenge to such theories is identifying the microscopic structures and explaining the exponential growth of microstates, providing a fundamental understanding of thermodynamic quantities. Since entropy is a single number, we explore other quantities to provide complete information about the black-hole microstates. We establish a one-to-one correspondence between entanglement energy, entropy, and temperature (quantum entanglement mechanics) and the Komar energy, Bekenstein-Hawking entropy, and Hawking temperature of the horizon (black-hole thermodynamics), respectively. We also show that this correspondence leads to the Komar relation and Smarr formula for generic 4-D spherically symmetric space-times. While offering an independent derivation of black-hole thermodynamics from field observables, the universality of results suggests that quantum entanglement is a fundamental building block of space-time. DOI : https://doi.org/10.1103/PhysRevD.102.125025

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Thermodynamics of Charged Black Hole

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This talk investigates thermodynamics, quasi-normal modes, thermal fluctuations and phase transitions of Reissner-Nordstrom black hole with the effects of non-linear electrodynamics. We first compute the expressions for Hawking temperature, entropy and heat capacity of this black hole and then obtain a relation between Davies point and quasi-normal modes with non-linear electrodynamics. We also observe the effects of logarithmic corrections on uncorrected thermodynamic quantities such as entropy, Hawking temperature, Helmholtz free energy, internal energy, Gibbs-free energy, enthalpy and heat capacity. It is found that presence of non-linear electrodynamics parameter induces more instability in black holes of large radii. Finally, we analyze the phase transitions of Hawking temperature as well as heat capacity in terms of entropy for different values of charge, horizon radius and coupling parameter. We obtain that Hawking temperature changes its phase from positive to negative for increasing values of charge and horizon radius while it shows opposite trend for higher values of coupling parameter. The heat capacity changes its phase from negative to positive for large values of charge, horizon radius and coupling parameter.

Black Hole Thermodynamics / 710

Superentropic black hole with Immirzi hair

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In this talk I will report an analytic solution describing asymptotically anti−de Sitter black holes with hyperbolic horizon, derived in the context of f(R) generalizations to the Holst action, endowed with a dynamical Immirzi field. These black holes exhibit scalar hair of the second kind, which ultimately depends on the Immirzi field radial behavior. In particular, the latter is reponsible for modifications to the usual entropy law associated to the black hole and it boils down to a constant value in the asymptotic region, thus restoring the standard loop quantum gravity picture. I will then discuss the black hole thermodynamics in the extended phase space approach, proving the violation of the reverse isoperimetric inequality, which results in the superentropic nature of the black hole, and discussing the thermodynamic stability of the solution.

Black Hole Thermodynamics / 288

Information recovery from evaporating black holes

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We show that the apparent horizon and the region near r=0 of an evaporating charged, rotating black hole are timelike. It then follows that for black holes in nature, which invariably have some rotation, have a channel, via which classical or quantum information can escape to the outside, while the black hole shrinks in size. We discuss implications for the information loss problem.

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Thermodynamics of AdS Black Holes: Central Charge Criticality

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We reconsider the thermodynamics of AdS black holes in the context of gauge-gravity duality. In this new setting where both the cosmological constant Λ and the gravitational Newton constant G are varied in the bulk, we rewrite the first law in a new form containing both Λ (associated with thermodynamic pressure) and the central charge C of the dual CFT theory and their conjugate variables. We obtain a novel thermodynamic volume, in turn leading to a new understanding of the Van der Waals behavior of the charged AdS black holes, in which phase changes are governed by the degrees of freedom in the CFT. Compared to the "old" $P-V$ criticality, this new criticality is

"universal" (independent of the bulk pressure) and directly relates to the thermodynamics of the dual field theory and its central charge.

Black Hole Thermodynamics / 925

Einstein-Maxwell-Dilaton-Axion mass formulas for black hole systems with struts and strings

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We derive Smarr-type mass formulas for black holes solutions with non-connected horizons, represented by their rod structure, in the framework of the EMDA theory, generalizing the results of the recent paper "On the Smarr formulas for electrovac spacetimes with line singularities - ScienceDirect". Our formalism covers such configurations as aligned multiple black holes joined by struts and possibly by Misner and Dirac strings when the individual components are endowed with magnetic mass or monopole charges. It is shown, that the axion and dilaton fields only modify the expressions for the electric and magnetic charges, but do not introduce new terms into the mass formulas. We discuss the thermodynamic interpretation of solutions with Misner and Dirac strings and discuss the relationship with previous literature on Misner string.

Black Hole Thermodynamics / 685

Why the black hole information problem is a false problem.

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I review the arguments supporting the idea that there is an information puzzle in black holes physics. Namely that unitarity is conflicting with local quantum field theory and the equivalence principle. I show that these arguments rely on speculative extra assumptions, justified only by faith in specific hypothesis on quantum gravity. Therefore the black hole information puzzle a problem only for these peculiar approaches to quantum gravity. Distinguishing thermodynamical entropy from von Neumann entropy and event horizons from apparent horizons shows that the black hole information problem is, by itself, a false problem.

Black Hole Thermodynamics / 462

Back-reaction of Matter Fluctuations in Asymptotically non-flat Black-hole Space-times

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Hawking radiation remains a crucial theoretical prediction of semi-classical gravity and is considered one of the critical tests for a model of quantum gravity. However, Hawking's original derivation used quantum field theory on a fixed background. Efforts have been made to include the space-time fluctuations arising from the quantization of the dynamical degrees of freedom of gravity itself and to study the effects on the Hawking particles. Using semi-classical analysis, we study the effects of quantum fluctuations of scalar field stress-tensors in asymptotic non-flat spherically symmetric black-hole space-times. Using two different approaches, a statistical mechanical approach and a quantum field theoretic approach, we obtain a critical length-scale from the horizon at which gravitational interactions become large, i.e., when the back reaction to the metric due to the scalar field becomes significant. The work can be found at [arXiv: 2008.00429].

Black Hole Thermodynamics / 897

Microscopic model building for Black Hole Membranes from Constraints of Symmetry

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Einstein equations projected on Black Hole horizons give rise to the equations of motion of a viscous fluid. This suggests a way to understand the microscopic degrees of freedom on the Black Holehorizon by focusing on the physics of this fluid. In this talk, we shall approach this problem by building a crude microscopic model for the Horizon-fluid(HF) corresponding to asymptotically flat Black Holes in 3+1 dimensions. The symmetry requirement for our model is that it should directly incorporate the S1 diffeo-symmetry on the BH horizon. The second constraint comes from the demand that the correct value of the Coefficient of the Bulk Viscosity of the HF can be deduced from the model. Both these requirements can be satisfied by an adoption of the eight vertex Baxter model on a S2 surface. We show that the adiabatic entropy quantisation proposed by Bekenstein also follows from this model. Finally, we argue the results obtained so far suggest that a perturbed Black Hole can be described by a CFT perturbed by relevant operators and discuss the physical implications.

Black Hole Thermodynamics / 834

Stress-energy Tensor for a Quantized Scalar Field When a Black Hole in Four Dimensions Forms From the Collapse of a Null Shell

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A method will be presented which allows for the numerical computation of the stress-energy tensor for a quantized massless minimally coupled scalar field in the region outside the event horizon of a 4D Schwarzschild black hole that forms from the collapse of a null shell. This method involves taking the difference between the stress-energy tensor for the in state in the collapsing null shell spacetime and that for the Unruh state in Schwarzschild spacetime. The construction of the modes for the in vacuum state and the Unruh state will be discussed. Applying the method, the renormalized stress-energy tensor in the 2D case has been computed numerically and shown to be in agreement with the known analytic solution. In 4D, the presence of an effective potential in the mode equation causes scattering effects that make the the construction of the in modes more complicated. The numerical computation of the in modes in this case will be presented.

Black Hole Thermodynamics / 438

Eddington gravity with matter: An emergent perspective

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We describe an action principle, within the framework of the Eddington gravity, which incorporates the matter fields in a simple manner. Interestingly, the gravitational field equations derived from this action is identical to Einstein's equations, in contrast with the earlier attempts in the literature. The cosmological constant arises as an integration constant in this approach. In fact, the derivation of the field equations demands the existence of a nonzero cosmological constant, thereby providing the raison d'être for a nonzero cosmological constant, implied by the current observations. Several features of our approach strongly support the paradigm that gravity is an emergent phenomenon and, in this perspective, our action principle could have a possible origin in the microstructure of the spacetime. We also discuss several extensions of the action principle, including the one which can incorporate torsion into the spacetime. We also show that an Eddington-like action can be constructed to obtain the field equations of the Lanczos-Lovelock gravity.

Black Holes in Alternative Theories of Gravity

Black Holes in Alternative Theories of Gravity / 660

Asymptotically flat black hole solution in modified gravity

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This abstract is primarily based on my paper EPJC 79 (2019) 877.

$f(R)$ gravity theory is one of the most popular alternate theories of gravity, which has been used to describe various phenomena in cosmology and astrophysics. In this talk, I will explore the properties of spacetime in the presence of $f(R)$ gravity. First, I will describe how it is used to obtain a spherically symmetric spacetime metric. It is observed that the properties of the spacetime and some other physics related to the marginal orbits deviate from those for the Schwarzschild metric, depending on the model's parameter. It is also well noted that this solution is actually asymptotically flat, which means the metric approaches the Minkowski metric as we move away from the compact object. Eventually, I will talk about using this solution in the accretion disk to understand its various properties.

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Infinitely degenerate exact Ricci-flat solutions in $f(R)$ gravity

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The evidence is mounting that the Universe is currently undergoing a phase of accelerated expansion. One possible alternative is the modification in gravity in the largest possible scales. This leads to the many questions related to black-holes: violation of Birkhoff theorem and no-hair theorem. To confirm/infirm, we need to obtain exact black-hole solutions in these modified gravity theories.

In this talk, we focus on the exact spherically symmetric solutions in $f(R)$ theories of gravity. We explicitly show that some $f(R)$ models contain an infinite number of exact static, Ricci-flat spherically symmetric vacuum solutions and, hence, violate Birkhoff's theorem in $f(R)$ theories. We analytically derive two exact vacuum black-hole solutions for the same class of $f(R)$ theories. The two black-hole solutions have the event-horizon at the same point; however, their asymptotic features are different. Our results suggest that the no-hair theorem may not hold for generic modified gravity theories. We discuss the implications of our work to distinguish modified gravity theories from general relativity. (Based on arXiv:2003.05139)

Black Holes in Alternative Theories of Gravity / 461

Analytical computation of quasi-normal modes of slowly-rotating black-holes in dCS gravity

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Following the direct detection of gravitational waves, modification to General Relativity (GR) at strong gravity regimes is one of the most important aspects of gravity research. Chern Simons (CS) gravity is one of the most frequently studied parity-violating models of strong gravity. CS gravity is indistinguishable from GR for all conformally flat space-times and for space-times that possess a maximally symmetric 2-dimensional subspace. Also, it is known that the Kerr black-hole is not a solution for CS gravity. At the same time, the only rotating solution available in the literature for dynamical CS (dCS) gravity is the slow-rotating case. In this work, for the slow-rotating case, we derive the linear perturbation equations governing the metric and the dCS field accurate to linear order in spin and quadratic order in the CS coupling parameter (α) and obtain the quasi-normal mode (QNM) frequencies. After confirming the recent results of Wagle et al. [arXiv 2103.09913], we find an additional contribution to the eigenfrequency correction at the leading perturbative order of α^2. Unlike Wagle et al., we also find corrections to frequencies in the polar sector. We compute these extra corrections by evaluating the expectation values of the perturbative potential on unperturbed QNM wavefunctions along a contour deformed into the complex-r plane. For $\alpha = 0.1M^2$, we find the ratio of the imaginary parts of the dCS correction to the purely GR correction in the first QNM frequency (in the polar sector) to be 0.263 implying a significant change. Also, for the $(l, m) = (2, 2)$ mode, the dCS corrections make imaginary part of the first QNM of the fundamental mode less negative, thereby decreasing the decay rate. Our results, along with future gravitational wave observations, can be used as a test for dCS gravity and to further constrain the CS coupling parameter values.

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emergent magnetic monopoles in degenerate theory

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We show that a magnetic charge in curved spacetime could be an artefact of a vacuum phase with zero metric determinant at a distance. This phase is characterized by a solution of the first-order field

equations with nontrivial torsion. The monopole charge has a topological origin, given precisely by a lower-dimensional counterpart of the Nieh-Yan invariant in absence of matter. In this geometric realization, the monopole core remains hidden from the observer living in the invertible metric phase, thus precluding its direct detection.

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Does the Penrose Suggestion as to Black Holes from a Prior Universe Showing Up in Today's Universe Have Credibility? Examined from a Singular, and Nonsingular Beginning of Cosmological Expansion

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We examine if there are grounds to entertain the Penrose suggestion as to black holes from a prior cycle of creation appearing in the present cosmos. There are two cases to consider. One a singular start to the Universe or as Karen Freeze and others have modeled a non-singular start. The two cases are different and touch upon the limits of validity of the Penrose singularity theorem. We will first of all state the two cases, singular and nonsingular, and then afterwards, briefly allude to the Penrose singularity theorem. The plausibility of the singular cosmological expansion start point w case analysis of Black holes from a prior universe will be discussed first Afterwards, a synopsis of the Penrose singularity theorem. After that, the Nonsingular case of a starting point of the expansion of the Universe will be entertained and described. Since the nonsingular start to the expansion of the Universe is not so well known, a considerable amount of space will be spent upon what I view as mathematical constructions allowing for its analysis. About the only way to ascertain these cases will be by GW astronomy, hence the details of GW production from the early Universe will be covered in excruciating detail. The methodology for that section is simple. Use a construction for a minimal time-step, then from there get emergent space-time conditions for a bridge from a nonsingular start to the universe, to potential Quantum gravity conditions. Our Methodology is to construct using a "trivial" solution to massive gravitons, and a nonsingular start for expansion of the universe. Our methodology has many consequences, not the least is a relationship between a small timestep, which is called t, and then the minimum scale factor and even the tension or property values of the initial space-time wall, .

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Scalar perturbations of Kerr black-holes in hybrid metric-Palatini gravity

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It is shown that the Kerr solution exists in the generalized hybrid metric-Palatini gravity theory and that for certain choices of the function $f(R,\mathcal{R})$ that characterizes the theory, the Kerr solution can be stable against perturbations on the scalar degree of freedom of the theory. We start by verifying which are the most general conditions on the function $f(R,\mathcal{R})$ that allow for the general relativistic Kerr solution be also a solution of this theory. We perform a scalar perturbation in the trace of

the metric tensor, which in turn imposes a perturbation in both the Ricci and Palatini scalar curvatures. To first order in the perturbation, the equations of motion, namely the field equations and the equation that relates the Ricci and the Palatini curvature scalars, can be rewritten in terms of a 4th order wave equation for the perturbation δR which can be factorized into two 2nd order massive wave equations for the same variable. The usual ansatz and separation methods are applied and stability bounds on the effective mass of the Ricci scalar perturbation are obtained. These stability regimes are studied case by case and specific forms of the function $f(R, \mathcal{R})$ that allow for a stable Kerr solution to exist within the perturbation regime studied are obtained.

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An overview of quasinormal modes in modified and extended gravity

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As gravitational waves are now being nearly routinely measured with interferometers, the question of using them to probe new physics becomes increasingly legitimate. In this article, we rely on a well established framework to investigate how the complex frequencies of quasinormal modes are affected by different models. The tendencies are explicitly shown for both the pulsation and the damping rate. The goal is, at this stage, purely qualitative. This opportunity is also taken to derive the Regge-Wheeler equation for general static and spherically symmetric metrics.
Based on: Moulin, Barrau, Martineau, Universe 5 (2019) 9, 202

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Bardeen Black Hole from a Self-Dual Radius in Spacetime

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From a phenomenological point of view, the singularities of ordinary black hole solutions hint at a breakdown of general relativity. The Bardeen black hole is a prototype of regular black hole solutions, i.e. those which are geodesically complete and avoid a curvature singularity.

The Bardeen solution is generally interpreted as a magnetically or electrically charged solution to gravity coupled to non-linear electrodynamics. In this talk, we derive that in a spacetime inheriting a self-dual radius from string theory, black holes naturally take on the Bardeen form.

The threshold mass for Bardeen black holes achieves a particular interpretation. During the evaporation process, a black hole undergoes a transition from an instable classical Schwarzschild phase to a stable quantum phase. In the end, there is a cold, thermodynamically stable remnant. The minimal black hole size of the order of the self-dual radius.

The self-dual radius can be tested by its impact on quantum mechanical systems. We find that it modifies the form of the atomic electrostatic potentials. We derive experimental bounds from high-precision spectroscopy of the hydrogen atom. The investigation of the 1S_{1/2}–2S_{1/2} transition frequency allows to constrain the self-dual radius down to below 3.9 × 10^(-19) m.

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Black holes in metric-affine gravity: properties and observational discriminators

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We present several families of black hole solutions in metric-affine theories of gravity with independent metric and affine connection. We show that the resolution of the singularity problem is a common feature of many such solutions, and discuss several strategies in terms of their observational discriminators as compared to GR canonical objects.

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Absorption by deformed black holes

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Alternative theories of gravity and the parameterized deviation approach allow black hole solutions to have additional parameters beyond mass, charge and angular momentum. Matter fields could be, in principle, affected by the additional parameters of these solutions. We compute the absorption cross section of massless spin-0 waves by static Konoplya-Zhidenko black holes, characterized by a deformation parameter introduced in the mass term, and compare it with the well-known absorption of a Schwarzschild black hole with the same mass. We compare our numerical results with the sinc approximation in the high-frequency limit, finding excellent agreement.

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Universe in a black hole with spin and torsion

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We consider gravitational collapse of a spherically symmetric sphere of a fluid with spin and torsion into a black hole. We use the Tolman metric and the Einstein-Cartan field equations with a relativistic spin fluid as a source. We show that gravitational repulsion of torsion prevents a singularity and replaces it with a nonsingular bounce. Quantum particle production during contraction strengthens torsion in opposing shear. Particle production during expansion can produce enormous amounts of matter and generate a finite period of inflation. The resulting closed universe on the other side of the event horizon may have several bounces. Such a universe is oscillatory, with each cycle larger in size then the previous cycle, until it reaches the cosmological size and expands indefinitely. Our universe might have therefore originated from a black hole existing in another universe.

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Shadow of a charged black hole surrounded by an anisotropic matter field

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A certain type of matter with anisotropic pressures can add to the Reissner-Nordström metric a term proportional to a power of the radial coordinate. Using the standard method of separating variables for the Hamilton-Jacobi equation, we study the shadow of the corresponding rotating solution, obtained through the Newman-Janis algorithm. We define and calculate three observables in order to characterize the position, size and shape of the shadow.

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Holography for Rotating Black Holes in f(T) Gravity

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The nonextremal Kerr black holes have been considered to be holographically dual to two-dimensional (2D) conformal field theories (CFTs). In this talk, we extend the holography to the case of an asymptotically anti–de Sitter (AdS) rotating charged black holes in f(T)=T+αT^2 gravity, where α is a constant. We find that the scalar wave radial equation at the near-horizon region implies the existence of the 2D conformal symmetries. We note that the 2π identification of the azimuthal angle ϕ in the black hole line element, corresponds to a spontaneous breaking of the conformal symmetry by left and right temperatures TL and TR, respectively. We show that choosing proper central charges for the dual CFT, we produce exactly the macroscopic Bekenstein-Hawking entropy from the microscopic Cardy entropy for the dual CFT. These observations suggest that the rotating charged AdS black hole in f(T) gravity is dual to a 2D CFT at finite temperatures TL and TR for a specific value of mass M, rotational, charge, and f(T) parameters, Ω, Q, and |α|, respectively.

Black Holes in Alternative Theories of Gravity / 971

Asymptotically flat hairy black holes in massive bigravity

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We study asymptotically flat black holes with massive graviton hair within the ghost-free bigravity theory. There have been contradictory statements in the literature about their existence, but we have been able to construct such solutions within a carefully designed numerical scheme. The masses of stable hairy black holes that would be physically relevant range form stellar values up to values typical for supermassive black holes. One of their two metrics is extremely close to Schwarzschild while all the “hair” is hidden in the second metric that is not coupled to matter and not directly

seen. However, the "hairy features" should manifest themselves in violent processes like black hole collisions and should be visible in the structure of the signals detected by LIGO/VIRGO.

Black Holes in Alternative Theories of Gravity / 859

Constraining modified gravity theories with physical black holes

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The existence of black holes is one of the key predictions of general relativity (GR) and therefore a basic consistency test for modified theories of gravity. In spherical symmetry, only two classes of GR solutions are compatible with the formation of a regular apparent horizon in finite time of a distant observer. In this talk, I will demonstrate how to derive constraints that any self-consistent modified gravity theory must satisfy to be compatible with their existence. In addition, I will discuss their properties, highlight characteristic features, and illustrate the construction on some popular modified theories of gravity, e.g. the Starobinsky model. Both of the GR solutions can be regarded as zeroth-order terms in perturbative solutions of this model. On the other hand, it is also possible to construct non-perturbative solutions without a well-defined GR limit.

Note: some of the results presented in this talk are summarized in arXiv:2012.11209.

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Some studies of black hole shadows in the conformal massive gravity and the Einstein-Aether gravity

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In the first part, we use a suitable conformal rescaling to construct static and rotating regular black holes in conformal massive gravity. The new metric is characterized by the mass M, the "scalar charge" Q, the angular momentum parameter a, the "hair parameter" λ, and the conformal scale factor encoded in the parameter L. We explore the shadow images and the deflection angles of relativistic massive particles in the spacetime geometry of a rotating regular black hole later.
In the second part, we will discuss the shadow cast by two types of charged and slowly rotating black holes in Eisntein-aether theory of gravity. This two types of black holes are corresponding to two specific combinations of the coupling constants of the aether field, i.e., c14=0 but c123≠0 for the first type and c123=0 for the second type, respectively. For both types of black holes, in addition to the mass and charge of the black holes, we show that the presence of the aether field can also affect the size of the shadow. For the first type black hole, it is shown that the shadow size increases with the parameter c13, while for the second type black hole, the shadow size still increases with c13 but decreases with the parameter c14. With these properties of these aether parameters, we also discuss the observational constraints on these parameters by using the data of the first black hole image by the Event Horizon Telescope.

Black Holes in Alternative Theories of Gravity / 996

Black holes, stationary clouds and magnetic fields

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As the electron in the hydrogen atom, a bosonic field can bind itself to a black hole occupying a discrete infinite set of states. When (i) the spacetime is prone to superradiance and (ii) a confinement mechanism is present, some of such states are infinitely long–lived. These equilibrium configurations, known as stationary clouds, are states "synchronized" with a rotating black hole's event horizon. For most, if not all, stationary clouds studied in the literature so far, the requirements (i)–(ii) are independent of each other. However, this is not always the case. In fact, massless neutral scalar fields can form stationary clouds around a Reissner–Nordström black hole when both are subject to a uniform magnetic field. The latter simultaneously enacts both requirements by creating an ergoregion (thereby opening up the possibility of superradiance) and trapping the scalar field in the black hole's vicinity. This leads to some novel features, in particular, that only black holes with a subset of the possible charge to mass ratios can support stationary clouds.

Compact Stars as Laboratories for Testing Strong Gravity

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Exotic thin-shell fluid stars with arbitrary compactess

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We propose two models for constant density relativistic perfect-fluid spheres supported by thin shell configurations. These models are obtained from the Schwarzschild constant density star solution: the first via the collapse of the external layers of the fluid into a thin shell by performing a matching with the exterior Schwarzschild solution at a matching radius smaller than the star radius; and the second via the creation of a vacuum bubble inside the star by matching it with an interior Minkowski spacetime. Both models are shown to satisfy both the weak and the strong energy conditions (WEC and SEC) and can have a compactness arbitrarily close to that of a black-hole without developing singularities at the center, thus being exceptions to the Buchdahl limit. We compute the stability regimes of the models proposed and we show that there are combinations of the star radius R and the matching radius R_Σ for which the solutions are stable, the dominant energy condition (DEC) is satisfied, and the radius of the object is smaller than $3M$, implying that these models could be used as models for dark matter or exotic compact objects.

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Magnetic field in Neutron stars, vacuum birrefrigence consequences

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Vacuum in presence of magnetic field exhibits birrefrigence. We have obtained this effect from linear correction of dispersion relation of photon travelling perpendicular to the magnetic field valid even for magnetic fields close to B_c=10¹³ G.
Although this phenomenon has not been yet detected evidenceof this effect has been reported for neutron star RX J1856.5−3764 by Mignani et al.. In the light of this finding we analyze our results.
In this context we discussed possible experiments in lab with pulsanting laser beams.

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Probing Strong Field Gravity and the Structure of Ultra-Dense Matter with the Thermal Evolution of Neutron Stars

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Thermal evolution of neutron stars is studied in the $f(R) = R + \alpha R^2$ theory of gravity.
We first describe the equations of stellar structure and evolution for a spherically symmetric spacetime plus a perfect fluid at rest.
We then present numerical results for the structure of neutron stars using four dense matter equations of state and a series of gravity theories for
α ranging from zero, i.e., General Relativity, up to $\alpha \approx 10^{16}$ cm^2.
We emphasize properties of these neutron star models that are of relevance for their thermal evolution as the threshold masses for enhanced neutrino emission
by the direct Urca process, the proper volume of the stellar cores where this neutrino emission is allowed, the surface gravitational acceleration that impact the observable effective temperature, and the crust thickness.
Finally, we numerically solve the equations of thermal evolution using the public code \texttt{NSCool} and explicitly analyze the effects of altering gravity.
We find that uncertainties in the dense matter microphysics, as its chemical composition and superfluidity/superconductivity properties, as well as the
astrophysical uncertainties on the chemical composition of the surface layers, have a much stronger impact than possible modification of gravity
within the studied family of $f(R)$ theories.
We conclude that within this family of gravity theories, conclusions from previous studies of neutron star thermal evolution are not significantly
altered by alteration of gravity.
Conversely, this implies that neutron star cooling modeling may not be a useful tool to constrain deviations of gravity from Einstein theory
unless these are much more radical than in the $f(R)$ framework.

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Effects of modified theories of gravity on neutrino pair annihilation energy deposition near neutron stars

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We present our studies on the neutrino pairs annihilation into electron-positron pairs ($\nu\bar{\nu} \rightarrow e^- e^+$) near the surface of a neutron star in the framework of extended theories of gravity. The latter modifies the maximum energy deposition rate near to the photonsphere and it might be several orders of magnitude greater than that computed in the framework of General Relativity. These results provide a rising in the Gamma-Ray Bursts energy emitted from a close binary neutron star system and might be a fingerprint of modified theories of gravity, changing our view of astrophysical phenomena.

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Neutron Stars in Scalar-tensor Theories: Analytic Scalar Charges and Gravitational-wave Constraints

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Neutron stars in scalar-tensor theories may undergo spontaneous scalarization, which is important for probing the theories with binary pulsar and gravitational wave observations. Since the effect is nonlinear, most studies of spontaneous scalarization were carried out numerically. In the first part of my talk, I explain how one can compute the effect of scalarization analytically based on a perturbative analysis and analytic modeling of neutron stars through the Tolman VII solution. I show that the analytic calculations match accurately with numerical ones. These findings improve our understanding of spontaneous scalarization and provide us quick and ready-to-use expressions of scalar charges. In the second part, I present current and future prospects of constraining scalar-tensor theories with gravitational waves from a mixed binary of a black hole and a neutron star. I show that future observations can significantly improve bounds on these theories.

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The Brach Cut Universe: from the origin of the universe to the formation of compact stars

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In this contribution we identify two scenarios for the evolutionary branch cut universe. In the first scenario, the universe evolves continuously from the negative complex cosmological time sector, prior to a primordial singularity, to the positive one, circumventing continuously a branch cut, and no primordial singularity occurs in the imaginary sector, only branch points. In the second scenario, the branch cut and branch point disappear after the {\it realisation} of the imaginary component of the complex time by means of a Wick rotation, which is replaced by the thermal time. In the second scenario, the universe has its origin in the Big Bang, but the model contemplates simultaneously a mirrored parallel evolutionary universe going backwards in the cosmological thermal time negative sector. A quantum formulation based on the WDW equation is sketched and preliminary conclusions are drawn. Finally, a description of the evolutionary process of the branch cut universe, from its beginnings to the creation phase of compact stars is proposed.

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Neutron stars in $f(R, T)$ gravity using realistic equations of state in the light of massive pulsars and GW170817

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In this work we investigate neutron stars (NS) in f (R, T) gravity for the case R + 2λT , R is the Ricci scalar, and T the trace of the energy-momentum tensor. The hydrostatic equilibrium equations are solved considering realistic equations of state (EOS). The NS masses and radii obtained are subject to a joint constrain from massive pulsars and the event GW170817. The parameter λ needs to be negative as in previous NS studies, however, we found a minimum value for it due to the existence of the NS crust. The pressure in this modified theory of gravity depends on the inverse of the sound velocity. Since, this velocity is lower in the crust, |λ| needs to be very small. We found that the increment in the star mass is less than 1%, much smaller than previous ones obtained not considering the realistic stellar structure, and the star radius cannot become larger, its changes compared to GR is less than 3.6% in all cases. The finding that using several relativistic and non-relativistic models the variation on the NS mass and radius is almost the same for all the EsoS, manifests that our results are insensitive to the high-density part of the EOS. It confirms that stellar mass and radii obtained in f(R,T) depends only on the NS crust, where the EoS is essentially the same for all the models. Finally, we highlight that our results indicate that conclusions obtained from NS studies done in modified theories of gravity without using realistic EsoS that describe correctly the NS interior can be unreliable.

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Application of a hierarchical MCMC follow-up to Advanced LIGO continuous gravitational-wave candidates

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We present the first application of a hierarchical Markov Chain Monte Carlo (MCMC) follow-up on continuous gravitational-wave candidates from real-data searches. The follow-up uses an MCMC sampler to draw parameter-space points following the F-statistic. As outliers are narrowed down, coherence time increases, imposing more restrictive phase-evolution templates. We introduce a novel Bayes factor to compare results from different stages: The signal hypothesis is derived from first principles, while the noise hypothesis uses extreme value theory to derive a background model. The effectiveness of our proposal is evaluated on fake Gaussian data and applied to a set of 30 outliers produced by different continuous wave searches on O2 Advanced LIGO data. The results of our analysis suggest all but three outliers are inconsistent with an astrophysical origin under the standard continuous wave signal model. We successfully ascribe two of the surviving outliers to an instrumental artifact and a strong hardware injection present in the data. The behavior of the third outlier suggests an instrumental origin as well, but we could not relate it to any known instrumental cause.

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Probing modified gravitational-wave propagation through tidal measurements of binary neutron star mergers

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Gravitational-wave(GW) sources can serve as standard sirens to probe cosmology by measuring their luminosity distance and redshift. Such standard sirens are also useful to probe theories beyond General Relativity with a modified GW propagation. Previous studies on the latter assume multi-messenger observations so that the luminosity distance can be measured with GWs while the redshift is obtained by identifying sources' host galaxies from electromagnetic (EM) counterparts. Given that GW events of binary neutron star(BNS) coalescences with associated EM counterpart detections are expected to be rather rare, it is important to examine the possibility of using standard sirens to probe gravity with GW measurements alone. In this paper, we achieve this by extracting the redshift from the tidal measurement of BNSs(originally proposed within the context of GW cosmology). We also improve previous work by considering multi-band GW observations between ground-based (e.g.Einstein Telescope) and space-based (e.g.DECIGO) interferometers. We find that such multi-band observations with the tidal information can constrain a parametric non-Einsteinian deviation in the luminosity distance more stringently than the case with EM counterparts (due to a larger number of events) by a factor of a few.

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Neutron Stars in Scalar-tensor Theories: Universal Relations and Analytic Investigations

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Neutron stars are ideal astrophysical sources to probe general relativity due to their large compactnesses and strong gravitational fields. For example, binary pulsar and gravitational wave observations have placed stringent bounds on certain scalar-tensor theories in which a massless scalar field is coupled to the metric through matter. A remarkable phenomenon of neutron stars in such scalar-tensor theories is spontaneous scalarization, where a normalized scalar charge remains order unity even if the matter-scalar coupling vanishes asymptotically far from the neutron star. On the other hand, certain quasi-universal relations have been found for global quantities of neutron stars (such as the moment of inertia and quadrupole moment) that are insensitive to the underlying equations of state. We find a new quasi-universal relation in massless scalar-tensor theories between the scalar charge and stellar binding energy (related to stellar compactness). Although the above finding is based on numerical calculations, we give mathematical support for this universal relation by computing for the first time scalar charges analytically for both Tolman VII and constant density stars. Such analytic results provide ready-to-use expressions for scalar charges in massless scalar-tensor theories.

Conformal Dilaton Gravity and Related Issues

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A Spinor Representation of Gravity

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We follow an old hypothesis that there exists an intimate connection between weak interaction and gravity, symbolized by the relationship between the Fermi and Newton's constants. We analyze the hypothesis that the effect of matter upon the metric that represents gravitational interaction in General Relativity is an effective one. This leads us to consider gravitation to be the result of the interaction of two neutral spinorial fields (g-neutrinos) with all kinds of matter and energy. We present three examples with only one g-neutrino: two static and spherically symmetric configurations and a cosmological framework for an isotropic dynamical universe. Without self-interaction, the associated effective geometry is precisely the Schwarzschild metric. On the other hand, a self-interacting g-neutrino generates a new gravitational black-hole.

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What does zero modes tell us about entanglement ?

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It has been known that the zero modes can contribute towards divergence in the entanglement entropy and the nature of the divergent term
can be either log or log(log). However, a clear understanding of what
leads to these two different forms of zero mode divergence is still lacking.
So, in order to throw some light along this direction, I will talk about how
these two different divergent behaviours can be seen as a signature of a
crossover in the zero mode limit for the ground state entanglement.

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Using Lorentz violation for early universe GW generation due to black hole destruction in the early universe as by Freeze

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We are using information from a paper deriving a Lorentz-violating energy-momentum relation entailing an exact momentum cutoff as stated by G. Salesi . Salesi in his work allegedly defines Pre Planckian physics, whereas we restrict our given application to GW generation and DE formation in the first 10^-39s to 10^-33s or so seconds in the early universe. This procedure is inacted due to an earlier work whereas referees exhibited puzzlement as to the physical mechanism for release of Gravitons in the very early universe. The calculation is meant to be complementary to work done in the Book "Dark Energy" by M. Li, X-D. Li, and Y. Wang, and also a calculation for Black hole destruction as outlined by Karen Freeze, et. al. The GW generation will be when there is sufficient early universe density so as to break apart Relic Black holes but we claim that this destruction is directly linked to a Lorentz violating energy-momentum G. Salesi derived, which we adopt, with a mass m added in the G. Salesi energy momentum results proportional to a tiny graviton mass, times the number of gravitons in the first 10^-43 seconds

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Conformal Dilaton Gravity and Warped Spacetimes in 5D

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We applied the conformal dilaton gravity model on a BTZ-like black hole spacetime in five dimensions using the warped Randall-Sundrum-1 variant.
We find exact (t, r)-dependent solutions for the dilaton field and the metric components, written as $g_{\mu\nu} = \omega^{\frac{4}{n-2}}\tilde{g}_{\mu\nu}$, from the 5D Einstein equations, as well as from the induced 4D Einstein equations on the brane.
Next, we write ${}^{(4)}\tilde{g}_{\mu\nu} = \bar{\omega}^{2(4)}\bar{g}_{\mu\nu}$.
The free parameters of the solution can be chosen in such a way that the spacetime is singular-free. The location of the horizon(s) and the ergosphere of the induced 4D spacetime are also determined by the gravitational field outside the brane.
This solution can also be used to calculate the functional integration over ω and then over $\tilde{g}_{\mu\nu}$ for the effective action.
The energy-momentum tensor for the dilaton field, as well as the surface gravity of the horizon determining the Hawking radiation, can be calculated exactly.
Because the use of a "large" extra dimension results in a fundamental Planck scale comparable with the electroweak scale, one can possible construct, although here without matter, a finite, renormalizable and anomaly-free effective action. A connection is made with the antipodal mapping in connection with the complementarity issue.

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From Neutrino Masses to the Full Size of the Universe - Some Intriguing Aspects of the Tetron Model

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The universe according to the tetron model consists of invisible tiny constituents, elastically bound with bond length about the Planck length and binding energy the Planck energy.
A tetron transforms as the fundamental fermion(=octonion) representation 8 of SO(6,1). With respect to the decomposition SO(6,1)−>SO(3,1)xSO(3) a tetron possesses spin 1/2 and isospin 1/2, i.e. it represents an isospin doublet of Dirac spinors.
The 24 known quarks and leptons arise as eigenmode excitations of a tetrahedral fiber structure, which is made up from 4 tetrons and extends into 3 additional 'internal' dimensions.
While the laws of gravity are due to the elastic properties of the tetron bonds, particle physics interactions take place within the internal fibers.
I will concentrate on two of the most intriguing features of the model:
-understanding small neutrino masses from the conservation of isospin, and, more in general, calculating the spectrum of quark and lepton masses. This is obtained from the tetron model's interpretation of the Higgs mechanism.
-the possibility to determine the full size of the universe from future dark energy measurements. This is obtained from the tetron model's interpretation of the dark energy phenomenon.

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Quantum communication through a partially reflecting moving mirror

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Motivated by the fact that the null-shell of a collapsing black hole can be described by a perfectly reflecting accelerating mirror, we investigate an extension of this model to mirror semi-transparency and derive a general expression for the corresponding Bogoliubov coefficients. In so doing, we introduce the concept of ''impulsive accelerated mirrors", corresponding to those mirrors that are accelerated via an impulsive force. We show this treatment guarantees analytic solutions of Bogolubov coefficients. In particular, we evaluate the corresponding particle production from the so-obtained Bogoliubov coefficients. Finally, we recognize the mirror as a Gaussian quantum channel acting between the spacetime regions of left-past and right-future.
As a consequence we study the loss/amplification properties of this quantum channel, alongside the noise it creates, through which we evaluate its capacities in transmitting classical and quantum information.

Cosmic Backgrounds from Radio to Far-IR

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High-redshift universe with redshifted 21 cm line

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The redshifted 21 cm line of neutral hydrogen is one of the most useful probes of the early universe. Several experiments are ongoing and are being planned to detect the signal from high redshifts. Detection of the signal will help in understanding the first stars in the Universe, the formation and evolution of galaxies and also constraining cosmological parameters. In this talk, we will discuss some of the most interesting problems in cosmology and the high-redshift universe that can be studied using the 21 cm line, highlighting possible synergies with observations in other wave bands.

Cosmic Backgrounds from Radio to Far-IR / 310

New Planck tSZ map and its cosmological analysis

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The thermal Sunyaev-Zeldovich (tSZ) effect is produced by the inverse Compton scattering of cosmic microwave background (CMB) photons by hot electrons, particularly in galaxies clusters. It has been used as a powerful probe to constrain the cosmological parameters, given its particular sensitivity to sigma8 and omega_m.

We present a new all-sky tSZ map constructed from the latest Planck PR4 data released in 2020 with the MILCA algorithm. We will review the obtained improvements in this tSZ map in terms of signal-to-noise and resolution with respect to the map produced by the Planck collaboration in 2015. We will also present the results of the cosmological analysis with this new tSZ map.

Cosmic Backgrounds from Radio to Far-IR / 727

The impact of the Lorentz symmetry violation on the CMB polarization

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In the standard cosmological scenario, no circular polarization is predicted for Cosmic Microwave Background (CMB) radiation. However, in the frame of moving particle, Lorentz symmetry can violate and lead to circular polarization for CMB radiation. We estimate the circular polarization power spectrum $C_l^{V(S)}$ in CMB radiation due to Compton scattering in presence of the Lorentz symmetry violation. We show that the V-mode power spectrum can be obtained in terms of linear polarization power spectrum at the last scattering surface.

Cosmic Backgrounds from Radio to Far-IR / 242

Cosmology with Radio Astrophysics

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In this talk we will consider several ways to use background radio radiation to learn about the large scale features of our universe as well as fundamental physics. In particular, we will highlight the power in cataloguing and understand a large number of Fast Radio Bursts and their background environments to learn about cosmology.

Cosmic Backgrounds from Radio to Far-IR / 464

Cosmological and astrophysical results exploiting magnification bias with high-z submillimeter galaxies

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The high-z submillimeter galaxies (SMGs) can be used as background sample for gravitational lensing studies thanks to their magnification bias (Gonzalez-Nuevo et al. 2017), which can manifest itself through a non-negligible measurement of the cross-correlation function between a background and a foreground source sample with non-overlapping redshift distributions. In particular, the choice of SMGs as background sample enhances the cross-correlation signal so as to provide an alternative and independent observable for cosmological studies regarding the probing of mass distribution.
In particular (Bonavera et al. 2020), the magnification bias can be exploited in order to constrain the free astrophysical parameters of a Halo Occupation Distribution (HOD) model and some of

the main cosmological parameters. Urged by the improvements obtained when adopting a pseudo-tomographic analysis (Gonzalez-Nuevo et al. 2021), we adopt a tomographic set-up to explore not only a ΛCDM scenario, but also the possible time evolution of the dark energy density in the ω_0CDM and $\omega_0\omega_a$CDM frameworks (Bonavera et al. tbs).
The results that have been obtained so far by our group will be discussed.

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The Planck Legacy Archive, present and future

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The Planck Legacy Archive (PLA) hosts the products from the European Space Agency mission to study the Cosmic Microwave Background (CMB). The PLA web interface (https://pla.esac.esa.int) directs the users to a wide variety of Planck products, e.g., time ordered data, CMB maps, frequency and astrophysical components maps (Dust, Synchrotron, Free-Free, CIB,..), source catalogues and other products needed for cosmological studies (angular power spectra, likelihood, lensing maps, simulations). Advance Search panels are available to extensively query the PLA database, in addition to embedded links to the Planck Explanatory Supplement documentation, multiple data download options, and Helpdesk support.

Three major releases of Planck products took place in 2013, 2015, and 2018 and a selection of products have been tagged as "Legacy" to identify the version of each product most appropriate for general scientific use. In 2021 a new release of products will take place with a joint reprocessing of LFI+HFI time ordered data that includes additional information not used in previous releases. In addition, EU funded projects reprocessing Planck data, or combining it with other experiments, are expected to the deliver to the PLA higher level data products of interest to the CMB Community.

The PLA also offers specialized tools that facilitate the processing of Planck products. These tools are mainly designed to help users who are not familiar with some of the particularities of the Planck products, and can be categorized into distinct groups: map operations including component subtraction, unit conversion, colour correction, bandpass transformation, and masking of map-cutouts/full-sky maps; component separation codes, map-making codes and effective beam-averaging. In addition, the PLA includes an interface to the latest version of the Planck Sky Model simulation tool, with a simple user interface that allows users to simulate the microwave/sub-millimetre sky with Planck, as well as future CMB experiments and custom-defined instruments.

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High angular resolution Sunyaev Zel'dovich observations: the case of MISTRAL

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The interaction of the Cosmic Microwave Background (CMB) photons with hot electron gas in Galaxy Clusters and surrounding medium can be detected through the Sunyaev Zel'dovich effect. When this effect is detected with high enough angular resolution (~10") it allows astrophysicists to study the physics of galaxy clusters, relaxed and non-relaxed clusters, and detect filamentary structures which could give the possibility to detect the Cosmic Web. These observations are one of the main targets of the MISTRAL instrument together with a long list of scientific targets spanning from extragalactic astrophysics to solar system science. MISTRAL (MIllimetric Sardinia radio Telescope Receiver based on Array of Lumped elements kids) is a millimetric camera working in the W–band (77–103 GHz) which will be hosted on the Sardinia Radio Telescope (SRT), the Italian 64-m radio telescope located near Cagliari at 600m above the sea level, managed by INAF. It is being built as a facility instrument by the Sapienza University for INAF, funded by a PON contract for the upgrade of the SRT at high frequency. It will consist of a compact cryostat hosting the re–imaging optics, cooled at 4 K, and a 408–pixel array of photon–noise limited lumped element kinetic inductance detectors, manufactured at CNR-IFN, and cooled at a base temperature lower than 300 mK.

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The CMB Dipole: Eppur Si Muove

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The largest temperature anisotropy in the cosmic microwave background (CMB) is the dipole. The simplest interpretation of the dipole is that it is due to our motion with respect to the rest frame of the CMB (with debate over the possibility of alternative explanations). As well as creating the $\ell = 1$ mode of the CMB sky, this motion affects all astrophysical observations by modulating and aberrating sources across the sky. It can be seen in galaxy clustering, as well as in principle through a dipole-shaped acceleration pattern in quasar positions. Additionally, the dipole modulates the CMB temperature anisotropies with the same frequency dependence as the thermal Sunyaev-Zeldovich (tSZ) effect, and so these modulated CMB anisotropies can be extracted from the tSZ maps produced by Planck. I will discuss this novel way of measuring our motion with respect to the CMB frame, as well as discussing other signatures that may be possible to measure in future.

Cosmic Backgrounds from Radio to Far-IR / 520

New gravitational degrees of freedom as a solution to the dark matter problem.

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Cosmological and astronomical observations indicate that the majority
of mass and energy density of fields in the universe are in a form

which interacts extremely weakly, if at all, with light. The standard interpretation is the existence of dark matter, commonly thought to be in the form of particles not part of the standard model of particle physics. At present a firm detection of such a particle is lacking, and moreover, all these observations concern a mismatch between the observed dynamics of visible matter with its gravitational influence. Hence, a less explored interpretation is that the underlying theory of gravity may not be General Relativity. A hint that this may be the case is the observation by Milgrom that discrepancies concerning galaxies are controlled by a single, seemingly universal, acceleration scale.

In this talk, I will discuss this possibility and focus on a particular relativistic realization constructed to reproduce Milgrom's Modified Newtonian Dynamics law at the scale of galaxies. I will show that this proposal leads to (i) correct gravitational lensing on galactic scales, (ii) tensor modes propagating at the speed of light, and (iii) cosmological evolution in line with observations of the Cosmic Microwave Background anisotropies and the large-scale structure power spectrum.

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Planck constraints on the tensor-to-scalar ratio

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I will present constraints on the tensor-to-scalar ratio r using Planck data as described in [Tristram et al., A&A, 647, A128 (2021)].
In this paper, we use the latest release of Planck maps (PR4), processed with the NPIPE code, which produces calibrated frequency maps in temperature and polarisation for all Planck channels from 30 GHz to 857 GHz using the same pipeline. We computed constraints on r using the BB angular power spectrum, and we also discuss constraints coming from the TT spectrum. Given Planck's noise level, the TT spectrum gives constraints on r that are cosmic-variance limited (withσr =0.093),butweshowthatthe-marginalisedposteriorpeakstowardsnegativevaluesofrataboutthe1.2σlevel.Wederived Planck constraints using the BB power spectrum at both large angular scales (the 'reionisation bump') and intermediate angular scales (the 'recombination bump') from l = 2 to 150 and find a stronger constraint than that from TT, with σr = 0.069. The Planck BB spectrum shows no systematic bias and is compatible with zero, given both the statistical noise and the systematic uncertainties. The likelihood analysis using B modes yields the constraint r < 0.158 at 95 % confidence using more than 50 % of the sky. This upper limit tightens to r < 0.069 when Planck EE, BB, and EB power spectra are combined consistently, and it tightens further to r < 0.056 when the Planck T T power spectrum is included in the combination. Finally, combining Planck with BICEP2/Keck 2015 data yields an upper limit of r < 0.044.

Cosmic Strings

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Thick brane structures in generalized hybrid metric-Palatini gravity

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In this work, we study 5-dimensional braneworld scenarios in the scalar-tensor representation of the generalized hybrid metric-Palatini gravitational theory. We start by considering a model for a brane supported purely by the gravitational scalar fields of the theory and then consider other distinct cases where the models are also supported by an additional matter scalar field. We investigate the stability of the gravity sector and show that the models are all robust against small fluctuations of the metric. In particular, in the presence of the additional scalar field, we find that the profile of the gravitational zero mode may be controlled by the parameters of the model, being also capable of developing internal structure.

Cosmic Strings / 332

Cosmic strings and pulsar timing

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Gravitational wave astronomy opens up a new window of exploration in fundamental physics. The recent analysis by the NANOGrav collaboration based on the 12.5-year pulsar-timing data set has shown evidence for a common red process which is compatible with a stochastic background of gravitational waves. In this talk, we will discuss the interpretation of this signal in terms of physics beyond the Standard Model with focus on cosmic strings, highly energetic topological defects arising as a consequence of cosmological phase transitions in the early Universe.

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Cosmic strings in generalized hybrid metric-Palatini gravity

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We consider the possible existence of gravitationally bound stringlike objects in the framework of the generalized hybrid metric-Palatini gravity theory, in which the gravitational action is represented by an arbitrary function of the Ricci and of the Palatini scalars, respectively. The theory admits an equivalent scalar-tensor representation in terms of two independent scalar fields. Assuming cylindrical symmetry, and the boost invariance of the metric, we obtain the gravitational field equations that describe cosmic stringlike structures in the theory. The physical and geometrical properties of the cosmic strings are determined by the two scalar fields, as well by an effective field potential, functionally dependent on both scalar fields. The field equations can be exactly solved for a vanishing, and a constant potential, respectively, with the corresponding string tension taking both negative and positive values. Furthermore, for more general classes of potentials, having an additive and a multiplicative algebraic structure in the two scalar fields, the gravitational field equations are solved numerically. For each potential we investigate the effects of the variations of the potential parameters and of the boundary conditions on the structure of the cosmic string. In this way, we obtain a large class of stable stringlike astrophysical configurations, whose basic parameters (string tension and radius) depend essentially on the effective field potential, and on the boundary conditions.

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New Evidence of the Azimuthal Alignment of Quasars Spin Vector in the LQG U1.28, U1.27, U1.11, Cosmologically Explained.

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There has been observational evidence about spin axes of quasars in large quasar groups correlated over hundreds of Mpc. This is seen in the radio spectrum as well as in the optical range. There is not yet a satisfactory explanation of this "spooky" alignment.
This alignment cannot be explained by mutual interaction at the time that quasars manifest themselves optically. A cosmological explanation could be possible in the formation of superconducting vortices (cosmic strings) in the early universe, just after the symmetry-breaking phase of the universe.
We gathered from the NASA/IPAC and SIMBAD extragalactic databases the right ascension, declination, inclination, position angle and eccentricity of the host galaxies of 3 large quasar groups to obtain the azimuthal and polar angle of the spin vectors.
The alignment of the azimuthal angle of the spin vectors of quasars in their host galaxy is confirmed in the large quasar group U1.27 and compared with two other groups in the vicinity, i.e., U1.11 and U1.28, investigated by Clowes (2013).
It is well possible that the azimuthal angle alignment fits the predicted azimuthal angle dependency in the theoretical model of the formation of general relativistic superconducting vortices, where the initial axially symmetry is broken just after the symmetry breaking of the scalar-gauge field.

Cosmography with Gravitational Lensing

Cosmography with Gravitational Lensing / 792

H_0 measurement from time-delay cosmography

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The Hubble constant (H_0) is one of the most important parameters in cosmology. Its value directly sets the age, the size, and the critical density of the Universe. Despite the success of the flat ΛCDM model, the derived Hubble constant from Planck data under the assumption of a flat LCDM model has 4.4-σ tension with the direct measurements. If this tension is not due to the systematics, it may indicate the new physics beyond the standard cosmological model. H_0 from time-delay lensing is a powerful independent tool for addressing the H_0 tension since it is independent of both Planck and the distance ladder. One way to do this is to increase the number of high-quality lens systems since this allows us to look for correlations and other effects due to systematics, and to do hierarchical approaches to assess known systematic effects.
Keck AO data is not only the key component to increase the precision of H_0 measurement but also provides systematic checks with the H_0 results based on HST imaging. In this talk, I will present the view of the current H_0 measurement, the systematic checks, and the future prospects of TDCOSMO collaboration.

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Cosmology and Stellar Physics with Strong Lensing

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Co-authors: Gabriel Caminha ; James H. H. Chan ; Frédéric Courbin ; Aleksi Halkola ; Markus Kromer ; Amata Mercurio ; Ulrich Noebauer ; Piero Rosati ; Yiping Shu ; Stuart Sim ; Dominique Sluse ; Stefan Taubenberger ; Christian Vogl ; Akın Yıldırım

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Strongly lensed supernovae (SNe) are emerging as a new probe of cosmology and SN progenitors. The time delays between the multiple images of a lensed SN can be used to determine the Hubble

constant (H0) that sets the expansion rate of the Universe. An independent determination of H0 is important to ascertain the possible need of new physics beyond the standard cosmological model, given the tension in current H0 measurements. I would like to present investigations of SN Refsdal, the first strongly lensed SN with multiple spatially-resolved SN images. While strongly lensed SNe are very rare with currently only 2 known systems, future surveys, particularly the Rubin Observatory Legacy Survey of Space and Time, are expected to yield hundreds of such exciting events. I present a new program aimed to find and study lensed SNe for cosmology and stellar physics.

Cosmography with Gravitational Lensing / 568

A strong Lensing Model of SDSS J1029+2623: prospects for cosmography

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In the last years, thanks to the increased precision of the measurements of the Hubble constant, H0, some tension has emerged between measurements from local and early-Universe probes. Strong gravitational (SL) lenses with measured time delays between the multiple images are yielding a competitive approach to estimate H0, that is independent and complementary to other techniques. Such studies are extremely timely since upcoming surveys, like LSST, are expected to discover hundreds of variable sources multiply lensed by galaxy clusters.
I will present a new SL analysis of the galaxy cluster SDSS J1029+2623 at a redshift of z=0.588, which is one of the few known lens galaxy clusters with multiple images of a background (z=2.1992) quasar, with a measured time delay. I have used archival HST multicolour imaging and MUSE IFS to identify cluster members, measure the stellar velocity dispersions for the brightest of them, and spectroscopically confirm lensed sources. With the newly acquired data, we are able to build a detailed parametric lens mass model, that can shed new light on the known flux ratio anomaly between the quasar images, and give some prospects on the use of this cluster lens to constrain cosmological parameters.

Cosmography with Gravitational Lensing / 765

Cosmography with space-based strong lensing observations

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In this talk, I will present my work on cosmography with strong-lensing in galaxy-clusters observed with the Hubble Space Telescope. I will detail some particular aspects of the analysis, in preparation for future surveys like Euclid and CSST.

Cosmography with Gravitational Lensing / 799

A tale of two double quasars: Hubble constant tension or biases?

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For a flat ΛCDM (standard) cosmology, a small sample of gravitationally lensed quasars with measured time delays has recently provided a value of the Hubble constant H_0 in agreement with data from SNe, but in tension with the Planck flat ΛCDM result. Identifying biases in some methods may solve this tension, avoiding hasty rejection of the standard cosmological model. As a case study, we use two double quasars of the GLENDAMA sample (SBS 0909+532 and SDSS J1339+1310) to discuss the H_0 value in a standard cosmology. Our preliminary analysis focus on the role of several parameters: astrometry for the lens system, time delay between images, external convergence and mass model for the main lens galaxy

Cosmography with Gravitational Lensing / 830

Time-delay cosmography in the age of JWST

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Our cosmological discourse is currently dominated by the discrepancy between early and late-time cosmological probes. This tension, if confirmed, can only be resolved by yet unknown physics or by our lack of accounting for systematic uncertainties in the methods. Given the drastic implications of the former, the latter has been of great interest lately. In the context of time-delay strong lensing (TDSL), which has been established as one of the few powerful and independent probes of H0, the prominent mass-sheet degeneracy (MSD) is commonly cited as being a significant source of systematics. This degeneracy is tightly linked to our lack of understanding of the inner mass density profiles of galaxies and introduces a full degeneracy with H0 in the models. Additional tracers of the underlying gravitational potential are needed to break the degeneracy. Yet, current observational facilities fall short in obtaining the required data. In my talk, I will show how JWST will help us to finally break the MSD, by tightly constraining the amount of mass-sheet that is physically associated with the lens. Based on detailed simulations with JWST-like stellar kinematics, we find that uncertainties of the time-delay distance and the lens angular diameter distance can be limited to better than 10%, without assumptions on the background cosmological model. These distance constraints would translate to a < 4% precision measurement on H0 in flat LCDM cosmology from a single lens. Based on these forecasts, TDSL will regain much of its precision while still allowing for models which are maximally degenerate with H0. This will enable us to obtain a < 2% precision measurement on H0 by means of only a few lens systems and potentially provide a smoking gun evidence to address the H0 tension within JWST's first few years of operation.

Cosmography with Gravitational Lensing / 678

Cluster strong lensing cosmography: robust cosmological constraints from a sample of galaxy clusters

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Galaxy cluster strong lensing has numerous applications in cosmology. Thanks to the wealth of multi-wavelength observations of clusters using state-of-the-art observatories, such as the Hubble Space Telescope and the Very Large Telescope, this field is providing significant contributions to the understanding of our Universe. One of the main points that are still not fully understood is the nature of the components of the Universe. The upcoming generation of observational surveys of the cosmos were designed to probe Dark Matter and Energy as one main scientific goals.

One cosmological probe not yet fully explored is the cluster strong lensing cosmography. Although the main contribution to the light deflection of lensed galaxies is the gravitational potential of foreground galaxies, the background geometry of the Universe has a non-negligible effect. Thanks to the high accuracy of current strong lens models, we can probe this "secondary" quantity with unprecedented precision. In the ΛCDM framework, these quantities are Dark Matter and Energy densities, and the Dark Energy equation of state.

In this talk, I will present the combined strong lensing constraints on the quantities above from a sample of galaxy clusters, in contrast to what was done in single systems until today. I will show that the combined constraints are powerful in probing the background geometry of the Universe, and are also nicely complementary to other probes such as the cosmic microwave background, Supernovae-Ia and Baryonic Acoustic Oscillations. Hence, cluster strong lensing will be a competitive cosmological probe and paramount in the observations of the next generation of surveys such as the Rubin Observatory Legacy Survey of Space and Time (LSST) and Euclid space telescope.

Cosmography with Gravitational Lensing / 1010

Search for lensing signatures in the gravitational-wave observations from the first half of LIGO-Virgo's third observing run

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The Advanced LIGO and Advanced Virgo detectors are now observing large numbers of gravitational-wave signals from compact binary coalescences, with 50 entries in the latest transient catalogue GWTC-2. The next detector upgrades will continue bringing rapidly growing event rates and redshift range, so our chances become better both to detect rare astrophysical effects on these novel cosmic messengers and to employ them as cosmological probes. Gravitational lensing, with its long and productive history in electromagnetic astronomy, holds particularly great potential for the future of GW astrophysics and cosmology. This presentation covers the first LIGO-Virgo collaboration search for signatures of gravitational lensing in data from O3a, the first half of the third advanced detector observing run. We study: 1) the expected rate of lensing at current detector sensitivity and the implications of a non-observation of strong lensing or a stochastic gravitational-wave background on the merger-rate density at high redshift; 2) how the interpretation of individual high-mass events would change if they were found to be lensed; 3) the possibility of multiple images due to strong lensing by galaxies or galaxy clusters; and 4) possible wave-optics effects due to point-mass microlenses. Overall, we find no compelling evidence for lensing in the observed GW signals from any of these analyses on current data, but we also highlight the future prospects of lensed GWs with the current detector network at design sensitivity and future detectors.

Dark Energy and the Accelerating Universe

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Tracker phantom field and a cosmological constant: dynamics of a composite dark energy model

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We study here phantom models of dark energy represented by a scalar field and with tracker properties. By means of a change of polar-like of variables, we study a general class of models classified in terms of a set of three free parameters. Upon comparison of the models with observations, and considering Bayesian evidence, our results suggest a preference for phantom-like dark energy and possibly a negative cosmological constant.

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Observational constraints on nonlinear matter extensions of general relativity

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We present a phenomenological but thorough analysis of current observational constraints on classes of FLRW cosmological models in which the matter side of Einstein's equations includes, in addition to the canonical term, a term proportional to some function of the energy-momentum tensor ($T^2 \equiv T_{\alpha\beta}T^{\alpha\beta} = \rho^2 + 3p^2$), or of its trace ($T = \rho - 3p$). Qualitatively, we may think of these models as extensions of general relativity with a nonlinear matter Lagrangian. As such they are somewhat different from the usual dynamical dark energy or modified gravity models: in the former class of models one adds further dynamical degrees of freedom to the Lagrangian (often in the form of scalar fields), while in the latter the gravitational part of the Lagrangian is changed. We study both of these models under two different scenarios: (1) as phenomenological two-parameter or three-parameter extensions of the standard ΛCDM, in which case the model still has a cosmological constant but the nonlinear matter Lagrangian leads to additional terms in Einstein's equations, which cosmological observations tightly constrain, and (2) as alternatives to ΛCDM, where there is no cosmological constant, and the nonlinear matter term would have to provide the acceleration

(which would be somewhat closer in spirit to the usual modified gravity models). A comparative analysis of the observational constraints obtained in the various cases provides some insight on the level of robustness of the ΛCDM model and on the parameter space still available for phenomenological alternatives.

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Testing Late Time Cosmic Acceleration with uncorrelated Baryon Acoustic Oscillations dataset

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Baryon Acoustic Oscillations (BAO) involve measuring the spatial distribution of galaxies to determine the growth rate of cosmic structure. We derive constraints on cosmological parameters from 17 uncorrelated BAO measurements that were collected from 333 published data points in the effective redshift range 0.106≤z≤2.36. We test the correlation of the subset using random covariance matrix. The ΛCDM model fit yields the cosmological parameters: Ωm=0.261±0.028 and ΩΛ=0.733±0.021. Combining the BAO data with the Cosmic Chronometers data, the Pantheon Type Ia supernova and the Hubble Diagram of Gamma Ray Bursts and Quasars, the Hubble constant yields 69.85±1.27km/sec/Mpc and the sound horizon distance gives: 146.1±2.15Mpc. Beyond the ΛCDM model we test ΩKCDM and wCDM. The spatial curvature is Ωk=−0.076±0.012 and the dark energy equation of states: w=−0.989±0.049. {We perform AIC test to compare the 3 models and see that ΛCDM scores best.

Dark Energy and the Accelerating Universe / 612

Observational signatures of dark energy and dark matter interactions

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We place observational constraints on two models within a class of scenarios featuring an elastic interaction between
dark energy and dark matter that only produces momentum exchange up to first order in cosmological perturbations. The first one corresponds to a perfect-fluid model of the dark components with an explicit interacting Lagrangian, where dark energy acts as a dark radiation at early times and behaves as a cosmological constant at late times. The second one is a dynamical dark energy model with a dark radiation component, where the momentum exchange covariantly modifies the conservation equations in the dark sector.
Using Cosmic Microwave Background (CMB), Baryon Acoustic
Oscillations (BAO), and Supernovae type Ia (SnIa) data, we show that the Hubble tension can be alleviated due to the additional radiation, while the σ_8 tension present in the Λ-cold-dark-matter model can be eased by the weaker galaxy clustering that occurs in these interacting models. Furthermore, we show that, while CMB+BAO+SnIa data put only upper bounds on the coupling strength, adding low-redshift data in the form of a constraint on the parameter S_8 strongly favours nonvanishing values of interaction parameters. Our findings are in line with other results in the literature that could signal a universal trend of the momentum exchange among the dark sector.

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Non-linear perturbations in the Galileon Ghost Condensate model

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Although the LCDM model is very successful in explaining current cosmological observations, in light of numerous tensions between data and theory, it is worth investigating the evolution of perturbations in alternative models, especially in the non-linear regime, where future surveys will provide a wealth of data. In this talk I will derive the relevant equations necessary to describe matter perturbations within the spherical collapse model for the Galileon Ghost Condensate, which extends the well known cubic covariant Galileon. I will show how the mass function is affected by the different evolution of perturbations and present a simple recipe which maps the linear matter power spectrum to the non-linear one. I will also extend the analysis to discuss the lensing convergence.

Dark Energy and the Accelerating Universe / 104

Cosmology with Type Ia supernovae: Searching for systematics and model independent reconstructions

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We analyze the Joint Light-curve Analysis (JLA) Type Ia supernovae (SN Ia) compilation implementing the non-parametric iterative smoothing method. We explore the SN Ia light-curve hyperparameter space and find no dark energy model dependence nor redshift evolution of the hyperparameters. We also analyze the more recent Pantheon SN Ia compilation to search for possible deviations from the expectations of the concordance ΛCDM model. We demonstrate that the redshift binned best fit parameter values oscillate about their full dataset best fit values with considerably large amplitudes. At the redshifts below $z \approx 0.5$, we show that such oscillations can only occur in 4 to 5% of the simulations. This might be a hint for some behavior beyond the predictions of the concordance model or a possible additional systematic in the data. In addition, we develop a non-parametric approach using the distribution of likelihoods from the iterative smoothing method. It determines consistency of a model and the data without comparison with another model. Simulating future WFIRST-like data, we show how confidently we can distinguish different dark energy models using this approach.

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The CMaDE Model: a simple Quantum Mechanical explanation for the Accelerated Expansion of the Universe

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Nowadays one of the greatest mysteries of science is to find out why the universe has an accelerated expansion. In this talk we show that by considering the quantum nature of the gravitational field, we can associate an effective Compton mass to the wavelength of the graviton. The Compton Mass Dark Energy (CMaDE) model proposes that this mass can be interpreted as dark energy, with a Compton wavelength given by the size of the observable universe R_H, implying that the dark energy varies depending on this size. We find that the dark energy density rate is given by $\Omega_\Lambda = 2\pi^2/3/R_H^2$, it has no free constants and depends exclusively on the radiation rate Ω_r. Using $\Omega_r = 9.54 \times 10^{-5}$, the theoretical prediction for a flat universe of the dark energy rate is $\Omega_\Lambda = 0.6922$. We perform a study in general for a non-flat universe, using the Planck data and a modified version of the CLASS code we find a very good fit with the Cosmic Microwave Background and Mass Power Spectrum profiles, provided that the Hubble parameter today is $H_0 = 66$ km/s/ for a flat universe and $H_0 = 72$ km/s/Mpc for an universe with curvature $\Omega_k = 0.05$. We conclude that the CMaDE model provides a natural explanation for the accelerated expansion and coincidence problem of the universe.

Dark Energy and the Accelerating Universe / 214

Cosmological reconstruction of gravity

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We use the CMB, BAO, SN and galaxy weak lensing data to jointly reconstruct the effective dark energy density and the two phenomenological functions (mu and Sigma) describing possible modified gravity effects in the evolution of large scale structure. I will focus on the dependence of such reconstructions on the underlying assumptions (priors) and their implications for dark energy and modified gravity theories.

Dark Energy and the Accelerating Universe / 452

Constraining the dark energy-dark matter interaction model using low-redshift observations

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Various observations have shown that dark energy accounts for nearly two-thirds of the energy density of the Universe.
The simplest model to explain the nature of dark energy is the cosmological constant (ΛCDM) model. Although Planck observations supports using ΛCDM model as the base cosmological model, there exist some inconsistencies in parameter estimates when compared with independent observations. The most important is the inconsistency in the H_0 estimates from the Planck collaboration which reports H_0=$67.5^{+0.5}_{-0.5}$ km s^{-1} Mpc^{-1}, a considerably lower value when compared with the direct local distance ladder measurements. This value shows a discrepancy at the level
greater than 4σ with the constraints reported by SH0ES collaboration in 2019, H_0=$74.3^{+1.42}_{-1.42}$ km s^{-1}

Mpc^{-1}. These disagreements, called the Hubble tension, point towards a new physics that deviates from the standard ΛCDM model and to resolve this various methods have been proposed.
In this talk, we focus on an interacting dark energy dark matter model where the interacting term is taken to be linear in the field (ϕ) and a quintessence scalar field with an inverse power potential ($V(\phi) \sim \phi^{-n}$) is assumed as a description of dark energy. We study in detail the evolution of the model and provide constraints on the model parameters using low redshift cosmological observations of Type Ia Supernovae (SN), baryon acoustic oscillations (BAO), direct measurements of Hubble parameter (Hz) and high redshift HII galaxy measurements (HIIG). We find that the model agrees with the existing values of the nonrelativistic matter density parameter, Ω_m and dark energy equation of state parameter, w_0. The analysis shows that the interacting model prefers a negative value of coupling constant and gives the best fit value of H_0= $69.9^{+0.46}_{-1.02}$ km s^{-1} Mpc^{-1} and thereby alleviates the H_0 tension between Planck measurements and the observations considered. [arxiv: 2102.12367].

Dark Energy and the Accelerating Universe / 705

Evidence for Emergent Dark Energy

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We discuss a generalised form of an emergent dark energy model with one degree of freedom for the dark energy sector that has the flexibility to include both ΛCDM model as well as the Phenomenologically Emergent Dark Energy (PEDE) model proposed by Li & Shafieloo (2019) as two of its special limits. The free parameter for the dark energy sector, namely Δ, has the value of 0 for the case of the Λ and 1 for the case of PEDE. We confront the model with various cosmological observations and put constraints on the Δ parameter and show that at the current status of cosmological observations, there is considerable evidence in favor of emergent dark energy with respect to the case of the cosmological constant. I will also briefly discuss how near future observations can make things clear in favor or against this model.

Dark Energy and the Accelerating Universe / 745

Soft Dark Energy and Soft Dark Matter

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Standard cosmology is based on the assumption that the dark fluids behave as standard, hard matter. On the other hand, soft matter is a well studied field in condensed matter physics. We investigate the possibility of soft cosmology", namely the appearance (intrinsically or effectively) of soft-matter properties in the dark sectors. We propose a novel parametrization introducing thesoftness parameters", which quantify the scale dependence of the dark sector's EoS, i.e the difference between large and intermediate scales. Although the background evolution remains unaffected, even a slightly non-trivial softness parameter improves the clustering behavior and alleviates e.g. the $f\sigma_8$ tension. Soft dark energy and soft dark matter seem to be favoured by the data comparing to LambdaCDM scenario.

Dark Energy and the Accelerating Universe / 18

Testing LCDM with eBOSS / SDSS

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In this talk I will review recent progress that the SDSS-IV / eBOSS collaboration has made in constraining cosmology from the clustering of galaxies, quasars and the Lyman-alpha forest. The SDSS-IV / eBOSS collaboration has measured the baryon acoustic oscillation (BAO) and redshift space distortion (RSD) features in the correlation function in redshift bins from z~0.15 to z~2.33. These features constitute measurements of angular diameter distances, Hubble distances, and growth rate measurements. A number of consistency tests have been performed between the BAO and RSD datasets and additional cosmological datasets such as the Planck cosmic microwave background constraints, the Pantheon Type Ia supernova compilation, and the weak lensing results from the Dark Energy Survey. Taken together, these joint constraints all point to a broad consistency with the standard model of cosmology ΛCDM + GR, though they remain in tension with local measurements of the Hubble parameter.

Dark Energy and the Accelerating Universe / 868

Probing the swampland with dark energy observations of Euclid, SKA, and LSST.

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We explore the ability of future cosmological surveys to put string theory under pressure through the Swampland program. It is well known that constructing consistent string theory solutions in a de Sitter background is tremendously difficult. This led to speculative constraints on the shape of the potential felt by the dark energy scalar field. This is known as the "de-Sitter conjecture" and low-energy effective theories that violate it are believed to live in the Swampland. Future experiments, such as the Vera Rubin Observatory, Euclid or SKA, will set strong constraints on dark energy and we investigated their potential conflict with the Swampland conditions. In particular, we show that the expected constraints on the equation of states of dark energy might be in severe contradiction with the de-Sitter conjecture. Our study is carried out for many different quintessence potentials and a very wide range of initial conditions. The improvements with respect to available measurements are precisely estimated. The analysis is also extended to very long term perspectives.
Based on: Barrau, Renevay, and Martineau, Astrophysical Journal 912 (2021) 2, 99

Dark Energy and the Accelerating Universe / 84

Testing F(Q) gravity with redshift space distortions

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A cosmological model with Symmetric Teleparallel Gravity where gravity is non-metrical is constrained with redshidt space distortions data. The cosmological background for the model mimics a ΛCDM evolution but differences arise in the perturbations. The linear matter fluctuations are numerically evolved and the study of the growth rate of structures is analysed in this cosmological setting. The best fit parameters reveal that the σ8 tension between Planck and Large Scale Structure data can be alleviated within this framework.

Dark Energy and the Accelerating Universe / 811

Simulation-wise Comparison of Yukawa and Newtonian Gravitational Forces

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In a cubic cosmological simulation box with three-dimensional periodicity, we determine the gravitational potential and force generated by a single particle. Using both the Newtonian approximation and Yukawa law of gravity within the cosmic screening approach [1,2], we zoom into the regions in the box where the distinction among them becomes significant. Extending the analysis to corresponding physical distances today as well as at late stages of matter domination, we show how employing Newtonian approximation over Yukawa gravity affects simulations of structure formation in terms of force computation. Additionally, we compare the plain Yukawa (non-periodic) and Yukawa-Ewald (periodic) forces in the box to study the impacts of periodic boundaries.

[1] M. Eingorn, First-order cosmological perturbations engendered by point-like masses. ApJ **825**, 84 (2016). arXiv:1509.03835.
[2] E. Canay, M. Eingorn, Duel of cosmological screening lengths. Phys. Dark Univ. **29**, 100565 (2020). arXiv:2002.00437.

Dark Energy and the Accelerating Universe / 883

A simple parametrisation for coupled dark energy

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As an alternative to the popular parametrisations of the dark energy equation of state, we construct a quintessence model where the scalar field has a linear dependence on the number of e-folds. Constraints on more complex models are typically limited by the degeneracies that increase with the number of parameters. The proposed parametrisation conveniently constrains the dark energy equation of state as it allows for a wide variety of time evolutions. We also consider a non-minimal coupling to cold dark matter. We fit the model with Planck and KiDS observational data. The CMB favours a non-vanishing coupling with energy transfer from dark energy to dark matter. Conversely, gravitational weak lensing measurements slightly favour energy transfer from dark matter to dark energy, with a substantial departure of the dark energy equation of state from -1.

Dark Energy and the Accelerating Universe / 914

Reconstructing the growth and expansion history. The case for negative dark energy?

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The consistency between the cosmic expansion and growth may hold clues about the nature of the acceleration of the Universe. Using model-independent methods, we reconstruct the growth history from redshift-space distortion and deduce the corresponding expansion history, which we test against supernovae data. Motivated by these results, we then introduce a model of two-component dark energy with a negative cosmological constant hidden behind a phantom-like fluid, and study the viability of such models against state-of-the-art data. While the model does not show better evidence than a cosmological constant, it is still consistent with the data.

Dark Energy and the Accelerating Universe / 100

On the Hubble constant tension in the SNe Ia Pantheon sample

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The Hubble constant (H0) tension between Type Ia Supernovae (SNe Ia) and Planck measurements ranges from 4 to 6 σ. To investigate it, we estimate H0 in the ΛCDM and w0waCDM models by dividing the Pantheon sample, a collection of 1048 SNe Ia, into 3, 4, 20, and 40 bins. A preliminary consistency check is performed, considering the compatibility of contours for 3 and 4 bins with the ones of the total Pantheon sample through a 2-D analysis where the nuisance parameters are H0 and Ω0m. For each bin, a 1-D Monte Carlo Markov-Chain analysis for H0 with the D'Agostini method is performed in order to extract the value of H0, considering a fiducial absolute magnitude of SNe Ia M~-19.25. We will show the MCMC application through the Cobaya package for Python. We fit the extracted H0 values with a function describing the redshift evolution: g(z)=H'0/(1+z)^α, where α is the evolutionary parameter and H'0=H0 at z=0. We find that H0 evolves with redshift, showing a slowly decreasing trend, with α coefficients in the order of 10^-2, consistent with zero only from 1.2 to 2.0 σ. Interestingly, in the extrapolation of H0 to z=1100, the redshift of the last scattering surface, we obtain values of H0 compatible in 1 σ with Planck measurements independently of cosmological models. Thus, we have reduced the H0 tension from 54% to 72% for the ΛCDM and w0waCDM models, respectively. If the decreasing trend of H0 is real, it could be due to astrophysical selection effects, such as the stretch evolution, or to modified gravity, such as the f(R) theories.

Dark Energy and the Accelerating Universe / 617

On the evolution of inhomogenous perturbations in the ΛCDM model and f(R) modified gravity theories

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In this talk we focus on weak inhomogeneous Universe models at low redshift, described by the Lemaître-Tolman-Bondi (LTB) metric within the framework of f(R) modified gravity theories. The principal aim of this study was to compare the evolution of inhomogeneous perturbations in the ΛCDM and alternative f(R) cosmological models, assuming a flat Friedmann-Lemaître-Robertson-Walker (FLRW) metric as the background. We used the equivalent scalar-tensor formalism in the Jordan frame, for which the extra degree of freedom of the f(R) function is translated into a non-minimally coupled scalar field. The evolution of perturbations was investigated at the first order in time and space, separately. We found spherically symmetric solutions using perturbative and numerical techniques. The results appear to distinguish between the presence of a cosmological constant and the scalar field. Moreover, the results are valid for any f(R) model, since the radial profiles of perturbations do not depend on the particular choice of the f(R) function.

Dark Energy and the Accelerating Universe / 88

Probing modified gravity with cosmology and solutions to the Hubble tension

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The late time cosmic acceleration is one of the most puzzling phenomena in modern cosmology. Its modeling within General Relativity (GR) through the cosmological constant (L) results in the LCDM scenario. Although the latter gives a precise description of the Universe, it is known that it still contains a number of unresolved problems. These lead researchers to look for modified gravity models, for example by including additional degrees of freedom. In this talk I will present the phenomenology and the cosmological bounds of theories consistent with the gravitational-wave event GW170817. In particular I will discuss models which solve the Hubble tension between Planck and local measurements and for which data show a statistically significant preference over LCDM.

Dark Energy and the Accelerating Universe / 517

Testing the equivalence principle on cosmological scales

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The weak equivalence principle is one of the cornerstone of general relativity. Its validity has been tested with impressive precision in the Solar System, with experiments involving baryonic matter

and light. However, on cosmological scales and when dark matter is concerned, the validity of this principle is still unknown. In this talk I will show how relativistic effects in the large-scale structure can be used to test whether dark matter obeys the weak equivalence principle. I will present forecasts for this new test of gravity for future surveys like DESI and the SKA, showing that deviations from the equivalence principle can be constrained with a precision of order 10 percent.

Dark Energy and the Accelerating Universe / 1011

Gravitational Interaction in the Chimney Lattice Universe

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We investigate the influence of the chimney topology TxTxR of the Universe on the gravitational potential and force that are generated by point-like massive bodies. We obtain three distinct expressions for the solutions. One follows from Fourier expansion of delta functions into series using periodicity in two toroidal dimensions. The second one is the summation of solutions of the Helmholtz equation, for a source mass and its infinitely many images, which are in the form of Yukawa potentials. The third alternative solution for the potential is formulated via the Ewald sums method applied to Yukawa-type potentials. We show that, for the present Universe, the formulas involving plain summation of Yukawa potentials are preferable for computational purposes, as they require a smaller number of terms in the series to reach adequate precision.

Dark Energy and the Accelerating Universe / 867

Observational Constraints of Dark D-Brane Cosmology

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"Dark energy", a matter/energy source whose nature is still not well understood, is widely assumed as an explanation for the observed accelerated expansion of the Universe. The standard model of cosmology, the ΛCDM model, consists of the simplest scenarios in which dark energy is a cosmological constant. Even though it provides an impressive fit to the available cosmic background radiation and large-scale distribution of galaxies observational data, this model is still hunted by conceptual problems and observational tensions.
To tackle some of these issues, it is common to take generalisations of the cosmological constant, such as promoting it to a dynamical scalar field, with the possibility of having interaction with the matter sector.
In this talk I will give a brief overview of interacting dark energy models, with particular focus on disformal couplings and its cosmological implications. More concretely, I will focus on the general Dark D-Brane scenario, that predicts a natural interaction in the dark sector related with the induced metric on a moving brane. Furthermore, I will present the main cosmological predictions of this setting, obtained through a numerical study, together with a statistical data analysis to produce observational constraints.

Dark Energy and the Accelerating Universe / 767

Anisotropic cosmological models in Horndeski gravity

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It was found recently that the anisotropies in the homogeneous Bianchi~I cosmology considered within the context of a specific Horndeski theory are damped near the initial singularity instead of being amplified. In this work we extend the analysis of this phenomenon to cover the whole of the Horndeski family. We find that the phenomenon is absent in the K-essence and/or Kinetic Gravity Braiding theories, where the anisotropies grow as one approaches the singularity. The anisotropies are damped at early times only in more general Horndeski models whose Lagrangian includes terms quadratic and cubic in second derivatives of the scalar field. Such theories are often considered as being inconsistent with the observations because they predict a non-constant speed of gravitational waves. However, the predicted value of the speed {\it at present} can be close to the speed of light with any required precision, hence the theories actually agree with the present time observations.
We consider two different examples of such theories, both characterized by a late self-acceleration and an early inflation driven by the non-minimal coupling. Their anisotropies are maximal at intermediate times and approach zero at early and late times. The early inflationary stage exhibits an instability with respect to
inhomogeneous perturbations, suggesting that the initial state of the universe should be inhomogeneous. However, more general Horndeski models may probably be stable.

Dark Matter and Rare Processes

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The Dark Matter Directionality Approach

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Dark Matter particle candidates able to induce nuclear recoils can be also studied using the so-called directionality technique. This approach is based on studying the correlation between the nuclear recoils direction and the Earth motion in the galactic rest frame.
Several experimental techniques to explore the directionality approach have been proposed. In this talk, a review of such experimental approaches will be addressed.

Dark Matter and Rare Processes / 450

Leptophillic Dark Matter at Linear Colliders

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Leptophilic dark matter (LDM) could naturally arise in many beyond the Standard Model scenarios and could address certain experimental anomalies. We will discuss some model-independent collider constraints on the LDM effective couplings with the Standard Model sector, considering its production at a future electron-positron linear collider (with polarized and unpolarized beam options) in the mono-photon and mono-Z channels.

Dark Matter and Rare Processes / 521

Indirect Search for Dark Matter signatures in the Cosmic Rays as seen from Space

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The Dark Matter (DM) problem, experimentally, is tackled in different ways that can fall into two main complementary areas: direct and indirect searches. Among the indirect searches for DM, the observation from space of possible indirect signatures in the Cosmic Rays and in the gamma-ray sector has triggered increasing interest in the last years, with space missions like PAMELA, AMS, FERMI, DAMPE and with the planned projects like GAPS (on stratospheric balloon) and HERD. This talk will give an overview on the current status of this field of research and on the perspectives awaited by future planned missions.

Dark Matter and Rare Processes / 277

Quantum mechanics tests in the Gran Sasso undergroud laboratory: collapse models and spin-statistics

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We are experimentally investigating possible departures from the standard quantum mechanics' predictions at the Gran Sasso underground laboratory in Italy.
In particular, with radiation detectors we are searching signals predicted by the collapse models (spontaneous emission of radiation) which were proposed to solve the "measurement problem" in quantum physics and signals coming from a possible violation of the Pauli Exclusion Principle.
I shall discuss our recent results published in Nature Physics under the title "Underground test of gravity-related wave function collapse", where we ruled out the natural parameter-free version of the gravity-related collapse model. I shall then present more generic results on testing CSL (Continuous Spontaneous Localization) collapse models and discuss future perspectives.
Finally, I shall briefly present the VIP experiment with which we look for possible violations of the Pauli Exclusion Principle by searching for "impossible" atomic transitions and comment the impact of this research in relation to Quantum Gravity models.

Dark Matter and Rare Processes / 573

Mirror Dark Matter: direct detection, ultra cold neutrons and gravitational waves

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We will discuss Mirror dark matter searches from
Direct detection underground experiments, ultra cold neutrons and gravitational waves physics.

Dark Matter and Rare Processes / 80

The dark matter: DAMA/LIBRA and its perspectives

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The recent results of DAMA/LIBRA–phase2 experiment deep underground at Gran Sasso are presented. The improved experimental configuration with respect to the phase1 allowed a lower software energy threshold. The DAMA/LIBRA–phase2 data confirm the evidence of a signal that meets all the requirements of the model independent Dark Matter annual modulation signature, at high C.L. The model independent DM annual modulation result is compatible with a wide set of DM candidates. Some of them and perspectives will be outlined.

Dark Matter and Rare Processes / 280

Improving the sensitivity to light dark matter with the Migdal effect

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The search for dark matter (DM) weakly interacting massive particles with noble elements has probed masses down and below a GeV/c^2. The ultimate limit is represented by the experimental threshold on the energy transfer to the nuclear recoil. Currently, the experimental sensitivity has reached a threshold equivalent to a few ionization electrons. In these conditions, the contribution of a Bremsstrahlung photon or a so-called Migdal electron due to the sudden acceleration of a nucleus after a collision might be sizeable. We present a recent work where, using a Bayesian approach, we studied how these effects can be exploited in experiments based on liquid argon detectors. In particular we develop a simulated experiment to show how the Migdal electron and the Bremsstrahlung photon allow to push the experimental sensitivity down to masses of 0.1 GeV/c^2, extending the search region for dark matter particles of previous results. For these masses we estimate the effect of the Earth shielding that, for strongly interacting dark matter, makes any detector blind. Finally, given the relevance of the Migdal electrons to the search for low mass DM, we discuss some new ideas on how to possibly measure such an effect with detectors based on a Time Projection Chamber exposed to an high neutron flux.

Dark Matter and Rare Processes / 527

Dark photon search

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The Heavy Photon Search (HPS) experiment searches for an electro-produced dark photon using an electron beam provided by the CEBAF accelerator at the Thomas Jefferson National Accelerator Facility.
HPS looks for dark photons through two distinct methods, a resonance search in the e+e- invariant

mass distribution above the large QED background (large dark photon-SM particles coupling region) and a displaced vertex search for long-lived dark photons (small coupling region).

HPS employs a compact spectrometer, matched to the forward kinematic characteristics of A' electroproduction. The detector consists of a silicon tracker for momentum analysis and vertexing and a lead tungstate (PbWO4) electromagnetic calorimeter for particle ID and triggering.
Three taking periods took place in 2015, 2016 and 2019, while a fourth run has been scheduled in summer 2021.

Results from the available data are presented together with an overview of future projects.

Dark Matter and Rare Processes / 208

DAMA/LIBRA annual modulation and Axion Quark Nugget Dark Matter Model

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The DAMA/LIBRA experiment shows 9.5σ evidence for an annual modulation in the $(1-6)$ keV energy range, strongly suggesting that the observed modulation has the dark matter origin. However, the conventional interpretation in terms of WIMP-nucleon interaction is excluded by other experiments. We propose an alternative source of modulation based on the so-called axion quark nugget (AQN) dark matter model which was originally invented long ago to explain the similarity between the dark and visible cosmological matter densities, i.e. $\Omega_{\rm dark} \sim \Omega_{\rm visible}$. This proposal can be directly tested by COSINE-100, ANAIS-112, CYGNO and other similar experiments. I will also mention other possible manifestations of the same model such as the solar corona heating problem, and the recently detected by Telescope Array the Mysterious Burst Events which are very distinct from conventional cosmic air showers.

The talk is based on several recent papers including:
1. A.~Zhitnitsky,DAMA/LIBRA annual modulation and Axion Quark Nugget Dark Matter Model," Phys. Rev. D {101}, no.8, 083020 (2020) [arXiv:1909.05320 [hep-ph]]
2. A.~Zhitnitsky,The Mysterious Bursts observed by Telescope Array and Axion Quark Nuggets," J. Phys. G {48}, no.6, 065201 (2021) [arXiv:2008.04325 [hep-ph]]

Dark Matter Detection

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Dark Matter Searches at Colliders

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Many new physics models like SUSY can have dark matter candidates. Collider experiment provides a unique approach search for dark matter candidates. Like neutrinos, dark matter candidates, once produced from high energy particle collisions, would escape from detection and leave a signature of missing energy. The production mechanism through effective field theory model, simplified model and UV-completed models have been proposed and searched. In addition, the mediator of interactions between dark matter and SM particles is another target which can be probed at collider experiments, which turn out to have a quite high sensitivity in some parameter space. In this talk, I will give an overview the strategy of collider search for dark matter and discuss the current experimental constraints. The collider's constraints can be combined with direct detection experiments to cover a large scope of dark matter parameter space.

Dark Matter Detection / 203

The SuperCDMS SNOLAB experiment: Mining Dark Matter in Northern Canada

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Cold Dark matter is one of the major constituents of the leading cosmological model for our Universe, with many ongoing experimental efforts at directly detecting interactions of the hypothetical particle with terrestrial detectors.

SuperCDMS SNOLAB is a Generation-2 dark matter experiment under construction at SNOLAB in Sudbury, Canada. The experiment will employ two types of state of the art cryogenic Ge and Si detectors capable of detecting sub-keV energy depositions from potential dark matter interactions. This talk will present the ongoing efforts in building the SuperCDMS SNOLAB experiment as well as future operational plans to ultimately deploy an array of 24 detectors with the goal of improving sensitivity to light dark matter particles by orders of magnitude compared to existing limits.

Dark Matter Detection / 325

Search of Light Dark matter with the CRESST-III experiment.

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The CRESST-III (Cryogenic Rare Event Search with Superconducting Thermometers) experiment, located in the Gran Sasso underground laboratory (LNGS, Italy), aims at the direct detection of light dark matter (DM) particles.
Scintillating $CaWO_4$ crystals operated as cryogenic detectors at mK temperatures are used as target material for elastic DM-nucleus scattering. The simultaneous measurement of the phonon signal from the $CaWO_4$ crystal and the emitted scintillation light in a separate cryogenic light detector provides particle discrimination on an event-by-event basis. The experiment, optimized for low-energy nuclear recoil detection, reached an unprecedented threshold of 30 eV for nuclear recoil energies and it is currently leading the field of low-mass dark matter search, for values as low as 160 MeV/c^2.

In this contribution, the current stage of the CRESST-III experiment, together with the most recent dark matter results will be presented. The perspective for the next phase of the experiment will be also discussed

Dark Matter Detection / 401

Understanding Axion Miniclusters: Formation and observational signatures

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Axion dark matter can be produced by the decay of cosmic strings, leading to large amplitude, small scale density perturbations in the axion field. These perturbations for the seeds for axion "miniclusters": small and dense dark matter clumps, with mass $M \approx 10^{-12}M_{\odot}$. The seeds go on to form minicluster halos via hierarchical structure formation. By comparison between the semi-analytic Peak-Patch model and N-body simulations, we show that these minicluster halos are too diffuse to produce a detectable microlensing signal. However, the halos also tend to have dense substructures due to the survival of the initial seeds. The dense substructures are formed by direct collapse in the radiation dominated epoch, and are morphologically distinct from the later-formed halos, and thus may have density profiles that enable them to produce their own lensing signal. Using our analytic model and simulations, we investigate this possibility and study in detail the formation, evolution, and survival of the minicluster seeds.

Dark Matter Detection / 634

Explaining the recent XENON1T excess with Inelastic Dark matter

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Measuring dark matter (DM) signals via electron recoil provides an important means
for the direct detection of light DM particles. In this talk, I will show that the recent XENON1T anomaly with electron recoil energy around (2 − 3) keV can be naturally explained by the exothermic inelastic scattering between DM and electrons in a 2-component DM scenario. The stability of the heavier component is guaranteed by the small mass gap which sources the electron recoil energy. We provide an effective field analysis on this scenario focusing on the direct detection and relic density constraints. I will also discuss probable UV completions of this scenario.

Dark Matter Detection / 1035

Dark matter search at the CEPC

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After the Higgs discovery, the precise determination of the Higgs boson properties became one of the top priorities for experimental particle physics. The Circular Electron Positron Collider is therefore proposed. Colliding the electron and positron at a tunnel with the main ring circumference of 100 km, the CEPC is expected to deliver 1 Million Higgs bosons in an extremely clean collision environment. In addition, the CEPC also produces 100 Million W bosons and nearly 1 Tera Z bosons. This large statistic of bosons generated in clean collision environment, and the model-independent tagging of the Higgs events, makes CEPC an excellent discovering window for the dark matter, via the Higgs invisible decay and other processes. This talk reports the simulation studies of dark matter search at the CEPC, as well as the anticipated accuracies at other future facilities.

Dark Matter Detection / 952

Halo uncertainties in electron recoil events at direct detection experiments

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The dark matter direct detection rates are highly correlated with the phase space distribution of dark matter particles in our galactic neighbourhood. In this paper we make a systematic study of the
impact of astrophysical uncertainties on electron recoil events at the direct detection experiments with Xenon and semiconductor detectors. We find that within the standard halo model there can be up to ~ 50% deviation from the fiducial choice in the exclusion bounds from these observational. uncertainties. For non-standard halo models we report a similar deviation from the fiducial standard halo model when fitted with state-of-art N-body simulation while even larger deviations are obtained in case of the observational uncertainties

Dark Matter Detection / 938

Detecting planetary-mass primordial black holes with resonant electromagnetic gravitational-wave detectors

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The possibility to detect gravitational waves (GW) from planetary-mass primordial black hole (PBH) binaries with electromagnetic (EM) detectors of high-frequency GWs is investigated. We consider two patented experimental designs, based on the inverse Gertsenshtein effect, in which incoming GWs passing through a static magnetic field induce EM excitations inside either a TM cavity or a TEM waveguide. The frequency response of the detectors is computed for post-newtonian GW waveforms. We find that such EM detectors based on current technology may achieve a strain sensitivity down to $h \sim 10^{-30}$, which generates an EM induced power of 10^{-10} W. This allows the detection of PBH binary mergers of mass around $10^{-5} M_{\odot}$ if they constitute more than 0.01 percent of the dark matter, as suggested by recent microlensing observations. We envision that this class of detectors could also be used to detect cosmological GW backgrounds and probe sources in the early Universe at energies up to the GUT scale.

This reasearch leads to an accepted publication in Physical Review D. More info: https://arxiv.org/abs/2012.12189

Dark Matter Detection / 577

Recent status and results of the Dark Matter Particle Explorer

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The DArk Matter Particle Explorer (DAMPE) is a satellite-borne, calorimetric type, high-energy-resolution space cosmic ray and gamma-ray detector. It was launched in December 2015 and has been stably operating for more than five years. Its three major scientific objectives are dark matter indirect detection, cosmic ray physics and gamma-ray astronomy. Precise measurements of the all-electron, proton and Helium spectra in wide energy ranges have been obtained, shedding new light on the research of cosmic ray physics and dark matter properties. We will also present the current status of the mission and its recent physical results.

Dark Matter Detection / 1005

Probing Axion Like Particles Using Time Dependent Magnetic Field

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From years ago, there have been established many different experiments for the detection of Axion Like Particles (ALPs) as a promising candidate of dark matter. The coupling of ALPs with the standard model particles has been explained with some interaction Lagrangians. Many experiments try to detect ALPs by their interaction with photons in the context of a static magnetic field using the well known interaction Lagrangian, $\mathcal{L}_{a\gamma\gamma} = \frac{1}{4}\, g_{a\gamma\gamma}\phi F_{\mu\nu}\widetilde{F}^{\mu\nu}$, where ϕ is the ALP field, $F_{\mu\nu}$ is the electromagnetic field with $\widetilde{F}^{\mu\nu} = \frac{1}{2}\epsilon^{\mu\nu\rho\sigma}F_{\rho\sigma}$ its dual, and $g_{a\gamma\gamma}$ is the coupling constant.

However, we try a sinusoidal magnetic field in order to check the effect of such a magnetic field pattern on the detection. Starting from Feynman diagrams and calculating the second-order S-matrix, the oscillating magnetic field generates two peaks in the Hamiltonian integrand. This results in an enhancement of the phase deviation of the interacting photon.

Also, Our setup is designed in a practical manner. A tabletop Fabry-Perot cavity is used and two perpendicularly polarized photons pump in the cavity. We show that one of these polarizations interact with ALPs and the other remains intact. Therefore, both polarizations will feel the same noise and there is no problem about different noise effects on the interacted and reference photons.

All in all, the resulting exclusion region illustrates the advantage of the setup. Using a 10 cm cavity with the finesse of 10^6 and also a magnetic field with the amplitude and frequency of 10 T and 1 MHz, respectively, one can detect ALPs with the coupling constant of $g_{a\gamma\gamma} > 10^{-13}$.

Dark Matter Detection / 481

Dark matter program of the CDEX collaboration at China Jinping Underground Laboratory

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The CDEX program pursues the direct detection of light dark matter candidates with an array of germanium detectors since 2009 at the deepest operating underground site located in Sichuan, China. Searches of modulation effect of light WIMPs[1], WIMPs-nucleus interaction via Midgal effect[2], dark photon model[3], solar axions and axion-like particles[4] as well as the effective-Field-theory-involved interactions[5] have been recently carried out based on the CDEX-1 and CDEX-10 experiments. An upgraded dark matter experiment of the CDEX-50dm is proposed and on-going together with the R&D programs on the key low radioactivity technologies including electroformed copper at the underground site, fabrication and the extra-low-background front-ends of the various germanium detector types, operations of a germanium detector with its bare crystal immersed in liquid nitrogen, possible hybrid Anti-Compton detectors of the mixed PEN and liquid/solid argon as well as radon mitigation of a 1725 meter cube liquid nitrogen tank. Results and the prospects of the CDEX dark matter program will be described and discussed.
1. L. T. Yang et al.,(CDEX Collaboration) "Light WIMPs Search by Annual Modulation Analysis with a Point-Contact Germanium Detector at the China Jinping Underground Laboratory", Phys. Rev. Lett. 123, 221301 (2019)
2. Z. Z. Liu(CDEX Collaboration) "Constraints on spin-independent nucleus scattering with sub-GeV WIMP dark matter from the CDEX-1B Experiment at CJPL", Phys. Rev. Lett. 123 161301 (2019)
3. Z. She(CDEX Collaboration) "Direct Detection Constraints on Dark Photons with CDEX-10 Experiment at the China Jinping Underground Laboratory" Phys. Rev. Lett. 124, 111301 (2020)
4. Y. Wang(CDEX Collaboration) "Improved limits on solar axions and bosonic dark matter from the CDEX-1B experiment using profile likelihood ratio method" Phys. Rev. D 101, 052003 (2020)
5. Y. Wang (CDEX Collaboration), "First experimental constraints on WIMP couplings in the effective field theory framework from CDEX" Sci. China-Phys. Mech. Astron. 64, 281011 (2021)

Dark Matter Detection / 736

Searching for ultralight vector dark matter with the cryogenic gravitational wave telescope KAGRA

Authors: Yuta Michimura[1]; Tomohiro Fujita[2]; Jun'ya Kume[3]; Soichiro Morisaki[4]; Hiromasa Nakatsuka[5]; Atsushi Nishizawa[3]; Ippei Obata[6]; KAGRA Collaboration[None]

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Recently, a considerable amount of attention has been given to the search for ultralight dark matter by measuring the oscillating length changes in the arm cavities of gravitational wave detectors. Although gravitational wave detectors are extremely sensitive for measuring the differential arm length changes, the sensitivity to dark matter is largely attenuated, as the effect of dark matter is mostly common to arm cavity test masses. In Phys. Rev. D 102, 102001 (2020), we proposed to use auxiliary length channels, which measure the changes in the power and signal recycling cavity lengths and the differential Michelson interferometer length. When our method is applied to a cryogenic gravitational wave detector KAGRA, the sensitivity to U(1)_{B−L} gauge boson dark matter with masses below 7x10^{−14} eV can be greatly enhanced, since KAGRA employs sapphire test masses and fused silica auxiliary mirrors. We showed that KAGRA can probe more than an order of magnitude of unexplored parameter space at masses around 1.5x10^{−14} eV, without any modifications to the existing interferometer. In this talk, we present the status of the data analysis pipeline development and discuss the prospects of our analysis using the data from KAGRA's first observing run in 2020.

Dark Matter Detection / 19

Strong constraints on thermal relic dark matter from Fermi-LAT observations of the Galactic Center

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The extended excess towards the Galactic Center (GC) in gamma rays inferred from Fermi-LAT observations has been interpreted as being due to dark matter (DM) annihilation. In a recent paper my collaborators and I performed a new likelihood analyses of the GC and showed that when including templates for the stellar galactic and nuclear bulges, the GC shows no significant detection of a DM annihilation template, even after generous variations in the Galactic diffuse emission (GDE) models and a wide range of DM halo profiles. We include Galactic diffuse emission models with combinations of 3D inverse Compton maps, variations of interstellar gas maps, and a central source of electrons. For the DM profile, we include both spherical and ellipsoidal DM morphologies and a range of radial profiles from steep cusps to kiloparsec-sized cores, motivated in part by hydrodynamical simulations. Our derived upper limits on the dark matter annihilation flux place strong

constraints on DM properties. In the case of the pure b-quark annihilation channel, our limits on the annihilation cross section are more stringent than those from the Milky Way dwarfs up to DM masses of ~TeV, and rule out the thermal relic cross section up to ~300 GeV. Better understanding of the DM profile, as well as the Fermi-LAT data at its highest energies, would further improve the sensitivity to DM properties.

Dark Matter Searches with Liquid Xenon and Argon Detectors and Self Gravitating Systems and Dark Matter

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Bose-Einstein condensate dark matter halos

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We consider the possibility that dark matter is made of self-gravitating Bose-Einstein condensates (BECs) described by the Schrodinger-Poisson or Gross-Pitaevskii-Poisson equations. We determine the mass-radius relation of self-gravitating BECs with repulsive or attractive self-interaction at zero temperature. When the self-interaction is attractive, we evidence the existence of a maximum mass above which the system (e.g. an axion star) collapses. This leads to a dense axion star, a bosenova, or a black hole. We apply these results to the case of bosonic dark matter halos with a core-halo structure made of a soliton surrounded by an isothermal atmosphere. We determine the core mass-halo mass relation of self-gravitating BECs with repulsive or attractive self-interaction and discuss the possibility of collapse of the quantum core.

[1] P.H. Chavanis, Derivation of the core mass — halo mass relation of fermionic and bosonic dark matter halos from an effective thermodynamical model, Phys. Rev. D, 100, 123506 (2019)

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Direct Detection Signals from Absorption of Fermionic Dark Matter

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In this talk I will present a class of direct detection signals; absorption of fermionic dark matter. I enumerate the operators through dimension six which lead to fermionic absorption, study their

direct detection prospects, and summarize additional constraints on their suppression scale. Such dark matter is inherently unstable as there is no symmetry which prevents dark matter decays. Nevertheless, I will show that fermionic dark matter absorption can be observed in direct detection and neutrino experiments while ensuring consistency with the observed dark matter abundance and required lifetime.

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Pico-charged particles from dark matter decay explain 511 keV line and XENON1T signal

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There is a robust signal for a 511 keV photon line from the galactic center which may originate from dark matter particles with masses of a few MeV. I will introduce a model in which dark matter first decays into a pair of intermediate pico-charged particles CC^- with a lifetime much larger than the age of the universe. The galactic magnetic field accumulates the relativistic CC^- that eventually annihilate, producing the e −e + pair that give rise to the 511 keV line. This model avoids the bounds from delayed recombination and from the absence of the line from dwarf galaxies which rule out more simplistic DM explanations for the 511 keV line.
The relativistic pico-charged C particles from dark matter decay can scatter on the electrons inside the direct dark matter search detectors imparting a recoil energy of Er ~ keV. I show that this model can account for the electron recoil excess recently reported by the XENON1T experiment. Moreover, we show that the XENON1T electron recoil data sets the most stringent bound on the lifetime of the dark matter within this model.

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Manifestations of new particles in underground laboratories and atomic experiments

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We perform accurate relativistic atomic many-body calculations of the effects of dark matter produced in underground laboratories. Our recent calculation of the ionization of atoms by absorption of scalar particles gives cross section, which is several orders of magnitude smaller than that calculated by other authors. The reason is that the traditional plain wave approximation for outgoing electron violates orthogonality condition with bound electron wave function which plays crucial role in the zero multipolarity transitions. Such plain wave non-relativistic approximation also gives wrong result (strongly underestimate cross section) for electron ionization by WIMP scattering.

Interaction between the standard model matter and low mass scalar dark matter field may be presented as variation of the fundamental constant while interaction with an axion-like field leads to oscillating effects of violation of the fundamental symmetries including electric dipole moments. New interactions mediated by hypothetical particles produce effects, which may be observed in atomic experiments. Our aim is to find enhanced effects, perform their calculations, motivate new

experiments and provide interpretation of their results.
New results of our group on these topics published recently in PRL, PRD, PRA, JHEP and arxiv papers will be presented.

Dark Matter Searches with Liquid Xenon and Argon Detectors and Self Gravitating Systems and Dark Matter / 620

The approach to equilibrium for idealized collisionless self-gravitating systems

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The evolution and equilibrium structure of dark matter halos has been well studied using N-body simulations. However, theoretical understanding, for example, based on statistical mechanics has been more challenging. A decade ago we showed that extremizing the number of microstates with a given energy per unit mass, under the constraints of conserved total energy and mass, leads to the maximum entropy state, known as DARKexp. Its differential energy distribution, and the resulting density structures provide very good fits to simulated dark matter halos. Here we define a non-equilibrium functional, which is maximized for DARKexp and increases monotonically during the evolution towards equilibrium of an idealized collisionless system, the Extended Spherical Infall Model.

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Preliminary results of rich galaxy clusters' spatial distribution analysis on CfA2 Redshift survey data: compact objects or dark matter presence at redshift less 0.022.

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Preliminary results of the investigation of the properties of 13 clusters of galaxies from CfA2 redshift survey are discussed in the presented article. The distributions on absolute magnitude and luminosity represent two areas for clusters ##88, 1101, 1046, 142, 933, 1242, 1652, 107, 150, 316, 317, 961, 977. Redshifts of these clusters are in the region 0.002 – 0.022. The distributions on groups members position, absolute magnitude and luminosity represent two areas for these clusters. Galaxies from these areas are paired accordingly its spectral characteristics and position. Also several anomalies of spatial dynamic of galaxies in these clusters were separated. Such structure could be caused by dark matter presence inside cluster in configuration similar to Zeldovich pancake or gravitational lensing on compact object or dark matter blob located between galaxy cluster and observer.
Several peculiarities have found on the spatial distributions of galaxies in clusters ##933, 142, 1046, and 1652. Moreover, these groups reveals associations with high-energy gamma-emission sources on Fermi/LAT 10-Year Point Source Catalog 4FGL DR2 data (4FGLJ1144.9+1937, 4FGLJ0152.2+3714, 4FGLJ1230.8+1223 and 4FGLJ1653.8+3945 correspondingly).These sources are active galaxies 3C 264, B2 0149+37, M87 and MRC 501. Furthermore, 3C 264 and M87 observed in subTeV energy band by

VERITAS data. Joint observations of such clusters by orbital gamma-ray observatories with high angular resolution and ground-based Cherenkov air-shower experiments could possibly clarify the type of gravitational lensing and processes of particle acceleration in these objects especially highest energy of emitted gammas. Thus we propose including these and similar clusters in the programs of observations of the planned experiment GAMMA-400 (Gamma Astronomical Multifunctional Modular Apparatus) with angular resolution ~0.01° at Eγ = 100 GeV and several TeV upper energy band. Also now it is discussed coordination of multiwavelength observations program of Cherenkov Telescope Array (CTA) and GAMMA-400 objects list for observations.

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Present and Future of Dark Matter direct detection with XENONnT

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The dual phase Time Projection Chamber detectors exploiting Xenon element is the leading technology in the field of direct Dark Matter searches, as testified by the most stringent upper Limit on WIMP-nucleon cross section set by the XENON1T experiment. The XENONnT experiment, currently, under commissioning at the Gran Sasso underground laboratories, is ready to start its physics program. It will exploit 5.9 tonnes of instrumented liquid xenon and most of the infrastructure already developed for its predecessor. The ultra-low background level reached in XENON1T, will be further reduced in the XENONnT by an improved capability of alpha and beta background-events reduction. Furthermore a new neutron veto system will enable identification of otherwise irreducible neutron backgrounds. This talk is devoted to report the most recent results from XENON1T and the current status of XENONnT commissioning and sensitivity studies on the expected performances of this detector.

Dark Matter Searches with Liquid Xenon and Argon Detectors and Self Gravitating Systems and Dark Matter / 1060

Hunt for the Sterile Neutrino Dark Matter

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In this talk, we present an effective model for the sterile neutrino dark matter candidate. Due to new physics at the UV scale, three sterile neutrinos couple with SM fermions and gauge bosons via the SM gauge symmetric four-fermion interactions. Upon the spontaneous symmetry breaking, sterile neutrinos become massive and possess effective couplings to SM particles. We will show that the sterile neutrinos with masses around 90 keV and specific effective coupling can explain the XENON1T anomaly preserving DM astrophysical and cosmological constraints. We point out that the presence of three right-handed sterile neutrino allows to obtain correct dark matter relic density by the late entropy production due to late decay of heavier right-handed neutrinos. Moreover, four sterile neutrinos interaction can form composite scalar and pseudo scalar particles, the latter plays the role of axion, while the former the role of massive WIMP particles. Some phenomenological consequences of these new states as dark matter are discussed.
Besides, with possible sterile neutrino spectra and new effective coupling to SM particles, we try

to explain the anomalies in other experiments such as muon g-2 and MiniBooNe experiment. Our scenario also offers some new distinctive features which may potentially produce observable signals in the sensitivity range of the next generation of XENON detectors such as XENONnT, LZ and DARWIN.

Dark Matter: Beyond LCDM

Dark Matter: Beyond LCDM / 193

Phase transitions in the self-gravitating Fermi gas

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We discuss the nature of phase transitions in the self-gravitating Fermi gas in Newtonian gravity and general relativity. When the particle number is above the Oppenheimer-Volkoff limit, we evidence the existence of a new turning point of mass-energy in the caloric curve leading to the collapse of the system towards a black hole. We mention possible applications of these results to the case of fermionic dark matter halos with a core-halo structure made of a fermion ball surrounded by an isothermal atmosphere.

[1] P.H. Chavanis, G. Alberti, Gravitational phase transitions and instabilities of self-gravitating fermions in general relativity, Phys. Lett. B 801, 135155 (2020)

Dark Matter: Beyond LCDM / 148

Constraints on the (warm) nature of dark matter from the first billion years

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Most astrophysical constraints on the warm dark matter particle mass have been limited to observations covering the last 12 billion years of the Universe. However, over the past few years, data from the Hubble Space Telescope and the EDGES (21cm) collaboration have allowed such constraints to be extended well into the first billion years, a crucial epoch inaccessible by any other means. In this talk I will present a semi-analytic model of galaxy formation & 21cm emission that jointly tracks the dark matter and baryonic assembly of galaxies through cosmic time. I will use this to highlight the role of different dark matter models in shaping the observable properties of early galaxies and show how forthcoming instruments such as the James Webb Space Telescope (JWST) can be used as an invaluable "Dark Matter Machine" in order to distinguish between cold and warm dark matter cosmologies using early galaxies. Finally, I will show how the EDGES data can already be used to rule out WDM lighter than 3 keV.

Dark Matter: Beyond LCDM / 547

An excess of small scale strong lenses observed in galaxy clusters

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Thanks to the CLASH and Frontier Fields (FF) programs of the Hubble Space Telescope, it has been possible to identify an unprecedented number of strongly lensed sources in the central regions of several galaxy clusters. Complementing these observations with MUSE spectroscopy, we obtain high fidelity mass models for MACSJ1206, MACSJ0416, and AS1063. The models are consistent with the presence of massive and compact dark matter halos in cluster galaxies. Consequently, we estimate large cross-sections for galaxy-galaxy strong lensing (GGSL) in these clusters. Indeed, to confirm these expectations, we discover several multiple images of distant sources lensed by cluster members. Besides, eight additional CLASH and FF clusters with lens models available from the literature have similarly high GGSL cross-sections. We compare these observations with theoretical expectations in the concordance LCDM model with the aid of state-of-the-art N-body and hydrodynamical simulations. We find that the simulated clusters have GGSL cross-sections ~10 times smaller than measured in observations. We suggest that hitherto undiagnosed systematic issues with simulations or incorrect assumptions about dark matter properties could explain our results.

Dark Matter: Beyond LCDM / 190

Imaging formation process for DM profiles

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The imaging formation process for some DM profiles is carried out.

We use the analytic information given for the surface mass density in each case (some classic profiles, and some recently proposed), to obtain the geometrical and physical characterization that could provide information to identify new types of DM. The goal of this work is to understand if there are trails of the physical information encoded in the observational data related with the imaging formation process, that determine if there are new species of DM (or observational data to identify new properties for these profiles).

The calculations are analytic, and the simulations are generated with the physical information for each profile.

Dark Matter: Beyond LCDM / 283

Where my DAEMON hides – The emergence of self-similar cosmic structures

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Large-scale N-body simulations have successfully reconstructed cosmic structure formation with increasing resolution and complexity, as observations corroborate. Complementary efforts have arrived at a hydrodynamical theory that explains cosmic structure evolution up to the non-linear regime. While the statistical properties of mass density perturbations for the observable universe as a whole become comprehensible, it is still unknown why our heuristic approaches for the characterisation of individual, locally collapsed mass agglomerations work so well.
In particular, we lack an explanation why mass density profiles like the Navarro-Frenk-White profile or other composites of power laws arise in dark-matter N-body simulations and successfully match halo profiles inferred by observations like gravitational lensing effects.

As a first step towards one general dark matter mass density profile that replaces the heuristically inferred fitting functions, I introduce the "DArk Emergent Matter halO explanatioN" (DAEMON) which explains self-similar dark matter halo morphologies forming under scale-free gravitational interaction. DAEMON thus bases power-law mass density profiles and composites thereof on sound mathematically and physically fundamental principles:
Understanding the particle distributions as discrete samplings of a corresponding smooth mass density, DAEMON explains the cusp-core problem in the halo centre as an inhomogeneous, statistical sampling. The transition to isothermality marks the shift to a homogeneously sampled region. As scale-free Newtonian gravity does not favour a specific halo boundary, our choice of a boundary relative to the particle distribution sets the power-law index in the outer regions.

This simple but powerful explanation of halo morphologies can be employed to make simulations more efficient or facilitate the choice of lens models in strong gravitational lensing to mention two applications that profit from this progress in understanding cosmic structures.

J. Wagner. *Cosmic structures from a mathematical perspective 1: dark matter halo mass density profiles.* **GReG** (2020)

Dark Matter: Beyond LCDM / 82

Probing the nature of dark matter with Milky Way subhaloes

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The nature of dark matter is expected to be most strongly expressed in dark matter subhaloes with mass $< 10^9 \mathrm{M}_\odot$. These subhaloes are accessible to us in the vicinity of the Milky Way (MW), through the abundance and structure of both luminous MW satellites and dark subhaloes that never form stars. In this talk I will present work on the properties of these subhaloes in two radically different dark matter models. First, I will demonstrate how a self-interacting dark matter (SIDM) model with a strongly velocity-dependent self-interaction cross-section can initiate gravothermal collapse in subhaloes, and can subsequently explain the surprisingly similar densities of bright and faint MW satellites. Second, I will switch to the warm dark matter (WDM) model, and consider its consequences for the radial distribution of luminous satellites and dark subhaloes relative to the cold dark matter (CDM) model. I will show that subhaloes closer to the MW centre (< 40kpc) are the remnants of relatively massive haloes that appear in similar numbers in CDM and WDM. This is the region in which gaps in stellar streams are used to constrain dark matter subhalo abundances, therefore we show that limits on WDM are somewhat weaker than if we had extrapolated the change in subhalo abundance from what we measure in the halo at large (< 300kpc). I will end my talk with a brief change of topic, making a prediction for the properties of possible dark matter decay X-ray emission lines in galaxy clusters to be probed by the upcoming XRISM observatory.

Dark Matter: Beyond LCDM / 874

Dark matter as Planck relics without too exotic hypotheses

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The idea that dark matter could be made of stable relics of microscopic black holes is not new. In this article, we revisit this hypothesis, focusing on the creation of black holes by the scattering of trans-Planckian particles in the early Universe. The only new physics required in this approach is an unusually high-energy scale for inflation. We show that dark matter emerges naturally and we study the question of fine-tuning. We finally give some lines of thoughts for a possible detection.
Based on: Barrau, Martineau, Moulin, Ngono, Phys.Rev.D 100 (2019) 12, 123505

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On the Random Motion of Nuclear Objects in a Fuzzy Dark Matter Halo

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Co-authors: Frank van den Bosch [1]; Victor Robles [1]; Pieter van Dokkum [1]; Hsi-Yu Schive [2]; Tzihong Chiueh [2]; Tom Broadhurst [3]

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Fuzzy Dark Matter (FDM), consisting of ultralight bosons ($m_{\rm b} \sim 10^{-22}$eV), is an intriguing alternative to Cold Dark Matter. Numerical simulations that solve the Schrodinger-Poisson (SP) equation show that FDM halos consist of a central solitonic core, which is the ground state of the SP equation, surrounded by an envelope of interfering excited states. These excited states also interfere with the soliton, causing it to oscillate and execute a confined random walk with respect to the halo center of mass. Using high-resolution numerical simulations of a $6.6 \times 10^9 M_\odot$ FDM halo with $m_{\rm b} = 8 \times 10^{-23}$eV in isolation, we demonstrate that the wobbling, oscillating soliton gravitationally perturbs nuclear objects, such as supermassive black holes or dense star clusters, causing them to diffuse outwards. In particular, we show that, on average, objects with mass $\leq 0.3\%$ of the soliton mass ($M_{\rm sol}$) are expelled from the soliton in ~ 3Gyr, after which they continue their outward diffusion due to gravitational interactions with the soliton and the halo granules. More massive objects ($\geq 1\% M_{\rm sol}$), while executing a random walk, remain largely confined to the soliton due to dynamical friction. We also present an effective treatment of the diffusion, based on kinetic theory, that accurately reproduces the outward motion of low mass objects and briefly discuss how the observed displacements of star clusters and active galactic nuclei from the centers of their host galaxies can be used to constrain FDM.

Dark Matter: Beyond LCDM / 548

Learning the properties of our Galaxy's dark matter with Stellar Streams

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The Galactic halo is criss-crossed by long stellar streams that are probably the remnants of defunct globular clusters and dwarf galaxies. I will present the recent discoveries of these structures from Gaia mission data. While streams clearly inform us in a direct way about past accretions onto our Galaxy, their most promising property is that they allow us to measure the Galactic acceleration field and they may allow us to quantify the prevalence of small-scale of dark matter overdensities in the halo. I will also present some novel unsupervised machine-learning methods that we are developing to fit the acceleration field from these streams (and field stars) while also learning the transformation from observed kinematic coordinates to canonical action-angle variables.

Dark Matter: Beyond LCDM / 106

A Multiple-Scales Approach to the Averaging Problem in Cosmology

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The Universe is homogeneous and isotropic on large scales, so on those scales it is usually modelled as a Friedmann-Lemaître-Robertson-Walker (FLRW) space-time. The non-linearity of the Einstein field equations raises concern over averaging over small-scale deviations form homogeneity and isotropy, with possible implications on the applicability of the FLRW metric to the Universe, even on large scales. In this talk I will present a technique, based on the multiple-scales method of singular perturbation theory, to handle the small-scale inhomogeneities consistently. I will obtain a leading order effective Einstein equation for the large-scale space-time metric, which contains a back-reaction term. The derivation relies on a series of consistency conditions, that ensure that the growth of deviations from the large-scale space-time metric do not grow unboundedly; criteria for their satisfiability are discussed, and it is shown that they are indeed satisfied if matter is non-relativistic on small scales. I will also estimate the magnitude of the back-reaction term relative to the critical density of the Universe in the example of an NFW halo. In this example, the back-reaction term can be interpreted as a contribution of the energy-density of gravitational potential energy, averaged over the small-scale, to the total energy-momentum tensor.

Dark Matter: Beyond LCDM / 91

Scalar field dark matter as an alternative explanation for the anisotropic distribution of satellite galaxies

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The scalar field dark matter also called ultralight bosonic dark matter, has received considerable attention due to the number of problems it might help to solve. Among these are the cusp-core problem and the abundance of small structures of the standard cold dark matter model. In this talk, we show that multi-state solutions of the Gross-Pitaevskii-Poisson equations, interpreted as galactic halo density profiles, can provide a possible explanation to the anisotropic distribution of satellite galaxies observed in the Milky Way, M31 and Centaurus A, where satellites trajectories seem to concentrate on planes close to the poles of the galaxies instead of following homogeneously distributed trajectories. In order to construct a proof of concept, we study the trajectories of a number of test particles traveling on top of the gravitational potential due to a multi-state halo with monopolar and dipolar modes. The result is that particles accumulate asymptotically in time on planes passing close to the poles. Satellite galaxies are not test particles but interpreted as such, our results indicate that in the asymptotic time their trajectories do not distribute isotropically, instead, they prefer to have orbital poles accumulating near the equatorial plane of the multistate halo. The concentration of orbital poles depends on whether the potential is monopolar or dipolar dominated.

Dense Matter in Compact Stars

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Elastic properties of the NS crust in the OCP approximation.

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We calculate the elastic properties of the outer crust of Neutron Stars (NSs) under the approximation of the one component plasma (OCP) in the high density limit. An electron sector under a degenerate Fermi sea is considered. This is of interest for the modelling of the gravitational wave signal strength emitted in the violent events of NS mergers and NS continuous emission. We use Molecular Dynamics simulations at finite temperature with Ewald sums and extract the relevant elastic quantities such as the stress tensor components for the long range multipolar expansion.

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Search for gravitational waves from r-mode oscillations in PSR J0537-6910

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PSR J0537-6910 is a young neutron star that regularly experiences pulsar glitches, and shows a rather high braking rate between them. Observed spin-down of the pulsar could be due to the r-mode oscillations, which in turn may generate gravitational waves in the sensitivity range of the LIGO and Virgo detectors.
Based on the analysis of the LIGO-Virgo-KAGRA observing run O3, and taking into account the NICER telescope pulsar timing, this search placed interesting constraints on theoretical models for the r-modes oscillations and on the J0537 neutron star parameters.

Dense Matter in Compact Stars / 204

Was GW190814 a Black Hole–Strange Quark Star System?

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The gravitational waves event GW190814 originated from the merger of a 23Msun black − hole and a compact object of 2.6 Msun. The nature of the low mass companion is quite puzzling since it could be either the lightest black -hole or the heaviest neutron star ever known. In particular, if such massive neutron stars do exist, it seems to be difficult to reconcile the indications from data suggesting a not too stiff equation of state of dense matter (such as e.g GW170817) and the possibility that the equation of state is instead so stiff to allow for a maximum mass value above 2.6Msun. In this talk, I will discuss the possibility that the low mass companion of the GW190814 system is a strange quark star, within the so-called two-families scenario. In this scenario hadronic stars and strange quark stars coexist, the first family being characterized by
light and very compact stars (in which delta resonances and hyperons do form) and the second family composed by massive and large strange quark stars. The many phenomenological implications of this scenario, also in connection with future gravitational waves detections, will also be discussed.
The talk is based on the recent PRL 126 (2021) 162702.

Dense Matter in Compact Stars / 530

A first sign from the neutron star in SN 1987A

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After three decades, the neutron star formed by SN 1987A has likely given us a first sign of its presence: a blob of warm dust near the center of the explosion. I will summarize our understanding of the explosion, the structure of the supernova remnant, and the characteristics of "the blob". I will describe in detail the possible explanations for the excess of energy coming out of the blob: radioactive heating, accretion onto a black hole or energy output from a neutron star. In the latter case, it could be either accretion energy, the power output from a pulsar or simply the thermal radiation from a hot young star. Our study strongly favors thermal radiation, but the alternatives cannot be totally ruled out. An important consequence of this is that this young neutron star is definitely not an energetic pulsar and more likely a new member of the growing family of Central Compact Objects (CCOs) that constitute about 25% of the young neutron star population and show no signs of pulsar activity.

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Bosonic Dark Matter in Neutron Stars and Gravitational Waves

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Compact astrophysical objects such as neutron stars (NSs) offer natural laboratories that can accrete sizable amount of Dark Matter (DM) in extreme density regimes. In this work, we study the presence of self-interacting bosonic DM in NSs through its effect on various properties of NSs. In our scenario, the bosonic DM and baryonic matter (BM) are mixed together which are interacting only through gravitational force. We show that depending on DM model parameters and the amount of DM fraction, DM can exist as a core inside the compact star or as an extended halo around it. Thanks to the recent detection of gravitational waves from binary NSs, in addition to the maximum mass of a compact object, we consider the tidal deformability as a new probe for the presence of DM coexisting with BM in NSs and to check the consistency with observational constraints. In this work, the parameter space of self-interacting bosonic DM such as the mass and the coupling have been explored from the mass-radius relation and the tidal deformability by considering various amounts of DM in the system.

As the conclusion, we show that a DM core decreases the total mass of the compact object and the tidal deformability while a DM halo could increase both of them. Finally, considering various DM fractions, boson's masses and coupling constants, some constraints have been obtained on our DM model by taking into account the maximum mass limit of NS, $M \geq 2M\odot$ ($M\odot \equiv$ Mass of the sun) and the tidal deformability upper limit from GW170817 event, $\Lambda < 800$ for $M = 1.4M\odot$.

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Parameter estimation for a two-component neutron star model with a Kalman filter

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Timing noise in a pulsar is the stochastic deviation of the pulse arrival times of the pulsar away from its long term spin down trend. In the classic two-component neutron star model, interactions between the crust and superfluid cause these perturbations to decay exponentially with a characteristic timescale. This research uses a Kalman filter to track the pulsar frequency through time and to calculate a posterior on the parameters of the two-component pulsar model. Our method is reliable on simulated data, which we show through both individual and large-scale Monte Carlo tests. We will also show some representative examples on publicly available data from real pulsars, where we aim to test the two-component model and to use it to efficiently measure physical properties of the star. Our measurements of the properties of neutron stars will provide insight into their internal structure and will also provide evidence for or against the two-component model.

Dense Matter in Compact Stars / 832

NEMO: a dedicated kHz gravitational-wave observatory for neutron star extreme matter

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Gravitational waves from the late inspiral, merger, and post-merger of a binary neutron star coalescence provide complementary information about the cold and hot equations of state of neutron star matter. These signals dominate in the kHz range, higher than the most sensitive part of the current generation of gravitational-wave interferometers. I will present the design concept and science case for NEMO: a gravitational-wave interferometer optimised to study nuclear physics with merging neutron stars. I will discuss the science NEMO can achieve, both in a network of A+-like interferometers, and also with next-generation electromagnetic telescopes. NEMO has the potential not only for ground-breaking science in its own right, but can also act as a technology driver for full-scale third-generation instruments such as Einstein Telescope and Cosmic Explorer.

Dense Matter in Compact Stars / 367

Extracting physics from the randomness in neutron star rotation

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Rotational irregularities in neutron stars, principally glitches and timing noise, are often regarded as nuisance phenomena which are subtracted from electromagnetic pulsar timing data in order to reveal the underlying, secular rotational evolution. This represents a missed opportunity. Glitches and timing noise excite internal degrees of freedom in the star impulsively and stochastically. The internal response leaves a distinctive imprint on pulsar timing data. Here we review two new data analysis techniques, which track rotational irregularities as a specific realization of a random process, whose physical parameters can be inferred within a Bayesian framework. The first technique tracks timing noise with a Kalman filter and can be used to infer the parameters of the classic, two-component, crust-superfluid model of a neutron star. The second technique tracks glitches with a hidden Markov model and can be used to infer the parameters of superfluid vortex pinning and mutual friction. Both techniques operate without human supervision and perform well on synthetic and real data. We show that automated measurements of glitch sizes and waiting times are a powerful tool to falsify theories of the stick-slip, stress-relax physics of glitches. We also show that contemporaneous gravitational-wave and electromagnetic timing experiments have the power to resolve important physical and parametric degeneracies in the future.

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Effects of anisotropy on strongly magnetized neutron and strange quark stars in general relativity

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We investigate the properties of anisotropic, spherically symmetric compact stars, especially neutron stars and strange quark stars, made of strongly magnetized matter. The neutron stars are described by a polytropic equation of state, the strange quark stars by an equation of state based on the MIT Bag model. The stellar models are based on an a priori assumed density dependence of the magnetic field and thus anisotropy. Our study shows that not only the presence of a strong magnetic field and anisotropy, but also the orientation of the magnetic field itself, have an important influence on the physical properties of stars. Two possible orientations are considered, a radial orientation, where the local magnetic fields point in the radial direction, and a transverse orientation, where the local magnetic fields are perpendicular to the radial direction. Interestingly, we find that for a transverse orientation of the magnetic field, the stars become more massive with increasing anisotropy and magnetic field strength and increase in size, since the repulsive, effective anisotropic force increases in this case. In the case of a radially orientated magnetic field, however, the masses and radii of the stars decrease with increasing magnetic field strength, because of the decreasing effective anisotropic force. Importantly, we also show that in order to achieve hydrostatic equilibrium configurations of magnetized matter, it is essential to account for both the local anisotropy effects as well as the anisotropy effects caused by a strong magnetic field. Otherwise, hydrostatic equilibrium is not achieved for magnetized stellar models.

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Quasi-universality of the magnetic deformation of neutron stars in general relativity and beyond

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Neutron stars (NSs) harbour extremely powerful magnetic fields, leading to their shape being deformed. The magnetic deformation of NSs depends both on the geometry - and strength - of their internal magnetic field and on their composition, encoded by the equation of state (EoS). However, both the details of the internal magnetic structure and the EoS of the innermost part of NSs are mostly unkown. We performed a study of numerical models of magnetised, static, axisymmetric NSs in general relativity (GR) and in one of its most promising extensions, scalar-tensor theories (STTs). We did so by using several realistic EoSs currently allowed by observational and nuclear physics constraints, considering also EoSs for strange quark stars. We show that it is possible to find simple relations among the magnetic deformation of a NS, its Komar mass and its circumferential radius. These relations are quasi-universal, in the sense that they mostly do not depend on the EoS and only slightly depend on the magnetic field geometry. Our results, being formulated in terms of potentially observable quantities, could help to constrain the magnetic properties of NSs interiors and better assess the detectability of continuous gravitational waves by isolated neutron stars, without knowing their equation of state. In the case of STTs, these relations depend also on the scalar charge of the NS, thus potentially providing a new way to set constraints on the theory of gravitation.

Dense Matter in Compact Stars / 1007

Probing the dense matter physics of neutron star cores with transiently-accreting neutron stars

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The composition of neutron stars is an open research problem. In particular, the lack of information on the behavior of the symmetry energy above saturation density has prevented a reliable first-principle calculation of neutron stars equation of state. However, recently, new observational data has become available, which allows for better constraining of the internal properties of the star, leading to an improved understanding of its behavior and characteristics. In particular, the long time search for a definite observation of a star with direct Urca reactions came to an end recently with the x-ray spectrum measurements of the neutron star in system MXB 1659-29. This was the first observation to unambiguously suggest the presence of fast neutrino-cooling processes in the star's interior, as described by 1. These measurements come from long term observations of outburst-quiescent cycles of neutron stars in low-mass X-ray binary (LMXB) systems, which allow us to calculate their cooling processes rate, in turn helping constrain the star's proton fraction. This calculation was performed in 1, where it was shown in a simple model that direct Urca reactions take place in 1% of the volume of the core of that neutron star, implying that its proton fraction is above threshold. In this presentation we use neutron star models that include detailed neutron star equations of state

and superfluid/superconductivity gaps to calculate a star's direct Urca luminosity and compare to the predictions in 1. We also discuss the implications of a star's high proton fraction on its core heat capacity. This is an important step towards a universal equation of state for neutron stars and therefore, towards a better understanding of the phase diagram of asymmetric matter at high densities.

1 Brown et al. Rapid Neutrino Cooling in the Neutron Star MXB 1659-29, Physics Review Letters, 10.1103/PhysRevLett.120.182701, ArXiv: 1801.00041

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Tidal deformations of hybrid stars with elastic phases

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Gravitational wave astronomy is expected to provide independent constraints on neutron star properties, such as their equation of state. This is possible with the measurements of binary components' tidal deformability, which alter the point-particle gravitational waveforms of neutron-star binaries. I'll discuss some tidal deformability effects due to the elasticity/solidity of the hadronic phase in a hybrid neutron star. I employ the framework of nonradial perturbations with zero frequency and study hadronic phases presenting elastic aspects when perturbed (with the shear modulus approximately 1% of the pressure). I'll show that the relative tidal deformation change in a hybrid star with a perfect-fluid quark phase and a hadronic phase presenting an elastic part is never larger than about $2-4\%$ (with respect to a perfect-fluid counterpart). These maximum changes occur when the elastic region of a hybrid star is larger than approximately 60% of the star's radius, which may happen when its quark phase is small and the density jump is large enough, or even when a hybrid star has an elastic mixed phase. For other cases, tidal deformation changes due to an elastic crust are negligible ($10^{-5}-10^{-1}\%$), therefore unlikely to be measured even with third generation detectors. Thus, only when the size of the elastic hadronic region of a hybrid star is over half of its radius, the effects of elasticity could have a noticeable impact on tidal deformations.

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Measuring Nuclear Matter Parameters with NICER and LIGO/Virgo

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Neutron star observations offer us an excellent testbed to measure nuclear parameters that are difficult to access with terrestrial experiments. Some of these nuclear parameters have strong correlations with radii and tidal deformabilities of neutron stars. In this talk, I focus on one of such parameters, K_{sym,0}, that corresponds to the curvature of symmetry energy at nuclear saturation density. I describe how one can use the correlations to constrain this parameter with the recent x-ray measurement of the radius with NICER and the gravitational-wave measurement of the tidal

deformability with LIGO/Virgo. I will also discuss recent improvements on the analysis by increasing the number of sampling equations of state, including higher-order nuclear parameters, and relaxing some of the assumptions in the original analysis.

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Binary neutron star mergers of quark matter based nuclear equations of state

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With recent observations of gravitational wave signals from binary neutron star(BNS) mergers and observations by NICER, the nuclear equation of state(EoS) is becoming increasingly testable by numerical simulations. Numerous simulations currently exist exploring the equations of state at different density regimes for the constituent neutron stars. In this work we perform full GR three-dimensional hydrodynamics simulations of BNS mergers for parameterized EoSs based on quark matter at the highest nuclear densities. We construct our initial data using Lorene followed by simulating the merger with Einstein Toolkit. The goal of this study is to extract the effects on the observed GW waveform as the merger happens caused by quark matter.

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Probing hybrid stars with gravitational waves via interfacial modes

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A hybrid star consisting of a defined quark matter core and a hadronic matter envelope has a unique internal structure that can have some influence on its observable properties. One possibility is the tidal effect during binary compact star coalescence, which is encoded in the phase of the emitted gravitational wave signal. In particular, the dynamical part of the tide which comes from the excitations of non-radial pulsation modes depends on the detailed features of the stellar internal structure. Out of the many pulsation modes, we focus on the interfacial mode of hybrid stars with a crystalline quark matter core and fluid nuclear matter envelope. This mode originates from the discontinuities in density and shear modulus at the interface separating the quark matter and nuclear matter phase. It is of interest due to its relatively large overlap integral with the external tidal field, which implies a significant excitation amplitude, and its resonant frequency might lie within the sensitive region of ground-based gravitational-wave detectors depending on the EOS. In this talk, I will describe how the interfacial mode affects the waveform of a binary hybrid star coalescence and show that the effects can potentially be detected with advanced LIGO and next-generation detectors based on a Fisher analysis.

Dense Matter in Compact Stars / 652

On the properties of metastable hypermassive hybrid stars

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Hypermassive hybrid stars (HMHS) are extreme astrophysical objects that could be produced in the merger of a binary system of two neutron stars. In contrast to their purely hadronic counterparts, hypermassive neutron stars (HMNS), these highly differentially rotating objects contain deconfined strange quark matter in their slowly rotating inner region. HMHS and HMNS are both metastable configurations and can survive only shortly after the merger before collapsing to rotating black holes. The properties of a HMHS/HMNS (e.g. rotational property, density and temperature distribution) and the space-time distortion it causes, have been computed by fully general-relativistic hydrodynamic simulations [1-7] and the complicated dynamics of the collapse from a HMNS to a more compact HMHS have been analysed in detail [5,7]. The interplay between the density and temperature distributions and the differential rotational profiles in the interior of the HMHS after the collapse produces a clear gravitational wave signature of the production of quark matter, if the hadron-quark phase transition is strong enough. During the collapse of the HMHS to a Kerr Black the color degrees of freedom of the pure strange quark matter core gets macroscopically confined by the formation of the event horizon [4,6].

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2 M. Hanauske, and L. Bovard, Journal of Astrophysics and Astronomy 39.4 (2018): 1-11.
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[4] E. Most, et al., PRL 122(6) (2019), 061101.
[5] L. Weih, M. Hanauske, and L. Rezzolla, PRL 124.17 (2020): 171103.
[6] A. Motornenko, et al., ⊠⊠⊠⊠⊠⊠ 37.3 (2020): 272-282.
[7] M. Hanauske, et al., The European Physical Journal Special Topics (2021): 1-8.

Dense Matter in Compact Stars / 892

Neutron star radius-to-mass ratio from accretion disc occultation

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The equation of state (EoS) of matter at supranuclear densities in the core of neutron stars (NSs) contains key information on the properties of the strong force and the possible existence of exotic states of matter; however it is only poorly constrained from earth-based experiments and theory. NS properties, the precise values of M and R in particular, encode unique information on the EoS, and different approaches have been proposed to measure, or at least constrain, NS radii. I present a new method to measure the R/M ratio of disk accreting NSs which display a relativistically broadened Fe-Kα profile: this method exploits the occultation of the inner disk region right behind the NS by the body of the NS itself as seen by an observer at infinity. The occultation imprints conspicuous features in the line profiles especially for disk inclinations > 65° and NSs of radius larger than R > 6 GM/c^2, and can provide a proxy of the NS R/M ratio. We developed a dedicated model within XSPEC and by fitting it to current data from a few high-inclination NS low mass X-ray binaries, we found that the signal to noise ratio of the X-ray spectra from present-generation instruments is probably insufficient to measure the R/M ratio. However, through XSPEC simulations adopting response matrices of the near-future eXTP mission we showed that R/M can be measured to ~3% precision over a range of inclinations. Such precision in radius determination is required to draw quantitative conclusions on the EoS of ultra-dense matter and represents the goal that other methods

too aim to achieve in the future.
If time allows, I will also talk about some factors that can influence the current and future analysis of disk-emitted radiation in the X-ray spectra, focusing in particular on the Fe-Kα line.

Dragging is Never Draggy: MAss and CHarge Flows in GR

Dragging is Never Draggy: MAss and CHarge Flows in GR / 272

Progress towards waveforms for extreme mass ratio inspirals

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Extreme mass ratio inspirals (EMRIs) are expected to be a key source of gravitational waves for the LISA mission. In order to extract the maximum amount of information from EMRI observations by LISA, it is important to have an accurate prediction of the expected waveforms. In particular, it will be necessary to have waveforms that incorporate effects that appear at second order in the mass ratio. In this talk we present the latest progress towards this goal, including recent results for the second-order gravitational-wave energy flux from black hole binaries.

Dragging is Never Draggy: MAss and CHarge Flows in GR / 284

Testing the general relativistic nature of the Milky Way Rotation Curve with Gaia DR2

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Gaia directly measures the kinematics of the stellar component of the Galaxy with the goal to create the largest, most precise three-dimensional map of the Milky Way (MW).
The very core of the Gaia data analysis and processing involves General Relativity (GR) to guarantee accurate scientific products. Nevertheless, any Galactic model should be developed consistently with the relativistic-compliant kinematics delivered by Gaia. In this respect, I will present the first test for a relativistic Galactic rotation curve (RC) with the Gaia second release (DR2) products (MNRAS, Issue 496, 2, 2020, M.Crosta at al.). Dark Matter (DM) is supposed to reside mostly in the Galactic halo. Both a GR model and a DM-based analogue were fit to the best-ever kinematics, derived exclusively from DR2 data, of a carefully selected homogenous sample of disk stars tracing the axisymmetric part of the Galactic potential.

The relativistic RC results statistically indistinguishable from its state-of-the-art DM-based analogue. This supports the ansatz that a gravitational dragging effect could drive the stellar velocities in the

plane of our Galaxy far away from its center and mimic DM. Furthermore, one of Einstein's equations provides the necessary baryonic matter density to close the observed gap with respect to the expected Newtonian velocities. Despite some inadequacies, the simplified GR model has proven also to be quite useful to estimate the (external) radial size of the Galactic bulge and the disc thickness at radial distances R>4 kpc.
These findings push on the fully use of Einstein's theory and state the need to develop more complex relativistic galactic "geometries" that take into account the MW multi-structures in concomitance of the incoming and increasingly accurate Gaia data releases and with other Galactic observations targeting the Galactic center.

Dragging is Never Draggy: MAss and CHarge Flows in GR / 562

Black Holes - Nature or Nurture?: The Roles of Rotation and Accretion in Powering Cosmic Sources

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Black holes power many of the most powerful sources in the universe through their disks, jets and winds. They are powered by their rotational energy (Nature) and by the gravitational energy of accreting gas and stars (Nurture). The balance of these two modes and their implications, will be re-examined in the light of recent, remarkable observations of the nearby galaxy M87 by the Event Horizon Telescope as well as other developments. The importance of the dragging of inertial frames for rotational energy extraction, particle acceleration and imaging will be highlighted.

Dragging is Never Draggy: MAss and CHarge Flows in GR / 441

Spinning particle: Is Newton-Wigner the only way?

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A rapidly spinning compact object couples to an ambient curved background via the so-called spin-curvature coupling. In expressing this, one has to deal with the ambiguity of the definition of the center of mass of the body. What is worse, in a Hamiltonian formalism, this choice corresponds to an unphysical "parasitic" degree of freedom in the dynamical system. A solution to this is to apply a Hamiltonian constraint on the system and to obtain a set of brackets where the center-of-mass degree of freedom is erased from the algebra. In this talk I will report on my progress in this procedure in the case of the so-called Tulczyjew-Dixon (or "covariant") supplementary spin condition and in my effort to cover the resulting phase space with canonical coordinates.

Dragging is Never Draggy: MAss and CHarge Flows in GR / 393

Magnetized black holes: the role of rotation, boost, and accretion in twisting the field lines and accelerating particles

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Combined influence of linear boost and rotation of a black hole can distort an ambient magnetic field to the extent that magnetic field lines develop a neutral point, where the magnetic intensity vanishes. This purely geometrical effect interacts with the accretion flow that can carry and distort the frozen-in magnetic lines, too. Near the event horizon, the magnetic null is threaded by a non-vanishing electric component; these are circumstances favourable for acceleration of electrically charged particles. We outline the mechanism which could operate in the magnetosphere of astrophysical black holes that rotate and move through diluted gaseous environment pervaded by an organized (super-horizon scale) magnetic field. This set-up may work as a pre-acceleration agent near the ergospheric boundary (cf. The Astrophysical Journal, Volume 900, id.119, 2020; https://arxiv.org/abs/2008.04630).

Dragging is Never Draggy: MAss and CHarge Flows in GR / 540

Gravitomagnetic resonance and gravitational waves

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Gravitational waves are usually described in terms of a transverse and traceless (TT) tensor, which allows to introduce the so-called TT coordinates. However, another possible approach is based on the use of a Fermi coordinates system, defined in the vicinity of the world-line of an observer arbitrarily moving in spacetime. In particular, Fermi coordinates have a direct operational meaning, since they are the coordinates an observer would use to perform space and time measurements; indeed, using these coordinates the metric tensor contains (up to the required approximation level) only quantities that are invariant under coordinate transformations internal to the reference frame. Using this approach it is simple to emphasise that what an observer measures depends both on the background field where he is moving and, also, on his kind of motion. This is quite similar to what happens when we study classical mechanics in non inertial frames: inertial forces appear, depending on the peculiar motion of the frame with respect to an inertial one. We show that using Fermi coordinates the effects of a plane gravitational wave can be described by gravitoelectromagnetic fields: in other words, the wave field is equivalent to the action of a gravitoelectric and a gravitomagnetic field, that are transverse to the propagation direction and orthogonal to each other. In particular, the gravito-magnetic field acts on spinning particles and we show that, due to the action of the gravitational wave field a gravitomagnetic resonance may appear. We give both a classical and a quantum description of this phenomenon and suggest that it can be used as the basis for a new type of gravitational wave detectors.

Dragging is Never Draggy: MAss and CHarge Flows in GR / 483

The measurement of the Lense-Thirring effect within the LARASE experiment

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The LAser RAnged Satellites Experiment (LARASE), funded by the National Scientific Committee 2 (CSN2) of the Italian National Institute for Nuclear Physics (INFN) in the years 2013-2019, had among its main objectives that of verifying the gravitational interaction in the weak-field and slow-motion limit of General Relativity. Three geodynamic satellites: LAGEOS (NASA, 1976), LAGEOS II (ASI/NASA, 1992) and LARES (ASI, 2012) were taken as test masses of the experiment and their motions were carefully studied and compared with that of a timelike geodesic of General Relativity. Among the various measurements performed, the precession of the orbits of the satellites produced by the Earth's rotation, that is the precession induced by the angular momentum of our planet, has a particular consideration. This precession is generally known in the literature as Lense-Thirring effect or frame-dragging effect and proves that mass-energy currents affect the geometry of spacetime and, consequently, participate in the creation of its curvature. The results obtained in measuring the Lense-Thirring effect will be presented, highlighting the difficulties that must be overcome to the extent of a very small effect compared to the overall classical precession produced by the Earth's gravitational field and which acts on the same orbital elements subject to this relativistic precession. Emphasis will be given to the discussion of the systematic errors of the measurement, with special attention to gravitational perturbations.

Dragging is Never Draggy: MAss and CHarge Flows in GR / 295

Gravitomagnetism in the Lewis cylindrical metrics

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The Lewis solutions describe the exterior gravitational field produced by infinitely long rotating cylinders, and are useful models for global gravitational effects. When the metric parameters are real (Weyl class), the metrics of rotating and static cylinders are locally indistinguishable, but known to globally differ. The significance of this difference, both in terms of concrete physical effects and of the mathematical invariants where the rotation imprints itself, remained however an open problem. In this talk we will address these issues. We show that the Weyl class metric can be put into a 'canonical' form which depends explicitly only on three parameters with a clear physical significance, and reveals that the two settings differ only at the level of the gravitomagnetic vector potential which, for a rotating cylinder, cannot be eliminated by any global coordinate transformation. It manifests itself in frame-dragging effects such as the Sagnac and gravitomagnetic clock effects. This mirrors the electromagnetic field of a rotating charged cylinder, which likewise differs from the static case only in the vector potential, responsible for the Aharonov-Bohm effect (formally analogous to the Sagnac effect). The notions of local and global staticity are also revisited.

Dragging is Never Draggy: MAss and CHarge Flows in GR / 123

Quantum detection of inertial frame dragging

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The Unruh De-Witt detector was introduced originally to give an operational meaning to particle detection in curved spacetimes. This simple two level quantum system interacts with the quantum field through a monopole type coupling, possibly exciting it to the excited state in the process. As the vacuum state of the field depends on global features of the background spacetime, the transition probability of a detector may be able to pick up these features too. As a result, UDW are better-than-classical-detectors. Due to inertial frame dragging, inertial observers inside of a spherical rotating shell are dragged into rotation with respect to distant stars. However to a classical observer inside the shell, the local surrounding spacetime is Minkowski — by performing local gravitational experiments, the observer cannot tell if the shell is rotating. In contrast, we shall see that the transition probability of a UDW detector is sensitive to the shell's rotation. This is true even when the "switched-on" time of the detector is shorter than the time it takes for a signal to travel to the shell and back.

Effects of Primordial Perturbations Enhancement: from Black Holes Formation to CMB Anomalies

Effects of Primordial Perturbations Enhancement: from Black Holes Formation to CMB Anomalies / 443

Primordial Black Holes Arise When The Inflaton Falls

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Primordial Black Holes (PBHs) have entered the forefront of theoretical cosmology, due their potential role in phenomena ranging from gravitational waves, to dark matter, to galaxy formation. While producing PBHs from inflationary fluctuations naively would seem to require a large deceleration of the inflaton from its velocity at the horizon exit of CMB scales, in this talk we demonstrate that an acceleration from a relatively small downward step in the potential that is transited in much less than an e-fold amplifies fluctuations as well. Depending on the location of the step, such PBHs could explain dark matter or the black holes detected by the gravitational wave interferometers. The perturbation enhancement has a natural interpretation as particle production due to the non-adiabatic transition associated with the step.

Effects of Primordial Perturbations Enhancement: from Black Holes Formation to CMB Anomalies / 955

Deep learning merger masses estimation from gravitational waves signals in thefrequency domain

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Detection of gravitational waves (GW) from compact binary mergers provide a new window into multi-messenger astrophysics. The standard technique to determine the merger parameters is matched

filtering, consisting in comparing the signal to a template bank. This approach can be time consuming and computationally expensive due to the large amount of experimental data which needs to be analyzed.

In the attempt to find more efficient data analysis methods we develop a new frequency domain convolutional neural network (FCNN) to predict the merger masses from the spectrogram of the detector signal, and compare it to time domain neural networks (TCNN). Since FCNNs are trained using spectrograms, the dimension of the input is reduced as compared to TCNNs, implying a substantially lower number of model parameters, and consequently less over-fitting. The additional time required to compute the spectrogram is approximately compensated by the lower execution time of the FCNNs, due to the lower number of parameters.
In our analysis FCNNs show a slightly better performance on validation data and a substantially lower over-fit, as expected due to the lower number of parameters, providing a new promising approach to the analysis of GW detectors data, which could be further improved in the future by using more efficient and faster computations of the spectrogram.

Effects of Primordial Perturbations Enhancement: from Black Holes Formation to CMB Anomalies / 747

Numerical simulations of Primordial Black Holes (PBHs)

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In this talk, I will talk about the recent developments in numerical simulations of PBHs under spherical symmetry on a FRW background. Specifically, I will focus on the threshold for PBH formation and the effect of the accretion and sizes of the PBHs formed in terms of the specific shape of the initial curvature profile.

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Predictions for the CMB in inflationary and anisotropic cosmologies

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The paradigm of slow-roll inflation provides a snapshot of the early universe that is in good agreement with present observations. Despite its success, most of the models studied so far rely heavily on the assumption that the universe is perfectly isotropic at early times. In this talk, I will discuss recent advances in anisotropic inflationary models. We adopt a Fock quantization for gauge-invariant perturbations. We evolve them through an anisotropic bounce within loop quantum cosmology. Despite anisotropies die out very rapidly just before the inflationary expansion, scalar and tensor perturbations keep memory of that anisotropic phase, and leave several types of anomalies in the Cosmic Microwave Background (CMB). With these imprints and current data, we constrain the departure from spatial isotropy of the early universe, as well as discuss modifications in the usual angular correlation functions and the generation of TB and EB correlations that are forbidden in the standard isotropic scenario.

Effects of Primordial Perturbations Enhancement: from Black Holes Formation to CMB Anomalies / **333**

tSZ in high ell CMB data as cosmological probe: SPT+Planck

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Small scale CMB data contain a lot of cosmological information hidden in the different components : primordial CMB, tSZ effect, kSZ effect, CIB. Standard analyses assume templates for non primordial CMB components and lose the cosmological signature of large scale structures contained in secondary anisotropies. I will present a new analysis of SPT data at small scales where the tSZ spectrum is derived from the halo model and bring additional constraints. I will show the cosmological and scaling relation parameter constraints obtained by combining SPT CMB data and Planck tSZ measurements.

Effects of Primordial Perturbations Enhancement: from Black Holes Formation to CMB Anomalies / **853**

A possible mass distribution of primordial black holes implied by LIGO-Virgo

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The LIGO-Virgo Collaboration has so far detected around 90 black holes, some of which have masses larger than what were expected from the collapse of stars. The mass distribution of LIGO-Virgo black holes appears to have a peak at ~ $30M_{\odot}$ and two tails on the ends. By assuming that they all have a primordial origin, we analyze the GWTC-1 (O1&O2) and GWTC-2 (O3a) datasets by performing maximum likelihood estimation on a broken power law mass function f(m), with the result $f \propto m^{1.2}$ for $m > 35M_{\odot}$ and $f \propto m^{-4}$ for $m > 35M_{\odot}$. This appears to behave better than the popular log-normal mass function. Surprisingly, such a simple and unique distribution can be realized in our previously proposed mechanism of PBH formation, where the black holes are formed by vacuum bubbles that nucleate during inflation via quantum tunneling. Moreover, this mass distribution can also provide an explanation for supermassive black holes formed at high redshifts.

Effects of Primordial Perturbations Enhancement: from Black Holes Formation to CMB Anomalies / **797**

Effects of the modification of gravity on the production of primordial black holes

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The enhancement of the spectrum of primordial comoving curvature perturbation $\mathcal{R}$ can induce the production of primordial black holes (PBH) which could account for part of present day dark matter. As an example of the effects of the modification of gravity on the production of PBHs, we investigate

the effects on the spectrum of $\mathcal{R}$ produced by the modification of gravity in the case of G-inflation, deriving the relation between the unitary gauge curvature perturbation ζ and the comoving curvature perturbation $\mathcal{R}$, and identifying a background dependent enhancement function $\mathcal{E}$ which can induce large differences between the two gauge invariant variables. We use this relation to derive an equation for $\mathcal{R}$, showing for the presence of a momentum dependent effective sound speed (MESS), associated to the intrinsic entropy which can arise in modified gravity theories, in agreement with the model independent MESS approach to cosmological perturbations.

When ζ is not constant in time it is different from $\mathcal{R}$, for example on sub-horizon scales, or in models exhibiting an anomalous super-horizon growth of ζ, but since this growth cannot last indefinitely, eventually they will coincide.
We derive the general condition for super-horizon growth of ζ, showing that slow-roll violation is not necessary.
Since the abundance of PBHs depends on the statistics of the peaks of the comoving density contrast, which is related to the spectrum of $\mathcal{R}$, it is important to take into account these effects on the PBHs abundance in modified gravity theories.

Electromagnetic Counterparts of Compact Binary Mergers

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Jet physics, ejecta properties and Hubble constant from the afterglows of neutron star mergers

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Radio afterglows of neutron star mergers are excellent probes of the fast ejecta (relativistic jets and fast tail of the dynamical ejecta) and provide strong constraints on the inclination angle, ejecta morphology and energetics. This information is complementary to the ejecta mass and composition derived from the early-time UV-optical-infrared emission (called the kilonova/macronova). Radio observations of GW170817 revealed an energetic and narrowly-collimated jet, similar to those seen in gamma-ray bursts, surrounded by a wider angle outflow (together called the structured jet or jet-cocoon). Very long baseline interferometric observations were especially important in constraining the geometry, thereby providing a (standard siren) measurement of the Hubble constant. I will present the latest results from GW170817 and discuss the prospects for detecting radio afterglows of mergers in the upcoming LIGO-Virgo-KAGRA observing runs.

Electromagnetic Counterparts of Compact Binary Mergers / 564

Diversity of Kilonova Emission from Binary Neutron Star Mergers

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The outcome of a binary neutron star depends sensitively on the mass of the binary and the equation of state of dense nuclear matter. All else being equal, lower mass binaries tend to produce rapidly rotating magnetar remnants that survive longer (if not indefinitely) before collapsing into black holes. I will discuss some of the implications of the resulting diversity imprinted by a range of binary masses on the properties of the kilonova emission. A long-lived remnant can influence the kilonova properties in a number of ways, ranging from the impact of strong neutrino irradiation from the remnant on the composition of the ejecta (and hence the colors of the kilonova imprinted by the ejecta opacity) to contributing an additional source of luminosity from a rotationally-driven outflow in excess of that from radioactivity alone. Insofar as the properties of a putative relativistic jet would also influenced by the remnant lifetime, we should expect close connections between the non-thermal (e.g. afterglow) and thermal kilonova signatures of the merger.

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Emission from Structured GRB Jets: Theoretical Overview

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The unprecedented coincident detection of a short gamma-ray burst (GRB) with gravitational waves from a binary neutron star (BNS) merger in GW170817/GRB170817A, followed by the long-lasting broadband afterglow, put our understanding of the structure of GRB jets to the test. GRB170817A turned out to be a particularly interesting event, due to its nearby distance (~40 Mpc) and emission from an off-axis jet, that gave us a range of new insights and confirmed some old ones. The most important of which is the unequivocal realization that GRB jets have angular structure. This has important implications for the detection and understanding of future such events. In this review talk, I will present the theory of emission from structured GRB jets, covering both prompt and afterglow emission. I will highlight the differences between off-axis emission from the simpler and often used top-hat jet model and the structured jets using the prompt and afterglow observations of GRB170817A. The full range of afterglow lightcurves that can be observed from an off-axis structured jet will be discussed. Important diagnostics, namely the afterglow flux centroid motion, image size, and polarization, that can be used to understand the outflow structure and properties of the post-shock magnetic field in future events will be discussed.

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Constraints on Kilonova Emission from Two Short GRBs at z=0.5

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The connection between binary neutron star mergers and short gamma-ray bursts (GRBs) was solidified by the simultaneous detection of GW170817 and GRB 170817A. These events were followed by bright kilonova emission arising from the radioactive decay of freshly synthesized r-process ejecta, which were expelled during the neutron star merger. Kilonova emission is a fundamental signature of neutron star mergers. The ability to distinguish kilonova emission from the GRB afterglow requires a well characterized multi-wavelength afterglow, and sensitive near-infrared (nIR) observations. The majority of short GRBs lack these features, and, therefore, no meaningful limits on the kilonova ejecta mass can be determined in most cases. As such, evidence for kilonova emission has only been identified in a handful of short GRBs. In this talk I will present a multi-wavelength study of two cosmological short GRBs, GRB 160624A at z = 0.483 and GRB 200522A at z = 0.554, targeted at constraining kilonova emission from these events. Although associated to a similar distance, these events display extremely different emission properties. The optical/nIR limits for GRB 160624A are among the most stringent for short GRBs, and strongly disfavor kilonova ejecta masses larger than 0.1 solar mass. Whereas GRB 200522A displays a bright, nIR emission component that can be explained either by a radioactively powered kilonova with large ejecta mass, ~ 0.1 solar mass, or by intrinsic extinction from its host galaxy. These observations further extend the small sample of short GRBs with nIR observations, and pave the way for future results from the James Webb Space Telescope.

Electromagnetic Counterparts of Compact Binary Mergers / 902

Kilonova signal in NS-BH merger

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A kilonova signal is generally expected after a Black Hole - Neutron Star merger. The strength of the signal is related to the Equation of State of neutron star matter and it increases with the stiffness of the latter. The recent results obtained by NICER suggest a rather stiff Equation of State and the expected kilonova signal is therefore strong, at least if the mass of the Black Hole does not exceed $\sim 10 M_{\odot}$. We compare the predictions obtained by considering Equations of State of neutron star matter satisfying the most recent observations with the results predicted in the two-families scenario. In the latter a soft hadronic Equation of State produces very compact stellar objects while a rather stiff quark matter Equation of State produces massive strange quark stars, satisfying NICER results. The expected kilonova signal in the two-families scenario is very weak: the Strange Quark Star - Black Hole merger does not produce a kilonova signal because, according to simulations, the amount of mass ejected is negligible and the Hadronic Star - Black Hole merger produces a signal much weaker than in the one-family case because the hadronic Equation of State is very soft. This prediction will be easily tested with the new generation of detectors.

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The Best Case Scenario: Towards prompt arcminute localization of a GW source with targeted joint sub-threshold GRB searches, intelligent scheduling, and early warning response

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The rich EM phenomenology in the first few hours after a compact object merger encodes the nature of the post-merger remnant, and a wide array of other compelling physics. Unfortunately, the requirement to find, and classify a counterpart within the large GW localization regions before followup with sensitive instruments can begin, excludes access to these first few hours, even for the most well localized GW sources. The ability to rapidly localize a GW source to within the field-of-view of a narrow field sensitive facility, would enable extraordinary science, and is uniquely enabled by GRB imagers with arcminute localization, like Swift/BAT. Such a prompt localization is the best case scenario. I will present the Swift/BAT-GUANO rapid spacecraft commanding and targeted sub-threshold GRB search pipeline, which allows significantly deeper searches for faint GRB 170817-like bursts, achieving the farthest detection range for such transients among current instruments. This pipeline has already increased the rate of arcmin localized GRBs by >15%. GW/GRB searches in the joint sub-threshold regime can also significantly extend the BNS detection horizon, and I will discuss methods and results from a joint search during LVC O3. The angular resolution of BAT allows good spatial discrimination and push to higher temporal FARs with the small spatial overlap, further increasing the sensitivity of joint searches. However, Swift/BAT's field of view (1/6 sky) decreases the expected detection yield compared to all-sky instruments, even with the increased horizon. I will discuss biased scheduling techniques that can increase the joint GRB/GW detection rate, and efforts to use GUANO-enabled rapid commanding capabilities to respond to early warning GW alerts and put the GW location within the BAT FoV at merger time. The combination of all of these will increase the chance of a best case scenario, and set the stage for next generation space telescope response.

Electromagnetic Counterparts of Compact Binary Mergers / 812

Electromagnetic Counterparts of Compact Binary Mergers: the recent case of GW170817

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I will provide a critical review of what we learned from the NS-NS merger GW170817 during year of electromagnetic follow up across the spectrum. Specifically, I will focus on recent developments from our coordinated radio-X-ray monitoring campaign that revealed the emergence of a new component of emission.

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Constraining and comparing short gamma-ray burst beam profiles using gravitational waves

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GRB 170817A was markedly dissimilar to any other detected short gamma-ray burst as it was observed off-axis. This was further made evident by the information gained from the accompanying observation of GW170817. The event has since sparked discussion into the short gamma-ray burst beam profile and how it can link the observed luminosity of GRB 170817A with the rest of the observed on-axis short gamma-ray burst population. By assuming the short gamma-ray burst beam profile is universal across events, we use a fully Bayesian analysis to place constraints on beam profiles associated with cocoon, structured and simple top-hat jet models, as well as the binary neutron star merger rate. The beam profiles are constrained to reconcile the discrepancy between GRB 170817A and the rest of the on-axis population, given the distance and inclination information from GW170817 and the neutron star merger rate inferred from LIGO's first and second observing runs. We further show that these models can be distinguished from one another given a population of future gravitational wave detections of neutron star mergers with and without a counterpart, promised by the observations made by third-generation detectors.

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CALET search for Gamma-ray Counterparts of Gravitational Wave Events

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The CALorimetric Electron Telescope (CALET) cosmic ray detector on the International Space Station (ISS) has been in operation since its launch in 2015.
The main instrument, the CALorimeter (CAL), is monitoring the gamma ray sky from ~1 GeV up to

~10 TeV with a field-of-view of about 2 sr for more than five years.
In this paper, we describe the analysis of gamma ray candidate events observed by CALET and report on a search for gamma-ray emission from gravitational wave event candidates announced by the LIGO/Virgo third observing run since 2019 April.

Electromagnetic Counterparts of Compact Binary Mergers / 195

Neutron Star properties and EM follow-up of Kilonovae

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When two Neutron Stars (NSs) merge a multi-band electromagnetic (EM) emission, known as Kilonova (KN), follows. It is believed to be powered by the radioactive decay of ejecta products. In this contribution we discuss how future measurements of KN light curves and spectra could constrain some interesting features of the NSs in the coalescing binary. In particular we will focus on the impact and uncertainties of the current knowledge of the equation of state of dense matter on the mass, velocity and other subsequent observables in the KN ejecta.

Exact Solutions (Including Higher Dimensions)

Exact Solutions (Including Higher Dimensions) / 412

New exact stationary cylindrical anisotropic fluid solution of GR

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The properties of interior spacetimes sourced by stationary cylindrical anisotropic fluids are analytically studied for both nonrigid and rigid rotation. The gravito-electromagnetic features of different classes of such GR solutions are described. Their regularity conditions and those for their junction to a vacuum exterior are provided. A new class of rigidly rotating exact solutions to Einstein's field equations satisfying a physically consistent equation of state for anisotropic fluids is displayed. Its physical properties are discussed.

Exact Solutions (Including Higher Dimensions) / 510

Freely-falling bodies in standing-wave spacetime

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The phenomena of standing waves is well known in mechanical and electromagnetic setting where the wave has the maximum and minimum amplitude at the antinodes and nodes, respectively. In the context of the exact solution to Einstein Field equations, we analyze a spacetime which represents standing gravitational waves in an expanding Universe. The study the motion of free masses subject to the influence of standing gravitational waves in the polarized Gowdy cosmology with a three-torus topology. We show that antinodes attract freely falling particles and we trace the velocity memory effect.

Exact Solutions (Including Higher Dimensions) / 24

Three-parameter solution for the null-surface formulation in 2+1 dimensions

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The null-surface formulation (NSF) of general relativity is equivalent to standard general relativity but uses families of null surfaces rather than the metric or a connection. The NSF can be constructed in dimension 3+1, in any dimension higher, and also in dimension 2+1, which is a special case: In 2+1 dimensions, the main NSF field equation is equivalent to Cartan's metricity condition. The latter arose in differential equation theory to address the problem of classifying solutions of third-order ordinary differential equations. Solving the NSF/Cartan equation has proved challenging, and only three solutions are known to date. This talk presents a fourth solution, which depends upon three independent parameters. Two of the previously known solutions are included as special cases. Energy conditions, Petrov classification, and possible source terms are examined. The physical interpretation is discussed in detail.

Exact Solutions (Including Higher Dimensions) / 300

Analytic and localized brane-world black holes

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We construct from first principles the geometry of an analytic, exponentially localized five-dimensional brane-world black hole. The black-hole singularity lies entirely on the 3-brane, while the event horizon is shown to have a pancake shape. The induced line-element on the brane assumes the form of the Schwarzschild solution while the bulk geometry is effectively AdS_5 outside the horizon. The derived geometry is supported by an anisotropic fluid in the bulk described only by two independent components, the energy density and tangential pressure, whereas no matter needs to be introduced on the brane for its consistent embedding in the bulk. Finally, we show that a brane-world Reissner-Nordstrom-(A)dS solution can be also obtained using the same procedure.

Exact Solutions (Including Higher Dimensions) / 603

Memory effects in Kundt geometries for Brans-Dicke gravity

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Understanding gravitational wave memory effects for exact radiative solutions in General Relativity (GR) have received considerable attention lately, following the work of Zhang, Duval, Gibbons and Horvathy (PRD, 2017). In principle, one can arrive at these effects by studying the separation of pairs of geodesics in such spacetimes. Radiative geometries such as Kundt waves have shown to possess distinct memory behaviour. In this talk, after a brief review of results in GR, we move on to discuss our recent work in Brans-Dicke gravity. Constructing an exact solution for Kundt waves and gyratons in this theory, we investigate memory by analysing both geodesics and geodesic deviation.

Our study reveals significant differences in memory effects obtained for both these geometries (i.e. with and without gyratonic terms) as well as with earlier related results obtained in GR.

Exact Solutions (Including Higher Dimensions) / 558

Scalar configurations in Quadratic Palatini Gravity: The Persistence of Wormholes

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Using the algorithm proposed to map solutions of General Relativity (GR) into Ricci-Based Gravity theories, we extend the search for scalar configurations in quadratic gravity theories with curvature dependence in both Ricci scalar, R, and Ricci-squared scalar, $Q = R_{\mu\nu}R^{\mu\nu}$. We describe the general method to map a scalar configuration of GR into $f(R, Q)$, and illustrate this procedure by applying it to the quadratic model $f(R, Q) = R + aR^2 + bQ$. We find scalar field solutions that, depending on the parameters a and b, can describe quite different compact objects, such as wormholes and compact balls. We compare the solutions found in the $f(R, Q)$ theory context with the GR seed solution and previous scalar configurations found in a quadratic $f(R)$ theory, pointing out some differences between them. We analyze some properties of the solutions found, in particular we study their geodesic structure.

Exact Solutions in Four and Higher Dimensions

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Multicenter and Rotating Solutions in Eddington-inspired Born-Infeld Gravity

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In the so-called Ricci-based Gravity theories (RBGs for short) it is possible to transform a modified gravity problem into a standard problem in GR coupled to a modified matter source. Taking advantage of this property, one can also take non-vacuum solutions of GR and use them as seeds to generate new solutions in other theories of the RBG family. I will present recent results in this direction in which exact solutions of the Kerr-Newman type and multicenter (Majumdar-Papapetrou) type are generated in the so-called Eddington-inspired Born-Infeld (EiBI) theory of gravity.

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Anisotropic Solutions through Decoupling in Curvature-Matter Coupling Gravity

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In this talk, we discuss the extended gravitational decoupling approach for a static sphere in the framework of f(R,T) gravity where R represents the Ricci scalar and T is the trace of the energy-momentum tensor. In this approach, the domain of a known solution is extended by incorporating a new gravitational source. Transformations in radial and temporal metric functions split the system of field equations into two subsystems corresponding to isotropic and additional sources. We consider the Korkina-Orlyanskii metric as a solution for the system related to the seed source and extend it to anisotropic domain using some physical constraints on the new source. The physical acceptability, compactness and redshift of anisotropic solutions are explored graphically for the compact star 4U 1538-52. It is found that well-behaved solutions can be constructed in the framework of f(R,T) gravity through the decoupling technique.

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Kundt spacetimes in the Einstein-Gauss-Bonnet theory

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Based on our recent results we present the complete class of vacuum solutions in the Einstein–Gauss–Bonnet gravity which admit non-expanding, shear-free and twist-free null geodesic congruence and thus form the Kundt family of geometries. We explicitly derive the field equations and classify their solutions into three distinct subfamilies. Algebraic structure of the curvature tensors is determined and using the corresponding scalars entering the invariant form of geodesic deviation equation we discuss the specific local physical properties of the gravitational field constrained by the EGB theory. Moreover, we analyse various interesting subclasses of such vacuum solutions, namely the Ricci type III spacetimes, all geometries with constant-curvature transverse space, and the whole pp -wave class admitting a covariantly constant null vector field.

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Tolman-Oppenheimer-Volkoff conditions beyond spherical symmetry

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In most cases the TOV equation appears as the relativistic counterpart of the classical condition for hydrostatic equilibrium, and characterises the static equilibrium of bound, spherical distributions of matter such as stars. In the present work we aim at showing that a generalised TOV equation also characterises the equilibrium of models endowed with other symmetries besides spherical. We resort to the dual null formalism applied to spacetimes with two dimensional spherical, planar and hyperbolic symmetries, and consider a perfect fluid as the source. Static configurations assume the existence of a time-like Killing vector field orthogonal to the surfaces of symmetry, and homogeneous dynamical solutions arise when the Killing field is space-like. In order to treat equally all the aforementioned cases, we discuss the definition of a quasi-local energy for the spacetimes with planar and hyperbolic foliations, since the Hawking–Hayward definition only applies to compact foliations. This procedure enables us to translate our geometrical formalism to the fluid dynamics language in a unified way, to find the generalised TOV equation, for the three cases when the solution is static, and to obtain the evolution equation, for the homogeneous spacetime cases. Remarkably, we show that the static solutions which are not spherically symmetric violate the weak energy condition (WEC). We also show that the counterpart of the TOV equation $\rho + P = 0$, defines a cosmological constant-type behaviour, both in the hyperbolic and spherical cases. This implies a violation of the strong energy condition in both cases, added to the above mentioned violation of the weak energy condition in the hyperbolic case. We illustrate our unified treatment obtaining analogs of Schwarzschild interior solution, for an incompressible fluid $\rho = \rho_0$ constant.

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Non-singualar spacetimes with the NUT parameter

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The spacetimes with the NUT parameter are commonly associated with an unwanted defect in the form of a singular axis of symmetry. In the case of the Taub-NUT spacetime the most common remedy is the Misner's interpretation: by compactifying the orbits of the cyclic time symmetry one discovers that the spacetime has a structure of the Hopf fibration. Then Taub-NUT may be regarded as a smooth "regularizer" of the Schwarzschild solution curing the curvature singularity at $r = 0$.
I will discuss how the above results may be extended to black hole spacetimes including more parameters – Kerr rotation, cosmological constant and acceleration. Suprisingly, additional parameters do not necessarily lead to harsher conditions for non-singularity. The basic premise of the extension of Misner's interpretation to more general spacetimes is to find Killing vector fields generating the non-singular orbit space and subsequently impose the U(1)-principle bundle structure onto the spacetime. This leads to spacetimes without singular axis for all admissible parameters, and even to completely singularity-free spacetime for a subfamily of accelerated Kerr-NUT-(anti-) de Sitter (i.e. general Plebański-Demiański, type D, black hole solution).
The application of the non-singular interpretation to Killing horizons and cosmology will be presented.

Experimental Gravitation

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A parallel plate approach to force metrology

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Understanding dark energy and dark matter is one of the most pressing problems in present day physics. In recent years, scalar field models have become popular as candidate theories. As the corresponding hypothetical particles have low masses, collider experiments may not be suitable to search for them. Force metrology at sub-mm scales, on the other hand has proven to be useful in this respect. Over the past decade, tight limits on most candidate models have been set but no confirmed signals have been found.
The Casimir And Non-Newtonian Force EXperiment (CANNEX) presently is the only force metrology experiment working in the geometry of plane parallel plates. This geometry maximizes the force generation between the two test masses, and thereby the sensitivity with respect to a range of dark matter, dark energy, and interfacial Casimir forces. In the present talk, we report on the recently completed proof of principle, discuss the status of the experiment, and give an overview of the manifold opportunities for measurements that are about to commence soon.

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Measurement of the gravitational redshift effect using the satellite Spectr-R in the "RadioAstron" mission

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We report on the recent results of testing one of the aspects of Einstein's principle of equivalence - the effect of gravitational redshift, by means of its precision measurement using the Spectr-R as part

of the VLBI mission Radioastron.
Satellite Spectr-R and two tracking stations (Green Bank (USA)) and Pushchino (Russia) were equipped with hydrogen frequency standards with relative stability no worse than 10^{-14}. Comparison of the onboard and ground standards made it possible to measure the frequency shift due to the difference in gravitational potentials on the ground and in orbit. Each measurement session consisted of alternating segments communication with carrier synchronized according to the onboard standard (1w mode) and according to the ground standard of the Pushchino station (2w mode). The use of a combination of both modes made it possible to compensate for the dominant 1st order Doppler effect and tropospheric shifts. The ionospheric shift was eliminated by measurements at two different carrier frequencies. The Doppler effect of the second order and the systematic error of the difference in the nominal values of the standards are compensated for when passing to the measurement of the modulation component of the gravitational shift during the orbital motion of the satellite, which is 10% of the stationary value due to the large ellipticity of the orbit. We report success in revising the bias value by re-processing the accumulated data from 5% to 15%. This makes it possible to bring the error of correspondence of the measured gravitational shift to the calculation formula of general relativity to the level of 10^{-3}. Although this is rougher than the result achieved with the Galileo satellites, it should be noted that never before has the gravitational redshift been measured with such accuracy at such large distances from the Earth of 350,000 km.

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Dark gravitomagnetism with LISA and gravitational waves space detectors

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The LISA interferometer, designed for detecting gravitational waves, lends an opportunity to measure the gravitomagnetic field linked by the device. The expected flux is due to the angular momentum of the sun, but could also have a contribution from the angular momentum of the Milky Way, including the dark halo in which our galaxy is likely to be immersed. According to current models, the total mass of the dark halo is expected to be several times the mass of the visible (baryonic) disk. The method that could be used to spot the total gravitomagnetism at the position of the solar system is based on the anisotropy in the propagation of electromagnetic waves, induced by the presence of the gravito-magnetic field. The asymmetry could be evidenced exploiting the Sagnac effect on pairs of EM pulses propagating in opposite directions along the contour of the interferometer. The peculiar orientation of the plane of LISA leads to a seasonal modulation of the projection of the area onto the galactic plane, thus offering a means to discriminate the signal from the Milky Way from that of the sun. The use of the Sagnac effect is already foreseen within LISA for the control of the configuration of the arms, but it could be extended here for research purposes. We will discuss both the problems of principle and the practical problems to be tackled.

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qBounce: Ultra-cold neutrons bound by Earth's gravity field, a tabletop search for hypothetical gravity-like interactions

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Very slow, so-called ultra-cold neutrons form bound quantum states in the Earth's gravitational field. These neutrons allow the fascinating possibility to investigate gravity at short distances using a simple quantum system. A spectroscopy method for ultra-cold neutrons bound to the surface of mirrors allows to drive transitions between eigen-states of quantum gravitational states. This enables us to measure the transition frequencies with high accuracy. A deviation from the expected gravitational energy states might point to hypothetical gravity-like interactions. Here we present the qBounce experiment, where we implement Ramsey's method of separated oscillating fields by mechanically exciting the neutrons with oscillating mirrors, a method we call Gravity Resonance Spectroscopy (GRS). Multiple transitions have been observed by qBounce in the past. The results of Rabi's Method have been used to constrain chameleon and symmetron dark energy. After extending the experimental capabilities to two separated oscillating mirrors we have succeeded in determining the transition frequency with an energy resolution $\Delta E \approx 10^{-16}$ eV.

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Using Bose-Einstein Condensates as Gravitational Wave Detectors

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With the recent direct observation of gravitational waves, a new avenue of observing the Universe has become available. As a result, much effort is being devoted to the design of new detectors sensitive to different gravitational wave sources. One unique proposal is to detect gravitational waves using a Bose-Einstein Condensate (BEC) by using quantum metrology.
In this talk, I will show that transient gravitational wave detection using BECs is limited at lower frequencies by methods in quantum optics and by damping at higher frequencies. For continuous sources, an oscillating speed of sound is considered as a means to amplify sensitivity. I will discuss the prospects and challenges for such detectors to be competitive to existing gravity wave detectors.

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Gravitomagnetic Field Generation using High Permittivity Materials in SMES Devices

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A method is described for creating a measurable unbalanced gravitational acceleration using a gravitomagnetic field surrounding a superconducting toroid as described by Forward (1962). An experimental Superconducting Magnetic Energy Storage (SMES) toroid configuration of wound superconducting nanowire is proposed to create a measurable acceleration field along the axis of symmetry,

providing experimental confirmation of the additive nature of a Lense-Thirring derived gravitomagnetic field. In the present paper gravitational coupling enhancement of this effect is explored using high permittivity material, as predicted by Sarfatti (2020) in his modification to Einstein's General Relativity Field Equations for gravitational coupling in matter.

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A Man-Made Experiment Aimed to Clarify the Gravity Law in The Solar System

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A new type of man-made experiment is precomputed and suggested to enforce the evidence base for general relativity (GR) as the Solar system gravity. We present a detailed analytical and numerical descriptions of a space-probe flight from the Earth towards Venus with Venus' gravity assist (GA) accelerating the probe to return it to the Earth's orbit. We demonstrate that any planet's GA is ultrasensitive to variation of the probe-planet impact parameter, so it can serve as a powerful amplifier (up to 10^5 times) of deviations from the assigned probe's trajectory. An empiric GA-sensitivity function is built with the help of the "conic patched approximation" method (e.g. [1,2]) and numerical orbit construction 3. To compare the classical and GR versions of the Sun's gravity we introduce a concept of the probe's "standard flight" and (solving geodesic equation in Schwarzschild coordinates with the tangent space technique) we show that the GR-field distorts the Earth-Venus classical trajectory and reduces probe-Venus GA-distance up to 1% (~40 km at the probe's altitude ~4000 km over planet's surface). Three constituents of the effect are the Einstein's "perihelion shift", the quasi-elliptic orbit compression, and the probe's earlier arrival at the GA point. This effect entails the difference between the flight endpoints (achieved at the same time) of few million km, the distance obviously observable from the Earth [4]. Thus, the proposed experiment makes it possible to distinguish classical and GR gravities. Moreover, using the standard flight scheme we compare the impact of two GR-gravities represented in Schwarzschild and isotropic coordinates. An analytical calculation yields ~0.25% difference between respective probe-Venus GA-distances, which entails ~0.5 million km endpoint distance, making possible to specify even a type of GR gravity [5]. We also discuss a need of convincing empiric statistic and measures to avoid the probe's trajectory random perturbances.

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Relativistic measurements with the Galileo Constellation: the Galileo for Science_2.0 (G4S_2.0) Project

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G4S_2.0 is a new project funded by the Italian Space Agency (ASI) that aims to perform a set of gravitational measurements with the Galileo satellites of the Full Operational Capability (FOC) constellation. Two of these satellites, GSAT 0201 and GSAT 0202, are characterized by a relatively high eccentricity of their orbits, about 0.16, with respect to that of the other satellites of the constellation, close to zero. From the accurate analysis of the orbits and clocks of these satellites it is possible to perform a series of relativistic tests. These tests mainly concern the motion of a "proof mass" along a timelike geodesic of space-time and the time dilation of on-board clocks.
After a general introduction to the goals of G4S_2.0 in the field of fundamental physics measurements, we present the preliminary activities of the project which are under development by IAPS-INAF in Roma, ASI-CGS in Matera and Politecnico in Torino.

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The Ginger project - preliminary results

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The debate on gravity theories to extend or modify general relativity is very active today and research efforts are devoted to test theories of gravity. Here, we present the GINGER experiment, which, being Earth based, requires little modeling of external perturbation, allowing a thorough analysis of the

systematics, crucial for experiments where sensitivity breakthrough is required.
We recently proposed the GINGER (Gyroscopes IN GEneral Relativity) experiment a tri-axial array of Ring Lasers (RL) that can reach the sensitivity, accuracy, and long term stability required to measure the inertial frame dragging induced by the rotating Earth, as predicted by General Relativity. This effect, also known Lense-Thirring effect, amounts for the Earth to 1 part in 10^9 of its rotation rate, thus requiring an unprecedented sensitivity and accuracy of experimental apparatus. The proposed array of at least 3 RLs would allow us to measure both the rotation rate, and the orientation of the instantaneous rotation axis. A top class Sagnac gyroscope prototype, GINGERINO, was built and its sensitivity investigated with standard statistical means and the available geodesic measurements of the Earth angular rotation rate. All features of the Earth rotation rate are correctly reproduced. The unprecedented sensitivity of fractions of frad/s is attained for long term runs. Work is in progress in order to further confirm this excellent sensitivity and stability, which certainly would put Sagnac gyroscopes at the forefront for fundamental physics.

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Review of Tokamak Physics and GW conditions in relic conditions before 10^- 26 reduction in frequency with predictions as to what may be obtained in eLISA GW measurements from 10^-4 Hz down to 10^-16 Hz for eLISA

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- We consider an inverse procedure as to predict what may be obtained in eLISA , near Earth Orbit, in GW frequency. Among other issues would be the duration of the GW pulse so observed, in eLISA measurements, the relative degree of noise in the signal, as observed by eLISA, and this by the device of a step down in frequency of GW from about 10^19 Hz, in the early universe, or at a minimum 10^10 Hz down to 10^-4 Hz to a low of 10^-16 Hz, as could be ascertained by eLISA. We use the Tokamak in order to obtain GW signals an average of 10^25 to 10^26 times larger than what eLISA would observe as a way to make guesses as to the turbulence of the LISA signal, how to consider and prepare for inevitable isotropic stochastic noise in the signal as well as guesses as to sources as to the noise and the duration of the signal. Which may be observed by eLISA. We do this as was mentioned before using Grischuk and Sachin (1975) amplitude for the GW generation due to plasma in a toroid, we generalize this result for Tokamak physics. We obtain evidence for strain values up to h ~ 10^-25 - 10^-26 in a Tokamak center. The GW frequency created by a Tokamak are due to Plasma physics interactions within the Tokamak Toroid, but can with an application of common sense allow us to know what to look for in e LISA in its commissioning and GW runs

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Polarization rotation in geometric optics approximation and its subleading order correction

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Geometric optics approximation is sufficient to describe the effects in the near-Earth environment. In this framework a careful analysis of the local standard polarization directions allows to obtain transparent expressions for polarization rotation. We provide a simple estimation of this emitter/observer-dependent phase and give its explicit form in different settings: 1) Considering the relative motion between the earth and the satellite and ignoring any gravitational effects. 2) Considering the gravitational effects of the earth up to the leading order post-Newtonian for light propagation between the earth and the satellite and ignoring any relative motions between them. Even if the gravitationally-induced polarization rotation also called gravitational Faraday effect is a pure gauge effect in the geometric optics approximation, it cannot be simply dismissed. Interpretation of the results of Faraday effects in the framework of geometric optics, and in the spin-optics approximation is sometimes contradictory. The reason is the crucial role of local reference frames and the ensuing introduction of the standard polarization directions sometimes were not treated in a fully satisfactory manner. Establishing local reference frame with respect to some distant stars leads to the Faraday phase error between the ground station and the spacecraft of the order of 10^{-10}, while the Wigner phase of special relativity is of the order 10^{-4}–10^{-5}. Both types of errors can be simultaneously mitigated.

We also present briefly the covariant formulation of geometric optic correction up to the subleading order approximation, which is necessary for the propagation of electromagnetic/ gravitational waves of large but finite frequencies.

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How a Laser Physics Induced Kerr-Newman Black Hole Can Release Gravitational Waves without Igniting the Black Hole Bomb (Explosion of a Mini Black Hole in a Laboratory)

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Note, that micro black holes last within micro seconds, and that we wish to ascertain how to build, in a laboratory, a black hole, which may exist say at least up to 10^−1 seconds and provide a test bed as to early universe gravitational theories. First of all, it would be to determine, if the mini black hole bomb, would spontaneously occur, unless the Kerr-Newmann black hole were carefully engineered in the laboratory. Specifically, we state that this paper is modeling the creation of an actual Kerr Newman black hole via laser physics, or possibly by other means. We initiate a model of an induced Kerr-Newman black Holes, with specific angular momentum J, and then from there model was to what would happen as to an effective charge, Q, creating an E and B field, commensurate with the release of GWs. The idea is that using a frame of reference trick, plus E + i B = −function of the derivative of a complex valued scalar field, as given by Appell, in 1887, and reviewed by Whittaker and Watson, 1927 of their "A Course of Modern Analysis" tome that a first principle identification of a B field, commensurate with increase of thermal temperature, T, so as to have artificially induced GW production. This is compared in part with the Park 1955 paper of a spinning rod, producing GW, with the proviso that both the spinning rod paper, and this artificial Kerr-Newman Black hole will employ the idea of lasers in implementation of their respective GW radiation. The idea is in part partly similar to an idea the author discussed with Dr. Robert Baker, in 2016 with the difference that a B field would be generated and linked to effects linked with induced spin to the Kerr-Newman Black hole.

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Height measures in relativistic geodesy

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The Newtonian gravity potential is one of the main notions for conventional geodesy and employed for basic concepts, such as the definition of heights. A modern height definition in terms of geopotential numbers can offer a variety of advantages. Moreover, from the theoretical point of view, such a definition is considered more fundamental.
We know, however, that relativistic gravity (here General Relativity) requires to reformulate basic geodetic notions and to develop a consistent theoretical framework, relativistic geodesy, to yield an undoubtedly correct interpretation of contemporary and future (high-precision) measurement results. The new framework of chronometric geodesy that builds on the comparison of clocks at different positions in the gravitational field offers fundamental insight into the spacetime geometry if a solid theoretical formulation of observables is underlying all observations. For chronometry, high-performance clock networks, i.e., optical clocks connected by dedicated frequency transfer techniques, are capable to observe the mutual redshift with incredible accuracy.
Here we approach a genuine relativistic definition of the concept of height. Based on the relativistic generalization of geopotential numbers, a definition of chronometric height is suggested, which reduces to the well-known notions in the weak-field limit. This height measure is conceptually based on the so-called time-independent redshift potential, which describes the gravitoelectric degree of freedom in General Relativity.

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The SaToR-G experiment: testing metric and non-metric theories of gravity in the Earth's field via laser tracking to geodetic satellites

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Satellite Tests of Relativistic Gravity (SaToR-G) is a new experiment in fundamental physics of the National Scientific Committee 2 (CSN2) of the Italian National Institute for Nuclear Physics (INFN). The experiment aims at testing gravitation beyond the predictions of Einstein's Theory of General Relativity in its weak-field and slow-motion limit, searching for effects foreseen by alternative theories of gravitation and possibly connected with ''new physics''. The predictions of General Relativity on the orbits of geodetic satellites, which play the role of test masses, will be compared with those of alternative theories of gravity both metric and non-metric in their essence. This will allow to test, in addition to other aspects of gravitation, the field equation of gravity. The natural theoretical framework to test gravitation will be that of the Parameterized Post-Newtonian (PPN) formalism. However, we will also try to apply, as far as possible, the approach suggested by R. H. Dicke more than 50 years ago, usually referred to as the Dicke framework. This is a fairly general framework that allows us to conceive experiments not connected, a priori, with a given physical theory and also provides a way to analyze the results of an experiment under primary hypotheses.
The activities of the experiment related to the development of perturbative models to better determine the dynamics of the orbits of the considered satellites will be presented together with preliminary results on possible new constraints to alternative theories of gravitation.

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Gravitational tidal forces bring Newton's equivalence principle to life in quantum mechanics

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Gravitational tidal forces conceal very interesting effects when combined with the extended nature of the wavefunction of a freely-falling quantum particle. The reason being that inertial properties of the particle get then mixed with the gravitational effects in such a way that, as in classical mechanics, the ratio of the gravitational mass to the inertial mass of the particle emerges in an isolated form. The equivalence principle in quantum mechanics then takes on a novel meaning thanks to the emergence of mass-independent dynamics during the free fall of the quantum particle.

Experimental Gravitation / 719

Large ring laser gyroscopes: geometry stabilization and control

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Ring laser Gyroscopes (RLG) are very versatile devices that find application in many fields as navigation, seismology and geophysics. Moreover, thanks to their sensitivity and accuracy, in the last years they have been used in fundamental physics research field.
GINGER (Gyroscopes IN GEneral Relativity) research group aims to exploit a large RLG to test general relativity theory. Our research team has two working RLG, both with a square shape, one installed in Pisa and named GP2.(1.6 m side), and the other installed in the INFN underground laboratory of Gran Sasso near L'Aquila named GINGERINO (3.6 m side). The final goal of GINGER is to measure the earth rotation rate with enough precision to take into consideration general relativity predicted corrections.
To reach this target, one of the requirements is the stability of the laser and the optical cavity of the RLG. We will show the last developed techniques aimed to satisfy this stability requirement. Working on GP2 we have tested two different techniques to control the ring shape. One is based on the stabilization of the two Fabry-Pèrot resonators formed along the square diagonals by the opposite mirrors of the RLG. The other consists of controlling the ring perimeter by monitoring its free spectral range through a beet-note between one of the counterpropagating beams and a frequency stabilized laser source. We will show the characteristics, the potentialities and the tests of these two methods.

Exploring the Black Hole Mass Gap

Exploring the Black Hole Mass Gap / 791

New Physics and the Black Hole Mass Gap

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The LIGO/Virgo collaboration is making astonishing discoveries at a fantastic pace, including a heavy binary black hole merger with component masses in the "black hole mass gap," which cannot be explained by standard stellar structure theory. In this talk, I will discuss how new light particles that couple to the Standard Model can act as an additional source of energy loss in the cores of population-III stars, dramatically altering their evolution and potentially explaining mass-gap objects. I will also demonstrate how new population catalogs can help distinguish different scenarios for the origin of these objects.

Exploring the Black Hole Mass Gap / 610

Relativistic Plasma Screening Effects on Pulsational Pair-Instability Supernova: Astornomoical Observables and the Black Hole Mass Gap

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If an astrophysical environment is hot enough, screening in the associated nuclear reactions can be modified by the presence of a relativistic electron-positron plasma. Additionally, strong magnetic fields can create an additional enhancement as the electron and positron energy distribution is modified by the altered Landau level occupancy. This can result in a further enhancement of nuclear reaction rates, and the reaction rate enhancement factor is studied in several relevant scenarios. Nearly every astrophysical site may undergo shifts in nuclear reaction rates due to electron-positron screening at high temperatures and magnetic fields. Massive stars that undergo pulsational pair-instability

can be affected by the relativistic plasma in the core, and results are presented including affects on the final black-hole mass, composition of matter ejected in the pulse, and stellar dynamical effects. Brief mention is made of the effects of relativistic screening and screening in highly magnetized plasmas on other astrophysical sites.

Exploring the Black Hole Mass Gap / 985

Avoiding Pair Instability in Massive Stars by Adding Non-Nuclear Energy

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Models of the evolution of stars with initial masses of approximately $80-240M_{\odot}$ include instability due to the production of electron positron pairs in some portion of the star. The resulting supernovae do not leave behind a black hole remnant, meaning that no black holes in the mass range $50-120M_{\odot}$ are expected to form. However, a fundamental assumption in these models is that the only source of energy injection into the star comes from nuclear fusion. However, there are scenarios in which nuclear reactions may not be the only energy source of note in a star. For instance, in the early universe, it may be possible for self-annihilation of dark matter in a star may provide a non-negligible source of energy. Therefore, we explore the effect that introducing a non-nuclear energy source into a star can have on its evolution, specifically on the pair instability. As a test case, we were able to show that a star with an initial mass of $180M_{\odot}$ can completely avoid a pair instability supernova if approximately half of the energy needed to support it comes from a non-nuclear source.

Exploring the Black Hole Mass Gap / 804

Lesson's from LIGO-Virgo's Biggest Black Holes

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Stellar theory predicts the existence of a black hole mass gap in the range ~50 to ~120 solar masses resulting from pair instability supernovae. The binary black holes of LIGO-Virgo's first two observing runs supported this prediction, showing evidence for a dearth of component black hole masses above 45 solar masses. Meanwhile, among the 30+ new observations from the third observing run, there are several black holes that appear to sit above the 45 solar mass limit. I will discuss how these unexpectedly massive black holes fit into our understanding of the binary black hole population. The data are consistent with several scenarios, including a mass distribution that evolves with redshift and the possibility that the most massive binary system, GW190521, straddles the mass gap, containing an intermediate-mass black hole heavier than 120 solar masses. I will also discuss applications of the binary black hole population to cosmology.

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Importance of Convective Overshoot for GW190521 formation from Population III binary stars

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We studied the formation of GW190521-like binary black holes (BHs) from Population (Pop) III binary stars by binary population synthesis technique. We adopted two kinds of Pop III star evolution models with different convective overshoot parameters, both of which can reproduce solar-metallicity star evolution if we change only metallicity from zero metallicity to the solar metallcity. We found that the Pop III star evolution model with the smaller convective overshoot can form GW190521-like merging binary BHs, although the other model cannot. In the first model, the merger rate is 0.04 per year per cubic Gpc at redshift of 0.82, comparable to the merger rate of GW190521-like events infered by gravitational wave observations. In the first model, a star with the initial mass of 90 solar masses can leave behind a BH with 90 solar masses, even if it is a member of a binary star. The star keeps a small radius until its collapse to a BH, and thus its hydrogen envelope is not stripped by its companion star. Moreover, its helium core is less than 40 solar masses, and it can avoid pair instability. We also found that Pop III binary stars in the first model cannot form merging BHs with 100-130 solar masses. If future observations discover a BH mass gap in 100-130 solar masses, Pop III binary stars should be a promising progenitor of GW190521.

Exploring the Black Hole Mass Gap / 594

Classical Binary Formation of GW190521

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LIGO/Virgo Collaboration reported the detection of the most massive BH-BH merger up to date with component masses of 85+66 Msun. Motivated by recent observations of massive stars and employing newly estimated uncertainties on pulsational pair-instability mass-loss we show that it is trivial to form such massive BH-BH mergers through the classical isolated binary evolution (with no assistance from either dynamical interactions or exotica). LIGO/Virgo observations show that the merger rate density of light BH-BH mergers (both components: M_BH}<50 Msun) is of the order of tens of mergers per Gpc^3 per yr, while GW190521 indicates that the rate of heavier mergers is 0.02-0.43 Gpc^-3 yr^-1. Our model (with standard assumptions about input physics) but extended to include 200 Msun stars and allowing for the possibility of stellar cores collapsing to 90 Msun BHs produces
consistent merger rates, masses and low effective spins for such massive BH-BH mergers. We do not claim that GW190521 was formed by an isolated binary, but it appears that such a possibility can not be excluded.

Exploring the Black Hole Mass Gap / 953

Parameter estimation for gravitational wave signals in or near the PISN mass gap: GW190521 and other high mass events

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In this talk we present a re-analysis of high mass gravitational-wave events with posterior support in or near the pair-instability supernova (PISN) mass gap with state-of-art phenomenological waveform models, IMRPhenomX and IMRPhenomT, One particularly interesting event is GW190521 - the most massive binary observed to data, with only a few observable wave cycles. We discuss challenges in estimating the source parameters due to the shortcomings of current waveform templates and the sensitivity to approximate degeneracies in the waveforms. We test the robustness of our results with a convergence analysis of our Bayesian inference runs and a comparison of different sampling codes. We discuss the parameter estimation results and provide updated probabilities of the component masses being in the PISN mass gap. We also provide update parameter estimation results for GW170729, the most massive binary black hole merger detected in the first and the second observational periods, and discuss relevant current and future developments in waveform development and parameter estimation.

Explosive Events Associated with Compact-Object Binary Mergers

Explosive Events Associated with Compact-Object Binary Mergers / 790

Searching for joint gravitational-wave and high energy neutrino events with LLAMA

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Multi-messenger detections allow us to learn more about the astrophysical sources by probing different physics and also by guiding the astronomers more precisely with low latency follow-ups. We will present the statistically optimal methods for multi-messenger searches and summarize the joint gravitational-wave and high energy neutrino event searches' results of Low Latency Algorithm for Multi-messenger Astrophysics (LLAMA) with IceCube's neutrinos and LIGO/Virgo's public detections and announcements.

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Selected topics on EM counterparts of gravitational waves

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I will discuss two less-discussed, yet physically-motivated channels for EM counterparts of gravitational wave events: brief FRB-like signals from charged CBCs (especially binary black hole mergers and plunging neutron star - black hole mergers) and short-GRB-less X-ray transients. I will also discuss the physical processes that contribute to the delay timescale between CBC signals and their associated GRBs and how future observations will help to reveal the jet launching and dissipation mechanisms from neutron star mergers.

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Binary neutron star merger simulations: long-lived remnants, short gamma-ray bursts, and kilonovae

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In the era of multi-messenger astrophysics, binary neutron star (BNS) mergers have proven to be one of the prime sources of gravitational waves (GWs), also able to produce short-gamma ray bursts (SGRBs) as well as radioactively powered kilonovae. General relativistic magnetohydrodynamic (GRMHD) simulations represent a fundamental tool to probe the underlying physical mechanisms involved in such merger events, including the crucial effects of magnetic fields. In this talk, I will discuss some of the key results from our recent GRMHD simulations of BNS mergers. In particular, I will focus on the importance of magnetic fields and their amplification mechanisms in merger events, the post-merger remnant structure and its rotation profile, magnetically driven mass outflows that could significantly contribute to kilonova emission, and the implications for the production of SGRB jets.

Explosive Events Associated with Compact-Object Binary Mergers / 302

On the Rate of Neutron Star Binary Mergers from Globular Clusters

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Tens of binary black hole (BH) mergers and a few binary neutron star (NS) mergers have been observed by LIGO/Virgo gravitational wave detectors, strongly advancing our understanding of the lives and deaths of compact objects. Recent realistic globular cluster simulations have shown that dynamical formations of binary BHs can entirely explain the observed rate of binary BH mergers. At the same time, it is well known that globular clusters are abundant in millisecond pulsars, with their production greatly enhanced by dynamical interactions. These naturally lead to the question of whether globular clusters could also efficiently produce NS-BH and NS-NS mergers. In this talk, I will show how we use a large sample of models that are representative of the present-day Milky Way globular clusters to quantify the merger rates of these two types of binary mergers. I will talk about the intertwined dynamical evolution of BHs and NSs in globular clusters and how it affects the formation rates of compact object binaries.

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Uncertainties in Modeling Kilonova Emission

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Neutron star mergers have long been believed to drive short-duration gamma-ray bursts, one of the most powerful explosions in the universe. They have also long been believed to be a promising source of the r-process isotopes observed in the Milky Way. These two theories were violently validated in the observation of the first neutron star merger in gravitational waves. The electromagnetic follow-up of this event proved that mergers could both produce relativistic jets and heavy r-process isotopes. But determining the exact composition of from the electromagnetic emission requires detailed physics and current models are currently forced to approximate this physics. I will discuss the uncertainties in these physical assumptions and their effect on the emission from neutron star mergers and our inference of the ejecta properties from events like the merger producing GW170817.

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Multi-messenger astrophysics in the Einstein Telescope era

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The next decade of Universe exploration is expected to undergo a revolution for the transient astrophysics. The third generation of gravitational-wave (GW) observatories, such as Einstein Telescope (ET) and Cosmic Explorer (CE) will allow us for the first time to observe GWs along the cosmic history back to the cosmological dark ages. These observatories will be an unprecedented resource to address open questions of fundamental physics, astrophysics and cosmology. They will operate in synergy with a new generation of innovative electromagnetic (EM) observatories, such as CTA, Athena, the Vera Rubin Observatory, JWST, ELT, SKA and the mission concepts THESEUS and HERMES. This network of observatories will probe the formation, evolution and physics of binary systems of compact object in connection with kilonovae and short gamma-ray bursts along with the star formation history and chemical evolution of the Universe. The talk will summarize the multi-messenger science case for ET and the perspectives for the next decade.

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Probing the progenitors of spinning binary black-hole mergers with long gamma-ray bursts

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Long gamma-ray bursts are associated with the core-collapse of massive, rapidly spinning stars. However, the believed efficient angular momentum transport in stellar interiors leads to predominantly slowly-spinning stellar cores. In this talk, I will report on binary stellar evolution and population synthesis calculations, showing that tidal interactions in close binaries not only can explain the observed sub-population of spinning, merging binary black holes, but also lead to long gamma-ray bursts at the time of black-hole formation, with rates matching the empirical ones. We find that ~10% of the GWTC-2 reported binary black holes had a long gamma-ray burst associated with their formation, with GW190517 and GW190719 having the highest probability of being among them.

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No Detectable Kilonova Counterpart is expected for O3 neutron star-black hole candidates

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As the new era of GW-led multi-messenger astronomy is ushered in, one may especially expect to catch GW signals from neutron star-black hole (NSBH) mergers and search for associated as-yet undiscovered NSBH kilonova emissions. However, in spite of many efforts for follow-up searches of potential NSBH candidates during the third run (O3) of LIGO/Virgo Collaboration (LVC), no surely EM counterpart candidate was identified. In this talk, I will show our simulated NSBH kilonova luminosity function based on our NSBH kilonova models and analyze the detectability of kilonova emissions from cosmological NSBH populations for present and future follow-up telescopes. Furthermore, I will analyze the tidal disruption probability of potential NSBH merger GW events detected during the O3 of LVC and the detectability of kilonova emissions in connection with these events. Plausible explanations for the lack of NSBH associated kilonova detection during O3 will be given.

Explosive Events Associated with Compact-Object Binary Mergers / 975

Using fast ejecta to distinguish neutron stars from black holes in gravitational wave events in the lower mass gap

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Gravitational wave events involving very massive neutron stars, such as GW190425, have just started to be detected. Although typically classified as binary neutron star mergers, the observed gravitational-wave signal is usually not able to clearly establish a neutron-star nature of the massive primary object in the system. Thus, a black hole–neutron star system cannot be fully ruled out by the gravitational wave detection alone.
In this talk, I will show how early fast ejecta – only produced in binary neutron star mergers – can potentially resolve this question and shed light on the nature of the binary system. By comparing simulations of binary neutron
star and black hole – neutron star mergers of exactly the same masses and spins, I will show that such fast ejecta are entirely absent, if the primary is a black hole. Because our simulations indicate that the
mass ejecta and accretion disks produced in the merger are comparable in both cases, the presence of fast ejecta might be the only distinguishing

feature present in the electromagnetic afterglow accompanying such a gravitational wave event.

Explosive Events Associated with Compact-Object Binary Mergers / 899

Kilonova signals in NS-BH mergers

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A kilonova signal is generally expected after a Black Hole - Neutron Star merger. The strength of the signal is related to the Equation of State of neutron star matter and it increases with the stiffness of the latter. The recent results obtained by NICER suggest a rather stiff Equation of State and the expected kilonova signal is therefore strong, at least if the mass of the Black Hole does not exceed $\sim 10M_\odot$. We compare the predictions obtained by considering Equations of State of neutron star matter satisfying the most recent observations with the results predicted in the two-families scenario. In the latter a soft hadronic Equation of State produces very compact stellar objects while a rather stiff quark matter Equation of State produces massive strange quark stars, satisfying NICER results. The expected kilonova signal in the two-families scenario is very weak: the Strange Quark Star - Black Hole merger does not produce a kilonova signal because, according to simulations, the amount of mass ejected is negligible and the Hadronic Star - Black Hole merger produces a signal much weaker than in the one-family case because the hadronic Equation of State is very soft. This prediction will be easily tested with the new generation of detectors.

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From Whisky to Spritz: Simulating Magnetized Binary Neutron Star Mergers

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Magnetic fields play an important role in the dynamics of binary neutron star mergers and on their gravitational wave and electromagnetic emission (such as the production of relativistic jets and short gamma-ray bursts). In this talk I will review some of the main results in the field of fully general relativistic magnetohydrodynamic (GRMHD) simulations of these systems focusing in particular on a set of simulations performed with my WhiskyMHD code. I will also briefly discuss the open problems in this field and the need for more accurate GRMHD codes, such as the recently published Spritz code.

Explosive Events Associated with Compact-Object Binary Mergers / 786

Importance of stable mass transfer and stellar winds for the formation of gravitational waves sources

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The isolated formation channel is one of the most studied formation scenarios for stellar mass black hole binary (BBH) mergers detected by LIGO and Virgo. Focusing on the effects of
uncertain stellar and binary physics, we investigate this BBH formation channel using the rapid binary population
synthesis code SeBa.

Regardless of our assumptions, the two must common formation path within the isolated binary scenario involves (i) a stable mass transfer followed by a common envelope evolution or (ii) two stable mass transfers. I will show that uncertainties in the first stable mass transfer can have a significant effect on the relative importance of these two channels. Based on a number of model variations that I simulated, I will show that merger rate of the channel with two stable mass transfers can change an order of magnitude depending on what we assume about the angular momentum lost from the system and the mass accretion efficiency during the first mass transfer phase. At the same time, the merger rates of the common envelope channel can be significantly lower than previously predicted, if we update our models based on recent developments on the mass transfer stability criteria with giants with radiative donors and predictions about at what stage the star develops a deep convective envelope. Finally, I also compare my results to gravitational wave observations and to High-mass X-ray binaries, where the latter can give us important clues about angular momentum lost from the system and the mass accretion efficiency.

Explosive Events Associated with Compact-Object Binary Mergers / 551

Binary neutron star formation and the origin of GW170817

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The first neutron star-neutron star merger (NS-NS: GW170817) was detected in gravitational waves by LIGO/Virgo in a galaxy in which the majority of star formation was taking place a long time ago (~11 Gyr). Only some extreme evolutionary models (with small NS natal kicks and high common envelope efficiency) can generate NS-NS merger rates in old host galaxies consistent with the LIGO/Virgo estimate (>100 Gpc−3yr−1). However, we show that these models generate rates exceeding empirical Galactic NS-NS merger rates based on the large population of Milky Way NS-NS binaries. Typically, evolutionary models produce NS-NS merger rates that are consistent with the Milky Way empirical rates (~10−200 Myr−1). However, these models generate local cosmic NS-NS merger rate in old host galaxies (~1−70 Gpc−3yr−1) below the LIGO/Virgo estimate. The reason behind this tension is the predicted delay time distribution between star formation and NS-NS mergers that favors short delays. Evolutionary models produce a generic steep power-law NS-NS delay time distribution. This limits NS-NS merger rates in old host galaxies. However, we show that such distribution is consistent with observations of Galactic NS-NS binaries; 50% of which show very long merger times (much longer than Hubble time). Once model distributions are convolved with continuous prolonged star formation in the Galactic disk, then~20−70% of the predicted NS-NS population has very long current Galactic merger times (>30 Gyr). Although NS-NS binaries are formed predominantly with short delay times, many of short delay time systems merge, while long delay time systems survive and contribute to the current Galactic NS-NS population. This study highlights the tension between the current evolutionary predictions and the observation of the first NS-NS merger in an old host galaxy. It is crucial to understand that models need to explain not only the LIGO/Virgo rate estimate, but also the merger site.

Extended Theories of Gravity and Quantum Cosmology

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Quantum gravity phenomenology from thermodynamics of spacetime

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On one hand, the formalism developed in thermodynamics of spacetime allows a derivation of Einstein equations from the proportionality of entropy to the area. On the other hand, low energy quantum gravity effects imply a modified entropy formula with an additional term logarithmic in the area. Combining both concepts, I will introduce the derivation of quantum modified gravitational dynamics from the modified entropy and discuss its main features. Moreover, I will show its physical implications on a simple cosmological model and show that it suggests the replacement of the Big Bang singularity by a regular bounce.

Extended Theories of Gravity and Quantum Cosmology / 301

Primordial Black Holes and Stochastic Gravitational Waves in the Sound Speed Resonance Cosmology

Author: Sheng-Feng Yan[1]

Co-authors: Bo Wang [2]; Chao Chen ; Chunshan Lin [3]; Dong-Gang Wang [4]; Xi Tong [5]; Yi-Fu Cai [6]

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Primordial black hole (PBH) is a kind of important Dark Matter candidate of cosmological origin. And it is also a potential seed of supermassive black holes. However, the formation and the astrophysical effects of PBH still remain unclear. From theoretical perspective, the speaker and his collaborators proposed sound speed resonance SSR mechanism as an efficient novel effect to produce PBH. The speaker will briefly review PBH and SSR mechanism and summarize what they have

done in this topic. After that, he will introduce their recent work on the SSR mechanism of stochastic gravitational waves which might be a new probe for new physics in the early universe.

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Chaotic Solutions and Black Hole Shadow in f(R) gravity

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We discuss the emergence of black hole shadow and photon-sphere inthe context of f(R) gravity. It is shown that the shadow is exponentially sensitive to linear instabilities of metric coming from some f(R) solutions. Thus, the instabilities of photon circular trajectories, delimiting the black hole photon-sphere, are double exponentialized. Specifically we individuate two Lyapunov exponents, rather than only one, related to two different sources of chaos in geodesic orbits as a sort of butterfly effect. Such a result violates the black hole chaos bound proposed by Maldacena, Shenker and Stanford for General Relativity. Wealso explore the impact of the black hole metric instabilities in f(R) gravity on the quasi-normal modes. In the framework of Extended Theories of Gravity, our analysis suggests a new paradigm to deal withblack hole shadow and gravitational waves observations coming from black hole merging in the ringdown phase.

Extended Theories of Gravity and Quantum Cosmology / 485

Gravitational Memory Waveforms in Brans-Dicke Theory

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Gravitational-wave (GW) memory effects are lasting changes in the GW strain and its time integrals following bursts of GWs. They are closely related to the symmetries of asymptotically flat spacetimes and their corresponding conserved charges. There are three types of GW memory effects (displacement, spin, and center-of-mass) that are related to different conserved charges and have different observable effects. GW memory effects are well studied in general relativity (GR), but have not been explored as carefully in theories beyond GR. One of the simplest modified theories of gravity is Brans-Dicke theory, which includes a massless scalar field nonmininally coupled to gravity. This theory has a scalar breathing polarization of GWs in addition to the tensor GWs in GR, and there can be scalar GW memory effects in addition to the tensor GW memory effects. The scalar memory effects are not related to symmetries or conserved quantities, but the scalar waves (and their memory) do affect the tensor memories. I will present the leading Newtonian corrections to the tensor displacement and spin GW memory effects from nonspinning, quasi-circular compact binaries in Brans-Dicke theory.

Extended Theories of Gravity and Quantum Cosmology / 865

Quantum Corrections to the Bianchi II Transition

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A semiclassical state is studied as it approaches a cosmological Bianchi II singularity, by means of the evolution of its moments. Classically this system undergoes a transition between two Bianchi I models, with a specific and well-known transition law, which is derived based on the conservation of certain physical quantities. In the quantum theory, however, these constants of motion are modified, due to effects produced by fluctuations and high-order quantum moments of the different variables. Therefore, quantum corrections arise in the transition rule. In order to compute them, we focus on the so-called locally rotationally symmetric (LRS) and vacuum cases, as a first step towards a more complete study. Indeed, the main goal will be to generalize this analysis to the Bianchi IX universe, which can be seen as a succession of Bianchi II models. Ultimately, these results will lead to a better understanding of the role played by quantum effects in the BKL conjecture.

Extended Theories of Gravity and Quantum Cosmology / 742

Teleparallel, f(T) and Torsional Gravity and Cosmology

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We review various theoretical models and scenarios based on teleparallel gravity and torsional modifications of gravity. Then we apply them in a cosmological framework, discussing the early and late time solutions as well as the observational constraints using various datasets. Finally we present the recent possibility of using multi-messenger astronomy, in order to investigate torsional modified gravity and test deviations from general relativity.

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Late time cosmology with derivatives of matter Lagrangian

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A class of modified gravity theories with higher order derivative terms of a function of the matter Lagrangian $f(L_m)$ is considered. We will consider the Newtonian limit of the theory and show that the model predicts the standard Poisson equation for a massive test particle due to the higher order nature of the derivative matter coupling. Generally the energy momentum tensor is not conserved, leading to the fifth force similar to $f(R,T)$ theories. We will however show that in the FRW background the energy-momentum tensor is conserved. Cosmological implications of this model with different functions of the matter Lagrangian f will be investigated in details and we will show that current observational data can be satisfied. Evolution of the matter density perturbation in the longitudinal gauge is also considered for dust matter sources and we will show that the observational data can be satisfied in this model.

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Tidal heating of black holes and exotic compact objects on the brane

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During the early phase of in-spiral of a binary system, the tidal heating of a compact object due to its companion plays a significant role in the determination of the orbital evolution of the binary. The phenomenon depends crucially on the 'hairs', as well as on the nature of the compact object. It turns out that the presence of extra dimension affects both these properties, by incorporating an extra tidal charge for braneworld black holes and also by introducing quantum effects, leading to the possible existence of exotic compact objects. It turns out that the phasing information from tidal heating in the gravitational wave waveform can constrain the tidal charge inherited from extra dimension to a value \sim 10^{-6}, the most stringent constraint, to date. Moreover, second-order effects in tidal heating for exotic compact objects, also reveal an oscillatory behavior with respect to spin, which has unique signatures.

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Investigating if a quark star - black hole binary may yield new astrophysics and insights as to gravitational waves and Bose-Einstein condensation

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We wish to investigate if we can extend the insights provided by the publication "Can stellar mass black holes be quark stars?" by Z. Kovacs,et.al. in MNRAS, 2009 as to answering their question via examining what may happen in a quark star - black hole binary in its Gravitational wave generation. In doing so, we also examine how to Use this idea to explore the idea of a black hole as a Bose-Einstein condensate of gravitons for black holez in lower mass ranges. Which extends the idea brought up by P.H. Chavanis, page 181 in "Self Gravitating Bose-Einstein condensates" in "Quantum Aspects of black holes" with Xavier Calmet as editor. In essence, full examination of what may be involved via Quark stars as well as investigating via a quark star- black hole binary some fundamental astrophysics questions. In addition, we wish to understand how fundamental Bose-Einstein condensation really is.

Extended Theories of Gravity and Quantum Cosmology / 843

Motion of a particle in the Bogoslovsky-Finsler space-time and the fate of the broken Lorentz invariance

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We study the motion of a particle in the Bogoslovsky-Finsler space-time, where a Lorentz violation takes place due to a non-zero continuous parameter in the action. We demonstrate that the broken Lorentz symmetries are substituted by a different type of symmetry. The new symmetry vectors are generators of higher order (or hidden) symmetries that are related to integrals of motion which are rational functions in the momenta. On mass shell the generators can be seen as space-time vectors producing disformal transformations.

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Data-driven Reconstruction of the Late-time Cosmic Acceleration with f(T) Gravity

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Along with the accumulated cosmological observations, while the standard paradigm of modern cosmology has been verified with high precision, some new challenges such as the H_0 tension appear. To address these issues, we in this article reconstruct the free function of $f(T)$ gravity in a model-independent manner using the combined observational data. The obtained function is consistent with the standard ΛCDM cosmology within 1σ confidence level, however the best-fit value experiences oscillatory features. Similar oscillatory dark-energy scenarios are known to be in good agreement with observational data, nevertheless this is the first time that such a behavior is proposed for $f(T)$ gravity. Finally, since the reconstruction procedure is completely model-independent, the obtained data-driven reconstructed $f(T)$ form could release the tensions between ΛCDM estimations and local measurements.

Extended Theories of Gravity and Quantum Cosmology / 712

Big-bounce in projectively invariant Nieh-Yan models: Bianchi I cosmology

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In this talk I will discuss the possibility to extend the notion of the Nieh-Yan topological invariant to generic metric-affine geometries, where both torsion and nonmetricity are taken into account. Notably, the properties of projective invariance and topologicity can be independently accommodated by a suitable choice of the parameters featuring this new Nieh-Yan term. Considering a special class of modified theories of gravity able to promote the Immirzi parameter to a dynamical scalar field coupled to the Nieh-Yan form, I will discuss in more detail the dynamics of the effective scalar tensor theory stemming from such a revised theoretical framework. I will focus, in particular, on cosmological Bianchi I models and report classical solutions where the initial singularity is safely removed in favor of a big bounce, which is ultimately driven by the nonminimal coupling with the Immirzi field. These solutions are characterized by finite time singularities, but it turns out that such critical points do not spoil the geodesic completeness and wave regularity of these spacetimes.

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Decoupled Quark Stars in Self-interacting Brans-Dicke Gravity

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We generate two anisotropic solutions for a static sphere filled with quark matter in the framework of self-interacting Brans-Dicke theory. For this purpose, we add an anisotropic source in the seed distribution and decouple the field equations through deformation in the radial metric function. As a result of this transformation, the field equations are disintegrated into two systems which separately include the effects of isotropic and anisotropic sources. The system related to the additional source is solved via the MIT bag model equation of state. We consider Tolman V spacetime and Karmarkar's condition to formulate two solutions for the isotropic sector which are extended to the anisotropic domain via decoupling technique. The junction conditions at the boundary determine the unknown parameters in terms of mass and radius of the spherical object. We investigate the viability and stability of the constructed strange star models in the presence of massive scalar field corresponding to three strange star candidates: Her X-1, PSR J1614-2230 and 4U 1608-52. It is concluded that the anisotropic models are well-behaved as they fulfill the necessary requirements for lower as well as higher values of the decoupling parameter.

Extended Theories of Gravity and Quantum Cosmology / 629

A Solution of the Cosmological Constant, Using Multiverse Version of Penrose CCC Cosmology, and Enhanced Quantization Compared

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We reduplicate the Book "Dark Energy" by M. Li, X-D. Li, and Y. Wang, zero-point energy calculation with an unexpected "length' added to the 'width' of a graviton wavefunction just prior to the entrance of 'gravitons' to a small region of space-time prior to a nonsingular start to the universe. We compare this to a solution worked out using Klauder Enhanced quantization, for the same given problem. The solution of the first Cosmological Constant problem relies upon the geometry of the multiverse generalization of CCC cosmology which is explained in this paper. The second solution, used involves Klauder enhanced quantization. We look at energy given by our methods and compare and contrast it with the negative energy of the Rosen model for a mini sub universe and estimate GW frequencies

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Inflationary supersymmetric FRLW quantum cosmology

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We consider inflationary scenarios of the supersymmetric quantum cosmology of FRLW models with a scalar field. We use the superfield formalism with a superpotential for the scalar superfield. From the probability amplitude solution of the supersymmetric Wheeler-DeWitt equation, we compute an effective probability density from which we get mean trajectories that are parametrized by the scalar. We analyse several superpotentials, for which the resulting evolutions of the scale factor are consistent with inflationary scenarios. For these cases, we show the acceleration, the e-folds and the horizon.

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Cosmic stringlike objects in hybrid metric-Palatini gravity

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We consider static and cylindrically symmetric interior string type solutions in the scalar-tensor representation of the hybrid metric-Palatini modified theory of gravity. As a first step in our study,we obtain the gravitational field equations and further simplify the analysis by imposing Lorentz invariance along the t and z axes, which reduces the number of unknown metric tensor components to a single function $W^2(r)$. In this case, the general solution of the field equations can be obtained,for an arbitrary form of the scalar field potential, in an exact closed parametric form, with the scalar field taken as a parameter. We consider in detail several exact solutions of the field equations, corresponding to a null and constant potential, and to a power-law potential of the form
$V() = V_0{}^{3/4}$, in which the behaviours of the scalar field, of the metric tensor components and of the string tension can be described in a simple mathematical form. We also investigate the string models with exponential and Higgs type scalar field potentials by using numerical methods. In this way we obtain a large class of novel stable string-like solutions in the context of hybrid metric-Palatini gravity, in which the basic parameters, such as the scalar field, metric tensor components, and string tension, depend essentially on the initial values of the scalar field, and of its derivative,on the $r = 0$ circular axis.

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Gravitational waves in spacetime with extra dimensions

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We study the effect of compact extra dimensions on the gravitational wave luminosity and waveform. We consider a toy model, with a compactified fifth dimension, and matter confined on a brane. We work in the context of five dimensional (5d) general relativity, though we do make connections with the corresponding Kaluza-Klein effective 4d theory. We show that the luminosity of gravitational waves emitted in 5d gravity by a binary with the same characteristics (same masses and separation distance) as a 4d binary is 20.8% less relative to the 4d case, to leading post-Newtonian order. The phase of the gravitational waveform differs by 26% relative to the 4d case, to leading post-Newtonian order. Such a correction arises mainly due to the coupling between matter and dilaton field in the effective 4d picture and agrees with previous calculations when we set black holes' scalar charges to be those computed from the Kaluza-Klein reduction. The above corrections to the waveform and

the luminosity are inconsistent with the gravitational-wave and binary pulsar observations and thus they effectively rule out the possibility of such a simple compactified higher dimensions scenario. We also comment on how our results change if there are several compactified extra dimensions, and show that the discrepancy with 4d general relativity only increases.

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Effective f(R) actions for modified Loop Quantum Cosmologies

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General Relativity is an extremely successful theory, at least for weak gravitational fields, however, it breaks down at very high energies, such as in correspondence of the initial singularity. Quantum Gravity is expected to provide more physical insights concerning this open question. Indeed, one alternative scenario to the Big Bang, that manages to completely avoid the singularity, is offered by Loop Quantum Cosmology (LQC), which predicts that the Universe undergoes a collapse to an expansion through a bounce. In this talk, I will discuss how, in a recent paper, we used metric f(R) gravity to reproduce the modified Friedmann equations which have been obtained in the context of modified loop quantum cosmologies. I will describe the order reduction method that was used and how this allowed us to obtain covariant effective actions that lead to a bounce, for specific models of modified LQC, considering matter as a scalar field.

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Quadratic curvature theories formulated as Covariant Canonical Gauge theories of Gravity

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The Covariant Canonical Gauge theory of Gravity is generalized by including at the Lagrangian level all possible quadratic curvature invariants. In this approach, the covariant Hamiltonian principle and the canonical transformation framework are applied to derive a Palatini type gauge theory of gravity. The metric gμν, the
affine connection γλμν and their respective conjugate momenta, kμνσ and qαξβη
tensors, are the independent field components describing the gravity. The metric is the basic dynamical field, and the connection is the gauge field. The torsion-free and metricity-compatible version of the space-time Hamiltonian is built from all possible invariants of the qαξβη tensor components up to second order. These correspond in the Lagrangian picture to Riemann tensor invariants of the same order. We show that the quadratic tensor invariant is necessary for constructing the canonical momentum field from the gauge field derivatives, and hence for transforming between Hamiltonian and Lagrangian pictures. Moreover, the theory is extended by dropping metric compatibility and enforcing conformal invariance. This approach could be used for the quantization of the quadratic curvature theories, as for example in the case of conformal gravity

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Probing multiverse using gravitational wave observations

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From the theory of the multiverse cosmology，it is possible that our universe collides with other universes locally in its history，which may result in local changes of the curvature of the spacetime．In this paper，we propose a method to probe the multiverse using gravitational wave observations for the first time．Our method firstly makes triangles using two detected gravitational wave sources and the Sun，and then measures the curvature of the triangles．We use 11 gravitational wave sources detected by LIGO and Virgo during O1 and O2，and make 55 triangles by combining them to measure their curvature．The curvature is measured by comparing the distance between two gravitational wave sources estimated by the gravitational wave observations with the one obtained with assumption of a simple model of the cosmological evolution．
As a result，we found that，for 43 of 55 triangles，the distances estimated by the model are greater than the ones obtained by the gravitational wave observations．This indicates a negative curvature，which may be due to the simplification of the cosmological evolution．For the rest 12，the distances are not determined because of uncertainty of the parameters of the gravitational wave observations. Further gravitational wave observations and more sophisticated model of the cosmological evolution is essential to test the multiverse cosmology observationally.

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Operator Ordering Ambiguity in Observables of Quantum Cosmology

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We discuss the status of observables and operator ordering ambiguities in the quantum cosmology model with Brown Kuchař dust as the matter field. In order to study the dynamics of the FRW universe, Hubble parameter and Ricci scalar are expressed as a function of phase space variables. As these functions exhibit operator ordering ambiguity, several Hermitian extensions corresponding to these observables can be written. For the unitarily evolving semiclassical wave packet constructed in Kiefer et al. [Phys.Rev.D 99 (2019) 12, 126010], we computed the expectation value of these observables, which shows that very early in collapsing branch and very late in expanding branch, the expectation values of the Hubble parameter and Ricci scalar matches the classically obtained results irrespective of the operator ordering chosen. The expectation value of Hubble parameter is same for all operator orderings. The expectation value of Hubble parameter vanishes, and Ricci scalar attains an extremum at the point of classical singularity for all orderings, showing a robust bounce. The magnitude of this extrema is sensitive to the operator ordering chosen. For Weyl orderings, the expectation value of Ricci scalar becomes negative for certain parameter values. We have computed the expectation value of other curvature invariants as well, which follows the trend.

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Semiclassical and quantum polymer dynamics of the Bianchi I cosmology in Ashtekar and volume-like variables

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We analyze the Bianchi I cosmology in the presence of a massless scalar field and describe its dynamics via a semiclassical and quantum polymer approach. We investigate the morphology of the emerging Big Bounce by adopting three different sets of configurational variables: the natural Ashtekar connections, the Universe volume plus two anisotropy coordinates and a set of anisotropic volume-like coordinates (the latter two sets of variables would coincide in the case of an isotropic Universe). In the semiclassical analysis we demonstrate that the Big Bounce has a universal nature in both the two sets of volume-like variables, i.e. its critical energy density has a maximum value fixed by fundamental constants and the Immirzi parameter only. On the contrary, when adopting the Ashtekar connections (the privileged variables as dictated by Loop Quantum Gravity) the value of the critical Big Bounce density depends on the Cauchy problem for the dynamics and specifically on the conjugate momentum to the scalar field, which is a constant of motion in the present analysis. Also, a cosmological constant is included in the Ashtekar connections' formulation and some interesting results are mentioned making a comparison between the synchronous dynamics and that one when the scalar field is taken as a relational time. From a pure quantum point of view, we investigate the Bianchi I dynamics only in terms of the Ashtekar connections. In particular, we apply the Arnowitt-Deser-Misner (ADM) reduction of the variational principle and then we quantize the system. We study the resulting Schr\"{o}dinger dynamics, stressing that the wave packet peak behavior over time singles out common features with the semiclassical trajectory, confirming the non-universal character of the emerging Big Bounce also on a quantum level.

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Ungravity and the Cosmological Constant.

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In this work we study an "ungravity" origin to the cosmological constant. We derive the modified Friedmann equations from the first law of thermodynamics and the "ungravity" entropy-area relationship. From the modified Friedmann equations (in the late time regime) we find an effective cosmological constant.

Extended Theories of Gravity and Quantum Cosmology / 1028

Observable traces of nonmetricity: constraining metric-affine gravity

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In this talk we will argue that, in generic metric-affine theories of gravity, non-linear $R_{(\mu\nu)}$ terms in the action do not introduce new degrees of freedom, but rather couple the rest of the degrees of freedom of the theory among themselves. At a perturbative level, this leads to a set of effective interactions among the matter degrees of freedom suppressed by a heavy mass scale that controls deviations from the Einstein-Hilbert action. From the geometrical point of view, we will see that we can associate these interactions to a piece of the nonmetricity tensor that is also suppressed by such heavy scale. Thus, one can see these interactions as a physical effect related to nonmetricity in generic metric-affine theories of gravity. We will also see how these effective interactions can be used to set bounds on metric-affine theories where nonlinear terms involving $R_{(\mu\nu)}$ occur in the action.

eXTP – Enhanced X-ray Timing and Polarimetry Mission

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The role of eXTP in the multi-messenger astronomy era

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The first detection of gravitational waves on 2015 with the Advanced LIGO and Advanced Virgo interferometers has opened a new observational window in the Universe. The last decade has also welcomed decisive discoveries in neutrino astronomy. Expected advances of gravitational wave and neutrino detectors by the end of the 2020s will mark the start of a golden era of multi-messenger astrophysics. The most promising multi-messenger sources in the high-energy sky, e.g. GRBs, AGNs, magnetars, are among the main targets for eXTP. This talk will focus on the role of eXTP in the context of multi-messenger astronomy and in particular on the synergies with gravitational wave interferometers.

eXTP – Enhanced X-ray Timing and Polarimetry Mission / 732

Testing fundamental physics laws in extreme density and gravity with eXTP

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Primary science goals for the Enhanced X-ray Timing and Polarimetry (eXTP) mission include studies of matter under conditions of extreme density and strong gravity. I will describe how eXTP's observations of neutron stars and black holes will lead to major advances in both of these areas.

eXTP – Enhanced X-ray Timing and Polarimetry Mission / 1058

Probing the strong magnetic field in astrophysics with eXTP

Author: Hua Feng[1]

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Strongly magnetized high energy astrophysical objects, including a variety of pulsars and magnetars, are expected to produce high degree of X-ray polarization, which can be used to diagnose the magnetic field, emission mechanism, and geometry of the objects, and also test the fundamental physics. In this talk, I will present possible science cases that the enhanced X-ray Timing and Polarimetry (eXTP) mission can do with these systems.

eXTP – Enhanced X-ray Timing and Polarimetry Mission / 549

Orbiting blobs in accretion discs in the era of high-angular resolution and polarimetry

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Energy shifts of radiation from accreting black holes may be caused by the fast orbital motion and the gravitational redshift near the event horizon. Individual clumps of matter experience the effects of general relativity as they gradually sink into a deep potential well. An episodic supply of material is maintained by tidal disruption events (TDE) and the emerging radiation is modulated in the X-ray domain and in longer wavelengths. Changes of polarization properties of the observed signal exhibit a specific dependence on energy. We will mention the polarimetric properties that can be revealed by the upcoming X-ray polarimetry.

eXTP – Enhanced X-ray Timing and Polarimetry Mission / 708

Observatory Science with eXTP

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In this talk we will present the potential of the enhanced X-ray Timing and Polarimetry (eXTP) mission for studies related to Observatory Science targets. These include flaring stars, supernova remnants, accreting white dwarfs, low and high mass X-ray binaries, etc.

eXTP – Enhanced X-ray Timing and Polarimetry Mission / 770

The Large Area Detector and Wide Field Monitor onboard eXTP

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The enhanced X-ray Timing and Polarimetry mission (eXTP) is a flagship observatory for X-ray timing, spectroscopy and polarimetry developed by an International Consortium led by the Chinese Academy of Science, with a large participation of European institutions.
Thanks to its very large collecting area, good spectral resolution and unprecedented polarimetry capabilities, eXTP will explore the properties of matter and the propagation of light in the most extreme conditions found in the Universe. eXTP will investigate three fundamental science areas: the equation of state of ultra-dense matter, the effects of strong-field gravity, the astrophysics and physics of very strong magnetic fields. eXTP will, in addition, be a powerful, wide-ranging X-ray observatory. The mission will continuously monitor the X-ray sky, characterizing the active X-ray Universe on a large range of time scales, and will enable multi-wavelength and multi-messenger studies for gravitational waves and neutrinos sources. The mission is currently undergoing its phase B study, targeting a launch in 2027.
In this paper I will present the European contributions to the eXTP payload: the Large Area Detector (LAD) and Wide Field Monitor (WFM) instruments.

eXTP – Enhanced X-ray Timing and Polarimetry Mission / 1057

The enhanced X-ray Timing and Polarimetry Mission

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The enhanced X-ray Timing and Polarimetry Mission – eXTP is a science mission designed to study the state of matter under extreme conditions of density, gravity and magnetism.
Primary targets include stellar-mass and supermassive black holes, isolated and binary neutron stars, and strong magnetic field systems like magnetars.
In addition to investigating fundamental physics, eXTP will be a very powerful observatory for astrophysics that will provide observations of unprecedented quality on a variety of galactic and extragalactic objects and will be highly instrumental to detect electro-magnetic counterparts of gravitational wave sources.
The mission carries a unique and unprecedented suite of state-of-the-art scientific instruments enabling for the first time ever the simultaneous spectral-timing-polarimetry studies of cosmic sources in the energy range from 0.5-30 keV (and beyond).
The program is led by the Chinese Academy of Sciences and universities in China, the eXTP international consortium includes major institutions in several European countries. The planned launch date of the mission is in 2027.

eXTP – Enhanced X-ray Timing and Polarimetry Mission / 666

Design of the SFA and PFA instrument onboard eXTP

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The eXTP (enhanced X-ray Timing and Polarimetry) mission is a flagship international collaboration mission led by China, with large contribution from European countries. The eXTP mission is designed to study the equation of state of ultra-dense matter under extreme conditions of strong gravity, density and magnetic field. Its primary targets contain the isolated and binary neutron stars, strong magnetic field systems like magnetars, and stellar-mass and supermassive black holes. The mission carries four main instruments, the Spectroscopy Focusing Array (SFA), the Polarimetry

Focusing Array (PFA), the Large Area Detector (LAD) and the Wide Field Monitor (WFM), enabling for the simultaneous spectral-timing-polarimetry observation of cosmic sources in the energy range from 0.5-30 keV. The LAD and WFM are led by European countries, the SFA and PFA are led by China (IHEP, CAS). The SFA and PFA payloads include 9 and 4 identical telescopes respectively. The SFA and PFA telescopes are based on Nickel electroforming Wolter-I mirror technology, with focal length 5.25m and a field of view 12 arcmin. The angular resolutions of SFA and PFA are 1 arcmin and 30 arcsec for spectral-timing and imaging requirements. To achieve good energy and time resolution, a 19 cells SDD is the baseline detector of SFA. The focal plane detectors of PFA use gas pixel detectors (GPDs), with a sensitive region of 1.5 cm×1.5 cm. In this paper we provide an overview of the SFA&PFA instrument designs, including optics and detectors.

eXTP – Enhanced X-ray Timing and Polarimetry Mission / 903

Masses and radii of compact stars in the two-families scenario

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I will outline the so-called two-families scenario in which neutron stars (composed also of hadronic resonances and of hyperons) exist together with strange quark stars, i.e. compact objects composed entirely of deconfined quark matter. The two-families scenario has rather precise and explicit predictions concerning masses and radii, which can be tested by eXTP. In particular we predict the existence of massive strange quark stars with large radii, as the ones recently observed by NICER, and the existence of rather compact and lighter hadronic stars as suggested by some analysis of the EM spectra.

1) Was GW190814 a Black Hole–Strange Quark Star System? Phys.Rev.Lett. 126 (2021) 16, 162702
2) Why can hadronic stars convert into strange quark stars with larger radii. Phys.Rev.D 102 (2020) 6, 063003
3) Are Small Radii of Compact Stars Ruled out by GW170817/AT2017gfo? Astrophys.J. 860 (2018) 2, 139
4) Speed of sound in dense matter and two families of compact stars. 2102.02357

From Cosmic Strings to Superstrings

From Cosmic Strings to Superstrings / 440

Scaling solutions of wiggly cosmic strings

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Cosmic strings may have formed in the early universe due to the Kibble mechanism. While string networks are usually modeled as being of Nambu-Goto type, this description is understood to be a convenient approximation, which neglects the typically expected presence of additional degrees of freedom on the string worldsheet. Previous simulations of cosmic strings in expanding universes have established beyond doubt the existence of a significant amount of short-wavelength propagation modes (commonly called wiggles) on the strings, and a wiggly string extension of the canonical velocity-dependent one-scale model has been recently developed. Here we improve the physical interpretation of this model, by studying the possible asymptotic scaling solutions of this model, and in particular how they are affected by the expansion of the universe and the available energy loss or transfer mechanisms—e.g., the production of loops and wiggles. In addition to the Nambu-Goto solution, to which the wiggly model reduces in the appropriate limit, we find that there are also solutions where the amount of wiggliness can grow as the network evolves or, for specific expansion rates, become a constant. Our results show that full scaling of the network, including the wiggliness, is much more likely in the matter era than in the radiation era, which is in agreement with numerical simulation results.

From Cosmic Strings to Superstrings / 581

Approach to scaling in axion string networks

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In the QCD axion dark matter scenario with post-inflationary Peccei-Quinn symmetry breaking, the number density of axions, and hence the dark matter density, depends on the length of string per unit volume at cosmic time t, by convention written ζ/t^2. The expectation has been that the dimensionless parameter ζ tends to a constant ζ_0, a feature of a string network known as scaling. It has recently been claimed that in larger numerical simulations ζ shows a logarithmic increase with

time. This case would result in a large enhancement of the string density at the QCD transition, and a substantial revision to the axion mass required for the axion to constitute all of the dark matter. With a set of new simulations of global strings we compare the standard scaling (constant-ζ) model to the logarithmic growth. We also study the approach to scaling, through measuring the root-mean-square velocity v as well as the scaled mean string separation x. We find good evidence for a fixed point in the phase-space analysis in the variables (x, v), providing a strong indication that standard scaling is taking place. We show that the approach to scaling can be well described by a two parameter velocity-one-scale (VOS) model, and show that the values of the parameters are insensitive to the initial state of the network. We conclude that the apparent corrections to ζ are artifacts of the initial conditions, rather than a property of the scaling network.

From Cosmic Strings to Superstrings / 1039

Large number of cusps in high-harmonic loops

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There has been significant progress in recent years on modelling the evolution of cosmic string and cosmic superstring networks. As we are targeting gravitational wave signals from strings, attention is shifting to the closed string (loop) component of those networks. The predicted signal depends on a number of parameters, some of which are assumed/argued to be of order unity. I will focus on one of these parameters, namely the number of cusps per period of oscillation of the loop and will present evidence, based on the study of high-harmonic loops, that this can be significantly larger than unity. This could potentially lead to an enhancement of the predicted gravitational wave signal; to quantify this effect one needs to model the loop distribution in the string network.

From Cosmic Strings to Superstrings / 503

High-resolution calibration of string modelling

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The canonical velocity-dependent one-scale (VOS) model for cosmic string evolution contains a number of free parameters which cannot be obtained ab initio. Therefore it must be calibrated using high resolution numerical simulations. We exploit our state of the art graphically accelerated implementation of the evolution of local Abelian-Higgs string networks to provide a statistically robust calibration of this model. In order to do so, we will make use of the largest set of high resolution simulations carried out to date, for a variety of cosmological expansion rates, and explore the impact of key numerical choices on model calibration, including the dynamic range, lattice spacing, and the choice of numerical estimators for the mean string velocity. This sensitivy exploration will show that certain numerical choices will indeed have consequences for observationally crucial parameters, such as the loop chopping parameter. To conclude, we will also briefly illustrate how our results impact observational constraints on cosmic strings.

From Cosmic Strings to Superstrings / 448

Loop decay in Abelian-Higgs string networks

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The evolution of cosmic strings, in particular cosmic string loops, has been an open question for a number of years. The dynamics observed by field theory lattice simulations and by the Nambu-goto approximation do not agree, giving big differences in the lifetimes of loops, which for example affects their gravitational wave production.

In this talk we will discuss the results obtained from lattice field theory loop evolution simulations, focusing on loops produced during the evolution of an actual realistic cosmic string network. We show that those loops decay proportional to L, but with a larger proportionality constant than the decay by GW. We see no dependency on the behaviour on the string decay on the string length. Moreover, motivated by recent results that show L^2 decay for loops created by artificially setting up string configurations, we propose another method that confirms the L^2 decay. This shows that the decay proportional to L is intrinsic to network loops, and requires further investigation.

From Cosmic Strings to Superstrings / 884

Electroweak axion string and superconductivity

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We study the axion strings with the electroweak gauge flux in the DFSZ axion model and show that these strings, called the electroweak axion strings, can exhibit superconductivity without fermionic zero modes. We construct three types of electroweak axion string solutions. Among them, the string with W-flux can be lightest in some parameter space, which leads to a stable superconducting cosmic string. We also show that a large electric current can flow along the string due to the Peccei-Quinn scale much higher than the electroweak scale. This large current induces a net attractive force between the axion strings with the same topological charge, which opens a novel possibility that the axion strings form Y-junctions in the early universe.

From Cosmic Strings to Superstrings / 552

Radiation from Global Cosmic Strings using Adaptive Mesh Refinement

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We present results from adaptive mesh refinement (AMR) simulations of global cosmic strings. Using the public code, GRChombo, we perform a quantitative investigation of the dynamics of single sinusoidally displaced string configurations. We study a wide range of string energy densities $\mu \propto \ln \lambda$,

defined by the string width parameter λ over two orders of magnitude. We investigate the resulting massless (Goldstone boson or axion) and massive (Higgs) radiation signals, using quantitative diagnostic tools to determine the eigenmode decomposition. Given analytic radiation predictions for global Nambu-Goto strings, we compare the oscillating string decay with a backreaction model accounting for radiation energy losses, finding excellent agreement. We establish that backreaction decay is accurately characterised by the inverse square of the amplitude being proportional to the inverse tension μ for $3 \leq \lambda \leq 100$. The investigation of massive radiation at small to intermediate amplitudes finds evidence that it is suppressed exponentially relative to the preferred massless channel with a $\sqrt{\lambda}$ dependence in the exponent. We conclude that analytic radiation modelling in the thin-string (Nambu-Goto) limit provides the appropriate cosmological limit for global strings.

Fundamental Physics in Space

Fundamental Physics in Space / **455**

Orbit and Constellation Design for TianQin: Progress Review

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The TianQin mission plans to deploy three drag-free controlled satellites in circular high Earth orbits at an altitude of 10^5 km. The satellites form a nearly equilateral-triangle constellation, and exchange high-precision laser interferometric links to detect low-frequency gravitational waves in the mHz frequency band. TianQin features a geocentric concept, and is facing the challenge of designing and utilizing high Earth orbits to the best effect. In this talk, we briefly summarize main progresses on TianQin's orbit and constellation design, including constellation stability optimization, orbital orientation and radius selection, the Earth-Moon's gravity disturbance evaluation, and eclipse avoidance (Ye et al, IJMPD 1950121(2019), Tan et al, IJMPD 2050056(2020), Zhang et al, PRD 062001(2021), Ye et al, PRD 042007(2021), Zhou et al, PRD 103026(2021)).

Fundamental Physics in Space / **730**

BECCAL (Bose Einstein Condensate and Cold Atom Laboratory

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BECCAL (Bose Einstein Condensate and Cold Atom Laboratory) is a joint mission between NASA and DLR. The payload will be installed to the international space station (ISS) to enable research on cold and condensed atoms in the unique microgravity environment. Consequently, BECCAL is not dedicated to a single experiment, but planned as a multi-purpose, multi-user facility.
To create a design baseline, six main areas of research for BECCAL were defined by the science definition team:
• Atom Interferometry
• Coherent Atom Optics
• Scalar Bose Einstein Condensates
• Spinor Bose Einstein Condensates and Quantum Gas Mixtures
• Strongly Interacting Gases and Molecules
• Quantum Information
With those areas as a baseline, BECCAL offers researchers several possibilities to work with cold

and condensed atoms using magnetic and optical fields. BECCAL operates with Rubidium and Potassium, also enabling the study of mixtures.
BECCAL is currently in the design phase, which will be completed by the end of this year with the critical design review. It is destined for a minimum of 1500 hrs of experimental operations over a time of three years after launch.
In my talk, I will give an overview over the payload and the possibilities offered by the mission.

Fundamental Physics in Space / 456

Ultracold quantum bubbles aboard the International Space Station

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Exploring the effects of geometry, topology, dimensionality, and interactions on ultracold atomic ensembles has proven to be a continually fruitful line of inquiry. One heretofore unexplored configuration for such ensembles is that of a bubble or shell, where trapped atoms are confined in the vicinity of a spherical or ellipsoidal surface. Such a system could offer new collective modes, topologically-sensitive behavior of quantized vortices, self-interference and shell collapse, as well as the exploration of trapped ultracold systems with mm-scale spatial extent. While techniques for the generation of bubble-shaped traps have been known since 2001, terrestrial gravity has thus far prevented the observation of ultracold shells. With the construction of the NASA Cold Atom Lab (CAL) facility and its subsequent delivery to the International Space Station (ISS) and commissioning as an orbital BEC facility in 2018, experimental schemes requiring a sustained microgravity environment are now possible. I will present recent CAL observations of trapped shells of ultracold atoms, including a variety of shell configurations that are possible with this apparatus. I will also discuss the thermodynamics of ultracold shells and review open questions being explored in the current second science run of CAL aboard ISS.

Fundamental Physics in Space / 590

MICROSCOPE error data analysis for a test of the principle equivalence in space

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MICROSCOPE aims to test the Weak Equivalence Principle with unprecendent accuracy. The satellite was launched in 2016 and terminated its operations end of 2018. Since then, the in-orbit collected data of science and technological experiments has been extensively analysed to evaluate the performance of each subsystem. While waiting for this final result, we can unveil the two major points

on which we pay some efforts to lead to the future release of EP test: the temperature sensitivity of the experiment and the disturbances brought by the satellite craking into the the data process. At this time, the data processing of all data is finished, the final result is under submission and should improve the previous publication [Touboul et al, 2017].

Fundamental Physics in Space / 989

Quantum Key Distribution from space

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Quantum Key Distribution (QKD) is essential for providing secure communication. For long distances QKD from space turns out to be most efficient. In this contribution the influence of general relativistic effects as well as of instrumental choices on secure QKD is analyzed. One aspects of the resut is that certain classes of orbits are not optimal for QKD. On the other hand, such orbits may be used for improved test of General Relativity and also for quantum theory.

Future Missions for High Energy Astrophysics

Future Missions for High Energy Astrophysics / 602

IXPE (Imaging X-ray Polarimetry Explorer) an upcoming new window in X-ray Astronomy and future opportunities.

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At last, in few months, the window of Astronomical X-ray polarimetry will be re-opened after more than 40 years. IXPE the Imaging X-ray Polarimetry Explorer, is the next NASA Small Explorer Mission with a decisive contribution of Italy. Three X-ray mirrors focalize the radiation into three detector units that host the polarization sensitive detectors entirely devised, built, tested and calibrated in Italy. For the first time it will be possible to perform polarimetry resolved in time, energy and space in 2-8 keV energy range.
IXPE mission was approved in January 2017. The flight is targeted for the end of 2021. Polarimetry is expected to provide a wealth of information determining either the emission processes themselves in celestial X-ray sources and the magnetic field configuration at the site of particle acceleration, disentangling the geometry of compact objects and probing fundamental physics effects. Future experiments are being devised on the path of what IXPE will discover and they will be briefly presented.

Future Missions for High Energy Astrophysics / 763

The Chasing All Transients Constellation Hunters — CATCH

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Modern astronomy has entered the multi-wavelength and multi-messenger era, and time-domain astronomy is one of the leading frontiers. Around 2030, a series of all-sky monitors and survey missions will discovery more than tens of thousands of transients every day. However, the existing and planned telescopes can not simultaneously perform follow-up observations for so many transients of different sky regions, and many important scientific discoveries will be inevitably lost. Thus, we propose a new space science mission—Chasing All Transients Constellation Hunters (CATCH). CATCH is a constellation, which consists of hundreds of satellites. Each satellite will carry a lightweight focusing X-ray telescope developed by China independently. A single satellite can track one or several transients, and hundreds of satellites can work together to achieve uninterrupted monitoring of a substantial amount of transients. In addition, many satellites can also form a large field of view or

a high-precision constellation to jointly chase some important targets (such as gravitational-wave bursts). CATCH has unprecedented scientific capabilities and will bring important scientific discoveries.

Future Missions for High Energy Astrophysics / 890

Laue lenses: focusing optics for hard-X/soft-Gamma rays

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Hard X-/soft Gamma-ray astronomy is a key field for the study of important astrophysical phenomena such as the electromagnetic counterparts of gravitational waves, gamma-ray bursts, black holes physics and many more. However, the spatial localization, imaging capabilities and sensitivity of the measurements are strongly limited for the energy range >70 keV due to the lack of focusing instruments operating in this energy band. A new generation of instruments suitable to focus hard X-/ soft gamma-rays is necessary to shed light on the nature of astrophysical phenomena which are still unclear due to the limitations of current direct-viewing telescopes.
Laue lenses can be the answer to those needs. A Laue lens is an optical device consisting of a large number of properly oriented crystals which are capable, through Laue diffraction, to focus the radiation into the common Laue lens focus. In contrast with the grazing incidence telescopes commonly used for softer X-rays, the transmission configuration of the Laue lenses allows us to obtain a significant sensitive area even at energies of hundreds of keV.
At the University of Ferrara we are actively working on the modelization and construction of a broadband Laue lens. In this talk we will present the main concepts behind Laue lenses, our Montecarlo modelization with our Laue Lens Library, and the latest technological developments of the TRILL (Technological Readiness Increase for Laue Lenses) project, devoted to the advancement of the technological readiness of Laue lenses by developing the first prototype of a sector of a lens made of cylindrically bent crystals of Germanium.

Future Missions for High Energy Astrophysics / 905

MeVCube- a noval compton camera and MeVGRO

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Aim to the MeV window of gamma-ray astronomy and the next generation of gamma-ray telescope, a prototype gamma-ray imaging detector—MeVCube funded by NSFC and DFG will be developed to demonstrates that even a tiny detector can reach the sensitivity of last generations large -scale instruments. I will present the preliminary design of MeVCube and the prospective performance yielded by simulation. Furthermore, a mission concept—MeVGRO proposed by IHEP will also be introduced.

Future Missions for High Energy Astrophysics / 893

ASTENA: a mission concept for a deep study of the transient gamma-ray sky and for nuclear astrophysics

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E. Virgilli, F. Frontera, P. Rosati, E. Caroli, L. Ferro, M. Moita, C. Labanti, R. Campana, F. Fuschino on behalf of a large collaboration

Gamma-ray astronomy is a branch whose potential has not yet been fully exploited. The observations of elemental and isotopic abundances in supernova (SN) explosions are key probes not only of the stellar structure and evolution but also for understanding the physics that makes Type-Ia SNe as standard candles for the study of the Universe expansion properties. In spite of its crucial role, nuclear astrophysics remains a poorly explored field mainly for the typical emission line intensity which is vanishingly small and requires very high sensitivities of the telescopes.
Furthermore, in spite that the Galactic bulge-dominated intensity of positron annihilation line at 511 keV has been measured, its origin is still a mystery due to the poor angular resolution and insufficient sensitivity of the commonly employed instrumentation at MeV and sub-MeV energy domain.
To answer these scientific issues a jump in sensitivity and angular resolution with respect to the present instrumentation is required. Conceived within the EU project AHEAD, a new high energy mission, capable of tackling the previously mentioned topics, has been proposed. This concept mission named ASTENA (Advanced Surveyor of Transient Events and Nuclear Astrophysics), includes two instruments: a Wide Field Monitor with Imaging and Spectroscopic (WFM-IS, 2 keV - 20 MeV) capabilities and a Narrow FIeld Telescope (NFT, 50 - 700 keV). Thanks to the combination of angular resolution, sensitivity and large FoV, ASTENA will be a breakthrough in the hard X and soft gamma–ray energy band, also enabling polarimetry in this energy band. In this talk the science goals of the mission are discussed, the payload configuration is described and expected performances in observing key targets are shown.

Future Missions for High Energy Astrophysics / 872

The X/Gamma-ray Imaging Spectrometer (XGIS) for THESEUS and other opportunities

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The Transient High-Energy Sky and Early Universe Surveyor (THESEUS) mission concept aims at fully exploiting Gamma-Ray Bursts (GRB) for early Universe and multi-messenger astrophysics, as well as providing a substantial advance in time-domain astronomy through detection, accurate location, multi-wavelength (0.3 keV – 10 MeV plus near IR) characterization, and redshift measurement, of many classes of high-energy transients. I will describe the science case, scientific requirements and concept of the X/Gamma-ray Imaging Spectrometer (XGIS), a GRB and transients monitor capable of covering an exceptionally wide energy band (2 keV – 10 MeV), with imaging capabilities and location accuracy <15 arcmin up to 150 keV over a Field of View of 2sr, a few hundreds energy resolution in the X-ray band (<30 keV) and few ⊠s time resolution over the whole energy band. In synergy with the Soft-X-ray Imager (0.3 – 5 keV) and the Infra-Red Telescope (IRT), combined with spacecraft fast slewing capabilities, the XGIS will allow THESEUS to detect, accurately localize and characterize any class of GRBs (long, short, high-z, sub-energetic, ultra-long, etc.), as well as further bright X/gamma-ray transients, for a fraction of which the IRT will provide detection, arcsec localization, moderate spectroscopy and on-board redshift determination. Thanks to a design based on a modularity approach, the XGIS can be easily re-scaled and adapted for fitting the available resources and specific scientific objectvies of other high-energy astrophysics missions.

Future Missions for High Energy Astrophysics / 911

Polarimetric prospects of a new hard X- soft gamma-ray space mission for next decades

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The polarization measurement of the high-energy photons from cosmic sources is today recognised as a key goal for understanding the emission mechanisms and the geometry of the active regions involved, and therefore to solve still open hot scientific issues. To achieve this challenging objective, a mandatory requirement for new instrumentation in this energy regime will be to provide high sensitivity for polarimetric measurements associated with spectroscopy and imaging. In this perspective the Advanced Surveyor of Transient Events and Nuclear Astrophysics (ASTENA) mission concept is under study. This mission includes two main instruments exploiting unprecedented sensitivity: the Wide field monitor (WFM-IS), with a large effective area and a broad energy passband (2-20 MeV), and the Narrow Field Telescope (NFT), with a broad energy passband (50-700 keV) with focusing capabilities based on the use of an advanced broad-band Laue lens. Both instruments will include new concept spectrometers with fine 3D spatial resolution allowing to perform scattering polarimetry along with spectroscopy, imaging and timing. The achievable high sensitivity of both these instruments coupled with the particular characteristics in terms of 3D spatial resolution of their spectrometer detectors will allow them to perform high reliable polarimetry measurements. Herein, we report on the results of a Monte Carlo study devoted to optimizing the configuration of both instruments, in particular, the modulation factor (Q), and the event detection efficiency. We present the dependence of these parameters from detector geometrical configurations (pixel/voxel shape, pixel/voxel scales), and from various filters that can be implemented. Finally, the Minimum Detectable Polarisation (MDP) results obtained for some case studies of real sources are also presented and discussed, showing that ASTENA can reach very low MDP levels, down to 1% in a reasonable observation time.

Future Missions for High Energy Astrophysics / 773

Gamma-Ray Polarimetry of GRBs with the POLAR andPOLAR-2 missions

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Despite over 50 years of Gamma-Ray Burst (GRB) observations many open questions remain about their nature and the environments in which the emission takes place. Polarization measurements of the GRB prompt emission have long been theorized to be able to answer most of these questions. The POLAR detector was a dedicated GRB polarimeter developed by a Swiss, Chinese and Polish collaboration. The instrument was launched, together with the second Chinese Space Lab, the Tiangong-2, in September 2016 after which it took 6 months of scientific data. During this period POLAR detected 55 GRBs as well as several pulsars. From the analysis of the GRB polarization catalog we see that the prompt emission is lowly polarized or fully unpolarized. There is, however, the caveat that within single pulses there are strong hints of an evolving polarization angle which washes out the polarization degree in the time integrated analysis. Building on the success of the POLAR mission, the POLAR-2 instrument is currently under development. POLAR-2 is a Swiss, Chinese, Polish and German collaboration and was recently approved for launch in 2024. Thanks to its large sensitivity POLAR-2 will produce polarization measurements of at least 50 GRBs per year with a precision equal or higher than the best results published by POLAR. POLAR-2 thereby aims to make the prompt polarization a standard observable and produce catalogs of the gamma-ray polarization of GRBs. Here we will present an overview of the POLAR mission and all its scientific measurement results. Additionally, we will present an overview of the future POLAR-2 mission, and how it will answer some of the questions raised by the POLAR results.

Gamma-Ray Burst Correlations: Observational Challenges and Theoretical Interpretation

Gamma-Ray Burst Correlations: Observational Challenges and Theoretical Interpretation / 157

Presenting backscattering dominated model for the prompt phase of GRBs to explain their key observational features

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We propose a Backscattering dominated prompt emission model for gamma ray bursts' (GRB) prompt phase in which the photons generated through pair annihilation at the centre of a GRB are backscattered through Compton scattering by an outflowing stellar cork. Using pair annihilation spectrum for seed photons, we show that the obtained spectra are capable of explaining the low energy and the high energy slopes in the observed prompt spectra of most GRBs. We also explain several observed features of GRB prompt phase such as Amati correlation, spectral lag etc.

Gamma-Ray Burst Correlations: Observational Challenges and Theoretical Interpretation / 961

Modelling flares, breaks, and energetic photons in GRB Fermi-LAT Light curves

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The Fermi-LAT collaboration presented the second gamma-ray burst (GRB) catalog covering its first ten years of operations. A large fraction of light curves (LCs) in this catalog cannot be explained by the closure relations of the standard synchrotron forward-shock (FS) model, suggesting that there could be an essential contribution from another process. Therefore, we derive the synchrotron self-Compton (SSC) LCs from the reverse shock in the thick- and thin-shell regime for a constant-density and stellar-wind medium. We show that this emission could explain the GeV flares exhibited in some LAT LCs. Additionally, we show that the passage of the FS synchrotron energy break in the LAT band could be responsible for the late time steepening of LAT LCs. In particular cases, we model the LAT LCs of GRB 160509A, GRB 131108A, and GRB 160816A.

Gamma-Ray Burst Correlations: Observational Challenges and Theoretical Interpretation / 342

Diversity in supernovae associated with gamma-ray bursts

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I will discuss supernovae associated with gamma-ray bursts and what they tell us about the progenitors of gamma-ray bursts. I will focus on the supernova diversity from gamma-ray bursts and what the diversity tells us.

Gamma-Ray Burst Correlations: Observational Challenges and Theoretical Interpretation / 1069

Consequences of a hot thermal electron distribution in GRB afterglows

Author: Donald Warren[None]

The broadband afterglows of gamma-ray bursts provide a wealth of information vital for interpreting these extremely energetic events: the progenitor systems, the hydrodynamics of the GRB, the microphysics of relativistic shocks, and more. A proper understanding of afterglows may even allow GRBs to extend the cosmic distance ladder. However, our interpretation of afterglows is shaped by the models we apply to the observations. The traditional theory of afterglows is based on a pure power law of electrons, but there should also be a hot, thermal population of electrons that don't enter the shock acceleration process. In this talk I will outline the theoretical justification for thermal electrons, and discuss some of their observational consequences: TeV emission, light curves, and decay indices used for closure relations.

Gamma-Ray Burst Correlations: Observational Challenges and Theoretical Interpretation / 1070

Theory of plateau phase in GRBs

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Since its discovery in 2005, the plateau phase seen in the early x-ray afterglow of a significant fraction (10's of %) of GRBs confuse theoreticians. A close look reveals that "plateau" bursts nearly never show evidence for LAT emission, neither a thermal component. Using this a hint, I argue that the plateau is due to the coasting of GRB jets in a "wind"-like medius. I will provide the theoretical arguments for the evolution of the lightcurve, and show how both the X-ray and optical lightcurves naturally fitted within the framework of this model. The end of the plateau thus marks the transition between the coasting and the self-similar motion phases.

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Cosmology through the Ep,i - Eiso correlation of Gamma-Ray Bursts

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The correlation between the photon energy at which the nuFnu spectrum in the cosmological rest-frame peaks, Ep,i, and the isotropic-equivalent radiated energy, Eiso, is one of the most investigated observaitonal properties of Gamma-Ray Bursts (GRB). In addition to its relevance for understanding the physics of prompt emission, identifying sub-classes of GRBs, shedding light on jet structure and viewing angle, the Ep,i - Eiso correlation is provide us with an the psosibility of using GRBs for measuring cosmological parameters. I provide an overview of the observaitonal status of the correlation, of the methods most used wordlwide for exploiting it as a cosmological tool and the perspective advancement expected thanks to next generation facilities.

Gamma-Ray Burst Correlations: Observational Challenges and Theoretical Interpretation / 1014

Remaining compact object during the collapse scenario: a neutrino approach

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Gamma-ray bursts (GRBs) correspond to the most energetic electromagnetic events known. These events can release a large amount of energy during a time scale ranging from a few milliseconds to tens of seconds. Based on their duration, we can classify them into short and long events, being the production process in each case different. In this work, we study this sort of astrophysical source through neutrinos. In particular, we focus our work on those neutrinos produced by thermal processes during the collapsar model that explain the production of the long GRBs (lGRBs). Within this model, the central remnant left after the star's collapse is either a neutron star (NS) or a black hole (BH). In the first case, several authors have even discussed a magnetar whose magnetic field is stronger than in the second case. Considering this additional contribution, we study neutrino oscillation and propagation in both scenarios to find how the neutrino flavor ratios are modified when propagating through both media with different background conditions. These results act as an additional detection channel to determine the surviving compact object left behind.

Gamma-Ray Burst Correlations: Observational Challenges and Theoretical Interpretation / 555

GRB correlations and physical implications

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I will review several GRB correlations reported in the literature and discuss possible physical mechanisms behind them. Topics to be covered include Amati/Yonetoku relations, Frail relation, Ghirlanda/Liang-Zhang relations, energy/luminosity-Lorentz factor (Liang-Lü relation), Dainotti relation, and several three-parameter fundamental-plane relations. These correlations provide hints on the jet composition, energy dissipation mechanism, jet structure, and central engine of GRBs.

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On the origin of very high-energy gamma-rays from GRBs

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Recently, very high-energy photons above 100 GeV were reported to be detected from GRB 190114C and GRB 180720B at, respectively, 100−1000 s and 10 hr after the burst. We model the available broadband data of both GRBs with the synchrotron plus synchrotron self-Compton (SSC) emission of the afterglow shocks. We find that the sub-TeV emission of GRB 180720B can be interpreted as the SSC emission from afterglow shocks expanding in a constant-density circumburst medium. The SSC emission of GRB 190114C dominates over the synchrotron component from GeV energies at ~100 s, which can explain the possible hard spectrum of the GeV emission at this time. The extrapolated flux of this SSC component to sub-TeV energies can explain the highsignificance detection of GRB 190114C by the MAGIC telescope. The parameter values (such as the circumburst density and shock microphysical parameters) in the modeling are not unusual for both gamma-ray bursts, implying that the detection of sub-TeV photons from these two bursts should be attributed to their large burst energies and low redshifts.

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A model for X-ray plateaux following short Gamma-Ray Bursts

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Many short Gamma-Ray Bursts (sGRBs) have a prolonged plateau in the X-ray afterglow lasting up to tens of thousands of seconds. A central engine injecting energy into the remnant may fuel the plateau. We develop a simple analytic model which naturally produces X-ray plateaux using a

magnetar as the central engine. Our model leverages well-established descriptions of young supernova remnants and applies the underlying physics to sGRB remnants. We calculate analytically the energy distribution of a bubble of electrons powered by the magnetar wind to obtain both the light curve and the spectrum. Using data from the Swift X-Ray Telescope, we find our model aligns with observed data. We also produce spectra in X-ray plateaux which allow for parameter estimation. The plerion contribution is accompanied by an ejecta contribution which we do not model here. If combined with a gravitational wave signal, our model could provide insight into multimessenger astronomy and neutron star physics.

Gamma-Ray Burst Correlations: Observational Challenges and Theoretical Interpretation / 880

Gamma-Ray Bursts and magnetars in the multi-messenger era

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Newly-born millisecond magnetars are competing with black holes as source of the gamma-ray burst (GRB) power. In ten years of activity, Swift has provided compelling but indirect evidences supporting the magnetar central engine for both long and short GRBs, that is currently the best way to interpret several correlations observed between prompt and afterglow properties. We review the main observational features that point to the magnetar central engine, and we discuss how the combined information provided by both the electromagnetic and gravitational signal is the most promising way to unveil the nature of the GRB central engine, which is one of the major breakthrough achievable in the next future.

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The X-ray fundamental plane of the Platinum Sample, the Kilonovae and the SNe Ib/c associated with GRBs and the fundamental plane in Fermi-LAT

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A large fraction of Gamma-Ray Bursts (GRBs) lightcurves (LCs) shows X-ray plateaus. We analyze all GRBs with known redshifts presenting plateaus observed by The Neil Gehrels Swift Observatory from its launch until August 2019. The fundamental plane relation between the rest-frame time and X-ray luminosity at the end of the plateau emission and the peak prompt luminosity holds for all the GRB classes when selection biases and cosmological evolutions are applied. We have discovered two important findings: 1) a new class of Long GRBs with good data coverage: the Platinum Sample; 2) the Platinum, the SNe-LGRB and the KN-SGRB samples, the second sample composed of GRBs associated spectroscopically with the SNe Ib,c, the third sample composed by 8 GRBs associated with Kilonovae or where there could have been such an association, yield the smallest intrinsic scatter, sigmaplatinum,GRB-SNe=0.22 +/ 0.10 and sigmaKN-SGRB=0.24 +/ 0.12. The highest correlation coefficients yield for the SN-LGRB-ABC sample, which are GRBs spectroscopically associated with SNe Ib/c or with a clear optical bump in the LC resembling the SNe Ib/c, (R2SN-LGRB-ABC = 0.95), for the SN-LGRBs (R2SN-LGRB = 0.91) and the KN-SGRBs (R2KN-SGRB = 0.90) when the redshift evolution is considered. These category planes are reliable candidates to be used as cosmological

tools. Furthermore, the distance from the Gold fundamental plane is a crucial discriminant among classes. In fact, we find that the distributions of the distances of the SNe-LGRB, SNe-LGRB-ABC, KN-SGRBs and SGRBs samples from the Gold fundamental plane are statistically different from the distribution of the Gold GRBs' distances from the Gold fundamental plane with and without considering evolution cases.
We will also show the applicability of the fundamental plane in high energy gamma-rays.

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The X-Ray Fundamental Plane of the Platinum Sample, the Kilonovae, and the SNe Ib/c Associated with GRBs

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A large fraction of gamma-ray Bursts (GRBs) lightcurves (LCs) show X-ray plateaus. We analyze all GRBs with known redshifts presenting plateaus observed by The Neil Gehrels Swift Observatory from its launch until 2019 August. The fundamental plane relation between the rest-frame time and X-ray luminosity at the end of the plateau emission and the peak prompt luminosity holds for all the GRB classes when selection biases and cosmological evolutions are applied.
We have discovered two important findings: (1) a new class of long GRBs with good data coverage: the platinum sample; and (2) the platinum, the SNe-LGRB and the KN-SGRB samples, yield the smallest intrinsic scatter with $\sigma_{platinum,GRB-SNe} = 0.22 \pm 0.10$ and $\sigma_{KN-SGRB} = 0.24 \pm 0.12$.
The SNe-LGRBs are composed of GRBs associated spectroscopically with the SNe Ib,c, the KN-SGRBs are composed by 8 GRBs associated with kilonovae or where there could have been such an association.
The highest correlation coefficients are yielded for the SN-LGRB-ABC sample, which includes GRBs spectroscopically associated with SNe Ib/c or with a clear optical bump in the LC resembling the SNe Ib/c, ($R^2_{SN-LGRB-ABC} = 0.95$), for the SN-LGRBs ($R^2_{SN-LGRB} = 0.91$), and the KN-SGRBs ($R^2_{KN-SGRB} = 0.90$) when the redshift evolution is considered. These category planes are reliable candidates to use as cosmological tools. Furthermore, the distance from the gold fundamental plane is a crucial discriminant among classes. In fact, we find that the distributions of the distances of the SNe-LGRB, SNe-LGRB-ABC, KN-SGRB and SGRB samples from the gold fundamental plane are statistically different from the distribution of the gold GRBs' distances from the gold fundamental plane with and without considering evolution cases.

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X-ray Plateaus in Gamma-Ray Burst Afterglows and Their Application in Cosmology

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For gamma-ray bursts (GRBs) with a plateau phase in the X-ray afterglow, a so-called L-T-E correlation has been found which tightly connects the isotropic energy of the prompt GRB ($E\gamma$,iso) with the end time of the X-ray plateau (Ta) and the corresponding X-ray luminosity at the end time (LX). Here we show that there is a clear redshift evolution in the correlation. Furthermore, since the power-law indices of LX and $E\gamma$,iso in the correlation function are almost identical, the L-T-E correlation is insensitive to cosmological parameters and cannot be used as a satisfactory standard candle. On the other hand, based on a sample including 121 long GRBs, we establish a new three parameter correlation that connects LX , Ta and the spectral peak energy Ep, i.e. the L-T-Ep correlation. This correlation strongly supports the so-called Combo-relation established by Izzo et al. (2015). After correcting for the redshift evolution, we show that the de-evolved L-T-Ep correlation can be used as a standard candle. By using this correlation alone, we are able to constrain the cosmological parameters as $\Omega m = 0.389+0.202-0.141$ (1σ) for the flat ΛCDM model, or $\Omega m = 0.369+0.217-0.191$, $w = -0.966+0.513-0.678$ 18 (1σ) for the flat wCDM model. Combining with other cosmological probes, more accurate constraints on the cosmology models are presented.

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The GRB plateau emission naturally explained within the classical "fireball" model

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The origin of the plateau phase seen in the early X-ray light curves of GRBs (up to thousands of seconds) is a debated topic. I will present a new model formulation as explanation of the plateau emission and its application to the observation in both X-ray and optical bands. Main outcomes of this application is that (i) the end of the plateau phase marks the transition from the coasting phase to the self-similar expansion phase, (ii) the initial Lorentz factor of the relativistically expanding jet is of the order of a few tens and (iii) the expansion occurs into a low-density wind.

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Searching for Fermi Short Gamma-Ray Bursts with DDOTI and Tomo-e Gozen

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Neutron-star mergers and their remnants are fascinating both as laboratories for physics at high energies and densities and because of their likely importance for the production of heavy elements. There are several approaches to observing these mergers. First, we can locate the EM counterparts of neutron-star GW events. This was spectacularly successful with GW170817, but despite huge efforts this remains the only GW event whose EM counterpart has been identified. This approach is now on hold until the resumption of GW observations, possibly in 2022. Second, we can study short gamma-ray bursts (SGRBs) detected and localized by the Swift satellite. Here we discuss a third approach, localizing SGRBs detected by the Fermi satellite. Enticingly, while Swift detects only about 10 SGRBs per year, Fermi detects about 45. The challenge is improving the detection localization from 10 degrees to 1 arcsec to allow deep observations with large telescopes. We will present our ongoing collaborations to do this with the Deca-Degree Optical Transients Imager (DDOTI), a wide-field telescope at the Observatorio Astronómico Nacional in Mexico, and with the Tomo-e Gozen wide-field camera on the Kiso Schmidt telescope of the University of Tokyo.

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The photospheric origin of E_p-L_p and E_p-E_{iso} correlations in GRBs

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In the current study, we present hydrodynamical simulations and post-process radiation transfer calculations of photospheric emission in GRBs. Our simulations show that the photospheric emission can reproduce the observed correlations among the spectral peak energy, E_p, peak luminosity, L_p, and isotropic energy, E_{iso}, as a consequence of the viewing angle dependence. We also find that the time-resolved property of the emission shows E_p–L_{iso} tracking behavior that is consistent which the observation.

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The structure of Gamma Ray Bursts: beyond GRB 170817

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Combining information from the first gravitational wave detected gamma-ray burst, GRB 170817 with observations of cosmological GRBs holds important lessons for understanding the structure of GRB jets and the required conditions at the emitting region. It also re-frames our understanding of more commonly observed phenomena in GRBs, such as X-ray plateaus, and sets our expectations

for future observations. I will present different lines of argument suggesting that efficient gamma-ray emission in GRBs has to be restricted to material with Lorentz factor > 50 and is most likely confined to a narrow region around the core. GRB jets viewed slightly beyond their jet cores, result in X-ray plateaus that are consistent with observed light-curves and naturally reproduce correlations between plateau and prompt emission properties. For jets viewed further off-axis (that are expected to be detected as future GW triggered events) we provide new analytical modelling that reveals two different types of light-curves that could be observed (single or double peaked) and outlines how the underlying physical properties can be recovered from such observations.

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Short Gamma-Ray Bursts: situation and future perspectives

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After 15 years of Swift observations, the knowledge of the class of short GRBs experienced an impressive boost. The discovery of short GRB afterglows in 2005, provided the first insight into their energy scale, environments and host galaxies. The lack of detection of associated supernovae proved that their progenitors are not massive stars. The spectacular detection of the first electromagnetic counterpart of a gravitational wave event detected by the LIGO/Virgo interferometers and originated by the coalescence of a double neutron star system (GW 170817) marked the dawn of a new era for astronomy. The short GRB 170817A associated to the GW event provided the long-sought evidence that at least a fraction of short GRBs are originated by NS-NS merging and suggested the intriguing possibility that relativistic jets can be launched in the process of a NS-NS merger. The extensive follow-up campaign carried out at all wavelengths over almost three years of GRB 170817A probed the GRB emission geometry, providing clear evidence for a successful jet endowed with an angular energy profile, featuring a narrow and energetic core (seen off-axis), surrounded by a slower, less energetic layer/sheath/cocoon. Besides the remarkable event associated to GW 170817, kilonova signatures have been tentatively identified in other short GRBs light curves, supporting a scenario where kilonovae are ubiquitous and can probe neutron star mergers well beyond the horizon of the gravitational wave detectors.
In this talk I will provide an overview of the observational properties of short GRBs and kilonovae, showing how the study of correlations and carefully selected samples of events can provide a useful tool to unveil the properties (progenitors, central engine, emission geometry, environment) of these elusive events.

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Searching for strange quark planets

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The central engine of gamma-ray bursts may be neutron stars. However, the internal structure of neutron stars is still largely uncertain. It has been suggested that strange-quark matter (SQM) may be the true ground state of hadronic matter, indicating that the observed pulsars may actually be strange stars (SSs), but not neutron stars. According to the SQM hypothesis, the existence of a hydrostatically stable sequence of SQM stars has been predicted, ranging from 1 to 2 solar mass SSs,

to smaller strange dwarfs and even strange planets. While gravitational wave (GW) astronomy is expected to open a new window to the universe, it will shed new light on the search for SQM stars. We show that due to their extreme compactness, strange planets can spiral very close to their host SSs without being tidally disrupted. We thus can try to identify strange quark objects by searching for close-in pulsar planets. Additionally, Like inspiraling neutron stars or black holes, a merging strange star-strange planet system would serve as new sources of GW bursts, producing strong GWs at the final stage. The events occurring in our local universe can be detected by GW detectors, such as Advanced LIGO and the future Einstein Telescope. This effect provides a unique probe to SQM objects and is hopefully a powerful tool for testing the SQM hypothesis. In this talk, we will present our recent studies concerning strange quark planets.

Ghost-Free Models of Modified Gravity: Massive Gravity, Horndeski and DHOST Theories, Other Related Models; Their Properties and Solutions

Ghost-Free Models of Modified Gravity: Massive Gravity, Horndeski and DHOST Theories, Other Related Models; Their Properties and Solutions. / 133

Shift-Symmetric Theories for Consistent Black-Hole Hair

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Scalar-tensor theories enjoying a shift symmetry can describe black holes with scalar hair. I will discuss which of these theories can give rise to acceptable black holes with hair, based on three requirements. These are stability under generic perturbations, consistency from the point of view of effective field theory, and the existence of a standard UV completion.
I will argue that in the most symmetric case, these requirements leave only one acceptable source of hair. This is the linear coupling of the scalar field to the Gauss-Bonnet invariant.
However, I will show that other shift symmetric scalar interactions must be included alongside the Gauss-Bonnet coupling when this can affect astrophysical black holes. If this were not the case, the effective theory would break down around the shortest length-scales currently probed by gravitational table-top experiments.

Ghost-Free Models of Modified Gravity: Massive Gravity, Horndeski and DHOST Theories, Other Related Models; Their Properties and Solutions. / 839

Ghosts in metric-affine gravity

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In this talk we will explicitly show how ghost degrees of freedom arise in a sub-class of metric-affine theories unless projective symmetry is enforced. Then, we will generalise the techniques

employed in that particular case to argue why ghosts will arise in generic metric-affine theories of gravity around arbitrary backgrounds. We will also discuss some results on possible ways to avoid them.

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Exact gravitational waves in non-local gravity

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We study exact solutions of infinite derivative gravity within the class of so-called almost universal spacetimes. For such an ansatz, the field equations reduce to a single non-local but linear equation which is exactly solvable with the ghost-free choice $\exp(-\ell^2$
$Box)$ of the non-local form factor by eigenfunction expansion or using the heat kernel method. This procedure allows us to obtain non-local analogues of Aichelburg–Sexl and Hotta–Tanaka solutions which represent gravitational waves generated by null sources propagating in Minkowski, de Sitter or anti-de Sitter backgrounds. We discuss properties of these non-local solutions and also point out that the non-locality regularizes curvature singularities at the locations of the sources.

Ghost-Free Models of Modified Gravity: Massive Gravity, Horndeski and DHOST Theories, Other Related Models; Their Properties and Solutions. / 887

Analytic infinite derivative gravity as the quantum gravity probe

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I will discuss the general aspects of the Analytic Infinite Derivative (AID) gravity theories. It will be shown in details why an infinite number of derivatives is required to eradicate ghosts. Explicit ghost-free construction will be presented. Then it will be explained how unitarity is maintained in this non-local setup upon accounting loop corrections. Observational aspects will be briefly touched.

Ghost-Free Models of Modified Gravity: Massive Gravity, Horndeski and DHOST Theories, Other Related Models; Their Properties and Solutions. / 657

Non-local self-healing of Higgs inflation

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Higgs inflation is known to be a minimal extension of the Standard Model allowing for the description of the early Universe inflation. This model is considered as an effective field theory since it has a relatively low cutoff scale, thus requiring further extensions to be a valid description of the reheating phase. We present a novel unified approach to the problem of unitarization and UV completion of the Higgs inflation model without introducing new massive degrees of freedom. This approach is based on an analytic infinite derivative modification of the Higgs field kinetic term. We construct a unitary non-local UV completion of the original Higgs inflation model while the inflationary stage is kept stable with respect to quantum corrections.

Ghost-Free Models of Modified Gravity: Massive Gravity, Horndeski and DHOST Theories, Other Related Models; Their Properties and Solutions. / 161

Is there a Gauss-Bonnet gravity in four dimensions?

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We comment on the recently introduced Gauss-Bonnet gravity in four dimensions. We argue that although the naive D->4 limit of the Gauss-Bonnet gravity does not work, a well-defined theory is obtained by generalizing a conformal trick employed by Mann and Ross to obtain a limit of the Einstein gravity in D=2 dimensions. This yields a scalar-tensor theory of the Horndeski type that can also be obtained by dimensional reduction methods. Some properties and solutions of this theory in four and three dimensions will be discussed.

Ghost-Free Models of Modified Gravity: Massive Gravity, Horndeski and DHOST Theories, Other Related Models; Their Properties and Solutions. / 339

Asymptotically flat hairy black holes in Massive Bigravity

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We study asymptotically flat black holes with massive graviton hair within the ghost-free Bigravity theory. There have been contradictory statements in the literature about their existence: such solutions were reported some time ago, but later a different group claimed the Schwarzschild solution to be the only asymptotically flat black hole in the theory. We have analyzed the issue ourselves and have been able to construct such hairy black holes within a carefully designed numerical scheme. We analyze their perturbative stability and find that some of them can be stable. The masses of stable hairy black holes that would be physically relevant range from stellar values up to values typical for supermassive black holes. One of their two metrics is extremely close to Schwarzschild, while all their "hair" is hidden in the second metric that is not coupled to matter and not directly seen. If the Massive Bigravity theory indeed describes physics, the hair of such black holes should manifest themselves in violent processes only, like black hole mergers, and should be visible in the structure of the signals detected by LIGO/VIRGO.

Ghost-Free Models of Modified Gravity: Massive Gravity, Horndeski and DHOST Theories, Other Related Models; Their Properties and Solutions. / 769

Anisotropic cosmological models in Horndeski gravity

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It was found recently that the anisotropies in the homogeneous Bianchi~I cosmology considered within the context of a specific Horndeski theory are damped near the initial singularity instead of being amplified. In this work we extend the analysis of this phenomenon to cover the whole of the Horndeski family. We find that the phenomenon is absent in the K-essence and/or Kinetic Gravity Braiding theories, where the anisotropies grow as one approaches the singularity. The anisotropies are damped at early times only in more general Horndeski models whose Lagrangian includes terms quadratic and cubic in second derivatives of the scalar field. Such theories are often considered as being inconsistent with the observations because they predict a non-constant speed of gravitational waves. However, the predicted value of the speed {\it at present} can be close to the speed of light with any required precision, hence the theories actually agree with the present time observations. We consider two different examples of such theories, both characterized by a late self-acceleration and an early inflation driven by the non-minimal coupling. Their anisotropies are maximal at intermediate times and approach zero at early and late times. The early inflationary stage exhibits an instability with respect to inhomogeneous perturbations, suggesting that the initial state of the universe should be inhomogeneous. However, more general Horndeski models may probably be stable.

Ghost-Free Models of Modified Gravity: Massive Gravity, Horndeski and DHOST Theories, Other Related Models; Their Properties and Solutions. / 621

Ultrarelativistic spinning objects in nonlocal ghost-free gravity

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We study the gravitational field of ultrarelativistic spinning objects (gyratons) in a modified gravity theory with higher derivatives. In particular, we focus on a special class of such theories with an infinite number of derivatives known as "ghost-free gravity" that include a nonlocal form factor such as exp(-\Box\ell^2), where \ell is the scale of nonlocality. First, we obtain solutions of the linearized ghost-free equations for stationary spinning objects. To obtain gyraton solutions we boost these metrics and take their Penrose limit. This approach allows us to perform calculations for any number of spacetime dimensions. All solutions are regular at the gyraton axis. In four dimensions, when the scale nonlocality \ell tends to zero, the obtained gyraton solutions correctly reproduce the Aichelburg–Sexl metric and its generalization to spinning sources found earlier by Bonnor. We also study the properties of the obtained four-dimensional and higher-dimensional ghost-free gyraton metrics and briefly discuss their possible applications.

Ghost-Free Models of Modified Gravity: Massive Gravity, Horndeski and DHOST Theories, Other Related Models; Their Properties and Solutions. / 930

Palatini kinetic scalar-tensor theory: analytical and numerical solutions

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We discuss different types of solutions (globally regular, black holes, wormholes and cosmological solutions), in the framework of the new two-parameter Palatini scalar-tensor theory with the derivative coupling of a scalar to the Ricci tensor. The metric version of the theory for generic values of two coupling constants is ghostly, but in Palatini version it is ghost-free. The theory admits an Einstein's frame with a non-canonical scalar field, and its one-parameter subfamily is reduced to the minimal Einstein-scalar theory in this frame Some analytical solutions can be constructed using disformal transformations from the Einstein frame. Usually, the singular solutions of Einstein-scalar gravity transform into non-singular solutions in the Jordan frame due to the strong violation of the NEC in this theory. We construct numerical solutions describing various alternatives to the static metrics of ultracompact objects, including solutions with non-singular centers and wormholes. Cosmological solutions, both analytical and numerical, typically exhibit genesis-type behavior.

Ghost-Free Models of Modified Gravity: Massive Gravity, Horndeski and DHOST Theories, Other Related Models; Their Properties and Solutions. / 936

DHOST theories

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The last few years have witnessed a great enthusiasm for modified theories of gravity and particularly for scalar-tensor theories. The motivations to modify gravity are to test the limits of general relativity on the one hand and also to propose "answers" to open
questions of cosmology and astrophysics. In this context, many theories have emerged and a very complex landscape of theories has appeared in the literature. In this talk, I will show how we can classify some of these theories and how we can construct the most general tensor-scalar theories (aka DHOST theories) that are physically viable (in a precise sense that I will give). Finally, we will show how these modified theories can be applied to cosmology (to account for dark energy) and in astrophysics.

Ghost-Free Models of Modified Gravity: Massive Gravity, Horndeski and DHOST Theories, Other Related Models; Their Properties and Solutions. / 390

Testing gravity with cosmic microwave background in DHOST theory

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We developed a CMB Boltzmann solver to test gravity theories in the framework of the degenerate higher-order scalar-tensor (DHOST) theory. This theoretical framework includes the wide class of dark energy models such as the Horndeski theory and its extensions as certain limits, and the general relativity can be also recovered. In this talk, we show how to formulate the linear perturbations of gravity and matter in the DHOST theory and derive their effective description parameterized by time-dependent effective field theory (EFT) parameters, α_i $(i = B, K, T, M, H, L)$ and β_i $(i = 1, 2, 3)$. We then show that the angular power spectra of the CMB temperature anisotropies, E-mode and lensing potential as a demonstration and find that the parameter characterizing the DHOST theory, β_1, provides the larger modifications of the spectra, compared with other EFT parameters. We also show the results in a specific model in which the cosmic expansion as well as the EFT parameters are consistently determined.

Ghost-Free Models of Modified Gravity: Massive Gravity, Horndeski and DHOST Theories, Other Related Models; Their Properties and Solutions. / 381

Non-local R^2-like inflation, Gravitational Waves and Non-Gaussianities

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The emergence of R^2 (Starobinsky) inflation from the semi-classical modification of gravity due to matter quantum fields clearly points out the importance of fundamental physics and the first principles in the construction of successful cosmological models. Along with the observational success, R^2 gravity is also an important step beyond general relativity (GR) towards quantum gravity. Furthermore, several approaches of quantum gravity to date are strongly indicating the presence of non-locality at small time and length scales. In this regard, ultraviolet (UV) completion of R^2 inflation has been recently studied in a string theory-inspired ghost-free analytic non-local gravity. We discuss the promising theoretical predictions of non-local R^2-like inflation with respect to the key observables such as tensor-to-scalar ratio, tensor tilt which tell us about the spectrum of primordial gravitational waves, and scalar Non-Gaussianities which tell us about the three-point correlations in the CMB fluctuations. Any signature of non-local physics in the early Universe will significantly improve our understanding of fundamental physics at UV energy scales and quantum gravity.

Gravitational Lensing and Shadows

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Killing tensors and photon surfaces in foliated spacetimes

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We present a purely geometric method for constructing a rank two Killing tensor in a spacetime with a codimension one foliation that lifts the trivial Killing tensors from slices to the entire manifold 1. The resulting Killing tensor can be nontrivial. A deep connection is found between the existence of such a Killing tensor and the presence of generalized photon surfaces in spacetime with two Killing vector fields. This technique generates Killing tensors in a purely algebraic way, without solving differential equations. The use of our method is demonstrated for Kerr, Kerr-Newman-NUT-AdS metrics and Kerr-NUT-AdS multicharge gauged supergravity solution.

1 K. Kobialko, I. Bogush, D. Gal'tsov, arXiv: 2104.02167 [gr-qc].

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Geodesic bilocal operators in Schwarzschild spacetime

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We present a unified formulation of geometrical optics in General Relativity. Consider two causally connected, locally flat neighborhoods. Suppose that each null geodesic originating in one neighborhood terminates at the other one, and the curvature along the trajectory is small enough, such that the linear geodesic deviation equation holds. Also, let the observation be performed by a number of nearby observers. One can show that all the optical observables like parallax and angular diameter distances are expressible in terms of bilocal geodesic operators (as defined in 1811.10284), which are functionals of the curvature along the line of sight, and the 4-velocities of the emitter and observer. In this talk, we present a complete solution of the geodesic deviation equation and use it to construct bilocal geodesic operators for Schwarzschild spacetime. Finally, we use these operators to study angular diameter and parallax distances as well as emitter-observer-velocity-independent distance slip (1912.04988).

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Fuzzball Shadows: Emergent Horizons from Microstructure

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I will present our imaging study of four-dimensional, string-theoretical, horizonless "fuzzball" geometries. Their microstructure traps light rays straying near the would-be horizon on long-lived, highly redshifted chaotic orbits. In fuzzballs sufficiently near the scaling limit this creates a shadow much like that of a black hole, while avoiding the paradoxes associated with an event horizon. Observations of the shadow size and residual glow can potentially discriminate between fuzzballs away from the scaling limit and alternative models of black compact objects.

Gravitational Lensing and Shadows / 723

Photon region and shadow in a spacetime with a quadrupole moment

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A black hole's shadow is expected to deform under the influence of an external gravitational field caused by matter present in its vicinity. This talk aims to characterise the distortion of a Schwarzschild black hole shadow due to a non-zero quadrupole moment c_2 by qualitatively investigating the behaviour of light rays close to the black hole horizon. In particular, the numerical investigation in the meridional plane for $1 \gg c_2 > 0$ finds four non-circular closed geodesics and their neighbouring geodesics exhibit chaotic behaviour that is not present in the undistorted Schwarzschild spacetime. The black hole shadow is therefore approximated by restricting the observational setup accordingly. In that case, the black hole shadow's eccentricity indicates a prolate deformation for static observers. The photon sphere in the Schwarzschild spacetime deforms into a photon region with a crescent-shaped projection on the meridional plane. Furthermore, the resulting boundary curve of the black hole shadow is visualised.

Gravitational Lensing and Shadows / 1008

Microlensing in terms of an exact lens map

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In spherically symmetric and static spacetimes, gravitational lensing can be formulated in terms of an exact lens map, in close analogy to the weak-field formalism of lensing. Whereas in the latter case the lens map is a map from a lens plane to a source plane, the exact lens map is a map from the celestial sphere of the observer to a sphere where the light sources are thought to be situated. It is demonstrated that, with the help of the exact lens map, microlensing light curves can be calculated exactly. Several examples are presented, including microlensing by a Barriola-Vilenkin monople and by a Schwarzschild black hole.

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A Morse-theoretical analysis of gravitational lensing by rotating traversable wormhole

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Consider, in the domain of wormhole, a point p (observation event) and a timelike curve γ (worldline of light source).
We prove that for infinitely many positive integers κ there is a past-pointing lightlike geodesic λ_κ of Morse index κ from p to γ , hence an observer at p sees infinitely many images of γ.

We will show that in the rotating traversable wormhole the occurrence of infinitely many images is intimately related to the occurrence of centrifugal-plus-Coriolis force reversal.

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Static, equipotential photon surfaces have no hair

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The Schwarzschild spacetime of positive mass is well-known to possess a unique "photon sphere" – meaning a cylindrical, timelike hypersurface P such that any null geodesic initially tangent to P remains tangent to P – in all dimensions. We will show that it also possesses a rich family of spatially spherically symmetric "photon surfaces" – general timelike hypersurfaces P such that any null geodesic initially tangent to P remains tangent to P. This generalizes a result of Foertsch, Hasse, and Perlick from $2+1$ to higher dimensions. Furthermore, we will discuss how these photon surfaces behave across the black hole horizon and towards infinity in the Kruskal–Szekeres extension.

Similar results can be obtained in a large class of static, spherically symmetric spacetimes, including for example sub-extremal Reissner–Nordström spacetimes, but also other relevant examples. We show that they are (almost) necessarily rotationally symmetric and give concrete ODEs for their radial profile, including a solvability analysis of said ODEs.

We will also present a general theorem that implies that any static, vacuum, asymptotically flat spacetime possessing a so-called "equipotential" photon surface must already be the Schwarzschild spacetime. The proof of the theorem uses and extends Riemannian geometry arguments first introduced by Bunting and Masood-ul-Alam in their proof of static black hole uniqueness. It holds in all dimensions $n+1 \geq 3+1$ and naturally generalizes to electro-vacuum.

Parts of this work are joint with Gregory J. Galloway, with Sophia Jahns and Olivia Vicanek Martinez, and with Markus Wolff.

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Decoding a black hole metric from interferometric patterns of relativistic images

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Photons emitted by light sources in the neighbourhood of a black hole can wind several times around it before fleeing towards the observer. For spherically symmetric black holes, two infinite sequences of images are created for any given source, asymptotically approaching the shadow border with decreasing magnitude. These sequences are reflected by a characteristic staircase structure in the complex visibility function that may be used to decode the properties of the black hole metric. Recalling the formalism of gravitational lensing in the strong deflection limit, we derive analytical formulae for the height, the width and the periodicities of the steps in the visibility as functions of the black hole parameters. These formulae can then be used to track the changes in the visibility for different metrics and ultimately test General Relativity.

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Geometric optics, its corrections, and Green functions in curved spacetimes

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Geometric optics and its corrections are typically derived using a high-frequency WKB ansatz, which results in a tower of transport equations along null geodesics. Separately, field propagation can be described using Green functions, which are known to have a Hadamard form involving certain bitensors. In this talk, it will be explained how these two perspectives on field propagation complement one another. For example, using a result from geometric optics, certain aspects of Green functions near the light cone can be shown to transform very simply under wide classes transformations applied to the background metric. One aspect with this property is the luminosity distance, which implies that it depends relatively little on the geometry in between the source and the observer.

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Shadow of black holes with a plasma environment in 4D Einstein-Gauss-Bonnet gravity

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We study the shadow cast by rotating black holes surrounded by plasma in the context of the novel 4D Einstein-Gauss-Bonnet theory of gravity. The metric for these black holes results from applying the Newman-Janis algorithm to a spherically symmetric solution. We obtain the contour of the shadow for a plasma frequency model that allows a separable Hamilton-Jacobi equation. We introduce three observables in order to characterize the position, size, and shape of the shadow.

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Aspects of neutrino mass hierarchy in gravitational lensing

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It is now clear beyond any doubt that neutrinos have masses, and that they mix. Experiments with solar, atmospheric, reactor and accelerator neutrinos have determined, with remarkable accuracy, values of $\Delta m^2_{ij} = m^2_i - m^2_j$. Absolute neutrino masses, however, are still unknown. We know neutrino vacuum oscillations only depend on Δm^2, hence, oscillations experiments are inadequate of providing information about absolute neutrino masses. In our work, we show that the lensing of neutrinos induced by a gravitational source substantially modifies this standard picture and it gives rise to a novel contribution through which the oscillation probabilities also depend on the individual neutrino masses. We show that the oscillation probability in the presence of lensing is sensitive to the absolute masses of neutrinos and sign of Δm^2_{ij}, unlike in the case of standard vacuum oscillation in flat spacetime. We demonstrate this explicitly by considering an example of weak lensing induced by a Schwarzschild mass and discuss various implications of gravitationally modified neutrino oscillations and means of observing them.
Further, We study decoherence effects in neutrino flavour oscillations in Schwarzschild geometry with particular emphasis on the lensing. Assuming Gaussian wave packets, we show that the decoherence is sensitive to the absolute values of neutrino masses as well as the classical trajectories taken by neutrinos between the source and detector along with the spatial widths of neutrino wave packets. We show that in presence of a Schwarzschild object the neutrino wave packets decohere later in comparison when the Schwarzschild object is absent. At distances beyond the decoherence length, flavour transition probability attains a value that depends only on the leptonic mixing parameters. Hence, the observability of neutrino lensing significantly depends on these parameters and in-turn the lensing can provide useful information about the latter.
Journal reference:Phys. Rev. D 102, 024043(2020)

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Gravitational Lensing by Charged Accelerating Black Holes

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Current astrophysical observations show that on large scale the Universe is electrically neutral. However, locally this may be quite different. Black holes enveloped by a plasma in the presence of a strong magnetic field may have acquired a significant electric charge. We can also expect that some of these charged black holes are moving. Consequently to describe them we need spacetime metrics describing moving black holes. In general relativity such a solution is given by the charged C-de Sitter-metric. In this talk we will assume that it can be used to describe moving charged black holes. We will investigate how to observe the electric charge using gravitational lensing. First we will use

elliptic integrals and functions to solve the geodesic equations. Then we will derive lens equation, travel time and redshift. We will discuss the impact of the
electric charge on these observables and potential limitations for its observation.

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Journeys in the maximal analytic extension of Kerr spacetime – General relativistic visualization

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The maximal analytic extension of slow Kerr spacetime contains an infinity of asymptotically flat ”exterior” regions connected by a strongly curved region. General relativistic ray tracing is used to calculate videos showing the view of an observer moving through Kerr spacetime. Covering the whole maximal analytic extension requires a multitude of coordinate patches. The calculated videos give an intuitive idea of its causal structure.

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Lensing of '69 – Free lensing from its lens models

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After more than a century of modern cosmology in which model assumptions were indispensable to interpret the sparse and vague data, we are finally able to replace model assumptions by observational evidence. With telescopes like Hubble, the development of adaptive optics for ground-based facilities, and installations of integrated field units, the amount of high-quality data has vastly increased in the last decades. It will continue to improve and increase with next generation telescopes like the James Webb Space Telescope. The gaps between data shrinking, the necessity to fill in blanks by models decreases.

Within the growing framework of data-driven cosmology, this talk introduces observation-based strong gravitational lensing. It reconstructs a deflecting mass density and properties of the multiply-imaged background source without employing any assumptions about the overall shape of the deflecting mass density profile or properties of the source object. Freeing strong gravitational lensing from its lens models, we can characterise the general class of invariance transformations rooted in the lensing formalism beyond the famous mass-sheet transform. We are also able to determine the maximum set of local lens and source properties all model-based reconstructions agree upon, and we can efficiently reconstruct multi-scale lensing phenomena, even for a single system of multiple images in an otherwise uncharted lensing region.

The method of reducing an under-determined system of equations to its local, uniquely determined, non-degenerate solutions can also be transferred to other astrophysical probes like plasma lensing. Being a dispersive phenomenon, the wavelength dependence of plasma lensing observables allows to break degeneracies that are inherently invincible in non-dispersive gravitational lensing.

Thus, using data not models, various applications become possible to gain new, less biased insights into light deflection phenomena.

J. Wagner. A Model-Independent Characterisation of Strong Gravitational Lensing by Observables. Universe (2019)

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Symplectic evolution of an observed light bundle

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Each and every observational information we obtain from the sky regarding the brightnesses, distances or image distortions resides on the deviation of a null geodesic bundle. In this talk, we will present the symplectic evolution of it on a reduced phase space. The resulting formalism is analogous to the one in paraxial Newtonian optics. It allows one to identify any spacetime as an optical device and distinguish its thin lens, pure magnifier and rotator components. We will show that the distance reciprocity in relativity results from the symplectic evolution of this null bundle. Other potential applications like wavization and quantization will also be summarized.

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Weighing spacetime along the line of sight using times of arrival of electromagnetic signals

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I will discuss a new method of determining the spacetime curvature and matter density along the line of sight using variations of times of arrival (TOA) of electromagnetic signals, measured in the vicinity of two given points. We measure the variations of the TOA's up to quadratic order in the displacements of the source and the receiver with the help two groups of synchronised clocks, equipped with transmitters and receivers. The TOA's are affected by the gravitational field along the lone of sight and it turns out that it is possible to determine from this data the first two moments of the matter density profile along the line of sight. The measurement is insensitive to the states of motion of the two groups of clocks, their angular positions or the influence of masses off the line of sight. Potential applications include precise binary pulsar timing and dark matter search. The talk is based on arXiv:2102.00095 [gr-qc].

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Rotation of polarization in the gravitational field of a laser beam—Faraday effect and optical activity

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We investigate the rotation of the polarization of a light ray propagating in the gravitational field of a circularly polarized laser beam. The rotation consists of a reciprocal part due to gravitational optical activity, and a non-reciprocal part due to the gravitational Faraday effect. We discuss how to distinguish the two effects: letting light propagate back and forth between two mirrors, the rotation due to gravitational optical activity cancels while the rotation due to the gravitational Faraday effect accumulates. In contrast, the rotation due to both effects accumulates in a ring cavity and a situation can be created in which gravitational optical activity dominates. Such setups amplify the effects by up to five orders of magnitude, which however is not enough to make them measurable with state of the art technology. The effects are of conceptual interest as they reveal gravitational spin–spin coupling in the realm of classical general relativity, a phenomenon which occurs in perturbative quantum gravity.

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Shadows of the past, shadows of the future

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What do archival observations tell us about the M87 black hole?

With the 2017 observations of the Event Horizon Telescope we observed the M87 supermassive black hole with linear resolution corresponding to about 3 Schwarzschild radii, revealing a bright ring surrounding dark center – a feature dubbed a "black hole shadow". Several archival observations of M87 with the EHT prototype arrays were obtained in 2009-2013. They are generally of far lower data quantity, quality, and resolution. Nevertheless, they allow to constrain certain geometric parameters of the source, confirming its persistent diameter and presence of the flux depression. I will discuss those observations and findings. Then I will discuss more generally what constitutes a minimal usable observation to meaningfully claim a detection of a black hole shadow, if it can be translated to a mass measurement, and what other assumptions do we need to make. This is relevant in the context of the future space very long baseline interferometry observations that may give us results for a larger set of sources, but likely with data sets resembling sparse 2009-2013 observations more than the 2017 results of the EHT.

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Plasma lensing

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Gravitational lensing is a widely used probe in the study of the dark universe. Besides the gravity, the free electrons in the plasma can also cause deflections of the light. Although plasma lensing has a distinct similarity to gravitational lensing, particularly in its mathematical description, plasma lensing introduces additional features, such as wavelength dependence, diverging deflection, etc. I will briefly introduce the basic phenomenon of plasma lensing and the lensing effects, such as the magnification and time delay in the plasma lensing. It shows some potentially interesting applications in the study of the pulsar, FRB as well as the interstellar and intergalactic medium.

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Images and photon rings of accretion disks surrounding compact objects

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The planet-size network of millimeter antennas Event Horizon Telescope (EHT) has recently delivered images of the surroundings of the supermassive compact object M87* at the center of the galaxy Messier 87. Such images are crucial to better understand the physics at play in a strong gravitational field environment. They might also allow to probe the extreme relativistic effects on the radiation emitted close to the compact object.

In this talk, I will present a simple semi-analytic model of the accretion flow surrounding M87* and discuss images of this flow. In particular, I will focus on the highly-lensed part of the image generally refered to as the « photon ring ». After providing a definition of this feature, I will discuss the prospect of using it as a probe of the underlying spacetime. I will also discuss how the highly-lensed part of the image changes when the compact object is not a black hole but a more exotic alternative object.

The final goal of my talk is to discuss to what extent can EHT-like images help constrain the nature of the compact objects at the center of M87 or our Milky Way.

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Gravitational lensing by rotating Simpson–Visser black holes

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We investigate strong-field gravitational lensing by rotating Simpson-Visser black hole, which has an additional parameter (l), apart from mass (M) and rotation parameter (a). It can admit Cauchy and event horizons for some parameters and free from the singularity and assess phenomenological differences from the Kerr black holes. We also find a decrease in the deflection angle α_D, angular position θ_1 decreases more slowly and x_m more quickly, but angular separation s increases more rapidly, and their behavior is similar to that of the Kerr black hole. We apply the formalism to discuss the astrophysical consequences in the supermassive black holes NGC 4649, NGC 1332, Sgr A*and M87* and find that the rotating Simpson-Visser black holes can be quantitatively distinguished from the Kerr black hole via gravitational lensing effects. However, the deviations of the angular positions of the first image from that of the Kerr black hole are not more than 0.194 μas for Sgr A*, 0.04565 μas for M87, 0.0920051 μas for NGC 4649, and 0.0487413 μas for NGC 1332 and thus required resolution is much higher than current astronomical observation capability like of EHT.

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Black hole shadow as a standard ruler in cosmology

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Advancements in the black hole shadow observations may allow us not only to investigate physics in the strong gravity regime, but also to use them in cosmological studies. We propose to use the shadow of supermassive black holes as a standard ruler for cosmological applications assuming the black hole mass can be determined independently. First, observations at low redshift distances can be used to constrain the Hubble constant independently.
Secondly, the angular size of shadows of high redshift black holes is increased due to cosmic expansion and may also be reachable with future observations.

Talk is mainly based on the paper:

O.Yu. Tsupko, Z. Fan and G.S. Bisnovatyi-Kogan, Black hole shadow as a standard ruler in cosmology, Classical and Quantum Gravity (2020)

see also:

G.S. Bisnovatyi-Kogan and O.Yu. Tsupko, Shadow of a black hole at cosmological distances, Physical Review D (2018);

V. Perlick, O.Yu. Tsupko and G.S. Bisnovatyi-Kogan, Black hole shadow in an expanding universe with a cosmological constant, Physical Review D (2018).

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Comparing Kerr-Sen and Kerr-Newman black hole shadows

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Celebrating the centennial of its first experimental test, the theory of General Relativity (GR) has successfully and consistently passed all subsequent tests with flying colors. It is expected, however, that at certain scales new physics, in particular, in the form of quantum corrections, will emerge, changing some of the predictions of GR, which is a classical theory. In this respect, black holes (BHs) are natural configurations to explore the quantum effects on strong gravitational fields. BH solutions in the low-energy effective field theory description of the heterotic string theory, which is one of the leading candidates to describe quantum gravity, have been the focus of many studies in the last three decades. The recent interest in strong gravitational lensing by BHs, in the wake of the Event Horizon Telescope (EHT) observations, suggests comparing the BH lensing in both GR and heterotic string theory, in order to assess the phenomenological differences between these models. In this work, we investigate the differences in the shadows of two charged BH solutions with rotation: one arising in the context of GR, namely the Kerr–Newman (KN) solution, and the other within the context of low-energy heterotic string theory, the Kerr–Sen (KS) solution. We show and interpret, in particular, that the stringy BH always has a larger shadow, for the same physical parameters and observation conditions

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Can different black holes cast the same shadow?

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We consider the following question: may two different black holes (BHs) cast exactly the same shadow? In spherical symmetry, we show the necessary and sufficient condition for a static BH to be shadow-degenerate with Schwarzschild is that the dominant photonsphere of both has the same impact parameter, when corrected for the (potentially) different redshift of comparable observers in the different spacetimes. Such shadow-degenerate geometries are classified into two classes. The first shadow-equivalent class contains metrics whose constant (areal) radius hypersurfaces are isometric to those of the Schwarzschild geometry, which is illustrated by the Simpson and Visser (SV) metric. The second shadow-degenerate class contains spacetimes with different redshift profiles and an explicit family of metrics within this class is presented. In the stationary, axi-symmetric case, we determine a sufficient condition for the metric to be shadow degenerate with Kerr for far-away observers. Again we provide two classes of examples. The first class contains metrics whose constant (Boyer-Lindquist-like) radius hypersurfaces are isometric to those of the Kerr geometry, which is illustrated by a rotating generalization of the SV metric, obtained by a modified Newman-Janis algorithm. The second class of examples pertains BHs that fail to have the standard north-south Z2 symmetry, but nonetheless remain shadow degenerate with Kerr. The latter provides a sharp illustration that the shadow is not a probe of the horizon geometry. These examples illustrate that nonisometric BH spacetimes can cast the same shadow, albeit the lensing is generically different.

Gravitational Lensing and Shadows / 915

Photon regions and umbilic conditions in stationary axisymmetric spacetimes

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A photon region in the black holes gravitational field is defined as a compact region where photons can travel endlessly without going to infinity or disappearing at the event horizon. In the Schwarzschild metric, the photon region degenerates to the photon sphere which is a three-dimensional umbilic hypersurface in spacetime (its second quadratic form is proportional to the induced metric). In the Kerr metric, the spherical photon orbits with constant Boyer-Lindquist coordinate r also exist and filling some spheres. However, these spheres do not correspond to umbilic hypersurfaces and underlying geometric structure was not fully identified so far. We suggest a new geometric description of the photon region in generic stationary axisymmetric spacetimes, showing that the photon region can be foliated by partially umbilic hypersurfaces, such that the umbilic condition holds for classes of null orbits defined by the foliation parameter 1. The new formalism provides novel methods of description of photon regions and shadows in stationary axisymmetric spacetimes with non-separable geodesic equations.

1 Kobialko, K.V., Gal'tsov, D.V. Photon regions and umbilic conditions in stationary axisymmetric spacetimes. Eur. Phys. J. C 80, 527 (2020).

GRB 170817A and Binary Models

GRB 170817A and Binary Models / 822

Search of local analogs of GRB 170817 with Swift

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A local population of faint short gamma-ray bursts (GRBs) with late afterglow onset and bright optical kilonova was revealed by the discovery of the first binary neutron star merger GW170817/GRB170817A. In our work we investigate whether similar nearby (<200 Mpc) events were observed by NASA's Neil Gehrels Swift observatory. We selected all the events not associated to any X-ray or optical counterpart, finding 4 cases possibly associated with galaxies at distance <200 Mpc. Although affected by low statistics, this number is higher than the one expected for chance alignments to random galaxies, and possibly suggests a physical association between these bursts and nearby galaxies. We discuss the nature of these objects, and use them to constrain the rate of local SGRBs. By comparing our inferred rates with the most recent results from the Advanced LIGO and Virgo O3 run we derive information about the outflow collimation and its structure.

GRB 170817A and Binary Models / 699

A new source of X-rays in GW170817 3.4 years after the merger

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GW170817 was detected 3.4 years ago as the first object to have both a gravitational wave and an EM counterpart. It provided the first confirmation of the connection between short gamma-ray bursts and binary neutron star mergers. For almost 3 years, the broadband EM observations of GW170817 from radio to X-rays showed a very well-behaved simple power-law spectrum, with no spectral evolution. The non-thermal emission across multiple wavelengths was best explained by a model

with a structured jet viewed off-axis. However, observations after 3.4 years narrate a story different from expectations. We have observed a statistically significant excess in X-rays compared to the predictions from a structured jet model at the current epoch, which was not accompanied by an excess in radio. We investigate several theoretical models that could lead to such an excess in X-rays only, including a plausible emergence of a kilonova afterglow, which if true, would make it the first-ever to be observed. We finally discuss the implications of these observations on the nature of the merger remnant.

GRB 170817A and Binary Models / 604

Kilonova emission observed so far: a comparison with AT2017gfo

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AT2017gfo is the first kilonova (KN) that could be extensively monitored in time both photometrically and spectroscopically. Moreover, it is the first optical counterpart of a gravitational wave source and it is associated with the short gamma-ray burst GRB 170817A. Here I present our search for the fingerprints of AT2017gfo-like kilonova emissions in the optical/NIR light curves of 39 short GRBs with known redshift. Afterwards, I show how, for the first time, our results allow us to study separately the range of luminosity of the blue and red components of AT2017gfo-like kilonovae in short GRBs. With these results at hand, I show up to which redshift a KN can be followed up by some of the current and future observatories.

GRB 170817A and Binary Models / 889

The robustness of the association of GW170817 and GRB 170817A

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The joint observation of GW170817 and GRB 170817A has provided the long sought for conclusive evidence for the connection between binary neutron star mergers and short-hard gamma-ray bursts. Following an overview of the observation of GW170817 by the LIGO-Virgo Collaboration, and of the observations of GRB 170817A by Fermi-GBM and INTEGRAL SPI-ACS, this talk reviews the unambiguous association of GW170817 and GRB 170817A both within a Frequentist approach and a Bayesian approach.

GRB 170817A and Binary Models / 478

Extragalactic Fast X-ray Transient Candidates Discovered by Chandra

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Fast X-ray Transients (FXRTs) are as-yet unexplained phenomena. They are energetic X-ray flares that last a few tens to a few thousand seconds. Over the past few years, $\sim$30 extragalactic FXRTs have been discovered in Chandra, XMM-Newton, Swift/XRT and eROSITA data. Numerous proposed explanations include a tidal disruption (TDE) of a white dwarf (WD) by an intermediate-mass black hole (IMBH), a supernova shock breakout (SBO), and a binary neutron star merger (BNS). So far, FXRTs lack multiwavelength counterparts, and hence we rely on their host properties to understand their nature. In this talk, I will present a new population of FXRTs serendipitous discovered from Chandra archival data (observation from the Chandra Data Release 2). This new sample of 14 FXRTs might have a mix of origins. We identify a sub-sample of FXRTs that show similar timing and spectral properties to CDF-S XT2 (a FXRT previously identified in the Chandra Deep Field South), and volumetric rate density, which suggest an association with BNSs. The improve in the detection of FXRTs by the current and future X-ray missions will open new opportunities to study and understand exotic astrophysics phenomena associated with FXRTs.

GRB 170817A and Binary Models / 623

Numerical relativity modeling of ejecta and kilonovae from binary neutron star mergers

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This talk will report on recent progresses in the simulations of binary neutron star mergers in numerical general relativity with focus on the modeling of merger remnants and electromagnetic counterparts. Applications to the observations of GW170817 and AT2017gfo will be discussed.

GRB 170817A and Binary Models / 1029

Kilonova AT2017gfo: which evidence of heavy r-process elements?

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The spectra of the optical/near-IR counterpart of the GW2017 binary neutron star merger show broad absorption features overimposed onto the continuum, that were interpreted as due to heavy elements formed through r-process nucleosynthesis. However, it is very arduous to identify individually the atomic species, owing essentially to the enormous amount of atomic transitions and to substantial line blending. I will review our present understanding of the available spectroscopic information.

High and Very High Energy Emission from Gamma-Ray Bursts

High and Very High Energy Emission from Gamma-Ray Bursts / 754

The H.E.S.S. gamma-ray burst program

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In the last few years, gamma-ray bursts (GRBs) have been detected at Very High Energy (>100 GeV) gamma rays for the first time since their initial discovery half a century ago. This breakthrough occurred thanks to years of technical and strategic improvements (as well as a bit of good luck). In this talk, I will give an overview of the H.E.S.S. GRB program — how H.E.S.S. follows up GRBs, how this has evolved, where we are pushing further — and discuss some of the latest highlights.

High and Very High Energy Emission from Gamma-Ray Bursts / 796

Prospects for VHE monitoring of Gamma-ray Bursts with SWGO

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It has been established that Gamma-Ray Bursts (GRB) can produce Very High Energy radiation ($E >$ 100 GeV), opening a new window through which to investigate particle acceleration and radiation properties in the most energetic domain. We expect that next-generation instruments, such as the Cherenkov Telescope Array (CTA), will mark a huge improvement in their observation. However, constraints on the target visibility and the limited duty cycle of Imaging Atmospheric Cherenkov Telescopes (IACT), affect their ability to react promptly to transient events and to characterize them as a population. Here we use a grid of instrument performance estimates, based on the Extensive Air Shower (EAS) array concept proposed by the Southern Wide Field-of-view Gamma-ray Observatory (SWGO) collaboration, to evaluate SWGO's potential to detect and track VHE emission from GRBs. Observations by the *Fermi* Large Area Telescope (*Fermi*-LAT) at high energy (E > 10 GeV), identified some events with a distinct spectral component, which can represent a substantial fraction of the emitted energy and even arise in early stages of the process. Using models based on these properties, we estimate the possibilities that a wide field of view and large effective area ground-based monitoring facility has to probe VHE emission from GRBs. We show that the ability to monitor VHE transients with a nearly continuous scanning of the sky grants us the opportunity to simultaneously observe electromagnetic counterparts to gravitational waves and relativistic particles sources up to cosmological scales, in a way that is not available to IACTs.

High and Very High Energy Emission from Gamma-Ray Bursts / 714

Observations of GRB 190829A at VHE with H.E.S.S.

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Major advancements in the study of gamma-ray bursts (GRBs) have arisen in the last few years thanks to the recent detections at very high energy (VHE). In this contribution, the observation of GRB 190829A at VHEs with H.E.S.S. is presented. This GRB is one of the closest-ever detected with a redshift z~0.08, a characteristic that allowed an extended temporal detection from 4 hours to 56 hours after the GRB onset over a broad energy range of 0.18 to 3.3 TeV. This proximity opened the possibility to accurately measure the intrinsic spectra, provided a relatively small absorption of photons through their travel to Earth. The H.E.S.S. detection of the afterglow shows similar temporal and spectral characteristics when compared to the observations in the X-ray band with Swift-XRT. We will discuss how these characteristics challenge the standard framework for VHE afterglows in GRBs.

High and Very High Energy Emission from Gamma-Ray Bursts / 480

GeV-GRB-SN: compare and contrast

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There is a small sample of long-duration gamma-ray bursts built on the intersection of two types of events: bursts associated with supernovae (GRB-SN) and bursts emitting high-energy photons (GeV-GRB). Being only few cases these GeV-GRB-SN can nevertheless shed some light on the emission mechanisms spanning the whole electromagnetic spectrum. We systematize the known events and analyze the new candidates. Then we discuss the results in light of current knowledge on high-energy emission from long-duration gamma-ray bursts.

High and Very High Energy Emission from Gamma-Ray Bursts / 1068

Prompt gamma-ray burst emission as a source of GeV/TeV photons

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The Fermi LAT spectra of many bright gamma-ray bursts have a power law component that extends to several GeV. This power law component is distinct from the Band function present at lower energies (< 10 MeV), and it suggests the importance of inverse Compton scatterings at high energies.
With the advent of GRB observations at very high energies by Imaging Atmospheric Cherenkov Telescopes (IACTs) such as Magic (GRB 190114C) and High Energy Stereoscopic System (H.E.S.S.; GRB 180720B and GRB 190829A), a new window has opened up for investigatingradiation models for GRBs.
In this talk, I will provide an overview of theoretical models where the prompt GRB emission is a source of GeV/TeV photons, and examine the possible constraints on models that future observations could provide. For the most discussed model for prompt GRB emission -internal shock model- I will also present the simulated spectra and light curves extending to very high energies.

High and Very High Energy Emission from Gamma-Ray Bursts / 240

Synchrotron and Synchrotron-Self-Compton emission components in GRBs detected at Very High Energies

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Gamma-Ray Bursts (GRBs) are energetic transients originating in a violent explosion of a massive star or merger of two compact objects. These explosions create relativistic blastwave whose expansion leads to external shocks. The emission thus produced is the afterglow observed in
GRBs after the prompt emission. The properties of the emitting region i.e. non-thermal
particle spectrum, magnetic amplification, and microphysical parameters, etc can be probed by monitoring and modelling the afterglow radiation. The recent detection of very high energy (VHE) gamma rays (> 100 GeV) from GRBs has opened a possibility to test theoretical models such as the synchrotron self-Compton (SSC) in GRBs till late times in the afterglow phase. In this work, we study few bright GRBs (Fermi-LAT detected GRB 130427A, MAGIC detected GRB 190114C and HESS detected GRB 180720B) using Synchrotron-Self-Compton model.

I will also discuss how early optical afterglows
and gamma ray giant flares can be useful to reveal the magnetic and baryonic nature of the jet composition in GRBs.

High and Very High Energy Emission from Gamma-Ray Bursts / 1006

High-Energy Emission from GRBs: Theoretical Perspectives

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This talk will provide an overview of our current knowledge and understanding of high energy (~0.1-100 GeV) emission from GRBs. Potentially relevant emission mechanisms will be discussed along with what we have learned from existing observations, most notably by Fermi, which has greatly contributed to our knowledge of GRB physics as well as in other areas. Fermi high-energy prompt GRB observations have shed light on its spectral and temporal properties (delayed and long-lived high-energy emission, distinct high-energy hard power-law spectral component, a possible quasi-thermal component), which bear on its emission mechanism. They have also provided valuable information on the outflow composition as well as on the Lorentz factor, location, and geometry of the emission region. GRB high-energy afterglow observations have probed the physics of relativistic collisionless shocks, and require changes to the standard picture. High-energy prompt GRB observations have also helped study fundamental physics, and in particular Lorentz Invariance Violation, as well as the Extra-galactic Background Light.

High and Very High Energy Emission from Gamma-Ray Bursts / 945

Very-high-energy gamma-ray follow-up observations of gravitational waves

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The precedented multi-messenger campaign launch by the gravitational wave (GW) signal GW170817 and the quasi-simultaneous gamma-ray burst GRB170817A, enabled the study of the various transient counterparts, over different energy bands and timescales, and confirmed for the first time, the hypothesis that binary neutron starts are the progenitor of at least a sub-sample of short GRBs, among many other implications. In this contribution, the different instruments currently observing the very-high-energy (VHE) gamma-ray sky and the main challenges these instruments face when performing GW follow-up observation will be described. An overview of the strategies and searches for VHE emission associated to GW follow-up observations by current gamma-ray experiments during LIGO-Virgo observing runs O1 to O3 will be presented. Finally, we will go through the implications and lessons learned from these observations and we will outline the prospects for the future generation of VHE gamma-ray instruments during the next LIGO-Virgo-KAGRA observing runs.

High and Very High Energy Emission from Gamma-Ray Bursts / 728

MAGIC view of gamma-ray bursts at very high energies

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The detection of gamma-ray bursts (GRBs) is one of the main scientific targets pursued by the MAGIC collaboration since almost 20 years. The MAGIC telescopes were specifically designed for this purpose: the main figures of merit are the fast slewing speed (7deg/s), the low energy threshold (~50 GeV at zenith) and the high sensitivity in the low energy regime. These features make MAGIC one of the most suitable instrument for the follow-up and detection of GRBs. After more than 15 years of dedicated searches, finally the first detection at teraelectronvolt energies of a GRB, namely GRB 190114C, was achieved by the MAGIC collaboration, revealing a new emission component in the afterglow phase. This discovery opened up a new era in field of GRB studies, which is now witnessing other detections, as demonstrated with the case of GRB 201216C. Furthermore, a hint of detection by MAGIC from the short and nearby GRB 160821B gives precious hints on the possible very high energy emission from this class of bursts, also in relation to searches of gravitation wave counterparts. Therefore, MAGIC is giving a crucial contribution to GRB physics, leading to a better understanding of the mechanisms underlying these peculiar objects. In this contribution I will introduce the MAGIC follow-up program, focusing on the aspects which led to the successfull detection of GRBs and highlighting some key results. Finally, I will present the future challenges in these observations, discussing how MAGIC can contribute even more to the field.

High and Very High Energy Emission from Gamma-Ray Bursts / 954

Searching for Gamma-Ray Bursts with the High-Altitude Water Cherenkov (HAWC) Observatory

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Satellites and imaging atmospheric Cherenkov telescopes (IACTs) have shown that gamma-ray bursts (GRBs) are capable of producing very-high-energy photons— most notably GRB 190114C, observed up to 1 TeV by the MAGIC telescopes approximately one minute after triggering the Fermi GBM and Swift BAT satellites. Particularly suited to such searches and follow-up studies is the High-Altitude Water Cherenkov (HAWC) Observatory, which monitors 1/6th of the sky at any one time, complementing the pointed observations of TeV telescopes. It covers 2/3 of the sky every day, with near continuous uptime. The HAWC GRB program comprises two dedicated analyses: a self-triggered all-sky search and a rapid response follow-up of GRBs reported by satellites. Both methods are performed in real time at the HAWC site and additionally repeated on archival data with improved calibration and reconstruction algorithms. Recent upgrades have HAWC poised for detection of the highest-energy gamma rays associated with GRBs, which are key to developing GRB emission models as well as constraining possible beyond-the-Standard-Model physics.

High and Very High Energy Emission from Gamma-Ray Bursts / 948

AGILE and GRBs: 13 years of observations

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After more than 14 years activity, the AGILE satellite continues its exploration of the high-energy sky, investigating galactic and extragalactic sources in the hard X- and gamma-ray energy range. Among its scientific targets, Gamma-Ray Bursts (GRBs) represent one of the most interesting topics. In particular, the AGILE minicalorimeter (MCAL; 0.4-100 MeV) offers the opportunity to detect GRBs in the poorly investigated MeV - tens of MeV energy range, providing insights on the high-energy

component of these events. Moreover, the coded mask X-ray SuperAGILE (18-60 keV), when available due to telemetry constraints, allows to compare the source emission in X-rays. A good coverage with the AGILE Scientific Ratemeters of the SuperAGILE, Anti-Coincidence, and MCAL detectors is available almost continuously, providing further GRB data over a wide energy range. The AGILE MCAL GRB sample is mostly constituted by short-duration, hard-spectrum bursts, as expected from a detector operating in the 0.4-100 MeV energy range, optimized for the detection of short-duration events, and offers a set of bursts with high-energy features, providing interesting data in the tens of MeV regime.

High and Very High Energy Emission from Gamma-Ray Bursts / 920

Probing GRB physics through high-energy observations with Fermi

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The Fermi Gamma-ray Space Telescope has provided unique insights into the Universe's biggest explosions over the past 13 years. With thousands of gamma-ray bursts (GRBs) detected by the Gamma-ray Burst Monitor (GBM) and hundreds by the Large Area Telescope (LAT), we have studied the properties of the populations of these events and obtained unique insights into their emission mechanisms, environment, and physical properties.
In this talk, I'll review highlights of GRB science from the Fermi mission at low (keV) and high (GeV) energy. I will also put them in context of the most recent discoveries of very-high (TeV) energy emission from a few bright GRBs (e.g. GRB 180720B, GRB 190114C) observed by the Cherenkov Telescopes of the H.E.S.S. and MAGIC experiments, respectively.

High and Very High Energy Emission from Gamma-Ray Bursts / 957

The LHAASO GRB program

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Observation of high energy and very high emission from Gamma Ray Bursts (GRBs) is crucial to study the gigantic explosion and the underline processes. With a large field-of-view and almost full duty cycle, the Water Cherenkov Detector Array (WCDA), a sub-array of the Large High Altitude Air Shower Observatory (LHAASO), is appropriate to monitor the very high energy emission from unpredictable transients such as GRBs. Nevertheless, the main issue for an extensive air shower array is the high energy threshold which limits the horizon of the detector. To address this issue a new trigger method is developed in this article to lower the energy threshold of WCDA for GRB observation. The proposed method significantly improves the detection efficiency of WCDA for gamma-rays around the GRB direction at 10-300 GeV. The sensitivity of the WCDA for GRB detection with the new trigger method is estimated. The achieved sensitivity of the quarter WCDA array above 10 GeV is comparable with that of Fermi-LAT.The GRB sample data collected from WCDA's 1/4 array between June 2019 and December 2019 were selected and analyzed. There is not significant excess from ten selected GRB samples within 2.5 hours before and after the outbreak. According to the assumed energy spectrum and the red shift, we give the upper limit of the integrated current intensity of these GRBs during the T_{90} time.

High and Very High Energy Emission from Gamma-Ray Bursts / 616

The VERITAS Gamma-Ray Burst Follow-up Program

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Recent detections of gamma-ray bursts (GRBs) at energies above 100 GeV demonstrate that imaging atmospheric Cherenkov telescopes (IACT) operating in the very high energy range (VHE; E > 100 GeV) can provide insight into the physics of GRBs. By searching for the highest-energy photons emitted by GRBs, these telescopes can help answer questions about the particle acceleration and emission processes that occur during both the prompt and afterglow phases of GRBs. VERITAS is a very-high-energy IACT array located at the Whipple Observatory in southern Arizona, which has maintained an active GRB observing program since mid-2006. In this presentation, we will share some of the recent achievements of the VERITAS GRB follow-up program. We will discuss the development of analysis methods tailored to transient signals, and how the upper limits on the VHE emission obtained from observations of prominent bursts by VERITAS allowed us to constrain radiation mechanisms in the afterglow (e.g., for GRB 130427A) and constrain properties of the environment in which the burst took place (e.g., for GRB 150323A). Compact binary mergers that trigger short GRBs may also result in gravitational wave emission, so we will review both our follow up program from LIGO/Virgo triggers, and also the use of archival VERITAS data to search for short GRBs based on sub-threshold events from LIGO/Virgo. Lastly, based on the properties of the VHE-detected GRBs, we will discuss recent changes to our follow-up strategy to account for the Swift/XRT properties for optimal VERITAS observing sensitivity.

High and Very High Energy Emission from Gamma-Ray Bursts / 923

The Cherenkov Telescope Array capabilities for GRB follow-up

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Gamma-ray Bursts (GRBs) have always been considered within the highest priority targets for all modern imaging atmospheric Cherenkov telescopes (IACTs). For a long time, the detection of such events in the very-high-energy band (VHE; E>100 GeV) posed a major challenge for IACTs from both the technical and the scientific point of view. On the other hand, it was well proven that the possibility to catch the VHE counterpart from GRBs is crucial for achieving a better comprehension of the physics of these objects. In this framework, the detection of VHE gamma rays from a bunch of events including GRB 180720B, GRB 190114C, GRB 190829A and GRB 201216C, represents a long-awaited result for VHE astrophysics community and a remarkable step forward in our understanding of GRBs dynamics. In the next future, the Cherenkov Telescope Array (CTA) will routinely perform follow-up observations of GRB triggers with a significant improvement in VHE photon statistics

allowing to produce good-quality, time-resolved spectra. The detection prospects for such a type of observations are necessarily still preliminary and dependent on the final array layout as well as the assumptions on the expected GRB population. Within the framework of the CTA Transient working group, a dedicated team is at work to establish the CTA capabilities in GRB science starting from a theoretical-based approach. In this contribution, we will report about the status and prospect of this work.

High and Very High Energy Emission from Gamma-Ray Bursts / 825

Theoretical implications on the very high energy emission from GRB 190114C

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Since their discovery in the late 1960s Gamma-Ray Burst (GRB) emission has been deeply investigated with the help of the huge amount of data collected covering the entire electromagnetic spectrum. This large and broadband dataset was essential to constitute a general picture describing the GRB physics, revealing the most credible underlying physical processes and environmental conditions ongoing at the GRB site. Huge leaps in the comprehension of the GRB physics have been achieved recently, thanks to the detection of the newly energetic component in the Very High Energy (VHE, E> 100 GeV) domain. The possible presence of a TeV spectral window in GRBs was predicted and theorized for several decades, but the first observational proofs of its existence were reached only in 2019 thanks to the discoveries claimed by the MAGIC and H.E.S.S. telescopes. GRB190114C was successfully detected in the TeV band by the MAGIC telescopes starting from around one minute after its trigger time and lasting for nearly 40 minutes. A successful follow-up campaign was performed and the multi-wavelength afterglow emission of the event was collected from 1 to about 2×10^{17} GHz. Such very broad dataset allows to perform unique studies on the radiation mechanisms and on the physical properties of such event. In this contribution I will describe the main results and the theoretical interpretations that have been derived from the multi-wavelength dataset of GRB190114C. In particular, the description of the TeV component detected by the MAGIC telescopes as produced via the Synchrotron Self-Compton (SSC) mechanism and its connection with the emission at lower energy bands will be presented. Such studies are a fundamental starting point for the interpretation of the current and upcoming events that will be observed in the VHE domain.

History of Relativity, Gravitation and Cosmology

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On Einstein´s last bid to keep a stationary cosmology

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It is commonly known that the Steady-state model was proposed and championed in a series of Influential papers around mid-twenty century by Fred Hoyle, Hermann Bondi and Thomas Gold. In contrast it is little known that, many years before, Albert Einstein briefly explored the same idea, that is of a dynamic steady state universe. Einstein tried to develop a model where the universe expanded and where matter was supposed to be continuously created. This latter process was proposed by him to keep the matter density of the Universe constant. However, Einstein shortly abandoned the idea. The whole event has already been pointed out by Cormac O'Raifeartaigh et al. in 2014 and almost simultaneously by al Harry Nussbaumer.
It is the purpose of this brief note to point out who might have prompted Einstein to consider a continuous creation of matter and the prevailing circumstances at that time that drove Einstein´s intent.

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Jayme Tiomno: Relativity, Gravity, Cosmology, and the Marcel Grossmann Meetings

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Jayme Tiomno belonged to the 'founders generation' of physicists in Brazil. He began working in relativity theory early in his career, at a time when it was not at all 'fashion-able', through the influence of his early mentor, Mario Schenberg in São Paulo. When he went to graduate school in Princeton, early in 1948, his advisor there, John Wheeler, gave him a project in General Relativity, even though this was more than 4 years before Wheeler's 'turn' from nuclear and particle physics to field theory and gravitation. Tiomno and Wheeler however soon discovered their mutual interest in meson decays, and Tiomno's Masters and PhD theses were on topics from particle physics, which remained his major field of interest for the following 20 years, when he collaborated among others with Abdus Salam. Only when he returned to Princeton in 1971, a refugee from the oppressive

dictatorship in Brazil, did he again begin working in gravitation and field theory, having missed the 'golden age' initiated in part by Wheeler's group. At the IAS, Tiomno experienced a renaissance of his interest in field theory, working with Remo Ruffini, among others. He continued this work in the 1980's after he was able to return to the CBPF in Rio de Janeiro (which he had helped to found). His participation in the Marcel Grossmann Meetings was limited but significant.

History of Relativity, Gravitation and Cosmology / 818

The Penrose 1965 singularity theorem in historical context of the Black Hole paradigm

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The first mention of a (Newtonian) BH dates back to 1783, when Michell presented a model of a massive "Dark Star", trapping light particles on its surface. The Schwarzschild solution from 1916 entailed two singularities – at the origin and at the Schwarzschild radius; their interpretation has been subject of an intense debate over the 20s-30s. Einstein argued that particle orbits lower than the innermost stable orbit are physically impossible. Moreover, he conceived the central singularity to arise as artifact of idealization in modeling stellar matter by the incompressible fluid ansatz. Eddington argued that quantum properties of matter will, at any scale, exert large enough pressure to impede gravitational implosion. He dismissed Chandrasekhar's rigorous calculations of an upper mass limit for a degenerate matter White Dwarf that sustains a Tolmann-Oppenheimer-Volkoff hydrostatic equilibrium. In 1939 Oppenheimer & Snyder found an evolved solution to the field equations that predicted gravitational collapse of stellar matter, forming a central singularity characterized by geodesic incompleteness and curvature divergence. Finkelstein in 1954 showed that the definition of an event horizon applies to the Schwarzschild radius, his calculation also allowed to introduce a set of coordinates for which the curvature at the Schwarzschild radius is finite. In the early 60s, Khalatnikov and Lifshitz argued that the central singularity is an idealization artifact arising from the spherical symmetry assumption, and that it does not arise under realistic conditions. Penrose's theorem from 1965 showed that the formation of geodesic incompleteness singularities is a generic prediction of General Relativity theory, under the premises that a trapped surface gets formed, the positive energy condition is always respected, and time-like geodesics do not close. The impact of the theorem with regard to the realism-antirealism-debate over the status of spacetime singularities will be discussed, and an outlook given on the cosmic censorship hypothesis.

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The October 10, 1912 solar eclipse expeditions and the first attempt to measure light-bending by the Sun

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In 1911 Einstein proposed that light-bending by the Sun's gravitational field could be measured during a total solar eclipse. The first opportunity in which this measurement would be tried, was during the total solar eclipse of October 10, 1912. We report about the expeditions sent to Brazil to observe this eclipse, including the one from the Córdoba Observatory, from Argentina, which aimed to measure this Einstein's effect.

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Towards detecting gravitational waves: a contribution by Richard Feynman

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We give an account of Richard Feynman's involvement with gravitational waves, which can be traced back to 1957, when he attended the famous Chapel Hill conference on the Role of Gravitation in Physics 1. Feynman's contribution was further developed in a subsequent letter to Victor Weisskopf 2, completed in February 1961, as well as in his Caltech Lectures on Gravitation 3, delivered in 1962-63. The focus is on the celebrated sticky bead argument, which Feynman devised in order to argue that gravitational waves must carry energy, if they exist at all. Further details on the calculation of the power radiated as gravitational radiation in the quadrupole approximation (which is the first non-vanishing term in the presence of a tensor source term) are given in the Weisskopf letter, where both classical and quantum field theoretical tools are used, ending with the relevant quadrupole formula and its application to gravitational radiation by a binary system. While giving a simple argument in favor of the existence of gravitational waves, Feynman's thought experiment paved the way for their detection and stimulated subsequent efforts by J. Weber (who also attended the 1957 Chapel Hill conference) in building a practical detecting device [4].

1 C. DeWitt-Morette and D. Rickles, The Role of Gravitation in Physics, Report from the 1957 Chapel Hill Conference, Edition Open Access (2011).
2 R. P. Feynman, Unpublished letter to Victor F. Weisskopf, February 1961; in Box 3, File 8 of the Papers of Richard P. Feynman, the Archives, California Institute of Technology.
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[4] J. Weber, Phys. Rev. Lett. 17 (1966) 1228.

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A look inside Feynman's route to gravitation

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In this contribution we report about Feynman's route to gravitation 1, which can be traced back to the Chapel Hill Conference of 1957 2. As well known, Feynman was concerned about the relation of gravitation with the rest of physics. Probably for this reason, he promoted an unusual, field theoretical approach to general relativity, in which, after the recognition that the graviton must be a massless spin-2 field, Einstein's field equations should follow from the general properties of Lorentz invariant quantum field theory for such a field. Quantization would then be implemented by considering loop diagrams. These ideas were further developed by Feynman in his famous lectures on gravitation, delivered at Caltech in 1962-63 3, and in a handful of published papers, where he also introduced some field theoretical tools which were soon found to be of general interest, such as ghosts and the tree theorem. The approach was later taken on by people such as Weinberg and Deser [4].

Some original pieces of Feynman's work on gravity are also present in a set of unpublished lectures delivered at Hughes Aircraft Company in 1966-67 and devoted primarily to astrophysics and cosmology [5].
Finally, some comments are made concerning the relation of Feynman's approach to gravity and his ideas on the quantum foundations of the fundamental interactions.

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2 C. DeWitt-Morette, D. Rickles, The Role of Gravitation in Physics, Report from the 1957 Chapel Hill Conference. Edition Open Access (2011).
3 R. P. Feynman, F. B. Morinigo, W. G. Wagner, The Feynman Lectures on Gravitation, Addison-Wesley (1995).
[4] S. Weinberg, Phys. Rev. 138, B988 (1965); S. Deser, D. G. Boulware, Ann. Phys, 89, 193 (1975).
[5] R.P. Feynman. Lectures on Astronomy, Astrophysics, and Cosmology. http://www.thehugheslectures.info/wp-content/uploads/lectures/FeynmanHughesLectures_Vol1.pdf (1966-7).

History of Relativity, Gravitation and Cosmology / 824

The Hamilton-Jacobi analysis by Peter Bergmann and Arthur Komar of classical general relativity

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Peter Bergmann initiated in 1966 an application of Hamilton-Jacobi techniques to general relativity. Little had been done by this time on extending this analysis to gauge theories. He proved that when, as in the case of Einstein's theory, the phase space generator of evolution consisted of a linear combination of constraints, the Hamilton principal function must be independent of spacetime coordinates. Also the Hamilton Jacobi equations that determined this functional of the 3-metric retained their form under phase space functionals that were invariant under the action of the spacetime diffeomorphism group. Komar followed up beginning in 1967 with a series of paper in which he proved that a complete solution of the Hamilton Jacobi equations was determined by a commuting set of diffeomorphism invariants. These invariants thereby labeled equivalence classes of solutions of Einstein's equations under the action of the full four-dimensional diffeomorphism group. Furthermore, this set satisfied canonical commutation relations with another invariant set. The hope and expectation was that these invariants could be promoted to quantum operators in a quantum theory of gravity. This framework will be contrasted with J. A. Wheeler's geometrodynamical program in which the only underlying covariance group is spatial diffeomorphisms. The full spacetime diffeomorphism symmetry is replaced by the notion of 'multi-fingered' time. A related dispute concerning the 'sandwich conjecture' will be discussed, relevant to the functional integral approach to quantum gravity. Two three geometries cannot determine a corresponding four geometry if they lie in distinct four dimensional diffeomorphism equivalence classes.

Hořava–Lifshitz Gravity

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Boundary conditions for the Klein-Gordon field on Lifshitz Spacetimes

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Boundary conditions have physical consequences. On Lifshitz spacetimes, the Klein-Gordon equation gives rise to an initial-boundary value problem. This means that for a given suitable initial data, corresponding solutions might not exist. If they exist, then each boundary condition selects a different solution, thus yielding inequivalent dynamics. In this talk I will show that there is a plethora of physically-sensible boundary conditions that generalize Dirichlet quantization. Specifically, I will consider a free, scalar, massive quantum field theory on a four-dimensional Lifshitz spacetime with critical exponent $z = 2$ and I will show that there are two-point functions for ground and thermal states, of local Hadamard form and satisfying the canonical commutation relations, compatible with Robin boundary conditions and with mode-dependent boundary conditions, depending on the value of the effective mass. Each of these generalized boundary conditions determine an inequivalent dynamics, but they are all equivalently physically-sensible—only an experiment could single one out. The results I will present are part of a joint work with C. Dappiaggi and D. Sina, arXiv:hep-th/2103.15391.

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Quark stars with isotropic matter in Hořava gravity and Einstein-æther theory

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We study non-rotating and isotropic strange quark stars in Lorentz-violating theories of gravity, and in particular in Hořava gravity and Einstein-æther theory. For quark matter we adopt both linear and non-linear equations-of-state, corresponding to the MIT bag model and color flavor locked state, respectively. The new structure equations describing hydrostatic equilibrium generalize the usual Tolman-Oppenheimer-Volkoff (TOV) equations of Einstein's General Relativity. A dimensionless parameter ν measures the deviation from the standard TOV equations, which are recovered in the limit $\nu \to 0$. We compute the mass, the radius as well as the compactness of the stars, and we show graphically the impact of the parameter ν on the mass-to-radius profiles for different equations of state describing quark matter. The energy conditions and stability criteria are also considered, and they are all found to be fulfilled.

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Dynamical system analysis of Bianchi-I spacetimes in $f(R)$ gravity

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We investigate a autonomous system analysis in terms of new expansion-normalized variables for homogeneous and anisotropic Bianchi-I spacetimes in $f(R)$ gravity in the presence of anisotropic matter. It is demonstrated that with a suitable choice of the evolution parameter, the Einstein's equations are reduced to an autonomous 5-dimensional system of ordinary differential equations for the new variables. Furthermore, for a large class of functions $f(R)$, which includes several cases commonly considered in the literature, all the fixed points are polynomial roots, and thus they can be determined with good accuracy and classified for stability. In addition, typically for these cases, any fixed point corresponding to isotropic solutions in the presence of anisotropic matter will be unstable. The assumption of a perfect fluid as source and or the vacuum cases imply some dimensional reductions and even more simplifications. In particular, it is found that the vacuum solutions of $f(R) = R^{\delta+1} with$\delta$ a constant are governed by an effective bi-dimensional phase space which can be constructed analytically, leading to an exactly soluble dynamics. It is also shown that several results already reported in the literature can be re-obtained in a more direct and easy way by exploring our dynamical formulation.

Reference: S. Chakraborty, K. Bamba and A. Saa, Phys. Rev. D 99, 064048 (2019).

Hořava–Lifshitz Gravity / 676

The BFV quantization of the nonprojectable 2+1 Horava theory and the measure of the second-class constraints

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The nonprojectable version of the Horava theory has a dynamics closer to general relativity than the projectable case, since it possesses the so-called Hamiltonian constraint. But the nonprojectable version is a field theory with second-class constraints, the Hamiltonian constraint being one of them. This feature poses challenges in understanding its quantization. The main unanswered question is to proof its renormalization. Due to the second-class constraints, adopting the Hamiltonian formalism seems appropriate. We present the quantization of the 2+1 dimensional nonprojectable theory in the BFV Hamiltonian scheme, considering explicitly all the terms in the potential up to the z=2 order required for power-counting renormalization. The BFV scheme allows to impose noncanonical gauge conditions, as the one used in the proof of renormalization of the projectable case. This scheme is compatible with the second-class constraints and exhibits a BRST symmetry. The effect of the measure associated to the second-class constraints on the propagators is studied. We obtain that the auxiliary fields associated to the second-class constraints get nonregular propagators.

1 J. Bellorin and B. Droguett, BFV quantization of the nonprojectable (2+1)-dimensional Horava theory, Phys. Rev. D 103 (2021) no.6, 064039 doi:10.1103/PhysRevD.103.064039 [arXiv:2102.04595 [hep-th]].

2 J. Bellorin and B. Droguett, Quantization of the nonprojectable 2+1D Horava theory: The second-class constraints, Phys. Rev. D 101 (2020) no.8, 084061 doi:10.1103/PhysRevD.101.084061 [arXiv:1912.06749 [hep-th]].

Hořava–Lifshitz Gravity / 292

Shadows of Kerr-like black holes in $4D$ Einstein–Gauss–Bonnet gravity and constraints from EHT observations

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Recently there has been a surge of interest in regularizing a $D \rightarrow 4$ limit of, the Einstein-Gauss-Bonnet (EGB) gravity, and the resulting regularized $4D$ EGB gravity has nontrivial dynamics. The theory admits spherically symmetric black holes generalizing the Schwarzschild black holes. Furthermore, the $4D$ non-relativistic Horava-Lifshitz theory of gravity also admits the identical black hole solution. We consider the rotating black holes in regularized $4D$ EGB gravity and discuss their horizon properties and shadow cast. The effects of the GB coupling parameter on the shape and size of shadows are investigated and analyzed in recent M87*observations from the EHT.*
We also estimate the parameters associated with $4D$ *EGB gravity Kerr black holes using the shadow observables. The inferred circularity deviation* $\Delta C \leq 0.1$ *for the M87* black hole is satisfied, whereas shadow angular diameter $\theta_d = 42 \pm 3\mu as$, within 1σ region on the GB parameter. Interestingly, the shadow axial ratio obeying $1 < D_x$
$lesssim 4/3$ is in agreement with the EHT results and thus eventuates in the $4D$ EGB gravity black holes being suitable candidates for astrophysical black holes.

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Bifurcations and Chaos in Ho\v{r}ava-Lifshitz Cosmology

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The nature of generic spacelike singularities in general relativity is connected with first principles, notably Lorentzian causal structure, scale invariance and general covariance. To bring a new perspective on how these principles affect generic spacelike singularities, we consider the initial singularity in spatially homogeneous Bianchi type VIII and IX vacuum models in Ho\v{r}ava-Lifshitz gravity, where relativistic first principles are replaced with anisotropic scalings of Lifshitz type. Within this class of models, General Relativity is shown to be a bifurcation where chaos becomes generic. To describe the chaotic features of generic singularities in Ho\v{r}ava-Lifshitz cosmology, we introduce symbolic dynamics within Cantor sets and iterated function systems. See https://arxiv.org/abs/2012.07614

Hořava–Lifshitz Gravity / 749

Horava-Lifshitz and Einstein-Aether Gravity in the light of Event Horizon Telescope Observations of M87

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We investigate Horava-Lifshitz Einstein- Aether gravity in light of the recent Event Horizon Telescope (EHT) observations of the M87. *The shape and size of the observed black hole shadow contains information of the geometry in its vicinity, and thus one can consider it as a potential probe to investigate different gravitational theories, since the involved calculation framework is enriched with different size-rotation features as well as with extra model parameters. We calculate the corresponding photon effective potential, the unstable photon sphere radius, and finally the induced angular size, which combined with the mass and the distance can lead to a single prediction that quantifies the black hole shadow, namely the diameter per unit mass d. Since d M87* is observationally known from the EHT Probe, we extract the corresponding parameter regions in order to obtain consistency. We find that Horava-Lifshitz and Einstein-Æther black hole solutions agree with the shadow size of EHT M87*, if the involved Æther parameters are restricted within specific ranges, along with an upper bound on the dimensionless spin parameter a, which is verified by a full scan of the parameter space within 1 sigma-error.

Hořava–Lifshitz Gravity / 912

Horava–Lifshitz gravity in (3+1) dimensions coupled with anisotropic matter and possible constraints from GRB 170817A

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In this talk, we shall present our recent studies on a (3+1)-dimensional Ho\v{r}ava-Lifshitz gravity coupled with an anisotropic electromagnetic (EM) field. This model is generated by a Kaluza-Klein reduction of a (4+1)-dimensional Ho\v{r}ava-Lifshitz gravity and it exhibits a remarkable feature that the gravitational waves and the electromagnetic waves, in spite of Lorentz invariance violation, have the same velocity. This feature makes it possible to restrict the parameters of the theory from GRB 170817A. In this talk we use this feature to discuss possible constraints on the parameter in this model. We analyze the potential Lorentz invariance violation effect of the GRB 170817A by analyzing potential time delay of gamma-ray photons in this event. It turns out that it places a stringent constraint on this parameter. In the most ideal case, it gives $|1-\sqrt{\beta}| < (10^{-19} - 10^{-18})$.

Hořava–Lifshitz Gravity / 970

Testing Einstein-aether theory by observations of gravitational wave

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Einstein-aether theory is a vector-tensor theory with the vector (aether) field that is always timelike and unity. It is self-consistent (such as free of ghosts and instability), and satisfies all the experimental tests carried out so far. Its Cauchy problem is well posed, and energy is always positive (as far as the hypersurface-orthogonal aether field is concerned). In addition, BHs exist and can be formed from gravitational collapse of realistic matter.

In this talk, we shall present our recent studies of gravitational waves (GWs) produced by massive and compact objects in Einstein-aether theory, including their waveforms, polarizations, response function, its Fourier transform, and energy loss rate through three different channels of radiation, the scalar, vector and tensor modes. Combination of such theoretical predictions with observations of GWs can bring severe
constraints on the theory.

Hořava–Lifshitz Gravity / 667

Wormholes in 2d Horava-Lifshitz quantum gravity

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We quantize the two-dimensional projectable Horava-Lifshitz gravity with a bi-local as well as space-like wormhole interaction. The resulting quantum Hamiltonian coincides with the one obtained through summing over all genus in the string field theory for two-dimensional causal dynamical triangulations. This implies that our wormhole interaction can be interpreted as a splitting or joining interaction of one-dimensional universes or strings. This talk will be based on a collaborative research with Jan Ambjørn, Yoshiyasu Ito and Yuki Hiraga.

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Cosmological Implications of Einstein-Aether Gravity

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We develop the various solutions of Einstein-Aether theory of gravity through reconstruction approach. In order to discuss the current cosmic acceleration corresponding to our reconstructed models, we evaluate different cosmological parameters. Also, we also discuss the consistency of our results of cosmological parameters with current observational data for ensuring the viability of models.

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Finite Action Principle and black holes in Horava-Lifszyc gravity

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It is expected that the quantum gravity should resolve the black-hole singularity problem, according to the finite action principle one may ask which of the microscopic actions remain finite for non-singular black holes and conversely interfere destructively for the singular ones. We also show that the finite action selection principle works for H-L gravity in the context of black holes (the action is finite for non-singular BH and conversely for the singular). Furthermore, we have found that wormholes possess a Finite Action and hence contribute to the path-integral of QG.

Based on: 2102.13556

Hořava–Lifshitz Gravity / 694

Nature of Singularities in Vector-Tensor Theories of Gravity

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The Vector-Tensor theories are a class of alternative theories of gravity that differ from the standard General Relativity (GR) with the presence of a vector field besides the metric. They are studied in attempts to understand spontaneous Lorentz violation, to generate massive gravitons, and as models of dark matter and dark energy. In this talk, I outline how the nature of singularities and horizons in VT theories differ greatly from GR even under ordinary conditions. This is illustrated with Einstein-aether theory where vacuum black hole solutions have naked singularities and vacuum cosmological solutions have new singularities that are otherwise absent in GR. I also summarize the results on other vector-tensor theories where multiple horizons and multiple singularities exist. I end with offering ways to explore these deviations using gravitational waves.

Hořava–Lifshitz Gravity / 681

Testing Horava-Lifshitz Gravity With I-Love-Q

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Relations between the neutron star moment of inertia, tidal Love number and quadrupole moment are known to be insensitive to the nuclear equation of state (the so-called I-Love-Q relations). Such universal relations are powerful for testing general relativity and beyond in the strong-field regime

with neutron star observations. Horava-Lifshitz gravity is one such alternative theory of gravity which has interesting properties such as ultraviolet completion of gravity while also inducing a preferred time direction. This theory is characterized by three coupling constants; two of them have been constrained stringently from existing neutron star observations, such as GW170817, while the remaining parameter is only weakly constrained. We thus studied how the I-Love-Q relations depend on this third parameter. We found that this sole parameter disappears from the field equations in Horava-Lifshitz gravity. Therefore, the I-Love-Q relations are universal against not only the nuclear physics uncertainty but also the gravitational physics uncertainty within Horava-Lifshitz gravity.

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Finite Action Principle and the beginning of the universe in Horava-Lifshitz gravity

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The path integral approach yields a powerful framework in the quantum theory. It emphasizes Lorentz covariance and allows for the description of non-perturbative phenomena. In the path integral, one sums over all possible configurations of a field(s) Φ weighted by $e^{iS[]}$, where S[Φ] is the classical action of the theory.
In the Minkowski path integral, the classical action approaching infinity causes fast oscillations in the exponential weight and hence the destructive interference of the neighboring field configurations. Such configurations do not contribute to the physical quantities. Furthermore, in Wick rotated path integral is weighted by $e^{S[]}$, and the field(s) configurations on which the action is infinite do not contribute at all. This provides theoretical motivation for the Finite Action Principle, saying that an action of the universe should be finite. This principle has a significant impact on the nature of quantum gravity and the cosmological evolution, once the higher-curvature terms are included. In the framework of Horava-Lifshitz gravity, field configurations with finite classical action describe a flat universe with a homogeneous and isotropic beginning without the ghost particles.

Interacting Dark Matter

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Primordial Black Holes

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I will review the present status of massive and clustered PBH that may constitute all of the Dark Matter in the Universe.

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LHC experiments for long-lived particles of the dark sector

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Dark matter scenarios are being tested at the LHC in the general-purpose experiments through *promptly* decaying states. In parallel, new dedicated detectors have been proposed for the LHC to probe dark matter portal theories predicting *long-lived* particles that decay away from the interaction point: MoEDAL-MAPP, MoEDAL-MALL, FASER, CODEX-b, MATHUSLA, AL3X, ANUBIS, milliQan. In addition, the SHiP beam-dump experiment is planned to operate with the SPS beam to extend the discovery reach for such particles. The detector design and expected physics sensitivity of these experiments will be presented with emphasis on scenarios explaining the nature of dark matter.

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Constraining the dark matter self-interaction cross section in low-mass halos with quadruple image strong gravitational lenses

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Collapsed structures, or halos, formed in models with self-interacting dark matter (SIDM) have unique properties that distinguish them from structures formed in cold dark matter (CDM). In particular, momentum and energy exchange inside SIDM halos drives the formation of a central core that may eventually undergo core collapse, such that the halo becomes extremely centrally concentrated. We demonstrate that the flux ratios in quadruply imaged quasar strong lens systems (quads) provide an avenue to statistically constrain the unique features of SIDM in halos with masses below $10^9 M_\odot$, providing a new, purely gravitational probe of SIDM structure on sub-galactic scales. In the low-mass halos probed by lensing, particles move at relative velocities below 30 km/sec, and thus an analysis of quads can provide a new window on the self-interaction cross section below the velocity scales accessible with galaxies or galaxy clusters. To determine how a sample of quads can constrain SIDM models, we implement a structure formation model that predicts the properties of cored and core collapsed halos given an interaction cross section, and show that SIDM structure produces flux ratio perturbations distinct from those arising in CDM. We then forecast, with simulated datasets, that a sample of 30-50 quads, a sample size attainable in the next few years, can place stringent constraints on the amplitude and velocity dependence of the cross section, potentially ruling out certain SIDM models, or falsifying CDM.

Interacting Dark Matter / 70

Dark energy and dark matter unification from dynamical space time: observational constraints and cosmological implications

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A recently proposed Dynamical Space-time Cosmology (DSC) that unifies dark
energy and dark matter is studied. The general action of this scenario includes a Lagrange
multiplier, which is coupled to the energy momentum tensor and a scalar field which is different
from quintessence. First for various types of potentials we implement a critical point analysis
and we find solutions which lead to cosmic acceleration and under certain conditions to stable
late-time attractors. Then the DSC cosmology is confronted with the latest cosmological
data from low-redshift probes, namely measurements of the Hubble parameter and standard
candles (Pantheon SnIa, Quasi-stellar objects). Performing an overall likelihood analysis and
using the appropriate information criteria we find that the explored DSC models are in very
good agreement with the data. We also find that one of the DSC models shows a small but
non-zero deviation from Λ cosmology, nevertheless the confidence level is close to ~ 1.5σ

Interacting Dark Matter / 262

Constraining the interactions in the dark sector with cosmological data

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In this talk I will show up-to-date cosmological constraints on the interactions between dark matter and the component that might be driving the current acceleration of the universe. In particular, I

will explain what is the status of two different theoretical models: (i) coupled quintessence, with a fifth force between dark matter particles, mediated by a scalar field that plays the role of dark energy; and (ii) the Ricci running vacuum models, with an energy exchange between the vacuum and dark matter sectors that is highy suppressed during the radiation-dominated era. In this case, the impact of a late-time activation of the interaction will be also discussed. We have constrained the models with the full Planck 2018 CMB data, together with the Pantheon compilation of supernovae of Type Ia, cosmic chronometers, baryon acoustic oscillations and the large-scale structure information obtained by various teams and galaxy surveys. I will of course also comment on the ability of these models to loosen the H0 and sigma8 tensions. This talk is based on the following two arXiv papers: 2004.00610 and 2102.12758.

Interacting Dark Matter / **32**

Hunting for light dark matter with gas-based detectors

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In this talk, I'll discuss ideas for new approaches in the hunt for light dark matter was gas-based detectors. I'll show that the sensitivity that may be achievable through the process of electron ionisation of gas targets in a Spherical Proportional Counter in very promising, going beyond current exclusion limits. I'll also pay particular attention to the potential benefits of molecular gas targets.

Interacting Dark Matter / **336**

Fornax globular cluster timing problem as a test of dark matter properties

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The Fornax dSph displays a variety of globular cluster at projected radii that seem at odds with the presence of a NFW profile. I will quantify this 'anomaly' (at the level of a 25% tuning) and discuss how different DM models can alleviate it.

Interacting Dark Matter / **118**

Fuzzy Dark Matter

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Fuzzy dark matter (FDM) is a general term for the lightest possible dark matter particle. FDM is distinct from CDM in manifesting wavelike effects on cosmic scales, which lead to a vast array of

methods to probe this model. Across more than 20 orders of magnitude, only two windows windows remain where FDM can constitute the entirety of the dark matter. I will discuss how these windows are arrived at using astrophysical and cosmological observables, including galaxy weak lensing, the dynamics of star clusters, and the properties of black holes. I will further derive precision bounds from the CMB and galaxy clustering that probe sub-dominant FDM populations at the 1% level. Improving these bounds with intensity mapping could test the possible connection between FDM and the grand unified scale. Finally, I will discuss how black hole superradiance caused by FDM can be used to test the topological invariants of string theory compactifications.

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DM halos from the maximum entropy principle and its link to particle physics

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We discuss the problem of formation of dark matter (DM) halos from the principle of maximum (coarse-grained) entropy, when including for the quantum nature of the DM particles. In the case of DM fermions, such a formation mechanism involves for (long-range) particle-particle interactions, and can lead to a most-likely phase-space distribution accounting for the Pauli-principle as well as particle escape effects. We show the full family of DM profiles which can be built out of the above mechanism for self-gravitating fermions, and analyze which solutions are stable, long-lived and of astrophysical interest. We emphasize on a novel kind of 'core − halo' DM profiles, where the compact and dense core of DM can work as an alternative to the supermassive BH scenario, while the extended halo can explain the "flateness" of the rotation curves. Finally, we show the possibility to model such DM fermions within minimial extensions of the SM of particle physics which include for right handed (keV-ish) neutrinos.

Interacting Dark Matter / 451

Interacting dark sector: mapping fields and fluids, and observational signatures

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In this talk, I will discuss a cosmological model with dark energy − dark matter interaction. Demanding that the interaction strength Q_ν in the dark sector must have a field theory description, a unique form of interaction strength can be obtained. I will show the equivalence between the fields and fluids for the $f(R, \chi)$ model where f is an arbitrary, smooth function of R and classical

scalar field χ, which represents dark matter. Up to first order in perturbations, there is a one-to-one mapping between the classical field theory description and the phenomenological fluid description of interacting dark energy and dark matter, which exists only for this unique form of interaction. Different formulations of interacting dark energy models in the literature can be classified into two categories based on the field-theoretic description. Then I will discuss the quantifying tools to distinguish between the interacting and non-interacting dark sector scenarios. I will focus on the variation of the scalar metric perturbed quantities as a function of redshift related to structure formation, weak gravitational lensing, and the integrated Sachs-Wolfe effect and show that the difference in the evolution becomes significant for lower redshifts (z<20), for all length scales. (Based on arXiv: 2006.04618)

Interacting Dark Matter / 98

The MoEDAL-MAPP Experiment - Extending the Physics Reach of the LHC

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MoEDAL-MAPP is a pioneering experiment designed to search for highly ionizing (HIP), feebly interacting (mQP) and long-lived particle (LLP) avatars of new physics in p-p and heavy-ions collisions at the LHC. The MoEDAL baseline detector first took data at LHC's Run-2. This detector was dedicated to the search for HIPs, such as magnetic monopoles or massive (pseudo-)stable charged particles, that are predicted to existing a plethora of models beyond the Standard Model. The MoEDAL-MAPP experiment, including the MALL detector, is designed to extend the search for new physics to include mQPs and LLPs for LHC's Run-3. MoEDAL's ground breaking physics program defines a number of scenarios that yield potentially revolutionary insights into such foundational questions as: are there extra dimensions or new symmetries; what is the mechanism for the generation of mass; does magnetic charge exist; and what is the nature of dark matter. The current results from Run-2, the status of the MoEDAL-MAPP detector for Run-3 and the physics program for Run-3, will be discussed.

Interacting Dark Matter / 314

Running vacuum interacting with dark matter or with running gravitational coupling. Phenomenological implications

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The cosmological constant is usually associated with the notion of vacuum energy density in quantum field theory (QFT). Whether Λ is a rigid quantity or a dynamical variable has been a matter of debate for many years, especially after the introduction of the general notion of dark energy (DE). In an expanding universe one may expect that Λ, and the corresponding vacuum energy density, $\rho_{\rm vac}$, evolve slowly with the cosmological expansion. In this talk I will consider the class of running vacuum models (RVMs), which can describe inflation followed by essentially the standard evolution. For these models, the vacuum energy density takes the form of a constant plus a series of (even) powers of the Hubble rate. Solid theoretical reasons will be given supporting this structure. In addition, the RVM's predict that the dark energy is mildly dynamical and appears effectively as quintessence. Running vacuum models can be of different types, in the two basic ones the vacuum can exchange energy with dark matter (type I) or just evolve with matter conservation but at the

expense of a mildly evolving gravitational coupling (type II). The RVM's prove very competitive against the standard ΛCDM model and give a handle for solving the σ_8 tension and alleviating the H_0 one.

Interacting Dark Matter / 498

Gravitational anomalies, dark matter and leptogenesis

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We consider physics beyond the standard model, which incorporates a see-saw mechanism for neutrino masses. This physics is augmented by incorporating gravitational degrees of freedom (dilaton, graviton and Kalb-Ramond field) found in the theory of closed strings. In the inflationary era the gravitational degrees of freedom and inflatons dominate. Due to quantum effects there is a gravitational anomaly term (breaking of diffeomorphism invariance). This leads to a background which breaks local Lorentz invariance in the radiation and matter domination era. This lays the foundation for a model for leptogenesis based on spontaneous breaking of Lorentz and CPT symmetry. The model involves, apart from standard model particles, a single very heavy right-handed neutrino and the above axion background. We explicitly show how leptogenesis leads to baryogenesis. With current bounds, our model is a viable model for baryogenesis. This model is more economical, in requiring only one right handed neutrino particle, than other similar models for leptogenesis. Furthermore, the coupling of our axions to standard model gauge fields may allow these axions to be dark matter candidates.

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Interaction Energy between a Charged Medium and its Electromagnetic Field as a Dark Matter Candidate

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In special relativity (SR) and in general relativity, the energy tensors of a charged medium and its electromagnetic field, $\mathbf{T}_{\mathrm{chg}}$ and $\mathbf{T}_{\mathrm{field}}$, add to give the total energy tensor $\mathbf{T}$ obeying $T^{\mu\nu}_{;\nu} = 0$: one has
$\mathbf{T} = \mathbf{T}_{\mathrm{chg}} + \mathbf{T}_{\mathrm{field}}$. (1)
In the "scalar ether theory of gravitation" (SET), assuming (1) leads to charge non-conservation [1]. In SET we must abandon (1), which means to introduce an "interaction energy tensor" $\mathbf{T}_{\mathrm{inter}}$ such that
$\mathbf{T} = \mathbf{T}_{\mathrm{chg}} + \mathbf{T}_{\mathrm{field}} + \mathbf{T}_{\mathrm{inter}}$. (2)
Imposing on $\mathbf{T}_{\mathrm{inter}}$ that, in SR, it should be Lorentz-invariant, leads to the form $T^{\mu}_{\mathrm{inter}\ \ \nu} = p\delta^{\mu}_{\nu}$, with p a scalar field [2]: one more equation is needed, which can be imposed to be charge conservation. Being gravitationally active and present virtually everywhere according to that theory, and having an exotic character, the interaction energy $E_{\mathrm{inter}} = T^{00}_{\mathrm{inter}}$ could contribute to the dark matter.

To check if the distribution of E_{inter} resembles a "dark halo", one needs to describe the interstellar radiation field in a galaxy (ISRF) as a solution of the Maxwell equations. Axisymmetry may be assumed, and for the ISRF the source-free Maxwell equations are appropriate [3]. In the axisymmetric case, we proved that any time-harmonic source-free Maxwell field has an explicit decomposition

based on a pair of scalar fields. Using this result, a model giving the ISRF as an exact Maxwell field has been proposed [3]. Its application to predict the variation of the spectral energy density in our Galaxy is being tested [4].

[1] Arminjon M., Open Physics 14 (2016) 395–409.

[2] Arminjon M., Open Physics 16 (2018), 488–498.

[3] Arminjon M., Open Physics 19 (2021), 77–90.

[4] Arminjon M., submitted for publication. HAL preprint hal-03160323 (2021).

Interacting Dark Matter / 434

Growth of Linear Perturbations in a Universe with Superfluid Dark Matter

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The Lambda-Cold Dark Matter (ΛCDM) model agrees with most of the cosmological observations, but has some hindrances from observed data at smaller scales such as galaxies. Recently, Berezhiani and Khoury proposed a new theory involving interacting superfluid dark matter with three model parameters in \cite{khoury2015}, which explains galactic dynamics with great accuracy. In the present work, we study the cosmological behaviour of this model in the linear regime of cosmological perturbations. In particular, we compute both analytically and numerically the matter linear growth factor and obtain new bounds for the model parameters which are significantly stronger than previously found. These new constraints come from the fact that structures within the superfluid dark matter framework grow quicker than in ΛCDM, and quite rapidly when the DM-baryon interactions are strong.
Link to the paper- https://doi.org/10.1088/1475-7516/2020/07/034

Loop Quantum Gravity

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Numerical techniques in covariant LQG

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The application of numerical techniques to covariant LQG may able to provide answers to many of the current open questions in theory. In this presentation, I first introduce the formalism currently used to implement numerical computations. I illustrate a recent application of numerical techniques concerning the study of divergences in the EPRL self-energy amplitude, on which so far there were only analytical upper and lower bounds spanning more than 9 orders of magnitude.

Loop Quantum Gravity / 980

Covariant phase space of standard GR and Palatini: metric vs tetrad formulation

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Gravity admits several formulations. Some of the most well-known are standard GR and Palatini both in tetrad and metric formulation. In this talk, I will show the equivalence, in the covariant Phase Space, of all four formulations on a spacetime manifold with boundary. To this end, we will rely on the cohomological approach provided by the relative bicomplex framework.

Loop Quantum Gravity / 491

On spin in spin networks

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It is reasonable to think that the spin labels of spin networks have nothing to do with physical rotation or spin. However, intriguingly, in situations involving rotating black holes, a connection between the spin of spin networks and angular momentum has been established. Here I want to consider this connection from another angle: Can we talk about the spin of fermions in loop quantum gravity? I will briefly review kinematical quantum states involving fermions. I will then report on work together with R. Mansuroglu and J. Große: We propose observables involving fermion spins, such as scalar products of spins or the total spin of a number of fermions. They involve parallel transport of spins with the Ashtekar-Barbero connection. I will then describe some of their properties and spectra. In particular there are plenty of gauge invariant states with nonzero total fermion spin, which demonstrates that the "gauge spin" of the spin networks and the fermion spin are distinct, although closely related, concepts.I will also comment on correlation between fermion spin and area, as it appears that aligning spins increases area. The effect seems much too small however, to be observable. Altogether, the results seem to show that in the presence of fermions, some of the spin in spin networks is actual physical spin. They also raise the question in how far this might even be true in the absence of fermions.

Loop Quantum Gravity / 496

Revisiting loop quantum gravity with selfdual variables

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Loop quantum gravity (LQG) in its current formulation is a the quantisation of the SU(2) gauge theory of gravity in Ashtekar-Barbero variables. It started out as an SL(2,C) gauge theory in Ashtekar's selfdual variables, but the quantisation program was never fully carried out in this formulation. The two main obstacles are the non-compactness of the gauge group SL(2,C) and the necessity to implement complicated reality conditions. The latter ensure reality of the spatial metric and its evolution.

We revisit the original formulation by considering the selfdual part of complexified general relativity in Ashtekar variables. These are a complex flux and an SL(2,C) connection. We show that one is lead to a classical theory that is holomorphic in the canonical variables, in order to have a non-degenerate symplectic structure. This does not allow to implement the reality conditions as additional constraints in the action, they have to be added by hand during the quantisation. We describe first steps to extend the holomorphic character also to the quantum theory, with SL(2,C) holonomies, holomorphic derivatives, and a notion of holomorphic spin networks. Thus, working in a holomorphic setup turns out to be natural, as anticipated by Ashtekar and others in early works on the selfdual theory. We will also comment on the implementation of the reality conditions.

Loop Quantum Gravity / 334

Supergravity in LQG

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This talk is devoted to the quantization of supergravity in a formulation in which (part of) supersymmetry manifests itself in terms of a gauge symmetry. Applications we have in mind are supersymmetric black holes and loop quantum cosmology.

We will derive the Holst variant of the MacDowell-Mansouri action for $\mathcal{N}=1$ and $\mathcal{N}=2$ supergravity in $D=4$ for arbitrary Barbero-Immirzi parameters. We will show that these actions provide unique boundary terms that ensure local supersymmetry invariance at boundaries. The chiral case is special. The action is invariant under an enlarged gauge symmetry, and the boundary theory is a super Chern-Simons theory. The action also implies boundary conditions that link the super electric flux through, and the super curvature on, the boundary.

We will also study chiral symmetry reduced models with local supersymmetry. The enlarged gauge symmetry of the chiral theory is essential as it allows for nontrivial fermionic degrees of freedom even if one imposes spatial isotropy.

Loop Quantum Gravity / 428

First-Order Quantum Correction in Coherent State Expectation Value of Loop-Quantum-Gravity Hamiltonian

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Given the Loop-Quantum-Gravity (LQG) non-graph-changing Hamiltonian $\widehat{H[N]}$, the coherent state expectation value $\langle\widehat{H[N]}\rangle$ admits an semiclassical expansion in $\ell_{\rm p}^2$. In this paper, we compute explicitly the expansion of $\langle\widehat{H[N]}\rangle$ on the cubic graph to the linear order in $\ell_{\rm p}^2$, when the coherent state is peaked at the homogeneous and isotropic data of cosmology. In our computation, a powerful algorithm is developed to overcome the complexity in computing $\langle\widehat{H[N]}\rangle$. In particular, some key innovations in our algorithm substantially reduce the computational complexity in the Lorentzian part of $\langle\widehat{H[N]}\rangle$. In addition, some effects in cosmology from the quantum correction in $\langle\widehat{H[N]}\rangle$ are discussed.

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Holographic maps from quantum gravity states as tensor networks

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We define bulk-to-boundary maps corresponding to quantum gravity states in the tensorial group field theory formalism, for quantum geometric models sharing the same type of quantum states of loop quantum gravity. The maps are defined in terms of a partition of the quantum geometric data associated to an open graph into bulk and boundary ones, in the spin representation. After showing that such maps formally correspond to tensor networks (quantum information structures that efficiently encode entanglement in many-body systems), we determine the general condition on the entanglement structure of the state that makes the bulk-to-boundary map isometric (a necessary condition for holographic behaviour), and we analyse different types of quantum states, identifying those that define isometric bulk-to-boundary maps.

Loop Quantum Gravity / 330

SL(2,R) Holonomies on the Light Cone

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This talk describes how the Barbero–Immirzi parameter deforms the SL(2,R) symmetries on a null surface boundary. Our starting point is the definition of the action and its boundary terms. We introduce the covariant phase space and explain how the Holst term alters the symmetries on a null surface. This alteration only affects the algebra of the edge modes on a cross-section of the null surface boundar, whereas the algebra of the radiative modes is unchanged by the addition of the Barbero–Immirzi parameter. To compute the Poisson brackets explicitly, we work on an auxiliary phase space, where the SL(2,R) symmetries of the boundary fields are manifest. The physical phase space is obtained by imposing both first-class and second-class constraints. All gauge generators are at most quadratic in terms of the fundamental SL(2,R) variables. Finally, we discuss various strategies to quantise the system.

Loop Quantum Gravity / 935

Causality in Spinfoams

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Current Lorentzian Spinfoams are formulated in terms of a two-complex with spins on faces and intertwiners on edges. In this talk, I discuss how to add a causal structure on wedges. The EPRL model turns out to be given by a sum over these wedge-causal structures. I will show how this sum can be restricted to a single causal configuration and its relation to Engle's proper vertex. [Based on work in collaboration with Pierre Martin-Dussaud]

Loop Quantum Gravity / 525

Spin foam framework for the black-to-white hole transition

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Black holes formation and evolution have been extensively studied at the classical level. However, not much is known regarding the end of their lives, a phase that requires to consider the quantum nature of the gravitational field. A black-to-white hole transition can capture the physics of this phenomenon, in particular the physics of the residual small black holes at the end of the Hawking evaporation. In this talk I discuss how the spin foam formalism achieve to describe this non-perturbative phenomenon. I examine the three distinct regions of the black hole spacetime in which quantum effects cannot be neglected. I argue that the scenario in which the black hole geometry undergoes a quantum transition in a white hole geometry is natural and conservative. I study this quantum transition using the spin foam formalism, explicitly computing the resulting transition amplitude. The ongoing numerical analysis of this transition amplitude may provide an estimation of the back-to-white transition timescales and improve the understanding of its phenomenology.

Loop Quantum Gravity / 682

Semiclassics of Spin-Foams with Generic Causal Character

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The Lorentzian EPRL spin-foam model has been shown to asymptote in an appropriate regime to a Regge-like theory of gravity. Analogous results have recently been obtained for the Conrady-Hnybida (CH) extension of the model, but several questions regarding the amplitudes of time-like triangles remain open. In this talk I will present new progress on the asymptotic analysis of such amplitudes, in particular by proposing an alternative coherent-state parameterization of the theory and by generalizing to non-simplicial polyhedra. I will argue that, unlike for the other cases considered in the CH extension, the amplitude of time-like polygons is not exclusively dominated by Regge-like contributions. Finally I will discuss how the so-called "Cosine Problem" may naturally be avoided.

This talk reports on joint work with Sebastian Steinhaus, soon to be out on the Arxiv.

Loop Quantum Gravity: Cosmology and Black Holes

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Loop quantum Schwarzschild interior and black hole remnant

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The interior of a Schwarzschild black hole is quantized by the method of loop quantum gravity. The Hamiltonian constraint is solved and the physical Hilbert space is obtained in the model. The properties of a Dirac observable corresponding to the Arnowitt-Deser-Misner mass of the Schwarzschild black hole are studied by both analytical and numerical techniques. It turns out that zero is not in the discrete spectrum of this Dirac observable. This supports the existence of a stable remnant after the evaporation of a black hole. Our conclusion is valid for a general class of schemes adopted for loop quantization of the model.

Loop Quantum Gravity: Cosmology and Black Holes / **286**

Black to White Hole Tunnelling

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Increasing theoretical evidence supports the possibility that quantum theory replaces the black hole singularity with a quantum tunnelling to an anti-trapped region, and the blackhole horizon tunnels into a white hole horizon. I review the different elements supporting this intriguing scenario, and mention its possible astrophysical and cosmological implications.

Loop Quantum Gravity: Cosmology and Black Holes / **477**

Properties of a class of spherically symmetric polymer black holes

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In this talk, we shall present our studies of a recently-proposed model of spherically symmetric polymer black/white holes by Bodendorfer, Mele
and M\"unch (BMM), which generically possesses five free parameters. However, we find that, out of these five parameters, only three independent combinations
of them are physical and uniquely
determine the local and global properties of the spacetimes. After exploring the whole 3-dimensional (3D) parameter space, we show that the model has very rich
physics, and depending on the choice of these parameters, various possibilities exist, including: (i) spacetimes that have the standard black/white hole structures, (ii) Spacetimes that have wormhole-like structures, and (iii) Spacetimes that still possess curvature singularities, which can be either hidden inside trapped regions or naked. However, such spacetimes correspond to only some limit cases. In particular, the necessary (but not sufficient)
condition is that at least one of the two polymerization" parameters vanishes. These results are not in conflict to the Hawking-Penrose singularity theorems, as the effective energy-momentum tensor, purely geometric and resulted from thepolymerization" quantization, satisfies none of the three (weak, strong or dominant) energy
conditions in any of the two asymptotically flat regions for any choice of the three independent free parameters, although they can hold at the throat and/or at the two
horizons for some particular choices of them. In addition, it is true that quantum gravitational effects are mainly concentrated in the region near the throat, however,
in this model even for solar mass black/white holes, such effects can be still very large at the black/white hole horizons, again depending on the choice of the parameters.
Moreover, in principle the ratio of the two masses (for both of the black/white hole and wormhole spacetimes) can be arbitrarily large.

Loop Quantum Gravity: Cosmology and Black Holes / 640

Infrared signature of quantum bounce in collapsing geometry

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We study the mode decomposition of the unitarily evolving wave packet constructed for the quantum model of spherically symmetric dust collapsing in marginally bound Lemaître-Tolman-Bondi (LTB) model. We consider the model developed by Kiefer et al. [Phys.Rev.D 99 (2019) 12, 126010], where black hole singularity is replaced by a bounce from collapsing phase to expanding phase in the quantum dynamics of the dust cloud. We identify the observable depicting mode decomposition and using the freedom of operator ordering ambiguity wrote Hermitian extension of this operator alongside the Hermitian Hamiltonian. After identifying incoming and outgoing modes with this operator's eigenstates, we estimate their contributions. True to a quantum description, the expanding and contracting branches do not entirely comprise of outgoing and incoming radiation. For large wavenumber, the contribution of incoming and outgoing radiation is equal and very small. However, the infrared sector of this process shows salient features. Near-infrared modes are very

sensitive to the dynamics of the dust cloud. Near the epoch of classical singularity, there is a significant contribution of incoming/outgoing modes of small wavenumber in the expanding/collapsing phase of the dust cloud. This contribution keeps on decreasing as one moves away from the singularity. Moreover for small wavenumber, the collapsing branch largely comprises of incoming modes, and the expanding branch comprises of outgoing modes. If one focuses on the infrared sector, the information of the bounce is carried over to the infrared modes, much before the information of the bounce comes about to any observer. A flip from largely incoming to largely outgoing radiation, as the evolution progressed from collapsing to expanding phase, is observed in the infrared regime. The information of the short scale physics is carried over to the longest wavelength in this quantum gravity model.

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Towards a reduced phase space quantization in loop quantum cosmology with an inflationary potential

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In this talk we discuss three different models for a reduced phase space quantization of loop quantum cosmology (LQC) for a spatially flat Friedmann-Lemaître-Robertson-Walker (FLRW) universe filled with reference fields and an inflaton field in a Starobinsky inflationary potential. All three models are two-fluid models and they differ by their choice of global clock which are chosen to be either Gaussian dust, Brown-Kuchař dust or a massless Klein-Gordon scalar field. Although two-fluid models are more complicated than models involving the inflaton only, it turns out that some of the technical hurdles in conventional quantum cosmological models can be bypassed in these models. Using the effective dynamics resulting from the reduced phase space quantization we discuss some phenomenological implications of these models including the resolution of the big bang singularity via a quantum bounce and in addition address the question whether different choices of clocks can leave an imprint on the inflationary dynamics.

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Initial Conditions in LQC/mLQCs

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The initial conditions are a subtle issue in loop quantum cosmology (LQC) and modified loop quantum cosmologies (mLQCs). This is mainly because in general there doesn't exist a preferred initial time and state for a quantum field in an arbitrarily curved space-time. If the universe is sufficiently smooth and its evolution is sufficiently slow, so the characteristic scale of perturbations
is much larger than the wavelengths of the relevant modes, a well justified initial state exists, the

so-called Bunch-Davies
(BD) vacuum. This is precisely the initial state commonly adopted in general relativity (GR) at the very beginning of the slow-roll inflation,
in which all the relevant perturbation modes are well inside the comoving Hubble radius.

However, in LQC/mLQCs, especially when near the quantum bounce, the evolution of the background is far from "slow", and its geometry
is also far from the de Sitter. In particular, for the perturbations near the bounce, the wavelengths could be larger, equal, or smaller than the
corresponding characteristic scale. Thus, it is in general impossible to assume that the universe is in the BD vacuum at the bounce.
In this talk, we shall consider this important issue within the framework of both the dressed metric and the hybrid approaches. Such conditions
in fact consist of two parts: (a) when to impose, and (b) what initial conditions need to impose consistently. In the literature, two different moments
have been chosen so far in these two approaches: (i) the remote past before the bounce (the contracting phase), and (ii) the bounce. We shall
show in detail that at each moment a consistent choice of the initial conditions depends not only on the specific potential of the inflaton field but
also on the two approaches. In addition, different moments also correspond to different choices of consistent initial conditions.

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Revisiting the Hamiltonian formalism of the Ashtekar-Olmedo-Singh black hole model

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In this talk, I will present the main features of the solutions to a recently-derived set of dynamical equations that governs the effective dynamics of black holes in loop quantum cosmology which were obtained via a revision of the Hamiltonian calculation underlying the Ashtekar-Olmedo-Singh black hole model. I will analyze the possibility that certain quantum parameters are treated as Dirac observables and that the radial and angular sectors of phase space are not dynamically decoupled in general. I will show how to derive in this way the corresponding Hamiltonian equations. Finally, I will discuss the features of the resulting model, emphasizing how this apparently slight modification of the formalism might open a door to the alleviation of some of the criticisms that the Ashtekar-Olmedo-Singh model has received.

Loop Quantum Gravity: Cosmology and Black Holes / 338

Primordial perturbations in kinetically dominated regimes of classical and quantum cosmology

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There is an increasing interest in very early stages of the Universe in which the energy density of the inflaton could be dominated by its kinetic part. This includes classical inflationary scenarios

with deviations from slow-roll regimes that can introduce modifications to the power spectra of the primordial fluctuations. Another example are quantum bouncing cosmologies. For instance, this is the typical situation in loop quantum cosmology if quantum corrections may leave observables traces in the power spectra. In models of this type, we discuss the leading-order effects of an inflaton potential on the primordial perturbations. These effects are of two kinds, referred to the case without potential. First, there are changes in the effective mass appearing in the dynamical equations of the perturbations in conformal time. Second, away from conventional slow roll, a Bunch-Davies vacuum may no longer be natural, and possible new choices depend on the potential.

Loop Quantum Gravity: Cosmology and Black Holes / 523

Predictions for the CMB in inflationary and anisotropic cosmologies

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The paradigm of slow-roll inflation provides a snapshot of the early universe that is in good agreement with present observations. Despite its success, most of the models studied so far rely heavily on the assumption that the universe is perfectly isotropic at early times. In this talk, I will discuss recent advances in anisotropic inflationary models. We adopt a Fock quantization for gauge-invariant perturbations. We evolve them through an anisotropic bounce within loop quantum cosmology. Despite anisotropies die out very rapidly just before the inflationary expansion, scalar and tensor perturbations keep memory of that anisotropic phase, and leave several types of anomalies in the Cosmic Microwave Background (CMB). With these imprints and current data, we constrain the departure from spatial isotropy of the early universe, as well as discuss modifications in the usual angular correlation functions and the generation of TB and EB correlations that are forbidden in the standard isotropic scenario.

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Anomalies in the CMB from a cosmic bounce

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We propose a cosmological model that can provide a common origin to several of the anomalous features observed at large angular scales in the cosmic microwave background (CMB). More concretely, we show that a power suppression, a dipolar asymmetry, and a preference for odd-parity correlations, with amplitude and scale dependence in consonance with observations, are expected from this scenario. The model also alleviates the tension in the lensing amplitude. These features originate from the indirect effect that non-Gaussian correlations between CMB modes and super-horizon wavelengths induce in the power spectrum. In the model we propose, a cosmic bounce precedes the inflationary era. Adopting a phenomenological approach for the profile of the bounce, we keep our analysis as general as possible but we complement it by mentioning well-established theories where our model can be materialized.

Loop Quantum Gravity: Cosmology and Black Holes / 638

Alleviating tensions in the CMB using Planck scale physics: A Cosmic Tango between the very large and very small

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The PLANCK satellite has observed certain anomalies in the Cosmic Microwave Background (CMB) that bring out a tension between the standard six-parameter ΛCDM cosmological model and observations. The possibility that these anomalies could be tell-tale signatures of fundamental physics at the Planck scale is exciting. We show that this possibility is realized within Loop Quantum Cosmology (LQC) where the primordial power spectrum is modified due to Planck scale physics. In particular, we will show that the primordial power spectrum generated in LQC alleviates the power anomaly at large angular scales and tension in the lensing amplitude. This talk is based on research carried out in collaboration with Abhay Ashtekar, Brajesh Gupt and Donghui Jeong and reported in PRL 125, 051302 (2020) and Front. Astron. Space Sci. 8:685288 (2021).

Loop Quantum Gravity: Cosmology and Black Holes / 298

The primordial power spectra in modified loop quantum cosmology

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In the talk, I will discuss the primordial power spectra in two modified models of loop cosmology. As compared with the standard loop quantum cosmology in a spatially flat Friedmann-Lema\^itre-Robertson-Walker (FLRW) universe, these two models arise from a separate treatment of the Lorentzian term in the Hamiltonian constraint. Both dressed metric approach and the hybrid approach are employed to numerically derive the power spectra in the two models. We find although both models predict consistent results with the current observations in the ultraviolet regime, there are indeed appreciable deviations in the intermediate and infrared regimes between the two models. Therefore, our results serve as a concrete example which explicitly shows how the quantization ambiguities can affect the phenomenological implications of the resultant quantized theories.

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Primordial power spectrum from a matter-ekpyrotic bounce scenario in loop quantum cosmology

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A union of matter bounce and ekpyrotic scenarios is often studied in an attempt to combine the most promising features of these two models. Since nonperturbative quantum geometric effects in loop quantum cosmology (LQC) result in natural bouncing scenarios without any violation of energy conditions or fine tuning, an investigation of matter-ekpyrotic bounce scenario is interesting to explore in this quantum gravitational setting. In this work, we explore this unified phenomenological model for a spatially flat Friedmann-Lemaître-Robertson-Walker (FLRW) universe in LQC filled with dust and a scalar field in an ekpyrotic scenario like negative potential. Background dynamics and the power spectrum of the comoving curvature perturbations are numerically analyzed with various initial conditions and a suitable choice of the initial states. By varying the initial conditions we consider different cases of dust and ekpyrotic field domination in the contracting phase. We use the dressed metric approach to numerically compute the primordial power spectrum of the comoving curvature perturbations which turns out to be almost scale invariant for the modes which exit the horizon in the matter-dominated phase. But, in contrast with a constant magnitude power spectrum obtained under approximation of a constant ekpyrotic equation of state using deformed algebra approach in an earlier work, we find that the magnitude of power spectrum changes during evolution. Our analysis shows that the bouncing regime only leaves imprints on the modes outside the scale-invariant regime. However, an analysis of the spectral index shows inconsistency with the observational data, thus making further improvements in such a model necessary.

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Loop Quantum Gravity on Dynamical Lattice and Improved Cosmological Effective Dynamics with Inflaton

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In the framework of reduced phase space Loop Quantum Gravity (LQG), we propose a new approach in coherent state path integral formulation which allows the spatial cubic lattice (graph) to change dynamically in the physical time evolution. The equations of motion of the path integral derive the effective dynamics of cosmology from the full LQG, when we focus on solutions with homogeneous and isotropic symmetry. The resulting cosmological effective dynamics with the dynamical lattice improves the effective dynamics obtained from the path integral with fixed spatial lattice: The improved effective dynamics recovers the FLRW cosmology at low energy density and resolves the big-bang singularity with a bounce. The critical density ρ_c at the bounce is Planckian $\rho_c \sim \Delta^{-1}$ where Δ is a Planckian area serving as certain UV cut-off of the effective theory. The effective dynamics gives the unsymmetric bounce and has the de-Sitter (dS) spacetime in the past of the bounce. The cosmological constant Λ_{eff} of the dS spacetime is emergent from the quantum effect $\Lambda_{eff} \sim \Delta^{-1}$. These results are qualitatively similar to the properties of $\bar{\mu}$-scheme Loop Quantum Cosmology (LQC). Moreover, we generalize the path integral formulation of the full LQG by taking into account the coupling with an additional real scalar field, which drives the slow-roll inflation of the effective cosmological dynamics. In addition, we discuss the cosmological perturbation theory on the dynamical lattice in full LQG, and the relation to the Mukhanov-Sasaki equation.

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How classical are Gaussian states in loop quantum cosmology?

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In traditional (Dirac quantized) quantum mechanics, Gaussian wave functions play an important role in understanding semi-classicality: they may be chosen to be as sharply-peaked around classical position coordinates and they saturate the uncertainty relation, thereby minimizing quantum fluctuations. Gaussian states may likewise be constructed on the kinematic volume Hilbert space of loop quantum cosmology (LQC), and are often viewed as good candidates for semi-classical quantum geometries. However, it is not obvious that they exhibit the same nice features as traditional Gaussian quantum states. In this talk, I show that contrary to common intuition, Gaussian states in LQC generally do not saturate their uncertainty relations, and indeed, that there exist LQC Gaussian states for which the fluctuations are arbitrarily large. It is shown, however, that the usual volume regularization procedure of LQC allows one to suppress these diverging fluctuations as much as one wishes, and so uncertainty minimization is obtained asymptotically as $V_0 \to \infty$. It is further illustrated that the relationship between the fiducial volume V_0 and holonomy length λ plays an important role in determining the fluctuations of the these states.

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Holonomy corrections in effective midisuperspace models

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We develop a systematic approach to obtain spherically symmetric midisuperspace models with modifications inherited from loop quantum gravity. We obtain a family of effective constraints that satisfy Dirac's deformation algebra and show that (scale-dependent) holonomy corrections can be consistently implemented in the presence of matter with local degrees of freedom. These deformed Hamiltonians are expected to modify the dynamics of general relativity and to avoid the singularities predicted for gravitational collapsing models.

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Effective black hole interior and the Raychadhuri equation

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We show that loop quantization leads to the emergence of defocusing terms in the expansion and its rate of change, the Raychaudhuri equation. These terms are suppressed in the region far from the singularity but dominate close to that region and prevent both the expansion and its rate from diverging everywhere inside the black hole. This in turn signals the disappearance of the caustic points and the resolution of singularity in the interior of the black hole.

Loop Quantum Gravity: Cosmology and Black Holes / 718

A family of metric-affine f(R) theories for Loop Cosmologies

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In this talk we will review the known result that the background evolution of standard LQC can be reproduced by a covariant metric-affine f(R) theory all the way up to bounce curvatures. We will then show that other Loop Cosmologies dubbed as mLQC-I and mLQC-II, differing on standard LQC due to quantisation ambiguities related to the Lorentzian term of the Hamiltonian, also admit covariant metric-affine Lagrangians of the f(R) class reproducing the background evolutions can also be found. Remarkably, the Lagrangians reproducing LQC, mLQC-I and mLQC-II can be embedded into a three-parameter family of f(R) theories, where two parameters are fixed by initial conditions at the bounce.

Loop Quantum Gravity: Cosmology and Black Holes / 871

Closer look at white hole remnants

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The idea that, after their evaporation, Planck-mass black holes might tunnel into metastable white holes has recently been intensively studied. Those relics have been considered as a dark matter candidate. We show that the model is severely constrained and underline some possible detection paths. We also investigate, in a more general setting, the way the initial black hole mass spectrum would be distorted by both the bouncing effect and the Hawking evaporation.
Based on Barrau, Renevey, Martineau, Ferdinand Phys. Rev. D 103 (2021) 4, 043532

Loop Quantum Gravity: Cosmology and Black Holes / 1002

Effect of loop quantization prescriptions on the physics of non-singular gravitational collapse

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We study some consequences of the loop quantization of the outermost shell in the Lema\^itre–Tolman–Bondi (LTB) dust spacetime using different quantization strategies motivated by loop quantum gravity. Prior work has dealt with this loop quantization by employing holonomies and the

triads, following the procedure in standard loop quantum cosmology. In this work we compare this quantization with the one in which holonomies and gauge-covariant fluxes are used. While both of the quantization schemes resolve the central singularity, they lead to different mass gaps at which a trapped surface forms. This trapped surface which is matched to an exterior generalized Vaidya spacetime disappears when the density of the dust shell is in the Planck regime. We find that the quantization based on holonomies and gauge-covariant fluxes generically results in an asymmetric evolution of the dust shell in which the mass associated with the "white hole" is about 2/3 of the "black hole" for an external observer. Further, unlike the quantization using only holonomies, there can be situations in which only a black hole forms without its white hole twin. These turns out to be a distinct phenomenological signature distinguishing these two quantization prescriptions.

Machine Learning in Astronomy: AGN, Transient Events, Cosmology and Others

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Deep learning to cluster continuous gravitational wave candidates in broad searches

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Searching continuous gravitational waves from unseen objects is computationally expensive and relies on hierarchies of follow-up stages for candidates above a given significance threshold. Clustering is a powerful technique that bunds together nearby candidates in a single follow-up to simplify the follow-ups and reduce the computational cost. We used deep learning methods to automate the clustering procedure. We implemented two networks, one can identify clusters due to large signals, and one can detect clusters due to much fainter signals. These two networks are complementary and using them in cascade achieves an excellent detection efficiency across a wide range of signal strengths. Also, this method shows a false alarm rate lower than the clustering methods currently in use.

Machine Learning in Astronomy: AGN, Transient Events, Cosmology and Others / 785

Encoding large scale cosmological structure with Generative Adversarial Networks

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Recent progresses in Machine Learning have unlocked new possibilities to tackle scientific problems by means of neural networks, and already many applications have been developed both in astrophysics and cosmology. In this presentation, using a Generative Adversarial Network (GAN), an unsupervised learning model, we demonstrate the possibility to learn the distribution of dark matter of the cosmic web, using as input the results of large-scale -dark matter only- simulations

such as Gadget. We provide a statistical analysis showing that the neural networks learn the underlying distribution. Finally, we show that, using the generator learned by the GAN it is possible to design an Auto-Encoder. The AE is then capable of both inferring the latent code of the GAN from a snapshot of dark energy density, therefore opening the way to new applications such as inferring missing values on a corrupted dataset or deducing from density distribution at lower z its possible evolution at higher redshift.

Machine Learning in Astronomy: AGN, Transient Events, Cosmology and Others / 788

Cosmological Density Field Emulation and Gravitational Wave Inference based on Dimensionality Reduction and Supervised Machine Learning

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Two major challenges in modern cosmology are the understanding of the origin and growth of cosmic structure and the progenitors of Gravitational Waves. Both scenarios require heavy computational resources to perform simulations and inference. In this work, we propose to adopt Machine Learning to alleviate these requirements, to enable significantly faster sampling and inference. We show that using Dimensionality Reduction and Supervised Learning, it is possible to generate high precision emulations of Dark Matter Density Fields given a set of cosmological parameters (the dark matter density and redshift). This led to orders of magnitude improvement in execution time and far less computational resources than running N-Body simulations. We also show that using the same approach it is possible to generate fast inferences of Chirp Masses from Binary Black Hole systems. The methods we present here may provide an important key to enabling fast and accurate data analysis for upcoming surveys like Euclid, LSST/Rubin, and LISA.

Machine Learning in Astronomy: AGN, Transient Events, Cosmology and Others / 722

Deep Learning in Searching the Spectroscopic Redshift of Quasars

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Study the cosmological sources at their cosmological rest-frames are crucial in order to track the cosmic history and properties of the compact objects. In view of increasing data volume of existing and upcoming telescopes/detectors we here apply the 1−dimensional convolutional neural network (CNN) to estimate the redshift of quasars in Sloan Digital Sky Survey IV (SDSS-IV) catalog from DR16 quasar-only (DR16Q) of eBOSS on a broad range of signal-to-noise ratios. The CNN takes the flux of the quasars as an 1−dimensional array and their redshift as labels. We compare and contrast our results and the configuration of our network with the existing CNNs both for spectroscopic and photometric redshift predictions for the similar training samples. The accuracy of our CNN

in predicting redshift in the range of 0 $\leq$~z~$\leq$ 5.45 is 98.3% for the velocity difference for redshift, $|\Delta\nu| < 6000$ km/s and 99.4% for $|\Delta\nu| < 12000$ km/s. For spectroscopic redshift prediction by QuasarNet, which utilizes a CNN to identify at least two emission lines in the quasar's spectra, the accuracy is 99.8% for both $|\Delta\nu| < 6000$ km/s and $|\Delta\nu| < 12000$ km/s. Finally, we show that, thanks to multiple convolutional layers, with different kernel sizes in order to search for both the \textit{global} and \textit{local} patterns in the flux, our CNN provides a prediction as accurate as the one of QuasarNet even by masking the prominent emission lines present in spectra.

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Unsupervised photometric detection of cluster candidates in large surveys

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Galaxy Clusters are essential to study galaxy evolution and sensitive probes of cosmology and the dynamics of the Universe Dark sector. Large galaxy surveys, such as Euclid, DES, LSST/Rubin will provide a wealth of information that can be used to detect many new clusters. For example, the Euclid mission survey may reveal more than 60000 clusters with S/N>3 up to redshift 2, representing a whole new era for cluster cosmology. A large fraction of these clusters will be unknown high-redshift cluster candidates, lacking spectroscopic information. Thus, a major challenge for cluster detection is the identification of member galaxies from photometry alone, and ideally without strong assumptions of what clusters are.

In this talk, we present the results of a modified version of the UPMASK (Unsupervised Photometric Membership Assignment) method for the detection of galaxy clusters. The method, originally created to study star clusters, uses heuristics and statistical analysis to separate cluster candidate galaxies from other field galaxies without assuming cluster profiles or any strong theoretical priors about what a cluster is. We show that the method operates in a fully unsupervised way and it can even work with minimal amounts of astrometry and photometry information, using Euclid and DES galaxy survey simulations. We then use Pan-STARRS data to assess the performance of the method to identify Planck clusters and present
possible detections of optical counterparts for cluster candidates in the second PlanckSZ data release catalog. Finally, we compare our findings with other Planck cluster candidate follow-up efforts and comment on possible extensions for automated cluster detections with the Euclid survey.

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Estimating the photometric redshifts of galaxies using regression techniques

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After recent technological advancements in astronomical surveys, modern astrophysics is concerned with the study and characterization of distant objects such as galaxies, stars and quasars. Obtaining the optical spectrum and consequently deriving the redshift could instantly classify these astronomical sources but as long as spectroscopic observations are not available for many galaxies and the process of measuring the shift can be time-consuming and infeasible for large samples, a machine learning approach could be applied to determine the redshifts of galaxies from their photometric colors. In the current manuscript, by using the flux magnitudes from the Sloan Digital Sky Survey (SDSS) catalog, we created a database of color indices acting as an approximation for the spectrum. These color indices are considered as our input features and a subset of sources containing spectroscopic redshifts were chosen as the training dataset. As the final step, we designed a decision tree algorithm to obtain a rather accurate estimation of the redshifts and then its evaluation procedures were investigated. Limitations of astronomical surveys which often lead to imaging a large number of faint galaxies, necessitated the requirement of sophisticated ML algorithms which can simplify the process of using the data to inform our view on understanding the universe.

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On parameters of fractal distribution of relic wormholes

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Abstract.

We discuss the possibility that the topological structure of the Universe may possess fractal properties.

Relic wormholes and their fractal distribution are predicted in a natural way by lattice quantum gravity models.

This gives a new approach to some long-standing problems. Those are the nature of dark matter phenomena, the origin of Faber-Jackson and Tully-Fisher relations, and the observed deficit of baryons.

We consider open Friedman model and construct an exact fractal model by means of a factorization of the space over a discrete subgroup of the group of motion. We derive some basic features of the resulting fractal space and discus applications of machine learning methods for the verification of the fractal properties.

Machine Learning in Astronomy: AGN, Transient Events, Cosmology and Others / 895

Machine Learning based classification of blazar candidates of an unknown type (BCUs)

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The fourth Fermi Large Area Telescope source catalog contains 5065 gamma-ray sources. Among these sources, 694 are flat-spectrum radio quasars (FSRQs), 1131 are BL Lac-type objects (BL Lacs), and 1312 are blazar candidates of an unknown type (BCUs). Using as a training sample the spectral energy distributions and the light curves of classified blazars, a supervised machine learning method based on an artificial neural network is employed to classify the blazar candidates of an unknown type. Initially using missForest method to fill the missing data in the spectral energy distribution of FSRQs and BLLacs, the model achieved an accuracy of 92% and F1 score of 92%(combines the

precision and recall of a classifier into a single metric by taking their harmonic mean) allowing the classification of BCUs.

Mathematical Problems of Relativistic Physics: Classical and Quantum

Mathematical Problems of Relativistic Physics: Classical and Quantum / 717

Mass loss law for weak gravitational fields: With or without a positive cosmological constant

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Bondi's celebrated mass loss formula measures the rate of change of energy carried away from an isolated system (in asymptotically flat space-time) by gravitational radiation. In this talk, we generalize this idea to the de Sitter setting. We derive a formula for the total canonical energy, and its flux, of weak gravitational waves on a de Sitter background. Based on arXiv:2003.09548 [gr-qc], arXiv: 2103.05982 [gr-qc].

Mathematical Problems of Relativistic Physics: Classical and Quantum / 1025

Orientability of space from electromagnetic quantum fluctuations

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Orientability is an important topological property of spacetime manifolds.
It is generally assumed that a test for spatial orientability requires a journey
across the whole 3-space to check for orientation-reversing paths.
Since such a global expedition is not feasible, theoretical arguments that combine
universality of physical experiments with local arrow of time, CP violation and CPT
invariance are offered to support the choosing of time- and space-orientable
spacetime manifolds. We show that it is possible to access spatial orientability of

Minkowski spacetime through local physical effects involving quantum electromagnetic fluctuations. To this end, we study the motions of a charged particle and an electric dipole under these fluctuations in Minkowski spacetime with orientable and non-orientable spatial topologies. We derive expressions for an orientability indicator for both point-like particles in two spatially flat topologies.
For the particle, we show that it is possible to distinguish the orientable from the non-orientable topology by contrasting the evolution of the indicators.
This result shows that it is possible to access orientability through electromagnetic quantum fluctuations. The answer to the question on how to locally probe the orientability of Minkowski 3-space intrinsically arises in the study of the dipole's motions.
We find that a characteristic inversion pattern exhibited by the dipole indicator curves is a signature of non-orientability.
This result makes it clear that it is possible to locally unveil spatial non-orientability by the inversion pattern of orientability indicator curves of an electric dipole under quantum electromagnetic fluctuations.
Our findings open the way to a conceivable experiment involving quantum electromagnetic fluctuations to locally probe the spatial orientability on the microscopic scale of Minkowski spacetime.

Mathematical Problems of Relativistic Physics: Classical and Quantum / 846

Wave propagation in the anti-deSitter optical metric

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An optical medium can be represented by a Riemannian manifold $(\mathcal{B}, g)$ where $\mathcal{B}$ is consider to be the physical space and g the optical spatial metric. A geodesic flow in the unitary tangent bundle can be represented by a contact transformation in the space of contact elements. This fact, allows us to describe the wavefront evolution in an optical medium solely in terms of the contact transformation. This technique serves to construct wavefronts in optical media without directly solving the wave equation. In this talk, we will present the wave propagation in the anti-deSitter optical metric using this technique and visualize wavefronts as they refract while passing through interfaces in this particular geometry.

Mathematical Problems of Relativistic Physics: Classical and Quantum / 982

New approaches to constrained dynamics and Hamilton-Jacobi procedures in general relativity

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Élie Cartan's invariant integral formalism is extended to gauge field theory, including general relativity. This constitutes an alternative procedure that is equivalent to the Rosenfeld, Bergmann, Dirac algorithm. In addition, a Hamilton-Jacobi formalism is developed for constructing explicit phase space functions in general relativity that are invariant under the full four-dimensional diffeomorphism group. These identify equivalence classes of classical solutions of Einstein's equations. Each member is dependent on intrinsic spatial coordinates and also undergoes non-trivial evolution in intrinsic time. The intrinsic coordinates are determined by the spacetime geometry in terms

of Weyl scalars. The implications of this analysis for an eventual quantum theory of gravity are profound.

Mathematical Problems of Relativistic Physics: Classical and Quantum / 1030

Essential Self-Adjointness of Dirac operators under the influence of general-relativistic gravity

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Physical reasoning give expressions for the Hamiltonian of a system. These Hamiltonians are differential operators that are mostly symmetric in a densely defined domain.
However, to study the dynamics of the unitary group corresponding to a Hamiltonian, it is required that the Hamiltonian be self-adjoint or essentially self-adjoint. I will present our study on how the static non-linear electromagnetic-vacuum space-time of a point nucleus affects the self-adjointness of the general- relativistic Dirac Hamiltonian for a test electron.

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Causal fermion systems: Classical gravity and beyond

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The theory of causal fermion systems is an approach to fundamental physics. It gives quantum mechanics, general relativity and quantum field theory as limiting cases and is therefore a candidate for a unified physical theory. The dynamics of causal fermion systems is described by a variational principle called the causal action principle (for more details see https://causal-fermion-system.com).

In the talk, I will outline how and in which sense the causal action principle gives rise to classical gravity. Moreover, I will explain in various examples how to go beyond classical gravity:
- The general definition of the total mass of a static causal fermion system
- A general connection between area change and matter flux
- Geometric structures giving a setting of Lorentzan quantum geometry
We conclude with an outlook on quantum gravity.

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Spacetime Harmonic Functions and the Mass of 3-Dimensional Asymptotically Flat Initial Data for the Einstein Equations

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We give a lower bound for the ADM mass of 3-dimensional asymptotically flat initial data sets for the Einstein equations. The bound is given in terms of linear growth 'spacetime harmonic functions' in addition to the energy-momentum density of matter fields, and is valid regardless of whether the dominant energy condition holds or whether the data possess a boundary. A corollary is a new proof of the spacetime positive mass theorem for complete initial data or those with weakly trapped surface boundary. The proof has analogy with both the Witten spinorial approach as well as the marginally outer trapped surface (MOTS) method of Eichmair, Huang, Lee, and Schoen. This is joint work with Sven Hirsch and Marcus Khuri.

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Hypercomplex medium as a storage of physical equations

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In a brief review, we draw attention to the "hypercomplex medium" with the accent on quaternion (Q) algebra and contiguous areas: biquaternion (BQ) numbers, Q-spinors, and related groups. Due to Heaviside-&-Gibbs' vector algebra, this "Q-set" was nearly abandoned in XX century rarely emerging as a math tool 1. However, it turns out to contain many geometric images and equations related to physics, thus appearing no less fruitful for current physics than differential geometry. By 1980 we knew three main "Q-physical coincidences": imaginary Q-units geometrically form a 3D Cartesian frame (Hamilton), Pauli matrices are BQ-units' representations, Cauchi-Riemann-type conditions for a Q-variable function are Maxwell equations of electrodynamics (Fueter 2). Within the last 40 years, new non-trivial observations were made. There are pure math facts, among them the existence of 3D Q-space's fractal 2D sub-structure (real unit being its metric) and an original geometric image of a complex number as a conic-gearing-type mechanism. There are also new Q-physical findings. A Q-vector version of SO(3,C)-invariant relativity theory emerges as a Q-square-root from special relativity 3; formulated on a tangent plane over a curved manifold, it admits a further fractalization into Q-spinors [4]. A stability condition for Q-algebra under distortions of fractal space becomes the Schrodinger equation (in physical units), in a more complicated case, it precisely becomes the Pauli equation [5]. This helps to show that the Bohr model of H-atom is an exact stationary solution of the Schrodinger equation [6]. Consequent "reduction" of obtained equations leads to classical mechanics (with a geometric image of the action function) and to relativistic mechanics; in sum, a "general theory of mechanics" can be formulated [7]. Other aspects concerning links of the Q-curvature with Yang-Mills field strength and use of 2C fractal instruments in the spacecraft control [8] are considered.

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The second Bianchi identity for spacetimes with timelike singularities

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The second Bianchi identity is a well-known and fundamental differential identity which holds on any smooth (semi-)Riemannian manifold. In general relativity, due to the relation of the curvature tesnor and the energy-momentum tensor via the Einstein equations, this identity then naturally implies energy and momentum conservation for matter fields. What happens in situations where curvature singularities associated with timelike singularities occur and the classical Bianchi identity no longer makes sense? In this talk we establish a distributional version of the contracted Bianchi identity, and investigate for which matter fields this identity holds. Surprisingly, the well-known Reissner-Weyl-Nordström spacetime of a single point charge does not belong to this class, but other electromagnetic theories and certain perfect fluids with one-dimensional timelike singularities satisfy the second Bianchi identity weakly. Joint work with Michael Kiessling and Shadi Tahvildar-Zadeh.

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Times of arrival and gauge invariance

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Arrival-time operators (or observables) describing time-of-flight experiments are naturally constrained by gauge invariance requirements. Surveying the literature on time operators, including POVMs, I will show that a natural generalization of Aharonov-Bohm-Kijowski's arrival-time distribution (referred to as the "standard arrival-time distribution" by some authors) fails to be gauge invariant. In particular, this undermines the associated time-energy uncertainty relations. A direct comparison to the quantum flux distribution, which does not exhibit this flaw, and which does not correspond to a quantum observable (or POVM), will be drawn (its acknowledged drawback concerning the quantum backflow effect notwithstanding). Ref: S. Das and M. Nöth, Proc. R. Soc. A. 477 (2021)

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On recent developments in the theory of dissipative relativistic fluids

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My goal in this talk is to address some of the fundamental mathematical questions in the field of relativistic dissipative fluid dynamics. This is an area that has witnessed progress within the physics community but for which many foundational mathematical questions remain open. Some of these problems, such as the study of causality, local well-posedness and breakdown of solutions, are crucial for for establishing solid theoretical foundations for the understanding of the quark-gluon plasma, a state of matter found in the very early universe. The talk is based on joint work with J. Noronha, F. Bemfica, M. Disconzi and M. Radosz.

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Division algebraic symmetry breaking

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Can the 32C-dimensional algebra R(x)C(x)H(x)O offer anything new for particle physics? Indeed it can. Here we identify a sequence of complex structures within R(x)C(x)H(x)O which induces a cascade of breaking symmetries: Spin(10) -> Pati-Salam -> Left-Right symmetric -> Standard model + B-L (both pre- and post-Higgs-mechanism). These complex structures derive from the octonions, then from the quaternions, then from the complex numbers.

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The point spectrum of the Dirac Hamiltonian on the zero-gravity Kerr-Newmann spacetime

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In relativistic quantum mechanics, the point spectrum of the Dirac Hamiltonian with Coulomb potential famously agrees with Sommerfeld's fine structure formula for Hydrogen. In the Coulomb approximation, the proton is assumed to only have an electric charge. However, the physical proton also appears to have a magnetic moment. The resulting hyperfine structure of Hydrogen is computed perturbatively. Aiming towards a non-perturbative approach, Pekeris in 1987 proposed taking the Kerr-Newmann spacetime with its ring singularity as a source for the proton's electric charge and magnetic moment. Given the proton's mass and electric charge, the resulting Kerr-Newmann spacetime lies well within the naked singularity sector which possess closed timelike loops. In 2014 Tahvildar-Zadeh showed that the zero-gravity limit of the Kerr-Newmann spacetime (zGKN) produces a topologically nontrivial flat spacetime which is no longer plagued by closed timelike loops. In 2015 Tahvildar-Zadeh and Kiessling studied the Hydrogen problem with Dirac's equation on the zGKN spacetime and found that the Hamiltonian is essentially self-adjoint and contains a nonempty point spectrum. In this talk, we show how some of their ideas can be extended to classify the point spectrum.

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The Maxwell-Bopp-Lande-Thomas-Podolsky-Einstein system for a static point source

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In this talk, we discuss the existence of a static, spherically symmetric spacetime that is the solution of the Einstein field equations coupled with an electric field obeying the equations of electromagnetism of Maxwell-Bopp-Lande-Thomas-Podolsky for a static point charge. Contrary to what happens with the Reissner-Nordstrom spacetime, it is shown that the electric field energy is finite, just as for this same theory on a background flat spacetime.

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Newman-Penrose-Debye formalism for fields of various spins in pp-wave backgrounds

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Using Newman-Penrose formalism in tetrad and spinor notation, we perform separation of variables in the wave equations for massless fields of various spins s=1/2, 1, 3/2, 2 on the background of exact plane-fronted gravitational wave metrics. Then, applying Wald's method of adjoint operators, we derive equations for Debye potentials generating these fields and find inverse projection operators expressing multicomponet fields in terms of scalar potentials. For a number of shock wave backgrounds, as a special case of non-vacuum pp-waves, the exact solutions for Debye potentials are constructed explicitly. The possibility of generalization to the case of massive fields, in particular, construction of exact solutions to the Dirac and Proca equations are discussed. These results can be used in supergravity models on pp-wave backgrounds.

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Gravitational geometric phase

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We show that spinors propagating in curved gravitational background acquire an interaction with spacetime curvature, which leads to a quantum mechanical geometric effect. This is similar to what happens in the case of magnetic fields, known as the Pancharatnam-Berry phase. As the magnetic and gravitational fields have certain similar properties, e.g. both contribute to curvature, this result is not difficult to understand. Interestingly, while spacetime around a rotating black hole offers Aharonov-Bohm and Pancharatnam-Berry both the kinds of geometric effect, a static spacetime offers only the latter. In the bath of primordial black holes, such gravity induced effects could easily be measured due to their smaller radius

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Wald-Zoupas charges in the asymptotically de Sitter spacetimes

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Our talk will start with a (hopefully) pedagogical introduction to the topic of asymptotically de Sitter spacetimes. Afterward, we will construct 'conserved' charges a'la Wald and Zoupas at a conformal infinity and prove their uniqueness under a natural set of assumptions. We will finish with a small comment on how to distinguish the de Sitter group within a group of all asymptotic symmetries.
Joint work with J. Lewandowski

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Averaging cosmological observables in the LSS surveys

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In this talk I will discuss a systematic and rigorous classification of all the possible choices for averaging observables in cosmology. In this regard, the use of the so-called Geodesic Light-cone gauge provides simple expressions as I will show here. These new results will be compared with the recent literature. Moreover, I will discuss their impact on the bias that they can induce in the estimation of statistical properties, such as mean value and dispersion. Finally, the connection between all the presented theoretical prescriptions, the observations and the numerical simulations for the case of the luminosity distance will be discussed.

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Adiabatic Solutions in General Relativity and Boundary Symmetries

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We use Weinberg's trick for adiabatic modes in a Manton approximation for general relativity on manifolds with spatial boundary. This results in a description of the time dependent solutions as null geodesics on the space of boundary diffeomorphisms, with respect to **a metric we prove to be composed solely of the boundary data**. We show how the solutions in the bulk space is determined with the constraints of general relativity. We also rephrase our description in the language of geometric continuum mechanics (see e.g. 1).
We show for the solutions we propose, the **Hamiltonian constraint becomes the real homogeneous Monge-Ampere equation** in the special case of two spatial dimensions.

1D. D. Holm, J. E. Marsden, and T. S. Ratiu, "The Euler-Poincare equations and semidirect products with applications to continuum theories",Advances in Mathematics 137 no. 1, (1998) 1-81.

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Retarded potentials and radiation in odd dimensions

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Free massless fields of any spin in flat D-dimensional spacetime propagate at the speed of light. But the retarded fields produced by the corresponding point-like moving sources share this property only for even D. Since the Green's functions of the d'Alembert equation are localized on the light cone in even-dimensional spacetime, but not in odd dimensions, extraction of the emitted part of the retarded field in odd D requires some care. We consider the wave equations for spins 0, 1, and 2 in five-dimensional spacetime and analyze the fall-off conditions for the retarded fields at large distances. It is shown that the farthest part of the field contains a component propagating at the speed of light, while the non-derivative terms propagate with all velocities up to that of light. The generated radiation will contain a radiation tail corresponding to the complete prehistory of the source's motion preceding the retarded moment of time. We also demonstrate that dividing the Green's function into a part localized on the light cone and another part that is not zero inside the light cone gives separately the divergent terms in the Coulomb field of a point source. Their sum, however, is finite and corresponds to the usual power-law behaviour.

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Quantum imprints of gravitational shockwaves

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Gravitational shockwaves are simple exact solutions of Einstein equations representing the fields of ultrarelativistic sources and idealized gravitational waves (shocks). Historically, much work has focused on shockwaves in the context of possible black hole formation in high energy particle collisions, yet they remain at the forefront of research even today. Representing hard modes in the bulk, shocks give rise to the gravitational memory effect at the classical level and implant supertranslation (BMS) hair onto a classical spacetime at the quantum level. The aim of this paper is to further our understanding of the 'information content' of such supertranslations. Namely, we show that, contrary to the several claims in the literature, a gravitational shockwave *does leave* a quantum imprint on the *vacuum state* of a test quantum field and that this imprint is accessible to local observers carrying Unruh–DeWitt (UDW) detectors in this spacetime.

MHD Processes Near Compact Objects

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Geometrically thick tori around compact objects with a quadrupole moment

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We study geometrically thick perfect-fluid tori with constant specific angular momentum, so-called “Polish doughnuts”, orbiting deformed compact objects with a quadrupole moment. More specifically, we consider two different asymptotically flat, static and axisymmetric vacuum solutions to Einstein’s field equation with a non-zero quadrupole moment, the q-metric and the Erez-Rosen spacetime. It is our main goal to find features of Polish doughnuts in these two spacetimes which qualitatively distinguish them from Polish doughnuts in the Schwarzschild spacetime. As a main result we find that, for both metrics, there is a range of positive (Geroch-Hansen) quadrupole moments which allows for the existence of double tori. If these double tori fill their Roche lobes completely, their meridional cross-section has the shape of a fish, with the body of the fish corresponding to the outer torus and the fish-tail corresponding to the inner torus. Such double tori do not exist in the Schwarzschild spacetime.

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Calculation of the tensor components of the kinetic coefficients of arbitrarily degenerate electrons in the neutron star crust.

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Analytical expressions are obtained for four tensors of kinetic coefficients from the solution of the Boltzmann equation by the Chapman-Enskog method in the 3-polynomial approximation, taking into account electron-electron collisions for the case of nondegenerate electrons in a magnetic field. For strongly degenerate electrons, asymptotically accurate analytical expressions for the thermal conductivity tensor, thermo-diffusion, diffusion, and diffusion thermal effect in the Lorentz approximation are obtained for the first time, taking into account the magnetic field. This solution has a much more complex dependence on the magnetic field than the dependencies in previous publications.
For the special case of partial degeneracy at $\epsilon_f/kT = 1.011$, analytical expressions for the kinetic coefficients in the absence of a magnetic field are obtained from the solution of the Boltzmann equation

in the 3-polynomial approximation. It is shown that the convergence of the polynomial approximation to the exact value is slower than for non-degenerate electrons.

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Magnetized Neutron Stars Propagating Through A Non-Uniform ISM

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Many neutron stars propagate through the interstellar medium with supersonic velocities, and their magnetospheres interact with the interstellar medium (ISM), forming bow shocks and magnetotails. Using numerical MHD simulations, we investigated the propagation of a magnetized neutron stars through a non-uniform ISM, the interaction of the magnetospheres with the ISM and the influence of ISM density on the shape of the magnetosphere tail. We consider the interaction of magnetized neutron stars with small-scale and large-scale inhomogeneities in the ISM. We conclude that the inhomogeneities in the ISM can change the shapes of the bow shocks and magnetotails at different values of the magnetization.

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Ultraluminous X-ray sources as magnetically powered advective flows around stellar-mass black holes

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Ultraluminous X-ray sources (ULXs) are very bright, off-nuclear, point sources with luminosity exceeding the standard Eddington limit of a stellar-mass black hole (BH). The existing physical scenarios to explain their unusual large luminosity and spectral nature are either super-Eddington accretion around a stellar-mass BH or the existence of the missing class of intermediate-mass BH (IMBH). However, most ULXs with a steep power-law spectrum can be well explained through super-Eddington accretion, while the IMBH scenario has been disputed extensively. Nevertheless, the interpretation of a significant fraction of ULXs with a hard power-law dominated state remains mysterious. For the first time, we have shown that the flow energetics of a magnetically dominated, advective, disc-outflow system around a stellar-mass BH are sufficient to explain the power of ULXs in their hard spectral states. To achieve such large luminosity, the magnetic field of the advective flow has to be larger than the corresponding Eddington magnetic field. Hence, there is neither need to incorporate the contentious IMBH scenarios nor super-Eddington accretions. We suggest that at least some ULXs are magnetically powered sub-Eddington accretors around a stellar-mass BH.

References

1 Mondal T., Mukhopadhyay B., MNRAS, 495, 350 (2020)
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The origin of hydrodynamic instability from noise in the Keplerian accretion flow and its rivalry with the magento-rotational instability

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Abstract:
We attempt to address the old problem of accretion flow: the origin of turbulence and hence transport of angular momentum in accretion flows. We undertake the problem by introducing an extra force in Orr-Sommerfeld and Squire equations along with the Coriolis force mimicking the local region of the accretion disk. Subsequently, we solve the equations with the WKB approximation method. We investigate the dispersion relation for the Keplerian flow for all possible combinations of wave vectors. Due to the very presence of extra force, we show that the flow becomes unstable for a certain range of wave vectors. We also study the Argand diagrams of the perturbation eigenmodes. This helps us to compare the different timescales corresponding to the perturbations as well as accretion. We ultimately obtain with this formalism that fluid gets enough time to be unstable and hence plausibly turbulent, particularly in the local regime of the Keplerian accretion disks. Repetition of the analysis throughout the disk explains the transport of angular momentum and matter along outward and inward directions, respectively. Apart from this, we also study the same problem in the presence of magnetic field. It helps us study whether the magneto-rotational instability (MRI) and the hydrodynamic instability due to the presence of the extra force in the flow act constructively or destructively. We obtain that it depends on the parameters (Reynolds number, the strength of the extra force, wavevenctors, etc.) involved in the problem.

Reference:
Ghosh, S., Mukhopadhyay, B., 2021, Physical Review Fluids, 6, 013903
doi:10.1103/PhysRevFluids.6.013903

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A semi-implicit multidimensional unstructured gas dynamical solver for astrophysical applications

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Astrophysical problems such as modelling of core-collapse supernovae, collapses of protostellar clouds as well as other processes, involving collapsing matter, deal with regions (e.g. protostars, protoneutron stars), where a speed of sound has much larger values, than in remaining parts of a computational domain. A time-step in explicit numerical schemes, thus, has to be bounded according to acoustic Courant-Friedrichs-Lewy condition, dictated mostly by the high speed of sound in these compact regions. In some cases, this condition can be very restrictive, and (semi-) implicit numerical schemes may outperform the explicit ones. We propose a semi-implicit solver on a collocated mesh for self-gravitating gas dynamical flows, in which only acoustic waves are treated implicitly. We use

an operator-difference approach to construct difference analogues of vector differential operators on unstructured meshes in two and three dimensions, which allows us to save the conjugacy properties of the operators. We use a Rusanov-type dissipation to get monotonic flow profiles and usual linear flux reconstruction to improve an order of spatial approximation. Results of test calculations are presented.

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Particle acceleration and high energy emission in the white dwarf binaries AE Aquarii and AR Sco

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In this presentation the white dwarf close binaries AE Aquarii and AR Sco are investigated to search for signatures of particle acceleration and associated non-thermal emission. A detailed investigation of the total Fermi-LAT data base reveal signatures of pulsed gamma-ray emission in AE Aquarii, which mimics earlier reports of transient burst-like pulsed TeV gamma-ray emission reported from this system in the 1990's. Although a similar analysis of the Fermi-LAT data of AR Sco does not reveal strong signatures of pulsed emission, our analysis allowed constraining the gamma-ray activity from this system. Recent meerKAT radio data from both these systems clearly reveal pulsar-like non-thermal emission, which clearly indicates that both these fascinating systems contain a strong particle accelerator of some sort.

Mid-Frequency Gravitational Waves (0.1-10 Hz): Sources and Detection Methods

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Space gravitational wave antenna DECIGO and B-DECIGO

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DECi-hertz Interferometer Gravitational-wave Observatory (DECIGO) is a future Japanese space gravitational-wave antenna. There are many science targets that DECIGO aims at, including the detection of primordial gravitational waves, direct measurement of the acceleration of the Universe, the revelation of the formation of massive black holes, and many others. DECIGO consists of four clusters of spacecraft, and each cluster consists of three spacecraft with three Fabry-Perot Michelson interferometers. As a pathfinder mission of DECIGO, we plan to launch B-DECIGO to demonstrate technologies necessary for DECIGO as well as to lead to fruitful multimessenger astronomy. B-DECIGO is a small-scale version of DECIGO with a sensitivity good enough to provide frequent detection of gravitational waves. In this talk, the aimed science, the mechanical and optical design, and the current status of DECIGO and B-DECIGO will be explained in detail.

Mid-Frequency Gravitational Waves (0.1-10 Hz): Sources and Detection Methods / 615

AION and AEDGE: Gravitational physics with atom interferometry

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I will discuss prospects for GW detection with AION and AEDGE, atom interferometry experiments focusing on the mid-frequency band.

Mid-Frequency Gravitational Waves (0.1-10 Hz): Sources and Detection Methods / 761

Fundamental Cosmology & Multi-band, Multi-messenger Astrophysics from the Moon

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With the advent of NASA's Artemis program, ESA's European Large Logistic Lander, and China's Chang'e mission, there is a growing impetus across funding agencies and private sectors for scientific payloads on the lunar surface. In this talk, I will review the ongoing efforts for Gravitational-Wave Lunar Observatory for Cosmology (GLOC) - the first concept design in the NASA Artemis era for a gravitational-wave observatory on the Moon. Such lunar-based detectors have a unique access to deci-Hz to 1 Hz frequencies, an astrophysically rich regime that is very challenging for the proposed Earth- and space-based detectors. I will focus on the fundamental cosmology and multi-band, multi-messenger astrophysics goals that are unique to GLOC. In doing so, I will compare the detection landscape of the elusive intermediate-mass black holes between GLOC and other prominent space-based missions, 3G detectors and deci-Hertz concepts.

Mid-Frequency Gravitational Waves (0.1-10 Hz): Sources and Detection Methods / 965

Generation, propagation and detection of gravitational waves in inhomogeneous universe

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In this talk, we shall present our recent studies on gravitational waves (GWs) produced by remote compact astrophysical sources. To describe such GWs properly, we introduce three scales, the typical wavelength of GWs, the scale of the cosmological perturbations, and the size of the observable universe. For GWs to be detected by the current and foreseeable detectors, we show that such GWs can be well approximated as high-frequency GWs. To simplify the field equations, we show that the spatial, traceless, and Lorentz gauge conditions can be imposed simultaneously, even when the background is not vacuum, as long as the high-frequency GW approximation is valid. Applying the general formulas we develop together with the geometrical optics approximation to such GWs, among several other things, we calculate the gravitational integrated Sachs-Wolfe effects due to the presence of the cosmological scalar and tensor perturbations, whereby the dependences of the amplitude, phase and luminosity distance of the GWs on these two kinds of perturbations are read out explicitly.

Mid-Frequency Gravitational Waves (0.1-10 Hz): Sources and Detection Methods / 181

Lunar Gravitational-Wave Antenna

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Gravitational waves excite quadrupolar vibrations of elastic bodies. Monitoring these vibrations was one of the first concepts proposed for the detection of gravitational waves by Joseph Weber. At laboratory scale, these experiments became known as resonant-bar detectors, which form an important part of the history of GW detection. Due to the dimensions of these bars, the targeted signal frequencies were in the kHz range. It was also Weber who suggested to monitor vibrations of Earth and Moon to search for gravitational waves in the mHz band. His Lunar Surface Gravimeter was deployed on the Moon in 1972 by the Apollo 17 crew. A design error made it impossible to carry out the intended search for GWs, but the idea remains intriguing. We have proposed a new concept, the Lunar Gravitational-Wave Antenna (LGWA), based on Weber's idea. LGWA would have a rich GW and multi-messenger science case with galactic binaries and massive black-hole binaries. It would also serve as a high-precision geophysical station shedding light on the interior structure of the Moon, the mechanisms of moonquakes, and the Moon's formation history. The key component is a next-generation, high-sensitivity seismometer to be deployed on the Moon. For its most sensitive realization, LGWA would have to be deployed in a permanent shadow near the south or north pole of the Moon to benefit from the natural cryogenic environment. This would improve the sensitivity of the seismometer and also provide a lower-noise environment due to the absence of thermally induced seismic events that were observed by the Apollo seismometers. Powering of the seismic stations and data transfer pose additional challenges for such a deployment.

Mid-Frequency Gravitational Waves (0.1-10 Hz): Sources and Detection Methods / 474

Direct Determination of Supermassive Black Hole Properties with Gravitational-Wave Radiation from Surrounding Stellar-Mass Black Hole Binaries

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A significant number of stellar-mass black-hole (BH) binaries may merge in galactic nuclei or in the surrounding gas disks. With purposed space-borne gravitational-wave observatories, we may use such a binary as a signal carrier to probe modulations induced by a central supermassive BH (SMBH), which further allows us to place constraints on the SMBH's properties. We show in particular the de Sitter precession of the inner stellar-mass binary's orbital angular momentum (AM) around the AM of the outer orbit will be detectable if the precession period is comparable to the duration of observation, typically a few years. Once detected, the precession can be combined with the Doppler shift arising from the outer orbital motion to determine the mass of the SMBH and the outer orbital separation individually and each with percent-level accuracy.

Mid-Frequency Gravitational Waves (0.1-10 Hz): Sources and Detection Methods / 460

TOBA: a Ground-Based Mid.-Frequency Gravitational-Wave Antenna

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TOBA (TOrsion-Bar Antenna) is a mid.-frequency gravitational-wave antenna. It is formed by two bar-shape test masses, each suspended as a torsion pendulum. Tidal effect originated by incoming

gravitational wave will be detected as differential angular motion of these two bars. The fundamental sensitivity is 10^(-19) Hz^(-1/2) at 0.1 Hz frequency band, assuming 10-m scale cryogenic detector. Though this sensitivity is not comparable with space antennae, it is sufficient to observe any intermediate-mass black-hole inspirals in our universe. Also, operation on ground is advantageous in development time and cost. In this presentation, we will overview the concept, development history and recent achievement of TOBA.

Mid-Frequency Gravitational Waves (0.1-10 Hz): Sources and Detection Methods / 929

Recent progress on ZAIGA

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The Zhaoshan long-baseline Atom Interferometer Gravitation Antenna (ZAIGA) is a proposed underground long-baseline atom interferometer facility, aiming for experimental research on gravitation and related problems. It will be equipped with long-baseline atom interferometers, high-precision atom clocks, and large-scale gyros. ZAIGA facility will take an equilateral triangle configuration with two 1-km-apart atom interferometers in each arm, a 300-m vertical tunnel with atom interferometers and atom clocks mounted, and a tracking-and-ranging 1-km-arm-length prototype with lattice optical clocks linked by locked lasers. The ZAIGA facility will be used for gravitational-wave detection, ultralight dark matter detection, high-precision test of the equivalence principle, clock-based gravitational red-shift measurement, rotation measurement and gravitomagnetic effect. In this talk, we will give a progress report on ZAIGA.

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Mid-Frequency Gravitational Waves (0.1-10 Hz): Sources and Detection Methods / 174

A cryogenic & superconducting inertial sensor for the Lunar Gravitational Wave Antenna and for… selenphysics

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The Lunar Gravitational-Wave Antenna (LGWA) is a proposed low-frequency gravitational-wave detector on the Moon's surface.
Its core will be composed of an array of high-end seismic sensors: CSIS (Cryogenic Superconducting Inertial Sensor).
A cryogenic environment will be used in combination with superconducting materials to open up pathways to low-loss actuators and sensor mechanics.
CSIS revolutionizes the (cryogenic) inertial sensor field by obtaining a displacement sensitivity at 0.5 Hz of 3 orders of magnitude better than current state-of-art. It will allow LGWA to be sensitive below 1 Hz, down to 1 mHz and It will also be employed in the forthcoming Einstein Telescope (ET) - a third-generation gravitational-wave detector which will make use of cryogenic technologies and that will have an enhanced sensitivity below 10 Hz. Moreover, CSIS seismic data could also be employed to get new insights about the Moon's interior… and the selenphysics (the Moon's geophysics).

Mid-Frequency Gravitational Waves (0.1-10 Hz): Sources and Detection Methods / 668

Outlook of the Mid-frequency GW Detection and AMIGO

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The mid-frequency GW band (0.1-10 Hz) between LIGO-Virgo-KAGRA detection band and LISA-TAIJI-TIANQIN detection band is rich in GW sources. In addition to the intermediate BH (Black Hole) Binary coalescence (an event is detected by LIGO-Virgo collaboration recently), the inspiral phase of stellar-mass coalescence and GWs from compact binaries falling into intermediate BHs, it also enable us to study the compact object population, to test general relativity and beyond-the Standard-Model theories, to explore the stochastic GW background, and so on. In addition to DECIGO and BBO, the detection proposals under study includes AEDGE, AIGSO, AION, AMIGO, ELGAR, INO, MAGIS, MIGA, SOGRO, TOBA, ZAIGA, etc. After a brief review of these activities in general, we focus on the progress of the AMIGO mission study.

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Multichannel Studies of Nonstationary Relativistic Stars

Multichannel Studies of Nonstationary Relativistic Stars / 360

GRB Observations on Cubsate Satellites in the "Universat-SOCRAT" Project

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Lomonosov Moscow State University Universat-SOCRAT program is aimed at using small satellites to monitor space threats
These satellites are equipped with instruments for space radiation monitoring, as well asprototypes of devices for observing transient phenomena in the Earth's atmosphere.
In particular, two satellites are equipped with scintillation phosphich detectors that detect charged particles and gamma quanta in the energy release range of 0.1–2 MeV.
The geometric factor of these instruments is≈50cm2·sr.
One of the Cubesats also carries an optical photometer, consisting of four silicon photomultipliers,which entrance windows are covered with different lightfilters.
First satellites were launched into solar-synchronous orbits with an altitude of≈550k from the Vostochny cosmodrome. This makes favorable conditions for space radiation monitoring in various areas of near-Earth space, including zones of trapped radiation, areas of precipitation,etc. Such an orbit also allows observations offlare phenomena both in the equatorial atmosphere and at high latitudes. The first results are discussed.

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Mergers, magnetars and multi-messengers

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Wide-field optical sky surveys are discovering a remarkable diversity in how stars merge, collapse and explode. The powering mechanism for many of these requires a source beyond radioactivity, plausibly a magnetic, rapidly spinning neutron star. The discovery of the electromagnetic counterpart to a pair of merging neutron stars and other rapid transients from merging binary systems illustrate the new types of explosion mechanisms in the transient sky. I will review some recent discoveries from explosive stellar mergers and discuss the future potential in the era of the Rubin Observatory.

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Three Stage Collapse From Prompt Multiwavelength Observations of GRB160625B

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We present the results of synchronous multiwave observations of the intrinsic gamma and optical radiation of the long GRB160625B gamma-ray burst by the MASTER Global Network, the Lomonosov Gamma-Observatory and the Konus-Wind gamma detector. We see traces of quasiperiodic optical pulsations of the intrinsic optical radiation on scales of several tens of seconds. We associate quasiperiodic pulsations with forced precession of a self-gravitating slowly collapsing object - a spinar. We also present the results of recording hard X-ray and gamma radiation, obtained by burst detectors on spacecraft. We propose a three-stage scenario for the collapse of the core of a massive star, which explains three characteristic phenomena - the X-ray precursor, the main peak of the gamma-ray burst, and the weak peak at the end of the active phase of the gamma-ray burst.

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Recent results on magnetar flares and their connections with gamma-ray bursts and fast radio bursts

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"2020 was a special year for magnetar studies. The first simultaneous detection of an FRB-like radio burst from a Galactic magnetar and its high-energy counterpart (FRB/SGR 200428) suggests that magnetars can produce FRBs.
Observations of the short γ-ray burst GRB 200415A, associated with a nearby galaxy and with properties closely resembling the huge initial pulses of magnetar giant flares (MGF), made this event, and its "twin" GRB 051103, the most promising candidates for extragalactic MGFs. We report on hard X-ray/gamma-ray properties of these events obtained with the Konus-Wind GRB experiment and discuss their implications for magnetar/FRB and magnetar/GRB connections

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Multifrequency Behaviour of High Mass X-ray Binary Systems

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In this talk the zoo of the High Mass X-ray Binary Systems (HMXBs) is presented. Among these I will discuss the X-ray/Be systems and in particular A0535 + 26/HDE245770. Through the multifrequency experimental data obtained in long observation campaigns it was possible to develop a particular model for the aforementioned system and then a general one that explains the delay between the flares in the X-band compared to those in the optical. This general model has been successfully applied to different binary systems for which the delay is known experimentally. This model can also be successfully extended to extragalactic systems in which a star is engulfed by tidal effects from the central black hole. Some examples will be shown.

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The role of the magnetic fields in GRB outflows

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We report multicolor optical imaging and polarimetry observations of the afterglow of the first TeV-detected gamma-ray burst (GRB), GRB 190114C, using the RINGO3 and MASTER II polarimeters. Observations begin 31 s after the onset of the GRB and continue until ~7000 s postburst. The light curves reveal a chromatic break at ~400-500 s, with initial temporal decay α = 1.669 ± 0.013 flattening to α ~ 1 postbreak, which we model as a combination of reverse and forward shock components with magnetization parameter RB ~ 70. The observed polarization degree decreases from 7.7% ± 1.1% to 2%-4% 52-109 s postburst and remains steady at this level for the subsequent ~2000 s at a constant position angle. Broadband spectral energy distribution modeling of the afterglow confirms that GRB 190114C is highly obscured (AV,HG = 1.49 ± 0.12 mag; NH HG = (9.0 ± 0.03) × 1022 cm-2). We interpret the measured afterglow polarization as intrinsically low and dominated by dust - in contrast to the P > 10% measured previously for other GRB reverse shocks - with a small contribution from polarized prompt photons in the first minute. We test whether first- and higher-order inverse Compton scattering in a magnetized reverse shock can explain the low optical polarization and subteraelectronvolt emission but conclude that neither is explained in the reverse shock inverse Compton model. Instead, the unexpectedly low intrinsic polarization degree in GRB 190114C can be explained if large-scale jet magnetic fields are distorted on timescales prior to reverse shock emission.

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MASTER optical observations of the blazar TXS0506+056 during the IC170922A

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MASTER Global Robotic Network of Lomonosov Moscow State University is the network of 8 robotic optical telescopes
located all over the world. One of their goals is the search for optical counterparts to short-living transients such as GRB, gravitational waves and high-energy neutrinos. It is helped by the fast reaction time of the telescopes on such alerts and their fast slewing. On September 22, 2017 the neutrino observatory IceCube detected a high-energy astrophysical neutrino candidate that was connected to the flaring blazar TXS 0506+056, located in the neutrino error-box. MASTER-Tavrida telescope started the observations of the error-box

73s after the trigger time and was able to detect the blazar minutes after the trigger. We present the earliest astronomical observation of a high-energy neutrino error box of which the variability was discovered after high-energy-neutrino detection. MASTER found the blazar TXS 0506+056 to be in the off-state after one minute and then switched to the on-state no later than two hours after the event. The effect is observed at a 50σ significance level. We also present own a unique 16 yr light curve of blazar TXS 0506+056 (518 data set).

Multiwavelength and Multi-Messenger Observations of Active Galactic Nuclei

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Radio-neutrino synergy: neutrinos are produced in numerous bright blazars

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We utilize radio interferometric (VLBI) observations to tackle the problem of determining high-energy neutrino origins. Specifically, we find blazars positionally associated with IceCube neutrino detections to exhibit stronger parsec-scale radio emission compared to the rest of the sample. The probability of a chance coincidence is only 4*10^-5 (4.1 sigma). There are at least 70 bright blazars emitting neutrinos at energies from TeVs to PeVs. Moreover, the continuous RATAN-600 monitoring helps us finding a correlation of radio flares in relativistic jets to neutrino arrival dates. The most pronounced example of such behavior is PKS 1502+106 that experienced a major flare in 2019. We demonstrate that radio blazars may explain the entire astrophysical neutrino flux derived from IceCube muon-track analyses. Our preliminary findings based on ANTARES observatory detections also show signs of neutrino-blazar association in an even wider energy range. We suggest that neutrinos can be born in photohadronic interactions within parsec-scale jets, indicating the presence of accelerated ultrarelativistic protons there.

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Multiwavelength study of high-redshift blazars

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High-redshift blazars are among the most powerful objects in the Universe. The spectral and temporal properties of 33 distant blazars (z > 2.5) detected in the high-energy gamma-ray band will be discussed using the Fermi-LAT and Swift Ultraviolet and Optical Telescope/X-ray Telescope (UVOT/XRT) data accumulated during 2008-2018. The properties of those blazar jets obtained by modeling the multiwavelength spectral energy distributions within a one-zone leptonic scenario assuming that the X-ray and gamma-ray emissions are produced from inverse Compton scattering of synchrotron and dusty torus photons will be presented and discussed.

Multiwavelength and Multi-Messenger Observations of Active Galactic Nuclei / 972

Could the flaring activities observed in Mrk 421 and 501 be explained in a lepto-hadronic scenario with two-zone emission?

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The BL Lacs Mrk 421 and Mrk 501 show fast variability in the TeV-band flares, indicating a compact emission region. The lack of correlation between X-ray and TeV flux hints at more than one emission zone. Both sources have shown temporary extreme behavior. In this work, we used a lepto-hadronic model with two-zone emission to explain the spectral energy distribution during the very high-energy flare activity. The first zone can explain the fast variability in the TeV band via photo-pion interactions where the seed photons come from a pair-plasma launched since the nuclear region. The second zone follows the standard one-zone SSC model with the main contribution in X-rays and sub-TeV energies. In addition, the first zone could emit neutrinos in TeV-energy, which can be testable by the IceCube's observations.

Multiwavelength and Multi-Messenger Observations of Active Galactic Nuclei / 861

Searching correlations between High Energy Neutrinos detected by IceCube and 4LAC Fermi-LAT Sources

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The progenitors of high-energy (HE) neutrinos detected by the IceCube observatory (> 30 TeV) remain on the discussion. Astrophysical events such as Gamma-ray bursts (GRBs), Supernova remnants (SNR), Tidal disruption events, and Active galactic nuclei (AGN) are proposed as HE neutrinos progenitors. So far, the only detection in space-time coincidence with a neutrino event is by the TXS 0506+056 blazar with the neutrino IC 170822A, in whose case, the blazar was observed in flare state at different energy bands. We use ten years of data reported by Fermi-LAT in the 4LAC catalog and search for spatial and temporal correlations between these sources with the track neutrinos detected by IceCube. We propose that photo-hadronic interactions might explain some neutrino events and the spectral energy distribution of those sources.

Multiwavelength and Multi-Messenger Observations of Active Galactic Nuclei / 726

Lepto-hadronic modeling of the emission processes in blazar jets

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The observation of a very-high-energy neutrino by IceCube (IceCube-170922A) and its association with the flaring blazar TXS 0506+056 provided the first multimessenger observations of a blazar jet, demonstrating the important role of protons in their dynamics and emission. In this paper, we present SOPRANO, a new conservative implicit kinetic code which follows the time evolution of the isotropic distribution functions of protons, neutrons and the secondaries produced in photopion and photopair interactions, alongside with the evolution of photon and electron/positron distribution functions. SOPRANO is designed to study leptonic and hadronic processes in relativistic sources such as blazars and gamma-ray bursts. Here, we use SOPRANO to model the broadband spectrum of TXS 0506+056 and 3HSP J095507.9+355101, which are associated with neutrino events, and of the extreme flaring blazar 3C 279. Each SEDs is interpreted within the guise of both a hadronic and a hybrid model. We discuss the implications of our assumptions in terms of jet power and neutrino flux.

Multiwavelength and Multi-Messenger Observations of Active Galactic Nuclei / 901

Photons and neutrinos from AGNs: a review on hadronic radiative models

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Jets from super-massive-black-holes radiate photons over the whole electromagnetic spectrum, from the radio band up to TeV gamma-rays. Understanding the radiative mechanisms at work is a fundamental step for the study of particle acceleration in black-hole's jets, and to constrain jets structure, composition, and propagation. Using the information from multi-wavelength observations, several radiative models have been developed in the last decades. They can be divided into two families, leptonic models and hadronic models, depending on the particles that are responsible for the high-energy emission: electrons/positrons or protons, respectively. While the two models are usually degenerate in their photon emission, neutrinos can only be produced in hadronic scenarios and can be seen as the smoking gun for proton acceleration in black-hole's jets. Recent results from neutrino astronomy, providing evidences for neutrino emission from active galactic nuclei, have renewed interest in hadronic radiative scenarios. In this talk I will review hadronic radiative processes with an emphasis on recent applications to multi-messenger (photon-neutrino) data.

Multiwavelength and Multi-Messenger Observations of Active Galactic Nuclei / 647

Magnetized disc-outflow symbiosis to unify blazar classification: FSRQ/BL Lac dichotomy

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The Fermi blazar observations show a strong correlation between γ-ray luminosities and spectral indices. BL Lac objects are less luminous with harder spectra than flat-spectrum radio quasars (FSRQs). Interestingly FSRQs are evident to exhibit a Keplerian disc component along with a powerful jet. We compute the intrinsic jet luminosities by beaming corrections determined by different cooling mechanisms. Observed γ-ray luminosities and spectroscopic measurements of broad emission lines suggest a correlation between the accretion disc luminosity and the intrinsic jet luminosity. Also, theoretical and observational inferences for these jetted sources indicate a signature of hot advective accretion flow and a dynamically dominant magnetic field at jet-footprint. Indeed it is difficult to imagine the powerful jet launching from a geometrically thin Keplerian disc. We propose a magnetized, advective disc-outflow symbiosis with explicit cooling to address a unified classification of blazars by controlling both the mass accretion rate and magnetic field strength. The large-scale strong magnetic fields influence the accretion dynamics, remove angular momentum from the infalling matter, help in the formation of strong outflows/jets, and lead to synchrotron emissions simultaneously. We suggest that the BL Lacs are more optically thin and magnetically dominated than FSRQs at the jet footprint to explain their intrinsic γ-ray luminosities.

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Multiwavelength and Multi-Messenger Observations of Active Galactic Nuclei / 783

Neutrino emission from hadronic X-ray Blazar Flares

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Blazars are a subclass of active galaxies with jets closely aligned to the observer's line of sight. In addition, they are the most powerful persistent sources across the electromagnetic spectrum in the universe. The detection of a high-energy neutrino from the flaring blazar TXS 0506+056 and the subsequent discovery of a neutrino excess from the same direction have naturally strengthened the hypothesis that blazars are cosmic neutrino sources. The lack, however, of gamma-ray flaring activity during the latter period challenges the standard scenario of correlated gamma-ray and high-energy neutrino emission in blazars. Motivated by a novel theoretical scenario where neutrinos are produced by energetic protons interacting with their own X-ray synchrotron photons, we make neutrino predictions for X-ray flaring blazars. Our sample consists of all blazars observed with the X-ray Telescope (XRT) on board Swift more than 50 times from November 2004 to November 2020. To statistically identify an X-ray flaring state we apply the Bayesian Block algorithm to the 1 keV XRT light curves of frequently observed blazars. Using X-ray spectral information during the flaring states, we compute for each flare the 1-10 keV energy fluence, which is a good proxy for the all-flavor neutrino fluence in the adopted theoretical scenario. We present the expected number of muon neutrino events above 100 TeV expected with IceCube for each source as well as the stacked signal from all X-ray flares of the selected sample. We discuss the implications of our results for IceCube and IceCube Gen-2.

New Horizons in Cosmology with CMB Spectral Distortions

New Horizons in Cosmology with CMB Spectral Distortions / 30

Testing the expansion rate with the cosmological recombination lines

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Current measurements of the CMB anisotropies have given us unprecedented precision surrounding the standard ΛCDM model of cosmology and the parameters that make up this model. The data accrued by collaborations like Planck have even allowed us to test additional models of fundamental physics. These models have grown more recently in the context of diluting the tension between low-redshift and high-redshift measurements of the Hubble constant. With the exquisite data, we required a deeper understanding of recombination physics, particularly focused on the relationship between the electrons and the photons. Consequently, we can now calculate the distortions to the CMB black body from such an interaction. In this talk, I am going to demonstrate how we could measure these distortions in future experiments (e.g., Voyage 2050) and discuss the impact on the recombination radiation when we add exotic physics such as early dark energy or fundamental constant variations.

New Horizons in Cosmology with CMB Spectral Distortions / 282

Primordial black holes and their relation with spectral distortions

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I will review the current status of primordial black holes and their relation with spectral distortions.

New Horizons in Cosmology with CMB Spectral Distortions / 1036

Testing dark matter interactions with CMB spectral distortions

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Possible interactions of dark matter (DM) with Standard Model (SM) particles can be tested with spectral distortions of the cosmic microwave background (CMB). In particular, a non-relativistic DM particle that scatters elastically with photons, electrons or nuclei imprints a negative chemical potential μ to the CMB spectrum, as I will explain in this talk. I will show how this effect can be used to derive upper bounds to the DM-SM elastic-scattering cross section for DM masses $m_\chi \lesssim 0.1$ MeV, from the non-detection of μ-distortions by FIRAS, and forecast the sensitivity of future spectral distortion measurements. As a specific example, I will discuss the sensitivity of spectral distortions to the electric and magnetic dipole moments of DM.

New Horizons in Cosmology with CMB Spectral Distortions / 576

Microwave spectro-polarimetry of matter and radiation across space and time

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I will discuss the science case for a sensitive spectro-polarimetric survey of the microwave sky. Such a survey would provide a tomographic and dynamic census of the three-dimensional distribution of hot gas, velocity flows, early metals, dust, and mass distribution in the entire Hubble volume. It would also exploit CMB temperature and polarisation anisotropies down to fundamental limits, and track energy injection and absorption into the radiation background across cosmic times by measuring spectral distortions of the CMB blackbody emission. Such a survey could be carried out with a large space mission featuring a broad-band polarised imager and a moderate resolution spectro-imager at the focus of a 3.5m aperture telescope actively cooled to about 8K, complemented with absolutely-calibrated Fourier Transform Spectrometer modules observing at degree-scale angular resolution in the 10-2000 GHz frequency range.

New Horizons in Cosmology with CMB Spectral Distortions / 311

New Planck tSZ map and its cosmological analysis

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The thermal Sunyaev-Zeldovich (tSZ) effect is produced by the inverse Compton scattering of cosmic microwave background (CMB) photons by hot electrons, particularly in galaxies clusters. It has been used as a powerful probe to constrain the cosmological parameters, given its particular sensitivity to sigma8 and omega_m.

We present a new all-sky tSZ map constructed from the latest Planck PR4 data released in 2020 with the MILCA algorithm. We will review the obtained improvements in this tSZ map in terms of signal-to-noise and resolution with respect to the map produced by the Planck collaboration in 2015. We will also present the results of the cosmological analysis with this new tSZ map.

New Horizons in Cosmology with CMB Spectral Distortions / 513

Theoretical and numerical aspects of CMB spectral distortions from non-thermal electromagnetic energy injections

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CMB spectral distortions is one of the cleanest probe for electromagnetic energy injection scenarios in the pre-recombination universe. Energy injection without the addition of extra photons gives rise to CMB spectral distortion below z<2*10^6 due to inefficiency of photon non-conserving processes. During this epoch, Compton scattering is the dominant process which drives the evolution of coupled CMB photons and the background electrons. Traditionally, the distorted CMB spectrum is evolved by solving the Kompaneets equation which assumes Compton scattering to be non-relativistic. We will verify the accuracy of this assumption by solving the exact Compton kernel equation. We will show that relativistic corrections to non-relativistic Compton scattering is important for predicting the precise shape of CMB spectral distortions. We will explore the implications of using the exact Compton kernel for non-thermal electromagnetic energy injections and deriving accurate constraints on dark matter decays or annihilation.

New Horizons in Cosmology with CMB Spectral Distortions / 760

Constraining dark photons from CMB data

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Photons propagating through the Universe acquire the effective mass that depends on the local density of free charges. This means that if a light new particle that mixes with photons (e.g. dark photon or axions) exists in Nature, photons can be resonantly converted into such particles at numerous places along a typical line of sight. In particular, this can result in specific distortions both in the energy spectrum and small-scale anisotropies in the CMB. Utilizing the results from the EAGLE 100 Mpc simulation, we predict the distribution of the conversion probability over the sky. Comparing these predictions with the brightness temperature measurements of COBE/FIRAS and the CMB anisotropy measurements of Planck and SPT allows us to rule out a significant portion of the parameter space of dark photon. The results are further applied to constrain a proposed model to explain the strength of 21 cm absorption observed by EDGES.

New Horizons in Cosmology with CMB Spectral Distortions / 413

Implications of magnetic field on IGM temperature and tSZ effect in presence of Baryon-DM interaction

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We investigate the combined effect of cosmic magnetic field and a possible non-standard interaction between baryons and dark matter (DM) on the thermal Sunyaev–Zel'dovich (tSZ) effect which depends on the temperature and the ionization state of the intergalactic medium. The drag force between the baryons and DM due to the relative velocity between them, and their temperature difference results in heat transfer between these two species. At the same time, the ambipolar diffusion and the decaying magnetic turbulence tends to heat up the baryons. This interplay of these two processes give rise to different evolution histories of the thermal and ionization state of the universe and hence influences the cosmic microwave background (CMB) spectrum at small scales through the tSZ effect. In this work, we have computed the evolution of the temperature, ionization fraction, and the y-parameter of the CMB for different strengths of the magnetic field and the interaction cross-section. We note that the y-parameter can be significantly enhanced with the inclusion of magnetic field and baryon–DM interaction as compared to the case when these are absent. The enhancement depends on the strength of the magnetic field.

New Horizons in Cosmology with CMB Spectral Distortions / 173

CMB μT cross-correlations as a probe of PBH scenarios

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We propose a new method for probing inflationary models of primordial black hole (PBH) production, using only CMB physics at relatively large scales. In these scenarios, the primordial power spectrum profile for curvature perturbations is characterized by a pronounced dip, followed by a rapid growth towards small scales, leading to a peak responsible for PBH formation. We focus on scales around the dip that are well separated from the peak to analytically compute expressions for the curvature power spectrum and bispectrum. The size of the squeezed bispectrum is enhanced at the position of the dip, and it acquires a characteristic scale dependence that can be probed by cross-correlatingCMB μ-distortions and temperature anisotropies. We quantitatively study the properties of such cross-correlations and how they depend on the underlying model, discussing how they can be tested by the next generation of CMB μ-distortion experiments. This method allows one to experimentally probe inflationary PBH scenarios using well-understood CMB physics, without considering non-linearities associated with PBH formation and evolution.

New Horizons in Cosmology with CMB Spectral Distortions / 857

Constraint on the dark matter halo formation in the early universe by the free-free emission

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We propose that the free-free spectrum in the CMB frequency range provides the constraint on the dark matter halo formation in the early universe
and the density fluctuations on small scales.
When dark matter halos form, gas in the dark matter halos can be heated
and ionized depending on their virial temperature.
Although such hot ionized gas is cooled and recombined to the neutral state by Compton scattering, they can produce free-free emission as long as the gas is heated enough to be ionized.
We show this emission can contribute to the background free-free spectrum and the amplitude depends on the fluctuations on small scales.
We find that the current observed free-free emission at high galactic latitude can provide the constraint on
the density fluctuations on $k \sim \mathcal{O}(10)\mathrm{Mpc}^{-1}$.

New Horizons in Cosmology with CMB Spectral Distortions / 919

CMB as backlight: Deeper look into galaxy clusters with lensing and SZ effects

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The cosmic microwave background (CMB) acts as a backlight to the entire observable universe, and the ideas for using its distortion signatures, imprinted upon by the intervening large-scale structure, are an endless source of astrophysical probes that are limited only by our experimental reach. I review some of the ideas collected while responding to ESA's Voyage 2050 proposal call, specifically focusing on lensing and SZ effect probes related to the study of galaxy clusters. Two recent examples that we have worked on are: an improved method for cluster mass reconstruction with CMB-lensing using a simple map-based technique, and the prospect of constraining the average magnetic field within galaxy clusters using nonthermal SZ effect measurements.

New Horizons in Cosmology with CMB Spectral Distortions / 664

Probing Axion-Like Particles from the upcoming CMB experiments

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Cosmic Microwave Background (CMB) is a powerful probe to the Universe which carries signatures of cosmic secrets over a vast range of redshifts. Along with spatial fluctuations, spectral distortions of CMB blackbody are also a rich source of cosmological information. In my talk, I will introduce a new kind of spectral distortion of CMB which can arise due to the conversion of CMB photons into Axion- Like Particles (ALPs) in the presence of an external magnetic field. This effect leads to both polarized and unpolarized spatially varying spectral distortion signals with a unique spectral shape when CMB photons undergo resonant and non-resonant conversion into ALPs in the presence of the magnetic field of the Milky Way, galaxy clusters, and voids. I will discuss the spatial structure of this distortion which can arise from Milky Way and galaxy clusters and will show its uniqueness

from other known cosmo- logical and astrophysical signals using which we can probe unexplored parameter space of photon ALPs coupling.

New Horizons in Cosmology with CMB Spectral Distortions / 1038

CMB spectral distortions: the COSMO experiment

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The COSmic Monopole Observer (COSMO) is an experiment to measure spectral distortions of the Cosmic Microwave Background (CMB). Deviations from a pure blackbody spectrum are expected at low level (< 1 ppm) due to several astrophysical and cosmological phenomena, and promise to provide important independent information on the early and late phases of the universe. They have never been detected due to the extreme accuracy required, the best upper limits being still those from the COBE-FIRAS mission. COSMO is based on a cryogenic differential Fourier Transform Spectrometer, measuring the spectral brightness difference between the sky and an accurate cryogenic blackbody. The first implementation of COSMO, funded by the Italian PRIN and PNRA programs (see http://cosmo.roma1.infn.it for details), will operate from the Concordia station at Dome-C, in Antarctica, and will take advantage of a fast sky-dip technique to get rid of atmospheric emission and its fluctuations, separating them from the monopole component of the sky brightness. In the talk we will describe the instrument design, its capabilities, the current status, and its subsequent implementation in a balloon-flight, which has been studied within the COSMOS program of the Italian Space Agency.

New Horizons in Cosmology with CMB Spectral Distortions / 79

The role of CMB spectral distortions in the Hubble tension

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Although both early and late-time modifications of the ΛCDM model have been proposed to address the Hubble tension, compelling arguments suggest that for a solution to be successful it needs to modify the expansion history of the universe prior to recombination. This greatly increases the importance of precise CMB observations, and in this talk I will make the argument for CMB spectral distortions (SDs), highlighting their potential role in constraining models (like e.g. Early Dark Energy) that introduce significant shifts in the standard ΛCDM parameters, such as the scalar spectral index, in attempt to solve the Hubble tension. Furthermore, in addition to the physical interpretation of the results I will also briefly present the novel numerical implementation of SDs in the cosmological codes CLASS and MontePython that was employed to investigate the aforementioned scenario.

New Horizons in Cosmology with CMB Spectral Distortions / 1037

Spectral distortion constraints on photon injection from low-mass decaying particles

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Spectral distortions (SDs) of the cosmic microwave background (CMB) provide a powerful tool for studying particle physics. We study the distortion signals from decaying particles that convert directly into photons at different epochs during cosmic history, focusing on injection energies Einj ≲ 20 keV. We consider the effect of blackbody-induced stimulated decay, which can modify the injection history significantly. Then, we use data from COBE/FIRAS and EDGES to constrain the properties of the decaying particles. We explore scenarios where these provide a dark matter (DM) candidate or constitute only a small fraction of DM. Our model-independent constraints exhibit rich structures in the lifetime-energy domain, covering injection energies Einj ≃ 10-10 eV - 10 keV and lifetimes τX ≃ 105 s - ≃ 1033 s. Finally, we will discuss the constraints on axions and axion-like particles that convert directly into two photons. Future CMB spectrometers could significantly improve the obtained constraints, thus providing an important complementary probe of early-universe particle physics and dark matter.

New Horizons in Cosmology with CMB Spectral Distortions / 1040

Unveiling the early universe with CMB spectral distortions

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Abstract not provided.

New Horizons in Cosmology with CMB Spectral Distortions / 983

Cross-correlation between CMB polarization and mu-distortion anisotropies as a path towards the detection of small-scale primordial non-Gaussianity

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The dissipation of primordial perturbation modes with wavenumbers $50\,\mathrm{Mpc}^{-1} < k < 10^4\,\mathrm{Mpc}^{-1}$ in the early Universe cause μ-type spectral distortions to the average CMB blackbody radiation. Besides, some inflation scenarios (multi-field or single-field inflation with modified initial state) predict large primordial non-Gaussianity at these scales, so that non-Gaussian couplings between short and long-wavelength modes can modulate the damping of small-scale perturbations across different directions in the sky, and thus induce *anisotropic* μ-distortions which are furthermore correlated with CMB temperature and polarization anisotropies.

Through signal enhancement by cross-correlation with CMB anisotropies, the μ-distortion anisotropies could potentially be detected by future CMB imagers like the *LiteBIRD* satellite, and would allow to

constrain $f_{\rm NL}$ at the very small scales $50\,{\rm Mpc}^{-1} < k < 10^4\,{\rm Mpc}^{-1}$ which are inaccessible to both CMB anisotropies and LSS surveys.

In this talk we will present our forecasts on the recovery of the cross-power spectra $C_\ell^{\mu T}$ and $C_\ell^{\mu E}$ between μ-distortion anisotropies and CMB temperature and E-mode polarization anisotropies in the presence of astrophysical foregrounds for a LiteBIRD-type experiment. In particular, we will show how μ-E correlations (i.e. $C_\ell^{\mu E}$) actually provide more constraining power on $f_{\rm NL}$ than μ-T correlations in the presence of foregrounds, and how the sensitivity to $f_{\rm NL}$ at small scales can be further increased by the joint analysis of μ-T and μ-E correlations.

New Horizons in Cosmology with CMB Spectral Distortions / 819

BISOU: a balloon project to measure the CMB spectral distortions

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With the success of the ESA Planck mission, the concordance cosmological models is established as the reference framework. However, outstanding questions about this model are still unanswered. In particular the simplest inflationary model proposed as the origin of the initial matter perturbations is favoured by Planck measurement of the spectral index and low non-Gaussianity. Nevertheless, it still needs to be confirmed through the measure of its smoking gun signature: the relic background of primordial gravitational waves. The latter can only be observed through the CMB polarisation:

namely B-modes. The CMB frequency spectrum is another key observable to probe the cosmological model. Departures of the CMB blackbody spectrum, i.e. spectral distortions, encode information about the full thermal history of the Universe from the early stages (primordial distortions from inflation and cosmological recombination lines) until today (star formation and galaxy clusters). Many of these processes (in particular the late time ones) are part of our standard cosmological model and are expected to leave spectral distortions.

The BISOU (Balloon Interferometer for Spectral Observations of the Universe) project aims to study the viability and prospects of a balloon-borne spectrometer, pathfinder of a future space mission dedicated to the measurements of the CMB spectral distortions, in order to achieve a first measurement. A balloon concept based on a Fourier Transform Spectrometer, covering a spectral range from about 90 GHz to 2 THz, adapted from previous mission proposals such as PIXIE and PRISTINE, is being studied and modelled. Taking into account the specificities of a balloon flight in term of requirements and conditions (i.e. residual atmosphere, observation strategy for instance), this CNES phase 0 study will evaluate if such an spectrometer is sensitive enough to measure at least the Compton y-distortion while consolidating the instrumental concept and improving the readiness of some of its key sub-systems.

Non Standard Cosmological Probes

Non Standard Cosmological Probes / 644

Cosmological constraints from Surface Brightness Fluctuations

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The surface brightness fluctuations (SBF) method is one of the most robust extragalactic distance indicators: with an accuracy comparable to SNe Ia and Cepheids (~5% per galaxy) without the limitations of the serendipitousness intrinsic of SNe, or the long observing campaigns needed for Cepheids. Moreover, it is used in a wide range of distances: from very local, up to values relevant for measuring H0.

In this talk, I will overview the technique and present its great potential with future applications based on forthcoming ground and space-based facilities.

Non Standard Cosmological Probes / 924

Cosmology with the Secular Redshift Drift

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In a non-empty universe, the Hubble expansion is dynamic. Under the current cosmological paradigm, the expansion decelerated when the universe was matter-dominated but is now accelerating due to dark energy. The dynamic expansion can be observed directly as a secular cosmological redshift drift, and this measurement does not rely on the cosmological distance ladder or any cosmological model. The expected drift is very small, reaching a peak acceleration of roughly 0.4 cm/s/yr, but the ability of future astronomical facilities to measure this effect is nevertheless promising. I will review the expected signal, its dependence on cosmological parameters, and measurement forecasts based on radio and UV observations of neutral hydrogen transitions.

Non Standard Cosmological Probes / 391

Standard siren cosmology

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By observing the gravitational waves from the coalescence of a compact binary merger, it is possible to directly infer the luminosity distance to the source. This measurement does not use a distance ladder; the calibration is provided directly from the theory of general relativity. We discuss the present state of the field of GW cosmology, and its future promise.

Non Standard Cosmological Probes / 352

Unraveling the Universe with cosmic voids

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Modern surveys provide access to high-quality measurements on large areas of the sky, sampling the galaxy distribution in detail also in the emptiest regions, voids. Void cosmology is becoming an increasingly active sector of galaxy clustering analysis: by measuring void properties, such as density profiles or void number counts, it is possible to constrain cosmological parameters. Cosmic voids are particularly sensitive to the properties of dark energy and neutrinos, and are a powerful tool to test modifications of the laws of general relativity. Studying voids provides a novel perspective to unravel the unsolved mysteries of our Universe.

In this talk I introduce cosmic voids as a tool for cosmology, I present recent results–with a particular focus on the advantages of calibration-free approaches–and I discuss future developments in the field.

Non Standard Cosmological Probes / 578

Gamma-ray bursts as cosmological probes

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Gamma-ray bursts are among the most luminous transients in the Universe, a characteristic that permits us to observe them at very high redshifts. For this reason, many efforts have been made to identify a method to use GRBs as cosmological distance indicators through the use of luminosity correlations between their high-energy observable quantities. In this talk, I will review some of the most promising methods proposed so far to standardize GRBs and discuss if they can provide a significant contribution to cosmology.

Non Standard Cosmological Probes / 781

Time-delay cosmography: the present and the future

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The arrival time delays of multiply imaged strong gravitationally lensed sources provides a one-step cosmological distance measurement. The methodology, known as time-delay cosmography, rose to prominence to provide precise measurements of the Hubble constant, independent of the local distance ladder and the cosmic microwave background. I introduce the methodology and key ingredients, as well as possible systematics. I will then highlight the progress made in the last decade, present the recent results obtained, and present an outlook in the near future.

Non Standard Cosmological Probes / 368

A new measurement of the expansion history of the Universe from cosmic chronometers in the LEGA-C survey

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Massive and passive galaxies can be used as *cosmic chronometers* to study the expansion history of the Universe. In particular, by following their differential age evolution over different cosmic epochs it is possible to obtain direct measurements of the Hubble parameter, $H(z)$. However, robust age estimates require deep spectroscopy to break internal degeneracies between stellar population parameters (e.g. age and chemical content). In this work, we take advantage of the high quality of LEGA-C survey Data Release 2 data in terms of spectral resolution and signal-to-noise ratio to constrain the physical properties of a population of 140 massive and passive galaxies at $z \sim 0.7$. From the analysis of the age-redshift relation of this sample, we obtain a new measurement of $H(z)$, assessing in detail its robustness and dependence on systematic effects. We use these data also to extract information on cosmological parameters, in particular on Ω_m and H_0, that we discuss in the framework of the current H_0 tension.

Non Standard Cosmological Probes / 312

Constraining neutrino mass using three-point mean relative velocity statistics

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Velocity field provides an alternative avenue to constrain cosmological information, and one of the commonly used statistics is the mean radial pairwise velocity. In this talk, we consider the three-point mean relative velocity (i.e. the mean relative velocities between pairs in a triplet), and show

that it is a novel probe of neutrino mass estimation. We explore the full cosmological information content of the halo mean pairwise velocities, and the mean relative velocities between halo pairs in a triplet using 22,000 simulations from the Quijote suite. We find that the mean relative velocities in a triplet allows a 1-sigma neutrino mass constraint of 0.065 eV, an order of magnitude better than the mean pairwise velocity constraint. We also introduce a new estimator based on three-point mean relative velocities, and showcase how it can constrain neutrino mass independent of sigma8 and optical depth alleviating the degeneracy with these parameters. These results illustrate the possibility of exploiting the mean three-point relative velocities for constraining the cosmological parameters accurately from future cosmic microwave background experiments and peculiar velocity surveys.

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Cosmology with neutral hydrogen (HI) intensity mapping

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I will describe how radio instruments like MeerKAT and the SKA can kick off an exciting new era in cosmology, by using the intensity mapping technique. I will emphasise the importance of synergies with optical galaxy surveys like Euclid and LSST. I will also talk about pathfinder data analysis work, in particular the recent GBT-eBOSS detections, and the analysis of Science Verification data from MeerKAT.

Non Standard Cosmological Probes / 385

What quasars can tell us on the accelerating Universe

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I will present the latest results on our analysis of the non-linear X-ray to ultraviolet luminosity relation in a sample of optically selected quasars from SDSS, cross-matched with the most recent XMM-Newton and Chandra catalogues. I will show that this correlation is very tight, implying that the observed relation is the manifestation of an ubiquitous (but still unknown) physical mechanism, that regulates the energy transfer from the accretion disc to the X-ray emitting corona in quasars. I will then discuss what the perspectives of quasars in the context of observational cosmology are and present new measurements of the expansion rate of the Universe in the redshift range z=0.5-7.5 based on a Hubble diagram of quasars.

Non Standard Cosmological Probes / 784

The Renaissance of Cosmography: new challenges from non standard cosmological probes

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Explaining the accelerated expansion of the Universe is one of the most challenging topic in physics today. Cosmography provides information about the evolution of the universe, assuming only that the space time geometry is described by the Friedman-Lemaitre-Robertson-Walker metric.Cosmography traditionally involves Taylor expansions of the observable quantities, and the results of this approach are independent from any hypothesis about the cosmological model at late-time epochs. However, this approach is weakened by the convergence problems of the Taylor polynomials at high redshifts. To overcome these problems, new expansion have been provided, as the rational Padé polynomials, which extend the convergence radius of the standard cosmographic series, or the Chebyshev polynomials. We perform a high-redshift analysis based not only on standard probes, as the Pantheon type Ia supernovae data set, but also on non standard cosmological probes, as the gamma-ray burst Hubble diagram, measurements of the Hubble parameter, quasar Hubble diagram. Our high-redshift cosmographic analysis confirms that the expansion of the universe currently accelerates; the estimation of the jerk parameter indicates a possible deviation from the standard ΛCDM cosmological model.

Non Standard Cosmological Probes / 457

Exploring new paths to constrain the expansion history of the Universe with Cosmic Chronometers:

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In this talk, I will present a novel approach to obtain constraints on the expansion rate of the Universe based on the differential age evolution of "cosmic chronometers". The strength of this method is that it allows a direct measurement of the Hubble parameter $H(z)$ without relying on any cosmological assumptions, providing an ideal framework to test cosmological models.
I will review the latest results obtained, both in terms of $H(z)$ measurements and of treatments of systematics, and I will discuss how this data can be used to constrain cosmological models, how these results compare with the ones obtained with more standard probes, and, finally, also how they can provide some helpful insight in the H_0 controversy.

Non Standard Cosmological Probes / 269

Closing the cosmological loop with the redshift drift

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The redshift drift (also known as the Sandage Test) is a model-independent probe of fundamental cosmology, enabling us to watch the universe expand in real time, and thereby to confirm (or not) the recent acceleration of the universe without any model-dependent assumptions. On the other hand, by choosing a fiducial model one can also use it to constrain the model parameters, thereby providing a consistency test for results obtained with other probes. The drift can be measured by the Extremely Large Telescope (Liske et al. 2008) and also by the full SKA (Klockner et al. 2015). Recently two alternative measurement methods have been proposed: the cosmic accelerometer (Eikenberry et al. 2020), and the differential redshift drift (Cooke 2020). Here we present a comparative analysis

of the various methods and their possible outcomes. We find that no single method is uniformly better than the others. Instead, their comparative performance depends both on experimental parameters (including the experiment time and redshift at which the measurement is made) and also on the scientific goal (e.g., detecting the drift signal with high statistical significance, constraining the matter density, or constraining the dark energy properties). In other words, the experiment should be optimized for the preferred scientific goal.

Non Standard Cosmological Probes / 873

Constraining cosmological parameters with cosmic environments

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The spatial distribution of matter depicts a complex pattern commonly referred to as the 'cosmic web' in which massive nodes are linked together by elongated filaments found at the intersection of thin mildly-dense walls, themselves surrounding large and empty voids.
The intrinsically different gravitational dynamics history that each environment experience leaves an imprint on the present matter distribution. One of the main objective of the forthcoming galaxy redshift surveys is to accurately constrain cosmological parameters, in particular the sum of neutrino mass, using clustering statistics.

In this work, using N-body simulations from the Quijote suite, we classify the matter into the different cosmic environments depending on their level of local tidal anisotropies. Focusing on the power spectrum multipoles and using a Fisher analysis, we find that the constraints on five cosmological parameters and the sum of neutrino mass show a sizeable gain in information when combining different cosmic environments rather than using all the particles. This gain is observed in both real and redshift space as the combination of power spectrum multipoles of different cosmic web environements is able to break some key degeneracies (e.g. the summed neutrino mass - σ_8).

Non Standard Cosmological Probes / 1018

The results of analysis of Ia supernovae redshift distribution on data of the Asiago Supernova and Open Supernova Catalogues

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The shape of redshift distribution for uniform sources set in our Metagalaxy defined by cosmological parameters and properties of space is Euclidean at small redshifts and de-Sitter at z>0.7. Firstly the parameters of our Metagalaxy Ω and Λ were determine due sample of Ia supernovae from the Supernova Cosmology Project analysis in 1998. Now several thousand supernovae characteristics analyzed in new catalogues. The results of the redshift distribution analysis for supernova from the Asiago Supernova and Open Supernova Catalogues are discussed in this work. The preliminary results of data analysis show that several peculiarities are presented in Ia supernovae redshift distribution at z>0.4.

Numerical Relativity and Gravitational Wave Observations

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Learning orbital dynamics of binary black hole systems from gravitational wave measurements

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We introduce a gravitational waveform inversion strategy that discovers mechanical models of binary black hole (BBH) systems. We show that only a single time series of (possibly noisy) waveform data is necessary to construct the equations of motion for a BBH system. Starting with a class of universal differential equations parameterized by feed-forward neural networks, our strategy involves the construction of a space of plausible mechanical models and a physics-informed constrained optimization within that space to minimize the waveform error. We apply our method to various BBH systems including extreme and comparable mass ratio systems in eccentric and non-eccentric orbits. We show the resulting differential equations apply to time durations longer than the training interval, and relativistic effects, such as perihelion precession, radiation reaction, and orbital plunge, are automatically accounted for. The methods outlined here provide a new, data-driven approach to studying the dynamics of binary black hole systems.

Numerical Relativity and Gravitational Wave Observations / 186

Dynamics of Quadratic Gravity in Spherical Symmetry

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We present the first numerically stable nonlinear evolution for the leading-order gravitational effective field theory (Quadratic Gravity) in the spherically-symmetric sector. The formulation relies on (i) harmonic gauge to cast the evolution system into quasi-linear form (ii) the Cartoon method to reduce to spherical symmetry in keeping with harmonic gauge, and (iii) order-reduction to 1st-order (in time) by means of introducing auxiliary variables. Well-posedness of the respective initial-value problem is numerically confirmed by evolving randomly perturbed flat-space and black-hole initial data. Our study serves as a proof-of-principle for the possibility of stable numerical evolution in the presence of higher derivatives. We also discuss physically (un)stable branches of black holes in quadratic gravity.

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An optimised PyCBC search for gravitational waves from intermediate-mass black hole mergers

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Current PyCBC-based searches detect gravitational-wave (GW) transients by matched-filtering the advanced LIGO-Virgo detector data with model waveforms. They have, to date, detected or confirmed more than 50 compact binary merger signals. But these searches perform poorly when it comes to identifying short-duration compact binary signals in Advanced LIGO-Virgo data. In this talk, we will present a new optimised PyCBC-based search that will help detect redshifted stellar-mass binary black holes and mergers producing low-range (100-1000 $M_{\odot}$) intermediate-mass black holes (IMBH). In the data collected during the first half of the third LIGO-Virgo observing (O3a) run, the search re-identified the putative IMBH binary event, GW190521, with a false alarm rate of 1 in 727 yrs, significantly lower than the previous estimate of 1 in 0.94 yr by a PyCBC-based search. Additionally, when searching for signals from simulated generically spinning binaries injected into O3a data, the search sensitivity at a false alarm rate of 1 in 100 years improves over the existing PyCBC broad parameter search by a factor of 1.2 to 3 depending on the system's total mass.

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Einstein Field Equations in Spherical Symmetry on Hyperboloidal Slices: Dual Foliation Formulation

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One of the challenges in numerical relativity is to include future null infinity in the computational domain with a well-posed formulation. Success will not only enable us to evolve any system of astrophysical interest, e.g. binary black holes and extracting the gravitational wave signal at future

null infinity, with any desired accuracy, but also help in studying various phenomena of fundamental interest. One proposal is to use hyperboloidal slices. In this talk, I will present our ongoing efforts for obtaining a well-posed formulation of the Einstein Field Equations on hyperboloidal slices, all in spherical symmetry. The natural extension will be to generalize these methods to full 3d.

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Intermediate mass black hole search in LIGO-Virgo's third observing period

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Intermediate-mass black holes (IMBHs) span the approximate mass range $100–10^5\ M_\odot$, between black holes (BHs) formed by stellar collapse and the supermassive BHs at the centers of galaxies. Mergers of massive BHs in a binary system are the most energetic gravitational-wave sources accessible by the ground-based gravitational-wave detector network, so is IMBH binary. The third observing run of the LIGO and Virgo detectors witnessed the first confirmed detection of an IMBH - GW190521, a system consistent with a binary merger with the total mass of $\sim 150\ M_\odot$. Here we report results from a gravitational wave search for IMBHs covering LIGO-Virgo's third observing period.

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Hyperbolicity of General Relativity in null folliations

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Characteristic formulations of General Relativity are based on a null folliation of the spacetime. When combined with the standard Cauchy evolution they can in principle provide highly accurate waveform modelling. During this modelling process it is typical that the full non-linear Einstein field equations are solved numerically. A numerical solution to a PDE problem can converge to the continuum one with increasing resolution only for well posed PDE problems. Well posedness of the initial value problem in the L2 norm is characterized by strong hyperbolicity of the PDE system. It was recently found that the PDE systems formed by Einstein's field equations in commonly used characteristic gauges are only weakly hyperbolic. I will review the basic features of the commonly used characteristic gauges of the Bondi family and argue that within this family a strongly hyperbolic PDE system from Einstein's field equations is not possible, if at most first derivatives of the metric are introduced as variables. I will further provide an example of how weak hyperbolicity may be demonstrated in numerical simulations.

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Optimization of model independent gravitational wave search using machine learning

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The Coherent WaveBurst (cWB) search algorithm identifies generic gravitational wave (GW) signals in the LIGO-Virgo data by looking for excess power events in the time-frequency domain, with minimal assumptions on the signal model. The standard cWB pipeline improves signal significance by removing excess noise through the application of a set of a priori defined vetoes on summary statistics estimated by the pipeline. Designing vetoes in the multidimensional space of the summary statistics is challenging, and requires re-tuning of the veto thresholds for each detector network configuration and each observing run. Furthermore, adding a detector to the detector network should improve detection efficiency, but this is not the case for the HLV network: when Virgo detector is added to the Hanford-Livingston (HL) detector network. We propose to use a machine learning (ML) method to automate the signal-noise classification in cWB, for each detector network, and optimize the pipeline sensitivity to a special class of GW events known as binary black hole (BBH) mergers. Here, we test the ML-enhanced cWB search on strain data from the first, second and first half of the third observing runs (O1, O2 and O3a) of Advanced LIGO and compare all BBH events previously reported by cWB from GWTC-1 and GWTC-2. We also discuss possible causes for the suboptimality of the HLV network. For simulated events found with a false alarm rate less than 1 yr^{-1}, we demonstrate the improvement in the detection efficiency of approximately 25% for stellar-mass BBH mergers and approximately 15% for intermediate mass black hole binary mergers. To demonstrate the robustness of the ML-enhanced search for the detection of generic BBH signals, we show that it has the increased sensitivity to the spin precessing or eccentric BBH events, even when trained on simulated quasi-circular BBH events with aligned spins.

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Gravitational-wave signatures of the hadron-quark phase transition in binary compact star mergers

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The long-awaited detection of a gravitational wave from the merger of a binary neutron star in August 2017 (GW170817) marked the beginning of the new field of multi-messenger gravitational wave astronomy. Reaching densities a few times that of nuclear matter and temperatures up to 100 MeV, such mergers also represent potential sites for a phase transition from confined hadronic matter to deconfined quark matter (HQPT). Gravitational-wave signatures of the HQPT can be subdivided according to the phase in which they are generated. A strong HQPT can already be detected in the late inspiral phase if the equation of state gives rise to a twin star property in the mass-radius curve 1. Depending on the properties of the HQPT, a signature can be created promptly after the merger or during the post-merger evolution. Especially during the postmerger evolution of the produced hypermassive/supramassive hybrid star the occurrence of a "delayed HQPT" might give a clear gravitational wave signature of the production of quark matter, if the HQPT is strong enough [2,3]. The appearance of a HQPT in the interior region of the remnant and its conjunction with the spectral properties of the emitted gravitational wave have been computed by fully general-relativistic hydrodynamic simulations.

1 Gloria Montana, Matthias Hanauske, and Luciano Rezzolla. "Constraining twin stars with GW170817." Physical Review D 99.10 (2019): 103009.

2 Lukas R. Weih, Matthias Hanauske, and Luciano Rezzolla. "Postmerger gravitational-wave signatures of phase transitions in binary mergers." Physical review letters 124.17 (2020): 171103.
3 Hanauske, Matthias, Lukas R. Weih, Horst Stöcker, and Luciano Rezzolla. "Metastable hypermassive hybrid stars as neutron-star merger remnants." The European Physical Journal Special Topics (2021): 1-8.

Numerical Relativity and Gravitational Wave Observations / 877

Localisation of a long-duration gravitational wave signal in time

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We propose a method for localising a long-duration signal (longer than a few hours) when the start time and duration of the signal are unknown. We show how the uncertainties in the time-localization of the signal reflect on signal-to-noise ratio (SNR) of the recovered signal.

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The detectability of long-duration gravitational wave signals

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Spinning neutron stars are sources of long-duration continuous waves that may be detected by interferometric detectors. We focus on long, but not infinite duration signals and derive the precise signal-to-noise ratio (SNR) when the duration is not a priori known. We illustrate the effect of gaps in the data on the SNR.

Numerical Relativity and Gravitational Wave Observations / 689

Memory-like effects due to relative velocity and acceleration

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A burst of gravitational waves creates a permanent change in separation between two initially comoving test particles; this is known as the gravitational wave memory effect. Near null infinity, two contributions to the memory effect arise: linear memory, which appears in linearized gravity and is due to changes in conserved quantities, and nonlinear memory, which arises due to the nonlinear

nature of general relativity. Moreover, the nonlinear memory is expected to be the dominant contribution to the memory effect for binary black hole mergers, such as those detected by LIGO and Virgo. In this talk, we discuss the case where the particles have initial relative velocity and acceleration, and determine the contributions of each to the final separation. Each contribution provides additional memory-like effects, and we show that a similar linear vs. nonlinear split arises near null infinity.

Numerical Relativity and Gravitational Wave Observations / 514

Eccentric binary black hole surrogate models for the gravitational waveform andremnant properties: comparable mass, nonspinning case

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We develop new strategies to build numerical relativity surrogate models for eccentric binary black hole systems, which are expected to play an increasingly important role in current and future gravitational-wave detectors. We introduce a new surrogate waveform model, NRSur2dq1Ecc, using 47 non-spinning, equal-mass waveforms with eccentricities up to 0.2 when measured at a reference time of 5500M before merger. This is the first waveform model that is directly trained on eccentric numerical relativity simulations and does not require that the binary circularizes before merger. The model includes the (2,2),(3,2), and (4,4) spin-weighted spherical harmonic modes. We also build a final black hole model,NRSur2dq1EccRemnant, which models the mass, and spin of the remnant black hole. We show that our waveform model can accurately predict numerical relativity waveforms with mismatches≈0.001, while the remnant model can recover the final mass and dimensionless spin with absolute errors smaller than ≈0.0005 and ≈0.002 respectively. We demonstrate that the waveform model can also recover subtle effects like mode-mixing in the ringdown signal without any special ad-hoc modeling steps. Finally, we show that despite being trained only on equal mass binaries, NRSur2dq1Ecc can be reasonably extended up to mass ratio q≈3 with mismatches of 0.01 for eccentricities smaller than ~0.05 as measured at a reference time of 2000M before merger. The methods developed here should prove useful in the building of future eccentric surrogate models over larger regions of the parameter space.

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Matter shells modifying gravitational wave signals

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As detections of mergers of compact bodies begin to flow in, and as we enter an era of precision GW measurements, our understanding of compact bodies, their physics and that of the surrounding astrophysical environment, will continue to grow and at times even be challenged. The need to revise the mass bounds of compact bodies such as BHs and NSs and the possibility of the existence of GW echoes are just some of consequences of the first few years of GW detection. In previous work, using linearised perturbation theory, we made the novel finding that a dust shell will cause a GW to be modified both in magnitude and phase, but without any energy being transferred to or from the dust. We extend our analysis to matter shells surrounding compact body mergers and to intervening matter in cosmology. Instead of only monochromatic GW sources, as we used in our initial

investigation, we also consider burst-like GW sources. The thin density shell approach is modified to include thick shells by considering concentric thin shells and integrating. Solutions are then found for these burst-like GW sources using Fourier transforms. In the context of cosmology, apart from the gravitational redshift, the effects are too small to be measurable. We show that GW echoes that are claimed to be present in the LIGO data of certain events, could not have been caused by a matter shell. We do find, however, that matter shells surrounding BBH mergers, BNS mergers, and CCSNe could make modifications of order a few percent to a GW signal. These modifications are expected to be measurable in GW data with current detectors if the event is close enough and at a detectable frequency; or in future detectors with increased frequency range and amplitude sensitivity.

Numerical Relativity and Gravitational Wave Observations / 922

Odd-dimensional gravitational waves from the binary system on three-brane

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If the number of extra dimensions is odd, the full spacetime becomes odd-dimensional and the formation of gravitational radiation is obscured by violation of the Huygens principle. Gravitational waves must travel with the speed of light, while the full retarded gravitational field of a localized source propagates with all velocities lower or equal to the speed of light. To calculate gravitational radiation of the system in odd dimensions is, therefore, a difficult task, so here we consider a simplified model consisting of two point masses moving on a three-brane embedded in five-dimensional spacetime and interacting only through a massless scalar field living on the same brane, while gravitational radiation is emitted into the full five-dimensional bulk.
Such a system admits the stable elliptical orbits and the interaction field is free from the problems mentioned above. We use the Rohrlich-Teitelboim approach to radiation, extracting the radiative component of the retarded gravitational field via splitting of the energy-momentum tensor. The source term consists of the local contribution from the particles and the non-local contribution from the scalar field stresses. The latter is computed using the DIRE approach to the post-Newtonian expansions. In the non-relativistic limit, we find an analog of the quadrupole formula containing the integral over the full history of the particles' motion, preceding the retarded moment of time. We analyze the gravitational radiation of the non-relativistic circular binary system and the corresponding evolution of the orbit.

Observations of HE and UHE Cosmic Rays

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The Cosmic Ray All-Particles Spectrum from the NUCLEON Experiment in comparison with EAS data

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The cosmic ray all-particles spectrum is a very important result obtained by the NUCLEON space experiment. This spectrum was directly measured up to energies near 500 TeV. The ground-based experiments provide very large statistics but their results depend on applied models. The NUCLEON experiment allows to compare results of direct measurements and data of ground-based experiments. The all-particles spectrum is presented. The shape of this spectrum differs from the power-law dependence. This difference is caused by the universal «knee» found in the rigidity spectra measured by the NUCLEON experiment. The obtained all-particles spectrum is well consistent with the data from ground-based experiments HAWC and TAIGA.

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AMS-02 Results on cosmic rays fluxes

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AMS-02 is a magnetic spectrometer operating on the ISS since May 2011. Its large acceptance and long exposure time allows to measure the fluxes of all the nuclear species in cosmic rays up to Iron. I will discuss the most recent AMS-02 measurements of primary and secondary nuclei in cosmic rays and their possible contribution to the understanding of the CR acceleration and propagation in the galaxy.

Observations of HE and UHE Cosmic Rays / 645

The fluxes of charged cosmic rays as measured by the DAMPE satellite

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The DArk Matter Particle Explorer (DAMPE) is a space mission, promoted by the Chinese Academy of Science with the collaboration of Italian and Swiss scientific institutions. Since December 2015, DAMPE orbits at the altitude of 500 km and collects data regularly. The detector is made of four sub-detectors: top layers of plastic scintillators, a silicon-tungsten tracker converter, a deep BGO calorimeter (32 radiation lengths), and a bottom boron-doped scintillator to detect delayed neutrons. A goal of the mission is the search for indirect signals of Dark Matter in the electron and photon spectra with energies up to 10 TeV. Furthermore DAMPE studies cosmic charged and gamma radiation. Indeed the calorimeter depth and the large effective area allow to measure cosmic ray fluxes in the range from 20 GeV up to hundreds of TeV. The recent measurements of the flux of electrons and positrons, protons and nuclei will be presented.

Observations of HE and UHE Cosmic Rays / 759

Recent results from the Pierre Auger Observatory

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The Pierre Auger Observatory has by now achieved an exposure of order 10^5 km^2 sr yr, exploring about 85% of the sky. In this talk I will review some of the latest results, including the detailed measurements of the features in the cosmic ray spectrum, the inferred mass composition, the tests of hadronic interactions, multimessenger searches and the study of anisotropies in the cosmic ray arrival directions both at large and small angular scales.

Observations of HE and UHE Cosmic Rays / 622

CALET on the ISS: the first 5 years

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The CALorimetric Electron Telescope CALET is collecting science data on the International Space Station since October 2015 with excellent and continuous performance. Energy is measured with a deep homogeneous calorimeter (1.2 nuclear interaction lengths, 27 radiation lengths) preceded by an imaging pre- shower (3 radiation lengths, 1mm granularity) providing tracking and 10^{-5} electron/proton discrimination. Two independent sub-systems identify the charge Z of the incident particle from proton to iron and above (Z<40). CALET measures the cosmic-ray electron+positron flux up to 20 TeV, gamma rays up to 10 TeV, and nuclei up to 1 PeV.
In this paper, we report the on-orbit performance of the instrument and summarize the main results obtained during the first 5 years of operation, including the electron+positron energy spectrum and

the individual spectra of protons, heavier nuclei and iron. Solar modulation and gamma- ray observations are also concisely reported, as well as transient phenomena and the search for gravitational wave counterparts.

Observations of HE and UHE Cosmic Rays / 553

POEMMA: Probe Of Extreme Multi-Messenger Astrophysics

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Developed as NASA Astrophysics Probe-class mission, the Probe Of Extreme Multi-Messenger Astrophysics (POEMMA) is designed to identify the sources of ultra-high energy cosmic rays (UHECRs) and to observe cosmic neutrinos with full-sky coverage for both of these extreme- energy messengers. POEMMA consists of two spacecraft flying in a loose formation at 525 km altitudes oriented to view a common atmospheric volume. Each spacecraft hosts a large Schmidt telescope with a novel focal plane optimized to observe both the UV fluorescence signal from extensive air showers (EAS) and the beamed, optical Cherenkov signals from EAS. In UHECR stereo fluorescence mode, POEMMA will measure the spectrum, composition, and full-sky distribution of the UHECRs above 20 EeV and will have remarkable sensitivity to UHE neutrinos in this energy range. In neutrino limb-viewing Cherenkov mode, POEMMA will be sensitive to cosmic tau neutrinos above 20 PeV by observing the upward-moving EAS induced from tau neutrino interactions in the Earth. POEMMA is designed to quickly re-orient to a Target-of-Opportunity (ToO) neutrino mode to view and follow transient astrophysical sources with exceptional neutrino flux sensitivity to models of both short-duration, including short gamma-ray bursts (sGRB), and long-duration transients, including binary neutron star (BNS) mergers. POEMMA's science goals and UHECR and neutrino measurement capabilities will be discussed along with a summary of POEMMA's instrument & mission designs.

Observations of HE and UHE Cosmic Rays / 910

The HERD space mission

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The High Energy cosmic-Radiation Detection (HERD) space mission is now being designed, as a result of an international collaboration
among several chinese and european institutions, to make cosmic ray (CR) direct measurements at the highest possible energies with current technologies.
HERD primary scientific goals include precise measurements of the energy spectra of CR individual species up to few PeV, reaching the knee of the all-particle spectrum, and study electrons and photon of spectra from GeV up to tens of TeV, also contributing to multi-messenger observations together with other satellites and ground-based experiments.
In order to reach these goals HERD is configured to accept incident particles from its top and the four lateral sides. The baseline design includes covering the top and fours sides with: the Silicon Charge Detector (SCD), for incident particle trajectory and charge measurement, the Plastic Scintillator Detector (PSD), for photon tagging and precise charge measurement, and a scintillating Fiber Tracker (FIT).
The core of the facility is made by a LYSO crystal calorimeter (CALO) that with its 3 interaction lengths and 55 radiation lengths will allow the measurement of incident gamma-rays, electrons and

cosmic ray nuclei with unprecedented resolution and 3D reconstruction. In addition, on one side a Transition Radiation detector (TRD) will be installed for on-orbit calibration of the CALO.

Photospheric Emission in GRBs

Photospheric Emission in GRBs / 539

Probing the jet launching mechanism from prompt emission of GRBs

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Despite years of extensive research, the launching mechanism and the nature of relativistic jets remain open questions. Using 3D RMHD simulations of GRB jets with different initial magnetizations and engine modulation timescales, we calculate the resulting prompt emission light curves by considering photospheric emission and internal shocks, and compare them with observations. Our results show that in order to reconstruct the observed high variability and efficiency of GRB light curves, the jets' degree of magnetization has to be at least ~1% and the central engine intermittency operates on ~10 ms timescales.

Photospheric Emission in GRBs / 241

Classification of Photospheric Emission in sGRBs

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In this talk, I will focus on the photospheric emission observed in the short gamma-ray bursts (GRBs). In our work, we find that several short GRBs are consistent with a pure, non-dissipative photospheric model, at least around the peak of the pulse. For these bursts, we find (i) a bimodal distribution in the values of the Lorentz factors and the hardness ratios and (ii) an anti-correlation between burst duration,T_90 and the peak energy, E_pk. These results thus imply that the short GRB population may in fact be composed of two separate populations. Our results also show that thermal emission is initially dominant, but is accompanied at longer times by additional radiation.

Photospheric Emission in GRBs / 544

A Cosmological Fireball with Thirty-Percent Gamma-Ray Radiative Efficiency

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Gamma-ray bursts (GRBs) are the most powerful explosions in the universe. The standard model invokes a relativistic fireball with a bright photosphere emission component\cite{Meszaros2000, Peer2015,Zhang2018}. How efficiently the jet converts its energy to radiation is a long-standing problem and it is poorly constrained. A definitive diagnosis of GRB radiation components and measurement of GRB radiative efficiency requires prompt emission and afterglow data with high-resolution and wide-band-coverage in time and energy. Here we report a comprehensive temporal and spectral analysis of the TeV-emitting bright GRB 190114C. Its fluence is one of the highest of all GRBs detected so far, which allows us to perform a high-resolution study on the prompt emission spectral properties and their temporal evolution down to a timescale of about 0.1 s. We identify a clear thermal component during the first two prompt emission pulses, which is fully consistent with the prediction of the fireball photosphere model. The third pulse is consistent with the afterglow onset, with emission of a synchrotron self-Compton origin in the reverse shock. These observations allow us to directly derive the fireball energy budget with little dependence on parameters\cite{Zhang2021} and to measure a nearly 30% radiative efficiency for this GRB. With the fireball energy budget derived, the afterglow microphysics parameters can be also constrained directly from the data.

Photospheric Emission in GRBs / 541

The photosphere emission spectrum of hybrid relativistic outflow for gamma-ray bursts

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The photospheric emission in the prompt emission is the natural prediction of the original fireball model for gamma-ray burst (GRB) due to the large optical depth ($\tau > 1$) at the base of the outflow, which is supported by the quasi-thermal components found in several Fermi GRBs. However, the main origin of the most prompt emission spectrum (photosphere or synchrotron) is still under hot debate. To explore this problem, the shape of the observed photosphere emission spectrum from a pure hot fireball or a Poynting-flux-dominated outflow has been investigated. In this work, we further study that for the hybrid outflow containing a thermal component and a magnetic component with moderate magnetization ($\sigma_0 = L_P/L_{\rm Th} \sim 2-9$), by invoking the probability photosphere model. It is interesting to find that the high-energy spectrum is a power-law rather than an exponential cutoff, compatible with the observed Band function in large amounts of GRBs. Also, the distribution of the low-energy indices (corresponding to the peak-flux spectra) is found to be quite consistent with the statistical result for the peak-flux spectra of GRBs best-fitted by the Band function, with the similar angular profiles of the dimensionless entropy η as those of the unmagnetized jet considered in our previous works. Finally, the observed distribution of the high-energy indices can be well understood after considering the different magnetic acceleration (due to magnetic reconnection and kink instability) and the angular profiles of η with the narrower core.

Photospheric Emission in GRBs / 318

Explaining GRB prompt emission with photospheric emission model

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Although the observed GRB prompt emission spectrum is well constrained, the underlying radiation mechanism is not very well understood. We have explored photospheric emission in GRB jets by modelling the Comptonization of fast cooled synchrotron photons whilst the electrons and protons are accelerated to highly relativistic energies by repeated energy dissipation events as well as Coulomb collisions. In contrast to the previous simulations, we implemented realistic photon-to-particle number ratios of ~100,000 or higher, that are consistent with the observed radiation efficiency of relativistic jets. Using our Monte Carlo radiation transfer code, we can successfully model the prompt emission spectrum when electrons are momentarily accelerated to highly relativistic energies (LF~50-100) powered by ~40-50 episodic dissipation events, for baryonic outflows originating from moderate optical depth ~20-30. We have shown that the resultant shape of the photon spectrum is independent of the photon energy distribution and jet baryonic energy content.

Photospheric Emission in GRBs / 127

Understanding prompt emission: where do we stand ?

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In recent years, there is a renewed debate about the origin of the observed prompt emission signal. Some authors found that synchrotron emission can dominate the spectra of several long bursts, and a recent analysis show that it may be possible to overcome the famous 'line of death' argument by a direct fitting procedure. On the other hand, several recent works showed that non-dissipative photosphere is preferred as the dominant emission model in at least 1/4 of long and 1/3 of short GRB population. In this talk I will critically review the arguments given as well as their physical consequences. I will then present some recent results that show a connection between the prompt spectra and the early afterglow emission, thereby argue for an independent method of discriminating the physical conditions that result in the different dominant radiative processes.

Photospheric Emission in GRBs / 543

Diffusive photospheres in gamma-ray bursts

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Photospheric emission from relativistic outflows may originate in two different regimes: photon decoupling within the outflow or radiative diffusion. I will discuss observed thermal component in the early afterglows of gamma-ray bursts as emission from such diffusive photospheres. In addition, I will discuss implications of photon diffusion for dissipative models of GRBs.

Photospheric Emission in GRBs / 713

Subphotospheric dissipation evaluated using joint Fermi-Swift observations

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Although the origin of gamma-ray burst (GRB) prompt emission remains an unsolved problem, progress is being made by the advent of better analysis tools and as the state of our physical models improve. It is becoming increasingly clear that the difficulties of consistently reconciling empirical models with any underlying physical processes means that we have much to gain from directly fitting physical models. Two of the main scenarios under consideration are optically thin synchrotron radiation and photospheric models based on the Comptonisation of thermal photons. In this presentation I describe my work on fitting a physical model for a particular scenario of subphotospheric dissipation to *Fermi* GRB data. I outline the physical scenario under consideration, as well as the relevant analysis tools. Additionally, I discuss goodness of fit and the issue of having multiple models that can seemingly adequately describe the observed data. Specifically, I show how we can use data outside of the *Fermi* energy range, such as *Swift*-XRT data, to help discriminate between different physical models

Photospheric Emission in GRBs / 376

Monte Carlo Simulations of Photospheric Emission in Gamma Ray Bursts

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The study of Gamma Ray Bursts (GRBs) has the potential to improve our understanding of high energy astrophysical phenomena. In order to reliably use GRBs to this end, we first need to have a well-developed grasp of the mechanism that produces the radiation within GRB jets and how that relates to their structure. One model for the emission mechanism of GRBs invokes radiation produced deep in the jet which eventually escapes the jet at its photosphere. While this model has been able to explain a number of observed GRB characteristics, it is currently lacking in predictive power and in ability to fully reproduce GRB spectra. In order to address these shortcomings of the model, we have expanded the capabilities of the MCRaT code, a state of the art radiative transfer code that can now simulate optical to gamma ray radiation propagating in a hydrodynamically simulated GRB jet. Using the MCRaT code, we have constructed mock observed light curves, spectra, and polarization from optical to gamma ray energies for the simulated GRBs. Using these mock observables, we have compared our simulations of photospheric emission to observations and found much agreement between the two. Furthermore, the MCRaT calculations combined with the hydrodynamical

simulations allow us to connect the mock observables to the structure of the simulated GRB jet in a way that was not previously possible. While there are a number of improvements that can be made to the analyses, the steps taken here begin to pave the way for us to fully understand the connection between the structure of a given GRB jet and the radiation that would be expected from it.

Photospheric Emission in GRBs / 869

Numerical simulations of photospheric emission in GRBs

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We explore the nature of photospheric emission in long and short GRBs by performing hydrodynamical simulations of relativistic jet and post-process radiation transfer calculations. Our simulations show that the structure of the jet developed during its propagation has strong imprints on the resulting light curves, spectra, and polarization. In particular, it is found that the viewing angle dependence of the emission gives rise to correlations among the spectral peak energy, E_p, peak luminosity, L_p, and isotropic energy, E_{iso}, which may provide natural explanations for the Yonetoku- and Amati-relations. We also find that the degree of polarization is small for the emission from the jet core (<2%), while it tends to increase with viewing angle outside of the core and can become as high as ~10-40% for energies larger than E_p.

Photospheric Emission in GRBs / 995

Spectroscopy of GRBs: Where are we now?

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As we are now in the era of fitting physical models to the MeV spectra of GRBs, we must address the proper way to analyze data from MeV GRB as well as how we check the quality of our fits. I will discuss the mathematically proven way to assess spectral fits, compare models, and treat the data with care. We will then apply these tools to physical models such as synchrotron emission and discuss the implications of the physical parameters. Furthermore, I will discuss where we can go from our current status to learn more about the emission mechanisms in GRBs.

Planning Gravitational Wave Detections form LISA

Planning Gravitational Wave Detections form LISA / 147

Probing Supermassive blackholes with LISA

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We study hydrodynamical simulations of galaxy formation, based on the GADGET-3 code, and investigate supermassive black hole binaries coalescence at $5.5 < z < 14$ and the expected gravitational waves emitted from the binary mergers for different AGN feedback models. A fraction of the accreted rest-mass energy is radiated away by each black hole. A fraction of this radiated energy is coupled to the surrounding gas as feedback energy. We consider the cases of AGNfiducial feedback where the feedback energy is thermal, as well as kinetic feedback,which includes AGNcone and AGNsphere,where in the former case the kinetic black hole feedback is distributed inside bicone (45\textdegree half opening angle) and in latter the kinetic feedback is distributed in sphere (90\textdegree half opening angle). We further consider the case in which no AGN feedback is implemented in the simulation. We find the merger rate for the kinetic feedback of the order between 100 to 1000 mergers per year for the chirpmass range less than 10^6
$msun$
and for the thermal feedback model to be between 100 to 500 in the same chirp mass range. We stress the comparisons to be made between simulations of same resolution: kinetic with R_{smooth}= 1ckpc/h and thermal with R_{smooth}=0.5 ckpc/h.
For each model, we estimate the expected characteristic strain of gravitational waves emitted by supermassive black hole binary mergers, the time to coalesce, and the expected number of resolved events and compare our predictions with the LISA sensitivity and resolution.
We further investigate the host galaxy properties for the events detectable by LISA and make predictions of the electromagnetic counter parts expected events to be detected by other electromagnetic instruments operating along the proposed operational time of LISA and present a panoramic view of merger events through different detectors.

Planning Gravitational Wave Detections form LISA / 149

The hierarchical assembly of galaxies and black holes in the first billion years: predictions for the era of gravitational wave astronomy

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The LISA detectability of GWs from supermassive black hole mergers will crucially depend on the physical properties of their host galaxies.
In this talk I will present a semi-analytic galaxy formation model, Delphi, that fully tracks the accretion- and merger-driven hierarchical assembly of the dark matter halo, gas, stellar, and black hole masses of high-redshift ($z > 5$) galaxies. We explore a number of physical scenarios that include (i) two types of black hole seeds (stellar and those from direct collapse); (ii) the impact of reionization; and (iii) the impact of instantaneous versus delayed galaxy mergers on the baryonic growth. Using a minimal set of mass- and redshift-independent free parameters associated with star formation and black hole growth, and their associated feedback, we show that our model successfully, and crucially, reproduces all available data sets for early galaxies and quasars. We then use this model to predict the LISA detectability of merger events at high-redshifts. We show that mergers of stellar BHs dominate the merger rates for all scenarios and our model predicts an expected upper limit of about 20 mergers using instantaneous merging and no reionization feedback over the 4-yr mission duration. I will end by showing the impact of reionization feedback and delayed mergers on the expected event rates and the most optimal LISA surveys required to reach these numbers.

Planning Gravitational Wave Detections form LISA / 199

Searching for binary black holes in the Milky Way and its neighborhood with LISA

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In 2034, within the rapidly changing landscape of gravitational-wave astronomy, the Laser interferometer Space Antenna will be the first space-based detector that will observe the gravitational spectra in the millihertz frequency band. It has recently been proposed that numerous LIGO/VIRGO sources will also be detectable by LISA. LISA will be able to detect binary black holes from our Milky Way galaxy and its neighbourhood, evolving from their early inspiral stages. Interestingly, the sources that appear to be circular in the LIGO band may be eccentric in the LISA band, depending on the earlier stages of their evolution. We aim to explore the gravitational waves emitted from black hole binaries in our Milky Way galaxy and its neighbourhood, as they are expected to be observable with LISA. Here, I will present models that combine simulation of Milky Way-like galaxy formation, and specifically, the Latte simulation from the Feedback in relativistic environments (FIRE-2) project, with the new binary population synthesis code POSYDON to investigate the detectability of inspiraling binary black hole populations in both the LISA and the LIGO frequency bands, as a function of eccentricity and their horizon distances, using a Monte-Carlo approach. Furthermore, I will discuss how one can disentangle different formation channels of these binaries using LISA, and estimate the rate and observable properties with which these binaries form in the Milky Way galaxy and other nearby galaxies.

Planning Gravitational Wave Detections form LISA / 648

Continuous gravitational waves observations from white dwarfs to constraint modified gravity theories

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This abstract is primarily based on my recent papers ApJ 909 (2021) 65 and ApJ 896 (2020) 69.

After predicting many sub- and super-Chandrasekhar limiting mass white dwarfs from the observations of peculiar type Ia supernovae, researchers have proposed various models to explain these two classes of white dwarfs separately. We showed that these two peculiar classes of white dwarfs, along with the regular white dwarfs, can be explained by a single form of the $f(R)$ gravity, whose effect is significant only in the high-density regime, and it almost vanishes in the low-density regime. However, since there is no direct detection of such white dwarfs, it is difficult to single out one specific theory of gravity. We estimate the amplitudes of all the relevant polarization modes of gravitational waves for the peculiar and regular white dwarfs. We further discuss their possible detections through future-based gravitational wave detectors, such as LISA, ALIA, DECIGO, BBO, or Einstein Telescope with a significant signal-to-noise ratio, thereby putting constraints or rule out various modified theories of gravity. This exploration links the theory with possible observations through the gravitational waves in $f(R)$ gravity.

Planning Gravitational Wave Detections form LISA / 850

Exploring Anisotropic Gravitational Wave Backgrounds and Foregrounds with LISA

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The future spaceborne gravitational wave detector LISA will probe a vast array of gravitational wave sources in the millihertz frequency band. Many of these sources will not be individually resolvable, instead adding incoherently to form stochastic gravitational wave backgrounds or foregrounds. The angular structure of these stochastic signals on the sky can be used to understand the spatial distributions, astrophysics, and evolution of their component sources. We present a technique for constraining this angular structure in the spherical harmonic basis, using Clebsch-Gordon coefficients to ensure a non-negative gravitational wave power distribution and render the problem suitable for Bayesian inference. We test this method using simulated anisotropic backgrounds as well as a simplified model of the gravitational wave foreground from galactic white dwarf binaries.

Planning Gravitational Wave Detections form LISA / 941

A new waveform model for eccentric double white dwarf binaries

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Close white dwarf binaries within our galaxy are promising sources of gravitational wave signals for Laser Interferometer Space Antenna (LISA). While the majority of such systems are expected to have circular orbits, a small portion of those formed through dynamical channels can have significant eccentricities. Analyzing the gravitational wave signals from these systems requires accurate

eccentric waveform templates. In this talk, I will describe a new waveform model for eccentric binary white dwarf systems taking tides into account. We propose a semi-analytical “kludge model” which aims to be computed fast while also being sufficiently accurate. This model gives the quadrupole radiation from a post-Keplerian orbit including the post-1-Newtonian effect on point masses as well as the quadrupolar tidal force. We include the effects on orbital evolution due to radiation reaction and tidal friction in the waveform through a Taylor series expansion of the gravitational wave phase and amplitude. I will also describe our ongoing progress in studying the effect of dynamical tides on the waveform model. The model aims to provide accurate and efficient templates to study eccentric double white dwarf binaries with LISA.

Post-Newtonian and Post-Minkowskian Corrections for Binary Gravitating Systems

Post-Newtonian and Post-Minkowskian Corrections for Binary Gravitating Systems / 76

Binary Black Holes and Scattering Amplitudes

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Future gravitational wave detectors will map out and characterize every binary merger in the history of the universe. The possibilities for new and unexpected scientific discoveries from this wealth of data is staggering, but hinges crucially on complementary advances in our theoretical understanding of the nature of gravitational wave sources. However, the path from Einstein's equation to precision binary dynamics is notoriously difficult, and conventional methods may not scale to the demands of future detectors. I will describe our recent efforts in solving the relativistic two body problem using modern tools from quantum field theory.

Post-Newtonian and Post-Minkowskian Corrections for Binary Gravitating Systems / 40

Tutti Frutti method: recent developments in the PN/PM/SF treatment of the gravitational two-body problem

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The main features of the "Tutti Frutti method" which has allowed
reaching the 6PN level of accuracy (modulo a few still unknown parameters)
in the relativistic treatment of the two-body system will be briefly introduced and discussed.
Special attention will be devoted to recent developments in the PN-PM structure of scattering angle of hyperboliclike encounters.

Post-Newtonian and Post-Minkowskian Corrections for Binary Gravitating Systems / 36

Traditional PN approach and synergy with the EFT

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Theoretical and numerical works on the two-body problem in general relativity (GR) play a very important role when detecting and interpreting the gravitational wave signals. In this talk, we review the present state-of-the-art on traditional post-Newtonian (PN) methods in GR, applied to the gravitational wave and phase evolotion of inspiralling compact binaries. In particular, we emphasize some recent developments done in synergy with the effective field theory (EFT).

Post-Newtonian and Post-Minkowskian Corrections for Binary Gravitating Systems / 22

Near zone and far zone contributions to compact binary dynamics

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The status of the EFT approach to the compact binary problem will be assessed, with a discussion of recent progress in the study of both conservative and radiative dynamics, and a glimpse on possible future developments.

Post-Newtonian and Post-Minkowskian Corrections for Binary Gravitating Systems / 75

Classical gravitational scattering from a worldline quantum field theory

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The quest of the perturbative post-Minkowskian study of the gravitational two body problem
has recently seen advances upon employing perturbative quantum field theory techniques. I report on a
novel approach based on a worldline quantum field theory that provides an efficient way to
study the classical scattering of two massive objects (BHs, neutron stars or stars) in GR. We are able to
efficiently compute the emitted Bremsstrahlung and other observables of such an invent.
Finally, I address the question of adding spin degrees of freedom to the scattered massive bodies and point out a curious relation of the scattering of Kerr BHs to an N=2 supersymmetric worldline theory.

Post-Newtonian and Post-Minkowskian Corrections for Binary Gravitating Systems / 21

Binary Black Holes at 5PN in Effective Field Theory

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Using effective field theory methods, we calculate the 5PN potential corrections to the binary black hole system, also including the tail terms, except the purely rational terms of O(\nu^2). Comparisons are made with the literature. The contributions of O(\pi^2 \nu^2) are calculated for the first time. We provide the Hamiltonian for harmonic coordinates and calculate the binding energy and periastron advance. We also present the 6PN potential contributions up to G_N^4.

Pulsar Power in Physics and Astrophysics and Pulsars and Pulsar Systems at High Energies

Pulsar Power in Physics and Astrophysics and Pulsars and Pulsar Systems at High Energies / 921

On the origin of the unique isolated X-Ray pulsar 1E 161348-5055 with 6.7 hr. spin period

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A scenario for the formation of an isolated X-ray pulsar 1E161348-5055 with an anomalously long period of 6.7 hours is proposed. It is shown that this pulsar can be a descendant of a massive X-ray binary system, which disintegrated about 2000 years ago after a supernova explosion caused by the core collapse of a massive component. X-ray radiation of this object in the present epoch is generated as a result of accretion of matter onto (about 10 million years old) neutron star from the residual accretion disk. The pulsar's nebula RCW 103 is a supernova remnant formed by the explosion of its massive companion in the final evolutionary phase of a massive binary system.

Pulsar Power in Physics and Astrophysics and Pulsars and Pulsar Systems at High Energies / 637

Pulsar timing and glitch detection with a hidden Markov model

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We present a new, complementary method of pulsar timing, which explicitly tracks the evolution of the pulse frequency and frequency derivative using a hidden Markov model (HMM). The HMM incorporates both stochastic spin wandering (timing noise) and glitches.
We describe how this framework can be used to detect glitches through Bayesian model selection with minimal human intervention and low computational cost, and how this allows for characterisation of the detector through synthetic data tests.
We also present early results of HMM-based analyses of real timing data, demonstrating the utility of this approach in two realistic contexts: searches for undetected glitches in archival data, and low-latency detection of glitches in freshly acquired data.

Pulsar Power in Physics and Astrophysics and Pulsars and Pulsar Systems at High Energies / 768

Timing PSR J2222-0137 - an important new laboratory for relativistic gravity

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In this talk, I will review the current status of the timing of PSR J2222-0137, which promises to be one of the most important laboratories for testing the nature of gravitational waves, for limiting the variation of Newton's gravitational constant, and for testing non-perturbative deviations from general relativity in the behavior of gravity (in particular the phenomenon of "spontaneous scalarization"). The occurrence of this phenomenon has been basically ruled out with our current measurements.

Pulsar Power in Physics and Astrophysics and Pulsars and Pulsar Systems at High Energies / 607

The MeerKAT relativistic binary timing programme

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Timing relativistic binary pulsar systems have enabled the measurements of precise neutron star masses and fundamental tests of gravity in the strong field regime. The measurement of neutron star masses not only provide insight into the elusive neutron star interior, but also help constrain binary evolution theories and supernova physics. For many binary systems in the southern hemisphere, the precision of these measurements have so far been limited by the sensitivity of radio telescopes. The new MeerKAT telescope, a 64-dish interferometer in South Africa that is an SKA-mid precursor, has overcome this limitation with its unparalleled sensitivity in the southern sky. The ongoing "RelBin" observing programme with MeerKAT is a part of the MeerTime large survey project that observes relativistic binary systems. In this talk, I will provide an overview of the RelBin programme and its goals, and discuss early results from the last 18 months of its operation.

Pulsar Power in Physics and Astrophysics and Pulsars and Pulsar Systems at High Energies / 942

Advantages of the Inclusion of Globular Cluster Millisecond Pulsars in Pulsar Timing Arrays

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Even if, at the moment, globular cluster (GC) millisecond pulsars (MSPs) cannot be timed with an extremely high precision, mainly due to the effects induced on the MSPs dynamics by the GC gravitational potential, we expect that the situation will change in the near future thanks to new powerful detectors, like the Square Kilometre Array (SKA). Therefore, we suggest the possibility of including GC MSPs in Pulsar Timing Arrays (PTA), discussing what are the advantages for the detection of ultra-low frequency gravitational waves (GWs). We explain how this can support the current research on continuous GWs, based on searching quadrupolar correlation in the MSPs timing residuals.

Pulsar Power in Physics and Astrophysics and Pulsars and Pulsar Systems at High Energies / 838

An updated glitch rate-age law inferred from radio pulsars

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Radio pulsar glitches probe far-from-equilibrium processes involving stress accumulation and relaxation in neutron star interiors. Previous studies of glitch rates have focused on individual pulsars with as many recorded glitches as possible. In this work we analyze glitch rates using all available glitch data, including objects that have glitched never or once. We assume the glitch rate λ scales phenomenologically with the characteristic spin-down age τ as $\lambda = A\,(\tau/\tau_{\mathrm{ref}})^{-\gamma}$, where $\tau_{\mathrm{ref}} = 1$ yr is a reference time scale and A and γ are constants. We produce Bayesian posterior distributions on A and γ for the data set containing pulsars with one or more observed glitches, and a a new data set where objects with zero recorded glitches are included. The updated estimates still support increased glitch activity for younger pulsars, while demonstrating that the large number of objects with zero glitches contain important statistical information about the rate, provided that they are part of the same population as opposed to a disjoint population which never glitches for some unknown physical reason.

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News and views regarding PSR J1757-1854, a highly-relativistic binary pulsar

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We provide an update on the ongoing monitoring and study of the highly-relativistic double neutron star binary system, PSR J1757-1854, a 21.5-ms pulsar in a highly eccentric, 4.4-hour orbit. The extreme nature of this pulsar's orbit allows it to probe a parameter space largely unexplored by other relativistic binary pulsars. For example, it displays one of the highest gravitational wave (GW) luminosities of any known binary pulsar, as well as the highest rate of orbital decay due to GW damping. PSR J1757-1854 is also notable in that it is an excellent candidate for exploring new tests of GR and other gravitational theories, with possible measurements of both Lense-Thirring precession and relativistic orbital deformation (through the Post-Keplerian parameter δ_θ) anticipated within the next 7-10 years.

Here we present the latest interim results from the ongoing monitoring of this pulsar as part of an international, multi-telescope campaign. This includes an update of the pulsar's long-term timing and Post-Keplerian parameters, new constraints on the pulsar's proper motion and corresponding Shklovski kinematic correction, and new limits on the pulsar's geodetic precession as determined by monitoring for secular changes in the pulse profile. We also highlight prospects for future work, including an updated timeline on new relativistic tests following the introduction of MeerKAT observations, as well as a brief discussion of the pulsar's potential detectability within the LISA band.

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Constraining the dense matter EOS and testing higher-order GR effects with the Double Pulsar

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Mass measurements of binary pulsars have provided significant constraints to the equation of state (EOS) of ultra-dense matter. The measurement of the moment of inertia (MOI) of a binary pulsar, however, would provide important additional constraints. The Double Pulsar, PSR J0737-3039A/B, is the most promising system for the first robust MOI measurement via high-precision pulsar timing. In this talk, I will summarise the current timing results, and present our predictions of the MOI measurement for PSR J0737-3039A by 2030 based on simulated data with the MeerKAT telescope and the upcoming SKA. Furthermore, I will discuss potential constraints on the Lense-Thirring precession and the next-to-leading order gravitational wave damping in the Double Pulsar, under the assumption that the EOS is sufficiently well known by 2030 from other observations, like LIGO/Virgo and NICER.

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Searching for Pulsars in Globular Clusters with the MeerKAT Radio Telescope

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Globular clusters are known to host an unusually large population of millisecond pulsar when compared to the Galactic disk. This is thanks to the high rate of dynamical encounters occurring in the clusters that can create the conditions to efficiently recycle neutron stars in millisecond pulsars. The result is a rich population of pulsars with properties and companions difficult to replicate in the Galactic disk.
For these reasons, globular clusters have been and still are a prime target for astronomers searching for new and exciting pulsars. Because of the large distances of the globular clusters, the limiting factor inhibiting these discoveries is the sensitivity. The MeerKAT radio telescope, a 64-dish interferometer in South Africa, guarantees unrivalled sensitivity to look at the globular clusters in the southern sky.
Observations of well-studied globular clusters with MeerKAT have already returned more than 30 new pulsars with many more expected. These exciting discoveries will help us to understand more about the neutron star equation of state, stellar evolution, accretion physics and to hunt for intermediate mass black holes. In this talk I will present the prospects and current discoveries of the globular cluster working group in the MeerTIME and TRAPUM programmes.

Pulsar Power in Physics and Astrophysics and Pulsars and Pulsar Systems at High Energies / 585

Understanding pulsar glitches with stress-relax models

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The physical mechanism underlying pulsar glitches, abrupt spin-up events that interrupt the secular spin-down of some pulsars, is unknown. Plausible models include superfluid vortex avalanches, starquakes, or hydrodynamic instabilities. Almost all such models are reducible to a system in which stress accumulates between glitches and is partially (or fully) released at a glitch. The phenomenological prescription of stress accumulation and release allows one to generate sequences of waiting times and sizes of arbitrary length, and compare the long-term statistical predictions of the 'meta-model' to what is seen in real glitching pulsars. Of particular importance are the shapes of both the waiting time and size distributions, as well as the cross-correlation between waiting times and sizes. Despite the paucity of pulsar glitches recorded in individual pulsars, one can use data from the pulsars that have glitched the most to falsify meta-models, which in turn falsifies the physical models they represent.

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Extended TeV Gamma-Ray Halos around Pulsar Geminga and B0656+14

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The HAWC gamma-ray observatory has discovered very extended TeV gamma-ray structures around two pulsars Geminga and B0656+14. The gamma-ray emission, with its size of tens of parsecs, is produced from high-energy electrons and positrons around these two nearby middle-aged pulsars. Morphology studies suggest that the diffusion in the vicinity of these two pulsars is 100 times slower than the average in our Galaxy. Nearby cosmic-ray accelerators, especially pulsar wind nebulae, are possible origins of the local multi-GeV positron excess. Pulsar Geminga and B0656+14, less than 300 pc from the Earth, have been postulated as the main sources of the positron excess. This result provides important constraints on the origin of positron excess, but raises questions like why diffusion is so slow near these pulsars. Observations of these TeV halos also provide a unique measurement on the diffusion coefficient in our Galaxy.

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Kinematics of Crab Giant Pulses

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The Crab Pulsar's radio emission is unusual, consisting predominantly of giant pulses, with durations of about a micro-second but structure down to the nano-second level, and brightness temperatures of up to 10^{37} K. It is unclear how giant pulses are produced, but they likely originate near the pulsar's light cylinder, where corotating plasma approaches the speed of light. We report observations in the 400-800 MHz frequency band, where the pulses are broadened by scattering in the surrounding Crab nebula. We find that some pulse frequency spectra show strong bands, which vary during the scattering tail, in one case showing a smooth upward drift. While the banding may simply reflect interference between nano-second scale pulse components, the variation is surprising, as in the scattering tail the only difference is that the source is observed via slightly longer paths, bent by about an arcsecond in the nebula. The corresponding small change in viewing angle could nevertheless reproduce the observed drift by a change in Doppler shift, if the plasma that emitted the giant pulses moved highly relativistically, with a Lorentz factor $\gamma \sim 10^4$ (and without much spread in γ). If so, this would support models that appeal to highly relativistic plasma to transform ambient magnetic structures to coherent GHz radio emission, be it for giant pulses or for potentially related sources, such as fast radio bursts.

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Spin-down evolution of magnetars: a novel approach to estimate their ages

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Magnetars are slowly rotating, young, and isolated neutron stars with surface dipole magnetic fields exceeding the quantum electrodynamic magnetic field limit. They exhibit highly energetic behavior, as in the case of soft-gamma repeaters (SGRs) and anomalous X-ray pulsars (AXPs). Recently, they have been studied with paramount interest by almost every modern X-ray telescope. Despite the success, the traditional picture of magnetars has been challenged by the discovery of low-field magnetar, SGR 0418+5729. It remains mysterious over the decades to interpret the evolutionary stage (or age) of such a puzzling source within the magnetar paradigm. Unlike ordinary radio pulsars, the characteristic age is not a reliable indicator for the true age of a magnetar. Here we provide a novel approach to estimate the realistic age of a magnetar. The methodology simultaneously accounts for the surface dipole magnetic field measurement as well. The previous studies for such field measurement are either based on an orthogonal vacuum rotator model or based on a force-free plasma-filled magnetospheric model of pulsars. In general, a real pulsar should be an oblique rotator surrounded by a plasma-filled magnetosphere with particle acceleration gaps to generate pulsar high-energy emissions. In this framework, we solve the self-consistent time evolution for magnetars, including the current state-of-the-art magnetic field decay mechanisms. The rotational period of magnetars increases over time due to the extraction of angular momentum by gravitational-wave radiations, magnetic dipole radiations, and particle winds. These torques also change the obliquity angle between the magnetic and rotation axes. In the peculiar case of SGR 0418+5729, we find a dipolar magnetic field of 1.0×10^{14} G and a realistic age of 18 kyr; both are consistent within the magnetar paradigm.

References

1 Mondal T., 2021, ApJ Letters, 913, L12

Quantum Fields

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Hydrodynamic representation for fermion particles in curved space-times.

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We study the hydrodynamic representation of the Dirac equation in arbitrary curved space-times coupled to an electromagnetic field. Using a generalized Madelung transformation we derive an integral of the corresponding Bernoulli equation for ferminos and show the corresponding Bernoulli equation. Using the comparison of the Dirac and the Klein-Gordon equations we derive the balance equations for fermion particles.

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Evaporation of four-dimensional dynamical black holes sourced by the quantum trace anomaly

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A first approximation to describe the interplay between quantum matter and gravity can be obtained in the quantum field theory on curved spacetimes by studying the back-reaction of a quantum field on the spacetime geometry, using the so-called semiclassical Einstein equation. In this framework, the evaporation of four-dimensional spherically symmetric dynamical black holes can be explained by the appearance of a **negative ingoing energy flux** at the apparent horizon, which induces a negative variation of the black hole mass. This negative flux can be sourced by the **trace anomaly** of the quantum stress-energy tensor in case of a free massless conformally-coupled scalar field, once a certain averaged energy condition is valid outside the horizon. This condition holds assuming that the semiclassical Einstein equation is fulfilled outside the horizon by the background geometry which is sourced by classical collapsing matter. As an example, both the negative flux and the rate of evaporation can be explicitly evaluated in the Vaidya spacetime, which describes the exterior geometry of a null radiating star. The talk is based on a joint work with N. Pinamonti, S. Roncallo and N. Zanghì (*arXiv:2103.02057 [gr-qc]*).

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Breakdown of the Equivalence Principle for a composite quantum body

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We investigate simplest composite quantum body – hydrogen atom – in a weak external gravitational field. Using the local Lorentz invariance of spacetime in general relativity, we calculate electron gravitational mass taking into account both kinetic and potential energies of electron in the atom. In addition to the expected change of electron mass due to total energy, we obtain the unexpected virial term, which is doubled kinetic energy plus potential one. The appearance of this term breaks the Einstein's Equivalence Principle both at microscopic and macroscopic levels. Indeed, if we perform the quantum measurement of gravitational mass of an individual hydrogen atom, it can be not equal to the expected value E/c2. As to macroscopic level, we conclude that for macroscopic ensembles of the stationary quantum states the Equivalence Principle survives. Nevertheless, for special quantum macroscopic ensembles – coherent macroscopic ensembles of the quantum superpositions of stationary states – the Equivalence Principle is strongly broken due to the virial term [1,2]. We discuss possible experiments in the Earth's laboratories, where the above mentioned phenomenon can be discovered.
1 A.G. Lebed, Int. J. Mod. Phys. D, v. 28, 1930020 (2019); 2 A.G. Lebed, Mod. Phys. Lett. A, v. 35, 2030010 (2020).

Quantum Fields / 359

Extended DeWitt-Schwinger subtraction scheme, heavy fields and decoupling

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We will present the extended DeWitt-Schwinger subtraction scheme 1 in order to consistently remove the divergent pieces of the one loop effective action for a scalar field in curved spacetime. This scheme includes a μ dependence that results in the running of the coupling constants. We will prove that this scheme is compatible with the decoupling of heavy massive fields in the low energy limit as stated by the Appelquist-Carazzone theorem for flat spacetime. We will also use this scheme to construct an effective field theory that avoids the obstacles associated with the cosmological constant problem.

1 A. Ferreiro and J. Navarro-Salas, Phys. Rev. D 102, 045021 (2020).

Quantum Fields / 515

GENERALIZED HEISENBERG UNCERTAINTY PRINCIPLE IN QUANTUM GEOMETRODYNAMICS AND GENERAL RELATIVITY

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We focus on the energy flows in the Universe as a simple quantum system and are concentrating on the nonlinear Hamilton–Jacobi equation, which appears in the standard quantum formalism based on the Schrodinger equation. The cases of the domination of radiation, barotropic fluid, and the quantum matter-energy are considered too. As a result, the generalized Heisenberg uncertainty principle (GHUP) is formulated for a metric tensor. We also use the Kuzmichev–Kuzmichev geometrodynamics as a way to quantify the interrelationship between the GHUP for a metric tensor and conditions postulated as to a barotropic fluid, i.e. a dust for the early Universe conditions

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Interior of Typical Black Holes

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We study an evaporating spherically-symmetric black hole that is statistically most likely to form. That can be considered as a black hole formed adiabatically in a heat bath. We construct it by solving conformal matter fields and the semiclassical Einstein equation in a self-consistent manner. Solving the trace component (using the 4D Weyl anomaly) and a general condition of static radial energy flow without specifying explicit boundary conditions determines uniquely the physical static metric for the interior. This represents a dense object with a near-Planck-scale curvature and a surface (instead of a horizon) just outside the Schwarzschild radius. When the object is taken out of the heat bath, it evaporates emitting a Hawking-like radiation. This should be the typical black hole in quantum theory.

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Einstein anomaly with tensors of odd order in six dimensional curved space

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By applying the covariant Taylor expansion method of the heat kernel, Einstein anomaly associated with the Weyl fermion of spin 1/2 interacting with tensor fields of 1 , 3 and 5 order in six dimensional curved space are given. From the relation between Einsterin and Lorentz anomalies, which are the gravitational anomalies, all terms of the Einsterin anomaly should form total derivatives.

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Causal measurements of quantum fields with local probes

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A recently introduced local measurement theory of quantum fields on possibly curved spacetime is the "FV framework" of Fewster and Verch \[CMP 378, 851 (2020)\]. It is founded on the operational idea that every reasonable interaction with a quantum field of interest (system) is realised by temporarily coupling it to a probe field in a local manner. In this talk I will demonstrate the consistency of the model-independent FV framework with causality [PRD, 103, 025017 (2021)] in particular with regard to Sorkin's impossible measurements. As a result, the FV framework equips us with a whole class of causal quantum operations, which opens the door to an investigation of fundamentally causal quantum information protocols \[arXiv:2103.13400\].

This talk reports in part on joint work with H. Bostelmann and C. J. Fewster.

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Ultracompact stars in semiclassical gravity

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We present evidence that semiclassical gravity can give place to ultracompact stars, indistinguishable from black holes up to current observations. We integrate the semiclassical equations of (spherically symmetric) stellar equilibrium for a constant-density classical fluid. The semiclassical contribution is modelled by a quantum massless scalar field in a genuinely-static vacuum state compatible with asymptotic flatness (Boulware vacuum). The Renormalized Stress-Energy Tensor (RSET) is firstly approximated by a cut-off version of the analytic Polyakov approximation. This approximation reveals a crucial difference with respect to purely classical solutions: stars whose compactness is nearing that of a black hole exhibit bounded pressures and curvatures up to central core of a very small relative size. For a subfamily of these ultracompact configurations, their mass can be made arbitrarily close to zero at the boundary of the core, just before the solution enters a singular regime. Our analysis suggests the absence of a Buchdahl limit in semiclasical gravity, while indicating that the cut-off regularized Polyakov approximation must be improved to describe equilibrium configurations of arbitrary compactness that remain regular at the center of spherical symmetry.

Quantum Fields / 748

Quantum memory and BMS symmetries

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Asymptotically flat spacetimes are known to possess an infinite number of symmetries known as the Bondi-Metzner-Sachs (BMS) supertranslations. These BMS symmetries were shown to be related, both, to the gravitational memory effect and Weinberg's soft theorems, the significance of which was recently realised by Hawking et. al. who conjectured that applying these relations to an asymptotically flat spacetime with a black hole in the interior would imply the existence of an infinite number of soft hairs for the black hole. We discuss the effect of BMS symmetries on quantum entanglement and its implications in the context of the black hole information paradox. In particular, we illustrate the gravitational memory effect for linear uniformly accelerated observers in a physical process involving a BMS shock-wave without planar/spherical symmetry. This classical memory is accompanied by a quantum memory that modulates the quantum entanglement between the opposing Rindler wedges in quantum field theory. A corresponding phenomenon across the Schwarzschild black hole horizon suggests that the Negativity measure of entanglement between infalling and outgoing Hawking pair should be degraded due to an infalling BMS shockwave while there should be linear order generation of Negativity between two outgoing Hawking particles. Implications are discussed.

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Chiral vortical effect for free fermions on anti-de Sitter space

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According to the axial vortical effect, an axial current J_A^μ is produced in a fluid undergoing a macroscopic vortical motion, which is equal to the local kinematic vorticity ω^μ multiplied by the axial vortical conductivity σ_A^ω. We probe the curvature corrections to σ_A^ω by computing the thermal expectation value of J_A^μ with respect to a rigidly-rotating quantum state at finite temperature. The calculation is computed in the real time formalism using a novel KMS relation which includes the effect of rotation, being based on an exact expression for the fermion vacuum two-point function (the analysis is restricted to subcritical rotations when no speed of light surface forms, such that the rotating and stationary vacua are identical). Our results confirm the Minkowski expression for σ_A^ω, revealing a novel contribution proportional to the Ricci scalar. At vanishing mass, the conservation of J_A^μ implies a non-vanishing flux through the adS boundary, while at non-vanishing mass, the flux of J_A^μ is completely converted into a volumetric density of pseudoscalar condensate $-i\bar{\psi}\gamma^5\psi$.

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Renormalization, running couplings and decoupling for the Yukawa model in curved spacetime

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Following the method presented in the talk "Extended DeWitt-Schwinger subtraction scheme, heavy fields and decoupling 1", we consider the renormalization of the one loop effective action for the Yukawa interaction with a background scalar field in curved spacetime 2. We compute the beta functions and discuss the decoupling in the running of the coupling constants. For the case of a quantized scalar field, all the beta function are compatible with the decoupling of heavy massive fields, including also the gravitational ones. For a quantized Dirac field, decoupling appears for all the beta functions except for the anomalous result of the mass of the background scalar field.

1A. Ferreiro and J. Navarro-Salas, Phys. Rev. D 102, 045021 (2020).
2 A. Ferreiro, S. Nadal-Gisbert and J. Navarro-Salas. arXiv:2104.14318 (2021)

Quantum Fields / 488

Black hole induced false vacuum decay from first principles

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We provide a method to calculate the rate of false vacuum decay induced by a black hole. The method uses complex tunnelling solutions and consistently takes into account the structure of different quantum vacua in the black hole metric via boundary conditions. We illustrate the technique on a two-dimensional toy model of a scalar field with inverted Liouville potential in an external background of a dilaton black hole.

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Thermalization of harmonic oscillator Unruh-DeWitt detectors

We consider a particle detector interacting with a scalar quantum field through the Unruh-DeWitt interaction Hamiltonian. We model the detector as an harmonic oscillator of finite size. The detector-field system is shown to be mathematically equivalent to a quantum Brownian motion (QBM) model for an oscillator in an Ohmic environment, the role of which is played by the field. We evaluate the density matrix of an accelerated oscillator, identifying the regimes where non-Markovian effects become significant and discussing the effect of the detector's size to its response. We show that in the long-time limit the detector reaches a thermal equilibrium state at the Unruh temperature.

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Stress energy correlator in de Sitter space-time : its conformal masking or growth in connected Friedmann universes

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Semiclassical Physics in gravitational scenario, in its first approximation (1st order) cares only for the expectation value of stress energy tensor and ignores the inherent quantum fluctuations thereof. In the approach of stochastic gravity, on the other hand, these matter fluctuations are supposed to work as the source of geometry fluctuations and have the potential to render the results from 1st order semiclassical physics irrelevant. We study the object of central significance in stochastic gravity, i.e. the noise kernel, for a wide class of Friedmann space-times. Through an equivalence of quantum fields on de Sitter space-time and those on generic Friedmann universes, we obtain the noise kernel through the correlators of Stress Energy Tensor (SET) for fixed co-moving but large physical distances. We show that in many Friedmann universes including the expanding universes, the initial quantum fluctuations, the universe is born with, may remain invariant and important even at late times. Further, we explore the cosmological space-times where even after long times the quantum fluctuations remain strong and become dominant over large physical distances, which the matter driven universe is an example of. The study is carried out in minimal as well as non-minimal interaction settings.

Quantum Gravity Phenomenology

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Discrete symmetries and quantum gravity phenomenology

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In my talk I will introduce kappa-deformation of discrete symmetries and I will discuss its phenomenological consequences.

Quantum Gravity Phenomenology / 934

Testing curvature-induced in-vacuo dispersion with gamma-ray-bursts

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We explore the phenomenological viability of scenarios, suggested by different approaches to quantum spacetime, where quantum-gravity effects in the propagation of particles are triggered by spacetime curvature/expansion.
We rely on a toy model of curvature-induced Lorentz violation for a preliminary exploration, and we find that, differently from what commonly believed, the double suppression due to Planck-length and spacetime curvature is compensated by the high energies and the long (cosmological) distances traveled of the gamma-ray-burst photons.

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Observing acceleration induced emission of Unruh deWitt Detector

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Some of the most prominent theoretical predictions of modern times, e.g., the Unruh effect, Hawking radiation, and gravity-assisted particle creation, are supported by the fact that various quantum constructs like particle content and vacuum fluctuations of a quantum field are observer-dependent. Despite being fundamental in nature, these predictions have not yet been experimentally verified because one needs extremely strong gravity (or acceleration) to bring them within the existing experimental resolution. We demonstrate that non-inertially moving Unruh deWitt Detectors along with optimized cavity experiences strongly modified quantum fluctuations in the inertial vacuum due to their non-inertial motions. As a result, the emission rate of an excited atom gets enhanced significantly along with a shift in the emission spectrum. We propose cavity based optomechanical set-ups capable of realizing such acceleration-induced particle creation with current technology. This approach provides a novel and potentially feasible experimental proposal for the direct detection of noninertial quantum field theoretic effects such as the Unruh effect.

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Quantum Gravity and Grand Unification

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In my talk I shall discuss how big is the parameter space of the couplings at the Planck scale leading to correct non-susy unification for the SO(10). To do so have calculated the renormalisation group equations for the model and run them down towards the IR and investigated the effective potential. As it turns out the initial parameters has to lie in the very small intervals and have a huge hierarchy between them. The string theory and asymptotic safety perspectives on this hierarchy will be discussed.

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Entanglement Entropy at Critical Points in the Multiverse

Author: Samuel Barroso Bellido[1]

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Recently the entanglement entropy between universes has been calculated, an entropy which somehow describes the quantumness of a homogeneous multiverse. The third quantization formalism of canonical quantum gravity is used here. I will show improvements of the results in a more general scenario, studying what happens at critical points of the evolution of a classical universe. We infer the relation of that entanglement entropy with the Hubble parameter of single universes.

Quantum Gravity Phenomenology / 107

Nonsymmetric metric tensor as an approach to quantum gravity

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We argue that the minimal length uncertainty emerging from the generalized uncertainty principle, in which the gravitational impacts on the noncommutative space are thoughtfully taken into account, modifies the whole spacetime geometry. The resulting spacetime metric tensor consists of the symmetric GR compatible metric tensor $g_{\mu\nu}$ and another term comprising $g_{\mu\nu}$ multiplied by $\beta_0(\ell_p/\hbar)^2$ squared. Towards approaching quantized spacetime geometry, we analyze the line element and discuss on the resulting geodesic, which encompasses acceleration, jerk, and snap (jounce) of a test particle in discretized gravitational field.

Quantum Gravity Phenomenology / 432

Test of Quantum Gravity in Statistical Mechanics

Authors: Saurya Das[1]; Mitja Fridman[1]

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We study Quantum Gravity effects on the density of states in statistical mechanics and its implications for the critical temperature of a Bose Einstein Condensate and fraction of bosons in its ground state. We also study the effects of compact extra dimensions on the critical temperature and the fraction. We consider both neutral and charged bosons in the study and show that the effects may just be measurable in current and future experiments.

Quantum Gravity Phenomenology / 937

Poincaré invariance with a minimal length

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A minimal length is generally expected to result in Lorentz-violating dispersion relations. I show how one can formulate a lattice theory that carries a representation of the Poincaré group in the Brillouin zone, and discuss how light cones arise for a subalgebra of observables. [Based on work in collaboration with Bekir Baytaş and Pietro Donà]

Quantum Gravity Phenomenology / 677

A model of polymer gravitational waves: theory and some possible observational consequences

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We derive the effective polymer Hamiltonian of gravitational waves propagating on an FLRW background. We overcome the problem of polymerizing a time-dependent system by using a novel approach by using the extended phase space approach. Using the resulting Hamiltonian, we study some of the possible observational consequences of such a polymerized gravitational wave Hamiltonian.

Quantum Gravity Phenomenology / 494

Quantum Gravity Phenomenology in the Infrared

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Quantum gravity effects are traditionally tied to short distances and high energies. In this talk I will argue that, perhaps surprisingly, quantum gravity may have important consequences for the phenomenology of the infrared. I will center my discussion around a conception of quantum gravity involving a notion of quantum spacetime that arises in metastring theory. This theory allows for an evolution of a cosmological Universe in which string-dual degrees of freedom decouple as the Universe ages. Importantly such an implementation of quantum gravity allows for the inclusion of a fundamental length scale without introducing the fundamental breaking of Lorentz symmetry. The mechanism seems to have potential for an entirely novel source for dark matter and dark energy. The simplest observational consequences of this scenario may very well be residual infrared modifications that emerge through the evolution of the Universe.

Quantum Gravity Phenomenology / 418

Baryon Asymmetry from the Generalized Uncertainty Principle

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We study Quantum Gravity effects in cosmology, and in particular that of the Generalized Uncertainty Principle on the Friedmann equations. We show that the Quantum Gravity induced variations of the energy density and pressure in the radiation dominated era provide a viable explanation of the observed baryon asymmetry in the Universe.

Quantum Gravity Phenomenology / 990

Spinfoams, γ-duality and Parity Violation in Primordial Gravitational Waves

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There has been an expectation that the presence of the *Barbero-Immirzi* parameter (γ) in Loop Quantum Gravity (LQG) results in a quantum correction to the classical theory of gravity in the form of parity violation in primordial gravitational waves. In this paper, we show that a discreet symmetry of the Spinfoams action, γ-duality, constrains the form of the effective action for gravitational perturbations. As a consequence, tensor perturbations with different helicities evolve differently, and their circular polarization depends explicitly on γ. In this manner, the observation of primordial parity violation together with the mechanism that we propose would provide a way to set a bound on the value of the Barbero-Immirzi parameter, and therefore on the scale of discreetness of geometrical observables, such as the area and volume of a quantum chunk of space.

Quantum Gravity Phenomenology / 273

Effective field theory from Relativistic Generalized Uncertainty Principle

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Theories of Quantum Gravity predict a minimum measurable length and a corresponding modification of the Heisenberg Uncertainty Principle to the so-called Generalized Uncertainty Principle (GUP). However, this modification is non-relativistic, making it unclear whether the minimum length is Lorentz invariant. We formulate a Relativistic Generalized Uncertainty Principle, resulting in a Lorentz invariant minimum measurable length and the resolution of the composition law problem. This proved to be an important step in the formulation of Quantum Field Theory with minimum length. We derived the Lagrangians consistent with the existence of minimal length and describing the behaviour of scalar, spinor, and U(1) gauge fields. We calculated the Feynman rules (propagators and vertices) associated with these Lagrangians. Furthermore, we calculated the Quantum Gravity corrected scattering cross-sections for a lepton-lepton scattering. Finally, we compared our results with current experiments, which allowed us to improve the bounds on scale at which quantum gravity phenomena will become relevant.

Quantum Gravity Phenomenology / 152

Presenting Different time steps, at the start of inflation, Using Kiefer Density Matrix, for the use of an Inflaton, in determining different conceivable time intervals for time flow Analysis

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We are using the book "Towards Quantum Gravity with an article by Claus Kiefer as to a quantum gravity interpretation of the density matrix in the early universe. The density matrix we are using is a one loop approximation, with inflaton value and potential terms, like V(phi) using the Padmanabhan values one can expect if the scale factor is a ~ a(Initial) times t ^ gamma , from early times . In doing so, we isolate out presuming a very small initial time step candidates initial time values which are from a polynomial for time values due to the Kiefer Density value.

Quantum Gravity Phenomenology / 417

Stelle Gravity as the limit of Quantum Gravity with a momentum cutoff

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Many quantum gravity theories predict several interesting phenomenological features such as minimal length scales and maximal momenta. Generalized uncertainty principles (GUPs), which are extensions of the standard Heisenberg uncertainty principle, have proven very useful in modelling the effects of such features on physics at sub-Planck energy scales. In this talk, we use a GUP modelling maximal momentum to establish a correspondence between the GUP modified dynamics of a massless spin 2 field and Stelle gravity with suitably constrained parameters. Thus, Stelle gravity can be regarded as the classical manifestation of the imposition of a momentum cutoff at the quantum gravity level. We then study the applications of Stelle gravity to cosmology. Specifically, we analytically show that Stelle gravity, when applied to a homogeneous, isotropic background, leads to inflation with exit. Lastly, using numerical simulations and data from CMB observations, we obtain strong bounds on the GUP parameter. Unlike previous works which fixed only upper bounds for GUP parameters, we show that we can bound the GUP parameter from above *and* from below.

Quantum Gravity Phenomenology / 649

Violation of Chandrasekhar mass-limit in noncommutative geometry

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This abstract is primarily based on my recent paper IJMPD 30, 05 (2021) 2150034, along with arXiv: 2101.06272.

Over the past decades, various researchers have indirectly predicted at least a dozen super-Chandrasekhar white dwarfs (white dwarfs which violate the Chandrasekhar mass-limit) from the luminosity observations of type Ia supernovae. Several research groups worldwide proposed different models (such as magnetic field, rotation, modified gravity, generalized Heisenberg algebra, etc.) to explain the massive white dwarfs. However, each of these models carries some drawbacks. In my presentation, I will explain that phase space noncommutativity is one of the prominent possibilities to explain the super-Chandrasekhar limiting-mass white dwarfs. Of course, there is no observational proof of noncommutativity so far. In the semi-classical limit, I will show that the uncertainty in length scale depends both on the Planck scale and the Compton scale of the electrons, which is followed by Wigner's idea of the scale of uncertainty. Moreover, if such systems rotate following specific conditions, they can emit gravitational radiation for a long duration, which in the future, various detectors, such as LISA, BBO, DECIGO, Einstein Telescope, etc., can detect with a significant signal-to-noise ratio. Thereby it would be an indirect proof of the existence of noncommutativity.

Quantum Gravity Phenomenology / 571

Nonunitarity problem in quantum gravity corrections to quantum field theory with Born-Oppenheimer approximation

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The problem of time arising in Quantum Gravity is a core problem for which a common solution is not yet identified. In this talk we will examine the semiclassical approach to the dynamics of a gravity-matter system, with the goal of reproducing the standard quantum field theory on a fixed Wentzel-Kramer-Brillouin metric background and, at the next order of expansion, computing the quantum gravity corrections to the matter fields dynamics. We discuss the suitable choice of expansion parameter and the starting hypotheses of the model that allowed us to obtain a unitary evolution, in contrast with the previous proposals where non-unitary corrections emerged. The proposed approach makes use of the kinematical action, an additional term in the action of the system, that ensures covariance under the choice of different ADM foliations on the background metric. The system is separated using a Born-Oppenheimer-like decomposition and the kinematical action is used as a quantum clock for the matter sector, resulting in a unitary dynamics with quantum gravity corrections. The analogies of the kinematical term with an incoherent dust are briefly presented and applications to cosmological models are discussed.

Radio Astronomy from Space

Radio Astronomy from Space / 1013

Space VLBI studies of AGN: Extreme physics at extreme baselines.

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Very long baseline interferometry (VLBI) probes cosmic phenomena at the highest angular resolution in astronomy, with the present record set at about 10 microsecond of arc. This record is achieved in space VLBI (SVLBI) observations of the Russian-led RadioAstron mission which combined a world-wide array of radio telescopes with a 10-m antenna in orbit around the Earth. Continuing on the path of SVLBI studies set off by the TDRSS experiments in the USA and the Japanese mission VSOP, RadioAstron provided the most detailed account of the inner jet regions and the highly energetic processes governing them. Results from RadioAstron Key Science Programs on AGN imaging have revealed an intricate structure and extreme brightness temperature of the jet plasma in these regions, probing the physical processes which govern formation and acceleration of jets. A brief summary of these results and some prospects for future space VLBI missions will be presented here.

Radio Astronomy from Space / 469

The Black Hole Photon Ring

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The photon ring is a narrow ring-shaped feature, predicted by General Relativity but not yet observed, that appears on images of sources near a black hole. It is caused by extreme bending of light within a few Schwarzschild radii of the event horizon and provides a direct probe of the unstable bound photon orbits of the Kerr geometry. The precise shape of the observable photon ring is remarkably insensitive to the astronomical source profile and can therefore be used as a stringent test of strong-field General Relativity. A space-based interferometry experiment targeting the photon ring of M87* could test the Kerr nature of the source to the sub-sub-percent level.

Radio Astronomy from Space / 940

Beyond the one ring: probing spacetimes with high-resolution mm-VLBI

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With the advent of the Event Horizon Telescope, the study of multiply lensed images of emitting material about black holes has become a reality. The direct detection of a bright, ring-like structure in horizon-resolving images of M87* is a striking validation of general relativity. However, this success raises a singular difficulty: the angular size and shape of these rings are potentially degenerate with the details of the emission region. On the other hand, this presents unique opportunities. I will discuss the benefits of resolving multiple photon rings, corresponding to multiple instances of the secondary image (n=1) across many days or secondary and tertiary images (n=1 and 2) on a single day. Both schemes present opportunities to disentangle gravitational and astrophysical properties, enabling unambiguous measurements of mass, spin, and even tests of GR.

Radio Astronomy from Space / 851

The Inner Shadow of the Black Hole in M87*: A Direct View of the Event Horizon

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Simulated images of a black hole surrounded by optically thin emission typically display two main features: a central brightness depression and a narrow, bright "photon ring" consisting of strongly lensed images superposed on top of the direct emission. The photon ring closely tracks a theoretical curve on the image plane corresponding to light rays that asymptote to unstably bound photon orbits around the black hole. This critical curve has a size and shape that are purely governed by the Kerr geometry; in contrast, the size, shape, and depth of the observed brightness depression all depend on the details of the emission region. For instance, images of spherical accretion models display a distinctive dark region – the "black hole shadow" – that completely fills the photon ring. By contrast, in models of equatorial disks extending to the black hole's event horizon, the darkest region in the image is restricted to a much smaller area – an inner shadow – whose edge lies near the direct lensed image of the equatorial horizon. Using both semi-analytic models and general relativistic magnetohydrodynamic (GRMHD) simulations, we demonstrate that the photon ring and inner shadow may be simultaneously visible in submillimeter images of M87*, where magnetically arrested disk (MAD) simulations predict that the emission arises in a thin region near the equatorial plane. We show that the relative size, shape, and centroid of the photon ring and inner shadow can be used to estimate the black hole mass and spin, breaking degeneracies in measurements of these quantities that rely on the photon ring alone. Both features may be accessible to direct observation via high-dynamic-range images with a next-generation Event Horizon Telescope.

Radio Astronomy from Space / 774

Universal Polarization of the Photon Ring

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Black hole images are dominated by a "photon ring," a ring of light with universal properties that are completely governed by general relativity. This talk will discuss the univesal features of polarimetric images of black holes. In particular, the photon ring exhibits a self-similar pattern of polarization that encodes the black hole spin. The corresponding polarimetric signatures on long interferometric baselines, extending to space, allow for measurements of the black hole spin using a sparse interferometric array.

Radio Astronomy from Space / 1001

Gravitational Lensing in Simulated and Observed Images of Black Holes

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In 2019, the Event Horizon Telescope published the first image of a black hole, paving the way for future efforts to improve our understanding of emission around compact objects. However, many of the most prominent and unexpected effects of black holes on their images are only visible at extremely fine resolutions. To analyze these features, I will describe an approach to adaptive ray-tracing that allows us to efficiently generate high-resolution images of black holes by concentrating rays near sharp features of the image. I will present examples that provide key insights into the turbulent accretion flow and photon ring, particularly showcasing the role of subring decompositions in probing strong lensing effects. Using these high-resolution simulations, I will then discuss applications to space interferometry. While a ground-based array is unlikely to resolve higher order photon subrings, a geosynchronous orbit could could extract the interferometric signature of the n=1 subring, particularly with an extension to 345 GHz observing frequency. I will discuss the role of baseline length, observing frequency, and mission duration in optimizing our chances to see the photon ring, and I will illuminate ways in which we can use simulations to make these efforts more robust.

Radio Astronomy from Space / 433

Fundamental Cosmology from the Cosmic Dark Ages: The Case for a Very-Low Frequency Lunar Radio Array

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The highly-redshifted 21 cm line of neutral hydrogen holds great promise for cosmology. Observing this signal, however, is exceedingly challenging. Experiments must contend with the signal's inherent faintness, overwhelmingly bright astrophysical foregrounds, human-generated radio interference, and the Earth's own ionosphere. And, these challenges are all exacerbated for experiments

looking to push to the highest redshifts where, during the time between the release of the CMB and the formation of the first stars, the 21 cm line is the only potential probe. However, measuring the spatial fluctuations of the hydrogen signal during these cosmic "dark ages" would be of tremendous cosmological value, providing multiple orders of magnitude more information than that available from the CMB. In this talk, I will review the cosmological promise of these measurements and present the basic attributes of a lunar-based radio interferometer that could hope to make such an observation. To conclude, I will discuss the research developments needed this decade to place such an experiment within the realm of possibility.

Radio Astronomy from Space / 882

Linear and Circular Polarization Images near Black Holes: Imprints of Magnetic Fields Structure

Author: Yuh Tsunetoe[1]

Co-authors: Shin Mineshige [1]; Ken Ohsuga [2]; Tomohisa Kawashima [3]; Kazunori Akiyama [4]

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The first imaging of the super massive black hole in M87 by the Event Horizon Telescope (EHT) has marked the beginning of a new era in black hole research that explores the properties through direct image observations. In particular, polarimetric images of the vicinity of black holes have attracted much attention because they reflect the magnetic field structure, which plays a key role in the formation of the jets. In this study, we calculatedd a general relativistic radiation transfer that takes into account the synchrotron emission, self-absorption, and Faraday effects for the Stokes parameters (I, Q, U, V), and predicted the polarimetric images with future EHT observations in mind.

First, we present a polarization image of M87* under the parameters consistent with the results of the black hole shadow published in 2019 April. We found that high black hole spin is favored and the linear polarization (LP) vectors undergo strong Faraday rotation. Furthermore, we suggest that the circular polarization (CP) components can be significantly detected in ring shape, due to the Faraday "conversion" from the LP components by the ordered magnetic field structure.

Secondly, for another target of EHT, Sgr A*, we predicted the polarimetric images using models with high disk temperature. The images obtained were found to be ring-shaped when the accretion disk was viewed from nearly face-on observer, and three-forked when it was viewed from nearly edge-on. As for the polarization components, we proposed a scenario in which the LP and CP components complementarily provide information on the magnetic fields configuration and plasma properties.

Radio Astronomy from Space / 951

Imaging and parameter estimation of supermassive black holes with the Event Horizon Imager Space VLBI concept

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The Event Horizon Telescope (EHT) has imaged the shadow of the supermassive black hole in M87 and aims to image the Galactic Center black hole Sagittarius A*(Sgr A*) as well. As a ground-based VLBI array, the resolution of the current EHT is limited by the size of the Earth and the maximum attainable observing frequency, which is set by the severity of tropospheric corruptions beyond millimeter wavelengths. The Event Horizon Imager is a Space VLBI mission concept consisting of two or three satellites in Medium Earth Orbits at slightly different radii. This setup results in a dense isotropic uv-coverage, with a nominal array resolution of 4 uas at an observing frequency of 690 GHz (this is 23 uas for the current EHT at 230 GHz), and hence excellent imaging capabilities. In this talk, I will give an overview of the EHI concept and show its black hole imaging and parameter estimation potential, based on realistically simulated VLBI data from general relativistic magnetohydrodynamics (GRMHD) source models. Our simulations show that the EHI could put constraints on the black hole spin and measure the photon ring size to sub-percent precision, allowing for precise tests of general relativity and the Kerr metric.

Radio Astronomy from Space / 1061

Shadows around at the Galactic Center and at M87* as a tool to test gravity theories

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The shadow around the supermassive black hole in M87 was reconstructed in 2019 based on its observations with the Event Horizon Telescope in 2017. Recently polarization map for the M87* shadow was presented. We discuss opportunities to evaluate parameters of alternative theories of gravity with shadow observations, in particular, a tidal charge could be estimated from these observations.

Radio Astronomy from Space / 1015

Imaging of M87 and Sgr A* with the Millimetron Space Observatory.

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Making a high resolution image of a supermassive black hole shadow is a direct method to verify the theory of general relativity at extreme gravity conditions. Very Long Baseline Interferometry (VLBI) observations at millimeter/sub-millimeter wavelengths can provide just provide angular resolution sufficient to start resolving supermassive black holes, located in Sgr A*and M87. Recent VLBI observations of M87 with the Event Horizon Telescope (EHT) has demonstrated such capability. The*

maximum obtainable spatial resolution of ground based VLBI is limited by Earth diameter and by atmospheric transmission and phase variations at the short wavelengths. In order to improve on space resolution a much larger Space-Earth baselines are required. In the cm wavelengths this has been successfully demonstrated by Radioastron Space mission. Millimetron is a next space mission with VLBI capabilities that operates at mm/submm wavelengths. It will have a cooled 10m diameter main dish. The base orbit of Millimetron will be located near the Anti-solar Lagrangian point - L2. In the later phase Millimetron can be pushed on to elongated elliptical orbit to optimize VLBI U-V coverage. We report simulation results of imaging capabilities of Space Earth VLBI consisting of Millimetron and EHT. We used General-relativistic magneto dynamic models (GRMHD) for back holes environment of Sgr A and M87 for dynamic and static imaging simulations. The impact of atmospheric phase fluctuations is evaluated. ETH-Millimetron observation will significantly improve spatial resolution for static images both from L2 and elliptical orbits. A short integration time snapshot images of Sgr A* from elliptical orbit may allow studying dynamical behavior at smaller timescales.

Radio Astronomy from Space / 964

Event Horizon Telescope Paper VII: imaging the polarized emission around M 87*

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In 2017, the Event Horizon Telescope (EHT) observed the supermassive black hole M 87*at the center of the giant elliptical galaxy Messier 87 using very-long baseline interferometry between a global network of radio telescopes. Operating at a high radio frequency of 230 GHz, EHT enables imaging of the optically thin emission region in the immediate vicinity of the event horizon of M 87*, achieving resolution of ~3 Schwarzschild radii. Recently, the first images of the linearly polarized emission component were published. They indicate that only a part of the M 87*ring is significantly polarized. The resolved fractional linear polarization has a maximum located in the southwest part of the ring, where it rises to the level of ~15%. The polarization position angles are arranged in a nearly azimuthal pattern. Properties of the compact emission were characterized and evidence for the temporal evolution of the polarized source structure over one week of EHT observations was found. I will present the challenges of polarimetric calibration and imaging and strategies to mitigate them with a variety of analysis tools. Then I will discuss the morphology of the polarimetric images of the M 87* and derived quantities characterizing these images, which enabled the theoretical interpretation of these results.

Radio Astronomy from Space / 962

Event Horizon Telescope Paper VIII: Dynamically Important Magnetic Fields at the M 87* Horizon

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In 2017, the Event Horizon Telescope (EHT) observed the black hole at the center of the giant elliptical galaxy, Messier 87 using very-long baseline interferometry between a global network of radio telescopes. The resulting linearly polarized images of the accretion flow near the horizon of the black hole (M 87*) show resolved polarized structure with a spiral pattern in the electric vector position angle. I will present the implications of these images for our understanding of accretion flows around* *supermassive black holes. In particular, I will present the theoretical analysis recently published by the EHT, in which the EHT image reconstructions were compared to ray traced images of general relativistic magnetohydrodynamic (GRMHD) simulations of M 87* according to five metrics: average linear polarization fraction, net linear polarization, net circular polarization, and the amplitude and phase of a complex coefficient corresponding to azimuthal structure in linear polarization, β_2. Regardless of the details of the scoring procedure used, only simulations with dynamically important fields, so-called magnetically arrested disks, yield images consistent with EHT observations while producing a jet of sufficient power. The polarized image constraints refine the previous EHT estimates of the M 87* accretion rate by an order of magnitude to the narrower range of $(3-20)\times 10^{-4} M_{\odot}\mathrm{yr}^{-1}$.

Rotation in Stellar Evolution

Rotation in Stellar Evolution / 1055

Angular momentum transport by magnetic fields

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The cores of (sub)giants rotate much slower than expected from known hydrodynamic braking mechanisms. Magnetic torques generated by differential rotation are potentially much more effective. I'll briefly review magnetorotational and Tayler instabilities, which in their current versions are also insufficient. A big problem facing improvement are a number of critical surprises encountered in numerical studies of 'magnetic turbulence'. These are the numerical convergence problem, the magnetic Prandtl number problem, and the conserved magnetic flux problem. Each of these is still unsolved. The result is a lack of theoretical basis for any proposed theory of magnetic torques. Progress will depend heavily on results from numerical simulations designed for specific clearly defined (sub)questions.

Rotation in Stellar Evolution / 587

The internal rotation of low-mass stars from solar and stellar seismology

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In this talk I will briefly review the knowledge on angular momentum transport acquired from helio- and asteroseismology of low mass stars. I will discuss how rotation is determined from the seismic data, what results it has brought us for the Sun first, than other stars thanks to the space-based photometry missions. I will present the current shortcomings of the models, the various solutions (magnetic and hydrodynamic) that have been proposed to explain the discrepancies between stellar evolutionary models and seismic constraints, as well as the intrinsic link between rotation and the transport of light elements. I will explain how this link is also deeply tied to what we consider as "standard stellar evolution models". I will also discuss what key features of the internal rotation profiles of stars measured from seismology can help us in trying to break the current stalemate in our description of angular momentum transport during the evolution of low-mass stars.

Rotation in Stellar Evolution / 627

Rotation of Population III Stars

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The first stars in the Universe, the so-called Population III (Pop III), formed at the end of the cosmic dark ages, a few million years after the Big Bang. Their impact on early cosmic history, in terms of ionizing radiation and the initial enrichment of the intergalactic medium with heavy chemical elements, crucially depends on the Pop III initial mass function (IMF). Numerical simulations indicate that the primordial IMF is top-heavy, with typical masses of a few tens of solar masses. To predict the final fate of the first stars, and the nucleosynthetic pattern of elements produced throughout their lives, a second key ingredient is the rotation state of this elusive stellar population. I will review our current understanding of Pop III stellar rotation, and will discuss select diagnostics and cosmological consequences of such rapidly rotating stars at the dawn of star and galaxy formation.

Rotation in Stellar Evolution / 589

Low effective spins of LIGO/Virgo binary black hole mergers

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All ten LIGO/Virgo binary black hole (BH-BH) coalescences reported from the O1/O2 runs have near zero effective spins. The similar trend seems to be seen also in O3 results, alas with some exceptions. Even the famous massive event (GW190521: 85+66 Msun BH-BH merger) is fully consistent with having zero effective spin. I will discuss possible astrophysical implications of this intriguing result. It appears that stellar-origin BHs are formed with low natal spins and this may allow to constrain angular momentum transport in stellar interiors.

Rotation in Stellar Evolution / 596

Rotation in massive stars

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We will discuss the initial rotation rates of massive stars, and the change of the rotation rates in single and binary
stars during their evolution, in connection to Be stars, accretion-induced spin-up and stellar mergers. We will then
consider the evolution of the core rotation of massive stars, and the corresponding expectations for the spins of compact
objects. In the end, we with highlighting currently open important questions.

Rotation in Stellar Evolution / 608

Internal rotation in β Cephei stars

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The β Cephei pulsating stars are unique targets to probe our knowledge of the interior of massive stars. By analysing their pulsations with asteroseismology, we can explore the mixing processes, e.g., convection and overshooting, in the core of these massive stars. Asteroseismology has delivered another success by revealing their internal rotation. I illustrate these results with a review of constraints obtained from the analysis of well-known β Cephei stars. I then present how, with the help of the rotational splittings of the pulsation frequencies, one can reconstruct the angular momentum transport history of the β Cephei star HD 129929.

Rotation in Stellar Evolution / 611

The Rotation of SuperMassive Stars

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Supermassive stars (SMSs), with masses $> 10^5$ M$_\odot$, have been proposed as the possible progenitors of the most extreme supermassive black holes observed at redshifts $z > 6 - 7$. In this scenario ('direct collapse'), a SMS accrete at rates > 0.1 M$_\odot$ yr^{-1} until it collapses to a black hole via the general-relativistic (GR) instability. Rotation plays a crucial role in the formation of such supermassive black hole seeds. The centrifugal barrier appears as particularly strong in this extreme case of star formation. Moreover, rotation impacts sensitively the stability of SMSs against GR, as well as the subsequent collapse. In particular, it might allow for gravitational wave emission and ultra-long gamma-ray bursts at black hole formation, which represents currently the main observational signatures proposed in the literature for the existence of such objects. I will present the latest models of SMSs accounting for accretion and rotation, and discuss some of the open questions and future prospects in this research line.

Rotation in Stellar Evolution / 698

On the dependence of magnetic fields and rotation of massive stars in the properties of their compact remnants

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Core-collapse supernova form a diverse class of explosions produced at the end of the lives of massive stars. We study numerically the process of formation of the compact remnants (proto-magnetars and black holes) resulting from the collapse of very compact, low-metallicity cores of high-mass stars. We aim at understanding the dependence of the stellar remnants properties on the stellar progenitor rotational and magnetic properties, as well as small variations thereof. Our models track the post-bounce evolution of the core for nearly 10 seconds, combining special relativistic MHD, an approximately generally relativistic gravitational potential, and two-moment neutrino transport. We find that the poloidal magnetic field strength in the pre-collapse core is of utmost importance in determining whether the proto-neutron star resulting from core bounce will be sufficiently long-lived to contribute significantly to the stellar explosion and the associated high-energy transients.

Scalar Fields in Cosmology

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Testing Modified Gravity theories with marked statistics

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In the last two decades, Modified Gravity (MG) models have been proposed to explain the accelerated expansion of the Universe. However, one of the main difficulties these theories face is that they must reduce to General Relativity (GR) at sufficiently high energy densities, as those found in the solar system. To achieve this, MG usually employs the so-called screening mechanisms: non-linear effects that lead them to GR in the appropriate limits. For this reason, low-energy regions where the screenings do not operate efficiently, such as cosmic voids, are identified as ideal laboratories for testing GR. Hence, the use of marked statistics that up-weight low energy densities are proposed for being implemented with data from future galaxy surveys. In this talk, we show how to construct theoretical templates for such statistics and test their accuracy with the use of N-body simulations.

Scalar Fields in Cosmology / 560

Scalar field in Schwarzschild-de Sitter spacetimes: circular orbits and synchrotron radiation

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We analyze the scalar radiation emitted by a source in geodesic circular orbits around a Schwarzschild-de Sitter black hole. We obtain the emitted power using quantum field theory in curved spacetimes framework at tree level. We compare our results with the scalar synchrotron radiation in Schwarzschild spacetime.

Scalar Fields in Cosmology / 57

Nonlinear perturbative theory of structure formation for modified gravity

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The most important results of nonlinear perturbative theory for alternative models to LCDM, in which a scalar field changes gravitational dynamics at cosmic scales, will be summarized. We focus on two-point statistical observables, such as the power spectrum and correlation function, and discuss the changes from the LCDM model.

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Timelike Circular Orbits and Efficiency of Compact Objects

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We prove the following result. For a stationary, axisymmetric, asymptotically flat, ultracompact object (*i.e.* an object with light-rings) with a $\mathbb{Z}_2$ symmetry fixing an equatorial plane, the possibility and stability of timelike circular orbits in the vicinity of the existing light-rings, for both rotation directions, depend exclusively on the stability of the light-ring itself. An unstable light-ring present, radially below it, no timelike circular orbits, and, radially above it, unstable timelike circular orbits. On the other hand, a stable light-ring presents, radially below it, stable timelike circular orbits, and, radially above it, no timelike circular orbits. Consequences of this theorem are presented for horizonless objects and black holes. The efficiency associated with converting gravitational energy into radiation by a material particle falling under an adiabatic sequence of timelike circular orbits is also studied for a variety of exotic star models and black holes. For most objects studied, it is possible to obtain efficiencies larger than the well-known maximal efficiency of Kerr black holes.

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Light in the dark: GW190521 as Proca star merger

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The detections of gravitational waves are opening a new window to the Universe. The nature of black holes and neutron stars may now be unveiled, but gravitational radiation may also lead to exciting discoveries of new exotic compact objects, oblivious to electromagnetic waves. In particular, Advanced LIGO-Virgo recently reported a short gravitational-wave signal (GW190521) interpreted as a quasi-circular merger of black holes, one at least populating the pair-instability supernova gap. We found that GW190521 is also consistent with numerically simulated signals from head-on collisions of two (equal mass and spin) horizonless vector boson stars (aka Proca stars). This provides the first demonstration of close degeneracy between these two
theoretical models, for a real gravitational-wave event.

Scalar Fields in Cosmology / 172

Testing the hypothesis of a bosonic star at Sgr A*

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The GRAVITY collaboration has recently a detected continuous circular relativistic motion during infrared flares of Sgr A*, which has been interpreted as orbital motion near the event horizon of a black-hole. In this work, we use the ray-tracing code GYOTO to analyze the possibility of these observations being consistent with a central bosonic star instead of a black-hole. Our model consists of an isotropically emitting hot-spot orbiting a central boson or Proca star. Images of the orbit at different times and the integrated flux were obtained for both models and compared with the case of a Schwarzschild black-hole. Although the overall qualitative picture is comparable, the bosonic star models present an extra image when the emitting hot-spot passes behind the central object caused by photons travelling through the interior of the star. Furthermore, there are also measurable differences in the angles of deflection, orbital periods, and centroid of the flux, which can potentially be detected.

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Dark Matter as a condensed phase of generic bosons

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We analyze the rotation curves that correspond to a Bose–Einstein Condensate (BEC) type halo surrounding a Schwarzschild–type black hole to confront predictions of the model upon observations of galaxy rotation curves. We model the halo as a BEC in terms of a massive scalar field that satisfies a Klein–Gordon equation with a self–interaction term. We also assume that the bosonic cloud is not self–gravitating. To model the halo, we apply a simple form of the Thomas–Fermi approximation that allows us to extract relevant results with a simple and concise procedure. We find that in the centre of galaxies we must have a supermassive compact central object, i.e., supermassive black hole, in the range of $\log_{10} M/M_{\odot} = 11.08 \pm 0.43$ which condensate a boson cloud with average particle mass $M_{\Phi} = (3.47 \pm 1.43) \times 10^{-23}$ eV and a self–interaction coupling constant $\log_{10}(\lambda \ [\mathrm{pc}^{-1}]) = -91.09 \pm 0.74$, i.e., the system behaves as a weakly interacting Bose–Einstein Condensate. We compare the Bose–Einstein Condensate model within the Thomas–Fermi approximation, with the Navarro–Frenk–White (NFW) model, concluding that in general the BEC model

using the Thomas–Fermi approximation is strong enough compared with the NFW fittings. Moreover, we show that BECs still well–fit the galaxy rotation curves and, more importantly, could lead to an understanding of the dark matter nature from first principles.

Scalar Fields in Cosmology / 317

Primordial Black Holes in a scalar field dominated universe.

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I review in this talk the mechanism of Primordial Black Hole (PBH) formation at the end of inflation from an oscillating scalar field. I will first present solutions to the Klein Gordon and Einstein equations in this regime for linear perturbations, as well as long-wavelength nonlinear solutions. I argue that these are indicators of the collapse of inhomogeneities onto PBHs. The tiny black holes produced in these models quickly evaporate and may produce Planck mass relics. I will show that these relics can be abundant enough to constitute all of dark matter, and present the constraints that this brings on the models of complex scalar field reheating.

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The imitation game: Proca stars that can mimic the Schwarzschild shadow

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Can a dynamically robust bosonic star (BS) produce an (effective) shadow that mimics that of a black hole (BH)? The BH shadow is linked to the existence of light rings (LRs). For free bosonic fields, yielding mini-BSs, it is known that these stars can become ultra-compact - i.e., possess LRs - but only for perturbatively unstable solutions. We show this remains the case even when different self-interactions are considered. However, an effective shadow can arise in a different way: if BSs reproduce the existence of an innermost stable circular orbit (ISCO) for timelike geodesics (located at rISCO=6M for a Schwarzschild BH of mass M), the accretion flow morphology around BHs is mimicked and an effective shadow arises in an astrophysical environment. Even though spherical BSs may accommodate stable timelike circular orbits all the way down to their centre, we show the angular velocity along such orbits may have a maximum away from the origin, at RΩ; this scale was recently observed to mimic the BH's ISCO in some scenarios of accretion flow. Then: (i) for free scalar fields or with quartic self-interactions, RΩ≠0 only for perturbatively unstable BSs; (ii) for higher scalar self-interactions, e.g. axionic, RΩ≠0 is possible for perturbatively stable BSs, but no solution with RΩ=6M was found in the parameter space explored; (iii) but for free vector fields, yielding Proca stars (PSs), perturbatively stable solutions with RΩ≠0 exist, and indeed RΩ=6M for a particular solution. Thus, dynamically robust spherical PSs can mimic the shadow of a (near-)equilibrium Schwarzschild BH with the same M, in an astrophysical environment, despite the absence of a LR, at least under some observation conditions, as we confirm by comparing the lensing of such PSs and Schwarzschild BHs.

Scalar Fields in Cosmology / 817

A stabilization mechanism for excited fermion-boson stars

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Gravitationally bound structures composed by fermions and scalar particles known as fermion-boson stars are regular and static configurations obtained by solving the coupled Einstein-Klein-Gordon-Euler (EKGE) system. As it happens for boson stars, there are different families of solutions labelled by the number of nodes in the radial profile of the scalar field; the ground state solutions have zero nodes in the radial profile, while excited states have 1 or more nodes. We study one possible scenario through which these fermion-boson stars may form by solving numerically the EKGE system under the simplifying assumption of spherical symmetry. Our initial models assume an already existing neutron star surrounded by an accreting cloud of a massive and complex scalar field. We considered an initial Gaussian radial profile for the cloud of scalar field. Our results show that from this generic initial data, we could form both ground and excited fermion-boson stars. Prompted by this finding we construct equilibrium configurations of excited fermion-boson stars and study their stability properties using numerical-relativity simulations. Contrary to purely boson stars in the excited state, which are known to be generically unstable, our study reveals the appearance of a cooperative stabilization mechanism between the fermionic and bosonic constituents of those excited-state mixed stars.

Sources of Gravitational Waves

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The phenomenology of late binary black hole gravitational waves via black hole perturbation theory

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The spectrum of ringdown waves which terminates the gravitational waveform of binary black hole merger contains information about both the properties of the merger's remnant black hole, as well as the geometry of the system as it enters its final plunge and merger. This suggests that measurements of the ringdown spectrum could teach us about a binary's geometry, provided we know how to invert the map between binary geometry and ringdown spectrum. In this talk, I will describe work that uses black hole perturbation theory to gain insight into this map. I will describe how we characterize the dynamics of a large mass-ratio binary, how we use those dynamics to build the source for a black hole perturbation theory solver, and how we use the radiation predicted by this solver to study such a binary's late-time ringdown spectrum. Though numerical relativity will be needed to calibrate how large a system's mass ratio must be for our results to apply, what we find indicates that well-measured ringdown waves can provide important complementary information about binary characteristics.

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Search for gravitational waves from Scorpius X-1 in the third observing run of Advanced LIGO

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We present an overview of a search for continuous gravitational waves from the low-mass X-ray binary Scorpius X-1 (Sco X-1), using two pipelines: a hidden Markov model (HMM) and a cross correlation approach. This search improves on previous Sco X-1 searches by introducing new features for each pipeline. For the HMM model, we use a new frequency domain matched filter. The cross correlation pipeline has been improved with a new re-sampling code, as well as a more efficient template bank, both of which significantly improve the computation times. We will also discuss projected sensitivities for the search using LIGO O3 data, and how that sensitivity compares to current best observational and indirect limits.

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Discriminating between correlated magnetic noise and a gravitational-wave background

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Ground-based gravitational-wave detectors are becoming more sensitive, and in the near future we hope to detect a gravitational-wave background. However, as these detectors become more sensitive they will continue to run into new forms of noise. Correlated noise between spatially separated detectors will limit our intrinsic sensitivity, and have the potential to give a false detection. In this talk, we discuss long-wavelength magnetic fields, which are a likely source of correlated detector noise. First, we will discuss how these long-wavelength fields can couple into gravitational-wave detectors. Next, we will discuss a novel Bayesian technique for separating correlated magnetic noise from a gravitational-wave background. Finally, we will discuss how we applied the new method to data from Advanced LIGO and Virgo's third observing runs.

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Constraining the NS EOS with merger and post-merger gravitational wave signals

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Detections of neutron stars in binaries through gravitational waves offer a novel way to probe the properties of extremely dense matter. In this talk I will describe the properties of the signals we have observed, what they have already taught us, and what we expect to learn in the future. I will also discuss how information from gravitational waves can be combined and compared against other astrophysical and terrestrial probes of neutron star matter to unveil to the properties of the most dense material objects that we know of.

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Physical insights from multi-messenger observations of compact binary mergers and their afterglows

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Gamma-ray bursts (GRBs) associated with gravitational wave events are, and will likely continue to be, viewed at a larger inclination than GRBs without gravitational wave detections. As demonstrated by the afterglow of GRB 170817A, this requires an extension of the common GRB afterglow models where it typically used to be sufficient to assume that the observer was looking straight into a jet without significant lateral structure in its outflow geometry. In response to 170817, we have

developed an updated modeling and interpretation framework that has been used from the X-ray afterglow discovery paper until the ongoing faint emission still observable to this day. Against this backdrop, I will present an overview of how multi-messenger events of this type present an opportunity to rethink our modeling. This includes approaches to model selection, to merging constraints from the different signals (gravitational waves, afterglow, very large baseline interferometry) and what physics is needed to interpret the long-term emission from GRBs seen off-axis and their aftermath including jets that may or may not emerge successfully from the merger debris carrying an imprint of the launching process.

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Deep learning for Core-Collapse Supernova detection

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The detection of gravitational waves from core-collapse supernova explosions is a challenging task, yet to be achieved, in which it is key the connection between multiple messengers, including neutrinos and electromagnetic signals. We present a method for detecting these kind of signals based on machine learning techniques. We tested its robustness by injecting signals in the real noise data taken by the Advanced LIGO-Virgo network during the second observation run, O2.
Using this novel approach we can classify signal from noise and identify the signal more efficiently, in fact, in the case of O2 run, it would have been possible to detect signals emitted at 1 kpc of distance, whilst lowering down the efficiency to 60%, the event distance reaches values up to 14 kpc.

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Recent searches for continuous gravitational waves and the implications

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Transient gravitational waves from catastrophic collisions of black holes and neutron stars have been observed by the Advanced LIGO and Virgo in the last few years. Studies are also carried out to look for something different – the much fainter continuous gravitational radiation emitted by non-axisymmetric spinning neutron stars, or ultralight-boson condensates from spinning black holes. In this talk, we will review the results of continuous gravitational-wave searches using the Advanced LIGO/Virgo data and discuss the astrophysical implications.

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Hunting for the Stochastic Gravitational-Wave Background

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I will first define the stochastic gravitational-wave background (SGWB) and highlight the method we are using to detect it in the presence of correlated magnetic noise. I will then discuss astrophysical and cosmological sources and report on the current constraints imposed from a non-detection during the first three observing runs of the LIGO/Virgo/KAGRA collaboration. I will also address the question of a simultaneous estimation of astrophysical and cosmological SGWB. Then I will present a search for circularly polarised SGWB and its relation to early universe cosmology. Finally, I will discuss how the SGWB can provide tests for gravity theories, including quantum gravity proposals.

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Joint Analysis Method on Gravitational Waves and Low-Energy Neutrinos to Detect Core-Collapse Supernovae

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Core-collapse supernovae are fascinating astrophysical objects for multimessenger studies. Gravitational waves (GWs) are expected to play a role in the supernova explosion mechanism, but their modelling is also challenging due to the stochastic nature of the dynamics and the vast possible progenitors, and moreover, the GW detection from these objects is still elusive with the already advanced detectors. Low-energy neutrinos will be emitted enormously during the core-collapse explosion and can help for the gravitational wave counterpart search. In this work we develop a multi-messengers strategy to search for such astrophysical objects by exploiting a global network of both low-energy neutrino and gravitational wave detectors. First, we discuss how to improve the detection potential of the neutrino sub-network by exploiting the temporal behaviour of a neutrino burst from a core-collapse supernova. Then, we combine the information provided by GW and neutrino in a multi-messenger strategy. Our method can better disentangle from noise the low statistical signals coming from weak (or far) supernovae giving us about 10^3 lower \textit{false-alarm-probability} for recovered signal injections.
Keywords: multimessenger supernova core-collapse low-energy neutrino gravitational wave.

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Gravitational waves from neutrino mass generating phase transitions

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Some particle physics models with an additional U(1) gauge interaction are interesting because those address the origin of neutrino masses. We show that, in a wide class of models, such an extra U(1) gauge symmetry breaking in the early universe can be first-order phase transition and hence generate a detectable amplitude of stochastic gravitational wave radiation in future experiments. We also discuss parameter dependence and a possible UV completion.

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GW190521: an intermediate-mass black hole observed with minimal assumptions

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The recent observing run of Advanced LIGO and Virgo was fruitful in gravitational-wave (GW) detections and the observation of GW190521 is one of the most important discoveries. With a remnant black hole of about 140 solar masses, this is the first strong evidence for the existence of intermediate-mass black holes that are heavier than stellar mass and lighter than supermassive black holes. In my presentation, I will present how the significance of this detection was established by the coherent WaveBurst (cWB) pipeline. This is an algorithm capable to detect GWs from unexpected sources, it operates with minimal assumptions and does not depend on a signal model. I will discuss the properties of GW190521 and why this event is exceptional. While cWB does not use a signal model for the detection, it allows determining what model fits the detected signal more accurately. I will show that GW190521 properties can be explained more exactly by models which incorporate the effects of precession and higher-order modes.

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Searches for continuous gravitational waves from young supernova remnants in the early third observing run of Advanced LIGO and Virgo

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Theories predict continuous gravitational waves may be emitted by rotating neutron stars. We present the results of three wide-band directed searches for continuous gravitational waves from young supernova remnants in the first half of the third Advanced LIGO and Virgo observing run. Using three complementary analysis pipelines, we search fifteen young supernova remnants between 10 Hz and 2 kHz. Each pipeline is optimized for a different signal model, allowing us to search a wider range of physical models than previous analyses.

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Measuring Individual Masses of Binary White Dwarfs with Space-based Gravitational-wave Interferometers

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Unlike gravitational waves from merging black holes and neutron stars that chirp significantly over the observational period of ground-based detectors, gravitational waves from binary white dwarfs are almost monochromatic. This makes it extremely challenging to measure their individual masses. Here, we take a novel approach of using finite-size effects and applying certain universal relations to measure individual masses of binary white dwarfs using LISA. We found quasi-universal relations among the mass, moment of inertia, and tidal deformability of a white dwarf that do not depend sensitively on the white dwarf composition. These relations allow us to rewrite the moments of inertia and tidal deformabilities in the waveform in terms of the masses. We then carried out a Fisher analysis to estimate how accurately one can measure the individual masses from the chirp mass and finite-size measurements. We found that the individual white dwarf masses can be measured with LISA for a 4-year observation if the initial frequency is high enough (~0.02Hz) and either the binary separation is small (~1kpc) or the masses are relatively large (m⊠0.8M⊠). This opens a new possibility of measuring individual masses of binary white dwarfs with space-based interferometers.

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Searching gravitational wave signals in the post-merger phase after a binary black hole coalescences.

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The current Gravitational Wave (GW) surveys of Binary Black Hole (BBH) mergers provide unprecedented probes of the dynamics in extreme gravitational fields and relativistic velocities. It will be presented a new method to search for possible low energetic signal with unknown morphologies features in the post merger phase of the gravitational wave signal from a BBH coalescences. Such transient features may reflect different theorized astrophysics processes: echoes of the merger signals from Blach Hole mimickers, repeated GW gravity memory effects, or multiple copies of the asymmetric BBH chirp expected for special orientations of the source relative to the observer.
The search methodology is based on the un-modelled GW transient search algorithm coherentWaveBurst (cWB), widely used in the analysis of LIGO-Virgo-KAGRA data. It will be described in the talk, as its performances in terms of detection and estimation of echoes' characteristics on actual data from past LIGO-Virgo observing runs. The performances have been investigated by injecting a large set of simulated signals on actual LIGO-Virgo data. There will be reported the new upper

limits in echoes detection set by this search on LIGO-Virgo open data and open catalogs of detected CBC.

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Importance of stable mass transfer and stellar winds for the formation of gravitational waves sources

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The isolated formation channel is one of the most studied formation
scenarios for stellar mass black hole binary (BBH) mergers detected by LIGO and Virgo. Focusing on the effects of
uncertain stellar and binary physics, we investigate this BBH formation channel using the rapid binary population
synthesis code SeBa.

Regardless of our assumptions, the two must common formation path within the isolated binary scenario involves (i) a stable mass transfer followed by a common envelope evolution or (ii) two stable mass transfers. I will show that uncertainties in the first stable mass transfer can have a significant effect on the relative importance of these two channels. Based on a number of model variations that I simulated, I will show that merger rate of the channel with two stable mass transfers can change an order of magnitude depending on what we assume about the angular momentum lost from the system and the mass accretion efficiency during the first mass transfer phase. At the same time, the merger rates of the common envelope channel can be significantly lower than previously predicted, if we update our models based on recent developments on the mass transfer stability criteria with giants with radiative donors and predictions about at what stage the star develops a deep convective envelope. Finally, I also compare my results to gravitational wave observations and to High-mass X-ray binaries, where the latter can give us important clues about angular momentum lost from the system and the mass accretion efficiency.

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Modelling neutron-star mountains

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Over the past few years, we have enjoyed a wide variety of gravitational-wave detections of compact binary coalescences. However, the wait continues for the first observation of a rotating neutron star via gravitational waves and, so far, only upper limits on the size of the involved deformations have been obtained. For these reasons, the maximum quadrupole deformation (or mountain) that a neutron star can sustain is of great interest. In this talk, I will outline how neutron-star mountains are calculated, while identifying issues with previous studies relating to boundary conditions. In light of these issues, I shall present a novel scheme for modelling neutron-star mountains, which requires a description of the fiducial force that takes the star away from sphericity. I will show some results computed in full general relativity, exploring the roles of both the deforming force and the equation of state in supporting mountains.

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Spin misalignment of black hole binaries from young star clusters: implications for the origin of GWTC-2 events

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The recent analysis of gravitational wave data by the Ligo-Virgo collaboration (arXiv:2010.14533) provides evidence of merging binary black holes with non-zero spins.
Spinning binary BHs with aligned spins can result from the tidal spin-up of a Wolf-Rayet binary that survived the common envelope phase. However, tidal spin-up results in spins aligned with the orbital angular momentum, a scenario that is strongly disfavoured by the observations.
We show that post-common envelope binaries in star clusters are likely to undergo a single dynamical encounter with other black holes before merging via gravitational waves. This dynamical interaction can tilt the binary orbital plane, leading to spin-orbit misalignment.
We have investigated the spin properties of merging binary black holes undergoing this pathway in young star clusters, by means of up-to-date binary population synthesis and accurate few-body simulations.
Adopting conservative limits on the binary-single encounter rates, we obtain a local BH merger rate density of 6.6 yr^-1 Gpc^-3.
Assuming low (<0.2) natal BH spins, this scenario can reproduce the distributions of effective spin Xeff and precession parameters Xp inferred from GWTC-2, including the negative values of Xeff and the peak at Xp ~ 0.2.

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A fast and flexible method to detect higher order modes in the inspiral phase of compact binary coalescences.

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As the gravitational-wave interferometers increase their sensitivity, they detect an ever larger number of compact binary coalescences: a small but significant fraction of which contains detectable higher multipoles in addition to the dominant (2, 2) mode. Such higher multipoles can be identified with a minimally-modeled extension of the coherent WaveBurst (cWB) burst pipeline.
During the inspiral phase, the higher multipoles produce chirps whose instantaneous frequency is roughly a multiple of the dominant (2, 2) mode: we use the cWB burst pipeline to perform a search for such spectral features within suitable regions of the time-frequency domain. This novel method has

already been used in the GW190814 discovery paper (Astrophys. J. Lett. 896 L44) and it is very fast and flexible. Here we describe in full detail the procedure to detect the (3, 3) multipole in GW190814 within the cWB framework, as well as additional searches for other subdominant modes. We also apply this method on another event that displays possible higher multipoles, GW190412.

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The IMRPhenom program: accurate and computationally efficient waveform models for compact binary gravitational wave signals

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The phenomenological waveform modelling program is one of the main approaches to accurately model gravitational wave signals from compact binary coalescences during all the emission stages, incorporating information from several analytical and numerical frameworks (Post-Newtonian theory, Numerical Relativity, Black-hole perturbation theory) in compact close-form computationally efficient expressions for the waveforms. This talk is dedicated to the most recent generation of IMRPhenom models: the frequency-domain IMRPhenomX family, a major improvement in accuracy over the previous IMRPhenomD-based generation of models, including sub-dominant harmonics calibrated to Numerical Relativity, enhanced computational efficiency through an implementation of the multi-banding technique, and the inclusion of generic spin treatment for precessing systems through the incorporation of the multiscale analysis approach for describing the Euler angles in an improved "twisted-up" formulation. A novel IMRPhenom waveform family constructed natively in the time domain is also presented, IMRPhenomT, highlighting the main improvements it carries over the traditional Fourier domain modelling, mainly the avoidance of the stationary phase approximation for modelling the precessing transfer functions, more robust treatment of the precessing merger-ringdown through the inclusion of analytical approximations, and a new computationally efficient numerical evolution of the spin degrees of freedom for modelling the precessing inspiral.

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Searching for Gravitational Waves from Scorpius X-1

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The low-mass X-ray binary Scorpius X-1 (Sco X-1) is a promising source of continuous gravitational waves for ground-based detectors. We use an improved method to search for signals with nearly constant frequency from Sco X-1 in the range of 40-180 Hz in LIGO O2 public data. Thanks to the efficiency of the search pipeline we can use a long coherence time and significantly improve the sensitivity. Our search has been able to probe gravitational wave amplitudes that could balance the accretion torque at the neutron star radius, for an inclination angle 44 ± 6 derived from radio observations, and assuming that the spin axis is perpendicular to the orbital plane. Our results are more constraining if the neutron star is magnetized, where the accretion torque is longer than the neutron star radius. This allows us to exclude certain mass-radius combinations and to place upper

limits on the strength of the star's magnetic field with a different probe than ever used before. We will present our results and the physical interpretation of the neutron star. In this talk, we will also discuss a spin evolution model of the neutron star in Sco X-1 and use it to predict the spin parameters, the detectability of the associated gravitational-wave signal and inspirations for gravitational-wave search setup.

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Detecting planetary-mass primordial black holes with resonant electromagnetic gravitational-wave detectors

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The possibility to detect gravitational waves (GW) from planetary-mass primordial black hole (PBH) binaries with electromagnetic (EM) detectors of high-frequency GWs is investigated. We consider two patented experimental designs, based on the inverse Gertsenshtein effect, in which incoming GWs passing through a static magnetic field induce EM excitations inside either a TM cavity or a TEM waveguide. The frequency response of the detectors is computed for post-newtonian GW waveforms. We find that such EM detectors based on current technology may achieve a strain sensitivity down to $h \sim 10^{-30}$, which generates an EM induced power of 10^{-10} W. This allows the detection of PBH binary mergers of mass around $10^{-5} M_{\odot}$ if they constitute more than 0.01 percent of the dark matter, as suggested by recent microlensing observations. We envision that this class of detectors could also be used to detect cosmological GW backgrounds and probe sources in the early Universe at energies up to the GUT scale.

This reasearch leads to an accepted publication in Physical Review D. More info: https://arxiv.org/abs/2012.12189

Sources of Gravitational Waves / 908

Jointly setting upper limits on multiple components of an anisotropic stochastic gravitational-wave background

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With the increasing sensitivities of the gravitational wave (GW) detectors and more detectors joining the international network, the chances of detection of a stochastic GW background (SGWB) is progressively increasing. Different astrophysical and cosmological processes are likely to give rise to backgrounds with distinct spectral signatures and distributions on the sky. The observed background will therefore be a superposition of these components. Hence, one of the first questions that will come up after the first detection of an SGWB will likely be about identifying the dominant components and their distributions on the sky. These questions were addressed separately in the literature, namely, how to separate components of the isotropic backgrounds and how to probe the anisotropy of a single component. In this presentation, we address the question of how to separate distinct anisotropic backgrounds with (sufficiently) different spectral shapes. We will present a novel

method to jointly set upper limits on multiple components of an anisotropic stochastic gravitational-wave background.

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Neutron Star Mountain Creation]{Mountain formation by repeated, inhomogeneous crustal failure in a neutron star

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The elastic crust of a neutron star fractures repeatedly as it spins down electromagnetically. An idealized, macroscopic model of inhomogeneous crustal failure is presented based on a cellular automaton with nearest neighbor tectonic interactions involving strain redistribution and dissipation. Predictions are made of the size and waiting-time distributions of failure events, as well as the rate of failure as a function of time, as the star spins down. The last failure event typically occurs, when the star spins down to $\approx (5 \pm 3)\%$ of its birth frequency, with implications for rotational glitch activity. Neutron stars are commonly suggested as sources of continuous gravitational waves. The output of the automaton is converted into predictions of the star's mass quadrupole moment and gravitational wave strain as functions of its age, with implications for future observations with instruments such as the Laser Interferometer Gravitational Wave Observatory (LIGO).

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Efficiency of registration of chirp bursts and signals of collapsing stars by the Euro-Asian network of GW interferometers

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In this report, we evaluate the performance of the proposed Euro-Asian network (EAN) of gravitational wave (GW) interferometers, which is planned taking into account the location of one of the detectors at the RAS Novosibirsk Scientific Center. EAN is formed by four detectors: VIRGO, KAGRA, LIGO India and Novosibirsk. The efficiency of this configuration is calculated based on typical numerical criteria for wide area networks (Raffai et al., Class. Quantum Grav. 30 (2013) 155004). One of the key criteria is the accuracy of reconstructing the parameters of GW bursts, which links the calculation of this criterion to a specific class of astrophysical sources. Previously, such calculations were performed for the "chirp" signals from the fusion of relativistic binaries. We are now adding estimates for signals from rotating collapsing stars at the "rebound" stages of the compression and bar-configuration formation process, preceding the final formation of the superdense remnant. The criterion of parameters, together with the criteria of polarization and localization, allows one to compare the integral efficiency of networks of various structures. As one of the important results, we find the optimal orientation of the Novosibirsk detector, which is specified by the angle between the south direction and the bisector of the Michelson arms of the GW interferometer. Comparison of the efficiency of EAN with two reference networks (HLVK, HLVI) when receiving "chirp" signals as well as signals of collapsing stars is performed. In the latter case, only sources within the Galaxy are taken into account; therefore, the averaging is performed over the celestial coordinates of the Milky Way. Numerical integration shows that the EAN predicts results comparable to known networks in

reconstructing the polarization and source parameters. However, the EAN copes somewhat worse with the source localization criterion, since all EAN detectors are located on the same Euro-Asian continent.

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Gravitational wave signatures of magnetic field generation in core collapse supernovae

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After the groundbreaking gravitational wave detections of compact binary mergers, core-collapse supernova explosions of massive stars have come into focus as one of the next big challenges for gravitational wave astronomy. Thanks to increasingly mature simulations, our understanding of the expected time-frequency structure of the core-collapse supernova gravitational wave signal has advanced considerably. In the event of a high signal-to-noise detection, this would allow us to derive quantitative constraints on the proto-neutron star structure, the explosion dynamics, and the rotation of the progenitor core. However, the impact of magnetic fields on the supernova gravitational wave signal has yet to be explored in depth, especially in the light of growing awareness of a more pervasive role of magnetic fields in supernovae than hitherto assumed. I will discuss gravitational wave signatures of magnetic field generation suggested by recent simulations and also comment on broader perspectives for magnetohydrodynamic modelling of core-collapse supernovae.

Status of the H_0 and Sigma_8 Tensions: Theoretical Models and Model-Independent Constraints

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Extra components solutions to the Hubble tension with BBN

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The standard Lambda CDM cosmological model now seems to face some puzzles. One of the most serious problems is the so-called Hubble tension; the values of the Hubble constant obtained by local measurements look inconsistent with that inferred from CMB. Although introducing extra energy components such as the extra radiation or early dark energy appears to be promising, such extra components could alter abundance of light elements synthesized by Big Bang Nucleosynthesis (BBN). We perform Monte Carlo simulation to evaluate the effect of those extra component scenarios for solving the Hubble tension to the BBN prediction.

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Parameter discordance in current cosmology: projection in the primordial power spectrum

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The discordance can be due to a wide range of non-standard cosmological or astrophysical processes as well as from some particular systematics. Here, without considering any particular astrophysical process or extension to the standard model at the background level, we look to project the effect of these differences in the values of the key cosmological parameters on to the shape of the primordial power spectrum. We show that there is a class of primordial power spectra that can fit the observed anisotropies in the cosmic microwave background well and that predicts a value for the Hubble parameter and S8 consistent with the local measurements. I also briefly discuss a theoretical inflationary model that can generate such features in the form of the primordial spectrum.

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A compelling resolution to H0 tension

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I will explain the limitations of resolutions to Hubble tension within Einstein gravity and the FLRW paradigm. I will then leverage persistent discrepancies in the cosmic radio dipole to argue that we must move beyond FLRW. I will provide hints across various cosmological probes that the Hubble constant is higher in the hemisphere aligned with the CMB dipole.

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Let us bury the prehistoric h: arguments against using Mpc/h units in observational cosmology

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It is common to express cosmological measurements in units of Mpc/h. Here, I review some of the complications that originate from this practice. A crucial problem caused by these units is related to the normalization of the matter power spectrum, which is commonly characterized in terms of the linear-theory rms mass fluctuation in spheres of radius 8 Mpc/h, $\sigma 8$. This parameter does not correctly capture the impact of h on the amplitude of density fluctuations. I show how the use of $\sigma 8$ has caused critical misconceptions for both the so-called $\sigma 8$ tension regarding the consistency between low-redshift probes and cosmic microwave background data and the way in which growth-rate estimates inferred from redshift-space distortions are commonly expressed. We propose to abandon the use of Mpc/h units in cosmology and to characterize the amplitude of the matter power spectrum in terms of $\sigma 12$, defined as the mass fluctuation in spheres of radius 12 Mpc, whose value is similar to the standard $\sigma 8$ for $h \sim 0.67$.

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Quantifying the S8 tension with the Redshift Space Distortion data set

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One problem of the ΛCDM model is the tension between the S8 found in Cosmic Microwave Background (CMB) experiments and the smaller one obtained from large-scale observations in the late Universe. The σ8 quantifies the relatively high level of clustering. Bayesian Analysis of the Redshift Space Distortion (RSD) selected data set yields: S8 = 0.700+0.038
−0.037. The fit has 3σ tension with the
Planck 2018 results. With Gaussian processes method a model-independent reconstructions of the growth history of matter in-homogeneity is studied. The fit yields S8 = 0.707+0.085
−0.085, 0.701+0.089
−0.089,
and 0.731+0.063
−0.062 for different kernels. The tension reduces and being smaller then 1.5 σ. With future measurements the tension may be reduced, but the possibility the tension is real is a plausible situation.

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Measuring Hubble's Constant with the Inverse Distance Ladder

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The precise value of Hubble's constant has become one of the most interesting cosmological tensions in recent years. Measurements of H_0 with Type Ia supernovae, in a series of papers by Reiss et al., use a distance ladder of parallax and Cepheid variable stars, and find a value of H_0 which is significantly higher than expected in a LCDM cosmology with Planck CMB parameters. In this work, we use an 'inverse distance ladder' method, using distance measurements from Baryon Acoustic Oscillations to calibrate the intrinsic magnitude of the SNe. We study 207 SNe from the Dark Energy Survey, at redshift 0.018 < z < 0.85, with existing measurements of 122 low redshift (z < 0.07) SNe. We find a value of H_0 = 67.8 +/- 1.3 km s-1 Mpc-1, which is consistent with the Planck + LCDM value. Our measurement makes minimal assumptions about the underlying cosmological model, and our analysis was blinded to reduce confirmation bias.

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Early and not so early dark energy. What do cosmological observations tell us about them?

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Dark energy might be in charge of the late-time acceleration of the universe, but not only so. Many quintessence models possess scaling or attractor solutions where the fraction of dark energy follows the one of the dominant component in previous epochs of the universe's expansion. Hence, they could play a role in some physical processes at redshifts z»O(1). For instance, the presence of a non-negligible early dark energy (EDE) component around the matter-radiation equality time teq has raised as an interesting mechanism of loosening the famous H0 tension. In this work we constrain the fraction of EDE using some simple fluid parametrizations and also a non-parametric approach based on the binning of the EDE density. The latter allows us to reconstruct the shape of Ωde(z) not only before the decoupling of CMB photons, but also after it. We have employed the CMB temperature, polarization and lensing data from Planck 2018, the Pantheon compilation of supernovae of Type Ia (SNIa), data on galaxy clustering from several surveys, the prior on the absolute magnitude of SNIa obtained from the first steps of the cosmic distance ladder by SH0ES, and weak lensing data from KiDS+VIKING-450 and DES-Y1. We update previous constraints on the constant fraction of EDE in the radiation- and matter-dominated epochs, and show that with such a simple shape EDE has a negligible impact on the cosmological tensions. We reconfirm that for more complicated forms of Ωde(z), with a significant value around teq, EDE can alleviate the H0 tension at the expense of enhancing the large-scale structure (LSS) formation processes in the universe with respect to the standard ΛCDM model. This holds not only when we employ σ8 and S8 as our LSS estimators, but also when we use the recently proposed σ12 and S12 parameters. This issue can be alleviated through the presence of EDE during the post-recombination era.

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Hubble speed from first principles

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We introduce a novel way of measuring H0 from a combination of independent geometrical datasets, namely Supernovae, Baryon Acoustic Oscillations and Cosmic Chronometers, without the need of calibration nor of the choice of a cosmological model. Our method builds on the distance duality relation which sets the ratio of luminosity and angular diameter distances to a fixed scaling with redshift, for any metric theory of gravity with standard photon propagation. In our analysis of the data we employ Gaussian Process algorithms to obtain constraints that are independent from the underlying cosmological model. We find H0 = 69.5+/- 1.7 Km/s/Mpc,showing that it is possible to constrain H0 with an accuracy of 2% with minimal assumptions.

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Prospect of Measuring Hubble Constant using Gravitational Wave Sources

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Several observations using electromagnetic signal have led to a paradigm shift in our understanding of the Universe, with the realization that two unknown quantities - namely dark matter and dark energy - constitute about 95% of the Universe, even though their existence could not be explained by the known laws of physics and fundamental particles discovered until now. Moreover, measurements of the current expansion rate of the Universe, known as the Hubble constant - using several independent methods based on observations of different cosmological probes have reached an enigmatic and startling conclusion. These Hubble constant measurements are strongly inconsistent with each other. This discrepancy has led us to question the foundations of cosmology, indicating either an entirely new physics or unknown systematics. I will discuss how the gravitational wave observations can play a pivotal role in resolving the tension in the value of the Hubble constant and provide a better understanding of the constituents of the Universe. I will explain novel techniques that will enable us to map the expansion history of the Universe up to high redshift using gravitational wave sources and how it can peer into new territories of fundamental physics that are currently unexplored from electromagnetic observations.

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Gravitational anomalies , axions and a string-inspired Running Vacuum Model in Cosmology

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In the talk, I review a string-inspired running vacuum model (RVM) of Cosmology, and its potential connection with the dark sector of the (observable) Universe. Specifically, I consider a gravitational model of the early Universe that is inspired by the low-energy effective actions of string theory. I assume that only gravitational degrees of freedom appear as external fields at early eras. I associate the spin-one Kalb-Ramond (KR) antisymmetric tensor field that exists in the fundamental massless (bosonc) gravitational multiplet of strings with a totally antisymmetric torsion. The latter is known to give rise to the string-model independent KR gravitational axion field, which couples to the gravitational-anomaly Chern-Simons terms, that characterise the model in a self-consistent manner, as I discuss. These terms are non-zero in the presence of primordial gravitational waves (GW), and their condensation leads to an inflationary era in this model, of a RVM type, without fundamental inflatons. A brief discussion on the potential origin of these GW, during a pre-inflationary era of this string-inspired Cosmology, is also presented. At the exit from the inflationary phase, chiral fermionic matter fields are generated in the model, which cancel the primordial gravitational anomalies. Chiral anomalies, though, remain in general, and may lead to a non-perturbative (instanton-induced) generation of the KR-axion mass during the QCD epoch of this Universe. This implies that the KR axion may play the role of a dark-matter component. The KR axion background can also lead to spontaneous Lorentz-violation during inflation, as a result of the presence of the anomaly condensate. It remains undiluted at the exit from inflation, leading to leptogenesis in theories with right-handed neutrinos. Finally, I discuss briefly the current-era phenomenology of this stringy RVM, as far as tensions in data and deviation from the standard concordance model of Cosmology are concerned.

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Exploring Cosmological Concordance with ACT DR4, Planck, and Beyond

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I will discuss recent and ongoing work focused on attempts to restore concordance amongst cosmological data sets in the context of the H0 and S8 tensions. Particular attention will be paid to models invoking new physics at or prior to recombination, including small-scale baryon-clumping models (e.g., due to primordial magnetic fields) and quasi-accelerating early dark energy models.

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Measuring the Hubble constant from Gravitational Lensing

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First proposed in 1964 by Sjur Refsdal, gravitational lensing provides a straightforward and elegant geometrical way of estimating the Hubble constant from cosmologically distant variable sources. The method relies on observationally determined time delays between light arriving through different multiple images, and the mass models of the lens, which are constrained by observed image properties and other information. While the time delays are obtained with increasing precision, the mass models, which are subject to lensing degeneracies, remain the main source of systematic uncertainty. Various modeling groups have adopted different strategies for dealing with degeneracies. In this talk I will describe the basics of extracting H0 from lensing, the observational successes, modeling challenges, current results, and future prospects.

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Alleviating H0 and sigma8 tensions with f(T) gravity, using the effective field theory approach

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We report how to alleviate both the H0 and sigma8 tensions simultaneously within torsional gravity from the perspective of effective field theory. Following these observations, we construct concrete models of Lagrangians of torsional gravity. Specifically, we consider a novel f(T) parametrization where two out of the three parameters are independent. This modified gravity model can efficiently fit observations alleviating the two tensions simultaneously, hence offering an additional argument in favor of gravitational modification.

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Testing Gravity on Cosmic Scales: A Case Study of Jordan-Brans-Dicke Theory

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I will present an end-to-end exploration of the simplest modified gravitational theory in Jordan-Brans-Dicke (JBD) gravity, from an analytical and numerical description of the background expansion and linear perturbations, to the nonlinear regime captured with a hybrid suite of N-body simulations, to the parameter constraints from existing cosmological probes. In the analysis, the nonlinear corrections to the matter power spectrum due to baryons, massive neutrinos, and modified gravity are simultaneously modeled and propagated in the cosmological analysis for the first time. I will show how the uncertainty in the gravitational theory alleviates the S_8 tension between the joint (3×2pt) dataset of weak gravitational lensing tomography and overlapping redshift-space galaxy clustering from the Kilo Degree Survey × 2-degree Field Lensing Survey and the cosmic microwave background (CMB) dataset of Planck, and the extent to which it alleviates the tension between the local measurement of the Hubble constant and that inferred by Planck. Despite the alleviation of S_8 and H_0 tensions, I will show that there is no substantial model selection preference for JBD gravity

relative to ΛCDM. I will further discuss how the uncertainty in the underlying gravitational theory complicates future inferences of small-scale physics from the CMB.

Status of the H_0 and Sigma_8 Tensions: Theoretical Models and Model-Independent Constraints / 814

Precision Cosmology and Hubble tension in the era of LSS surveys

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We present a fully relativistic framework to evaluate the impact of stochastic inhomogeneities on the prediction of the Hubble-Lemaitre diagram. To this aim, we relate the fluctuations of the luminosity distance-redshift relation in the Cosmic Concordance model to the intrinsic uncertainty associated to the estimation of cosmological parameters from high-redshift surveys (up to z = 4). We apply this framework and, according to the specific of forthcoming surveys as Euclid Deep Survey and LSST, we show that the cosmic variance associated with the measurement of the Hubble constant is at most of 0.1 %. Thanks to our results, we infer that deep surveys will provide an estimation of the the Hubble constant H_0 which will be more precise than the one obtained from local sources, at least in regard of the intrinsic uncertainty related to a stochastic distribution of inhomogeneities.

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Dark matter-dark energy interactions and their cosmological implications

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In this talk I will consider a very popular scenario where the dark energy is a dynamical fluid whose energy density can be transferred to the dark matter, and vice versa, via a coupling function proportional to the energy density of the dark energy. In particular, I will discuss this model's ability to address the H_0 and S_8 tensions showing that considering data from Planck, BAO and Pantheon the model 1) can only minimally alleviate the H_0 tension but 2) can significantly reduce the significance of the S_8 tension without exacerbating nor introducing any other tension (such as the H_0 tension) and without worsening the fit to the considered data sets with respect to the ΛCDM model.

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The Hubble tension and the magnetic universe

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Magnetic fields, if present in the plasma prior to last scattering, would induce baryon inhomogeneities and speed up the recombination process. As a consequence, the sound horizon at last scattering would be smaller, helping to relieve the Hubble tension and the S8 tension. Intriguingly, the strength of the magnetic field required to alleviate the Hubble tension happens to be of the right order to also explain the observed magnetic fields in galaxies, clusters of galaxies and the intergalactic space. I will review this proposal and provide an update on its status in the context of the latest data.

Status of the H_0 and Sigma_8 Tensions: Theoretical Models and Model-Independent Constraints / 711

Measuring H(z) in a cosmology-independent way

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I present a method to estimate H(z)/H_0 without assuming a cosmological model. The method employs the clustering of standard candles from future surveys like LSST. We find that LSST can constrain H(z)/H_0 up to z=0.7 with uncertainties, in the best cases, around 5%. The method can be further improved by including large galaxy surveys.

Status of the H_0 and Sigma_8 Tensions: Theoretical Models and Model-Independent Constraints / 909

Interacting vacuum cosmology and observational constraints

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An interacting vacuum, with fixed equation of state w=-1, provides a simple model for dark energy in our Universe today, distinct from models with a varying equation of state. I will review the phenomenology of simple models where the vacuum can exchange energy and momentum with dark matter and consider the observational bounds on the interaction coming from the cosmic microwave background and large-scale structure. Such models introduce a degeneracy between the Hubble constant and the interaction strength, which determines the evolution of the dark matter density. I will present some recent work modelling structure formation in this model and perturbations in the vacuum energy. I will discuss breaking the Hubble degeneracy in this model and the implications for current tensions in cosmology.

Status of the H_0 and Sigma_8 Tensions: Theoretical Models and Model-Independent Constraints / 442

BD-ΛCDM and running vacuum models: theoretical background and current observational status

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We study Brans-Dicke gravity with a cosmological constant and cold dark matter (BD-ΛCDM hereafter). This theory is the first historical attempt to extend Einstein's General Relativity by promoting the Newtonian coupling constant G_N to a dynamical one $G(t)$. We present the background and the perturbation equations, which allows us to test the theoretical predictions with a complete and updated data string, formed by: CMB+BAO+LSS+$H(z)$+SNIa. Additionally, we contemplate the possibility of including alternative data in order to cover a wide variety of different scenarios. The BD-ΛCDM turns out to be observationally favored as compared to the concordance model (GR-ΛCDM). We pay special attention to the ability of the BD-ΛCDM model to smooth out not only the H_0-tension but also the σ_8 one. An exhaustive study can be found in arXiv:2006.04273. Due to the possible connection with the running vacuum models (RVM's) (see arXiv:2102.12758 and references therein), where a time-evolving vacuum energy density in the context of QFT is considered, we deem it is worthwhile to also present the background and the perturbation equations, as well as, the performance, of this kind of models, when they are put in the light of the observational data.

Status of the H_0 and Sigma_8 Tensions: Theoretical Models and Model-Independent Constraints / 580

The Tale of H0 Crisis and the Gravitational Transition

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We propose a late time gravitational transition at low redshifts $z_t < 0.1$ as a possible solution of both the Hubble and growth tensions. Such a transition would naturally lead to a transition of the intrinsic SnIa luminosity and absolute magnitude M at z_t and could also be accompanied by a transition in the dark energy equation of state parameter w. Thus we would have a late $w - M$ phantom transition ($LwMPT$). Such a model does not belong to the category of dark energy models with late time smooth deformations of the Hubble expansion rate $H(z)$, that as we have shown fail to address the growth tension. Therefore, the $LwMPT$ model has the potential of resolving the growth tension by reducing the growth of density perturbations without affecting the Planck/ΛCDM background expansion. Finally, we offer observational hints for a gravitational transition that would support the $LwMPT$ hypothesis via the study of the evolution of the baryonic Tully-Fisher relation. Specifically, we use a recently published data compilation, finding hints at $\approx 3\sigma$ level for a transition at critical distances $D_c \simeq 9Mpc$ and $D_c \simeq 17Mpc$.

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Cosmological tensions: hints for a new concordance model?

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The Cosmic Microwave Background temperature and polarization anisotropy measurements have provided strong confirmation of the LCDM model of structure formation. Even if this model can explain incredibly well the observations in a vast range of scales and epochs, with the increase of the

experimental sensitivity, a few interesting tensions between the cosmological probes, and anomalies in the CMB data, have emerged with different statistical significance. While some portion of these discrepancies may be due to systematic errors, their persistence across probes strongly hints at cracks in the standard LCDM cosmological scenario. The most statistically significant is the Hubble constant puzzle and I will show a couple of interesting extended cosmological scenarios that can alleviate it.

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Renormalized ρ_{vac} without m^4 terms

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The cosmological constant (CC) term, Λ, in Einstein's equations has been for some three decades a fundamental building block of the concordance or standard ΛCDM model of cosmology. Even though the model is not free of fundamental problems, they have not been circumvented by any alternative dark energy
proposal either.

However, an interesting alternative is that the vacuum energy is a "running quantity" in quantum field theory in curved spacetime. Several works have shown that this is option can compete with the ΛCDM with a rigid Λ term. The so-called, "running vacuum models" (RVM) are characterized by a vacuum energy density, ρ_{vac}, which is evolving with time as a series of even powers of the Hubble parameter and its time derivatives. This form has been motivated by renormalization group arguments in previous works.

In this talk we show how to compute the renormalized energy-momentum tensor with the help of adiabatic regularization procedure as it has been done in arXiv/2005.03164 (Eur. Phys. J. C (2020) 80 : 692). The final result is a RVM-like form of the vacuum energy, with $\rho_{vac}(H)$ being a constant term plus others $\sim H^2$ and $\sim H^4$. Besides, it does not carry dangerous terms proportional to m^4, the quartic powers of the masses of the fields, which are a well-known source of exceedingly large contributions.

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Unparticles and H_0-tension in the late-time universe

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ΛCDM is increasingly challenged by observations in the late-time Universe. Here we consider unparticle cosmology for its potential to alleviate some of these issues. Unparticles offer a scale invariant contribution by an extra parameter δ, here studied for $\delta \in [-6, 1]$ (corresponding to scaling dimension $d_u \in [-2, 3/2]$). For most values of δ, the model predicts the distant future to be Minkowski or stable de Sitter, the latter in common with ΛCDM. For some $\delta \approx -3$, it predicts a diverging $H(z)$ in the future of universe accompanied by a turning point at some $-1 < z < 0$. However, in a detailed confrontation with $H(z)$-data within the radius of convergence of this model, the

data show a clear preference for the holographic limit $\delta = -2$ without any additional assumptions. This pointer to holography is remarkable because of recent studies suggesting it may ameliorate H_0-tension, even though in unparticle cosmology this limit fails to resolve this tension evidenced by a pronounced gap in our qQ-diagram.

Status of the H_0 and Sigma_8 Tensions: Theoretical Models and Model-Independent Constraints / 313

Cluster cosmology: impact of the mass calibration on the sigma8 tension.

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In this talk, we discuss cosmological constraints inferred from detection of galaxy clusters in the mm-wavelengths (through the thermal Sunyaev-Zeldovich effect), using Planck observations.
We focus in particular on the well known sigma8 tension. We provide a novel analysis of Planck clusters (also in combination with the power spectrum of the total tSZ signal), showing that constraints are now fully in agreement with results from CMB primary anisotropies.
Nevertheless, a discrepancy is still present when comparing results on the mass bias parameter.
We therefore focus on how the cluster mass evaluation stands as the major source of systematic effects in current cluster cosmology and how an incorrect mass calibration can largely bias the cosmological results.
We highlight that the current remaining tension between tSZ clusters and CMB anisotropies can be due to an incorrect description of the interplay between astrophysics and cosmology when describing the cluster formation and evolution.

Strong Electromagnetic and Gravitational Field Physics: From Laboratories to Early Universe

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On Kerr black hole perfect MHD processes in Doran coordinates

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Doran horizon penetrating coordinates are adopted to study specific perfect MHD processes around a Kerr black hole, focusing in particular on the physical relevance of selected electrodynamical quantities.

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On the origin of the LIGO ”mystery” noise and the high energy particle physics desert

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One of the most ubiquitous features of quantum theories is the existence of zero-point fluctuations in their ground states. For massive quantum fields, these fluctuations decouple from infrared observables in ordinary field theories. However, there is no "decoupling theorem" in Quantum Gravity, and we recently showed that the vacuum stress fluctuations of massive quantum fields source a red spectrum of metric fluctuations given by ~ mass5/frequency in Planck units. I show that this signal is consistent with the reported unattributed persistent noise, or "mystery" noise, in the Laser Interferometer Gravitational-Wave Observatory (LIGO), for the Standard Model of Particle Physics. If this interpretation is correct, then it implies that: 1) This will be a fundamental irreducible noise for all gravitational wave interferometers, and 2) There is no fundamental weakly-coupled massive particle heavier than those in the Standard Model.

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Tadpole contribution to magnetic photon-graviton conversion

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Photon-graviton conversion in a magnetic field is a process that is usually studied at tree level, but the one-loop corrections due to scalars and spinors have also been calculated. Differently from the tree-level process, at one-loop one finds the amplitude to depend on the photon polarization, leading to dichroism. However, previous calculations overlooked a tadpole contribution of the type that was considered to be vanishing in QED for decades but erroneously so as shown by Gies and Karbstein in 2016. Here we compute this missing contribution in closed form and study its numerical relevance compared to the standard one.

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Perspectives of measuring gravitational effects of laser light and particle beams

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High energy laser beams and particle beams, such as the one of the Large Hadron Collider (LHC) at CERN, can be used as lab-scale, relativistic sources of gravitational fields. We present a study of the creation and possibility of detection of oscillating gravitational fields from lab-scale, relativistic sources. Lab-based sources allow for signal frequencies much higher and far narrower in bandwidth than what most celestial sources produce. In addition, by modulating the source beams, the source frequency can be adjusted over a very broad range. In this talk we show an analysis of the gravitational field produced by these sources and the responses of a variety of detectors, with the outlook that an adapted version of a recently experimentally demonstrated high-Q monolithic pendulum might be able to detect the gravitational signal produced by the planned high-luminosity upgrade of

the LHC. This opens new perspectives of studying general relativistic effects and possibly quantum-gravitational effects with ultra-relativistic, well-controlled terrestrial sources.

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Why quantum field theory in curved space–time is very far from being well understood

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We discuss equilibration process in expanding universes as opposed to the thermalization one in Minkowski space–time. The goal is to answer the question: Does the equilibrium reached before the rapid expansion stops and has negligible effect on the background geometry? Or stress–energy fluxes in a universe of GUT scale curvature have strong effects on the expansion rate and the equilibrium is reached only after the drastic decrease of the space–time curvature? We discuss the notion of observables in highly curved space–times. We argue that consideration of more generic non–invariant Hadamard states in theories with invariant actions is a necessary ingredient to understand quantum field dynamics in strongly curved backgrounds. The reason for the consideration of such states is the presence of secular memory effects in generic time dependent backgrounds, which are totally absent in equilibrium.

Strong Electromagnetic and Gravitational Field Physics: From Laboratories to Early Universe / 772

Breaking of adiabatic invariance in the production of particles by strong fields

Authors: Pau Beltrán-Palau[1]; Jose Navarro-Salas[2]; Antonio Ferreiro[3]; Silvia Pla Garcia[4]

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Particles are spontaneously created from the vacuum by time-varying gravitational or electromagnetic backgrounds. It has been proven that the particle number operator in an expanding universe is an adiabatic invariant. In this talk we show that, in some special cases, the expected adiabatic invariance of the particle number fails in presence of electromagnetic backgrounds. In order to do this, we consider as a prototype a Sauter-type electric pulse. Furthermore, we also show a close relation between the breaking of the adiabatic invariance and the emergence of the axial anomaly. This talk is based on the paper Phys. Rev. **D** 100, 085014 (2019).

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Amplifying the entanglement of detectors around rotating BTZ black holes

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The quantum vacuum has long been known to be characterized by field correlations between spacetime points. These correlations can be swapped with a pair of particle detectors, modelled as simple two-level quantum systems (Unruh-DeWitt detectors) via a process known as entanglement harvesting. We study this phenomenon in the presence of a rotating BTZ black hole, and find that rotation can significantly amplify the harvested vacuum entanglement. Concurrence between co-rotating detectors is amplified by as much as an order of magnitude at intermediate distances from the black hole relative to that at large distances. The effect is most pronounced for near-extremal small mass black holes, and allows for harvesting at large spacelike detector separations. We also find that the entanglement shadow − a region near the black hole from which entanglement cannot be extracted − is diminished in size as the black hole's angular momentum increases.

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Gravitational properties of laser light

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The properties of light are premises in the foundations of modern physics: they were used to derive special and general relativity and are the basis of the concept of time and causality in many alternative models. Therefore, it is worthwhile to study the back-action of light on the gravitational field with its rich phenomenology, even though the effects are in general very weak. In this talk, an overview is given of the gravitational properties of light, in particular, of laser pulses and focused laser beams with well-defined angular momentum. The time-dependence in the case of a laser pulse enables the investigation of the formation of the gravitational field of light. The stationary case of the gravitational field of a focused laser beam shows effects of the fundamental wave properties of light. I will also present results on the effect of angular momentum of light: frame dragging, the gravitational Faraday effect and gravitational spin-spin coupling of light.

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Most Reliable Strong and Electroweak Evolution

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Both QCD and EW eras play essential roles in laying seeds for nucleosynthesis and even dictating the cosmological large-scale structure. Taking advantage of recent developments in ultrarelativistic nuclear experiments and nonperturbativ and perturbative lattice simulations, various thermodynamic quantities including pressure, energy density, bulk viscosity, relaxation time, and temperature have

been calculated up to the TeV-scale, in which the possible influence of finite bulk viscosity is characterized for the first time and the analytical dependence of Hubble parameter on the scale factor is also introduced.

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Neutral Fermion pair production by Sauter-like magnetic step

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In this talk, we discuss recent results on neutral fermion pair production from the vacuum by an inhomogeneous Sauter-like magnetic field. We find exact solutions of the Dirac-Pauli equation in this field and calculate differential and total quantities characterizing vacuum instability. Special attention is paid to cases where the gradient of the magnetic field varies either gradually or abruptly over a spatial coordinate.

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Particle creation by strong fields and quantum anomalies

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Particle creation by strong and time-varying backgrounds is a robust prediction of quantum field theory. Another well-stablished feature of QFT is that classical symmetries do not always extend to the quantized theory. When this occurs, we speak of quantum anomalies. In this talk we discuss the intwining relationship between both predictions. First, we point out that the particle number (which can be rigorously proved to be an adiabatic invariant in an isotropic expanding universe) is not longer an adiabatic invariant in some special situations, which turn out to be those for which the chiral symmetry is also broken. Furthermore, we also argue that the symmetry under electric-magnetic duality rotations of the source-free Maxwell theory is anomalous. This implies that the net polarization of photons propagating in a strong gravitational field could change in time. This is a quantum effect, and it can be understood as the generalization of the fermion chiral anomaly to fields of spin one.

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Magnetic field screening in strong crossed electromagnetic fields

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We consider crossed electric and a magnetic fields $\left(\vec{B} = B\hat{z},\ \vec{E} = E\hat{y}\right)$, with $E/B < 1$, in presence of some initial number of $e^{\pm}$ pairs. We do not discuss here the mechanism of generation of these initial pairs. The electric field accelerates the pairs to high-energies thereby radiating high-energy synchrotron photons. These photons interact with the magnetic field via magnetic pair production process (MPP), i.e. $\gamma + B \to e^{+} + e^{-}$, producing additional pairs. We here show that the motion of all the pairs around the magnetic field lines generates a current that induces a magnetic field that shields the initial one. For instance, for an initial number of pairs $N_{\pm,0} = 10^{10}$, an initial magnetic field of 10^{12} G can be reduced of a few percent. The screen occurs in the short timescales $10^{-21} \leq t \leq 10^{-15}$ s, i.e. before the particle acceleration timescale equals the synchrotron cooling timescale. Our results indicate that the screening of magnetic fields can be very relevant in some astrophysical systems such as pulsars and gamma-ray bursts.

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New partial resummation of the QED effective action

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The goal of this talk is to present a conjecture which states that the proper-time series expansion of the one-loop effective Lagrangian of quantum electrodynamics can be partially summed in all terms containing the field-strength invariants $\mathcal{F} = \frac{1}{4}F_{\mu\nu}F^{\mu\nu}(x)$, $\mathcal{G} = \frac{1}{4}\tilde{F}_{\mu\nu}F^{\mu\nu}(x)$, including those that also have derivatives of the electromagnetic field strength. This summation is encapsulated in a factor with the same form as the (spacetime-dependent) Heisenberg-Euler Lagrangian density. I will then discuss some implications and a possible extension in presence of gravity. This talk is based on the article: Phys.Rev. **D** 103 (2021) 8, L081702.

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Experimental Observation of Acceleration-Induced Thermality

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We examine the radiation emitted by high energy positrons channeled into silicon crystal samples. The positrons are modeled as semiclassical vector currents coupled to an Unruh-DeWitt detector to incorporate any local change in the energy of the positron. In the subsequent accelerated QED analysis, we discover a Larmor formula and power spectrum that are both thermalized by the acceleration. Thus, these systems explicitly exhibit thermalization of the detector energy gap at the celebrated Fulling-Davies-Unruh (FDU) temperature. Our derived power spectrum, with a nonzero energy gap, is then shown to have an excellent statistical agreement with high energy channeling experiments and also provides a method to directly measure the FDU temperature. We also investigate the Rindler horizon dynamics and confirm that the Bekenstein-Hawking area-entropy law is satisfied in these experiments. As such, we present the evidence for the first observation of acceleration-induced thermality in a non-analogue system.

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Does a detector detect soft photons?

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BMS supertranslation symmetries are related to both the gravitational memory effect and the Weinberg's soft graviton theorem; the significance of which was recently realised by Hawking, Perry and Strominger (HPS) who conjectured that applying these relations to an asymptotically flat spacetime with a black hole in the interior would imply the existence of an infinite number of soft hairs for the black hole. We explore the question whether the presence of soft photons in a system can have direct or indirect consequences in the outcome of suitably defined quantum processes involving the system. We consider an local quantum detector with dual energy levels and coupled to the background gauge invariant charged scalar field in a flat spacetime. The transition rate for such a system on an inertial trajectory, for downward transitions $E < 0$, is found to depend on the soft charges Q_ϵ corresponding to the radial component of the electric field dressing chosen at the asymptotic boundary. The implications are discussed.

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Laboratory-based intense gamma-ray and lepton beams for strong-field QED and laboratory astrophysics

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Sources of high-energy, dense and collimated photon and lepton beams enable new avenues for research in strong-field QED and relativistic laboratory astrophysics 1-2.

Here we show that a high-current ultrarelativistic electron beam interacting with multiple thin conducting foils can undergo strong self-focusing accompanied by efficient emission of gamma-ray synchrotron photons. Physically, self-focusing and high-energy photon emission originate from the beam interaction with the near-field transition radiation accompanying the beam-foil collision. This

near field radiation is of strength comparable with the beam self-field, and can be strong enough that a single emitted photon can carry away a significant fraction of the emitting electron energy. After beam collision with multiple foils, collimated electron and photon beams with number density exceeding that of a solid are obtained 3.

The relative simplicity, unique properties, and high efficiency of this gamma-ray source open up new opportunities for both applied and fundamental research including laserless investigations of strong-field QED processes with a single electron beam 3 and the generation of dense electron-positron jets that are essential for laboratory astrophysics investigations of electron-positron plasma 1-2.

Based on these findings, the E-332 experiment on solid-density gamma-ray pulse generation in electron beam-multifoil interaction has been developed and approved with maximal ranking, and will be carried out at the FACET-II facility at SLAC.

Finally, we show that high-energy and dense lepton beams enable precision studies of fundamental quantum processes in the supercritical QED regime, where the beam particles experience rest-frame electromagnetic fields which greatly exceed the QED critical one 4.

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Dynamics of relativistic electron in non-uniform magnetic field and its applications in astrophysics and quantum computing

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It is known that when charged fermions gyrate in uniform magnetic field, their energy quantizes into discrete levels, called Landau levels. The problem of Landau quantization is typically solved in presence of uniform magnetic fields. Under such condition, the Landau levels are degenerate with overlapping of spin-up fermions in a lower energy level with spin-down fermions in the next higher energy level.

We explore for the first time, quantum properties of fermions, particularly electrons, in **spatially variable magnetic fields in relativistic regime**. We show that the modification of Landau quantization in presence of non-uniform magnetic fields results in **lifting the spin degeneracy**, and such an effect depends on the rapidity of field change. The important consequences of non-uniform magnetic fields leading to lifting the degeneracy of the levels include the splitting of Landau levels of particles with zero angular momentum from those with positive one, which is absent in uniform fields, and the change of equation of state of degenerate Fermi gas.

Landau quantization in non-uniform magnetic fields can have important consequences in different branches of physics, ranging from condensed matter to astrophysics to quantum information. Here we will discuss two of such examples. One is related to **magnetized white dwarfs**, where spatially decaying magnetic fields simultaneously affect the Landau quantization and the Lorentz force. Their combined effect is to change the Chandrasekhar mass-limit – this has far-reaching implications in astrophysics since the Chandrasekhar limit is used to determine the luminosity of the type Ia supernovae, which helps in understanding the size and expansion history of universe. We also show in another example that transition speed of an electron from a state to other increases for spatially growing magnetic fields. This may be very useful in developing **faster processing of quantum information** – which has applications to quantum computing.

Strong Electromagnetic and Gravitational Field Physics: From Laboratories to Early Universe / 944

The Validity of the Semiclassical Approximation in 1+1 Electrodynamics: Numerical Solutions to the Linear Response Equation

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From previous work, *Phys. Rev. D 103, 105003 (2021)*, the semiclassical backreaction equation (SBE) in 1+1 dimensions was solved and a criterion was implemented to assess the validity of the semiclassical approximation in this case. The criterion involves the behavior of solutions to the linear response equation (LRE) which describes perturbations about solutions to the SBE. The LRE involves a time integral over the current-current commutator for the quantum field. It is expected that significant growth in the current-current commutator (and therefore in quantum fluctuations) will result in significant growth in solutions to the LRE. It was found for early times that the difference of two nearby solutions to the SBE, with similar initial conditions, can act as an approximate solution to the LRE. A comparative analysis between the approximate solutions and numerical solutions to the LRE will be presented for the case of a massive, quantized spin ½ field. The objectives are (i) to determine how robust the approximation method is for representing solutions to the LRE, and (ii) to investigate in detail the relationship between quantum fluctuations and solutions to the LRE.

Strong Electromagnetic and Gravitational Field Physics: From Laboratories to Early Universe / 124

Vacuum instability effects in strong field QED with asymmetric electric field of analytic form

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The vacuum instability effect (the Schwinger effect) in an asymmetric electric field of an analytic form is studied nonperturbatively representing a so-called exactly solvable case. Among t-electric potential steps that belong to exactly solvable cases (Sauter-like electric field, T-constant electric field, exponentially increasing and exponentially decreasing electric field, and inverse square electric field) the external field under consideration is, along with the Sauter-like electric field, the second known example when the field and its potential are given by analytic functions and admits explicit exact solutions of the Dirac equation. However, in contrast to the symmetric Sauter-like field, the asymmetric field is free of an artificial symmetry characterizing the vacuum instability. We have found exact solutions of the Dirac equation with the asymmetric electric field and construct with their help the so-called in- and out-states in strong-field QED. On this base, we calculated differential numbers of created pairs and analyzed them in the regimes of a rapidly and slowly varying field. In addition, in the slowly varying case, the total number of created pairs was obtained. This exact result was compared with the one obtained by the help of the slowly varying field approximation demonstrating effectiveness of the latter.

Strong Electromagnetic and Gravitational Field Physics: From Laboratories to Early Universe / 729

Electromagnetic and gravitational radiation from particles in intense electromagnetic fields

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Accelerated charges emit electromagnetic radiation and the consequent energy-momentum loss alters their trajectory. This phenomenon is known as radiation reaction and the Landau-Lifshitz (LL) equation is the classical equation of motion of the electron, which takes into account self-consistently radiation-reaction effects in the electron trajectory. By using the analytical solution of the LL equation in an arbitrary plane wave, we compute the analytical expression of the classical emission spectrum via nonlinear Thomson scattering including radiation-reaction effects. Both the angularly-resolved and the angularly-integrated spectra are reported, which represent the exact classical expressions of the spectra in the sense that neglected contributions are smaller than quantum effects. Also, we have obtained a phase-dependent expression of the electron dressed mass, which includes radiation-reaction effects. Finally, the corresponding spectra within the locally-constant field approximation have been derived. In addition to electromagnetic radiation, an accelerated particle emits gravitational waves. Not just the charge itself but also the electromagnetic field generated by it and the background field are sources of gravitational radiation. This fact makes the problem of calculating the gravitational spectrum produced during a nonlinear Thomson scattering non-trivial and here we present some results in this direction.

Strong Electromagnetic and Gravitational Field Physics: From Laboratories to Early Universe / 380

Constraints on the non-minimal coupling of Electromagnetic fields from astrophysical observations

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Strong gravity regions, like the neighborhood of black holes or neutron stars, can induce non-minimal couplings between electromagnetic fields and gravity. In these regions, gravitational fields behave as a non-linear medium in which the electromagnetic fields propagate. For a system of mass M and size R, the surface potential scales as M/R. Pulsar timing array, Double pulsar Shapiro delay, and Event horizon telescope probe that largest surface potentials [10 −4 – 10 −2]. With many future experiments, it is possible to constrain the non-minimal coupling between electromagnetic fields and gravity. As a step in this direction, we consider the non-minimal coupling of EM field tensor through Riemann tensor for a dynamical black-hole, described by the Sultana-Dyer metric. The
non-minimal coupling leads to modified dispersion relations of photons, which get simplified at E/L » 1 regime, where E and L are two conserved quantities obtained by taking into account the symmetries of the metric. We calculate polarization-dependent photon deflection angle and arrival time from these dispersion relations, which we evaluate considering different astrophysical sources of photons. We compare the analytical results with the current astrophysical observations to constraint the non-minimal coupling parameters to Riemann tensor more stringently.

Teaching Einsteinian Physics to School Students

Teaching Einsteinian Physics to School Students / **845**

Newtonian force or non-inertial motion

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In this talk we present how the Newtonian force of gravity of a central field corresponds exactly to the force experienced by a stationary observer in Schwarzschild spacetime. This exercise does not require any approximation nor further assumptions and relies solely in the geometrised Newton's second law.

Teaching Einsteinian Physics to School Students / **177**

Solar astrometry at arcsecond level with a pencil, a meter and a watch at the Clementine Gnomon (1702)

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In this second contribution to the MG16 on Relativity's teaching, again on the meridian line of S. Maria degli Angeli, I publish the new tables of calibration of this meridian line in order to obtain a single measurement with absolute accuracy of 2-5 arcseconds. The lower limit of 2 arcsec is for winter observations with focal length of nearly 50 meters, while 5 arcsec is reached in summer with less than half of the length involved.
The pencil is used for signing the limbs' positions on the meridian line, the meter is sufficient to measure the distances of these limbs from the nearest reference point (there are 42 of them along the line), the watch synchronized with UTC is videorecorded along with the solar transit to get the single frame accuracy on contact's times. A timing accuracy down to 0.3 s is reached with the average air turbulences conditions. Examples on application of Cassini's and Laplace's corrections for air refraction on the observed data to obtain the real celestial coordinates of the date are presented.
This historical instrument gives the possibility to see the arcsecond, as half of a millimiter during winter, as no other instrument in the World, at the same time to many people. A set of nearly 200 transits video is also presented for remote observations during all year's seasons.

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Ingress of the Sun in Taurus 2021
Identifying Cassini and Laplace terms in atmospheric refraction at Santa Maria degli Angeli meridian line

Teaching Einsteinian Physics to School Students / 178

A soccer school field sundial with 20 arcseconds accuracy to study the ecliptic

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The shadow of a 10 meters wall casted on the soccer field of the Technical Institute Galileo Ferraris in Rome, 41.878415° N, 12.454662° E coordinates WGS84 of the gnomon, is used to perform daily measure with an accuracy within a millimiter.
The gnomon's shadow, measured from the bottom and from the side of the field with a tape meter, in the best sets of measurements, presented rms below 1 mm.
The hyperbolae drawn by the Sun through these shadows change their aperture coefficient from winter to summer, passing to zero at the equinox.
The students learn "on field" what means accuracy to the millimiter level, during several months. They learn how to do linear interpolations and extrapolations to predict the positions of the shadows in the next 10 minutes…or in the day without data. The changing curvature radius of the hyperbola is also measurable with three points along 20 minutes, repeated 3 times in a hour lesson. All these achievements are possible during a single hour of lesson, owing to the memory of the students of past situations, that are practical, so easier to remember, even for the most distracted students. The experience presented here with 14 and 15 years old students, started on 15 february 2021 and is still ongoing in may 2021, already with the spring equinox phenomenon detected by interpolation of aperture's parameters and all the ecliptic's projections in these months. The activity in open air and the use of the chalk on the field to mark the shadows' limits, the use of the meter and the care for the zero positions, are appreciated alternatives to the normal indoor teaching.

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Equinox and osculating parabolae
Tracing a meridian line with zodiacal signs

Teaching Einsteinian Physics to School Students / 126

Teaching relativity: Dynamics first

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The teaching of relativity usually starts with kinematics: The invariance of the speed of light, clock synchronization, time dilatation and length contraction, the relativity of simultaneity, Lorentz transformation and Minkowski diagram. The change of the reference frame is a central topic. Only afterwards problems of relativistic dynamics are discussed. Such an approach closely follows the historical development of the Special Theory of Relativity.
We believe that this access to relativity is unnecessarily complicated, and especially unsuitable for beginners. We present the basics of a teaching approach in which the initial postulate of relativity

is the identity of energy and relativistic mass. Reference frame changes are largely avoided.
The difference of the proper times for different world lines, which connect two points in spacetime, and which is usually discussed in terms of the twin paradox and calculated by means of the Lorentz transformation, is introduced as a basic relativistic phenomenon, which is a manifestation of the linkage between space and time.

Teaching Einsteinian Physics to School Students / 688

Einstein-First Science Education: Obsolete Science Curriculum Fuels Anti-science and World Instability

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Obsolete scientific concepts are embedded in school primary school education. This means that the large majority of people who do not study specialised physics beyond middle school are barely exposed to modern scientific concepts. Moreover they lack the language of modern science and hence are entirely disenfranchised when it comes to science policy on issues such as climate change, 5G mobile phones and vaccination, as well as modern scientific discoveries.
Students perceive the obsolete nature of the current curriculum because they are aware of concepts such as black holes from an early age.
Einsteinian physics (relativity and quantum physics) provides explanatory power for all aspects of physical reality. The Einstein-First project has created a new science curriculum that explicitly introduces modern concepts at an early age. It has been well received in a broad range of primary schools and high schools where trials are underway.

Teaching Einsteinian Physics to School Students / 918

Interactive Visualization of Relativistic Phenomena

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The introduction of Special Relativity inevitably leads to phenomena that contradict everyday experience. Immersive virtual environments provide a laboratory where relativistic effects can be investigated directly and thus, a higher level of understanding for these unfamiliar concepts is achievable. Using the method of ray tracing, computer graphics applications are able to generate photo-realistic images. We generalized this concept to represent relativistic physics and to create interactive simulations of a relativistic world. Due to this framework, we are able to interactively render accelerated and uniformly moving objects. On top of that, the user is able to perform relativistic motion. Hence, the consequences of changing the point of view can be explored.
With the help of example scenes, we demonstrate the operation of the relativistic flight simulation and present a corresponding teaching strategy.

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Teaching relativity: computer aided modeling

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Mathematical derivations alone do not necessarily lead to physical understanding. A tool that can replace the mathematical treatment of a physical process and at the same time increase physical understanding are interactive computer programs, also known as *system dynamics* software, such as Stella, Berkeley Madonna, Wensim, Dynasys, Powersim or Coach. Such interactive software solves differential equations and systems of differential equations using numerical methods. One works with a graphical user interface that is for the most part self-explanatory. We want to show how, for example, using Coach 7, one can start from a model from classical physics with only minimal changes, and arrive at a relativistic model. It is sufficient to set mass and energy equal and the model provides essential statements of relativistic dynamics: the existence of a terminal velocity for all physical movements, the relativistic dependence of the velocity of a body on its momentum, the relation between momentum and energy of a body. All this is done without any change of the reference frame and without any calculations and is even suitable for teaching in the high school.

Teaching Einsteinian Physics to School Students / 653

General Relativity in the Theater of the Absurd

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Einstein's theory of space-time curvature and its impressive astrophysical and philosophical consequences, not only since the experimental evidence of gravitational waves and the first image of a black hole, represent milestones in human knowledge, and the presentation of these insights in a popular scientific manner is an important undertaking. How can bizarre concepts such as the curvature of space–time or the event horizon of a black hole be understood? Learned things that seem outlandish to personal experience are quickly forgotten. Simple stories and familiar images can make it easier for the layperson to retain what they have learned, and one can also use absurd analogies to confront the audience with the facts of general relativity. For example, the different phases of a neutron star collision can be illustrated as an omnium-gatherum of different ballroom dances 1, or the essential properties of black holes are reflected in the architecture of the German Reichstag building 2.

1 https://itp.uni-frankfurt.de/~hanauske/TanzNeutronensterne.mp4
2 Hanauske, Matthias. "Black holes and the german reichstag." Physics World 18.10 (2005): 64.

Teaching Einsteinian Physics to School Students / 864

Virtual sector models: Exploring the curved spacetime near a neutron star

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In general relativity, the paths of light and freely falling particles are described as geodesics in curved spacetime. Sector models allow the construction of these geodesics without having to introduce the usual mathematical apparatus. Virtual sector models, provided by the web-based application ViSeMo, enable students to explore physical phenomena in a given spacetime. Examples include light deflection, redshift, and free fall onto and even into a neutron star.

Teaching Einsteinian Physics to School Students / 886

A mathematical program for teaching early high school students about Black holes.

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Modern science understanding depends on fundamental mathematical areas that go beyond primary school arithmetic. One of Einstein-First's goals is to create seamless learning progressions that begin in early primary school, designed to ensure that everyone develops an intuitive understanding of mathematical concepts and ideas that allow us to comprehend everything from the reality around us to the amazing things we can see with the internet. Understanding of things like the scales of the universe, the electromagnetic spectrum and the quantum world of light and atoms enable children to visualise and imagine things that otherwise might as well be magic. The maths concepts we are introducing from an early age also have social importance for understanding money, weather, risks and gambling. Starting at the youngest ages, using fun activities, we open children's minds to ideas that maths is more than numbers.
Astronomy is often in the news. Our place in the universe is a topic of universal human interest. Primary and secondary school scientific curriculums, however, still rely on outdated scientific paradigms and students have to use the Internet to find the answers. I my talk I will present the mathematical part of a modern program called "Discovering Black holes" for year 7 and Year 8 students to support their learning.

Teaching Einsteinian Physics to School Students / 949

Teaching the equivalence principle in year 7

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The process of choosing appropriate educational content to teach Einsteinian physics in middle school is a challenge for researchers and teachers. The Einstein-First project in Australia is designing and implementing an Einsteinian physics curriculum for schools. My research is designed to trial a learning progression of Einsteinian concepts within an overall curriculum structure for year 7. The main concepts related to Einstein's theory of gravity will be integrated into the existing year 7 curriculum in Australia. We will evaluate how to teach Einstein's "happiest thought", the equivalence

principle. This core idea is crucial to understanding our modern theory of gravity, which was developed by Einstein in his general theory of relativity in 1916. We will exhibit 4 objects that students investigate in free fall. This allows for representations that focus on the essential building blocks that lead to a better understanding of gravity. We will mainly explore learning outcomes, mental models and teachers' perspectives.

Teaching Einsteinian Physics to School Students / 200

Relativistic Astrophysics and Einsteinian physics through a scientific novel

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Here I share my experience in communicating some knowledge from relativistic astrophysics and associated Einsteinian physics in a scientific novel, named Blue Infinity, which I've written one year ago. What is special when we try to transmit the scientific truth through fictional characters representing researchers and students working in real scientific centers?

Teaching Einsteinian Physics to School Students / 829

The three royal summer solstice markers unveiled at Santa Maria degli Angeli meridian line in Rome

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The Meridian Line of Santa Maria degli Angeli in Rome has been realized in 1700-1702 upon the will of Pope Clement XI, since when he was Cardinal, after the project of Francesco Bianchini (1662-1729) to measure with unprecedented accuracy the tropical year and the variation of the obliquity of the ecliptic.
At this *Great Gnomon* for the first time in the history of astronomy, the seasonal effects on the atmospheric refraction and the effects of stellar aberrations were measured, but while the first were recognized the latter become systematic effects included in the errors of measurements. At the Marcel Grossmann Meeting of Berlin (2006) this discovery was firstly presented; after other historical data were analyzed (2014), while in IAU GA 2018 in Vienna the recognition of summer solstice markers was announced. The two markers are solsticial because they are on the same daily hyperbola of the solar center entering Cancer in 1721. The King's one is no longer illuminated by the Sun since 1750 Vanvitelli's renovations. A third marble marker on the same hyperbola is on the floor of the Basilica, dedicated to the King James III in 1721: FELIX TEMPORVM REPARATIO meaning "Return to good times", after 1719 marriage with Maria Klementyna Sobieska. **These markers are offset** with respect to the Great Gnomon, because it was unmodifiable at the Cancer's solstice. This chronological sequence explains also why in 1703 book Bianchini did not mention these markers.
The game of chess, the constant measurements with school students (2018-2021 IGEA campaign), the reply of this Meridian's functionalities on the school soccer-field, the Science Polish Academy allowed this unthinkable discovery.
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MG11 on Clementine Gnomon (2006)
Journées Systèmes de Références (2014)
IAU XXXGA on Clementine Gnomon (2018)

Teaching Einsteinian Physics to School Students / 422

Sungrazing comets as General Relativistic gravitational probes

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The sungrazing comets are a class of comets whose number significantly increased in the last 26 years, since the SOHO coronographes entered in function, at the rithm of about hundred per year.
A review in the gravitational studies on such comets, starting from Newton is presented.
Their orbital parameters suggest their grouping as related to a few parent bodies, and the pionieristic statistical work of Fermi made in 1922 at the Normal School of Pisa for the comets is recalled.
The sungrazing comets are the celestial bodies which approach more closely the mass of the Sun, the larger of the solar system: then their orbital parameters are influenced by both General Relativity and non gravitational effects, like mass loss and outgassing.
The comparison between the General Relativity effects and the non gravitational effects is made to understand the observational accuracy required on Mercury's perihelion in the second part of XIX century, in the studies carried by Le Verrier and Newcomb, with objects that may graze the solar surface. The accuracy on the determination of the orbital parameters of sungrazing comets is also investigated, to enforce with observations all these theoretical concepts.
The identification of new sungrazing comets is possible online, at the SOHO website, and it has been realized with the high school students of Galileo Ferraris Institute, Rome, as curricular activity, with great enthousiasm, especially for the nearly real time discoveries.

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The Clementine Gnomon (1702) recalibrated to measure stellar aberration

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The stellar aberration was discovered by James Bradley in 1727, and the same astronomer discovered the nutation of the Earth's axis in 1737. At the meridian line of S. Maria degli Angeli, the giant Clementine Gnomon, built by Francesco Bianchini (1662-1729) and funded by Cardinal Gianfrancesco Albani (1649-1721), elected pope on 23 november 1700 with the name of Clement XI, the effects of stellar aberration have been detected on the Polaris, and on Sirius.
The aberration of the Polaris influenced the measure of the latitude.
The aberration on Sirius affected the instant of the equinoxes and the solstices, calculated with the

difference between solar and stellar meridian transit, the latter observed also in full daylight. To obtain such evidence of the first special relativistic effect observable, a complete calibration of the meridian line has been carried since 2018. With the IGEA observational campaign (Informatized Geometric Ephemerides for Astrometry) nearly all the reference points of the 45 meters long meridian line have been calibrated, by comparing solar observations and ephemerides. On MG11 (2006) the evidences of Polaris' aberration were discovered in the latitude measured by Bianchini at the Gnomon, and now MG16 we can afford the evidences on Sirius. The eccentricity of the Earth's orbit in 1703 and now can be also measured with such instrument.

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Calibration of the Clementine Gnomon with IGEA observational campaign
Teaching Relativity with the Clementine Gnomon, 2021

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Teaching Relativity at the AstroCamp

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The AstroCamp is an academic excellence program in the field of astronomy and physics for students in the last 3 years of pre-university education, i.e. roughly 15-18 year olds. It was created in 2012 and is organized by CAUP and several national and international partners, and now accepts applications from 42 eligible countries. Academic activities include two courses (each with 15h of lectures and a 2h written exam), given by currently active researchers with a PhD in a relevant area. In most of the 10 editions, one course or a significant part thereof was devoted to Relativity (both Special and General). This is to a large extent driven by the camp students themselves: one of the principles of the camp is that students are involved in the choice of the courses offered in the camp, and Relatively is clearly the prime example of a topic that the students feel is not satisfactorily covered in their school classes (if it is at all), and for which their school teachers are often unable to provide further information.

In this presentation, after a brief introduction to the principles, goals and structure of the camp, I will describe the approach followed by camp lecturers (myself and others) for teaching Special and General Relativity, and some lessons learned and feedback from the students. Time permitting I will also provide some thoughts on the differences between the physics and mathematics secondary school curricula in Portugal and in other countries, and on how these curricula could be modernized.

The "Fall and Rise" of Betelgeuse

The "Fall and Rise" of Betelgeuse / 950

Standing on the Shoulders of Giants: New Mass and Distance Estimates for Betelgeuse through Combined Evolutionary, Asteroseismic, and Hydrodynamic Simulations with MESA

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We find that the famous giant star Betelgeuse is closer, smaller, and less massive than previously thought. Our theoretical predictions include results from three different modeling techniques: evolutionary, oscillatory, and hydrodynamic simulations conducted with the Modules for Experiments in Stellar Astrophysics (MESA) software suite. We use MESA stellar models and statistical techniques to infer that the star is undergoing its core helium burning giant branch phase. This in combination with estimates of Betelgeuse's present-day mass provides a rough constraint on its remaining lifetime before the onset of a supernova: our simulations revise the timeline for this event from 10,000 to 100,000 years.

This discovery was made possible by drawing on the synthesis of new observational data and exploiting multi-timescale simulations of the evolution and structure of stars. Seismic results from both perturbed hydrostatic and evolving hydrodynamic simulations constrain the frequencies and underlying physics of Betelgeuse's periodic brightness variations in new ways, allowing us to determine conclusively, and for the first time, the reasons for Betelgeuse's most prominent oscillation modes. In this talk, I will discuss the novel ways in which I combine precision stellar evolution calculations with seismology and observational and theoretical constraints to build a predictive timeline for Betelgeuse and other stars, revise best estimates for their fundamental parameters, and conquer their notorious modeling difficulties.

The "Fall and Rise" of Betelgeuse / 618

Betelgeuse: Twinkle, Twinkle Bright Red Star How We Wonder What You Are?

Authors: Conor Larsen[1]; Don Carona[2]; Edward Guinan[1]; Graham Harper[3]; Lindsay Dickerman[1]; Richard Wasatonic[1]

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Betelgeuse (alpha Ori; M2-M4Iab) is the brightest red supergiant (RSG) and (probable) core-collapse supernova (SN) progenitor. In <105-yrs. Betelgeuse should explode and shine nearly as bright as the full moon. Last year Betelgeuse underwent an unprecedented dimming, decreasing in brightness by more than 50% (~1.0 mag) by Feb-2020. This notorious "Great Dimming" caught the attention of astronomers and the public as a possible harbinger of an impending supernova. But no such luck! However, this surprising behavior stimulated many studies using a wide variety of instruments & techniques covering X-ray to radio wavelengths.

We discuss the analysis of ~180-yrs. of photometry from its discovery as a variable star by Sir John Herschel in 1837 up to now. The *Period Analysis Software (Peranso-3)* package [with the CLEANest and Wavelet (WWZ) programs] were used to study the "periods". The early observations of Herschel, Argelander, Baxendell and others were included along with those from BAA-VSS, and over 40,000 observations from AAVSO observers. We also studied the high-precision V and TiO/Near-IR photometry of Wasatonic and Guinan (1996-2021). The analyses of all data indicate two dominant periods of ~5.3-6.1 yrs, & ~385-435 days but also show other significant transient periodicities. There is evidence of period variations: the long-period is P~5.3-yr during 1837-1884 & P~6.1-yr during ~2000-2021; the ~420-d period is also time-variant. The WWZ-wavelet analyses show the complexity of the time-domain period variations. Radial velocities from Granzer et al. 2021 are also included and show correlations with TiO (=Teff) and brightness (see Harper-this meeting). These indicate mass-motions (convection) and pulsations with the ~420-d and ~6-yr periods. We discuss efforts to unravel the behavior of Betelgeuse and the cause(s?) of the "great dimming": ejected dust and/or pulsation /convection-induced cooling/dimming.

Thanks for efforts of over six generations of observers, including the AAVSO, for making this study possible.

The "Fall and Rise" of Betelgeuse / 831

The dust settles: Did Betelgeuse undergo a critical transition?

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The origin of the dimming and brightening event of 2019–20 in Betelgeuse has been subject to much speculation. Various causes, such as external dust or spots on the surface of the star, have been proposed for this sudden change in luminosity. We examine the light curve of Betelgeuse from 1990 for variations in the nonlinear dynamics of the star. Critical transitions in dynamical systems are known to be preceded by a 'slowing down' of dynamics, which can be measured from the system response using quantifiers such as the autocorrelation at lag-1, variance, spectral coefficient and recurrence quantifiers. We find that all hypothesized quantifiers showed a significant increase ($p<.05$) in the light curve of Betelgeuse, well before the dimming episode. These results indicate that the sudden dimming was preceded by critical slowing down. This indicates a dynamical origin to the dimming event, possibly in the pulsation dynamics of the star.

The "Fall and Rise" of Betelgeuse / 425

Visual observations of Betelgeuse near the solar conjunction

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The AAVSO database of stellar magnitudes starts, for Betelgeuse, in 1890 and includes both visual and digital measures. In scientific publications the few digital photometries are limited to some observations, not sufficent to have an homogeneous and smooth lightcurve.
The classical time series analysis has been adapted to the case of variable stars, recognizing the yearly signal of the invisibility when the star in solar conjunction.
This case presents an enhancement of the sky background, when the star is observed at the horizon near the sunset or sunrise time and azimut: the exctinction of the atmosphere is larger at low altitudes; the Mie scattering along the line of sight makes the sky much brighter than normally; the mean free path of photons depends on wavelength and makes the sky redder.
The comparison of Betelgeuse with other reference stars requires the inclusions and the calibration of all such effects.
This is particularly interesting to observe the rising part of the light curve of Betelgeuse after the deep minimum of February 2020, started already at the end of March 2020, and the new minimum of Betelgeuse now ongoing (April-May 2021).
Full daylight observations are also possible, with less sky brightness than near the horizon, and their history and tradition in Rome, since 1701, is presented.

References

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The "Fall and Rise" of Betelgeuse / 960

The curious case of Betelgeuse

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Betelgeuse is the nearest red supergiant, one of the brightest stars in our sky, and statistically speaking it would be expected to be "typical". Yet it exhibits many features that seem "curious", to say the least. For instance it has a high proper motion. It rotates fast. It has little dust. It dimmed unexpectedly. Is any of these, and other, phenomena atypical, and taken together does it make Betelgeuse atypical? This is important to know, because we need to know whether Betelgeuse might be a prototype of red supergiants in general, or certain subclasses of red supergiants, since we can study it in such great detail. It is also important to know as it may be a link to understanding other, apparently atypical cases such as supernova 1987A, and maybe even such exotica as Thorne-Zytkov objects. Studying this question in itself helps us understand how we deal with rarity and coincidence in understanding the Universe we live in.

The "Fall and Rise" of Betelgeuse / 1012

The Formation History of Betelgeuse

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Betelgeuse is a familiar M-type red supergiant and also the tenth brightest star in the sky. Nevertheless, it is also a very peculiar star. Its kinematics and the bow shock around it indicate that it is a runaway star moving at more than 30 km/s relative to the local standard of rest. At the same time, its rotation rates, also supported by the enhanced nitrogen abundances, are too high compared to regular red supergiants. Due to this reason, it was suggested that Betelgeuse was likely initially dynamically ejected as a runaway binary from its birth environment and later merged, producing a rapidly spinning giant. In our study, we use a Monte Carlo approach to model the dynamical interactions in Galactic clusters and a custom binary evolution code to synthesise a mock population of Galactic runaway rapidly spinning red supergiants like Betelgeuse. We compare the synthesised population to the observed samples of runaway O and B stars and runaway supergiants and find that the statistics of stellar populations in the solar neighbourhood indeed support the idea that Betelgeuse formed through a binary merger. It is quite possible that one needs to take this recent merger history into account when explaining its recent dimming.

The "Fall and Rise" of Betelgeuse / 967

The hypergiants VY Canis Majoris, Eta Carinae, V766 Centauri and the red supergiants Betelgeuse, Antares and Aldebaran in the 2.5K SGQ AAVSO database

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I observe variable stars since 1997. The "candidacy" of Mira Ceti as Betlehem Star because close to Jupiter-Saturn triple conjunction of 6-7 b.C. started at Pontifical University of Lateran and continued in Yale (2001-2004). Maxima correlation function ruled out Mira for having two consecutive bright maxima, but this property was confirmed in the "oldest" Myra-type: R Leonis, R Hydrae and Chi Cygni, from their almost four-century-long lightcurves.
To a bright maximum normally a dim one follows, as the correlation function of their consecutive maxima shows.
These studies were supported by historical and personal visual observations. Since 2011 I observe first magnitude variable stars, with airmass correction to reach 0.01 magnitudes accuracy with naked eye. AAVSO observer Sebastian Otero first claimed this accuracy, as for NovaCentauri 2013, observed by me from Porto Alegre and Rio de Janeiro.
Betelgeuse's 801 observations in 10 years, include the deep minimum of 2020.
My SGQ contributions to AAVSO-database, paralleled with Betelgeuse's V-band measurements, help to define the "personal equations" present in all 25M visual observations before CCD era (1911-on) going back to 1893 for Betelgeuse.
The temporal extension of lightcurves is crucial to understand the stellar behaviour.
More complicate cases are Antares and Aldebaran, less variable and with distant comparison stars.
The Southern hypergiants VY CMa, low in the roman horizon, V766 Cen and Eta Carinae from South America in 1999, 2003 and 2013-2014 are also monitored with binoculars or small telescopes.
DeltaScorpii (Be close binary at periastron) has also been studied form Rio, since 2011.
Concluding: my 2.5K direct visual observations in nearly 25 years help to understand and simulate the accuracy of the World largest visual observations database for variable stars, the AAVSO one.

References

Mira maxima long-term (JAAVSO 2001)

Four Mira-type (JAAVSO 2004)
SGQ for AAVSO

The "Fall and Rise" of Betelgeuse / 1032

Celestial mechanics and variable stars before the telescope: from the meridian line of the Vatican obelisk (1586-1817), to the stars on Santa Maria degli Angeli meridian line (1702) in Rome.

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Ancient observations were transmitted to posterity through mythology, cities and temples' orientations and mere time and position data. While stellar variability does not fit Aristotles' aetherian-eternal nature of the last celestial sphere, Greek myths on the painful shoulder of Orion explained the observed Betelgeuse's variability.
The meridian line in saint Peter's square was designed by Egnazio Danti (1586) and realized by Filippo Luigi Gigli and Pietro Maccarani (1817); it exploits the Vatican obelisk as gnomon.
Here black stars mark only the zodiacal signs, hit by the obelisk top's shadows at their ingress' dates. The alignments of Bianchini and Gigli lines are respectively 5' and 1' from true North. The measurements of Summer solstice are compared for both indoor-outdoor cases, with a special technique adopted in the sunny square to catch the obelisk's shadows penumbral limit. The sampietrini, cobblestones paving circularly the square, allow to measure the shadow's length also off-meridian. In night-time this the stellar, lunar and planetary transits are still observable from the square.
Betelgeuse is reported on the pinhole-illuminated meridian line of Francesco Bianchini (1702) in Santa Maria degli Angeli as Orionis Humerus Orientalis, along with Rigel (Orionis Pes Lucidus), Bellatrix and the tree Orion's belt stars. From the traditional latin names the magnitudes respects Almagest's order (150 AD).
The accuracy of the positional observations, is valorized when compared with similar measurements before/after centuries, to measure the tropical year and the obliquity's secular variation.

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The "Fall and Rise" of Betelgeuse / 528

Fall and raise of Betelegeuse

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The opportunity of this session is to focus on
1) observations and their criticities in the AAVSO 130 years database on Betelgeuse
a) V-Band
b) R obs in daylight
c) Before AAVSO

d) visual near the horizon
2) time series analyses of Betelgeuse's light curve
a) mathematical properties
b) other Supergiants: VY Canis Majoris, Eta Carinae
3) spectral data on Betelgeuse during the deep minimum and in other phases
a) SOFIA, airborne NASA telescope
b) Caucasian Observatory
c) Asiago Telescopes
4) high resolution imaging of Betelgeuse
a) HST
b) ALMA
5) models of Betelgeuse
a) CfA
b) star unusual rotation
c) no further dust ejection
d) overview
The goal of this session would be a general vision on that star, and on the tools to study it. In other words not only a case study, but the concourse of all astrophysics, astronomy and history of human culture, and the possibility to an interdisciplinary audience to understand and to be stimulated by this star, easily visible from both hemispheres.
For these reasons the Scientific Committee of the Grosmmann meeting wanted this special session HR1.
On January 17 2020 we had a meeting on the deep minimum,
now we hope to open wider the attendance, including the major protagonists of this phenomenon which was visible to everyone at naked eye. Something similar occurs only to lunar eclipses for less than three hours, Betelgeuse did it for more than 3 months.
References
Betelgeuse dimming: the state of the star
International workshop

The "Fall and Rise" of Betelgeuse / 775

Photometry of Betelgeuse at daylight

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In a backyard observatory in Mainz, Germany, several stars have been observed at daylight using a 250mm Newton telescope and a CCD camera (ATIK 460exm). To measure the intensity of the sky background, the intensity of a background aperture was compared to the intensity of the star aperture and normalized to the known star magnitude. In this way sky background values of 1.8 - 4.7 mag/arcsec2 were found at angles of 10°-100° distance to the sun. Photometry of Betelgeuse was performed as a first attempt in 2020 with stacked images of Betelgeuse; Aldebaran (Alpha Tau) was used as comparison star on 4 days (July 22 to Sept 07, 2020). The measured magnitudes were comparable to results of the STEREO A spacecraft in July 2020. Photometry was improved in 2021 by using a neutral density filter (1% transmission) and measuring calibration and extinction coefficients on 4-8 bright reference stars. Photometry of Betelgeuse resulted in calculated errors of less than 0.05 mag from February to June 2021. Photometry of a 2 mag star (alpha Ari) at a distance of 10° to the sun gave also results with an error of less than 0.05 mag. The daylight observations of Betelgeuse will be continued this year, hopefully the observational gap, when Betelgeuse is near to the sun, can be filled in this way with reliable data.

The "Fall and Rise" of Betelgeuse / 963

The Great Dimming of Betelgeuse as viewed by high-resolution

spectra from the Stratosphere, and ground based TiO Photometry

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NASA-DLR's Stratospheric Observatory for Infrared Astronomy (SOFIA) observed Betelgeuse during the 2019/2020 Great V-Band Dimming event. High spectral resolution emission-line spectra were obtained with EXES at [Fe II] 25.99 microns and [S I] 25.25 microns before and during the event, and with upGREAT at [O I] 63.2 microns and [C II] 157.5 microns shortly after minimum. The line fluxes and profiles revealed that the circumstellar envelope was essentially unchanged in February/March 2020.

An analysis of ground-based TiO photometry revealed that the mean photospheric temperature had dropped significantly, to a record low, and that it correlated strongly with the photospheric radial velocity. ESO Very Large Telescope-SPHERE images also revealed a non-uniform photosphere during the Great Dimming. A cool multi-component photosphere can explain the multi-band photometry, and it is not necessary to invoke dust as an explanation for the Great V-band Dimming. This does not, however, exclude the possibility that some dust formed during this dynamic event.

The "Fall and Rise" of Betelgeuse / 966

The Mysterious Great Dimming of Betelgeuse

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Betelgeuse, a bright star in the shoulder of the Orion constellation has been known for centuries - even appearing in drawing on the walls of the Lascaux Caves in Southwestern France. And an unexpected amazing phenomenon occurred last year.

The bright cool supergiant Betelgeuse became historically faint in February 2020. Various explanations have been offered for its unusual behavior – including conjectures this foreshadows an imminent supernova event. Many astronomical resources – from the ground and space – tracked the star's unusual behavior.

With photometry, direct imaging, spatially resolved spectroscopy, polarization measures, infrared, optical and ultraviolet spectra helped us to unravel what happened to this supergiant star. These measurements allow this historic event to be followed from its origin in the stellar surface, through the extended atmosphere, and into the circumstellar medium. We now think we understand what occurred and caused the anomalous dimming.

And this informs fundamental characteristics of the evolution of all stars.

The "Fall and Rise" of Betelgeuse / 1016

Betelgeuse as didactic introductory tool for stellar variabilty, airmass computation and spectral analysis

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According to Dorrit Hoffleit Mira is the educational star. But it requires the use of a telescope at its minimum, and a binocular for its maximum phase, to spot in in city lights. Betelgeuse is a semiregular variable star of first magnitude, in the most famous constellation, achievable from both hemispheres. It is available to the naked eye for nine months a year. Its magnitude estimate, according to the Argelander method, requires other first magnitude stars, separated by several degrees, at rather different airmasses. Procyon, Aldebaran, Pollux, Castor as well as Gamma Geminorum, Regulus, Denebola, Mars and even Mercury have been used as comparison stars, and their airmass corrections included. Since January 2019 a project in schools (Liceums Morgagni and Ferraris in Rome and in Ostia and Galilei in Pescara) to observe Betelgeuse and its comparison stars with a special colored quadrant where the angular height in sight corresponds to the airmass exctinction with respect to the zenit. The great dimming of Betelgeuse was then observed and measured to the nearest 0.01 magnitude at naked eye. These observations have been sent to AAVSO, contributes of students to citizen science. Similar operations have been realized with the students inscribed to Sapienza University of Rome, Astrophysics Laboratory exam. The Newton's disk for solar spectrum has been replicated for Betelgeuse with red-yellowish tonalities.
Summer holidays' homeworks are offered by Antares, a first magnitude stars greatly separated by its more suitable comparison stars. Recently Saturn worked as reference, but a planet is not a constant standard candle. The introduction to photometry, colorimetry and spectrometry with these naked-eye cases is complete and historically meaningful.

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Evaluating the 2020 minimum from visual data
Betelgeuse, Sirius and Antares since Ptolemy

The Black Hole in M87

The Black Hole in M87 / **463**

A kinetic view at black hole magnetospheres

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Spinning black holes have long been suspected to be involved in some of the most extreme astrophysical phenomena such as AGN and their relativistic jets for supermassive black holes, and gamma-ray bursts for stellar-mass black holes. The activity of black holes is often associated with the creation and the launching of a relativistic magnetized plasma jet accompanied by efficient particle acceleration and non-thermal radiation. Horizon-scale observations of supermassive black holes reveal that these processes occur in the closest vicinity to the black-hole horizon: the magnetosphere, the inner parts of the accretion flow and the jet. Yet, the underlying physical mechanisms are still poorly understood because they result from a complex interplay between general relativity, electrodynamics and plasma physics. I will review our current efforts to model black hole magnetospheres from first principles with the help of general relativistic radiative particle-in-cell simulations. These numerical methods can capture plasma processes at a microscopic kinetic level where particle acceleration takes place, and therefore they may hold the key to bridge the gap between theoretical models and horizon-scale observations of black holes.

The Black Hole in M87 / **507**

What do the EHT observations tell us about the source?

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The Event Horizon Telescope collaboration has released 1.3mm interferometric observations of the core of the galaxy M87. I will review the observations and the general physical principles involved in their interpretation. After describing the basic heuristics needed to understand the effect of a black hole on the observational appearance of nearby emission, I will emphasize that gravitational lensing is largely irrelevant at EHT resolution. Instead, the observational appearance of a given source is determined entirely by the emission profile and redshift effects. I will comment on the specific interpretation of the public 2017 observations and discuss what we can expect going forward.

The Black Hole in M87 / **849**

Magnetic Reconnection in Jet-Accretion disk Systems

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Magnetic Reconnection is currently regarded as a rather important process in magnetically dominated regions of galactic and extragalactic sources like the surrounds of black holes and relativistic jets. In this contribution, we discuss briefly the theory of fast magnetic reconnection, especially when driven by turbulence which is very frequent in astrophysical flows, and its implications for relativistic particle acceleration. Then we discuss these processes in the context of the sources above, showing recent analytical and multidimensional numerical MHD studies that indicate that fast reconnection can be a powerful process to accelerate particles to relativistic velocities, produce the associated high energy non-thermal emission, and account for efficient conversion of magnetic into kinetic energy in these flows.

The Black Hole in M87 / 584

Is there a Narrowness Tension in M87*?

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The 2017 Event Horizon Telescope (EHT) observations of the core of the galaxy M87 are the first electromagnetic observations probing event horizon scales of a black hole. The data strongly favor an observational appearance dominated by a ring of approximately 40 micro-arcseconds in diameter. However, many interesting questions remain about the appearance of the source. In particular, the thickness of the ring is much less certain. I will argue that the most likely parameter region is in tension with theoretical expectations - the observed ring is too narrow - and explore whether this tension can be resolved by alternative data analysis methods.

First, I will report on our independent verification of a subset of the EHT collaboration's geometric modeling results, using a new code built from scratch. Second, I will discuss some subtleties in the choice of likelihood function used in model-fitting, and test the sensitivity of the results on the choice of method. We find that the choice of likelihood function does in fact bias the results for ring width in particular, but not enough to completely remove the tension.

The Black Hole in M87 / 569

Orientation of the crescent image of M87*

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The first image of the black hole (BH) M87*obtained by the Event Horizon Telescope (EHT) has the shape of a crescent extending from the E to WSW position angles, with a possibly distinct bright hotspot in the ESE sector. We have explored highly simplified toy models for geometric distribution and kinematics of* *emitting regions in the Kerr metric, assuming that the BH spin vector is fixed to the jet axis and that the emitting regions are stationary and symmetric with respect to the BH spin. Since the observed direction of the large-scale jet is WNW, emission from the crescent sector between SSE and WSW can be readily explained in terms of an equatorial ring with either circular or plunging geodesic flows, regardless of the value of BH spin. We have also considered plane-symmetric polar caps with plunging geodesic flows, in which case the dominant image is that of the cap located behind the BH. Within the constraints of our model, we have not found a viable explanation for the ESE hotspot. Most likely, it has been produced by a non-stationary localised perturbation in the inner accretion flow. The recent polarimetric EHT image of M87* shows that the ESE hotspot is essentially unpolarized, which seems to support its distinct origin. Possible causes for this apparent depolarization will be discussed.

The Black Hole in M87 / 466

Synthetic observables from simulations of black-hole magnetospheres

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GRMHD simulations have been very successful in interpreting observations from M87*. However, they are unable to account for several important features, such as the plasma loading of the jet or the details of non-thermal radiation, from first principles. Kinetic simulations, on the other hand, are well suited to the task. In this talk, I will review what we have learned from these kinetic simulations. Including radiative processes allows modeling plasma supply realistically, proving that the Blandford-Znajek mechanism can be activated self-consistently. I will also highlight the role of current sheets in the extraction and conversion of energy from the black hole. Finally, I will put the emphasis on extracting synthetic observables from these simulations, such as gamma-ray lightcurves and millimeter images. That allows us to model accurately the non-thermal radiation emitted from the innermost regions of black-hole magnetospheres, which can be directly compared to the EHT observations, for example.

The Black Hole in M87 / 207

Black hole flares: Accretion-driven accumulation and reconnection-driven ejection of magnetic flux

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Magnetic reconnection in current sheets is conjectured to power bright TeV flares from the black hole in the center of the M87 Galaxy. It is unclear how, where, and when current sheets form in black-hole accretion flows. We show extreme resolution 3D general-relativistic magnetohydrodynamics and 2D general-relativistic particle-in-cell simulations to model reconnection and plasmoid formation in black hole magnetospheres. Plasmoids can form in thin current sheets In the inner 15 Schwarzschild radii from the event horizon, after which they can merge, grow to macroscopic hot spots of the order of a few Schwarzschild radii and escape the gravitational pull of the black hole. Large plasmoids are energized to relativistic temperatures via magnetic reconnection near the event horizon and they significantly heat the jet, contributing to its limb-brightening. We find that only hot plasmoids forming in magnetically dominated plasmas can potentially explain the energetics of flares. The flare period is determined by the reconnection rate, which we find to be consistent with studies of reconnection in isolated Harris-type current sheets.

The Early Universe

The Early Universe / **68**

Quintessential Inflation from Lorentzian Slow Roll

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From the assumption that the slow roll parameter
ε has a Lorentzian form as a function of the e-folds number N, a successful model of a quintessential inflation is obtained. The form corresponds
to the vacuum energy both in the inflationary and in the
dark energy epochs and satisfies the condition to climb from
small values of ε to 1 at the end of the inflationary epoch.
We find the corresponding scalar Quintessential Inflationary
potential with two flat regions. Moreover, a reheating mechanism is suggested with numerical estimation for the homogeneous evolution of the universe. The suggested mechanism is consistent with the BBN bound

The Early Universe / **337**

Helical magnetic fields lead to baryogenesis

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The origin of primordial magnetic fields and baryon asymmetry of the Universe are still unresolved issues and require physics beyond the standard models of cosmology and particle physics. Since both require physics beyond the standard model, there is a possibility that the same new physics can solve both.

In this talk, I will discuss our model, where non-minimal coupling to the Riemann tensor generates sufficient primordial helical magnetic fields at all observable scales during inflation. Interestingly, the generation of helical magnetic fields leads to baryogenesis and the model predicts the observed amount of baryon asymmetry of the Universe for a range of reheating temperatures consistent with the observations. The talk will be based on the preprint 2103.05339.

The Early Universe / 764

No slow-roll inflation à la generalized Chaplygin gas in general relativity

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The Generalized Chaplygin Gas (GCG) model is characterized by the equation of state P = −A ρ^{−α}, where A>0 and $\alpha < 1$. The model has been extensively studied due to its interesting properties and applicability in several contexts, from late-time acceleration to primordial inflation. Nonetheless we show that the inflationary slow-roll regime cannot be satisfied by most of the parameter space of the GCG model when General Relativity (GR) is considered. In particular, although the model has been applied to inflation with $0 < \alpha < 1$, we show that for $-1 < \alpha \leq 1$ there is no expansion of the Universe but an accelerated contraction. For $\alpha \leq -5/3$, the second slow-roll parameter ηH is larger than unity, so there is no sustained period of inflation. Only for α very close to -1 the model produces enough e-folds, thus greatly reducing its parameter space. Moreover, we show that the model is ruled out by the Planck 2018 results. Finally, we extend our analysis to the Generalized Chaplygin-Jacobi Gas (GCJG) model. We find that the introduction of a new parameter does not change the previous results. We thus conclude that the violation of the slow-roll conditions is a generic feature of the GCG and GCJG models during inflation when GR is considered and that the models are ruled out by the Planck 2018 results.

The Early Universe / 601

Examination of Schrodinger equation in pre planckian space-time early universe

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We look at Viutilli (1999) write up of a generalized schrodinger equation with its Ricci scalar inclusion, in curved space-time. This has a simplified version in Pre Planckian regime, which leads to comparing a resultant admissible wave function with Bohmian reformulations of quantum physics. As was done earlier, we compare this result with a formulation of a modified 'Poisson' equation from Poisson and Will from 2014, and then use inflaton physics . The resulting inflaton is then compared to the wave functional in the first part of this document.

The Early Universe / 844

Warm inflation and its observational constraints

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The theory of primordial inflation has been highly successful in resolving theoretical difficulties of standard FRW cosmology. Moreover, many of the general predictions of inflation have been confirmed by observation. However, higher precision measurements of the cosmic microwave background (CMB) now disfavor many inflation-driving potentials due to a suppression of the tensor-to-scalar ratio. Alternatively, one scenario of interest is "warm" inflation, whereby the primordial field converts its energy into radiation during the expansion. I will show how warm inflation allows some inflation potentials that are otherwise excluded by the CMB data. I will discuss how warm inflation allows the symmetry breaking scale to remain below the Planck energy as well as how it impacts the production of primordial black holes.

The Early Universe / **256**

Condensed Light, Quantum Black Holes and L-CDM Cosmology: Experimentally Suggested and Tested Unified Approach to Dark Matter, Dark Energy, Cosmogenesis and Two-Stage Inflation

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Over the last decade, experimental physics and observational cosmology have made many fundamental discoveries: gravitational waves (LIGO), Higgs bosons (LHC), photon condensates with rest energy and rest mass trapped in "mirror cavities" (Bonn University).
Through these remarkable results, Nature suggests that at pressures and temperatures well above the Higgs field level (246 GeV), only the 2-d and 3-d photon condensates trapped in their own "gravitational cavities" should be unique sources of gravity during the early Universe. Moreover, we conclude that the real "prima materia" at the "beginning of the times" was a 3-dimensional Planck photonic condensate as "explosive" accompanied by Planck fluctuations as "fuse".
Our approach is based on the laws that govern birth and death, accretion, quantum particles emission and gravitational waves radiation of quantum black holes, which are taken as spherical 2-d photon condensates trapped in their own gravitational fields.
According to our calculations, relic gravitational waves with Planck energies Ep and Ep/2 make up 93.38% of the dark energy in the Universe. As we can see, S. Weinberg was absolutely right: only the energy of Hot Bing Bang causes the universal expansion process.
Using this unified approach, we can calculate that at the end of the epoch of baryogenesis, when stage I of inflation ends, the rest energies of black holes (dark matter) and energy of gravitational waves (dark energy) are 28.68% and 66.42%, respectively. But 6÷8 billion years ago, the II stage of inflation began. Now, accordingly to "Planck-2018" data, we find the 26.63% and 68.47%, respectively. Comparison with stage I clearly shows that the increase in dark energy is caused by a decrease in the energy associated with dark matter. This leads to the unambiguous conclusion that stage II of inflation is provided by binary coalescences of black holes.

The Early Universe / **794**

Entropy and irreversible processes in gravity and cosmology

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Due to the quantum origin of primordial perturbations and the energy scales of the primordial plasma, the early universe is an ideal setup for the interplay between gravity, quantum physics and thermodynamics. Even though most of the expansion history of the universe is adiabatic, irreversible processes play a role in key cosmological events. In this talk I will discuss results and ongoing work on the role that entropy and irreversibility play in gravity and cosmology.

The Early Universe / 720

Constraining beyond ΛCDM models with 21 cm intensity mapping forecast observations combined with latest CMB data

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Observations of the 21 cm signal through intensity mapping techniques are expected in the near future. This new observable will allow to probe evolution of the Universe in a very wide redshift range, from the dark ages, through the epoch of reionization up to the present time. We constrain cosmological parameters from forecast measurements of the 21 cm signal power spectrum $P_{21}(k, z)$ combined with the latest CMB data from Planck 2018 observations. In the same framework, we test also modified gravity models to unveil beyond ΛCDM features coupling information from primordial probes, such as the CMB, to lower redshift ones. We extend the codes EFTCAMB/EFTCosmoMC to compute the likelihood function for $P_{21}(k, z)$ and we construct a mock data set of forecast intensity mapping observations. At the time being we are bound by the experimental state-of-the-art to consider the redshift bin $z = 0.39$. However, in the future it may be possible to study also wider redshift ranges. We describe our likelihood implementation and present the results we obtained from the statistical Monte-Carlo Markov-Chain analysis we conducted.

The Early Universe / 27

A Solution of the Cosmological Constant and DE and Arrow of Time, Using Model of a Nonsingular Universe from Rosen from Volume (56) Ettore Majorana International Science Series, Physics, 1991

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We reduplicate the Book "Dark Energy" by M. Li, X-D. Li, and Y. Wang, given zero-point energy calculation with an unexpected "length' added to the 'width' of a graviton wave just prior to specifying the creation of 'gravitons', using the Rosen and Israelit model of a nonsingular universe. In doing so we are in addition to obtaining a wavelength 10^30 times greater than Planck's length so we can calculate DE, may be able to with the help of the Rosen and Israelit model have a first approximation as to the arrow of time, and a universe with massive gravity. We have left the particulars of the nonsingular starting point undefined but state that the Rosen and Israelit model postulates initial temperatures of 10^-180 Kelvin and also a value of about Planck temperature, at 10^-3 centimeters radii value which may satisfy initial conditions asked by t'Hooft for describing an arrow of time. A key assumption is that the DE is formed at 10^-3 cm, after an expansion of 10^30 times in radii, from the Planck length radius nonsingular starting point. The given starting point for DE in this set of assumptions is where there is a change in the cosmic acceleration, to a zero value, according to Rosen and Israel, with time t = 1.31 times 10^-42 seconds. Which may be where we may specify a

potential magnitude, V, which has ties into inflaton physics. The particulars of the model from Rosen and Israelit allow a solution to be found, without discussion of where that nonsingular starting point came from, a point the author found in need of drastic remedies and fixes.
Subject Areas

The Early Universe / 672

General Relativistic Evolution Equations for Density Perturbations in FLRW universes and the Problem of Structure Formation

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Due to the general covariance of the Einstein equations and conservation laws, the linearized equations have solutions which are gauge-dependent and have, therefore, no physical significance.

In this talk I will show that the decomposition theorems for symmetric second-rank tensors of the maximally symmetric subspaces of constant time imply that there are exactly two, unique, gauge-invariant quantities which describe the true, physical perturbations to the energy density and particle number density. In the limit of zero spatial fluid velocity, and hence zero pressure, the set of linearized Einstein equations and conservation laws, combined with the new gauge-invariant quantities reduce to the Poisson equation of the Newtonian Theory of Gravity and the energy-mass relation of the Special Theory of Relativity. The relativistic gauge transformation reduces to the Newtonian gauge transformation in which time and space are decoupled.

The cosmological perturbation theory consists of a second-order ordinary differential equation (with source term entropy perturbations) which describes the evolution of perturbations in the total energy density, and a first-order ordinary differential equation which describes the evolution of entropy perturbations.

The cosmological perturbation theory is applied to a flat FLRW universe. For large-scale perturbations the entropy perturbations do not play a role, so that the outcome is in accordance with treatments in the literature. In the radiation-dominated era small-scale perturbations grew proportional to the square root of time and perturbations in the CDM particle number density were, due to gravitation, coupled to perturbations in the total energy density. Therefore, structure formation could have begun successfully only after decoupling of matter and radiation. After decoupling density perturbations exchanged heat with their environment. This heat exchange may have enhanced the growth rate of their mass sufficiently to explain structure formation in the early universe, a phenomenon which cannot be understood from adiabatic density perturbations.

https://arxiv.org/abs/1410.0211

https://arxiv.org/abs/1601.01260

The Early Universe / 470

Polymer Quantization of the Isotropic Universe: comparison with the Bounce of Loop Quantum Cosmology

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We implement Polymer Quantum Mechanics on the Hamiltonian formulation of the isotropic Universe in both the representations of the standard Ashtekar-Barbero-Immirzi connection and of a new generalized coordinate conjugate to the Universe volume. The resulting morphology is a bouncing cosmology; when quantizing the volume-like variable the Big Bounce is an intrinsic cut-off on the cosmological dynamics, while when using the standard connection the Bounce density results to be dependent on the initial conditions of the prepared wave packet. Then we compare the nature of the resulting Bounce with what emerges in Loop Quantum Cosmology, where the dependence of the critical density on the initial conditions is present when the minimum area eigenvalue is implemented in a comoving representation instead of the physical one. We conclude that the preferable scenario in this framework should be a Big Bounce whose density depends on initial conditions, in view of the privileged SU(2) character that the Ashtekar-Barbero-Immirzi connection possesses in the full Loop Quantum Gravity.

The Early Universe / 870

A pure general relativistic non-singular bouncing origin for the Universe

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It is argued that the past of the Universe, extrapolated from standard physics and measured cosmological parameters, might be a non-singular bounce without any exotic hypothesis. We show that, in this framework, stringent constraints can be put on the reheating temperature and number of inflationary e-folds. We draw some conclusions about the shape of the inflaton potential and raise the "naturalness" issue in this context. The primordial tensor spectrum is also calculated and possible observational footprints of the model are underlined.
Based on :
Barrau, Eur. Phys. J. C 80 (2020) 6, 579
Renevey, Barrau, Martineau, Touati, JCAP 01 (2021) 018

The Effects of (Non)Linear Electrodynamics on the Properties of Astrophysical/Gravitational Compact Objects

The Effects of (Non)Linear Electrodynamics on the Properties of Astrophysical/Gravitational Compact Objects / **532**

Correspondence of gamma radiation coming from GRBs and magnetars based on the effects of nonlinear vacuum electrodynamics

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ABSTRACT

It appears that studying the data from the catalogue of Gamma-Ray Bursts (GRBs) can be used to study the birefringence phenomenon in the magnetosphere of the magnetars. By analysing the data from the McGill Online Magnetar and HEASARC Fermi Burst Catalogues, in this work we studied the angular distances between the nearest GRBs and magnetars in projection, built their distribution map as detected by 2020, and the relative lag time periods of lights coming from GRBs and magnetars. It is confirmed that there are 29 galactic magnetars and their candidates, while the other two are located out of the Milkyway. The maximum separation angle for GRB and Magnetar projectiles was 3.76 degrees (4U0142+61 and GRB110818860), while minimum angular resolution was 0.54 degrees (SGR 1627-41 and GRB090829672). Currently, we discuss the relationship of GRB light intensity by their lag time as it would come after bending by the magnetosphere.

The Effects of (Non)Linear Electrodynamics on the Properties of Astrophysical/Gravitational Compact Objects / **559**

Absorption of Massless Scalar Waves by Ayón-Beato-García Regular Black Holes

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Along the last decades, several regular black hole (BH) solutions, i.e., singularity-free BHs, have been proposed and associated to nonlinear electrodynamics models minimally coupled to general relativity. Within this context, it is of interest to study how those nonlinear-electrodynamic-based regular BHs (RBHs) would interact with their astrophysical environment. We investigate the propagation of a massless test scalar field in the background of an electrically charged RBH solution, obtained by Eloy Ayón-Beato and Alberto García. Using a numerical approach, we compute the absorption cross section of the massless scalar field for arbitrary values of the frequency of the incident wave. We compare the absorption cross sections of the Ayón-Beato and García RBH with the Reissner-Nordström BH, showing that they can be very similar in the whole frequency regime.

The Nature of Galactic Halos

The Nature of Galactic Halos / **538**

Virial Clouds Evolution-I: From the surface of last scattering up to the formation of population-III stars

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The detailed analysis of *Planck* CMB data has shown the presence of temperature asymmetries towards the halos of several spiral galaxies. This is probably due to the rotation of cold clouds (which we called" virial clouds ") present in the halos, that rotate about the rotational axis of the galaxies. It had been proposed that these are pure hydrogen clouds that *should* be in equilibrium with the CMB. However, the equilibrium of such clouds at the very low CMB temperature was not deemed possible, but it was recently shown that the equilibrium *could* be stable. This still does not give the cloud concentration or that the observed temperature asymmetry is due to clouds in equilibrium with the CMB. To investigate the matter further, it would be necessary to trace the evolution of such clouds, from their formation epoch to the present, so as to compare the model with the observational data. The task is to be done in two steps: (1) from the cloud formation up to the formation of the first generation of stars; (2) from that time to the present. Here we only deal with the first step leaving the second one to subsequent analysis.

The Nature of Galactic Halos / **244**

Giant cosmic ray halos around M31 and the Milky Way

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Recently, a diffuse emission of 1-100 GeV gamma-rays has been detected from the direction of M31, extending up to ~ 200 kpc from its center.
The interpretation of the extended gamma-ray emission by the escape of cosmic rays produced in the galactic disk or in the galactic center is problematic.
Here we argue that a cosmic ray origin (either leptonic or hadronic) of the gamma-ray emission is possible in the framework of non standard cosmic ray propagation scenarios or is caused by *in*

situ particle acceleration in the galaxy's halo. Correspondingly, the halo is powered by the galaxy's nuclear activity or by the accretion of intergalactic gas.
If the formation of cosmic ray halos around galaxies is a common phenomenon, the interactions of cosmic ray protons and nuclei with the circumgalactic gas surrounding Milky Way could be responsible for the isotropic diffuse flux of neutrinos observed by Icecube.

The Nature of Galactic Halos / 34

Primordial black holes as dark matter candidates in the Galactic halo

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There has recently been interest in Primordial Black Holes (PBHs) as a dark matter (DM) candidate. Constraints on the PBH abundance is obtained through lensing, accretion, dynamical effects and also the analysis of the gravitational wave (GW) events. PBHs may exist and populate today the galactic halos with a wide mass range, from about 10-14MSun up to thousands, or more, of solar masses. Gravitational microlensing is a powerful method to constrain the PBH abundance in the Milky Way halo. We calculate the optical depth and the rate of microlensing events caused by PBHs eventually distributed in the Milky Way halo, towards some selected directions of observation, as the Galactic bulge, the Large and the Small Magellanic Clouds and the M31 galaxy. The capability of the Euclid space telescope to constraint the PBH abundance is also discussed.

The Nature of Galactic Halos / 400

Searching for Intermediate Mass Black Holes in the Milky Way's galactic halo

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Intermediate Mass Black Holes (IMBHs) are a class of black holes with masses in the range 10^2-10^5 solar masses, which can not directly derive from stellar evolution. Looking for these objects and estimating their abundance is important for understanding the nature and distribution of the Dark Matter in the galactic halo. Since February 2018 to January 2020 the LMC and SMC have been intensively monitored by the DECAM instrument, installed on the 4m V. Blanco Telescope (CTIO, Chile) with the main objective to find microlensing events possibly due to IMBHs.
Here we outline the data analysis pipeline and test it versus known variable sources. We then find a number of not previously known variable sources with a few of them showing a light curve similar to that expected for a microlensing event. Further analysis is required.
For these sources, and in particular for the uncatalogued variable stars, we try to determine if they are periodic or not via a periodogram analysis.

The Nature of Galactic Halos / 862

Analysis of the velocity Rotational Curves Via Weyl-Interaction Modified Gravity

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Instead of appealing to dark matter to explain the flat rotation curves of galaxies, it had been proposed that the law of gravitation should be modified. However, the idea had been to modify Newton's law. Harko et al. (Phys. Rev. D 84 (2011) 024020) suggested that modified gravity be used. Qadir, Lee and Kim (Int. J. Mod. Phys. D 26 (2017) 1741001) had proposed a modification of the Einstein-Hilbert Lagrangian with cosmological constant by adding a product of the Ricci and matter tensors. Later Qadir and Lee (Int. J. Mod. Phys. D 28 (2017) 1741001) proposed coupling the matter with Weyl curvature, reminiscent of the way the charge couples with the electromagnetic field in QED, and provided the equations of motion for it. They considered the rotational velocity curves for a simple model, for different values of the coupling constant. The value of the coupling constant has been determined for the M31 galaxy for this simple model used and compared with that for the Milky Way to see if the suggestion seems consistent, barring minor adjustments in the matter distribution in the galaxies.

The Nature of Galactic Halos / **375**

A nearly complete census of intergalactic gas using the kinematic Sunyaev-Zel'dovich effect

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A complete census of baryons in the late universe is a long-standing challenge due to the intermediate temperate and rarefied character of the majority of cosmic gas. To gain insight into this problem, we extract measurements of the kinematic Sunyaev-Zel'dovich (kSZ) effect from the cross-correlation of angular redshift fluctuations, a novel probe that contains precise information about the cosmic density and velocity fields, and CMB maps high-pass filtered using aperture photometry. Remarkably, we detect significant cross-correlation for a wide range of redshifts and apertures using 6dF galaxies, BOSS galaxies, and SDSS quasars as tracers, yielding an 11 sigma detection of the kSZ effect. We then leverage these measurements to set constraints on the location, density, and abundance of gas inducing the kSZ effect, finding that this gas resides outside dark matter haloes, presents densities ranging from 10 to 250 times the cosmic average, and comprises half of all baryons predicted by early-universe studies. Taken together, these findings suggest that our technique provides a nearly complete census of intergalactic gas from $z = 0$ to 5.

The SRG Mission: First Results from eROSITA and ART-XC

The SRG Mission: First Results from eROSITA and ART-XC / 247

A first complete X-ray view of the Magellanic system with eROSITA and X-ray observations of SN 1987A

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The Magellanic Clouds are an ideal site to study X-ray source population of a galaxy including supernova remnants, high mass X-ray binaries (HMXBs) and super-soft sources. This is facilitated by their well-determined distances and low foreground absorption conducive for performing detailed studies. The population of HMXBs in the Magellanic Clouds is especially overabundant owing to the relatively recent star-formation history of these tidally interacting galaxies. However, only a small-fraction of the entire Magellanic Cloud System (which covers nearly 200 square degrees on the sky) was covered in the X-ray regime, until recently. eROSITA onboard SRG has now completed nearly its first three all-sky surveys and has roughly doubled the number of X-ray sources discovered over the last 60 years history of X-ray astronomy. This has also allowed a complete coverage of the Magellanic Cloud system for the first time in X-rays in a broad energy band (0.2-10 keV) and with unprecedented sensitivity. The talk will present the first results on the eROSITA view of the Magellanic Clouds, with a special emphasis on the HMXB population and the flux and spectral evolution of SN 1987A traced by the latest observations.

The SRG Mission: First Results from eROSITA and ART-XC / 416

eROSITA's First Look on Galaxy Groups and Clusters

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The eROSITA Final Equatorial-Depth Survey (eFEDS) carried out during the Performance Verification phase of the Spectrum-Roentgen-Gamma/eROSITA telescope is designed to provide the first eROSITA-selected sample of clusters and groups and to test the predictions for the all-sky survey in the context of cosmological studies with clusters of galaxies. I will present the first results on groups and clusters of galaxies from the eFEDS and summarize the plans for the All-Sky Survey.

The SRG Mission: First Results from eROSITA and ART-XC / 1034

Highlights from the Mikhail Pavlinsky ART-XC telescope on board SRG

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The Mikhail Pavlinsky ART-XC telescope is the hard X-ray instrument with grazing incidence imaging optics on board the SRG observatory which successively works in the orbit from July 2019. The ART-XC telescope is designed to provide the first ever true imaging all-sky survey in the 4-30 keV energy band and to study spectral and timing characteristics of X-ray sources. The review of scientific results obtained with ART-XC during the CalPV phase and two all-sky surveys will be presented.

The SRG Mission: First Results from eROSITA and ART-XC / 308

Prospect for WHIM detection in the cosmic web by SRG/eROSITA

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Hydrodynamical simulations predict that the cosmic web contains the majority of the missing baryons in the form of plasma, called the warm-hot intergalactic medium (WHIM). However, its direct measurement through X-ray emission has been prevented for decades due to the weakness of the signal and to the complex morphology of cosmic filaments.

We identified more than 15,000 large-scale filaments, spanning 30-100 Mpc length, in the SDSS survey and statistically detected the X-ray emission from the WHIM at ~4 sigma confidence level using the ROSAT and Planck data. We expect a much more significant detection from SRG/eROSITA. We indeed predicted the detectability to the WHIM. The prediction shows that stacking ~2000 filaments only would lead to a 5σ detection with an average gas temperature of the WIHM as low as ~0.3 keV.

The SRG Mission: First Results from eROSITA and ART-XC / 169

X-ray blasts from two previously quiescent galaxies

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A new type of exotic X-ray signal from supermassive black holes within galactic nuclei was recently discovered and called Quasi-Periodic Eruptions (QPEs). We have used the eROSITA telescope aboard SRG to systematically search for new QPEs and found two (doubling the sample of known sources) in the first year of operations. The new QPEs brought many new insights, since they were found in two

previously quiescent galaxies, which was not the case for the two QPEs in the literature. This might suggest that no pre-existing accretion flow typical of active galactic nuclei is required to trigger QPEs. Currently, the most promising scenario for their origin is the presence of a second compact object orbiting the supermassive black hole, and data suggest it should be much smaller than the main body (even of the order of a stellar object). This is reminiscent of a channel of gravitational waves emission detectable by LISA in the future, called Extreme mass-ratio inspirals (EMRIs). We still do not know whether QPEs are indeed the electromagnetic counterpart of EMRIs. However, data incoming already over the next year will allow us to test this model by studying the quasi-period and the putative orbital evolution of the system. QPEs could then cover a fundamental role in the future of multi-messenger astrophysics over the next decades.

The SRG Mission: First Results from eROSITA and ART-XC / 249

The X-ray view of the Galactic outflow: from XMM to eROSITA

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Being located at only ~8 kpc from us, the center of our Galaxy provides us with the unique opportunity to study the physics occurring in the core of normal galaxies at very high spatial resolution. Thanks to its penetrating power, the X-ray band is particularly suited for studies of the Galactic center, allowing us to have a direct view of the central heart of the Milky Way. The outstanding results obtained with the current generation of X-ray instrumentations have showcased the power of such X-ray studies, by demonstrating the presence of flows of hot plasma within the Galactic corona connecting the central parsecs with the base of the Galactic halo. However, the limited filed of view of the current X-ray instrumentation have hampered the coverage of such outflow on scales larger than few square degrees (i.e., few hundred parsecs at the Galactic center). I will start describing the latest results on the field and then I will focus on the potential provided by eROSITA to mend this state of affairs.

Theoretical and Observational Studies of Astrophysical Black Holes

Theoretical and Observational Studies of Astrophysical Black Holes / 232

Chaos in the Gravitational Three-Body Problem

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The gravitational three-body problem has a long history, extending all the way back to Sir Isaac Newton. In spite of hundreds of years of research, we still do not have a complete solution to the general case, where no restrictions are placed on the nature of the interaction. Historically, this has been attributed to the appearance of chaos in large regions of parameter space, implying that a probabilistic theory is the only way to go. In this talk, I will briefly review the general three-body problem and its present-day astrophysical significance. I will then go on to introduce a probabilistic solution for the outcomes of chaotic three-body interactions mediated by gravity, and describe how my collaborators and I are using this new tool to build a model that evolves entire populations of binary stars in dense star clusters due to three-body interactions with single stars. The model is entirely analytic, and covers regions of parameter space that are only accessible to modern simulations with great computational cost.

Theoretical and Observational Studies of Astrophysical Black Holes / 212

Three Extraordinary Theorems On Black Hole Rotation

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We reveal three new theorems on black hole rotation previously unexplored in the Hawking era. These results are based on the quasi-local energy investigation of the black hole in Kerr spacetime.

1. The *Horizon Mass Theorem* states that the mass at the event horizon of any black hole is always twice its irreducible mass. In particular, the irreducible mass does not contain rotational energy.

2. The *External Energy Theorem* asserts that the rotational energy of a Kerr black hole exists completely outside the horizon. There is no rotational energy inside the Kerr black hole.
3. The *Moment of Inertia Theorem* states that a black hole with an angular momentum and an angular velocity at the horizon has a moment of inertia. When the rotation stops, there is an irreducible moment of inertia which is equal to *mass x (Schwarzschild radius)^{2}*. This is recognized as the rotational equivalent of the rest mass of a moving body in relativity.

These surprising discoveries indicate that what is believed to be a black hole is a mechanical body with an extended structure. Singularity does not exist. A new paradigm for black holes is presented. Astrophysical black holes are likely to be massive compact objects from which light cannot escape.

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Theoretical and Observational Studies of Astrophysical Black Holes / 206

Super-Penrose process: classification of possible scenarios

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If two particles collide near a rotating black hole, their energy in the centre of mass frame E_c.m. can become unbounded under certain conditions. In doing so, the Killing energy E of debris at infinity is, in general, remain restricted. If E is also unbounded, this is called the super-Penrose process. We elucidate when such a process is possible and give full classification of corresponding relativistic objects for rotating space-times. In particular, we show that it is possible for rotating wormholes. We also discuss briefly the case of a pure electric super-Penrose process that is valid even in the flat space-time. The key role in consideration is played by the Wald inequalities.

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Reconstruction of a star motion in the vicinity of black hole from the redshift of the electromagnetic spectrum

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The problem of calculating of redshift of electromagnetic spectrum of the star, moving in the vicinity of Schwarzschild black hole is solved in the framework of General Theory of Relativity. The inverse problem: determining of the parameters of motion of a star from observational data of redshift is considered. The approach that gives possibilities to solve the inverse problem is proposed. The approach is tested on the numerical model that gives possibilities to calculate redshift as function of time of observation for a star moving in the vicinity of Schwarzschild black hole. The parameters of

the star in numerical model are close to parameters of the S-stars, moving in the vicinity of the Sgr A*.

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On the Gravitational Redshift Detection in the Nucleus of NGC 4258

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By using a general relativistic approach to study Schwarzschild black hole (BH) rotation curves, we reveal the detection of the gravitational and the kinematic boosted redshifts in the strong gravitational regime of the Active Galactic Nucleus of NGC 4258, and estimate its BH mass-to-distance ratio in terms of astrophysical observable quantities.
The total relativistic redshift/blueshift comprises three components: the gravitational redshift due to the spacetime curvature generated by the mass of the BH in its vicinity, the kinematic shift, originated by the photons' local Doppler effect, and the redshift due to a special relativistic boost that describes the motion of a galaxy from a distant observer.
We apply our method to the largest data set of highly redshifted water megamaser measurements on the accretion disk of the NGC 4258 active galaxy.

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Near-horizon particle collisions in spherically symmetric spacetimes

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The occurence of infinite center of mass energies in particle collisions close to the horizon of an extremal Kerr black hole was first presented by Banados, Silk and West (BSW) in 2009. For their scenario, the rotation and the extremality of the black hole are key factors. Since their seminal paper, this phenomenon was studied for a large variety of spacetimes and for different particle setups. Here, we focus on static and spherically symmetric spacetimes and on a slightly different scenario than BSW. In particular, we discuss the physical feasability of infinite energies in our setup for both geodesic and spinning particles.

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Shadows of hairy Kerr black holes and constraints from M87*

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We take on an extensive study of the rotating hairy Kerr black holes, which encompasses, in particular cases, the Kerr black hole ($\alpha = 0$). We investigate ergosphere and shadows of the black holes to infer that their size and shape are affected due to the l_0 and are found to harbour a richer chaotic structure. In particular, the hairy Kerr black holes possess smaller size but more distorted shadows when compared with Kerr black holes. We also estimate the parameters l_0 and a associated with hairy Kerr black holes using the shadow observables. The inferred circularity deviation $\Delta C \leq 0.1$ for the M87* black hole is satisfied, whereas shadow angular diameter $\theta_d = 42 \pm 3 \mu as$, within 1σ region, for a given choice of α, places bounds on the parameters a and l_0. Interestingly, the shadow axial ratio obeying $1 < D_x$
$lesssim 4/3$ is in agreement with the EHT results and thus eventuates in the hairy Kerr black holes being suitable candidates for astrophysical black holes.

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Gravitational multipole moments for asymptotically de Sitter spacetimes

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We provide a prescription to compute the gravitational multipole moments of compact objects for asymptotically de Sitter spacetimes. Our prescription builds upon a recent definition of the gravitational multipole moments in terms of Noether charges associated to specific vector fields, within the residual harmonic gauge, dubbed multipole symmetries. We first derive the multipole symmetries for spacetimes which are asymptotically de Sitter; we also show that these symmetry vector fields eliminate the non-propagating degrees of freedom from the linearized gravitational wave equation. We then apply our prescription to the Kerr-de Sitter black hole and compute its multipole structure. Our result recovers the Geroch-Hansen moments of the Kerr black hole in the limit of vanishing cosmological constant.

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Observation of a multimode quasi-normal spectrum from a perturbed black hole

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When two black holes merge, the late stage of gravitational wave emission is a superposition of exponentially damped sinusoids. According to the black hole no-hair theorem, this ringdown spectrum depends only on the mass and angular momentum of the final black hole. An observation of more than one ringdown mode can test this fundamental prediction of general relativity. Here we provide strong observational evidence for a multimode black hole ringdown spectrum using the gravitational wave event GW190521, with a Bayes factor of ~40 preferring two fundamental modes over one. The dominant mode is the ℓ=m=2 harmonic, and the sub-dominant mode corresponds to the ℓ=m=3 harmonic. We estimate the redshifted mass and dimensionless spin of the final black hole as 330+30-40 Solar masses and 0.87+0.05-0.10 respectively. The detection of the two modes disfavors a binary progenitor with equal masses; the mass ratio is constrained to 0.4+0.2-0.3. We find that the final black hole is consistent with the no hair theorem and constrain the fractional deviation from general relativity of the sub-dominant mode's frequency to be -0.01+0.07-0.11.

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Physical black holes in semiclassical gravity

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Assuming only the existence of an apparent horizon and its regularity, we derive universal properties of the near-horizon geometry of spherically symmetric black holes. General relativity admits only two distinct classes of physical black holes, and both appear at different stages of the black hole formation. Using a self-consistent semiclassical approach, we find that the resulting near-horizon geometry differs considerably from the one that is obtained using classical notions of a horizon. If semiclassical gravity is valid, then accretion after horizon formation inevitably leads to a firewall that violates quantum energy inequalities. Consequently, physical black holes can only evaporate once a horizon has formed. Comparison of the required energy and time scales with the known semiclassical results suggests that the observed astrophysical black holes are horizonless ultra-compact objects, and the presence of a horizon is associated with currently unknown physics. This has interesting implications for the information loss paradox.

Note: the results presented in this talk are summarized in Phys. Rev. D **103**, 064082 (2021).

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TWO-TEMPERATURE ACCRETION FLOWS AROUND COMPACT OBJECTS

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Accretion mechanism is one of the most efficient processes by which gravitational potential energy of matter can be converted into energy. This phenomenon provides us with an explanation regarding the huge amount of energy liberated and high luminosities observed in AGN's, X-ray binaries, etc. Therefore, modelling these accretion flows are necessary to obtain a proper picture of the system and to understand the underlying physical processes. Since electrons are the ones that radiate via processes like synchrotron, bremsstrahlung and inverse-Compton scattering, therefore the electron gas and proton gas, present in the ionised plasma of the accretion disc, are supposed to settle down into two different temperature distributions; thus the name two-temperature modelling. We

investigated these flows in greater details in the pure general-relativistic regime. The problem with two-temperature flow is that, there is one more unknown than the number of equations. Solving the equations of motion for a given set of constants of motion, we find that no unique solution exists, unlike in the case of one-temperature flows. In other words, the solutions are degenerate. So, we get different kinds of transonic solutions with drastically different topologies but for the same constants of motion. In addition, there is no known principle dictated by plasma physics that may constrain the relation between these two-temperatures in any of the boundaries. We removed the degeneracy with the help of second law of thermodynamics. We show that only one of the solutions among all has the maximum entropy and therefore is the correct solution, thus eliminating degeneracy. As far as we know, no methodology of obtaining unique transonic two-temperature solutions has been reported so far in the literature. This is the first time we have attempted towards getting the general picture of the physical solutions.

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Displacement memory and BMS symmetries

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The direct detection of gravitational wave (GW) from binary black hole (BBH) mergers has set a strong evidence for the general theory of relativity. These observations have enabled researchers to look for various aspects of black hole spacetimes; Gravitational wave memory (GW-memory) is one of such physical effects which has not been detected yet. The GW-memory manifests a permanent displacement in the spacetime which is a relative change in the position of freely falling LIGO test masses. It has been shown that the memory effect is related to the asymptotic symmetries of spacetimes originally discovered by Bondi-van der Berg-Metzner-Sachs (BMS). From theoretical perspectives, recovering asymptotic symmetries near the horizon of black holes has become a matter of interest to the researchers as Hawking, Perry and Strominger conjectured that the charges corresponding to BMS symmetries would help to retrieve the information in the Hawking information paradox. Therefore, the memory effect must be well studied in the context of BMS symmetries from both theoretical and experimental perspectives. In this direction, I would focus on investigating some of these aspects by estimating measurable effects on the detectors after the passage of GWs. My aim would be to provide some theoretical features of the displacement memory effect near the horizon of black holes and its possible connection with near-horizon BMS symmetries.

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Emergence of Intrinsic Gravitational Modes Associated with Emissions of (GR) Gravitational Waves

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Intrinsic Gravitational Modes (IGM) involving electromagnetic field fluctuations are found that are sustained by the time-dependent tridimensional gravitational field of Black Hole binaries when their collapse is approached. These "disk-rippling" modes, emerging from a plasma disk structure surrounding a binary, have ballooning amplitude profiles in the "vertical" direction (referring to the binary angular momentum vector) and rotate mainly with a frequency of twice the binary rotation

frequency within the limited region where the Newtonian gravity modulation is valid. Modes with considerably higher frequencies can be sustained by the modulated gravitational potential through the coupling of modes of this kind whose frequencies differ by twice the binary roatation frequency. Relevant mode-particle resonances 1 can provide a means to transfer energy from high to low energy populations (a process evidenced by laboratory experiments) and offer an explanation for the absence of detectable high energy radiation emission as the observed collapse of Black Hole binaries is approached. When the disk structure is immersed in a (stationary) magnetic field 1, another class of modes can emerge and extend the range of processes resulting from mode-particle resonant interactions.

1 B.Coppi, Pl. Phys. Rep. 45, 438 (2019).

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GRAVITY: Optical/IR Interferometry and General Relativity in the Galactic Centre

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The GRAVITY instrument at the Very Large Telescope (VLT) has transformed the Galactic centre into a laboratory to test the strong field regime of gravity theories. The supermassive black hole in the center of the Milky Way (Sgr A*) is, at a distance of 8kpc, the closest of its kind and the largest in the sky. It is surrounded by a nuclear cluster of high velocity stars called S-stars, whose trajectories are governed by the gravitational field of the black hole. The GRAVITY instrument combines the light of four 8m telescopes in the K-band and is equipped with a separate fringe-tracking channel and an adaptive optics system. This allows long integration times on faint objects and enables a resolution of a few 10s of microarcseconds in the Galactic centre and thus a day-by-day monitoring of stellar orbits. Following the star S2/S-02, we have detected the combined gravitational redshift and transverse Doppler effect as well as the Schwarzschild precession of the orbit. GRAVITY is able to detect emission from the location of Sgr A* at all times.* During the high emission state, GRAVITY records the continuous changes in position and polarisation of flaring material near the innermost stable circular orbit. I will discuss how we obtained our recent results and put them in the context of gravity theories.

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The quasi-static approximation in Horndeski models

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The quasi-static approximation (QSA) is a useful tool to get a quick and clear physical understanding of the phenomenology of modified gravity which is encoded in two functions (of scale and time): the effective gravitational constant (describing the modified evolution of matter perturbations) and the slip (parametrizing the relations between the two gravitational potentials). This approximation is often used to put constraints on cosmological models using phenomenological expressions. In this talk I will consider three different formulations based on the QSA for Horndeski models and assess their performance on some cosmological observables and assess the range of validity of this approximation. I will also highlight why different schemes lead to different expressions on very large scales and how we can improve them.

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Unifying baryogenesis with dark matter production

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According to several observational evidences, the Hot Big Bang Model is the best framework in which to explain the origin and the evolution of the universe. By the way, it is still not the definitive model. Among its weaknesses, we have to count the lack of a satisfying explanation of how baryons and dark matter formed. In this article we attempt to describe these phenomena through a new interpretation of the model itself. We propose baryogenesis can occur as the environment field, associated with universe's expansion, couples to effective quark and lepton fields. Consequently, we propose how to unify the baryogenesis with dark matter production during reheating and evaluate the corresponding densities. Soon after dark matter's born, we justify how to cancel out vacuum energy degrees of freedom through a mechanism that counterbalance vacuum energy with dark matter pressures. We thus predict both dark matter and baryon densities, showing which dark matter

constituent is expected to guarantee the mechanism above described. Here, for simplicity, we do not consider strong interactions, so a generalization of this work will be necessary in order to obtain a complete and realistic physical model.

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Quasinormal modes in the field of a dyon-like dilatonic black hole

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Quasinormal modes of massless test scalar field in the background of gravitational field for a non-extremal dilatonic dyonic black hole are explored. The dyon-like black hole solution is considered in the gravitational $4d$ model involving two scalar fields and two 2-forms. It is governed by two 2-dimensional dilatonic coupling vectors $\vec{\lambda}_i$ obeying $\vec{\lambda}_i(\vec{\lambda}_1 + \vec{\lambda}_2) > 0$, $i = 1, 2$. The first law of black hole thermodynamics is given and the Smarr relation is verified. Quasinormal modes for a massless scalar (test) field in the eikonal approximation are obtained and analysed. These modes depend upon a dimensionless parameter a ($0 < a \leq 2$) which is a function of $\vec{\lambda}_i$. For limiting strong ($a = +0$) and weak ($a = 2$) coupling cases, they coincide with the well-known results for the Schwarzschild and Reissner-Nordstr\"om solutions. It is shown that the Hod conjecture, connecting the damping rate and the Hawking temperature, is satisfied for $0 < a \leq 1$ and all allowed values of parameters.

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A post Newtonian modification of the gravitational potential at the extreme length/energy scales

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The Post Newtonian (PN) expansion of General Relativity (GR) yields a series of potentials that accurately describe the trajectories of compact binaries to a very high degree of accuracy. In the mathematical treatment of PN expansion of GR, a relation is established between the ratio of the orbital velocity to the speed of light and the compactness-to-closeness ratio: the ratio between average orbital radii and the distance between the Center of Mass (COM) of the binary counterparts. Over the evolution of the binary, the aforementioned relation establishes a series of potentials sourced by a particular multipole moment of the sources at a particular PN order. Whereas the standard PN expansion works at a range of distances (usually in the order of a few thousand kilometers to a few kilometers) for compact binaries with mass-radii ratios comparable to unity, the method fails at reproducing the behavior of such objects at *large* length scales; and is also theoretically expected to not hold for the *very short* lengths. In this talk, a generalized gravitational action, which is a simple example of a quadratic extension to GR, is PN expanded in the same spirit of the Landau-Lifshitz formalism, and a series of potentials are obtained that reproduces Einsteinian behavior at appropriate scales, with non-trivial behavior at scales where GR is expected to break down. This talk will cover both the infrared and the ultraviolet energy scales and the modifications expected at such scales for a quadratic extension to the GR action.

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Healing the cosmological constant problem through a vacuum energy geometric cancellation

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We explore a geometrical mechanism of cancellation that heals the cosmological constant problem. To do so, during the primordial universe we assume quantum fluctuations to hold and the effective cosmological constant built up in terms of its bare and quantum contributions. We thus notice that if we assume a discontinuity of the Friedmann-Robertson-Walker metric, a corresponding phase of energy release is expected. We motivate such a discontinuity in terms of particle and apparent horizons in an Einstein-deSitter universe dominated by the cosmological constant. We propose this energy release gets rid of particle production. Thus, once quantified the corresponding particle candidate, we model the universe through three phases. The intermediate one is metastable and overcomes the physical issue related to geometric discontinuity, suggesting a phase transition could occur. As a benchmark we there assume an anisotropic universe, computing the corresponding particle production using the Weyl tensor. Finally, we show the corresponding particles are dark matter component, whose mass limits are predicted to guarantee the cosmological constant contribution from vacuum energy is canceled out. The remaining effective constant, namely the bare cosmological one, is therefore interpreted as responsible for the current acceleration, removing de facto the fine-tuning issue.

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The Model of Dark Energy Based on the Quantum-Mechanical Uncertainty Relation

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Existence of the Dark Energy became now a commonly-accepted paradigm of cosmology, but the physical essence of this quantity remains absolutely unknown and its numerical values are drastically different in the early and modern Universe. In fact, the Dark Energy is usually introduced in literature either by postulating some additional terms in the Lagrangians or by employing the empirical equations of state. In the present report, we try to look at this problem from a more specific point of view, namely, employing the quantum-mechanical uncertainty relation between the time and energy in the Mandelstam-Tamm form, which is appropriate for the long-term evolution of quantum systems [Yu.V. Dumin. Grav. & Cosmol., v.25, p.169 (2019); v.26, p.259 (2020); v.27, in press (2021)]. This leads us to the time-dependent effective Lambda-term, decaying as 1/t. The corresponding cosmological model possesses a number of quite appealing features: (1) While in the standard cosmology there are a few very different expansion stages (governed by the Lambda-term, radiation, dust-like matter, and Lambda-term again), our model provides a universal description of the entire evolution of the Universe by the same "quasi-exponential" function. (2) As follows from the analysis of causal structure, the present-day cosmological horizon comprises a single domain developing from the Big Bang. Therefore, the problems of homogeneity and isotropy of the matter, the absence of topological defects, etc. should be naturally resolved. (3) Besides, our model naturally explains the observed approximately flat 3D space, i.e., solution with zero curvature is formed "dynamically", starting from the arbitrary initial conditions.

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Model-Independent test of Scalar-Tensor gravity theory by reconstructing scalar mode of GW170817

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Einstein's general relativity predicts that a gravitational wave is allowed to have two polarizations called tensor-mode: plus and cross modes. On the other hand, the general metric theory of gravity predicts that a gravitational wave is allowed to have up to six polarizations: two scalar and two vector modes in addition to tensor modes. In case the number of laser-interferometric gravitational wave telescopes is larger than the one of the polarizations the gravitational waves have, all the polarizations can be reconstructed separately. Since it depends on theories of gravity which polarizations the gravitational waves have, the investigation of polarizations is important for the test of theories of gravity.
In this paper, in order to test the scalar-tensor gravity theory, one of important alternative theories of gravity, we search for the scalar-mode of GW170817 observed by LIGO Livingstone, Hanford and Virgo without prior information about any tensor-scalar gravity theories. As a result, we found the maximum SNR of the scalar-mode of GW170817 was 2.77, the p-value was 0.01, and the band-limited h_{rss} was $1.55\times10^{-21}[1/\sqrt{Hz}]$ with the time window of 2[s] and frequency window of 60~120[Hz].

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$f(R)$ Dual Theories of Quintessence : Expansion-Collapse Duality

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The accelerated expansion of the universe demands presence of an exotic matter, namely the dark energy. Though the cosmological constant fits this role very well, a scalar field minimally coupled to gravity, or quintessence, can also be considered as a viable alternative for the cosmological constant. We study $f(R)$ gravity models which can lead to an effective description of dark energy implemented by quintessence fields in Einstein gravity, using the Einstein frame-Jordan frame duality. For a family of viable quintessence models, the reconstruction of the $f(R)$ function in the Jordan frame consists of two parts. We first obtain a perturbative solution of $f(R)$ in the Jordan frame, applicable near the present epoch. Second, we obtain an asymptotic solution for $f(R)$, consistent with the late time limit of the Einstein frame if the quintessence field drives the universe. We show that for certain class of viable quintessence models, the Jordan frame universe grows to a maximum finite size, after which it begins to collapse back. Thus, there is a possibility that in the late time limit where the Einstein frame universe continues to expand, the Jordan frame universe collapses. The condition for this expansion-collapse duality is then generalized to time varying equations of state models, taking into account the presence of non-relativistic matter or any other component in the Einstein frame universe. This mapping between an expanding geometry and a collapsing geometry at the field equation level may have interesting potential implications on the growth of perturbations therein at late times.

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Cosmological barotropic fluids in geometrothermodynamics

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Geometrothermodynamics (GTD) can be used in relativistic cosmology to generate models of barotropic fluids. As an alternative approach, we use the GTD formalism to find the most general thermodynamic fundamental equations that describe the barotropic fluids of the Lambda-CDM model. This allows us to investigate the thermodynamic properties of these barotropic fluids from the point of view of GTD. As a result, we can describe the evolution of the cosmological fluids from a thermodynamic perspective.

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On the Interaction Between Electromagnetic, Gravitational, and Plasma Related Perturbations on LRS Class II Spacetimes

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I will talk about a recent work, where we have investigated the interaction between electromagnetic, gravitational, and plasma related perturbations on homogeneous and hypersurface orthogonal LRS class II spacetimes. By using these spacetimes, which allow for the inclusion of a non-zero magnetic field, as backgrounds in a perturbative approach, we are able to see interactions between the electromagnetic and gravitational variables already to first order in the perturbations. This is in contrast to earlier works using FLRW backgrounds, where one is usually faced with going to second order in the perturbations. To get the equations governing our perturbations, we use a $1 + 1 + 2$ covariant approach and gather relations from the Ricci and Bianchi identities, Maxwell's equations, particle conservation, and energy-momentum conservation for the individual plasma components. After linearising these equations around a LRS background, performing a harmonic decomposition, and using the MHD approximation for a cold plasma, we then arrive at a closed system for the first order perturbations. This system, consisting of ordinary differential equations in time and a set of constraints, is then reduced to two separate subsectors, containing seven and nine variables respectively. These results could be of interest when considering the large scale cosmic magnetic fields, as their origin still seems to elude us.

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Effects of non-vanishing dark matter pressure in the Milky Way galaxy

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We consider the possibility that the Milky Way's dark matter halo possesses a non-vanishing equation of state. Consequently, we evaluate the contribution due to the speed of sound, assuming that the dark matter content of the galaxy behaves like a fluid with pressure. In particular, in the galactic core we compare two scenarios: a supermassive black hole in vacuum and a dark matter distribution without black hole. We model the dark matter distribution via an exponential sphere profile in the galactic core, and inner parts of the galaxy whereas we assume three widely-used profiles for the halo, i.e. the Einasto, Burkert, and Isothermal profiles. We show a posteriori that Newtonian gravity works well in the proposed scenarios far from the galactic center and investigate the expected experimental signature provided by gravitational lensing in the presence of dark matter.

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Testing generalized logotropic models with cosmic growth

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We check the dynamical and observational features of four typologies of logotropic dark energy models, leading to a thermodynamic cosmic speed up fueled by a single fluid that unifies dark energy and dark matter. We first present two principal Anton-Schmidt fluids where the Gruneisen parameter is free to vary and then fixed to the special value We also investigate the pure logotropic model, corresponding to Finally, we propose a new logotropic paradigm that works as a generalized logotropic fluid, in which we split the role of dark matter and baryons. We demonstrate that the logotropic paradigms may present drawbacks in perturbations, showing a negative adiabatic sound speed which make perturbations unstable. We thus underline which model is favored over the rest. The Anton-Schmidt model with is ruled out while the generalized logotropic fluid seems to be the most suitable one, albeit weakly disfavored than the ΛCDM model. To fix numerical constraints, we combine low- and higher-redshift domains through experimental fits based on Monte Carlo Markov Chain procedures, taking into account the most recent Pantheon supernovae Ia catalogue, Hubble measurements and σ8 data points based on the linear growth function for the large scale structures. We also consider two model selection criteria to infer the statistical significance of the four models under exam. We conclude there is statistical advantage to handle the Anton-Schmidt fluid with the Gruneisen parameter free to vary and/or fixed to The generalized logotropic fluid indicates suitable results, statistically favored than the other models, until the sound speed is positive, becoming unstable in perturbations elsewhere. We emphasize that the ΛCDM paradigm works statistically better than any kinds of logotropic and generalized logotropic models, while the Chevallier-Polarski-Linder parametrization is statistically comparable with logotropic scenarios.

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Emergent Planck mass and dark energy from affine gravity

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We introduce a novel model of affine gravity, which implements the no-scale scenario. Namely, in our model the Planck mass and Hubble constant emerge dynamically, through the mechanism of spontaneous breaking of scale invariance. This naturally gives rise to the inflation, thus introducing a new inflationary mechanism. Moreover, the time direction and non-degenerate metric emerge dynamically as well. We show that our model is phenomenologically viable, both from the perspective of the direct tests of gravity and cosmological evolution.

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Alternatives to Lambda: Torsion, Generalized Couplings, and Scale Invariance

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We present a comparative analysis of current observational constraints on three recently discussed alternative models for explaining the low-redshift acceleration of the universe: the generalized coupling model by Feng and Carloni, the scale invariant model by Maeder (an example of a broader class first proposed by Canuto et al., which we also study), and the so-called steady-state torsion model of Kranas et al. These are compared to the traditional parametrization of Chevallier, Polarski and Linder. Each of the candidate models is studied under two different assumptions: as genuine alternatives to LambdaCDM (where a new degree of freedom would be expected to explain the recent acceleration of the universe without any cosmological constant) and as parametric extensions of LambdaCDM (where both a cosmological constant and the new mechanism can coexist, and the relative contributions of both are determined by the data). Our comparative analysis suggests that, from a phenomenological point of view, all such models neatly divide into two classes, with different observational consequences.

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Entanglement production in Einstein-Cartan theory

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We study the entanglement production for Dirac and Klein-Gordon fields in an expanding spacetime characterized by the presence of torsion. Torsion is here considered according to the Einstein-Cartan theory with a conformally flat Friedmann-Robertson-Walker spacetime. In this framework, torsion is seen as an external field, fulfilling precise constraints directly got from the cosmological constant principle. For Dirac field, we find that torsion increases the amount of entanglement. This turns out to be particularly evident for small values of particle momentum. We discuss the roles of Pauli exclusion principle in view of our results, and, in particular, we propose an interpretation of the two maxima that occur for the entanglement entropy in presence of torsion. For Klein-Gordon field, and differently from the Dirac case, the model can be exactly solved by adopting the same scale factor as in the Dirac case. Again, we show how torsion affects the amount of entanglement, providing a robust physical motivation behind the increase or decrease of entanglement entropy. A direct comparison of our findings is also discussed in view of previous results derived in absence of torsion. To this end, we give prominence on how our expectations would change in terms of the coupling between torsion and the scale factor for both Dirac and Klein-Gordon fields.

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Astrophysical bounds from red and blue shift limits in spherical and axisymmetric spacetimes

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Testing gravity on low and high energy domains is essential to reconcile primordial and late times. Focusing on local and cosmic scales, red and blue shift measures between two observers plays a crucial role. We revise their use in two distinct contexts, making use of de Sitter–Schwarzschild solution and q-metric to describe low and higher energy regimes. First, we assume de Sitter–Schwarzschild space-time whose contribution comes from the cosmological constant. We study this model both for Earth and Mars (in the Solar System regime) and for neutron stars and white dwarfs, as different sources of the gravitational field. By assuming the value of Λ given by Planck's measurements, we get a suitable red and blue shift range as function of the position of the observer who receives the photon emitted by the other one. Analogously, we consider the q-metric, i.e. the first extension to the spherically symmetric Schwarzschild solution, for the same sources as before. By fixing the value of the δ parameter of the theory, we get another suitable red and blue shift range as function of the position of the photon detector. Thus, a non-direct test of the theory can be exploited through an experimental setup that measures the red or the blue shift from a given gravitational source.

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Cosmology in scalar-tensor f(R,T) gravity

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We apply cosmological reconstruction methods to *f(R,T)* modified gravity, in its recently developed scalar-tensor representation. We do this analysis assuming a perfect fluid in a Friedmann-Lemaître-Robsertson-Walker (FLRW) universe. Solutions with general scale factor, curvature parameter and equation of state are found for the energy density, pressure, and one of the dynamical fields of the scalar-tensor representation. We then apply three particular forms of the scale factor: an exponential expansion (in analogy with the de Sitter solution); and two types of power-law expansion (radiation domination and matter domination). This allows us to find, in each particular case, a complete solution. We do so for each of the three values of the curvature parameter, and with three different values of the equation of state corresponding, in general relativity, to the equation of state of a cosmological constant, of matter and of radiation.

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Black hole mimickers and the limits of GR

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We consider a class of exact solutions of Einstein's equations that describe a black hole mimicker for which the relativistic description would fail close to the horizon scale. We investigate how such an hypothetical object may be distinguished from a black hole via observations.

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The effect of screening mechanisms on black hole binary inspiral waveforms

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Scalar-tensor theories leaving significant modifications of gravity at cosmological scales rely on screening mechanisms to recover General Relativity (GR) in high-density regions and pass stringent tests with astrophysical objects. Much focus has been placed on the signatures of such modifications of gravity on the propagation of gravitational waves through cosmological distances while typically assuming their emission from fully screened regions with the wave generation strictly abiding by GR. In this talk, I will question the hypothesis of a fully screened source in gravitational wave emissions and examine the impact of screening mechanisms on the inspiral gravitational waveforms from compact sources. For that purpose, I will present the leading corrections to the GR waveform from general Horndeski theories and apply the results to the cubic Galileon model. In particular, we will see that the current sensitivity of our ground-based interferometers on the amplitude of gravitational waves is not yet sufficient to detect the deviation, supporting fully screened wave emissions. However, the predicted effect of the scalar field is not so small as to remain undetected by the future generation of detectors, such as LISA or the Einstein telescope.

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Inertial Horizon

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We investigate radiation from asymptotic zero acceleration motion where a horizon is formed and subsequently detected by an outside witness.

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CGHS Moving Mirror

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CGHS black holes have rightfully garnered much attention over the last few decades as the models are simplified (1+1)-dimensional versions of black hole evaporation. Their solubility has lead to tractable physical insights into the radiative process. Concurrently, moving mirrors are well-known simplified (1+1)-dimensional models for black hole evaporation. We synthesize the two by finding an exact correspondence between the CGHS black hole and exponentially accelerated moving mirror. The equivalence of these two models can be seen from several matching quantities such as trajectory of the moving mirror that, in turn, corresponds to the center of the black hole; spectrum of the particle radiation; the event horizon locations and the temperatures.
Furthermore, a novel derivation and understanding of the mirror power and self-force are applied to this particular moving mirror, CGHS mirror.

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A model independent approach to the study of f(R) cosmologies with expansion histories close to ΛCDM

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We propose a new framework for studying the cosmology of f(R) gravity which completely avoids using the reconstruction programme. This allows us to easily obtain a qualitative feel of how much the ΛCDM model differs from other f(R) theories of gravity at the level of linear perturbation theory for theories that share the same background dynamics. This is achieved by using the standard model independent cosmographic parameters to develop a new dynamical system formulation of f(R) gravity which is free from the limitation of having to first specify the functional form of f(R). By considering a set of representative trajectories, which are indistinguishable from ΛCDM, we use purely qualitative arguments to determine the extent to which these models deviate from the standard model by including an analysis of the linear growth rate of density fluctuations and also whether or not they suffer from the Dolgov-Kawasaki instability. We find that if one demands that a late time f(R) cosmology is observationally close to the ΛCDM model, there is a higher risk that it suffers from a Dolgov-Kawasaki instability. Conversely, the more one tries to construct a physically viable late time f(R) cosmology, the more likely it is observationally different from the ΛCDM model.

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Thermodynamics of scalar-tensor gravity: a new approach

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We propose a new approach to the thermodynamics of scalar-tensor gravity and its possible diffusion" toward general relativity, previously regarded as an equilibrium state in spacetime thermodynamics. The main idea is describing scalar-tensor gravity as an effective dissipative fluid and applying Eckart's first order thermodynamics to it. This gives explicit effective quantities: heat current density,temperature of gravity", viscosity coefficients, entropy density, plus an equation describing

the "diffusion" to Einstein gravity. These quantities, otherwise missing in spacetime thermodynamics, pop out with minimal assumptions.

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Do gamma-ray burst measurements provide a useful test of cosmological models?

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Context. We study eight different gamma-ray burst (GRB) data sets to examine whether current GRB measurements — that probe a largely unexplored part of cosmological redshift (z) space — can be used to reliably constrain cosmological model parameters.
Aims. We use three Amati-correlation samples and five Combo-correlation samples to simultaneously derive correlation and cosmolog- ical model parameter constraints. The intrinsic dispersion of each GRB data set is taken as a goodness measurement. We examine the consistency between the cosmological bounds from GRBs with those determined from better-established cosmological probes, such as baryonic acoustic oscillation (BAO) and Hubble parameter H(z) measurements.
Methods. We use the Markov chain Monte Carlo method implemented in MontePython to find best-fit correlation and cosmological parameters, in six different cosmological models, for the eight GRB samples, alone or in conjunction with BAO and H(z) data. Results. For the Amati correlation case, we compile a data set of 118 bursts, the A118 sample, which is the largest — about half of the total Amati-correlation GRBs — current collection of GRBs suitable for constraining cosmological parameters. This updated GRB compilation has the smallest intrinsic dispersion of the three Amati-correlation GRB data sets we examined. We are unable to define a collection of reliable bursts for current Combo-correlation GRB data.
Conclusions. Cosmological constraints determined from the A118 sample are consistent with — but significantly weaker than — those from BAO and H(z) data. They also are consistent with the spatially-flat ΛCDM model, in which dark energy is the cosmological constant Λ, as well as with dynamical dark energy models and non-spatially-flat models. Since GRBs probe a largely unexplored region of z, it is well worth acquiring more and better-quality burst data which will give a more definitive answer to the question of the title.

Time and Philosophy in Physics

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The Issue of Time in Fundamental Physics

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Notion of Time in fundamental physics has undergone radical revisions over centuries and issues at the forefront of cosmology and quantum gravity pose new conceptual and technical challenges. This talk will provide an short overview of the evolution of ideas and the current status.

Time and Philosophy in Physics / 684

Time in quantum gravity: a false problem.

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Many tentative quantum gravity theories, from the Wheeler-deWitt equation to Loop Quantum Gravity, do not specify a time variable, and yet they are predictive. The discussion to clarify this strangeness has been long, but has been resolved and the issue should not be controversial anymore. I give a rapid and simple overview of the solution.

Time and Philosophy in Physics / 696

Time in General Relativity and Quantum Mechanics

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Within the formalism of General Relativity it is possible to operationally define or characterize a distinguished clock and time. This is the so-called standard clock providing proper time. Also within Quantum Mechanics it is possible to define a clock and the corresponding time. This clock is an atomic clock and it provides time in the unit of the second. Both clocks are compatible though they

are based on completely different notions. This compatibility breaks down in strong gravitational fields and also in generalized theories of gravity. In this contribution the principal operational foundations of these two types of clocks are discussed as well as possible causes leading to a different time provided by these two types of clocks.

Time and Philosophy in Physics / 795

A glimpse to Feynman's contributions to the debate on the foundations of quantum mechanics

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The wide debate on foundational issues in quantum mechanics, which took place at the famous 1957 Chapel Hill conference on "The Role of Gravitation in Physics", is here critically analysed with an emphasis on Richard Feynman's contributions [1, 2, 3]. One of the most debated questions at Chapel Hill was whether the gravitational field had to be quantized at all and its possible role in wave function collapse. Feynman's arguments in favor of the quantization of the gravitational field, based essentially on a series of gedanken experiments, are here discussed. Then we switch to the related problem of the wave function collapse, for which Feynman hints to decoherence as a possible solution. Finally, another topic is analysed, concerning the role of the observer in a closed Universe. In this respect, Feynman's many-worlds characterization of Everett's approach is discussed together with his later contributions, involving a kind of Schroedinger's cat paradox, scattered throughout the 1962-63 Lectures on Gravitation 4. Philosophical implications of Feynman's ideas in relation to foundational issues are also discussed.

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2 M. Di Mauro, S. Esposito, A. Naddeo, A road map for Feynman's adventures in the land of gravitation, arXiv: 2102.11220, submitted to Eur. Phys. J. H (2021).
3 D. Zeh, Feynman's interpretation of quantum theory, Eur. Phys. J. H 36 (2011) 63.
4 R. P. Feynman, F. B. Morinigo, W. G.Wagner and B. Hatfield, Feynman Lectures on Gravitation, Addison-Wesley, Reading, MA, 1995.

Time and Philosophy in Physics / 388

Explaining Time's Passage

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The way we experience time is in the accumulation of experiences and events that happen in the moment, and then are behind us. Since the time of Anaximander at least; philosophers have tried to explain both the nature of time and its origin or basis. In modern times; scientists are the ones exploring the domain of time, so now they attempt to explain the nature and basis of time – with varying degrees of success. This is complicated because explanations from Classical Physics or Relativity are different from, and incompatible with, answers from Quantum Mechanics, so we hope

Quantum Gravity theories will help resolve this. Recent advances in Mathematics hold promise for a unified basis explaining both the thermodynamic and quantum-mechanical time arrows in a way that consistently informs our Philosophy. However; we may need to explore beyond the island of familiar Maths, to reconcile the divergent pictures of how and why time passes.

Time and Philosophy in Physics / 595

Temporal orderings in philosophy and physics

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Time is one the oldest and most eminent concepts in both philosophy and physics. In my talk I will highlight some pertinent discussions from philosophy and how they relate to issues in current physics. More specifically, I will introduce two different types of temporal orderings and will explain why both are relevant for everyday life, whereas only one of them seems to be of importance to physics.

Time and Philosophy in Physics / 326

The passage of time and top-down causation

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It is often claimed that the fundamental laws of physics are deterministic and time-symmetric and that therefore our experience of the passage of time is an illusion. This talk will critically discuss these claims and show that they are based on the misconception that the laws of physics are an exact and complete description of nature. I will argue that all supposedly fundamental deterministic and time-symmetric laws have their limitations and are supplemented by stochastic and irreversible elements. In fact, a deterministic description of a system is valid only as long as interactions with the rest of the world can be ignored. The most famous example is the quantum measurement process that occurs when a quantum system interacts with a macroscopic environment such as a measurement apparatus. This environment determines in a top-down way the possible outcomes of the measurement and their probabilities. I will argue that more gnerally the possible events that can occur in a system and their probabilities are the result of top-down influences from the wider context. In this way the microscopic level of a system is causally open to influences from the macroscopic environment. In conclusion, indeterminism and irreversibility are the result of a system being embedded in a wider context.

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Temporal asymmetry and causality

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The temporal asymmetry between past and future permeates virtually every aspect of the world of our experience. It has no counterpart, as far as we know, in the laws of fundamental physics. One reaction to this is to trace this asymmetry to a fact about the early state of the universe, either taken as a brute, unexplained fact, or as a consequence of some physical principle. In this talk I will suggest an alternate route to explaining temporally asymmetric phenomena, one that is better in accord with how work on the process of equilibration is done. This doesn't involve any hypothesis about the past, but a condition of independence of incoming influences, closely related to the concept of cause, that may be invoked at any time. I will argue that the absence of temporally asymmetry in the fundamental laws is no obstacle to explaining that asymmetry. What is invoked is a temporal asymmetry in the very notion of explanation.

Topological Methods, Global Existence Problems, and Spacetime Singularities

Topological Methods, Global Existence Problems, and Spacetime Singularities / 35

Strong cosmic censorship theorem in Bakry-Emery spacetimes

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A class of naked strong curvature singularities is ruled out in Bakry-Emery spacetimes by using techniques of differential topology in Lorentzian manifolds.
These spacetimes adimit a Bakry-Emery-Ricci tensor which is a generalization of the Ricci tensor. This result supports to validity of Penrose's strong cosmic censorship conjecture in scalar-tensor gravitational theories, which include dilaton gravity and Brans-Dicke theory.

Topological Methods, Global Existence Problems, and Spacetime Singularities / 238

On the scattering laws of bouncing universes

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I will present recent developments on the geometric analysis of Einstein's field equations for spacetimes containing singularity hypersurfaces, which represent gravitational waves, shock waves, or phase interfaces. I will explain the formulation and classification of scattering laws and junction conditions at singularities, and will discuss bouncing cosmologies (big bang, big crunch). I will then apply this formalism to the resolution of the global evolution problem for the Einstein equations when two gravitational plane-symmetric waves collide and generate a cyclic spacetime. This is a research project in collaboration with B. Le Floch (ENS, Paris) and G. Veneziano (CERN, Geneva).

Topological Methods, Global Existence Problems, and Spacetime Singularities / 331

Open problems in the nature of singularities in relativistic spacetimes

Author: Deborah Konkowski[1]

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I will discuss the status of our understanding of singularities in general relativistic spacetimes. I will cover briefly their definition, location, and existence, while focusing on their classical and quantum nature. I will emphasize what we know, and what we do not know about the effect of test particles and waves on a zoo of singularities, from quasiregular to nonscalar curvature to scalar curvature in both localized and cosmological scenarios.

Topological Methods, Global Existence Problems, and Spacetime Singularities / 499

Brane-world singularities in a fluid bulk

Authors: Ifigeneia Klaoudatou[1]; Ignatios Antoniadis[None]; Spiros Cotsakis[None]

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We present new results on the singularity structure and asymptotic analysis of a brane-world that consists of a flat 3-brane embedded in a five-dimensional bulk. The bulk matter is modelled by a fluid that satisfies a non-linear equation of state of the form $p = \gamma\rho^{\lambda}$, where p is the 'pressure' and ρ is the 'density' of the fluid. We show that for appropriate ranges of the parameters γ and λ, it is possible to construct a regular solution, compatible with energy conditions, that successfully localizes gravity on the brane. These results improve significantly previous findings of the study of a bulk fluid with a linear equation of state.

Topological Methods, Global Existence Problems, and Spacetime Singularities / 501

Asymptotic synchronization of Mixmaster spatial points

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We consider the problem of asymptotic synchronization of different spatial points coupled to each other in inhomogeneous spacetime and undergoing chaotic Mixmaster oscillations towards the singularity. We demonstrate that for couplings larger than some threshold value, two Mixmaster spatial points A, B, with A in the past of B, synchronize and thereby proceed in perfect unison towards the initial singularity. We further show that there is a Lyapunov function for the synchronization dynamics that makes different spatial points able to synchronize exponentially fast in the past direction. We provide an elementary proof of how an arbitrary spatial point responds to the mean field created by the oscillators, leading to their direct interaction through spontaneous synchronization. These results ascribe a clear physical meaning of early-time synchronization, the two BKL maps corresponding to two distinct oscillating spatial points converge to each other and become indistinguishable at the end of synchronization, and suggest that the universe organizes itself gradually through simpler, synchronized, states as it approaches the initial singularity. A discussion of further implications of early-time inhomogeneous Mixmaster synchronization for the horizon problem and the behavior of entropy is also provided.

Topological Methods, Global Existence Problems, and Spacetime Singularities / 328

Geodesics near a curvature singularity of stationary and axially symmetric space-times

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In this work we study the local behavior of geodesics in the neighborhood of a curvature singularity contained in stationary and axially symmetric space-times. Apart from these properties, the metrics we shall focus on will also be required to admit a quadratic first integral for their geodesics. In particular, we search for the conditions on the geometry of the space-time for which null and time-like geodesics can reach the singularity. These conditions are determined by the equations of motion of a freely-falling particle. We also analyze the possible existence of geodesics that do not become incomplete when encountering the singularity in their path. The results are stated as criteria that depend on the inverse metric tensor along with conserved quantities such as energy and angular momentum. As an example, the derived criteria are applied to the Plebanski-Demianski class of space-times. Lastly, we propose a line element that describes a wormhole whose curvature singularities are, according to our results, inaccessible to causal geodesics.

Unusual and New Types of Gamma-Ray Bursts

Unusual and New Types of Gamma-Ray Bursts / **305**

A possible link between normal long GRBs and a short GRB 200826A

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We propose a possible model of explaining recently discovered short GRB 200826A, unifying this event and normal long GRBs from collapsars. The turbulent nature of relativistic jets is responsible for inhomogeneity, resulting in a lot of patchy emission regions in the jet. If such an emission patch is viewed, a short single pulse is observed, while the usual long GRBs are observed when several/many of them are along the line of sight.

Unusual and New Types of Gamma-Ray Bursts / **534**

A genuinely short GRB from massive-star collapse

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On 26th August 2020,gamma-ray burst monitor onboard Fermi satellite was triggered by an unprecedented genuinely short burst GRB 200826A which is totally different from either of the previous strange ones. The undoubtedly short duration and its proximity, together with large f parameter, prove its genuine short-duration fact. For more metrics, we immediately exploit the prompt and afterglow data as fully as we can with and without redshift info. In addition to spike profile huge f value and other normal spectral behaviors as a short GRB, GRB 200826A does show an incredible similarity to Type II GRBs. What need to settle down is to figure out mechanism behind it, a white dwarf-involved systema GRB in "supranova" scenario,dirty medium block the most of the radiation or Parameter-modified model of differential-rotation-induced magnetic bubbles of a new-born magnetar? we still don't know.

Unusual and New Types of Gamma-Ray Bursts / **533**

Ultra long GRBs: current and future prospects

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We present the current state of the art of observational properties of the class of ultra-long GRBs and discuss of any potential method to classify them as ultra-long while the prompt emission is still active. We also discuss their detectability in light of the new experiments currently planned.

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Fermi-GBM and Swift-BAT detection of an extragalactic magnetar giant flare

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We present the observations of the first unambiguous magnetar giant flare from outside of our galactic neighborhood. Initially, GRB 200415A was identified as a short GRB, but upon further investigation and observations from additional instruments, we concluded this event was a giant flare from a magnetar located in the Sculptor galaxy, 3.5 Mpc away. The GBM lightcurve shows very fast (shorter than 0.1 ms) variability, which is unprecedented among both magnetar giant flare and GRB observations. Based on the MeV range photons that Fermi-GBM detected, we find proof of relativistic expansion. We will show the detailed data analysis, the fast spectral evolution and the interpretation of this unique event.

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Magnetar Giant Flare Origin of Gamma-Ray Burst

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The giant flares of soft gamma-ray repeaters (SGRs) have long been proposed to contribute to at least a subsample of the observed short gamma-ray bursts (GRBs). We performed a comprehensive analysis of the high-energy data of the bright short GRB 200415A, which was located close to the Sculptor galaxy. Our results suggest that a magnetar giant flare provides the most natural explanation for most observational properties of GRB 200415A, including its location, temporal and spectral features, energy, statistical correlations, and high-energy emissions. On the other hand, the compact star merger GRB model is found to have difficulty reproducing such an event in a nearby distance.

Future detections and follow-up observations of similar events are essential to firmly establish the connection between SGR giant flares and a subsample of nearby short GRBs.

Unusual and New Types of Gamma-Ray Bursts / 582

Discovery and confirmation of the shortest gamma ray burst from a collapsar

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Gamma-ray bursts (GRBs) are among the brightest and most energetic events in the universe. The duration and hardness distribution of GRBs has two clusters, now understood to reflect (at least) two different progenitors. Short-hard GRBs (SGRBs; T90 <2 s) arise from compact binary mergers, while long-soft GRBs (LGRBs; T90 >2 s) have been attributed to the collapse of peculiar massive stars (collapsars). The discovery of SN 1998bw/GRB 980425 marked the first association of a LGRB with a collapsar and AT 2017gfo/GRB 170817A/GW170817 marked the first association of a SGRB with a binary neutron star merger, producing also gravitational wave (GW). Here, we present the discovery of ZTF20abwysqy (AT2020scz), a fast-fading optical transient in the Fermi Satellite and the InterPlanetary Network (IPN) localization regions of GRB 200826A; X-ray and radio emission further confirm that this is the afterglow. Follow-up imaging (at rest-frame 16.5 days) reveals excess emission above the afterglow that cannot be explained as an underlying kilonova (KN), but is consistent with being the supernova (SN). Despite the GRB duration being short (rest-frame T90 of 0.65 s), our panchromatic follow-up data confirms a collapsar origin. GRB 200826A is the shortest LGRB found with an associated collapsar; it appears to sit on the brink between a successful and a failed collapsar. Our discovery is consistent with the hypothesis that most collapsars fail to produce ultra-relativistic jets.

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Off-axis jet scenario for early afterglow emission of low-luminosity gamma-ray burst GRB 190829A

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Recently, ground-based Imaging Atmospheric Cherenkov Telescopes, such as MAGIC and H.E.S.S., have reported the detection of very-high-energy (VHE) gamma-rays from three gamma-ray bursts (GRB 180720B, 190114C, 190829A). One of them, GRB 190829A, was triggered by the Swift satellite, and about 20000 s after the burst onset the VHE gamma-ray emission was detected by H.E.S.S. with ~ 5 sigma significance. This event had more unusual features than the other VHE gamma-ray events. First, it had much smaller isotropic equivalent gamma-ray energy than typical long gamma-ray bursts and is classified as low luminosity GRB. Second, early X-ray and optical afterglow emission showed a rising part and simultaneously peaked at about 1400 s. We propose an off-axis jet scenario that explains these observational results. In this model, the relativistic beaming effect is responsible

for the apparently small isotropic gamma-ray energy and spectral peak energy. Using a jetted afterglow model, we find that the narrow jet, which has the initial Lorentz factor of 350 and the initial jet opening half-angle of 0.015 rad, viewed off-axis can describe the observed achromatic behavior in the X-ray and optical afterglow. Another wide, baryon-loaded jet is necessary for the later-epoch X-ray and radio emissions. Also, we suggest that some of low luminosity GRBs could be explained by off-axis jet scenario.

Variation of the Fundamental Constants, Tests of the Fundamental Symmetries and Probes of the Dark Sector

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Direct limits for scalar field dark matter from a gravitational-wave detector

Authors: Sander Vermeulen[1]; et al. see full author list on Arxiv: https://arxiv.org/abs/2103.03783[None]

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We report on the first direct search for low-mass scalar field dark matter utilising a gravitational-wave detector. We set new upper limits for the coupling constants of scalar field dark matter as a function of its mass by excluding the presence of signals that would be produced through the direct coupling of this dark matter to the beamsplitter of the GEO600 interferometer. The new constraints improve upon bounds from previous direct searches by more than six orders of magnitude and are more stringent than limits obtained in tests of the equivalence principle by one order of magnitude.

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Linking the lithium problem and the H_0 tension: the gravitational constant at BBN

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The primordial abundance of lithium is still a subject of controversy, given the disagreement between numerical results and observational estimates. We show how this discrepancy can be undestood in the context of variation of fundamental constants at the epoch of Big Bang Nucleosynthesis. The variation of Newton's constant plays a crucial role. In particular, its interpretation in terms of additional relativistic degrees of freedom suggests an alleviation to the H_0 tension.

Variation of the Fundamental Constants, Tests of the Fundamental Symmetries and Probes of the Dark Sector / 1071

Probing the TeV scale and beyond via particle electric dipole moments

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Revolutionary progress is underway in the ability to detect CP-violating electric dipole moments (EDMs) of particles such as the electron and proton. I will describe recent searches for the electron EDM that are already sensitive to new physics at scales around 10 TeV. I will also discuss new techniques projected to soon enable orders of magnitude further improvement in the field.

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Variation of the fundamental constants, violation of the fundamental symmetries and dark matter

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Interaction between the standard model matter and low mass scalar dark matter field may be presented as variation of the fundamental constant while interaction with an axion-like field leads to oscillating effects of violation of the fundamental symmetries including electric dipole moments. New interactions mediated by hypothetical particles produce effects, which may be observed in atomic experiments. Our aim is to find enhanced effects, perform their calculations, motivate new experiments and provide interpretation of their results.

Another direction is accurate relativistic atomic many-body calculations of the effects of dark matter produced in underground laboratories. Our recent calculation of the ionization of atoms by absorption of scalar particles gives cross section, which is several orders of magnitude smaller than that calculated by other authors. The reason is that the traditional plain wave approximation for outgoing electron violates orthogonality condition with bound electron wave function which plays crucial role in the zero multipolarity transtions. Such plain wave non-relativistic approximation also gives wrong result (strongly underestimate cross section) for electron ionization by WIMP scattering.

Finally, we consider quark nugget model of dark matter and observable effects of quark nuggets.

New results of our group on these topics published recently in PRL, PRD, PRA, JHEP and arxiv papers will be presented.

Variation of the Fundamental Constants, Tests of the Fundamental Symmetries and Probes of the Dark Sector / 737

Towards the test of local Lorentz invariance with $^{172}Yb^{+}$ ion Coulomb crystals

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We report on our progress of an improved test of local Lorentz invariance (LLI) in the electron-photon sector using the highly sensitive meta-stable electronic F-state of the ^{172}Yb$^+$ ion 1.

The Zeeman structure of the F-state contains two orthogonally oriented orbitals which gives us access to test LLI violation. To suppress the magnetic field noise during the measurement, we mix the Zeeman substates via dynamical decoupling 2. This method allows us to profit from a long coherence time and high spatial homogeneity of the radio-frequency source used for interrogation, which enables easy up-scaling of the ion number.

In preparation of this measurement, we demonstrated the first coherent excitation to the F-state via the highly forbidden electric octupole (E3) transition with a reduced uncertainty of less than 10 Hz 3, improving on earlier measurements 4 by about 5 orders of magnitude. Recently, we observed a coherence time of 1.5 s when applying the dynamical decoupling sequence in the electronic ground state of Yb$^+$.

With these results, we are ready to perform the first test of LLI with a single Yb$^+$ ion, after which we will scale it up to $\approx$ 10 ions to improve on the current best upper bound 5.

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5 C. Sanner et al., *Nature* **567**, 204-208 (2019).

Variation of the Fundamental Constants, Tests of the Fundamental Symmetries and Probes of the Dark Sector / 835

Towards precision tests of fundamental physics using a highly-charged-ion optical clock

Authors: Steven A. King[1]; Lukas J. Spieß[1]; Peter Micke[1]; Alexander Wilzewski[1]; Erik Benkler[1]; Tobias Leopold[1]; José R. Crespo López-Urrutia[2]; Piet O. Schmidt[1]

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Precision measurements of isotope shifts could reveal new physics beyond the Standard Model. Measurements of these shifts for two transitions in at least three pairs of isotopes for a given element allows the construction of a so-called King plot, where deviations from linear behaviour could point to a previously unknown boson mediating a fifth fundamental force that couples electrons to neutrons. Adding more transitions to the analysis allows suppression of nuclear effects which could themselves lead to nonlinearity, and also the uncertainties in the experimentally-determined isotope masses. Unfortunately, singly-charged and neutral atoms generally do not offer enough additional narrow electronic transitions that can be measured with the required precision and accuracy.
Interest in highly charged ions (HCI) has intensified over recent years due to their high sensitivity to fundamental physical effects, but a reduced sensitivity to the kinds of external electric fields that cause some of the leading systematic uncertainties for modern optical atomic clocks. Recently, we demonstrated the first quantum logic spectroscopy of an HCI, namely boron-like Ar13+ (Ar XIV). Using novel laser cooling techniques, the equivalent temperature of the HCI can be reduced to less than 200 μK in each of its motional modes. These breakthroughs finally unleashed the full potential

of HCI for ultra-high precision spectroscopy at the level of state-of-the-art optical atomic clocks. We will present a brief overview of our experiment, along with an overview of our progress towards spectroscopy of highly charged calcium ions, with expected relative frequency uncertainties below the 1e-15 level. As this clock transition has a very different character to those already measured in singly-charged calcium, this has the potential to improve the bounds on the coupling strength of any potential fifth force by several orders of magnitude.

Variation of the Fundamental Constants, Tests of the Fundamental Symmetries and Probes of the Dark Sector / 430

Zero-dead-time Differential Spectroscopy Beyond the Laser Coherence Limit

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To avoid ambiguity in the phase readout, optical clock measurements are constrained to operate with an interrogation time that is short enough that the accumulated optical local oscillator (OLO) phase wander remains within ±π/2 radians. This constraint, known as the coherence limit, has motivated a variety of techniques to allow interrogations beyond this limit. A recent proposal has been put forward to take advantage of the different clock frequencies of two distinct optical clocks, affording interrogation which extends beyond the coherence limit 1.

In this scheme, the two clock interrogations are synchronized with each other, and their OLOs are locked together by means of an optical frequency comb. By quickly feeding forward the results of phase measurements from one clock (an Yb optical lattice clock), the interrogation time of the other (an Al^+ single-ion clock) can be extended by a factor of the frequency ratio of the clocks. By sending phase corrections from both Yb clocks in a zero-dead-time configuration, interrogation can be extended much further, with only technical limitations remaining. With this configuration, we realize quantum-projection-noise-limited clock instability for interrogation times of several seconds.

We have demonstrated a novel and highly versatile interrogation protocol which has allowed the achievement of a record inter-clock instability representing a nearly order-of-magnitude improvement over our previous measurement. This level of performance can facilitate the achievement of 10^{-19} decade ion clock instabilities in the course of a single day of measurement and is extendable to a wide variety of inter-clock comparisons, including systems with high sensitivities to variation in the fundamental constants, such as the Yb^+ E3 clock.

1 Hume, D. B., & Leibrandt, D. R. (2016). Probing beyond the laser coherence time in optical clock comparisons. Physical Review A, 93, 032138. https://doi.org/10.1103/PhysRevA.93.032138

Variation of the Fundamental Constants, Tests of the Fundamental Symmetries and Probes of the Dark Sector / 891

Test of gravitational redshift with optical lattice clocks and their applications to relativistic geodesy

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A clock in a higher place ticks faster than one in a lower place in accordance with Einstein's general relativity. A pair of atomic clocks serve as a quantum sensor for the gravitational potential. The relativistic effects of the 450-meter height difference of a broadcasting tower, Tokyo Skytree, were measured using a pair of optical lattice clocks to verify the general theory of relativity. The 10^{-18}-level of uncertainties in the comparison of the clocks verified Einstein's general relativity with a fractional uncertainty of ~10^{-5}. Field operation of such transportable system can extend the role of atomic clocks not only to timekeeping but also to their application as gravitational potential meters to monitor spatial and temporal variations in geopotential.
In this presentation, we introduce the development of a transportable optical lattice clock and the precise measurement of the gravitational redshift in Tokyo Skytree. In addition, we will introduce our recently developed on-vehicle optical lattice clocks, which will make it a more practical tool for relativistic geodesy.

Variation of the Fundamental Constants, Tests of the Fundamental Symmetries and Probes of the Dark Sector / 691

Testing Fundamental Physics and Searching for Dark Matter using Precision Resonators and Oscillators

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In this work we present our latest results using photonic, atomic, and mechanical oscillators to undertake experimental searches for dark matter and tests of fundamental physics. First, we will focus on our recent results on searching for scalar dark matter through frequency comparisons, due to oscillations in fundamental constants 1. Next we will discuss upconverting low mass axion signals to microwave frequencies, a proof of principle experiment was undertaken and will be presented 2. Finally, we will discuss on how our technology can be used for other fundamental experiments, such as the search for high frequency gravitational waves 3 and tests of Lorentz invariance violations.
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3 M Goryachev et. al. arXiv:2102.05859 [gr-qc]

Variation of the Fundamental Constants, Tests of the Fundamental Symmetries and Probes of the Dark Sector / 898

Precision isotope-shift spectroscopy in neutral Yb and joint Yb/Yb^+ King-plot analysis

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The isotope shifts (IS) in the frequency of an atomic transition are approximately linearly correlated with the shifts in another transition. This linearity is reflected in the so-called King-plot analysis. It has been suggested to search for deviations from linearity as a way to probe beyond-Standard-Model

interactions mediated by light bosons 1. These searches require availability of precision IS data in a chain of isotopes of a given element. In a recent report on precision spectroscopy in a pair of Yb^+ transitions 2, a large nonlinearity was observed in the King-plot, that primarily arises due to the quadratic field shift 2, or the influence of the nuclear deformation on the field shift 3. Further availability of precision IS data in the same element is crucial to check modeling of the cause of the nonlinearity 3, and potentially separate within Standard-Model effects from possible new physics contributions to the nonlinearity 4.
We will discuss an experiment involving precision spectroscopy of the $^1S_0 - ^1D_2$ optical transition in neutral Yb, in order to determine the IS in the naturally abundant, nuclear-spin zero Yb isotopes. We will present our preliminary experimental results, and show a joint King-plot of our data combined with those on Yb^+, that reveals an order of magnitude larger nonlinearity, compared to that of the Yb^+ work.

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3 Saleh O. Allehabi, V. A. Dzuba, V. V. Flambaum, and A. V. Afanasjev. Phys. Rev. A 103, L030801 (2021).
4 J. C. Berengut, C. Delaunay, A. Geddes, and Y. Soreq, Phys. Rev. Research 2, 043444 (2020)

Variation of the Fundamental Constants, Tests of the Fundamental Symmetries and Probes of the Dark Sector / 92

Atomic clocks sensitive to variation of the fine structure constant.

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The hypothetical variation of the fine structure constant alpha can be studied in a laboratory by comparing two exceptionally accurate atomic clocks over a long period of time. It is especially convenient when the two clock transitions, sensitive to the variation of alpha are found in the same atom. We identify two such systems, the neutral ytterbium and gold atoms. The Yb I atom has at least three clock transitions between ground state and the metastable states at E=17288, 19710, and 23188 cm-1, and Au I has two transitions between ground state and metastable states at E=9161 and 39535 cm-1. While first of these transitions in Yb is already used as a clock transition of extremely high accuracy, four new proposals have all features of atomic clock transitions with good prospects for very accurate measurements. They also have large and different sensitivity to the variation of the fine structure constant. In particular, clock transitions in Au have the largest sensitivity found so far in neutral systems.

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Studies of Exotic Physics with Antiprotons and Protons

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The Standard Model of particle physics is both incredibly successful and glaringly incomplete. Among the questions left open is the striking imbalance of matter and antimatter in our universe, which inspires experiments to compare the fundamental properties of matter/antimatter conjugates with high precision. The BASE collaboration at the antiproton decelerator of CERN is performing such high-precision comparisons with protons and antiprotons. Using advanced cryogenic particle traps, we have performed the most precise measurement of the proton-to-antiproton charge-to-mass ratio with a fractional uncertainty of 69 parts per trillion 1. In another measurement, we have invented a novel spectroscopy method, which allowed for the first ultra-high precision measurement of the antiproton magnetic moment with a fractional precision of 1.5 parts in a billion 2. Together with our recent measurement of the proton magnetic moment 3 this improves the precision of previous experiments 4 by more than a factor of 3000. A time series analysis of this recent magnetic moment measurement furthermore enabled us to set first direct constraints on the interaction of antiprotons with axion-like particles (ALPs) 5, and most recently, we have used our ultra-sensitive single particle detection systems to derive narrow-band constraints on the conversion of ALPs into photons 6. In my talk I will review the recent achievements of BASE and will outline strategies to further improve our high-precision studies of matter-antimatter symmetry. This outlook will involve the implementation of sympathetic cooling of antiprotons using quantum logic methods, and the development of the transportable antiproton trap BASE-STEP.

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Varying fundamental constants and dark energy in the ESPRESSO era

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The observational evidence for the recent acceleration of the universe shows that canonical theories of cosmology and particle physics are incomplete and that new physics is out there, waiting to be discovered. A compelling task for astrophysical facilities is to search for, identify and ultimately characterize this new physics. I will present very recent developments in tests of the stability of nature's fundamental constants, as well as their impact on physics paradigms beyond the standard model. Specifically I will discuss new observational constraints at low redshifts and at the BBN epoch, and highlight their different implications for canonical quintessence-type models and for non-canonical string-theory inspired models. Finally I will also present new forecasts, based on realistic simulated data, of the gains in sensitivity for these constraints expected from ELT-HIRES, on its own and in combination with Euclid.

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New bounds on macroscopic scalar-field topological defects from non-transient signatures due to environmental dependence and spatial variations of the fundamental constants

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We point out that in models of macroscopic topological defects composed of one or more scalar fields that interact with standard-model fields via scalar-type couplings, the back-action of ambient matter on the scalar field(s) produces an environmental dependence of the fundamental constants

of nature, as well as spatial variations of the fundamental constants in the vicinity of dense bodies such as Earth due to the formation of a "bubble-like" defect structure surrounding the dense body. In sufficiently dense environments, spontaneous symmetry breaking may be inhibited altogether for ϕ^2 interactions, potentially delaying the cosmological production of topological defects to rather late times. We derive bounds on non-transient variations of the fundamental constants from torsion-pendulum experiments that search for equivalence-principle-violating forces, experiments comparing the frequencies of ground- and space-based atomic clocks, as well as ground-based clocks at different heights in the recent Tokyo Skytree experiment, and measurements comparing atomic and molecular transition frequencies in terrestrial and low-density astrophysical environments. Our results constrain the present-day mass-energy fraction of the Universe due to a network of infinite domain walls produced shortly after the BBN or CMB epochs to be $\Omega_{\mathrm{walls},0} \ll 10^{-10}$ for the symmetron model with a ϕ^4 potential and ϕ^2 interactions, improving over CMB quadrupolar temperature anisotropy bounds by at least 5 orders of magnitude. Our newly derived bounds on domain walls with ϕ^2 interactions via their effects of non-transient variations of the fundamental constants are significantly more stringent than previously reported clock- and cavity-based limits on passing domain walls via transient signatures and previous bounds from different types of non-transient signatures (by about 10 orders of magnitude for wall thicknesses comparable to the size of Earth), under the same set of assumptions.

Reference: [Stadnik, PRD **102**, 115016 (2020)]

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Dark matter searches with atomic and nuclear clocks

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The extraordinary advances in quantum control of matter and light have been transformative for precision measurements enabling probes of the most basic laws of Nature to gain fundamental understanding of the physical Universe. The development of atomic clocks with systematic uncertainties in the 10^{-18} range enables searches for the variation of fundamental constants, dark matter, and violations of Lorentz invariance. I will discuss recent advances in theory of clocks based on highly-charged ions (HCIs) including the detailed investigation of optical clocks based on Cf^{15+} and Cf^{17+} 1. Development of a broadly applicable approach based on a parallel (MPI) configuration interaction code that drastically increases the ability to predict the properties of complex atoms accurately is also discussed. We recently used this approach to evaluate the electronic bridge process in $^{229}Th^{35+}$ for a laser excitation of a nuclear transition 2. I will also report a release of the new online portal for high-precision atomic data and computation 3 and discuss future efforts in adding HCI data.

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2 S. G. Porsev, C. Cheung, M. S. Safronova, arXiv:2105.00512, submitted to Quantum Science and Technology (2021).
3 Parinaz Barakhshan, Adam Marrs, Bindiya Arora, Rudolf Eigenmann, Marianna S. Safronova, Portal for High-Precision Atomic Data and Computation (version 1.0). University of Delaware, Newark, DE, USA. URL: https://www.udel.edu/atom.

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Axion Quark Nuggets and Matter-Antimatter asymmetry as two

sides of the same coin: theory, observations and future experimental searches

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In this talk I want to discuss the (unorthodox) scenario when the baryogenesis is replaced by a charge segregation process in which the global baryon number of the Universe remains zero. In this, the so-called axion quark nugget (AQN) dark matter model the unobserved antibaryons come to comprise the dark matter in the form of dense nuggets. In this framework, both types of matter (dark and visible) have the same QCD origin, form at the same QCD epoch, and both proportional to one and the same fundamental dimensional parameter of the system, which explains how the two, naively distinct, problems could be intimately related, and could be solved simultaneously within the same framework. I specifically focus on several recent papers written with AMO (Atomic-Molecular-Optic), Nuclear physics and Astro-physics people to apply these generic ideas to several recent proposals: 1. on broadband strategy in the axion searches; 2. on daily modulations and amplifications generated by the AQN dark matter and how they can be studied; 3. on recently detected by Telescope Array the Mysterious Burst Events which are very distinct from conventional cosmic air showers.

The talk is based on several recent papers including:

D.Budker, V.V.Flambaum, X.Liang and A.Zhitnitsky,
"Axion Quark Nuggets and how a Global Network can discover them,"
Phys. Rev. D 101 no.4, 043012 (2020)
[arXiv:1909.09475 [hep-ph]].

A.~Zhitnitsky,
"The Mysterious Bursts observed by Telescope Array and Axion Quark Nuggets,"
Journal of physics G: Nuclear and Particle Physics (2021) [arXiv:2008.04325 [hep-ph]]

Variation of the Fundamental Constants, Tests of the Fundamental Symmetries and Probes of the Dark Sector / 977

Constraining modified gravity with quantum optomechanics

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In this talk, I will present some recent results on estimating the performance of quantum optomechanical sensors for searches of modified gravity. Specifically, I will show how we derive the best possible bounds that can be placed on Yukawa- and chameleon-like modifications to the Newtonian gravitational potential with a cavity optomechanical quantum sensor. We do so by modelling the effects from an oscillating spherical source on the optomechanical system from first-principles. To then estimate the sensitivity to chameleon-like modifications, we take into account the size of the optomechanical probe and quantify the resulting screening effect for the case when both the source and probe are spherical. Our results show that an optomechanical system in high vacuum could, in principle, further constrain the parameters of chameleon-like modifications to Newtonian gravity.

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Improved Limits for Violations of Local Position and Local Lorentz Invariance from Atomic Clock Comparisons

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Co-authors: Nils Huntemann [1]; Richard Lange [1]; Johannes Rahm [1]; Christian Sanner [1]; Hu Shao [1]; Burghard Lipphardt [1]; Christian Tamm [1]; Stefan Weyers [1]

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Searches for violations of Einstein's equivalence principle, such as tests of local Lorentz invariance and local position invariance, have become one of the leading applications of low-energy, high-precision experiments with laser-cooled atoms. In our laboratory, we operate atomic clocks based on the microwave ground state hyperfine splitting frequency of Caesium and optical clocks based on optical transitions of single trapped Ytterbium ions. The frequency ratio of an electric quadrupole and an electric octupole (E3) transition of Yb^+ has been determined with $3 \cdot 10^{-17}$ fractional uncertainty, improving upon previous measurements by an order of magnitude. Using two caesium fountain clocks, we measure the E3 transition frequency at 642 THz with 80 mHz uncertainty, the most accurate determination of an optical transition frequency to date. Repeated measurements of both quantities over several years are analyzed for potential violations of local position invariance 1. We improve by factors of about 20 and 2 the limits for fractional temporal variations of the fine structure constant to $1.0(1.1) \cdot 10^{-18}$/yr and of the proton-to-electron mass ratio to $-8(36) \cdot 10^{-18}$/yr. Using the annual variation of the Sun's gravitational potential at Earth, we improve limits for a potential coupling of both constants to gravity. Operating the two optical clocks both on the E3 reference transition enables an even more accurate comparison and allows us to improve previous limits on a Lorentz symmetry violation for electrons by two orders of magnitude 2.

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Very High Energy Gamma Rays

Very High Energy Gamma Rays / 365

First result of LHAASO: Implication for extreme particle accelerators

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The Large High Altitude Air Shower Observatory is a new-generation multi-component instrument for TeV-PeV gamma rays and TeV-EeV cosmic rays. Recently, LHAASO has published its first result on the discovery of 12 ultrahigh-energy (E>100TeV) gamma-ray sources at more than 7 sigma confidence level. Among them, there are famous sources like the Crab Nebula, the Cygnus Cocoon, as well as new sources without TeV counterpart. The discovery indicates the prevalence of PeV particle accelerators in our Galaxy.

Very High Energy Gamma Rays / 1065

Insights into the the Galactic Center environment from VHE gamma-ray observations with ground-based facilities

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The dynamic center of our galaxy is known to host a source of TeV gamma rays since the very beginning of the 21st century and a link to the supermassive black hole at the Galactic Center has been speculated on ever since. But not only the point-like source, spatially coincident with SgrA*, can be observed from the ground using the Imaging Air Cherenkov Telescope technique, but also diffuse emission from the vicinity, spanning more than one degree along the Galactic plane and emitting a remarkably hard energy spectrum, reaching energies well beyond 10 TeV.

Recent observations by the H.E.S.S., MAGIC and VERITAS facilities have enabled detailed studies of the dynamics of high-energy particles in Galactic Center region that indicate a link between the diffuse component and central point-like gamma-ray source. These studies suggest the presence of a powerful cosmic-ray accelerator in close proximity to SgrA*. This could potentially even be one of the long-sought-after Galactic PeVatrons, needed in order to explain the cosmic-ray spectrum up to the the feature called 'knee' at around 10^{15} eV.

Very High Energy Gamma Rays / 1066

The TAIGA experiment

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The Tunka Advanced Instrument for Gamma-ray and cosmic ray Astrophysics (TAIGA) is a hybrid experiment for the measurement of Extensive Air Showers (EAS) with good spectral resolution in the TeV to PeV energy range. In this domain, the long-sought Pevatrons can be detected. Currently the hybrid TAIGA detector combines two wide angle shower front Cherenkov light sampling timing arrays (HiSCORE and Tunka-133), two ~4m class, ~10° aperture Imaging Air Cherenkov Telescopes (IACTs) and ~240 m² surface and underground charged particle detector stations. Our goal is to introduce a new hybrid reconstruction technique, combining the good angular and shower core resolution of HiSCORE with the gamma-hadron separation power of imaging telescopes. This approach allows to maximize the effective area and simultaneously to reach a good gamma-hadron separation at low energies (few TeV). At higher energies, muon detectors are planned to enhance gamma-hadron separation. During the commissioning phase of the first and second IACT, several sources were observed. First detections of known sources with the first telescope show the functionality of the TAIGA IACTs. Here, the status of the TAIGA experiment will be presented, along with first results from the current configuration.

Very High Energy Gamma Rays / 1052

Probing Lorentz Invariance Violations with the MAGIC telescopes

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Abstract: Lorentz Invariance Violation (LIV), as predicted by several quantum gravity models, can manifest in very tiny energy-dependent gradients of light speed in vacuum, dispersing time of flight (ToF) along the path from source to observer for photons of different energy. Despite being suppressed by the Planck energy, LIV effects in the ToF of photons can be amplified by huge cosmological distances. Gamma-Ray Bursts (GRBs) are therefore perfect candidates for detecting LIV. On January 14, 2019, the most energetic photons ever observed from a gamma-ray burst were recorded by the Major Atmospheric Gamma Imaging Cherenkov (MAGIC) telescopes. GRB190114C was used to probe LIV effects in the ToF of gamma rays. From a set of conservative assumptions on the possible intrinsic spectral and temporal evolution, competitive lower limits on the quadratic leading order modification of the speed of light were obtained. The first LIV test ever performed on a gamma-ray burst signal at TeV energies has been performed, which will serve as a stepping stone to future studies.

What Can We Learn from a Growing Sample of Fast Radio Bursts?

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Searching for Lensed Fast Radio Bursts with CHIME/FRB

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Gravitational lensing of fast radio bursts (FRBs) on timescales of nanoseconds to milliseconds is sensitive to the presence of massive bodies up to $100 M_{\odot}$–including brown dwarves, rogue stars, and exotic objects like MACHOs or primordial black holes. The CHIME telescope, a widefield low-frequency radio interferometer operating over the frequency range of 400-800 MHz, detects several FRBs every day, and I will describe the status of our search for a lensed FRB. Our coherent time-domain search uses data from the CHIME/FRB baseband system and a procedure similar to geodetic VLBI cross-correlation. This allows us to resolve images with 10^{-8} to 10^{-1} second lensing delays, and disentangles intrinsic FRB morphology from genuine multipath propagation induced by a lens.

What Can We Learn from a Growing Sample of Fast Radio Bursts? / 860

Fast Radio Burst detections and discoveries with Apertif, and LOFAR

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Apertif, the wide-field receiver system currently operating on the Westerbork Synthesis Radio Telescope, offers an unprecedented combination of sensitivity and speed at 1.4 GHz. Its time-domain supercomputing back end (ARTS) performs real-time detection and localisation of Fast Radio Bursts (FRBs). In stand-alone mode, this SKA pathfinder is already the globally most productive 1.4 GHz FRB machine. It is, furthermore, directly connected to LOFAR. That unique combination of two world-class telescopes has recently allowed us to detect the same, repeating FRB over more than an order of magnitude in wavelength, down to 120 MHz, for the first time.

Fast Radio Bursts must be powered by uniquely energetic emission mechanisms. Identifying their physical nature arguably requires such good localisation of more detections, and broadband studies enabled by real-time alerting. We will describe ALERT, the Apertif FRB survey. It has discovered two dozen new FRBs so-far, each localised to 0.4-10 sq. arcmin. We will present our latest discoveries and detections of one-off and repeating FRBs. Four FRBs cut through the halos of M31 and M33.

We demonstrate that Apertif can localise one-off FRBs with an accuracy that maps magneto-ionic material along such well defined lines of sight. The combination of detection rate and localisation accuracy from these Apertif/ARTS FRBs thus marks a new phase in which a growing number of bursts can be used to probe our Universe.

Using simultaneous Apertif and LOFAR multi-wavelength observing, we next showed that repeating FRB 20180916B emits down to 120 MHz, and that its activity window is both narrower and earlier at higher frequencies. Our detections establish that some FRBs live in clean environments that do not absorb or scatter low-frequency radiation, a prerequisite for future FRB applications to cosmology.

What Can We Learn from a Growing Sample of Fast Radio Bursts? / 619

Localising FRBs with CHIME/FRB Outriggers

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The Canadian Hydrogen Intensity Mapping Experiment (CHIME) telescope has detected more than 1,000 fast radio bursts (FRBs) with its dedicated transient-search backend (CHIME/FRB). With the goal of localising 1,000 bursts to ~50mas precision in less than two years, CHIME/FRB is now expanding to include a dedicated very long baseline interferometry (VLBI) array of transcontinental outrigger stations. In this talk, I will motivate the Outrigger project and its goals, discuss how we are overcoming the challenges of low-frequency VLBI, and give a project update and timeline.

What Can We Learn from a Growing Sample of Fast Radio Bursts? / 823

A search for periodicity in multi-component FRB profiles

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A millisecond periodicity in the signal of fast radio bursts (FRBs) has long been searched for, as such a signal could be present if these sources are rapidly rotating neutron stars. Here we report a periodic separation of 218 ms at a 6-sigma significance in the single components of a 3-s long FRB detected by the CHIME/FRB experiment. With its nine or more single components, this FRB represents an outlier in the FRB population. In addition, CHIME/FRB has detected at least two other FRBs showing more than five separate components in their pulse profiles with hints of periodic separations, albeit not as significant as in the first case. I will present the results on these remarkable sources and discuss possible models to explain the observed signal.

What Can We Learn from a Growing Sample of Fast Radio Bursts? / 848

The First CHIME/FRB Catalog

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Over the past decade, population studies of fast radio bursts (FRBs) have been challenging to undertake due to the small number of known sources detected with different telescopes and detection pipelines. However, the Canadian Hydrogen Intensity Mapping Experiment Fast Radio Burst (CHIME/FRB) project has now detected a large sample of FRBs which is well suited for such studies. The first CHIME/FRB catalog contains 474 non-repeating sources and 61 bursts from 18 previously reported repeating sources observed in the frequency range of 400-800 MHz. Detailed characterization of burst properties has revealed differences in morphology between repeating and non-repeating sources. Additionally, absolute calibration of selection effects has enabled measurements of the all-sky FRB rate and source-counts distribution and has provided evidence for a large fraction of the FRB population having scattering times greater than 10 ms (at 600 MHz). In this talk, I will present an overview of the catalog and discuss results from associated analyses. I will also present preliminary results from a population synthesis study assessing the astrophysical implications of the existence of a large population of highly scattered FRBs.

What Can We Learn from a Growing Sample of Fast Radio Bursts? / 89

Fast radio bursts and their high-energy counterpart from magnetar magnetospheres

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The recent discovery of a Galactic fast radio burst (FRB) occurring simultaneously with an X-ray burst (XRB) from the Galactic magnetar SGR J1935+2154 implies that at least some FRBs arise from magnetar activities. We propose that FRBs are triggered by crust fracturing of magnetars, with the burst event rate depending on the magnetic field strength in the crust. Crust fracturing produces Alfvén waves, forming a charge starved region in the magnetosphere and leading to non-stationary pair plasma discharges. An FRB is produced by coherent plasma emission due to nonuniform pair production across magnetic field lines. Meanwhile, the FRB-associated XRB is produced by the rapid relaxation of the external magnetic field lines. In this picture, the sharp-peak hard X-ray component in association with FRB 200428 is from a region between adjacent trapped fireballs, and its spectrum with a high cutoff energy is attributed to resonant Compton scattering. The persistent X-ray emission is from a hot spot heated by the magnetospheric activities, and its temperature evolution is dominated by magnetar surface cooling. Within this picture, magnetars with stronger fields tend to produce brighter and more frequent repeated bursts.

What Can We Learn from a Growing Sample of Fast Radio Bursts? / 475

High energy observations of FRBs

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The origin of Fast Radio Bursts (FRBs) remains a mystery even as we are collecting important roadsigns that point towards preferred source models. A key piece of the puzzle is the search for their multi-wavelength counterparts. Many observations at high energies of FRB sources have been performed to date, but two recent discoveries perhaps provide the most information: the detection last year of a FRB-like event from the Galactic magnetar SGR 1935+2154 with a simultaneous X-ray burst points to a magnetar origin for some FRBs, but also shows that FRB-like emission can be accompanied by prompt high-energy emission. Second, the recent discovery by CHIME/FRB of a nearby FRB source associated with a M81 globular cluster at 3.6 Mpc, FRB 20200120E, both perhaps points away from a magnetar origin and allows us to probe much deeper for high-energy counterparts than for previously known, much more distant FRB sources. In this talk I will review the high-energy observations of FRB sources performed to date, present the most recent observations of FRB 20200120E, and discuss what the resulting limits can tell us about the nature of FRBs.

What Can We Learn from a Growing Sample of Fast Radio Bursts? / 956

The long-term periodicities in FRB burst times.

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Fast Radio Bursts (FRBs) are extremely energetic, millisecond-duration events of unknown origin. Some FRB sources emit repeat bursts, which offer great opportunities for follow-up observations. The Canadian Hydrogen Intensity Mapping Experiment (CHIME), with 1024 beams observing the sky simultaneously has increased the number of known repeating FRBs by orders of magnitude. The regular daily exposure of the instrument facilitates the search of periodicity on the timescale of days. Regular searches of long-timescale periodicities are carried out on CHIME repeaters. Last year, we found a 16-day periodicity on our most active FRB source. I will present the current status of the long-term periodicity searches and review different observation properties and theories corresponding to this periodic source and how it would improve our understanding of the progenitor.

White Dwarf Explosions

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Type Ia Supernovae: Astrophysics and Cosmology

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I will review current cosmological applications of Type Ia Supernovae (SN Ia) to measure the Hubble constant and constrain the nature of dark energy, with an emphasis on the limiting factors in these measurements. I will describe how near-infared observations of SN Ia provide an alternate path for future supernova cosmology. Astrophysical systematic uncertainties arise from our lack of detailed understanding of the progenitors and explosion physics of SN Ia, and I will explore their potential implications for current and future surveys.

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Mass-Radius relation for magnetized white dwarfs from SDSS

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A large number of magnetized white dwarfs (WDs), with surface field strength generally less than 10^9 G, identified from wide-field surveys have helped us to understand their physical and chemical properties and the effect of magnetic field strength (B) on them. Though these weaker fields are not expected to modify their properties significantly, it is an excellent step for probing the impact of higher fields on the stellar structure. Observationally, it is very difficult to detect highly magnetized WDs directly, but the presence of over-luminous Type Ia supernovae has indirectly given evidence for their existence, since their progenitors are proposed to be super-Chandrasekhar (M$> 1.4M_{\odot}$) mass WDs . In recent work, we derived the mass-radius (M—R) relation for a sample of magnetized WDs, identified from SDSS data release 7 with B ranges between 1 and 773 MG. Our results show excellent agreement with the theoretical M—R relation derived by assuming a lower surface B and a constant temperature from the center to the core-envelop interface. Hence, we propose that our model can be further extrapolated to higher surface fields, which may indicate the existence of super-Chandrasekhar mass WDs at higher fields.

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Multidimensional simulations of Type Ia supernovae

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Despite substantial progress in theoretical modeling and numerical simulations over the past years, our understanding of the physical mechanism of Type Ia supernovae remains incomplete. This has two main reasons. (i) The progenitor systems from which these explosions arise have not been identified, and therefore the initial conditions for the explosion simulations are uncertain. (ii) Modeling the explosion stage itself is a severe multi-scale multi-physics challenge and relies on assumptions and approximations.
Some of these approximations could be mitigated with multidimensional hydrodynamical simulations. They form a cornerstone of a consistent modelling pipeline that follows a progenitor model over explosion and nucleosynthesis to the formation of observables. By avoiding tuneable parameters, this approach facilitates a direct comparison of model predictions with astronomical data and conclusions on the validity of the assumed progenitor scenarios. I will describe the construction and the application of such a pipeline of multidimensional models and discuss achievements and shortcomings of current models of Type Ia supernovae.

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The Sub-Chandrasekhar Mass Pathway to Type Ia Supernovae

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Type Ia supernovae (SNe) are some of the most common cosmic transients, yet their progenitors are still not known. I will discuss the sub-Chandrasekhar mass pathway to these explosions, known as the double detonation scenario, where a White Dwarf (WD) is able to explode below the Chandrasekhar mass limit through the aid of an accreted helium shell. An ignition of this helium can send a shock wave into the center of the WD which, upon convergence, can ignite the core causing a thermonuclear runaway resulting in a Type Ia-like explosion. I will describe the hydrodynamic techniques I use to simulate these explosions as well as the radiation transport methods I use to translate the hydrodynamical output into synthetic light curves and spectra. Using these methods, I have calculated some distinct observational signatures that should be exhibited by double detonation explosions in both the photospheric and nebular phase. I will discuss the populations of SNe Type Ia which are consistent with these features. Lastly, I will present the first observed supernova, SN 2018byg, that exhibits the "smoking gun" signatures predicted, establishing the most direct evidence to date that there are multiple pathways through which WDs explode.

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Type Ia supernovae in the near infrared

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Infrared light curves of type Ia supernovae have been shown to provide an interesting pathway to extragalactic distances and a physical understanding of the explosions. The double peak provides interesting characteristics. The peak phases of the infrared relative to optical light curves gives an indication of the radiation physics and hints on why type Ia supernovae might be better standard candles than in the optical. The second peak holds information on the power source and the total mass in the explosion and also selects peculiar explosions.

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Supernova Cosmology in the 2020s

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Type Ia supernovae (SNe Ia) are excellent cosmological distance indicators. With them, one can precisely measure the expansion history of the Universe and constrain cosmological parameters such as the current expansion rate, H0, and the dark energy equation-of-state parameter, w. I will present new results from four current and upcoming surveys. The Swope Supernova Survey is a large, high-cadence, six-band Southern survey that will be extremely useful for measuring H0 and understanding the physics of SNe Ia. The Foundation Supernova Survey is currently the largest and best-calibrated low-redshift SN Ia sample. The recently started Young Supernova Experiment will obtain high-quality light curves for ~10^4 SNe Ia, anchoring the Hubble diagram, allowing for measurements of sigma_8, and being a training set for Vera C. Rubin Observatory data. The Roman Space Telescope, to be launched in the middle of this decade, will discover >10^4 SNe Ia to z ~ 3. I will discuss new analysis techniques, new tests of systematic biases, new cosmological results, and predictions for the state of SN cosmology in 2030.

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Type Ia Supernovae from Double Detonations in Merging Double White Dwarf Systems: The D6 Scenario

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Our theoretical understanding of the progenitors of Type Ia supernovae has undergone a revolution in the last decade, with sub-Chandrasekhar-mass scenarios quickly coming to the forefront of research. In this talk, I will focus on the "dynamically driven double-degenerate double-detonation" (D6) scenario, in which a double detonation on a sub-Chandrasekhar-mass white dwarf takes place during the merger of two white dwarfs. Our theoretical work shows that such explosions can accurately reproduce the entire observable range of Type Ia supernovae, from subluminous to overluminous. The scenario also predicts the possibility of a unique hypervelocity survivor. The discovery of three such stars makes this the only Type Ia supernova scenario that has been directly confirmed. This combination of theoretical and observational successes makes the D6 scenario an extremely promising channel to explain the bulk of Type Ia supernovae.

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Type Ia Supernova Explosions and their Nucleosynthesis: Constraints on Progenitors

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What the progenitors of Type Ia supernovae (SNe Ia) are, whether they are Chandrasekhar mass or sub-Chandrasekhar mass white dwarfs, has been matter of debate for decades. Various observational hints are supporting both models as the main progenitor. In this talk, I will review the explosion physics and their chemical abundance patterns of SNe Ia from these two classes of progenitors. I will discuss how the observational data of SNe Ia, their remnants, the Milky Way Galaxy and galactic clusters can help us to determine the essential features where numerical models of SNe Ia need to match.

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Type Ia explosions and progenitors: insights from spectral time series"

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The progenitor scenarios of Type Ia supernovae remain a mystery having a crippling effect on the many area that have strong connections to these explosive events (e.g. cosmology, chemical evolution of the Universe, stellar evolution, etc.). The current viable scenarios can be divided into two broad categories: 1) 1.4 $M_\odot$ white dwarves that are likely created in an accretion process and self-ignite due to high central pressure/density. 2) White dwarves of considerably lesser mass ($\approx 1\ M_\odot$) can be ignited in shell detonations or in the merging process that formed them. Both scenarios are able to correctly predict the bulk properties of Type Ia observations and thus determining which scenario is responsible for these events is difficult.

One difference in their scenarios is that the heavy white dwarf progenitor requires a deflagration with a subsequent detonation process, while the other reproduces the observations with a simple detonation. The former process is turbulent and results in a mixed ejecta, while the latter will result in a highly stratified remnant. Observed spectral time series have the power to distinguish between both of those burning modes through a technique known as supernova tomography.

In this talk, I will present the supernova tomography technique which uses observed spectral time series and radiative transfer code to reconstruct the explosion. I will focus on recent works that have shown how to infer supernova parameters by coupling traditional radiative transfer codes, Bayesian statistics, and machine learning to study observed spectral time series. The results can then quantitatively compared to explosion simulations to verify either scenario.

I will conclude with our study of Type Ia supernova SN 2002bo and will give an outlook of the next steps in determining the still mysterious origins of these events.

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The value of the Hubble–Lemaitre constant queried by Type Ia supernovae

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In this presentation I analyze the robustness of the value of the Hubble-Lemaitre constant yielded by the cosmic distance ladder for Type Ia supernovae, which involves three rungs. In this analysis I hold fixed Rung 1 as the distance to the LMC determined to 1% using Detached Eclipsing Binary stars, in order to focus on the highest rungs. For Rung 2 I analyze two methods, the TRGB and Cepheid distances for the luminosity calibration of Type Ia supernovae in nearby galaxies. For Rung 3 I analyze various modern digital supernova samples in the Hubble flow, such as the Calán-Tololo, CfA, CSP, and Supercal datasets. This metadata analysis demonstrates that the TRGB calibration yields 5% smaller H0 values than the Cepheid calibration, a direct consequence of the systematic difference in the distance moduli calibrated from these two methods. If Rung 1 and Rung 2 are held fixed, the different formalisms developed for standardizing the supernova peak magnitudes yield consistent results, that is, Type Ia supernovae are able to anchor Rung 3 with 2% precision.

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Redshift evolution of the underlying type Ia supernova stretch distribution

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The detailed nature of type Ia supernovae (SNe Ia) remains uncertain, and as survey statistics increase, the question of astrophysical systematic uncertainties arises, notably that of the evolution of SN Ia populations. We study the dependence on redshift of the SN Ia light-curve stretch, which is a purely intrinsic SN property, to probe its potential redshift drift. The SN stretch has been shown to be strongly correlated with the SN environment, notably with stellar age tracers. We modeled the underlying stretch distribution as a function of redshift, using the evolution of the fraction of young and old SNe Ia as predicted using the SNfactory dataset, and assuming a constant underlying stretch distribution for each age population consisting of Gaussian mixtures. We tested our prediction against published samples that were cut to have marginal magnitude selection effects so that any observed change is indeed astrophysical and not observational. In this first study, there are indications that the underlying SN Ia stretch distribution evolves as a function of redshift, and that the age drifting model is a better description of the data than any time-constant model, including the sample-based asymmetric distributions that are often used to correct Malmquist bias at a significance higher than 5 σ. The favored underlying stretch model is a bimodal one, composed of a high-stretch mode shared by both young and old environments, and a low-stretch mode that is exclusive to old environments. The precise effect of the redshift evolution of the intrinsic properties of a SN Ia population on cosmology remains to be studied. The astrophysical drift of the SN stretch distribution does affect current Malmquist bias corrections and thereby the distances that are derived based on SN that are affected by observational selection effects. This bias will increase with surveys covering increasingly larger redshift ranges.

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Measuring Hubble's Constant with the Inverse Distance Ladder

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The precise value of Hubble's constant has become one of the most interesting cosmological tensions in recent years. Measurements of H_0 with Type Ia supernovae, in a series of papers by Reiss et al., use a distance ladder of parallax and Cepheid variable stars, and find a value of H_0 which is significantly higher than expected in a LCDM cosmology with Planck CMB parameters. In this work, we use an 'inverse distance ladder' method, using distance measurements from Baryon Acoustic Oscillations to calibrate the intrinsic magnitude of the SNe. We study 207 SNe from the Dark Energy Survey, at redshift 0.018 < z < 0.85, with existing measurements of 122 low redshift (z < 0.07) SNe. We find a value of H_0 = 67.8 +/- 1.3 km s-1 Mpc-1, which is consistent with the Planck + LCDM value. Our measurement makes minimal assumptions about the underlying cosmological model, and our analysis was blinded to reduce confirmation bias.

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A new measurement of the Hubble constant using Type Ia supernovae calibrated with surface brightness fluctuations

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We present a new measurement of the Hubble constant (H_0) using supernovae type Ia (SNe Ia) based on the Surface Brightness Fluctuations (SBF) distance measurement method. We build a sample of calibrating anchors consisting of 24 SNe hosted in galaxies having SBF distance measurements. Applying a hierarchical Bayesian approach, we calibrate the SNe peak luminosity and extend it into the Hubble flow by using a sample of 96 SNe Ia in the redshift range 0.02<z<0.075. Our estimated H0 value sits midway in the range defined by the current Hubble tension. We find that the SNe Ia distance moduli calibrated with SBF are on average larger by 0.07 mag than the ones calibrated with Cepheids. Our results point to possible differences among SNe hosted in different types of galaxies, which could originate from different local environments and/or SNe Ia progenitor properties. Sampling different host galaxy type, SBF offers a complementary approach to Cepheids which is important in addressing possible systematics and providing an alternate path to the measurement of the Hubble constant in the local universe.

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Unified Theory of Detonation Initiation in Type Ia Supernovae and Terrestrial Chemical Systems

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The nature of stellar progenitors and the associated explosion mechanism of type Ia supernovae (SNIa) remains one of the major open questions in astrophysics. Virtually all existing theoretical models require formation of a supersonic detonation wave capable of providing nearly complete incineration of the stellar material of a WD after it becomes gravitationally unbound. The mechanism of detonation initiation in unconfined systems, such as the interior of a WD, remains poorly understood. Modern large-scale numerical models of SNIa are unable to capture detonation formation from first principles due to the extreme range of dynamical scales involved, and instead they are forced to trigger detonations artificially. As a result, the time and location of the detonation initiation are free parameters present in all existing SNIa models. This limits predictive power of SNIa models and does not allow them to be conclusively and rigorously confirmed or disproved using observations.

We discuss recent advances in our understanding of the physics of detonation initiation in unconfined turbulent reacting flows, both terrestrial and astrophysical. In particular, we present the general theory of turbulence-induced deflagration-to-detonation transition (tDDT). We use direct numerical simulations (DNS) of unconfined turbulent thermonuclear flames in a degenerate 12C stellar plasma to show for the first time that under conditions representative of those in a SNIa explosion this tDDT mechanism can result in the spontaneous formation of strong shocks and subsequently detonation ignition. We also describe results of experimental and numerical studies in terrestrial chemical systems corroborating this theory. Finally, we discuss the implications of this DDT theory for the classical single-degenerate Chandrasekhar-mass model. These results open path for the new generation of the first-principles predictive SNIa models, in which detonation initiation conditions can be determined accurately and self-consistently.

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Charged polarized white dwarfs with finite temperature as a possible source of type Ia supernovae

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In this work, we investigate the structure of polarized charged white dwarfs (WDs) with finite temperature as a possible type Ia supernovae source. The WD is considered with an isothermal core and an envelope where there is a temperature distribution that depends on the density. Regarding the hot fluid, we assume that it is composed of nucleons and electrons with temperature contributions. The structure of the polarized charged white dwarfs is obtained by solving the Einstein-Maxwell equations with charge densities represented by two Gaussians, forming an electric dipole layer at the stellar surface. We obtain larger and more massive white dwarfs when polarized charge and the Gaussians distance are increased. We found that to appreciate effects in the white dwarf's structure, the electric polarized charge must be in the order of 5.0×10^{20}[C]. We obtain a maximum white dwarf mass of around $2M_{\odot}$ for a polarized charge of 1.5×10^{21}[C]. These results could indicate polarized charged white dwarfs as possible progenitors of superluminous type Ia supernovae. Furthermore, we show that the curves we obtain are very similar to the ones of strongly magnetized white dwarfs obtained recently.

White Dwarfs, Magnetic Compact Stars, and Nuclear Astrophysics

White Dwarfs, Magnetic Compact Stars, and Nuclear Astrophysics / 557

Highly magnetized white dwarfs: implications and current status

Authors: Banibrata Mukhopadhyay[1]; Mukul Bhattacharya[2]; Alex Hackett[3]; Surajit Kalita[4]; Drisya Karinkuzhi[1]; Christopher Tout[3]

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Since last 10 years or so, we have been developing the possible existence of highly magnetized white dwarfs. While the primary aim was to explain peculiar overluminous type Ia supernovae, later on, they have been found to have multiple implications including soft gamma-ray repeaters and anomalous X-ray pulsars, and gravitational radiation. Recently, we have successfully simulated their formation from magnetized main sequence stars. In this talk, I will touch upon all these findings and conclude with their current status in the community.

White Dwarfs, Magnetic Compact Stars, and Nuclear Astrophysics / 988

Study the effects of anisotropy on the highly magnetized white dwarfs

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The equilibrium configuration of white dwarfs composed of anisotropic fluid distribution in the presence of a strong magnetic field is investigated in this work. By considering a functional form of the anisotropic stress and magnetic field profile, some physical properties of magnetized white dwarfs, such as mass, radius, density, radial and tangential pressures, were derived; their dependency with the anisotropy and central magnetic field is also explored. We show that the orientations of the magnetic field along the radial direction or orthogonal to the radial direction influence the stellar structure and physical properties of white dwarf significantly. Importantly, we show that ignoring anisotropy governed by the fluid due to its high density in the presence of a strong magnetic field would destabilize the star. Through this work, we can explain the highly massive progenitor of peculiar over-luminous SNeIa, and low massive under-luminous SNeIa, which poses a question of considering 1.4 solar mass white dwarf to be related to the standard candle.

White Dwarfs, Magnetic Compact Stars, and Nuclear Astrophysics / 626

Signs of multipolar magnetic field on light-curves analysis

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Mass and radius constraints of compact stars (CS), i.e. Neutron stars (NS) and White Dwarfs (WD), based on electromagnetic data are challenging. Radius measurements are mainly based on observation of thermal emission and comparison with theoretical models. Modeling, however, due to the complex and relativistic nature of compact objects, suffers from a number of complications such as parameter degeneration, the unknown equation of state for NS (EOS), among other uncertainties.
In this work, we show the results of our newest software that calculates theoretical pulse profiles for a CS with thermal spots on its surface, and then finds the best parameters to fit a real pulse. We follow a procedure that allows us to treat circular spots of arbitrary size and location on the stellar surface within a spacetime described by Schwarzschild. We also take into account beaming and scattering effects through a partially ionized hydrogen atmosphere. Searching for the best parameters – e.g. stellar radius, hot spot sizes, viewing angles - is done using a bayesian procedure that also returns a statistical distribution for each parameter.

White Dwarfs, Magnetic Compact Stars, and Nuclear Astrophysics / 863

Particle acceleration and high energy emission in the white dwarf binaries AE Aquarii and AR Sco

Authors: Pieter Meintjes[1]; Spencer Madzime[1]; Quinton Ka[plan[1]; Hendrik van Heerden[1]

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In this presentation the white dwarf close binaries AE Aquarii and AR Sco are investigated to search for signatures of particle acceleration and associated non-thermal emission. A detailed investigation of the total Fermi-LAT data base reveal signatures of pulsed gamma-ray emission in AE Aquarii, which mimics earlier reports of transient burst-like pulsed TeV gamma-ray emission reported from this system in the 1990's. Although a similar analysis of the Fermi-LAT data of AR Sco does not reveal strong signatures of pulsed emission, our analysis allowed constraining the gamma-ray activity from this system. Recent meerKAT radio data from both these systems clearly reveal pulsar-like non-thermal emission, which clearly indicates that both these fascinating systems contain a strong particle accelerator of some sort.

White Dwarfs, Magnetic Compact Stars, and Nuclear Astrophysics / 981

Static and rotating white dwarfs at finite temperatures

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Static and uniformly rotating, cold and hot white dwarfs are investigated both in Newtonian gravity and general theory of relativity, employing the well-known Chandrasekhar equation of state. The mass-radius, mass-central density, radius-central density etc relations of stable white dwarfs with $\mu = A/Z = 2$ and $\mu = 56/26$ (where A is the average atomic weight and Z is the atomic charge) are constructed for different temperatures. It is shown that near the maximum mass the mass of hot rotating white dwarfs is slightly less than for cold rotating white dwarfs, though for static white dwarfs the situation is opposite.

White Dwarfs, Magnetic Compact Stars, and Nuclear Astrophysics / 386

CTCV J2056-3014: a fast-spinning and magnetic white dwarf

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In this talk, we present the recent determination of the spin period of CTCV J2056-3014, a magnetic white dwarf in a cataclymisc binary system. Its X-ray and optical emission is clearly modulated with a 29.6 s period and points to an accretion origin. We briefly discuss this object in the context of other fast-spinning white dwarfs.

White Dwarfs, Magnetic Compact Stars, and Nuclear Astrophysics / 570

Electron Captures in Magnetic White Dwarfs and Magnetars

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Electron captures by atomic nuclei in dense matter are among the most important processes governing the late evolution of stars. Although these reactions have been known for a long time, most studies have focused on nonmagnetized matter. However, some white dwarfs are endowed with magnetic fields of the order of 10^9~G. Even more extreme magnetic fields might exist in super Chandrasekhar white dwarfs, the progenitors of overluminous type Ia supernovae like SN 2006gz and SN 2009dc. The onset of electron captures, which limits the stability of the most massive white dwarfs, may be shifted to higher or lower densities depending on the magnetic field strength due

Landau-Rabi quantization of electron motion [[1],[2]]. Electron captures could also be a viable internal heating mechanism to power the observed persistent thermal luminosity of magnetars and their outbursts [[3]]. During this talk, I will briefly review our recent studies of the role of a strong magnetic field on electron captures in these extreme stellar environments.

1. N. Chamel, A. F. Fantina, and P. J. Davis, Phys. Rev. D 88, 081301(R) (2013). https://doi.org/10.1103/PhysRevD.88.081

2. N. Chamel and A. F. Fantina, Phys. Rev. D 92, 023008 (2015). https://doi.org/10.1103/PhysRevD.92.023008

3. N. Chamel, A.F. Fantina, L. Suleiman, J.-L. Zdunik, P. Haensel, Universe 7, 193 (2021). https://doi.org/10.3390/univers

White Dwarfs, Magnetic Compact Stars, and Nuclear Astrophysics / 631

A study of the infrared emission of SGR/AXPs in a disk scenario and its implications for their origin

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Soft Gamma-Ray Repeaters and Anomalous X-ray Pulsars (SGR/AXPs) are isolated compact stars identified due to a characteristic quiescent soft X-ray emission as well as bursts events. They can also emit in other energy ranges, from radio up to hard X-rays. Their nature is still a question for debate, and several emission mechanisms have been proposed, such as neutron star (NS) with a super-strong decaying magnetic field (magnetar model), accreting NSs, white dwarf (WD) pulsars, and accreting WDs. Among its broad energy range, the infrared (IR) emission, exhibited by about 50 % of the class, is perhaps the least studied energy range. For 4U 0142+61, this IR is well modeled by an irradiated disk, reinforced by an unconfirmed silicate feature around 9.5μm. Nonetheless, some authors still argues in favor of an IR magnetospheric emission for the class. Unfortunately, the classical approaches to distinguish between those two models (search for polarization and pulsed fractions) can be inconclusive. For this reason, we propose a different method: the search for a correlation between the luminosities in IR and X-rays that can be confronted with the expected correlation for a disk and magnetospheric models. Our results point out a correlation consistent with an irradiated disk.

This disk surrounding SGR\AXPs can open a different path to test SGR/AXPs origin. For instance, if the leftover of a supernova event formed the disk, it probably contains iron, silicon, oxygen, helium, and traces of hydrogen. On the other hand, if SGR\AXPs were WDs formed after a merger, the disk would contain mainly carbon and oxygen, with traces of other elements such as neon, magnesium, and silicon. In this sense, an IR spectroscopy of 4U 0142+61, the magnetar with the brightest quiescent emission, could give essential clues to the origin of the class.

White Dwarfs, Magnetic Compact Stars, and Nuclear Astrophysics / 529

Gravitational waves from fast-spinning white dwarfs

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Two mechanisms of gravitational waves (GWs) emission in fast-spinning white dwarfs (WDs) are investigated: accretion of matter and magnetic deformation. In both cases, the GW emission is generated by an asymmetry around the rotation axis of the star. However, in the first case, the asymmetry is due to the amount of accreted matter on the magnetic poles, while in the second case it is due to the intense magnetic field. We have estimated the GW amplitude and luminosity for three binary systems that have a fast-spinning magnetized WD, namely, AE Aquarii, AR Scorpii and RX J0648.0-4418. We find that, for the first mechanism, the systems AE Aquarii and RX J0648.0-4418 can be observed by the space detectors BBO and DECIGO if they have an amount of accreted mass of $\delta m \geq 10^{-5} M_{\odot}$. For the second mechanism, the three systems studied require that the WD have a magnetic field above $\sim 10^9$ G to emit GWs that can be detected by BBO. We also verified that, in both mechanisms, the gravitational luminosity has an irrelevant contribution to the spindown luminosity of these three systems. Therefore, other mechanisms of energy emission are needed to explain the spindown of these objects.

White Dwarfs, Magnetic Compact Stars, and Nuclear Astrophysics / 606

The stability of massive hot white dwarfs: Consequences of finite temperature in the structure and on the onset of instabilities

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In this work, we investigate the structure, the radial stability, pycnonuclear reaction and inverse β-decay in white dwarfs with a finite temperature. Regarding the matter within hot white dwarfs, we consider that it is composed of nucleons and electrons confined in a Wigner-Seitz cell surrounded by free photons. Since photons are being considered, in order to connect smoothly the interior solution with the vacuum solution outside the star, i.e., with the aim to obtain a null pressure at the star's surface, a temperature distribution is implemented. The temperature depends on the mass density considering the presence of the isothermal core. We found that the temperature produces remarkable effects on the equilibrium and radial stability of white dwarfs. We compare our results with massive white dwarfs estimated from the Extreme Ultraviolet Explorer Survey and Sloan Digital Sky Survey. We note that these massive white dwarfs are well described by our curves with higher central temperatures. Our results suggest that these hot massive stars detected are within the range of white dwarfs with more radial stability. This result is important since it could explain their existence. We also obtain that the maximum mass point and the zero eigenfrequency of the fundamental mode are determined at the same central energy density. Furthermore, we show that pycnonuclear reactions occur in almost similar central energy densities, and the central energy density threshold for inverse β-decay is not modified. For central temperatures $T_c \leq 1.0 \times 10^8$ [K], the onset of the radial instability is attained before the pycnonuclear reaction and the inverse β-decay.

Why and How the Sun and the Stars Shine: the Borexino Experiment

Why and How the Sun and the Stars Shine: the Borexino Experiment / **1023**

Electron neutrino survival probability in the energy range: 5 keV-15 MeV

Author: Marco Pallavicini[1]

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Solar neutrinos provide a sample of electron neutrinos of different energies. They are therefore a unique probe of the electron neutrino propagation through solar matter and for the experimental study of the MSW effect. Borexino, with its unique purity and sensitivity, has been able to study individually all components, extracting the best test of electron neutrino survival probability to date. The talk with summarise the results and the state of the art in the field.

Why and How the Sun and the Stars Shine: the Borexino Experiment / **907**

Implications of pp-cycle and CNO-cycle neutrino measurements for solar physics

Authors: Aldo Serenelli[None]; Francesco Villante[None]

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The detection of neutrinos produced by pp-chain and CNO-cycle provide us fundamental informations on the thermal stratification and on the chemical composition of the solar core.

These can be used to verify the predictions ot the so-called Standard Solar Models (SSMs), which represent a benchmark for stellar evolution, and to constrain standard and non/standard energy generation and transfer mechanisms, standard and non/standard chemical evolution paradigms for the Sun, etc.

The CNO neutrino measurements, combined with precise determinations of 8B and 7Be fluxes, can also provide clues for the solution of the so-called solar abundance problem, i.e. the fact that SSMs implementing the latest determination of surface heavy element abundances, obtained by 3D hydrodynamic models of the solar atmosphere, do not reproduce helioseismic constraints. All proposed modifications to physical processes in SSMs (e.g. anomalous diffusion, accretions, mass loss, etc) offer, at best, only partial solutions to this unsolved puzzle.

Why and How the Sun and the Stars Shine: the Borexino Experiment / 1045

Role of the CNO cycle in massive stars

Author: Aldo Ianni[1]

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The CNO cycle consists of a series of nuclear reactions that provide energy in stars. There exist multiple different cycles depending on temperature and relative abundance of elements in stars. In the Sun the CNO cycle is a catalyst cycle where nuclear reactions cycle through carbon, nitrogen and oxygen. Initially, a free proton fuses with a carbon-12 nucleus starting a sequence of reactions which transform hydrogen into helium and produce energy. We can identify four catalytic cycles. The first cycle produces about 1% of the energy in the Sun. The second cycle, which involves production of fluor-17, occurs rarely in the Sun, while the third and fourth cycles are only present in very massive stars. The Borexino measurement on CNO neutrinos has offered the opportunity to probe experimentally this scheme which turns to be crucial for energy production in stars with a mass larger than 1.3 Msun. In the talk the idea of catalytic cycles is reviewed and the impact of the Borexino measurement is discussed.

Why and How the Sun and the Stars Shine: the Borexino Experiment / 725

Unveiling the engine of the Sun: measurements of the pp-chain solar neutrinos with Borexino

Author: Oleg Smirnov[1]

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About 99 percent of solar energy is produced through sequences of nuclear processes that convert hydrogen into helium in the so-called pp-chain. The neutrinos emitted in five of these reactions represent a unique probe of the Sun's internal working and, at the same time, offer an intense natural neutrino beam for fundamental physics research.
The Borexino experiment consists of a large-volume liquid-scintillator detector designed and constructed for real-time detection of low energy solar neutrinos. It is installed at the underground INFN Laboratori Nazionali del Gran Sasso (L'Aquila, Italy) and started taking data in May 2007.
Borexino has been the only experiment so far capable of performing a complete study of the pp-chain by directly measuring the neutrino-electron elastic scattering rates for the neutrinos produced in four of its reactions: the initial proton–proton (pp) fusion, the electron capture of beryllium-7, the proton–electron–proton (pep) fusion, and the boron-8 beta+ decay. A limit on the neutrino flux produced in the helium-proton fusion (hep) was also set. This set of measurements further probes the solar fusion mechanism via the direct determination of the relative intensity of the two primary terminations of the pp-chain, and the computation of the solar neutrino luminosity. Moreover, the beryllium-7 and boron-8 fluxes are indicative of the Sun's core temperature, and their measurement shows a mild preference for the higher temperature expected from the high-metallicity Standard Solar Model scenario.
Finally, the experimental survival probability of these solar electron neutrinos allows to simultaneously probe the MSW neutrino flavor conversion paradigm, both in vacuum and in matter-dominated regimes, at different energies.
The details of the strategy adopted by the Borexino collaboration for successfully isolating the spectral components of the pp-chain neutrinos signal from residual backgrounds in the total energy spectrum will be presented.

Why and How the Sun and the Stars Shine: the Borexino Experiment / 1042

Electron neutrino survival probability in the energy range: 5 keV-15 MeV

Author: Marco Pallavicini[1]

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Solar neutrinos provide a sample of electron neutrinos of different energies. They are therefore a unique probe of the electron neutrino propagation through solar matter and for the experimental study of the MSW effect. Borexino, with its unique purity and sensitivity, has been able to study individually all components, extracting the best test of electron neutrino survival probability to date. The talk with summarise the results and the state of the art in the field.

Why and How the Sun and the Stars Shine: the Borexino Experiment / 1043

Electron neutrino survival probability in the energy range: 5 keV-15 MeV

Author: Marco Pallavicini[1]

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Why and How the Sun and the Stars Shine: the Borexino Experiment / 1044

Implications of pp-cycle and CNO-cycle neutrino measurements for solar physics

Authors: Francesco Villante[None]; Aldo Serenelli[None]

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The detection of neutrinos produced by pp-chain and CNO-cycle provide us fundamental informations on the thermal stratification and on the chemical composition of the solar core.

These can be used to verify the predictions ot the so-called Standard Solar Models (SSMs), which represent a benchmark for stellar evolution, and to constrain standard and non/standard energy generation and transfer mechanisms, standard and non/standard chemical evolution paradigms for the Sun, etc.

The CNO neutrino measurements, combined with precise determinations of ^{8}B and ^{7}Be fluxes, can also provide clues for the solution of the so-called solar abundance problem, i.e. the fact that SSMs implementing the latest determination of surface heavy element abundances, obtained by 3D hydrodynamic models of the solar atmosphere, do not reproduce helioseismic constraints. All proposed

modifications to physical processes in SSMs (e.g. anomalous diffusion, accretions, mass loss, etc) offer, at best, only partial solutions to this unsolved puzzle.

Why and How the Sun and the Stars Shine: the Borexino Experiment / 1046

Role of the CNO cycle in massive stars

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The CNO cycle consists of a series of nuclear reactions that provide energy in stars. There exist multiple different cycles depending on temperature and relative abundance of elements in stars. In the Sun the CNO cycle is a catalyst cycle where nuclear reactions cycle through carbon, nitrogen and oxygen. Initially, a free proton fuses with a carbon-12 nucleus starting a sequence of reactions which transform hydrogen into helium and produce energy. We can identify four catalytic cycles. The first cycle produces about 1% of the energy in the Sun. The second cycle, which involves production of fluor-17, occurs rarely in the Sun, while the third and fourth cycles are only present in very massive stars. The Borexino measurement on CNO neutrinos has offered the opportunity to probe experimentally this scheme which turns to be crucial for energy production in stars with a mass larger than 1.3 Msun. In the talk the idea of catalytic cycles is reviewed and the impact of the Borexino measurement is discussed.

Why and How the Sun and the Stars Shine: the Borexino Experiment / 1027

Role of the CNO cycle in massive stars

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The CNO cycle consists of a series of nuclear reactions that provide energy in stars. There exist multiple different cycles depending on temperature and relative abundance of elements in stars. In the Sun the CNO cycle is a catalyst cycle where nuclear reactions cycle through carbon, nitrogen and oxygen. Initially, a free proton fuses with a carbon-12 nucleus starting a sequence of reactions which transform hydrogen into helium and produce energy. We can identify four catalytic cycles. The first cycle produces about 1% of the energy in the Sun. The second cycle, which involves production of fluor-17, occurs rarely in the Sun, while the third and fourth cycles are only present in very massive stars. The Borexino measurement on CNO neutrinos has offered the opportunity to probe experimentally this scheme which turns to be crucial for energy production in stars with a mass larger than 1.3 Msun. In the talk the idea of catalytic cycles is reviewed and the impact of the Borexino measurement is discussed.

Why and How the Sun and the Stars Shine: the Borexino Experiment / 1049

Borexino detector performances

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Borexino, a large volume detector for low energy neutrino spectroscopy, is currently taking data underground since 2007 at the Laboratori Nazionali del Gran Sasso, Italy. The main goal of the experiment is the real-time measurement of solar neutrinos, especially the low energy part of the spectrum. Neutrinos are detected via neutrino-electron scattering in an ultra-pure organic liquid scintillator. The light generated by the interaction is detected by 2212 phototubes.
During many years of data taking the experiment provided several remarkable results as the first evidence of pep neutrinos, the real-time detection of the pp neutrinos, the evidence of CNO neutrinos, and the detection of antineutrinos from the Earth. All these results are based on an accurate modelling of the detector's response and performances.
The contribution shows the design, the modelling of the detector's response, and the performances. Moreover it will be discussed how the performances and the response were studied by means of extensive calibration campaigns.

Why and How the Sun and the Stars Shine: the Borexino Experiment / 1051

Geoneutrino observation

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Geoneutrino observation is reviewed.
The latest data of KamLAND and Borexino are included as well as the prospects of near future experiments.

Why and How the Sun and the Stars Shine: the Borexino Experiment / 424

Study of antineutrinos from the Cosmos and from the Earth

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The largest amount of antineutrinos detected about the Earth is emitted by the natural radioactive decays inside the Earth: more than 99% of the present-day Earth's radiogenic heat is originated by the β^- decays of ^{40}K and of ^{232}Th and ^{238}U chains isotopes. Other flux components are provided by cosmic rays interactions in the atmosphere or by possible extra-terrestrial sources such as supernovae explosions, gamma ray bursts, GW events and solar flares.
Large underground ultrapure liquid scintillators are very suitable to antineutrinos studies. Electron antineutrinos are detected through the inverse beta-decay mechanism on the free proton: the fast time coincidence between the emitted positron annihilation and the neutron capture provides an almost background free signature, that allows to investigate also tiny flux components.
The extreme radiopurity of the BOREXINO detector has allowed to set new limits on diffuse supernova antineutrino background for $\bar{\nu}_e$ in the previously unexplored energy region below 8 MeV, and to obtain the best upper limits on all flavor antineutrino fluences in the few MeV energy range from gamma-ray bursts and from gravitational wave events.
Moreover, BOREXINO has robustly detected the geo-neutrino signal and begun to place constraints on the amount of radiogenic heating in the Earth's interior: the null-hypothesis of observing a geoneutrino signal from the mantle has been excluded at a 99.0% C.L. and the overall production of

radiogenic heat constrained to $38.2^{+13.6}_{-12.7}$ TW.
The talk presents a complete review of the results obtained by BOREXINO about antineutrinos from the Earth and from other possible extraterrestrial sources.

Why and How the Sun and the Stars Shine: the Borexino Experiment / 943

Experimental detection of the CNO cycle

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Borexino recently detect solar neutrinos from the CNO cycle.
In the talk I will review the experiment, the analysis method, the CNO result and its implications.

Why and How the Sun and the Stars Shine: the Borexino Experiment / 753

Experimental detection of the CNO cycle

Author: Barbara Caccianiga[None]

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Stars are fueled by nuclear reactions occurring in their core. In massive stars (approximately 1.3 more massive than our Sun) the dominant reactions are believed to be those belonging to the so-called CNO cycle, while in lighter stars (including our Sun) the proton-proton chain prevails. Until now, we had no direct experimental evidence of the existence of the CNO cycle.
Recently, the Borexino collaboration has announced the first observation of neutrinos emitted by the CNO reactions in the Sun's core, experimentally proving that this mechanism envisaged by Bethe and Weizsacker in the 30's indeed exists.
In this talk, I will describe some details of this challenging quest, which has started approximately 5 years ago, when we realized that Borexino, which had already performed a complete spectroscopy of neutrinos from the proton-proton chain in the Sun, had the sensitivity to also tackle CNO neutrinos.
The capability to observe CNO neutrinos is strictly connected to the possibility to disentangle their signal in the detector from the noise produced by several backgrounds, in particular, the radioactive decay of the isotope 210Bi.
The story of how we were able to measure the faint CNO signal coming from our Star by keeping as stable as possible the temperature of our detector is an interesting one and I will try to tell it underlying the main issues and complications we had to overcome.

Why and How the Sun and the Stars Shine: the Borexino Experiment / 335

Unveiling the engine of the Sun: measurements of the pp-chain solar neutrinos with Borexino

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About 99 percent of solar energy is produced through sequences of nuclear processes that convert hydrogen into helium in the so-called pp-chain. The neutrinos emitted in five of these reactions represent a unique probe of the Sun's internal working and, at the same time, offer an intense natural neutrino beam for fundamental physics research.
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Finally, the experimental survival probability of these solar electron neutrinos allows to simultaneously probe the MSW neutrino flavor conversion paradigm, both in vacuum and in matter-dominated regimes, at different energies.
The details of the strategy adopted by the Borexino collaboration for successfully isolating the spectral components of the pp-chain neutrinos signal from residual backgrounds in the total energy spectrum will be presented.

Why and How the Sun and the Stars Shine: the Borexino Experiment / 265

Antineutrinos from the Sun and Cosmos

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Astrophysical neutrinos cover at least 18 orders of magnitude in energy, starting from meV (relic neutrinos) till PeV, the highest energy neutrinos ever detected as of today. Among the possible extraterrestrial sources of antineutrinos are the supernovae explosions, gamma ray bursts, neutron and black hole mergers and solar flares. In the Sun, the conversion of solar neutrinos into antineutrinos in the strong magnetic field could cause a small antineutrino flux in the case of an anomalous neutrino magnetic moment.
Neutrino detectors start playing a substantial role in multi-messenger astronomy. The Borexino detector at the Laboratori Nazionali del Gran Sasso in Italy has proven its potential in the various fields of experimental neutrino astronomy.
The extreme radiopurity of the detector allowed to set new limits on diffuse supernova antineutrino background in the previously unexplored energy region below 8 MeV, and to get, even with very conservative assumptions, competitive results between 7.8 and 16.8 MeV. Among the recent achievements there are the best upper limits on all flavor antineutrino fluences in the few MeV energy range from gamma-ray bursts and from gravitational wave events. Finally a limit for a solar $\bar{\nu}_e$ flux of 384 cm^{-2} s^{-1} (90% C.L.) was obtained, that corresponds to a transition probability $p_{\nu_e \to \bar{\nu}_e} < 7.2 \times 10^{-5}$ (90% C.L.) for $E_{\bar{\nu}_e} > 1.8$ MeV.
In the talk a comprehensive review of the all the Borexino results on antineutrinos fluxes from astrophysical sources will be presented.

Why and How the Sun and the Stars Shine: the Borexino Experiment / 917

Implications of pp-cycle and CNO-cycle neutrino measurements

for solar physics

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The detection of neutrinos produced by pp-chain and CNO-cycle provide us fundamental informations on the thermal stratification and on the chemical composition of the solar core.

These can be used to verify the predictions ot the so-called Standard Solar Models (SSMs), which represent a benchmark for stellar evolution, and to constrain standard and non/standard energy generation and transfer mechanisms, standard and non/standard chemical evolution paradigms for the Sun, etc.

The CNO neutrino measurements, combined with precise determinations of ^{8}B and ^{7}Be fluxes, can also provide clues for the solution of the so-called solar abundance problem, i.e. the fact that SSMs implementing the latest determination of surface heavy element abundances, obtained by 3D hydrodynamic models of the solar atmosphere, do not reproduce helioseismic constraints. All proposed modifications to physical processes in SSMs (e.g. anomalous diffusion, accretions, mass loss, etc) offer, at best, only partial solutions to this unsolved puzzle.

Why and How the Sun and the Stars Shine: the Borexino Experiment / 309

Unveiling the engine of the Sun: measurements of the pp-chain solar neutrinos with Borexino

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About 99 percent of solar energy is produced through sequences of nuclear processes that convert hydrogen into helium in the so-called pp-chain. The neutrinos emitted in five of these reactions represent a unique probe of the Sun's internal working and, at the same time, offer an intense natural neutrino beam for fundamental physics research.
The Borexino experiment consists of a large-volume liquid-scintillator detector designed and constructed for real-time detection of low energy solar neutrinos. It is installed at the underground INFN Laboratori Nazionali del Gran Sasso (L'Aquila, Italy) and started taking data in May 2007.
Borexino has been the only experiment so far capable of performing a complete study of the pp-chain by directly measuring the neutrino-electron elastic scattering rates for the neutrinos produced in four of its reactions: the initial proton–proton (pp) fusion, the electron capture of beryllium-7, the proton–electron–proton (pep) fusion, and the boron-8 beta+ decay. A limit on the neutrino flux produced in the helium-proton fusion (hep) was also set. This set of measurements further probes the solar fusion mechanism via the direct determination of the relative intensity of the two primary terminations of the pp-chain, and the computation of the solar neutrino luminosity. Moreover, the beryllium-7 and boron-8 fluxes are indicative of the Sun's core temperature, and their measurement shows a mild preference for the higher temperature expected from the high-metallicity Standard Solar Model scenario.
Finally, the experimental survival probability of these solar electron neutrinos allows to simultaneously probe the MSW neutrino flavor conversion paradigm, both in vacuum and in matter-dominated regimes, at different energies.
The details of the strategy adopted by the Borexino collaboration for successfully isolating the spectral components of the pp-chain neutrinos signal from residual backgrounds in the total energy spectrum will be presented.

Why and How the Sun and the Stars Shine: the Borexino Experiment / 140

Experimental detection of the CNO cycle

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The Borexino has recently reported the first experimental evidence of neutrinos from the CNO cycle. Since this process accounts only for about 1% of the total energy production in the Sun, the associated neutrino flux, is extremely low as compared with the one from the pp-chain, the dominant process of hydrogen burning.
This experimental evidence of the CNO neutrinos was obtained using the highly radio-pure liquid scintillator of Borexino. Improvements in the thermal stabilization of the detector over the last five years enabled us to exploit a method to constrain the rate of Bi-210 background. Since the CNO cycle is dominant in the massive starts, this result proves the evidence of the primary mechanism for the stellar conversion of hydrogen into helium in the Universe.

Why and How the Sun and the Stars Shine: the Borexino Experiment / 217

Borexino detector performances

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Borexino, a large volume detector for low energy neutrino spectroscopy, is currently taking data underground since 2007 at the Laboratori Nazionali del Gran Sasso, Italy. The main goal of the experiment is the real-time measurement of solar neutrinos, especially the low energy part of the spectrum. Neutrinos are detected via neutrino-electron scattering in an ultra-pure organic liquid scintillator. The light generated by the interaction is detected by 2212 phototubes.
During many years of data taking the experiment provided several remarkable results as the first evidence of pep neutrinos, the real-time detection of the pp neutrinos, the evidence of CNO neutrinos, and the detection of antineutrinos from the Earth. All these results are based on an accurate modelling of the detector's response and performances.
The contribution shows the design, the modelling of the detector's response, and the performances. Moreover it will be discussed how the performances and the response were studied by means of extensive calibration campaigns.

Why and How the Sun and the Stars Shine: the Borexino Experiment / 1050

Study of antineutrinos from the Cosmos and from the Earth

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The largest amount of antineutrinos detected about the Earth is emitted by the natural radioactive decays inside the Earth: more than 99% of the present-day Earth's radiogenic heat is originated by the β^- decays of ^{40}K and of ^{232}Th and ^{238}U chains isotopes. Other flux components are provided by cosmic rays interactions in the atmosphere or by possible extra-terrestrial sources such as supernovae explosions, gamma ray bursts, GW events and solar flares.
Large underground ultrapure liquid scintillators are very suitable to antineutrinos studies. Electron

antineutrinos are detected through the inverse beta-decay mechanism on the free proton: the fast time coincidence between the emitted positron annihilation and the neutron capture provides an almost background free signature, that allows to investigate also tiny flux components.
The extreme radiopurity of the BOREXINO detector has allowed to set new limits on diffuse supernova antineutrino background for $\bar{\nu}_e$ in the previously unexplored energy region below 8 MeV, and to obtain the best upper limits on all flavor antineutrino fluences in the few MeV energy range from gamma-ray bursts and from gravitational wave events.
Moreover, BOREXINO has robustly detected the geo-neutrino signal and begun to place constraints on the amount of radiogenic heating in the Earth's interior: the null-hypothesis of observing a geoneutrino signal from the mantle has been excluded at a 99.0% C.L. and the overall production of radiogenic heat constrained to $38.2^{+13.6}_{-12.7}$ TW.
The talk presents a complete review of the results obtained by BOREXINO about antineutrinos from the Earth and from other possible extraterrestrial sources.

Wormholes, Energy Conditions and Time Machines

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Circularly symmetric thin-shell wormholes in F(R) gravity with (2+1)-dimensions

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Within the framework of F(R) theories of gravity with (2+1)-dimensions and constant scalar curvature R, we construct a family of thin-shell wormholes with circular symmetry and we analyze the stability of the static configurations under radial perturbations. We show an example of asymptotically anti-de Sitter thin-shell wormholes with charge, finding that stable configurations with normal matter are possible for a suitable range of the parameters.

Wormholes, Energy Conditions and Time Machines / **1000**

Perfect Fluid Warp Drive Solutions with the Cosmological Constant

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This is the fourth paper of a series where we examine solutions of the Einstein equations with the Alcubierre warp drive geometry having different matter and field sources (Santos-Pereira et al. 2020, 2021; Refs. [1–3]). The Alcubierre metric describes a spacetime geometry that allows a massive particle inside a spacetime distortion, called warp bubble, to travel with superluminal global velocities. In this work we advance solutions of the Einstein equations with the cosmological constant for the Alcubierre warp drive metric having the perfect fluid as source. We also considered the particular case of non interacting particles content, or dust, with the cosmological constant, which generalizes our previous dust solution 1 which led to vacuum solutions connecting the warp drive with shock waves via the Burgers equation. The energy conditions for these cases were also
analyzed. The results show that the shift vector in the direction of the warp bubble motion creates a coupling in the Einstein equations that requires off-diagonal terms in the energy-momentum

source. Therefore, it seems that to achieve superluminal speeds by means of the Alcubierre warp drive spacetime geometry may require a complex source configuration and distribution of energy, matter and momentum in order to produce a warp drive bubble. In addition, warp speeds seem to require more complex forms of matter than dust for stable solutions and that the negative matter might not be a strict requirement to achieve global superluminal speeds.

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Double photon ring of asymmetric thin-shell wormhole in Palatini f(R) gravity

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We discuss the stability and appearance of an asymmetric thin-shell wormhole supported by positive energy sources within the Palatini f(R) gravity. Such object is build using a matching procedure of two Reissner-Nordström space-times with different masses and charges via suitable junction conditions.

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Gravitational perturbations in the Newman-Penrose formalism: Applications to wormholes

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In this work we study the problem of linear stability of gravitational perturbations in stationary and spherically symmetric wormholes. For this purpose, we employ the Newman-Penrose formalism which is well-suited for treating gravitational radiation in General Relativity, as well as the geometrical aspect of this theory. With this method we obtain a "master equation" that describes the behavior of gravitational perturbations that are of odd-parity in the Regge-Wheeler gauge. This equation is later applied to a specific class of Morris-Thorne wormholes. The analysis of the equation yielded by this class of space-times reveals that there are no unstable vibrational modes generated by the type of perturbations here studied.

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Geometry, matter, quasi-normal modes and echoes in a family of ultrastatic wormholes

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We investigate a family of ultra-static, Lorentzian wormholes for which the wormhole shapes and sizes are controlled by two metric parameters –b_0 (the throat radius) and n (an even integer). The well-known Ellis- Bronnikov wormhole is a special case (n= 2) in this family. The n>2 spacetimes are however, distinctly different geometrically, a fact evident from their embedding features. As expected, we note that the required matter stress-energy violates all energy conditions. Interestingly, we find that the stress-energy (for all even n) can be split into a part due to a phantom scalar and another extra piece which satisfies the Averaged Null Energy Condition (ANEC) along radial null geodesics. For n= 2, the additional stress energy and therefore, the ANEC integral, vanishes. A stability analysis of this family of wormholes is then carried out by first looking at scalar perturbations. Using time domain profiles as well as other standard methods, we find the quasi-normal modes. The n>2 geometries have double barrier effective potentials (in the scalar perturbation equation) and hence harbour echoes arising due to multiple reflections. We show how the scalar quasi-normal modes can be used as a tool for distinguishing and identifying the small 'n' wormholes. For large 'n', characteristic echoes act as signatures. All wormholes of this family are found to be stable under scalar as well as axial gravitational perturbations. In summary, with additional future work (especially on metric perturbations) our family of wormholes could turn out to be viable templates for black hole mimickers in gravitational wave physics.
(1) Revisiting a family of wormholes: geometry, matter, scalar quasinormal modes and echoes; P. Dutta Roy, S. Aneesh and Sayan Kar, Eur. Phys. J. C 80:850 (2020).

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Relic magnetic wormholes as a possible source of toroidal magnetic fields in galaxies

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Magnetic fields observed in galaxies have the toroidal component. We present the hypothesis that such fields maybe remnants of relic magnetic torus - shaped wormholes. Such magnetic wormholes produce the two important effects. The first effect is that in the primordial plasma before the recombination magnetic fields of wormholes trap baryons whose energy is smaller than a threshold energy. They collect baryons from the nearest (horizon size) region and form clumps of baryonic matter. Such clumps may serve as seeds for the formation of ring galaxies and smaller objects having the ring form. Upon the recombination torus- like clumps may decay and merge. The second effect is that upon the recombination epoch such wormholes cease to strongly interact with baryon clumps and may expand or collapse. However, the large - scale toroidal magnetic field retains and may leave a trace in galaxies. In particular, such configurations of the magnetic field may serve as natural accelerators of charged particles and may give an essential contribution to high energy cosmic rays.

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The warp drive geometry

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In this talk I will give a brief historical review of the original warp bubble geometry, as well as the main problems with it, namely the need for negative energy and the horizon problem.

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Introducing Physical Warp Drives

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Alcubierre warp drive spacetimes allow timelike observers to travel superluminally relative to other timelike observers through the use of negative energy densities. In our study, we develop a general framework for describing warp drives. We show that any such object may be thought of as a shell of inertially moving material that modifies the properties of spacetime enclosed by the shell. Using the framework, we introduce a model of subluminal physical warp drives based on positive energy densities and satisfying the weak, strong and dominant energy conditions. Likewise, we show that all physical superluminal solutions would have to violate the dominant energy condition. We demonstrate the diversity of warp drive spacetimes by constructing example solutions in which the time or the volume deformation in the enclosed area may be chosen in a controlled manner. Our study, and the recent studies by other groups, show that the full diversity of warp drive classes is yet to be uncovered.

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GRAVITATIONAL LENSING BYWORMHOLES IN BINARY SYSTEMS

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Lensing by wormholes has been explored by several authors and the demagnification effect has been found as a distinctive signature which is not present in lensing from ordinary matter.

We study compact objects made up by ordinary and exotic matter in binary systems with $1/r^n$ potentials, where $n = 2$ corresponds to the Ellis wormhole, both in the symmetric case, where the two lenses have the same index n, and in the asymmetric case in which the lenses have different indexes n and m.
These mixed binary lenses are important from the astrophysical point of view also in the investigation of pairs of galaxies with different halos, or in the case in which one object is made up of exotic matter and the other one is a normal star. Another point of relevance is the proof that a deflection with $n > 1$ would be the signature of a violation of the weak energy condition and that it also implies an effective negative surface-mass density.

In our investigation we have found the presence of a pseudocaustic in the $n = 0$ limit and that an elliptic umbilic catastrophe exists for $mn < 1$. We derive analytical and numerical approximations

for the three cases analyzed (close, intermediate and wide separation) in order to have a deeper understanding in the caustic evolution, in its shape and size.

The model described here is able to open a new channel in the search for these mysterious objects when they appear in a non-isolated environment.

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Looking at quantization of a wave function, from Weber(1961), to signals from wavefunctions at the mouth of a wormhole

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We utilize how Weber in 1961 initiated the process of quantization of early universe fields to the problem of what may be emitted at the mouth of a wormhole. While the wormhole models are well developed, there is as of yet no consensus as to how, say GW or other signals from a wormhole mouth could be quantized, or made to be in adherence to a procedure Weber cribbed from Feynman, in 1961.
In addition, we utilize an approximation for the Hubble parameter parameterized from Temperature using Sarkar's H ~ Temperature relations, as given in the text . Finally after doing this we go to the Energy as E also ~ Temperature, and from there use E (energy) as ~ signal frequency. This gives us an idea of how to estimate frequency generated at the mouth of a wormhole.

Wormholes, Energy Conditions and Time Machines / 1026

Symmetries and geometric spacetime: towards a new paradigm

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In this talk the geometrical methods and symmetry principles in gravitation are explored motivating a new perspective into the spacetime paradigm. The effects of post-Riemann spacetime geometries with torsion are briefly studied in applications to fundamental fermionic and bosonic fields, cosmology, astrophysics and gravitational waves. The physical implications and related phenomenological considerations are addressed, and the fundamental ideas related to spacetime physics, motivated by geometrical methods and symmetry principles, are also discussed in the context of the possible routes towards a new spacetime paradigm in gravitation and unified field theories.

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Hyper-Fast Positive Energy Warp Drives

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Solitons in space–time capable of transporting time-like observers at superluminal speeds have long been tied to violations of the weak, strong, and dominant energy conditions of general relativity. This talk presents an approach to identify soliton solutions capable of superluminal travel that are sourced by purely positive energy densities. This is the first example of hyper-fast solitons satisfying the weak energy condition, reopening the discussion of superluminal mechanisms rooted in conventional physics. Remaining challenges to autonomous superluminal travel are also discussed, such as the dominant energy condition, horizons, and the identification of a creation mechanism.

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Shadows and photon rings of asymmetric thin-shell wormholes

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considering the asymmetric thin-shell wormhole (ATSW) model, we find that the impact parameter of the null geodesics is discontinuous through the wormhole in general and hence we identify novel shadows whose sizes are dependent of the photon sphere in the other side of the spacetime. Furthermore, we shoe evident additional photon rings from the ATSW spacetime. Moreover, a potential lensing band between two highly demagnified photon rings is found. Our analysis provides an optically observational signature to distinguish ATWs from black holes.

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A singularity theorem for evaporating black holes

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The classical singularity theorems of General Relativity rely on energy conditions that are easily violated by quantum fields. In this talk I will provide motivation for an energy condition obeyed by semiclassical gravity: the smeared null energy condition (SNEC), a proposed bound on the weighted average of the null energy along a finite portion of a null geodesic. I will then then present the proof of a semiclassical singularity theorem using SNEC as an assumption. This theorem extends the Penrose theorem to semiclassical gravity and has interesting applications to evaporating black holes.
The talk is based on arXiv:2012.11569

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Would we know a wormhole if we saw one?

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I will discuss the observational appearance of wormholes if they were observed by a very long baseline interferometry (VLBI) array such as the Event Horizon Telescope, or some more powerful future VLBI array. Certain properties, like change of the diameter of the critical curve with respect to the Kerr black hole of the same mass are difficult to interpret given typically poor constraints we have on observed object mass and distance, others, like minor deviation of the critical curve shape, would be likely hidden away by uncertainties such as the unknown spin axis inclination with respect to a distant observer. However, not all hope is lost. Topological differences, such as presence of multiple critical curves corresponding to several photon shells (at two sides of the wormhole, or possibly also at the wormhole throat) could be detected without too many doubts. I will describe how capabilities of future VLBI instruments could possibly allow us to detect a wormhole, if we saw one.

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Gravitational Waves Generated by a Slowly Rotating Wormhole

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In this talk, the gravitational wave generation by a slowly rotating wormhole with radially pulsating throat is considered. Two types of rotating wormholes are used as the model of the wave generation: the slightly rotating Ellis wormhole and the thin-shell wormhole. The later was made from two Kerr black hole solutions. To treat the problem, the assumption of the slightly rotating is validated by the ranges of the mass. We calculated the strain amplitudes and the powers emitted in gravitational wave for each cases and life times of the wormhole through the radiation.

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Tractor beams, pressor beams, and stressor beams within the context of general relativity.

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Both wormholes and warp drives, concepts originally developed within the context of science fiction, have now (for some 30 odd years) been studied and carefully analyzed within the framework of general relativity. An overarching theme of the general relativistic analysis is unavoidable violations of the classical energy conditions. Another science fiction trope, now over 80 years old, is the tractor beam and/or pressor beam. I shall discuss how to formulate both tractor beams and/or pressor beams, and a variant to be called a stressor beam, within the context of reverse engineering the spacetime metric. (While such reverse engineering is certainly well beyond our civilization's current capabilities, we shall be more interested in asking what an arbitrarily advanced civilization might be able to accomplish.) We shall see that tractor beams and/or pressor beams can be formulated by suitably modifying the notion of warp drives, and that, as for wormholes and warp drives, violations of the classical energy conditions are utterly unavoidable.

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From black-bounce to traversable wormhole, and beyond

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A recently proposed interesting class of black hole mimickers are the so-called "black-bounce" spacetimes. In static spherical symmetry, a candidate spacetime was explored which neatly interpolates between a classical Schwarzschild black hole, a regular black hole, and a traversable wormhole depending on the value of an additional scalar metric parameter. Since this analysis, the discourse surrounding "black-bounce" spacetimes has been exported into many varied contexts, exploring qualitatively different physical and geometrical frameworks. These include spherical symmetry with dynamics, axisymmetry, models inspired by the Fan–Wang mass function, and finally the full family of charged rotating black-bounce spacetimes, analogous to the classical Kerr–Newman black holes. Beyond analysing the qualitative features of each of these candidate spacetimes and extracting astrophysical observables for observational astronomers, a new look at developing a minimally modified alternative theory of gravity where the black-bounce spacetimes are vacuum solutions is discussed.

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Scalar absorption: Black holes versus wormholes

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We study the absorption of massless scalar waves in a geometry that interpolates between the Schwarzschild solution and a wormhole that belongs to the Morris-Thorne class of solutions. In the middle of the interpolation branch, this geometry describes a regular black hole. We use the partial wave approach to compute the scalar absorption cross section in this geometry. Our results show that black holes and wormholes present distinctive absorption spectra. We conclude, for instance, that the wormhole results are characterized by the existence of quasibound states which generate Breit-Wigner-like resonances in the absorption spectrum.

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Particle creation by wormholes: a toy model.

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Taking advantage of the simplicity of the quantum field theory of a free massless scalar field in 1+1 dimensions, a toy model that explores the effects of the interaction of wormholes and quantum fields is constructed. The conditions for the existence of quantum particle production are discussed in terms of the symmetries of the two-point function of the scalar field theory.

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Traversable wormhole geometries in symmetric teleparallel gravity

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The current interests in the universe motivate us to go beyond Einstein's General theory of relativity. One of the interesting proposals comes from a new class of teleparallel gravity named symmetric teleparallel gravity, i.e., $f(Q)$ gravity, where the non-metricity term Q is accountable for fundamental interaction. These alternative modified theories of gravity's vital role are to deal with the recent interests and to present a realistic cosmological model. This manuscript's main objective is to study the traversable wormhole geometries in $f(Q)$ gravity. We construct the wormhole geometries for three cases: (i) by assuming a relation between the radial and lateral pressure, (ii) considering phantom energy equation of state (EoS), and (iii) for a specific shape function in the fundamental interaction of gravity (i.e. for linear form of $f(Q)$). Besides, we discuss two wormhole geometries for a general case of $f(Q)$ with two specific shape functions. Then, we discuss the viability of shape functions and the stability analysis of the wormhole solutions for each case. We have found that the null energy condition (NEC) violates each wormhole model which concluded that our outcomes are realistic and stable. Finally, we discuss the embedding diagrams and volume integral quantifier to have a complete view of wormhole geometries.

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Double-layer wormholes in quadratic hybrid metric-Palatini gravity

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In this work, we explore the existence of traversable wormhole solutions supported by double-layer thin-shells and satisfying the Null Energy Condition (NEC) throughout the whole spacetime, in a quadratic form of the generalized hybrid metric-Palatini gravity. We start by showing that for a particular quadratic form of the action, some of the junction conditions of the theory can be discarded without the appearance of undefined distribution terms in the field equations. As a consequence, a double-layer thin-shell arises at the separation hypersurface. We then outline a general method to find traversable wormhole solutions satisfying the NEC at the throat and provide an example. Finally, we use the previously derived junction conditions to match the interior wormhole solution to an exterior vacuum and asymptotic flat solution, thus obtaining a full traversable wormhole solution supported by a double-layer thin-shell and satisfying the NEC. Unlike the wormhole solutions previously obtained in the scalar-tensor representation of this theory, which were scarce and required fine-tuning, the solutions obtained through this method are numerous and exist for a wide variety of metrics and actions.

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Wormhole geometries induced by action-dependent Lagrangian theories

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In this work, we explore wormhole geometries in a recently proposed modified gravity theory arising from a non-conservative gravitational theory, tentatively denoted action-dependent Lagrangian theories. The generalized gravitational field equation essentially depends on a background four-vector λ^μ, that plays the role of a coupling parameter associated with the dependence of the gravitational Lagrangian upon the action, and may generically depend on the spacetime coordinates. Considering wormhole configurations, by using "Buchdahl coordinates", we find that the four-vector is given by $\lambda_\mu = (0, 0, \lambda_\theta, 0)$, and that the spacetime geometry is severely restricted by the condition $g_{tt}g_{uu} = -1$, where u is the radial coordinate. We find a plethora of specific asymptotically flat, symmetric and asymmetric, solutions with power law choices for the function λ, by generalizing the Ellis-Bronnikov solutions and the recently proposed black bounce geometries, amongst others. We show that these compact objects possess a far richer geometrical structure than their general relativistic counterparts.

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Public lecture: IceCube: Cosmic Neutrinos and Multimessenger Astronomy

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IceCube detects more than 100,000 neutrinos per year in the GeV to 10 PeV energy range. Among those, we have isolated a flux of high-energy neutrinos of cosmic origin, with an energy densityin the extreme universe similar to that of high-energy photons and cosmic rays.We identified their first source:on September 22, 2017, following an IceCubeneutrino alert, observations by other astronomical telescopes pinpointed a flaring active galaxy, powered by a supermassive black hole, as the source of a cosmic neutrino with an energy of 290 TeV. We will review recent progress in measuring the cosmic neutrino spectrum and in identifying its origin.

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Public lecture: Diverse Production Sites of Cosmic and Gamma-Rays Discerned Through Selected Observations of MAGIC

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MAGIC is the pioneering imaging air Cherenkov telescopes (IACT) instrument, which started performing high-sensitivity measurements in the sub-200 GeV energy range, down to few 10s of GeVs.

Since 2009 MAGIC is operating as a double system of 17m diameter IACTs for performing astrophysical measurements in the very high energy range 30GeV – 100TeV. In recent years, by using novel observation techniques, we further enhanced the sensitivity of MAGIC both at the lowest energies of 20-30 GeV as well as at the highest energy of ~100TeV. The very high sensitivity is allowing us to perform original studies, deepening our understanding of selected important aspects of the Universe. In this report we want to show selected observational results of MAGIC of both galactic and extragalactic origins. These, supported by multi-messenger and multi-wavelength measurements, help us to discern and learn important details about the possible production sites of cosmic and gamma rays.

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Public lecture: The neutrino in stellar evolution and in the Sun

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Motivated in part by the recent measurements of the Borexino Collaboration, I will describe the current status of solar neutrino physics, including the impact of measurements on our knowledge of neutrino properties. Questions remain about the sun's metallicity and the equivalence of its weak and electromagnetic luminosities — topics relevantly, respectively, to early solar evolution and to possible "new physics" tests involving solar neutrinos. Additional aspects of the flavor mixing first identified through solar and atmospheric neutrino experiments arise in explosive astrophysical environments, such as supernova cores, neutron star mergers, and the Big Bang. I will describe some of the associated open issues and how they affect current efforts to better characterize such environments through "multi-messenger" observations and analysis.

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Public lecture: The long-lived X-ray counterpart of GW170817

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Our understanding of compact binary mergers was transformed by the spectacular discovery of GW170817, the first neutron star merger observed through gravitational waves and light. The electromagnetic counterpart of GW170817 was initially dominated by a luminous kilonova, peaking at optical and then infrared wavelengths. At 9 days, we detected in X-rays the onset of a different component of emission, best described as non-thermal afterglow radiation from a structured relativistic jet viewed off-axis. I will review the current status of observations of GW170817 and show that the X-ray counterpart continues to be detected at 3.3 years after the merger. Such long-lasting signal is not a natural prediction of the structured jet model and is spurring a renewed interest in the origin of the X-ray emission. I will discuss possible interpretations of the long-lived X-ray counterpart and how future observations could break the degeneracy between models.