

# **18th Italian-Korean Symposium on Relativistic Astrophysics**

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## **Book of Abstracts**



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## Cosmology with Gamma-Ray Bursts (online talk)

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The huge luminosity, the redshift distribution extending at least up to  $z \sim 10$  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 probes for shedding light on main open issues in our understanding of the early Universe: star formation rate evolution up to the first generation of stars (pop-III), cosmic reionization, luminosity function and metallicity evolution of primordial galaxies up to the "cosmic dawn". At the same time, the correlation between radiated energy and spectral photon peak energy ("Amati relation" is under intensive investigations for "standardizing" GRBs and using them for measuring cosmological parameters, investigating the nature and evolution of "dark energy" and testing non-standard cosmological models. I will also report on the status, concepts and expected performances of space mission projects (e.g., THESEUS) aiming at fully exploiting these potentialities of the GRB phenomenon, also in synergy with the large e.m. facilities of the future like LSST, ELT, TMT, SKA, CTA, ATHENA

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## Study of Decoupled Cosmological Solutions in $f(R,T)$ Theory (online talk)

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In this paper, we consider a non-static spherical geometry and formulate its extension for the case of anisotropic matter configuration through minimal gravitational decoupling in curvature-matter coupled gravity. We apply a particular transformation only on the radial metric function that divides the modified field equations into two distinct sectors corresponding to their parent (original and additional) sources. The unknowns in the first (isotropic) set are reduced by taking the Friedmann-Lemaître-Robertson-Walker cosmic model. We then obtain the isotropic solution by employing a linear equation of state and power-law form of the scale factor. The other set involves the decoupling function and components of an extra source, therefore we adopt a density-like constraint to close it. Finally, we analyze the role of this modified gravity and the decoupling parameter on three different eras of the cosmos by graphically observing the developed extended solution. It is concluded that the resulting solutions fulfill all the physical requirements only for the matter and radiation-dominated eras.

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## Constraining the neutron star critical mass with long gamma-ray bursts

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The binary-driven hypernova (BdHN) model explains long GRBs associated with type Ic supernovae (SNe) with a binary composed of a carbon-oxygen (CO) star and a neutron star (NS) companion in close orbit. The CO core-collapse SN generates a newborn NS (new-NS) at its center and ejects the CO outer layers. This process triggers the GRB, starting from the accretion of ejecta onto the new-NS (via fallback) and the NS companion. We use a new, improved version of the numerical code for BdHN 3D simulations, which evolves the accreting NS in full general relativity for realistic nuclear equations of state (EOS). We shall catalog the outcome for different CO mass, NS mass, SN explosion energy and anisotropy, and orbital separations (periods) for various EOS to use GRB statistics to constrain the NS critical mass so the nuclear EOS. We also discuss additional astrophysical consequences of our calculations.

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## Detection of gravitational waves by electromagnetic cavity: a review

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Gravitational wave (GW) detection using electromagnetic (EM) cavities has garnered significant attention in recent years. With ongoing experiments on axion detection using highly sensitive electromagnetic cavity, there is potential to apply these existing facilities to GW detection, opening up a new channel of GW observation. In this review, we comprehensively examine the principles of GW detection using EM cavities within the framework of general relativity. We expect that it not only provides analysis of existing EM cavity experiments and but also offers insights for the design of new ones.

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## Discretized Finsler-Hamilton Structure: a framework to quantize the general relativity (online talk)

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To reconcile principles of general relativity (GR) and quantum mechanics (QM), differential and quantum geometry, duality-symmetry configurations of distance and momentum, the Born reciprocity principle (BRP), and noncommutative algebra, especially the relativistic generalized uncertainty principle (RGUP), are simultaneously applied on GR and QM. The latter integrates gravitational fields in the fundamental theory of QM. The earlier extends the four-dimensional Riemann to eight-dimensional Finsler-Hamilton geometry. The resulting structure is then characterized by coordinates and directions coupled to the momenta of a free particle,  $\hat{x}_0^\mu$  and  $\hat{p}_0^\nu$ , respectively. With RGUP, the momentum operator  $\hat{p}_0^\nu$  is modified to  $\phi \hat{p}_0^\nu$ , so that the resulting discretized Finsler-Hamilton structure  $F(\hat{x}_0^\mu, \phi \hat{p}_0^\nu)$  is also 1-homogeneous in  $\hat{p}_0^\nu$ . The quantity  $\phi = 1 + \beta \hat{p}_0^\rho \hat{p}_{0\rho}$ , which exclusively depends on  $\hat{p}_0^\nu$ , is 0-homogeneous. The corresponding metric tensor could be deduced from the Hessian of  $F^2(\hat{x}_0^\mu, \phi \hat{p}_0^\nu)$ .

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## Searching for Dark Matter with White Dwarves

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Weakly interacting massive particles (WIMPs) can be captured in compact stars such as white dwarves (WDs) if they are in a dark matter-rich environment, leading to an increase in the star luminosity through their annihilation process. I will show that if the WIMP interacts with nuclear targets through inelastic scattering the data on low-temperature large-mass WDs in the Messier 4 globular cluster can probe a part of the WIMP parameter space not accessible by terrestrial direct detection searches and from solar neutrino searches. I will discuss this new class bounds in the specific WIMP scenario of a self-conjugate bidoublet in the left-right symmetric model (LRSM), introduced to explain maximal parity violation in weak interactions, showing that it significantly reduces its cosmologically viable parameter space.

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## Light from a quasar interacting with gravitational waves: a geometrical-optics analysis

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We consider a situation in which a quasar contains a source of gravitational waves (e.g. binary black holes) and electromagnetic waves from the quasar interact with gravitational waves from the source. The effect will be appreciable if the interaction initially takes place close to the source of gravitational waves where the strain amplitude can be large. This situation can be modeled effectively using spherical gravitational waves (rather than plane-fronted gravitational waves); i.e., transverse-traceless radially propagating waves, with the strain amplitude varying by the distance between the source and an observer. Our analysis employs geometrical-optics methods in curved spacetime and a particular focus is placed on the effect of gravitational Faraday rotation (or Skrotskii/Rytov effect) resulting from the interaction between light from a quasar and spherical gravitational waves from binary black holes within the quasar.

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## Massive particle pair production and oscillation in Friedman Universe: its effect on inflation

**Author:** She-Sheng Xue<sup>1</sup>

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We study the classical Friedman equations for the time-varying cosmological term  $\tilde{\Lambda}$  and Hubble function  $H$ , together with quantised field equations for the production of massive  $M \gg H$  particles, namely, the  $\tilde{\Lambda}$ CDM scenario of dark energy and matter interactions. Classical slow

components  $\mathcal{O}(H^{-1})$  are separated from quantum fast components  $\mathcal{O}(M^{-1})$ . The former obeys the Friedman equations, and the latter obeys a set of nonlinear differential equations. Numerically solving equations

for quantum fast components, we find the production and oscillation of massive particle-antiparticle pairs in microscopic time scale  $\mathcal{O}(M^{-1})$ . Their density and pressure averages over microscopic time do not vanish.

It implies the formation of a massive pair plasma state in macroscopic time scale  $\mathcal{O}(H^{-1})$ , whose effective density and pressure contribute to the Friedman equations. Considering the inflation driven by the time-varying cosmological term and slowed down by the massive pair plasma state, we obtain the relation of spectral index and tensor-to-scalar ratio in agreement with recent observations. We discuss the singularity-free pre-inflation, the CMB large-scale anomaly, and dark-matter density perturbations imprinting on power spectra.

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## The mirage of luminal modified gravitational-wave propagation

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Using conformal invariance of gravitational waves, we show that for a luminal modified gravity theory, the gravitational-wave propagation and luminosity distance are the same as in general relativity. The relation between the gravitational-wave and electromagnetic-wave luminosity distance gets however modified for electromagnetism minimally coupled to the Jordan frame metric. Using effective field theory we show that the modified relation obtained for luminal theories is also valid for non-luminal theories with Jordan frame matter-gravity coupling. We generalise our analysis to a time-dependent speed of gravitational waves with matter minimally coupled to either the Jordan or Einstein frame metrics.

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## Schwinger pair production in relativistic plasma

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We consider pair production in uniform electric field in presence of electron-positron plasma. Depending on initial pair distribution in momentum space pairs are either created or annihilated in external field. Pairs are either created or annihilated depending on their initial distribution. We show that electric field cannot be enhanced by inverse Schwinger process.

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## Asymptotic electromagnetic field of a charged particle, radially falling onto a Schwarzschild black hole

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We determine multipole coefficients of electromagnetic field for charged particle, radially falling into Schwarzschild black hole by approximating the Regge-Wheeler potential by the Dirac delta-function. Considering the limit when the particle is approaching the event horizon of the black hole we show analytically that all multipoles except for the monopole vanish exponentially fast.

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## Probing electromagnetic-gravitational wave emission coincidence in type I binary-driven hypernova family of long GRBs at very-high redshift (online talk)

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Due to the technical time delay of the XRT instrument on board the Neil Gehrels Swift Observatory satellite, we cannot observe the X-ray emission occurring less than  $\sim 40$  s after a gamma-ray burst (GRB) trigger time. We here indicate a new strategy of using the cosmological time dilatation in high redshift GRBs to observe the earliest X-ray emission by Swift/XRT in the GRB cosmological rest-frame. We illustrate this procedure using 354 GRBs with a well-defined cosmological redshift selected from the Swift GRB catalog. We compare and contrast the time delay between the trigger of the source and the first observation by Swift/XRT as measured in the observer frame (OTD) and the corresponding delay measured in GRBs' cosmological rest-frame (RTD). We consider as specific prototypes three binary-driven hypernovae of type I (BdHNe I): GRB 090423 at  $z=8.2$  with an RTD of 8.2 s, GRB 090429B at  $z\sim 9.4$  with an RTD of 10.1 s, as well as the GRB 220101A at  $z=4.6$  with an RTD of 14.2 s. This opens a new possibility for probing Episode (1) of BdHNe, linked to the origin and early appearance of the newborn neutron star (vNS) and its transition from a Jacobi triaxial ellipsoid (JTE) to a Maclaurin spheroid configuration that originates the GRB afterglow onset. We also present the methodology to compute the sweeping frequencies and the energetics of the associated conspicuous gravitational wave emission.

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## GRB220101A the most powerful GRB with seven BdHN Episodes observed

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## Properties of a rotating black hole with anisotropic matter fields

**Author:** Wonwoo Lee<sup>None</sup>

We report the charged rotating black hole with an additional matter field. The geometry is obtained by adopting the Newman-Janis algorithm, and the solution of Maxwell fields is also obtained by that. We discuss the properties of that rotating black hole with the energetics, black hole shadow, and others.

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## Are we prepared to observe the next Galactic Supernova? (online talk)

Optical surveys have been proven inefficient in detecting Supernovae events in our galaxy. In the face of 7 expected core-collapse SNe in the last 4 centuries, zero SNe have actually been observed. Present and future neutrino telescopes such as Super-Kam or Hyper-Kam have the capabilities to observe large numbers of neutrinos from SNe occurring inside the Milky Way and Local Group of Galaxies, respectively.

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## Constraining the neutron star critical mass with long gamma-ray bursts

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The binary-driven hypernova (BdHN) model explains long GRBs associated with type Ic supernovae (SNe) with a binary composed of a carbon-oxygen (CO) star and a neutron star (NS) companion in close orbit. The CO core-collapse SN generates a newborn NS (new-NS) at its center and ejects the CO outer layers. This process triggers the GRB, starting from the accretion of ejecta onto the new-NS (via fallback) and the NS companion. We use a new, improved version of the numerical code for BdHN 3D simulations, which evolves the accreting NS in full general relativity for realistic nuclear equations of state (EOS). We shall catalog the outcome for different CO mass, NS mass, SN explosion energy and anisotropy, and orbital separations (periods) for various EOS to use GRB statistics to constrain the NS critical mass so the nuclear EOS. We also discuss additional astrophysical consequences of our calculations.

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## Introduction to Space Science Activities in Korea

**Author:** Dong-hun Lee<sup>None</sup>

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## Some Modified Gravity Models and Cosmological Implications

**Author:** Bum-Hoon Lee<sup>None</sup>

Recent precise measurements suggest the needs beyond the standard lambda CDM cosmological model. We specifically consider gravity with the additional Gauss-Bonnet higher curvature term and study some astrophysical and cosmological implications.

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## Exploring the Progenitor of the Crab Nebula and Crab Pulsar: Insights from Binary-Driven Hypernovae (online talk)

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We propose that the progenitor of the Crab Nebula and the Crab pulsar shares similarities with binary-driven hypernovae. The understanding of binary-driven hypernovae has revealed the crucial role played by the explosion of the supernova, as well as the hypercritical accretion of the supernova ejecta onto the binary companion neutron star (NS) and the newborn NS (vNS) in determining the dynamics of gamma-ray bursts (GRBs). The synchrotron emission resulting from the vNS-pulsar emission and the accreted supernova ejecta onto the vNS gives rise to X-ray afterglows. Notably, we find evidence that the X-ray afterglow luminosity of GRB 190114C, selected as a prototype binary-driven hypernova, when extrapolated to 1000 years, coincides with the presently observed emission of the Crab Nebula. To model the vNS, we employ the equilibrium sequence of Maclaurin spheroids. By ensuring that the vNS period extrapolated to 1000 years matches that of PSR B0531+21 (the Crab pulsar), we determine the initial spin of the vNS to be 0.9 ms. Subsequently, we track the evolution of the eccentricity, which manifests itself through the release of rotational and gravitational energy of the vNS-pulsar.

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## Entanglement entropy in expanding universes

**Author:** Chanyong Park<sup>None</sup>

We study the time evolution of entanglement entropy in expanding universes with various matters. To describe expanding universes holographically, we take into account a braneworld moving in an asymptotic AdS space involving a uniform p-brane gas. In the braneworld model, an observer living in the braneworld detects the bulk motion of the braneworld as an expanding universe. We show that the entanglement entropy of expanding universes increases by the volume law in the early time and by the area law in the late time. We further consider the cosmological horizon, which is the border of the visible and invisible universe, and then investigate the time-dependent quantum entanglement between them across the cosmological horizon.

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## Post-Newtonian approximation for a wormhole binary system

**Author:** Sung-Won Kim<sup>None</sup>

We consider a binary system consisting of two traversable wormholes as one of the gravitational wave source candidates. If the two wormholes are far enough apart from each other, they can be treated as point masses, and the properties of gravitational waves generated by the system is very similar to those of a binary compact star system. However, when they approach each other and the system is at the late inspiral state, the finite-size effect becomes very important. When the Post-Newtonian approximation is applied to the wormhole binary system, we have to adopt the effective mass definition from gravitational potential of the wormhole. If the wormhole matters are distributed in delta-function type, wormhole can be considered as the point mass with the effective mass. If matters are distributed differently, such as the power-law, the finite-size effect can be seen using the effective one-body method.

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## Emission from Magnetized Black Holes and KN Black Holes

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Charged black holes have been proposed as a central engine for GRBs. Damour and Ruffini proposed Schwinger mechanism of KN black holes as the central engine [Phys. Rev. Lett. 35, 332 (1975)] while Blandford and Znajek proposed that the magnetic fields surrounding rotating black holes supported by current of disks induce strong electric fields to produce electron-positron pairs for GRBs [Mon. Not. R. Astron. Soc. 179, 433 (1977)]. In this talk, strong field QED effects such as the Schwinger mechanism, vacuum polarization of magnetized black holes [Moss, Stasiak, arXiv:2303.01119, 2023] and KN black holes are studied and possible methods are discussed to probe underlying physical scenarios through observations by space telescopes in the future.

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## The transformation of the rotational energy of a Kerr BH

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We analyze the “ballistic method” of rotational energy extraction from an (extreme) Kerr black hole (BH) by massive particle decay in the BH ergosphere pioneered by Roger Penrose. We focus on the negative energy counterrotating particles in-going to the horizon and evaluate the feedback on the BH irreducible mass ( $\Delta M_{\text{irr}} > |E_1|$ ). The change in irreducible mass is a function of the ratio of the particle mass  $\mu_1$  to the mass of BH. In the limit  $\mu_1/M \rightarrow 0$ ,  $\Delta M_{\text{irr}}/|E_1| \rightarrow \infty$ , all the reduced extractable energy goes into the irreducible mass, resulting in high irreversibility.

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## Examples of Machine Learning in Astrophysics

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I will provide two examples of machine learning applications in astrophysics. The first example is using deep neural networks to test the unification model of active galactic nucleus (AGN). The second example is a comparison between a simple specific neural network and a Fine-Tuned GPT model for the estimation of spectral redshift.

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## Transition from a Riemann ellipsoid to a Mclaurin spheroid: gravitational wave emission and some astrophysical implications (online talk)

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Semi-analytical models of gravitational wave (GW) radiation are constructed following first principles. They are more than mere academic exercises and can be used to compute qualitative and quantitative results. We study a semi-analytical approach to gravitational radiation from rotating ellipsoids (Riemann ellipsoids), whose internal matter is described by a polytropic equation of state. It was found an early period when the GW has an increasing frequency and amplitude. This object is called a chirping ellipsoid (CEL), and its waveform when the polytropic index is close to 3, is almost identical to one of an inspiral binary. The almost perfect match occurs when the mass of the CEL is of the order of the chirp mass of the binary. These CELs are detectable by low-frequency detectors such LISA, Taiji or TianQin. The equivalent binary can be identified with an extreme-mass-ratio inspiral composed of an intermediate-mass black hole and planet-like object or with a double-detached white dwarf. On the other hand, these CELs can be also used to model the post-merger object of BNS merger or a DWD merger. It will be shown the transition from a Riemann ellipsoid to a Mclaurin spheroid. From the conservation of angular momentum and baryonic mass, some parameters of the initial state of the ellipsoid can be obtained. Also, the time it takes the CEL to make the transition can be used to constrain the initial ellipticity of the CEL.

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## An Approach to Quantizing GR (online talk)

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General theory and quantum mechanics are fundamentally very different theories with distinct formulations. Nevertheless, both of them claim to predict how Nature works! The everlasting battle for exploring and understanding the Universe and for privileging a consistent perception of reality is therefore awaiting a consolidator rather than a conqueror. This should be capable of either unifying those two different benchmarks or at least bringing one closer to the other! The latter describes the consolidating approach we are introducing here. We are not suggesting alternatives to GR. Also, we are not aiming at replacing QM by another theory. The present approach preserves the current versions of both theories. The applicability of GR and QM are solely enlarged so that sensical predictions become feasible at all scales. This was only possible when finite gravitational fields are integrated in QM and quantum-mechanical aspects are then properly imposed on GR. We find that the additional curvatures that emerged with the quantization are associated with a maximal proper force, which is apparently related to the quantum-mechanical jumps characterizing the quantized metric tensor.

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**TBD**

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