



Cosmic  
Antennae

# Dynamic Universe

*from Galileo to FAST/Cosmic Antennae*

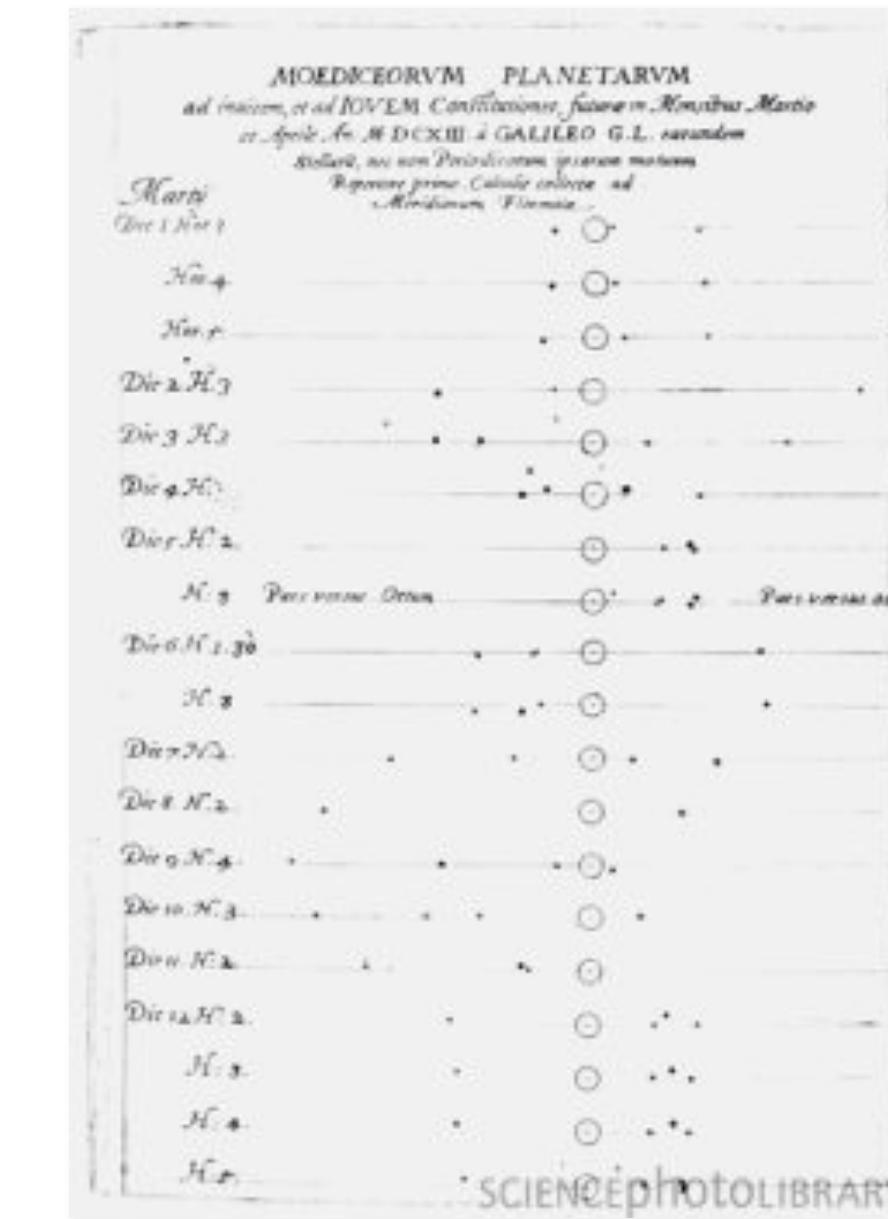
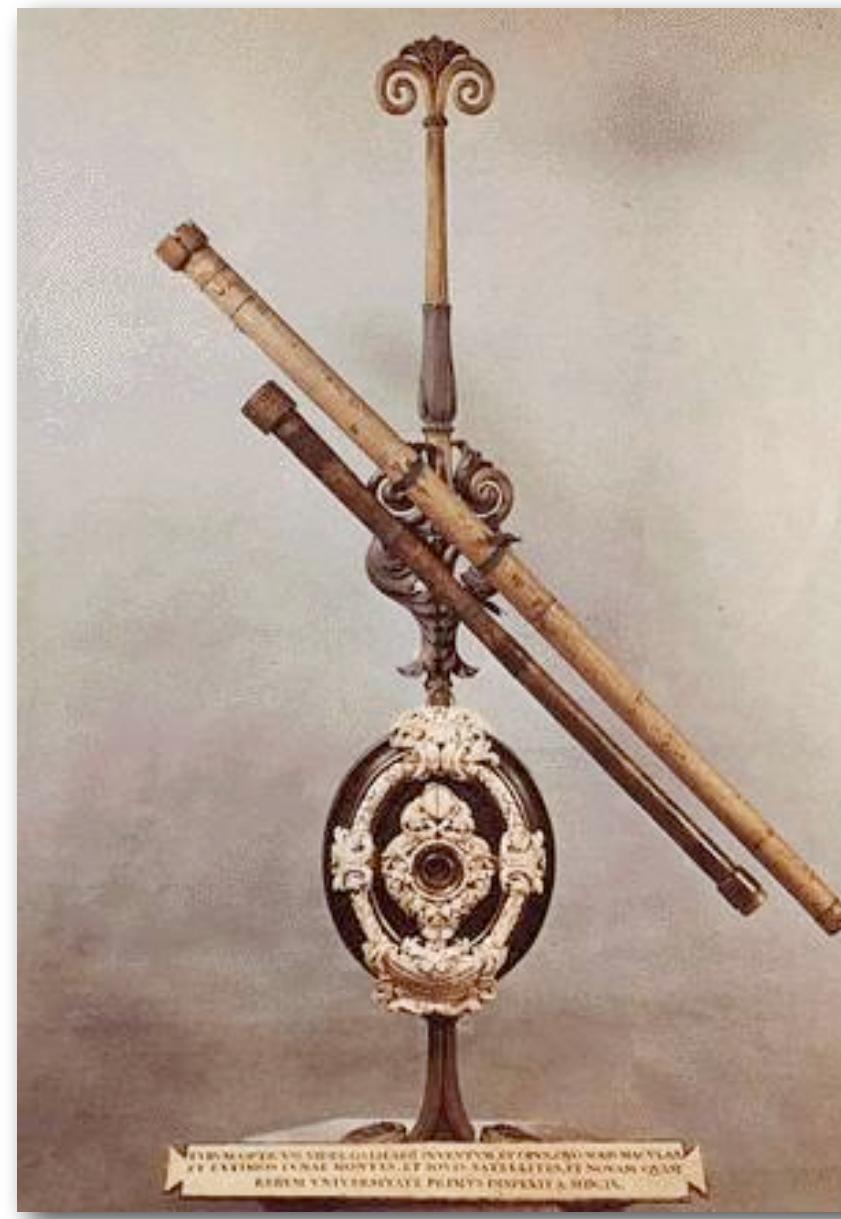
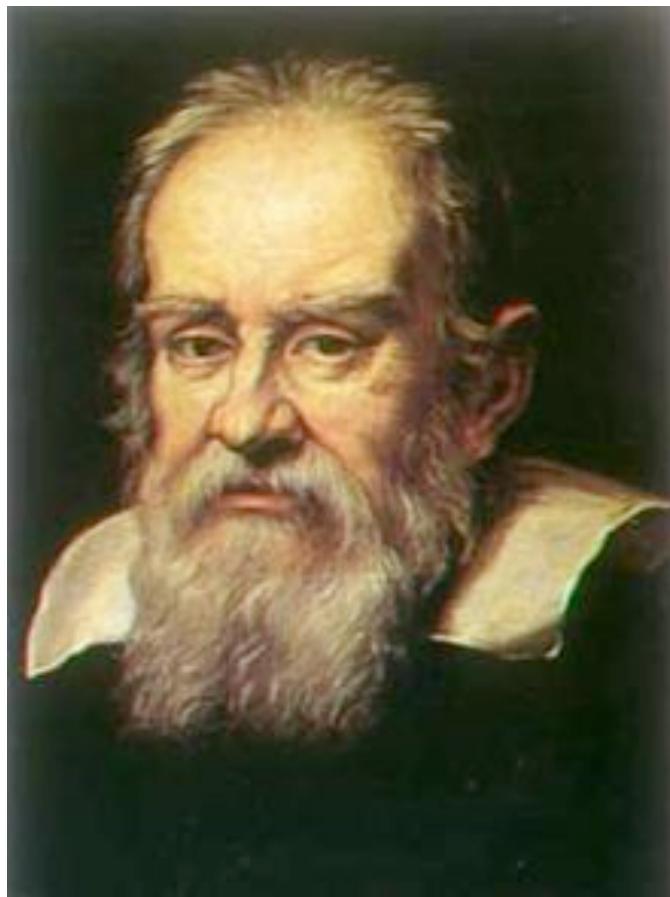
李菂 *Di Li*

清华大学天文系  
Department of Astronomy, Tsinghua University



# Galileo Galilei 伽利略

1564 - 1642 Italian astronomer, physicist and engineer, polymath

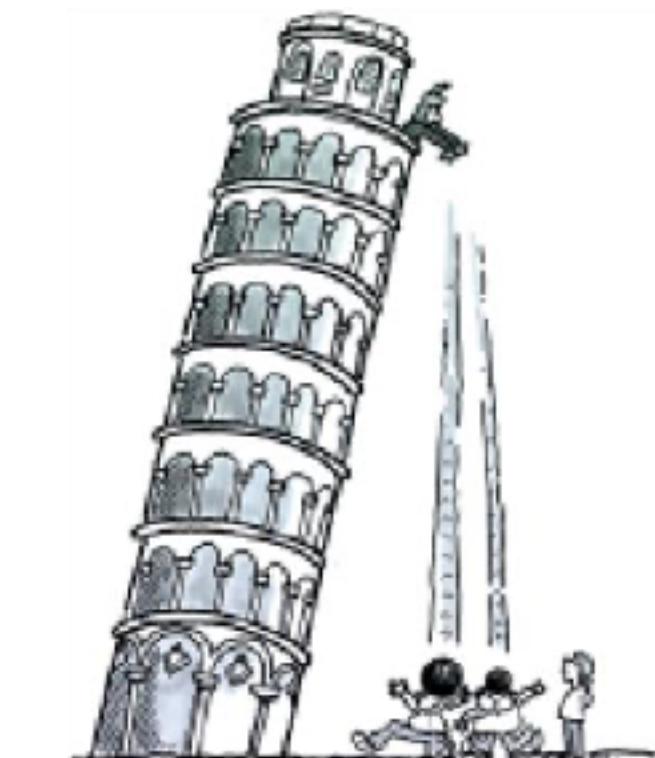


# 宗教裁判所 Inquisition

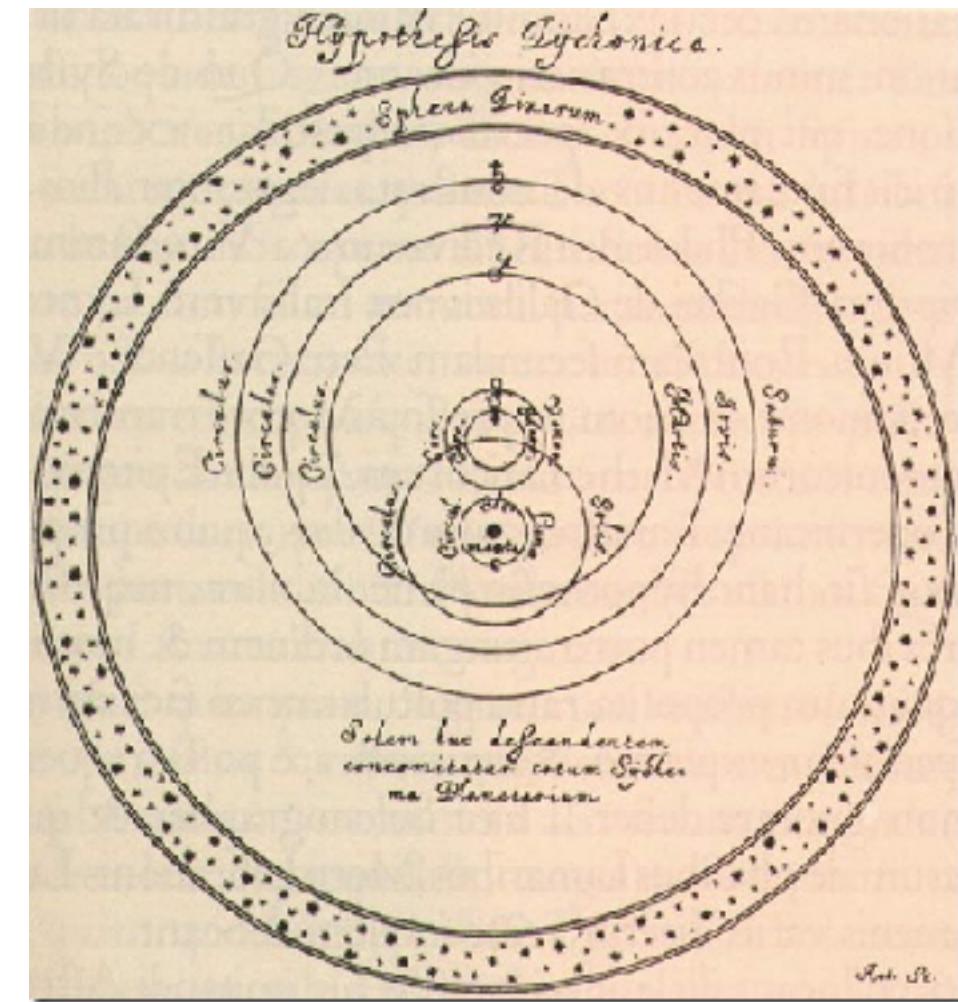


伽利略

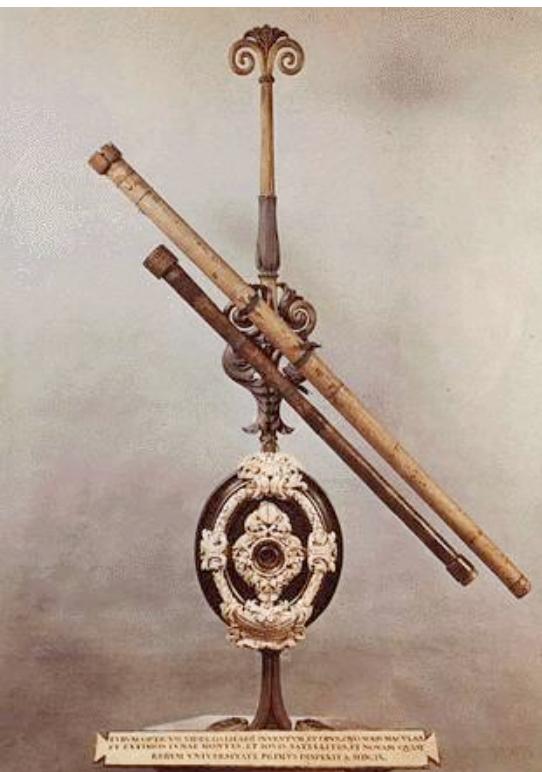
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Audacity  
muove 1633



原理  
Physics

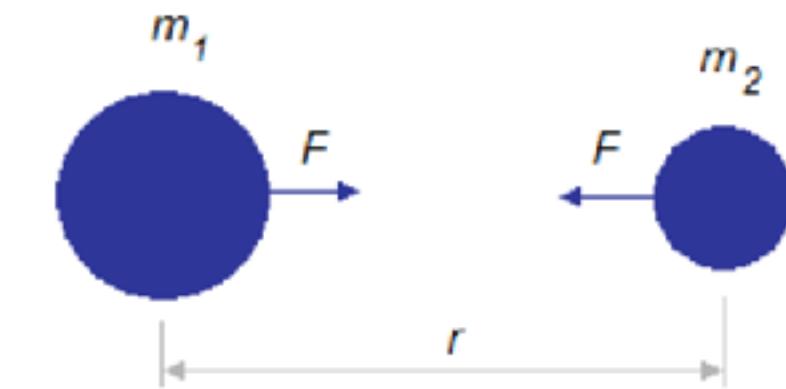
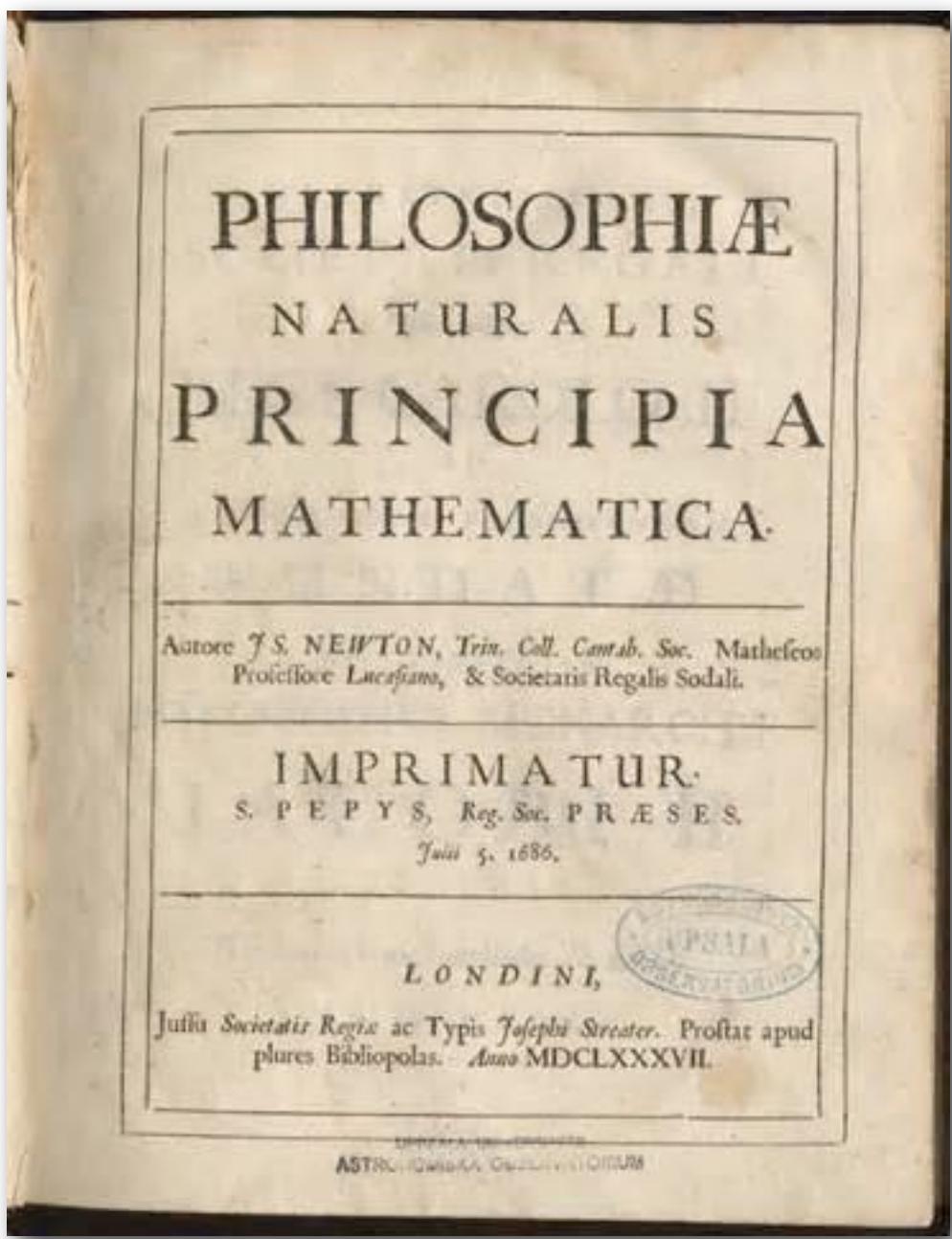


发现  
Astronomy

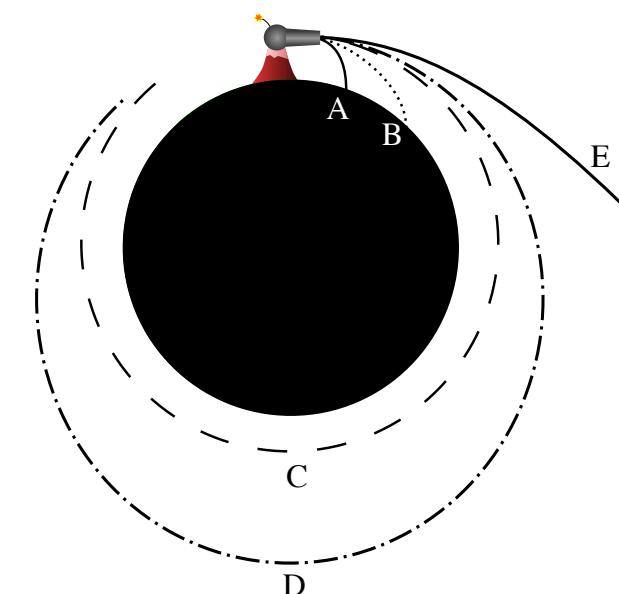


# Newton

(1642 - 1726) mathematician, physicist, astronomer, alchemist, theologian

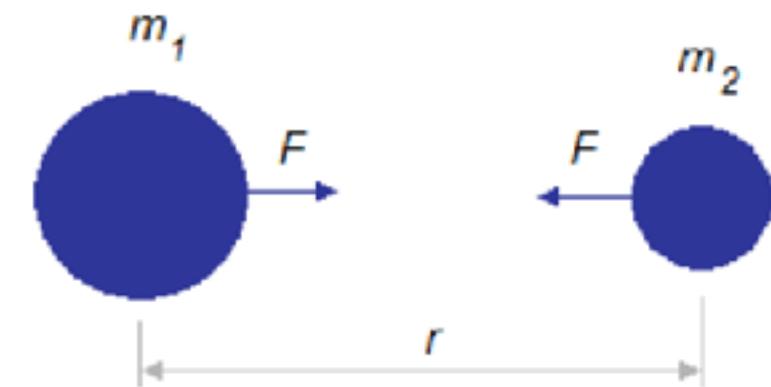
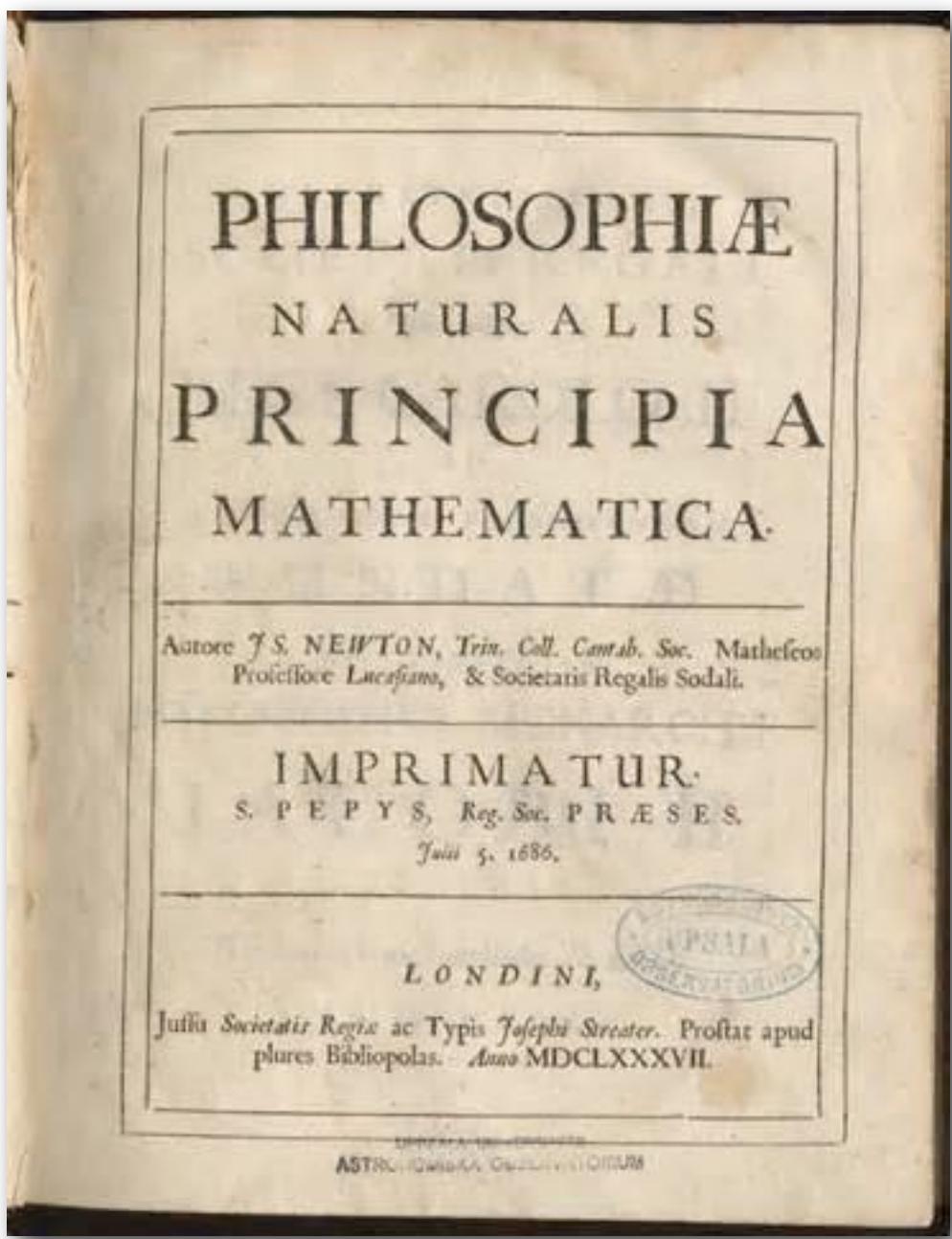


$$F = G \frac{m_1 m_2}{r^2}$$

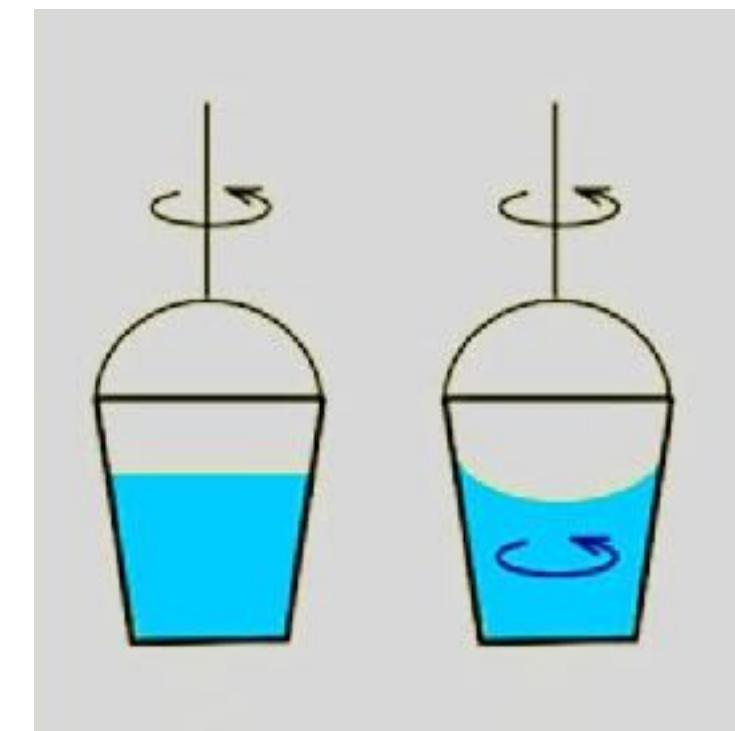


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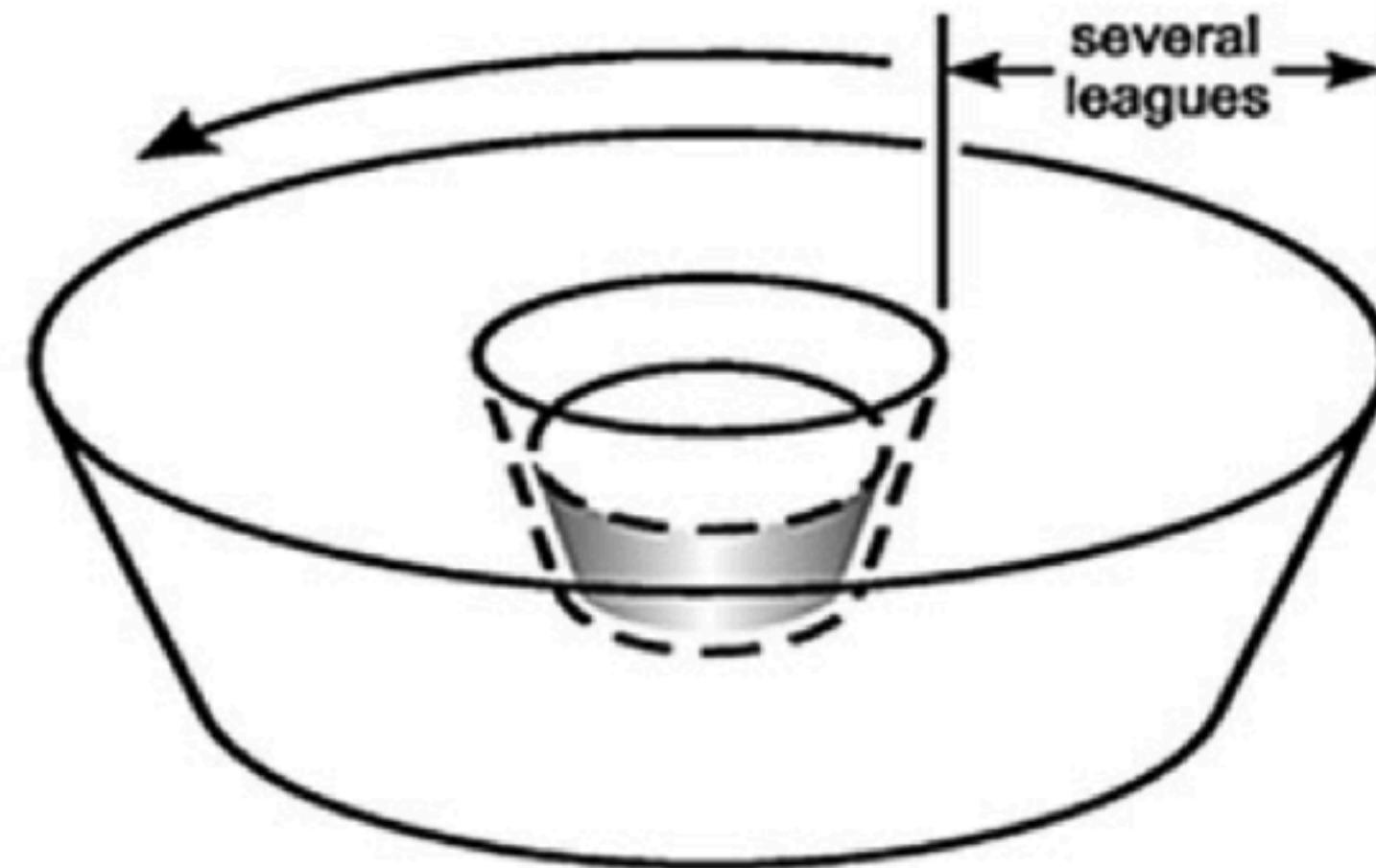


$$F = G \frac{m_1 m_2}{r^2}$$



# Ernst Mach

(1838 - 1916) Austrian German; physicist and philosopher

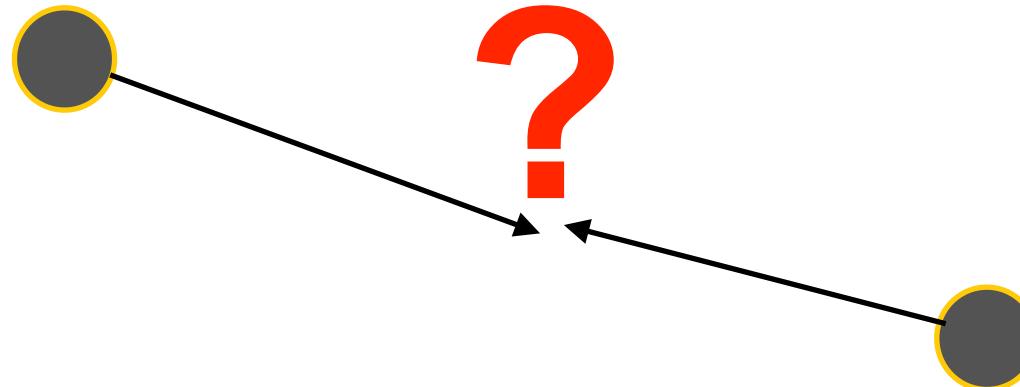
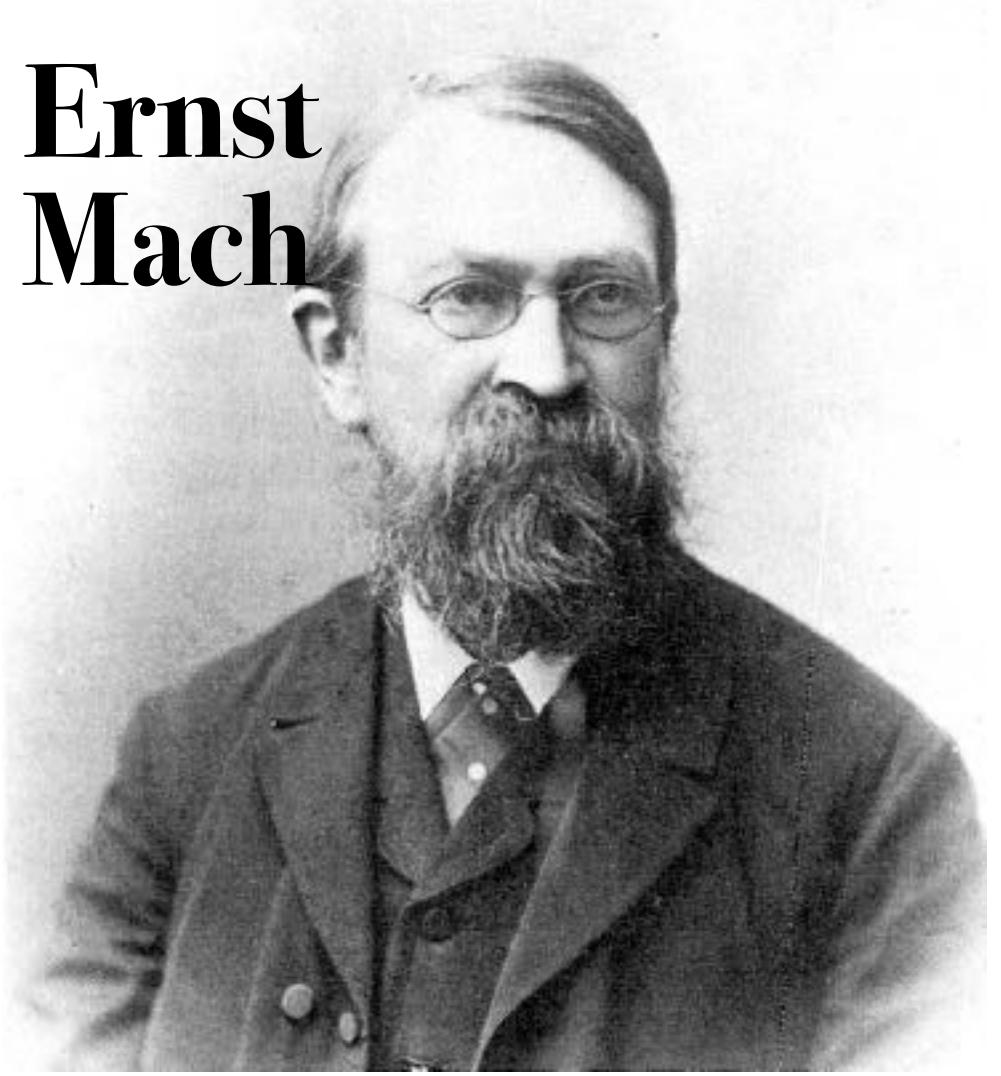


“Space, Time, and Spacetime” edited by Petkov (chapter: Overduin)

Ernst Mach (1838–1916) and his revision of Newton’s bucket experiment: would the water still climb up the walls if the bucket were *arbitrarily large and massive*?

Everitt et al. (2011) "Gravity Probe B: Final Results of a Space Experiment to Test General Relativity"  
*Physical Review Letters.* **106** (22): 221101.

# Ernst Mach



“An empty space, that there is no space field, is non-existent.” — Einstein

«*Relativity: the special and the general theory* » 1916  
(English translation by Robert W. Lawson)



# Max Planck

1858 - 1947 German theoretical physicist

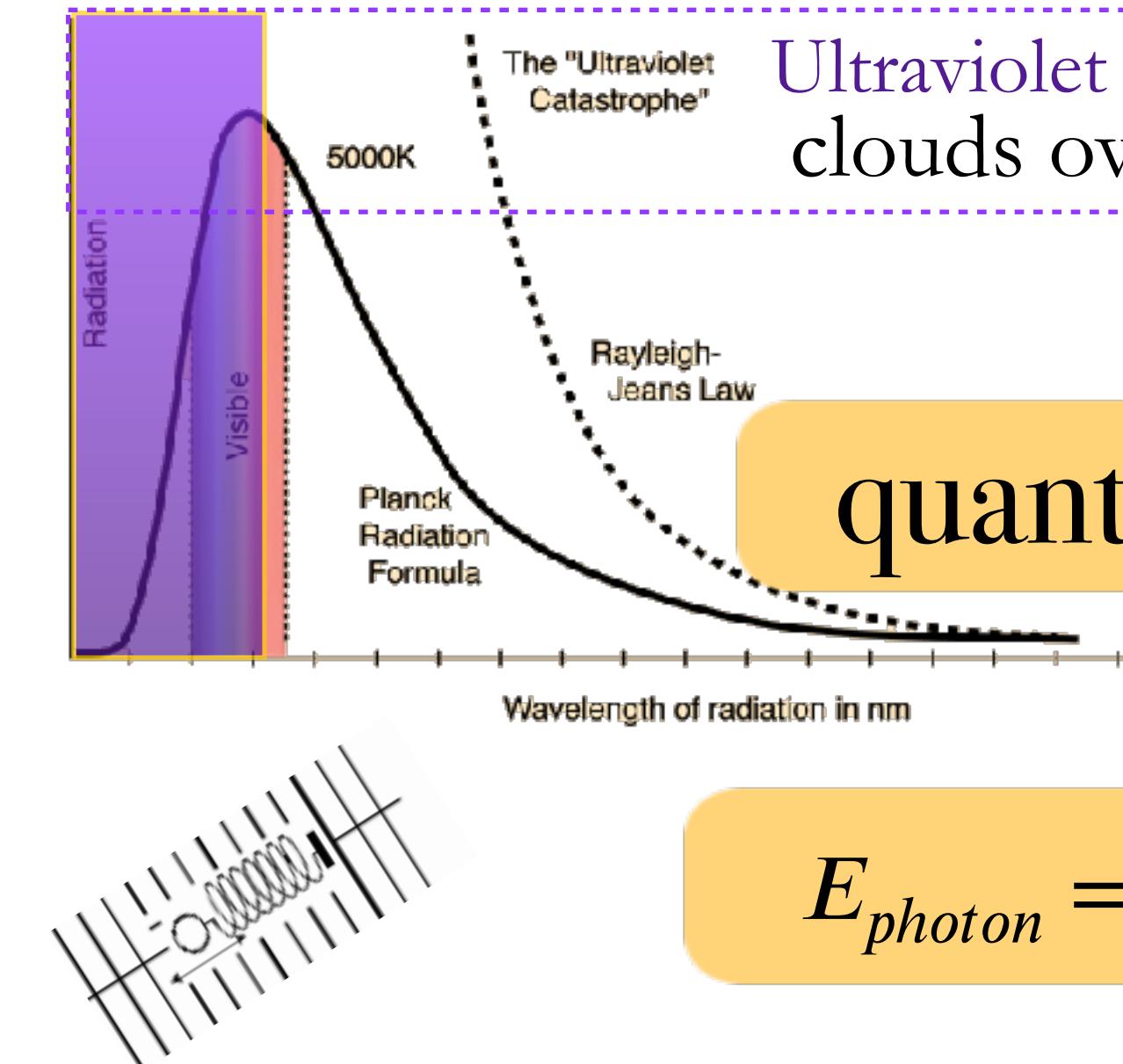


*Ueber eine Verbesserung der Wien'schen Spectralgleichung; von M. Planck.*  
(Vorgelesen in der Sitzung vom 19. October 1900.)  
(Vgl. oben S. 181.)

Die von Hrn. KURLBAUM in der heutigen Sitzung mitgeteilten interessanten Resultate der von ihm in Gemeinschaft mit Hrn. RUEGEN auf dem Gebiete der längsten Spectralwellen ausgeführten Energiemessungen haben die zuerst von den Herren LUMMER und PRINGSHEIM auf Grund ihrer Beobachtungen aufgestellte Behauptung nachdrücklich bestätigt, dass das Wien'sche Energieverteilungsgesetz nicht die allgemeine Bedeutung besitzt, welche ihm bisher von mancher Seite zugeschrieben worden war, sondern dass dies Gesetz vielmehr höchstens den Charakter eines Grenzgesetzes hat, dessen überaus einfache Form nur einer Beschränkung auf kurze Wellenlängen bez. tiefen Temperaturen ihren Ursprung verdankt.<sup>1)</sup> Da ich selber die Ansicht von der Notwendigkeit des Wien'schen Gesetzes auch an dieser Stelle vertreten habe, so sei es mir gestattet, hier kurz darszulegen, wie sich die von mir entwickelte elektromagnetische Theorie der Strahlung zu den Beobachtungsthatsachen stellt.

Nach dieser Theorie ist das Energieverteilungsgesetz bestimmt, sobald die Entropie  $S$  eines auf Bestrahlung ansprechenden linearen Resonators als Function seiner Schwingungsenergie  $U$  bekannt ist. Ich habe indes schon in meiner letzten Arbeit über diesen Gegenstand hervorgehoben<sup>2)</sup>, dass der Satz der Entropievermehrung an und für sich noch nicht hinreicht, um diese Function vollständig anzugeben; zur Ansicht von der Allgemeinheit des Wien'schen Gesetzes wurde ich vielmehr durch eine besondere Betrachtung geführt, nämlich durch die Berechnung einer unendlich kleinen Entropievermehrung eines in einem stationären Strahlungsfelde befind-

1) Auch Hr. PASCHEN hat, wie er mir brieflich mitteilte, ziemlich Abweichungen vom Wien'schen Gesetz festgestellt.  
2) M. PLANCK, Ann. d. Phys. I. p. 180. 1900.



$$E_{\text{photon}} = h\nu$$

$$B_\nu(\nu, T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{h\nu/kT} - 1}$$

# Dynamic Universe

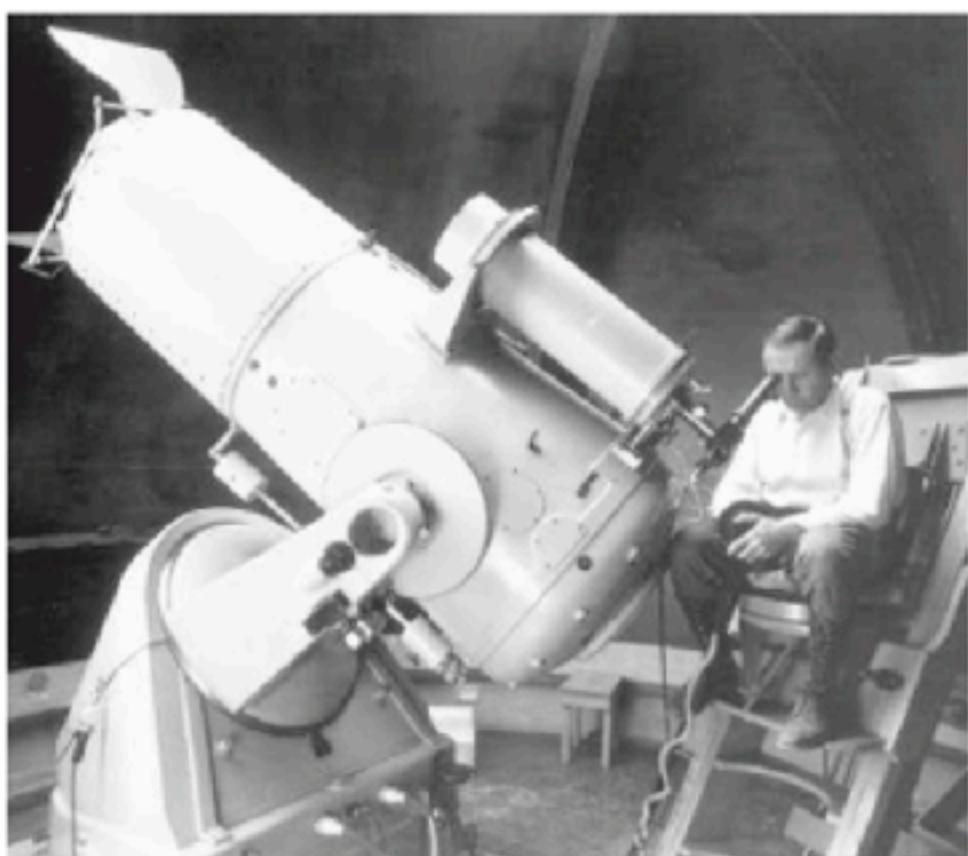
The first person to carry out a modern survey of the night sky, Fritz Zwicky's astronomical observations led to a new picture of a turbulent Universe that is punctuated by violent events.

## Freeman Dyson

The Swiss physicist Fritz Zwicky (1898–1973) was responsible, more than anyone else, for a profound change in our view of the astronomical Universe. Before Zwicky, the ancient aristotelian view of the celestial sphere as a region of eternal harmony and tranquillity was still largely intact, and the job of an astronomer was to make accurate maps of an unchanging landscape. After Zwicky, the modern view of the Universe emerged, as a dynamic scene dominated by violent events. The job of an astronomer today is to record and interpret the processes of change.

Zwicky's great work was done in the 1930s when he was an associate professor of physics at Caltech, the California Institute of Technology. He had been trained at the Swiss Federal Institute of Technology as an X-ray crystallographer and had no official credentials as an astronomer. But he saw an opportunity arising from two unconnected events that happened almost simultaneously.

First, in 1928, the Rockefeller Foundation awarded a large sum of money to Caltech for the construction of a major astronomical observatory. Second, in 1930,



Using the Schmidt telescope, Fritz Zwicky discovered dark matter.

the northern sky. Two major discoveries that emerged from his survey were supernovae and dark matter. Zwicky observed 20 supernovae, a large enough sample to allow him to classify them into several types and infer their different modes of origin. His discovery of dark matter came from studying the motions of individual galaxies in rich clusters of galaxies, and from calculating that the visible mass in the clusters was insufficient by a large factor to cause the observed motions.

flict with his colleagues at Caltech. They considered him crazy and he considered them stupid. He never became an accepted member of the astronomical community, but followed his own path. During the Second World War he was director of research at the Aerojet Corporation, which developed rockets for the military. At the same time he organized the Committee for Aid to War-stricken Scientific Libraries. This collected massive quantities of scientific books and journals and distributed them to

libraries that had been disrupted or destroyed during the war. He founded the committee in 1941 and ran it with his habitual enthusiasm and efficiency. For this work he received the Medal of Freedom from President Harry Truman in 1949.

Besides his revolutionary work as an observer and organizer, Zwicky made revolutionary contributions to theoretical astronomy. He published papers about neutron stars, supernovae, black holes and gravitational lenses, long before these subjects became fashionable. His thinking was based on a personal philosophy which he called the 'morphological approach'. The idea is that you first make a complete list of all

动态宇宙

"The first person to carry out a modern survey of the night sky, Fritz Zwicky's astronomical observations led to a new picture of a turbulent Universe that is punctuated by violent events."



[Home](#) > [Prizes and Laureates](#) > [The Prize in Astronomy](#) > [Matthew Bailes, Duncan Lorimer, Maura McLaughlin](#)

## *The 2023 Prize in Astronomy*

# Matthew Bailes Duncan Lorimer Maura McLaughlin

for the discovery of fast radio bursts (FRBs).

[Learn More About the Laureate >](#)



# Astronomy the ‘New’ Frontier



## SHAW PRIZE

Shaw  
+  
Nobel

since 2000: laureates 19  
10 achievements in 7 years



R.Davis,Jr. M.Koshiba  
R.Giacconi

2002

cosmic neutrinos  
cosmic X-ray sources **2004**

J.C.Mather G. Smoot

2006

CMB anisotropy

S.Perlmutter B.P.Schmidt A.G.Riess

2011

accelerating expansion  
of the Universe

T.Kajita A.B.McDonald

2015

neutrino oscillations

R.Weiss B.C. Barish K.S. Thorne

2017

gravitational waves

James Peebles

2019

physical cosmology

Michel Mayor Didier Queloz

Habitable exoplanet

Roger Penrose

2020

black hole formation

Reinhard Genzel Andrea Ghez

Galactic center supermassive  
compact object

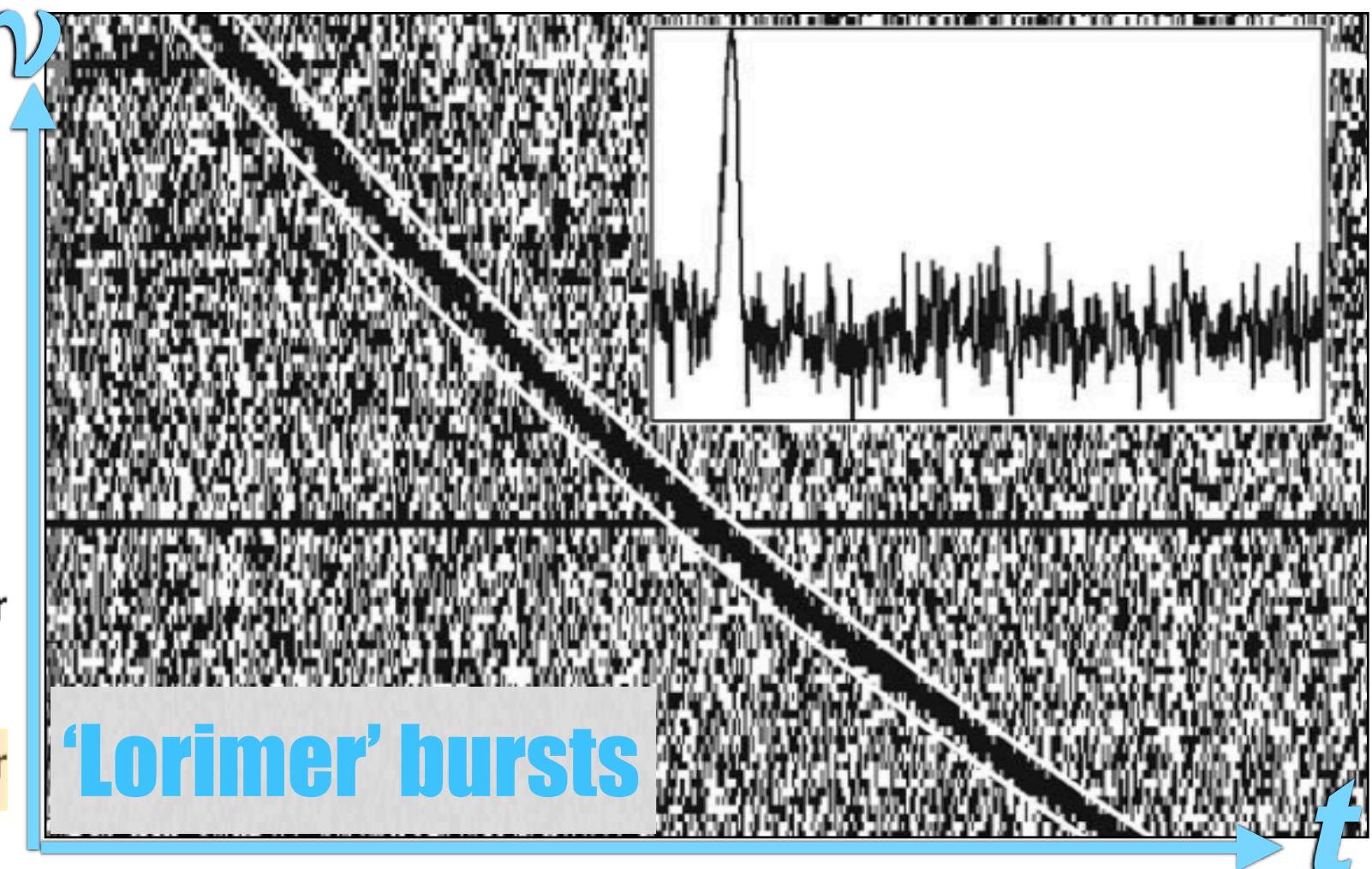
# A Bright Millisecond Radio Burst of Extragalactic Origin

2007

D. R. Lorimer,<sup>1,2\*</sup> M. Bailes,<sup>3</sup> M. A. McLaughlin,<sup>1,2</sup> D. J. Narkevic,<sup>1</sup> F. Crawford<sup>4</sup>

Pulsar surveys offer a rare opportunity to monitor the radio sky for impulsive burst-like events with millisecond durations. We analyzed archival survey data and found a 30-jansky dispersed burst, less than 5 milliseconds in duration, located  $3^\circ$  from the Small Magellanic Cloud. The burst properties argue against a physical association with our Galaxy or the Small Magellanic Cloud. Current models for

Hundreds of similar events could occur every day...<sup>10</sup>  
Hundreds of similar events could occur every day and, if detected, could serve as cosmological probes.



# A Population of Fast Radio Bursts at Cosmological Distances

2013

D. Thornton,<sup>1,2\*</sup> B. Stappers,<sup>1</sup> M. Bailes,<sup>3,4</sup> B. Barsdell,<sup>3,4</sup> S. Bates,<sup>5</sup> N. D. R. Bhat,<sup>3,4,6</sup> M. Burgay,<sup>7</sup> S. Burke-Spolaor,<sup>8</sup> D. J. Champion,<sup>9</sup> P. Coster,<sup>2,3</sup> N. D'Amico,<sup>10,7</sup> A. Jameson,<sup>3,4</sup> S. Johnston,<sup>2</sup> M. Keith,<sup>2</sup> M. Kramer,<sup>9,1</sup> L. Levin,<sup>5</sup> S. Milia,<sup>7</sup> C. Ng,<sup>9</sup> A. Possenti,<sup>7</sup> W. van Straten<sup>3,4</sup>

Searches for transient astrophysical sources often reveal unexpected classes of objects that are useful physical laboratories. In a recent survey for pulsars and fast transients, we have uncovered four millisecond-duration radio transients all more than  $40^\circ$  from the Galactic plane. The bursts' properties indicate that they are of celestial rather than terrestrial origin. Host galaxy and

Determine the baryonic content of the universe

ASSOCIATION WITH THE BURSTS. Characterization of the source population and identification of host galaxies offers an opportunity to determine the baryonic content of the universe.

## FRB Discovers



Lorimer



Bailes



McLaughlin

Host Galaxy

FRB121102

nature

## MYSTERY OBJECT

Precise localization of fast radio bursts reveals distant host and extremely persistent source. [PAGES 1-2](#)

## FRB 121102 localization

"The most important discovery in astronomy since LIGO"—AAS Press 2017

FRBs is the most energetic cosmic signal in radio bands. Their equivalent energy can reach years' worth of Solar radiation, but concentrated in a thousandth of a second.



FRB 121102 was discovered by Arecibo in 2015

# Arecibo (1963 - 2020)

A large, grey, parabolic-shaped dish antenna is situated in a lush green valley. It is supported by a complex network of white cables and metal towers. The dish is angled upwards towards the sky. The surrounding landscape is dense with tropical vegetation.

1963 commissioned  
mercury spin, double neutron stars, the first exoplanet etc.



1993 Nobel prize in Physics

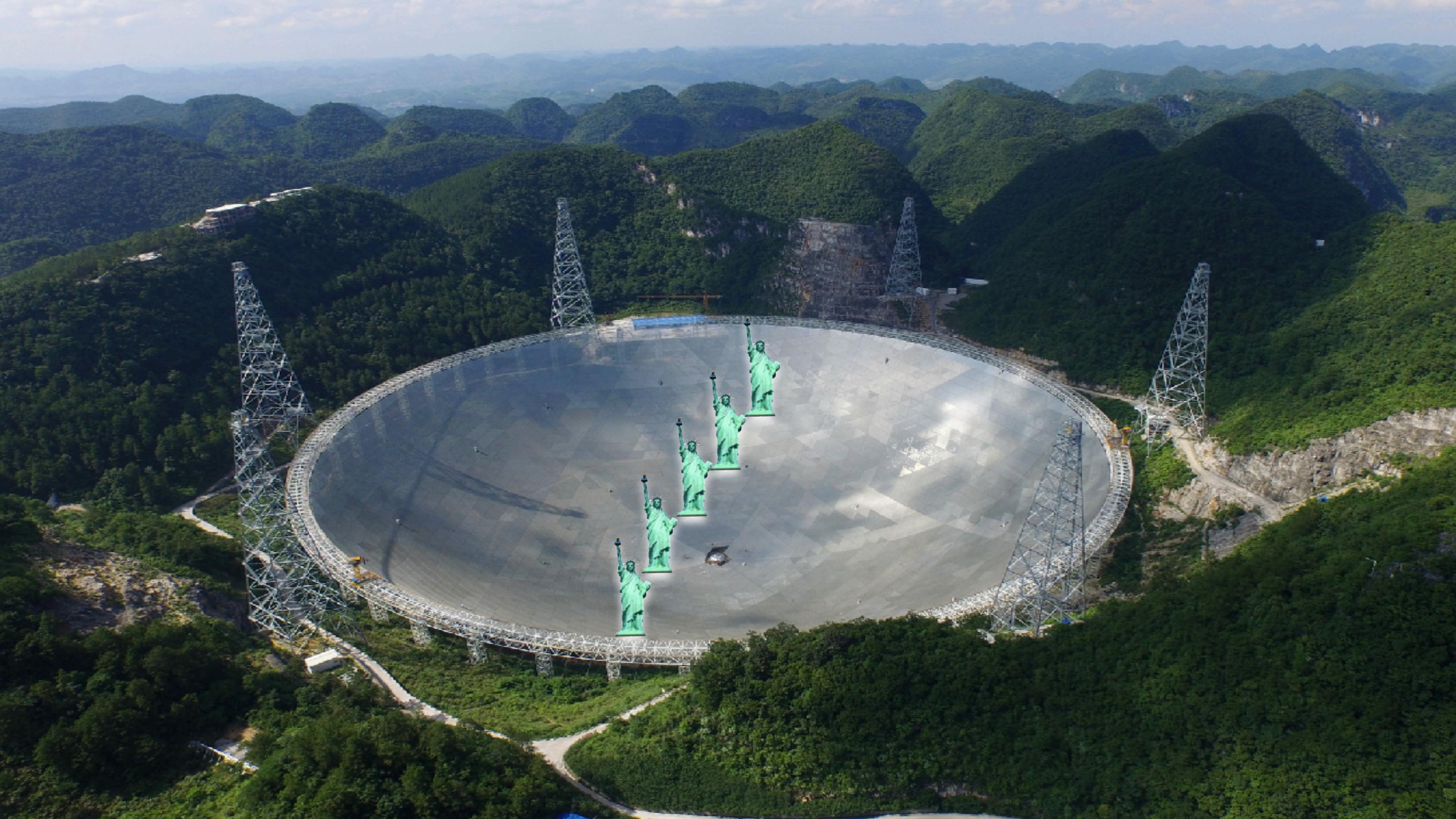
2020.12.1 collapsed

**Arecibo**  
(1963 – 2020)

**FAST**  
(2020 – now)



the largest antennae ever built by mankind



# Five-hundred-meter Aperture Spherical radio Telescope (FAST) Guizhou, China

**FAST**

¥ 1.15 billion; 5.5 year  
2011.3-2016.9  
(Nan, Li et al. 2011)

- ▶ 4,500 moving panels
- ▶ 30-ton feed cabin
- ▶ 6 towers, 100+ meters tall
- ▶ 100,000+ optical fibers



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- ▶ 100,000+ optical fibers

Full Operation  
since 2020

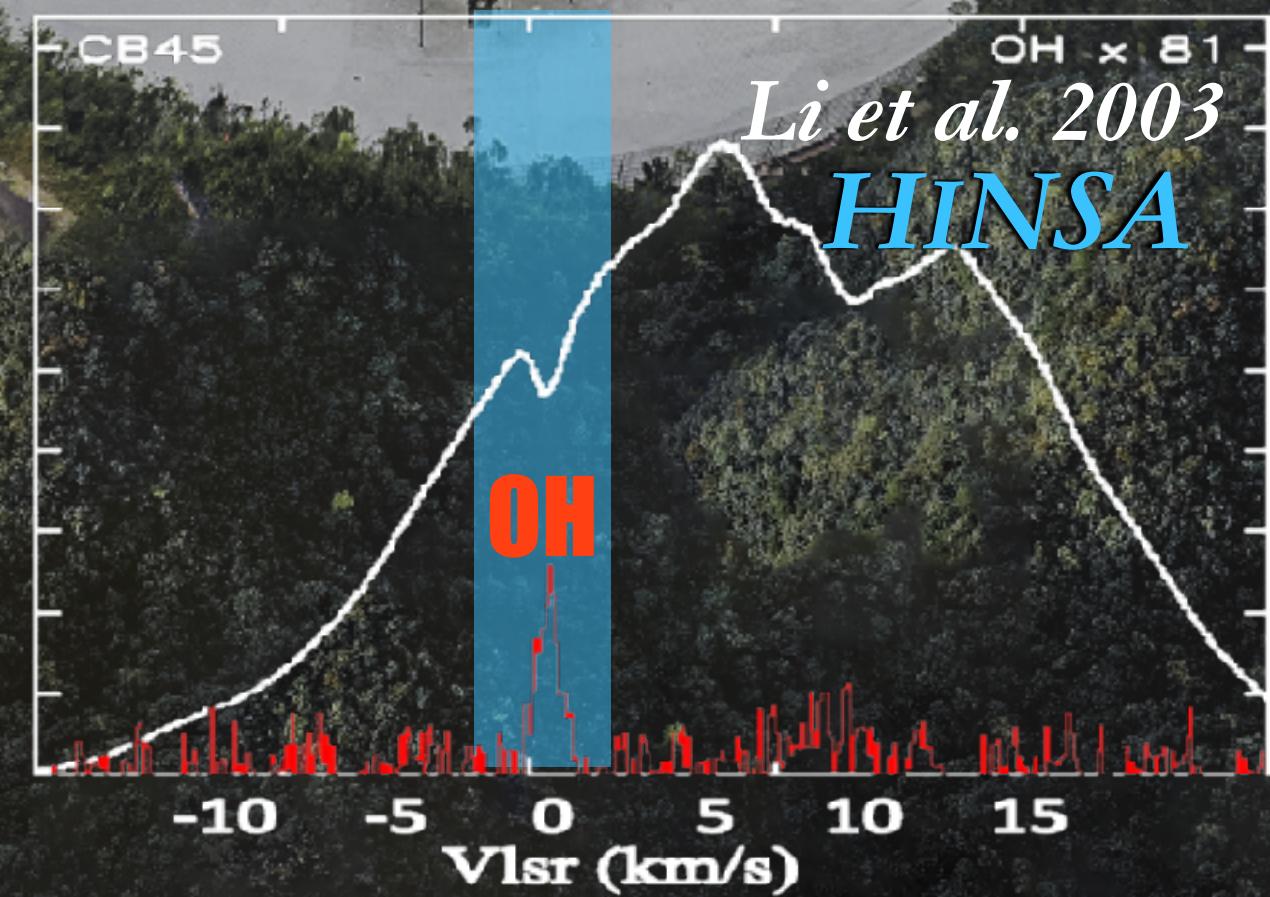
- ▶ ~400 projects from 30+ countries
- ▶ 400+ papers, 12 on **Nature/Science** (main journal)
- ▶ Main achievements
  - pulsar search
  - HI imaging
  - interstellar magnetic fields
  - FRBs.

the most sensitive cosmic radio detector

# $HIN_{arrow} S_{elf} A_{bsorption}$

## 原子氢的窄自吸收

2001.11



2012.02



2022.01



### First HINSA Zeeman Detection

reveals a weak  $B = 3.8 \pm 0.3 \mu\text{G}$  coherent field  
that puts molecular cores in supercritical state  
«Science» news:

“...revolutionary (革命性).”



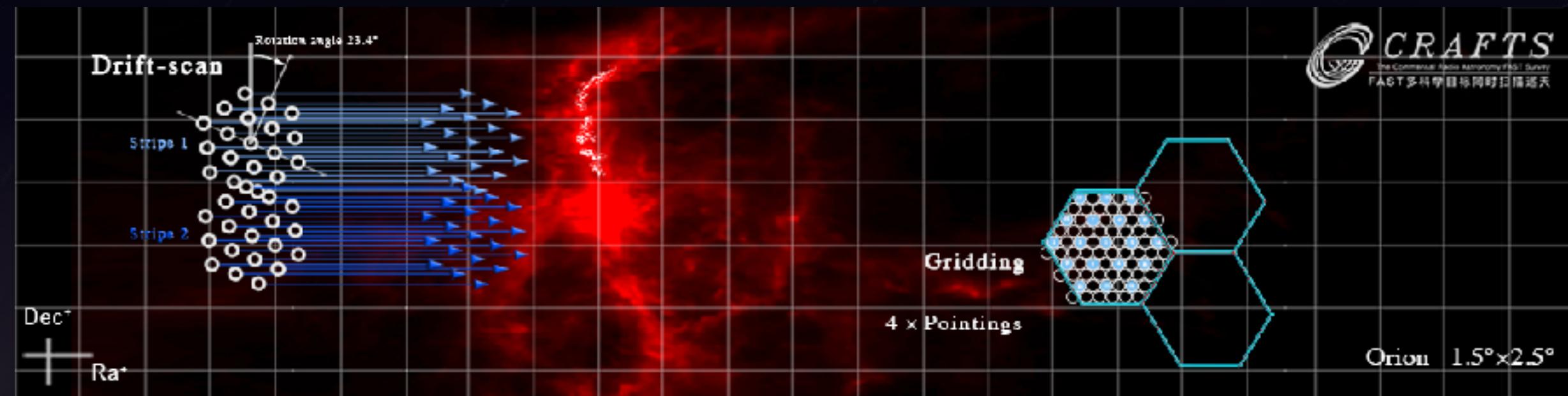
Based on a novel high-cadence CAL technique, CRAFTS is the **first commensal survey** of HI imaging, pulsars, galaxies, and FRBs .

Commensal Radio Astronomy FAST Survey  
 CRAFTS  
The Commensal Radio Astronomy FAST Survey  
FAST多科学目标同时扫描巡天      Li et al. 2018  
IEEE Microwave

# Status of pulsar discoveries from CRAFTS



CRAFTS  
The Commercial Radio Astronomy FAST Survey  
FAST多科学目标同时扫描巡天



Confirmed  
222 New Pulsars  
Discovery

- 65 MSPs
- 21 Binary (including 3 DNS)
- ~35 RRATs
- ~90 Pulsars were Published

## CRAFTS Catalog & Data Release

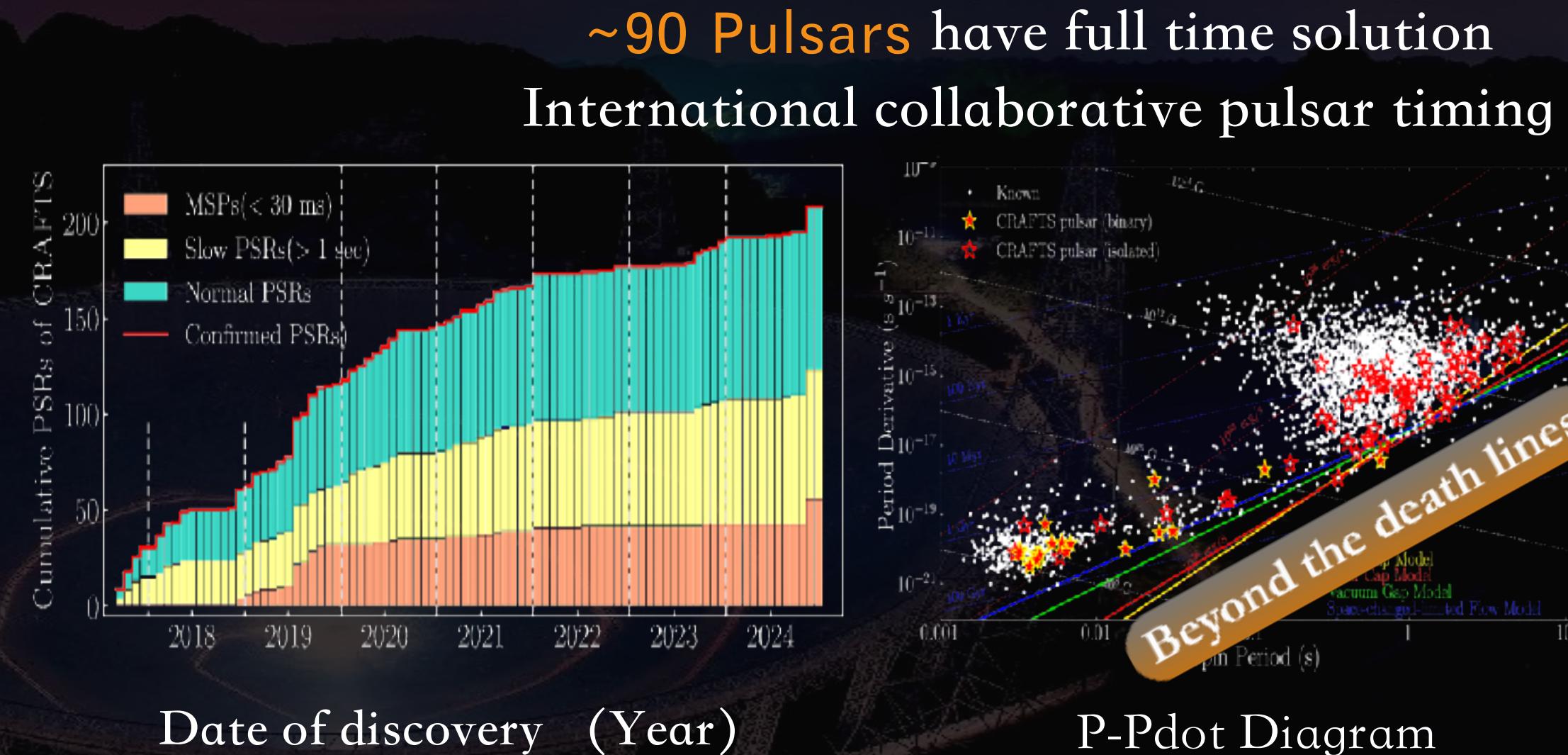
<http://crafts.bao.ac.cn/pulsar/>

<https://fastro.scidb.cn/en>

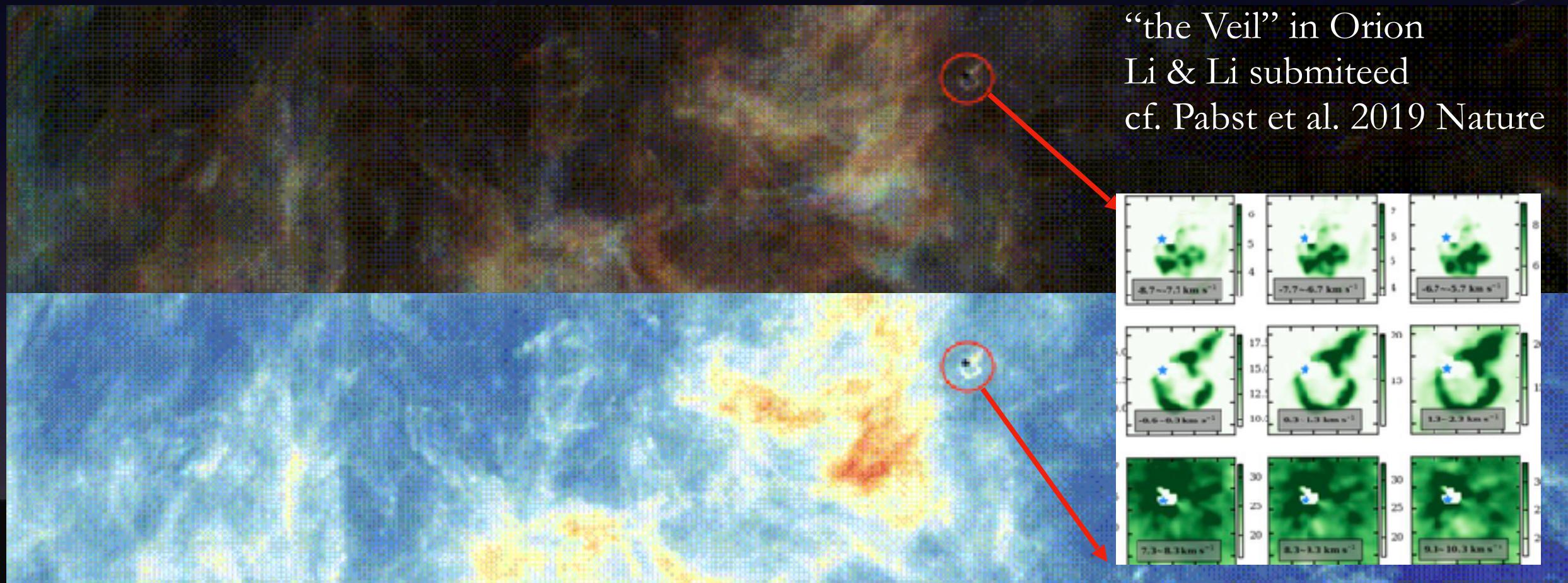
86GB+, 7 datasets

100,000 Views, 5200+ Downloads

>200 Citation, from 20+ Countries



# CRAFTS HI Data Release

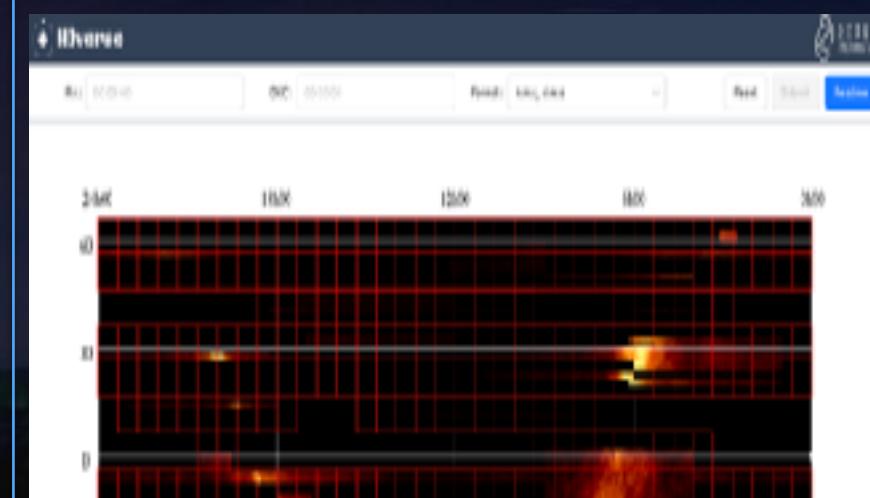


“the Veil” in Orion  
Li & Li submitted  
cf. Pabst et al. 2019 Nature

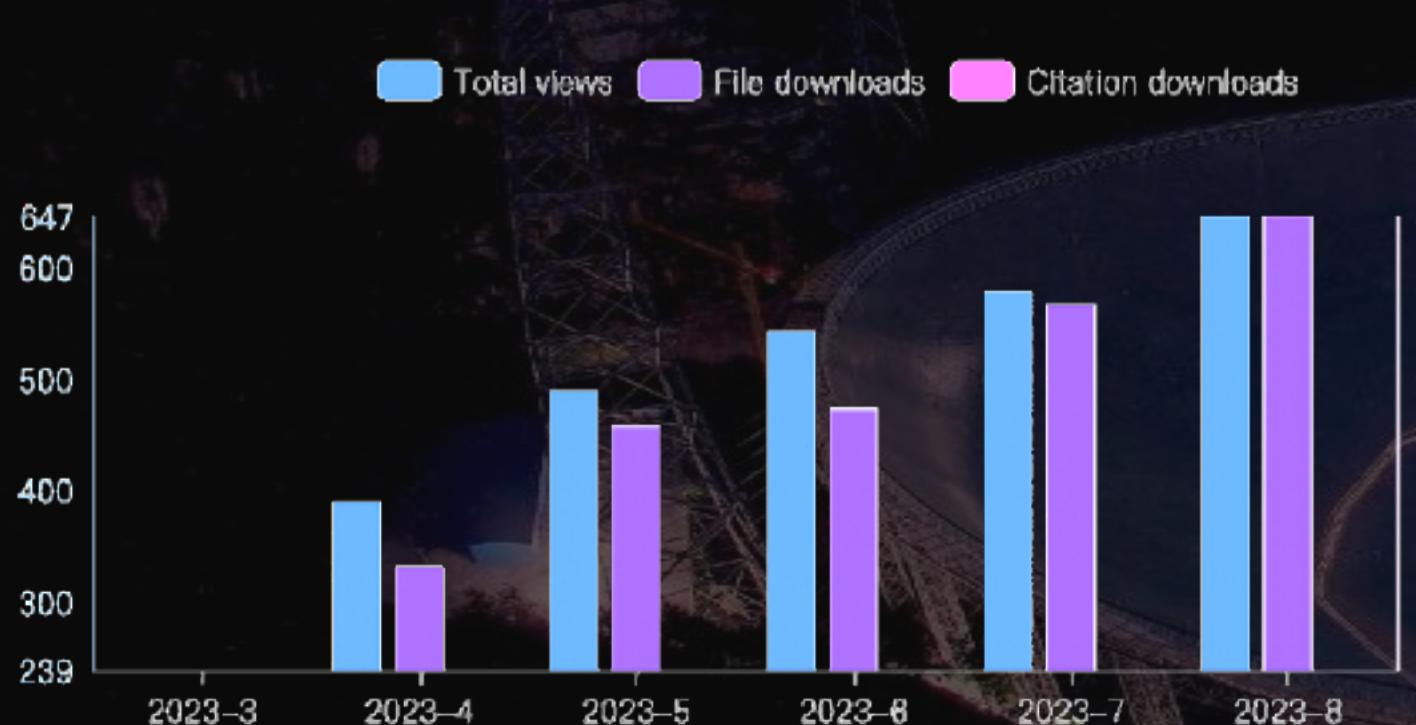
2024.2 Release

4738 deg<sup>2</sup>

Narrow-band Data Cube



<https://hiverse.alkaidos.cn/>



## ● Pre-release (Orion)

[http://groups.bao.ac.cn/ism/CRAFTS/202303/t20230321\\_736552.html](http://groups.bao.ac.cn/ism/CRAFTS/202303/t20230321_736552.html)

## ● Narrow band HI data releases

<https://doi.org/10.57760/sciencedb.07779>

## ● CRAFTS Data Community

[http://groups.bao.ac.cn/ism/CRAFTS/202309/t20230906\\_752058.html](http://groups.bao.ac.cn/ism/CRAFTS/202309/t20230906_752058.html)





CRAFTS

The Commercial Radio Astronomy FAST Survey

FAST多科学目标同时扫描巡天

**CRAFTS** reveals a high event rate **>120K** per day!

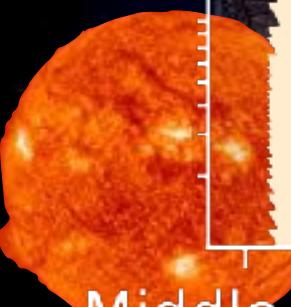
Equivalent Solar Energy

10year

1year

1month

1day



Middle age

Dynamic Universe

*“a turbulent Universe that is punctuated by violent events.” —Freeman Dyson*

Zhu+ 2020 *ApJL*  
Niu+ 2021 *ApJL*

FRB 190520

Cosmic Age

Kids

Toddler

- ASKAP
- Arecibo
- CHIME
- DSA-100
- ENVE
- FAST
- GBT
- Haoping
- LOFAR
- MeerKAT
- NRT
- Parkes
- Pushchino
- SRT
- Tianlai
- UTMOST
- VLA
- WSRT
- Wb-RT1
- uGMRT

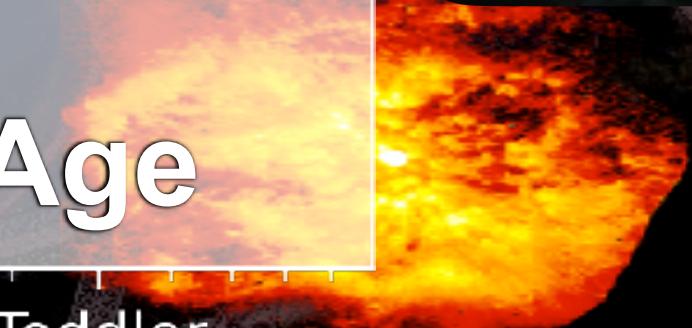
Canada  
**CHIME**



**CRAFTS**  
*Li et al. 2018*

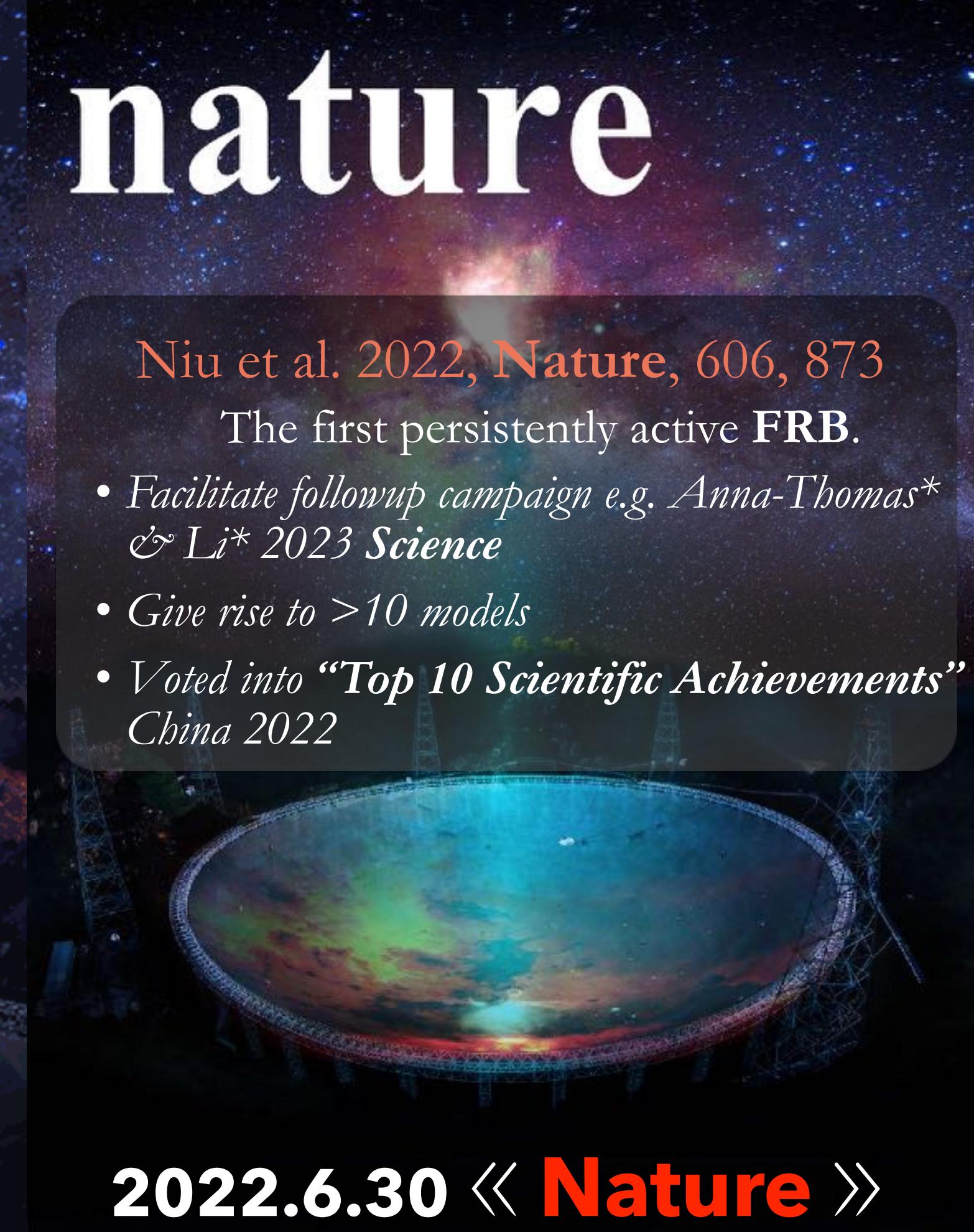


**Big Bang**





2019.5.20 **CRAFTS** scan: discovery

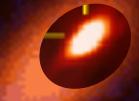


Niu et al. 2022, **Nature**, 606, 873

The first persistently active **FRB**.

- Facilitate followup campaign e.g. Anna-Thomas\* & Li\* 2023 **Science**
- Give rise to >10 models
- Voted into “**Top 10 Scientific Achievements**” China 2022

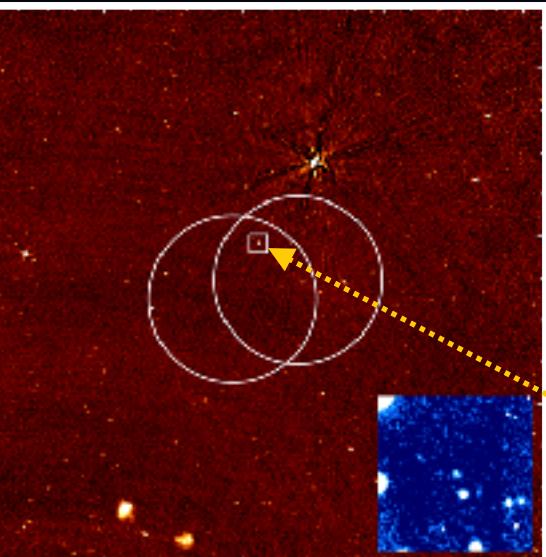
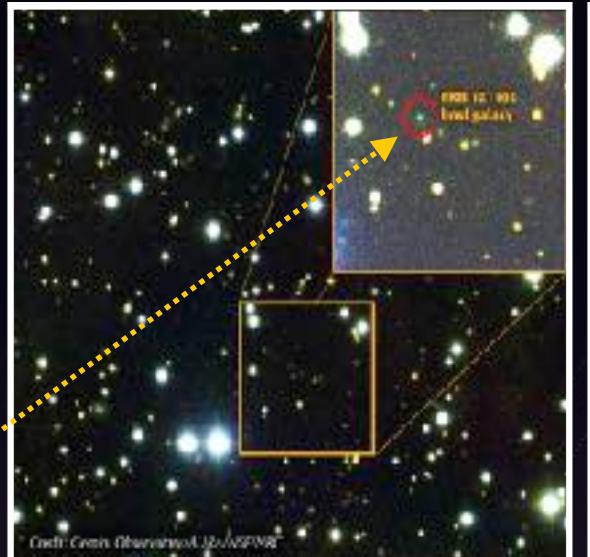
2022.6.30 « **Nature** »



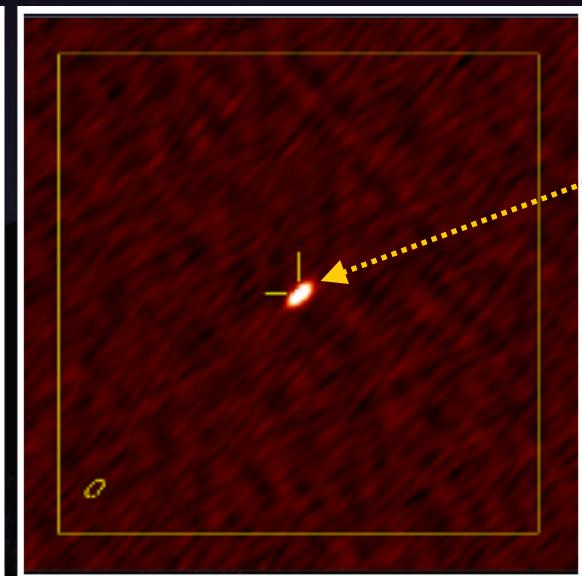
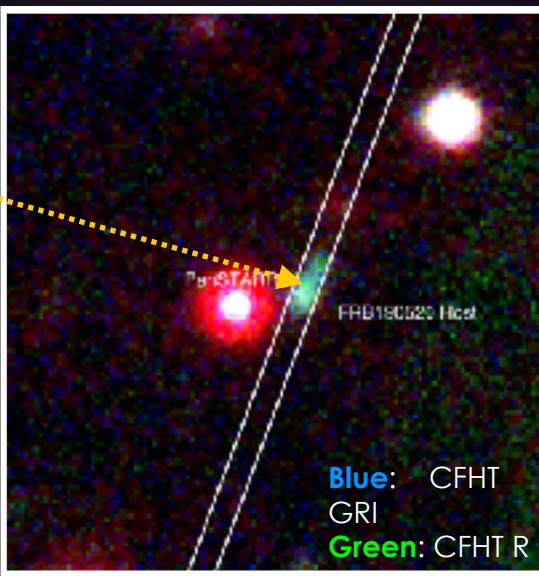
持续射电源 **PRS**

*Persistent Radio Source PRS*

# FRB 121102



**HOST  
GAL**



**HOST  
GAL**

# FRB 190520

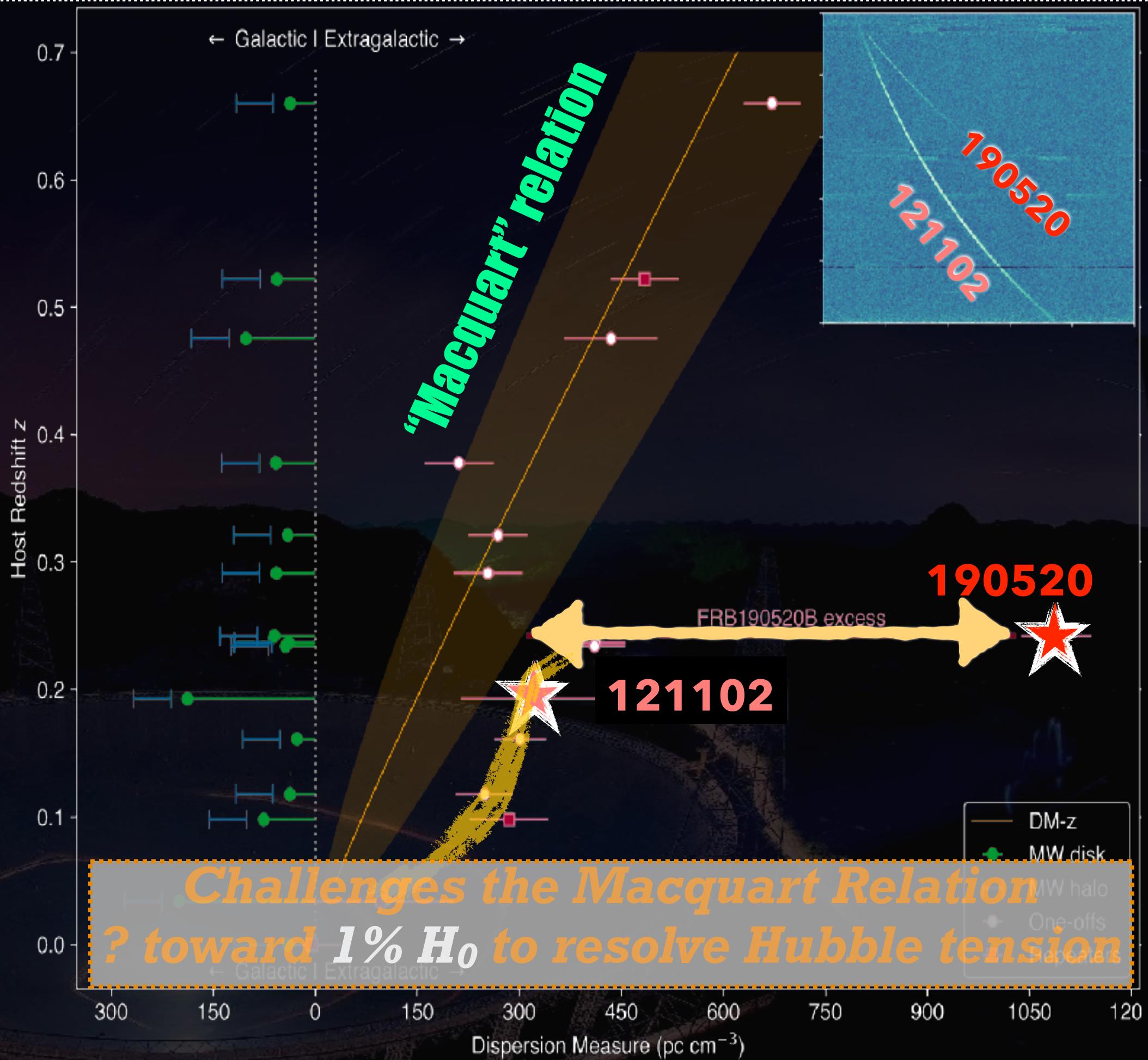
**190520**

a *hipper* and *weirder* brother of **121102**

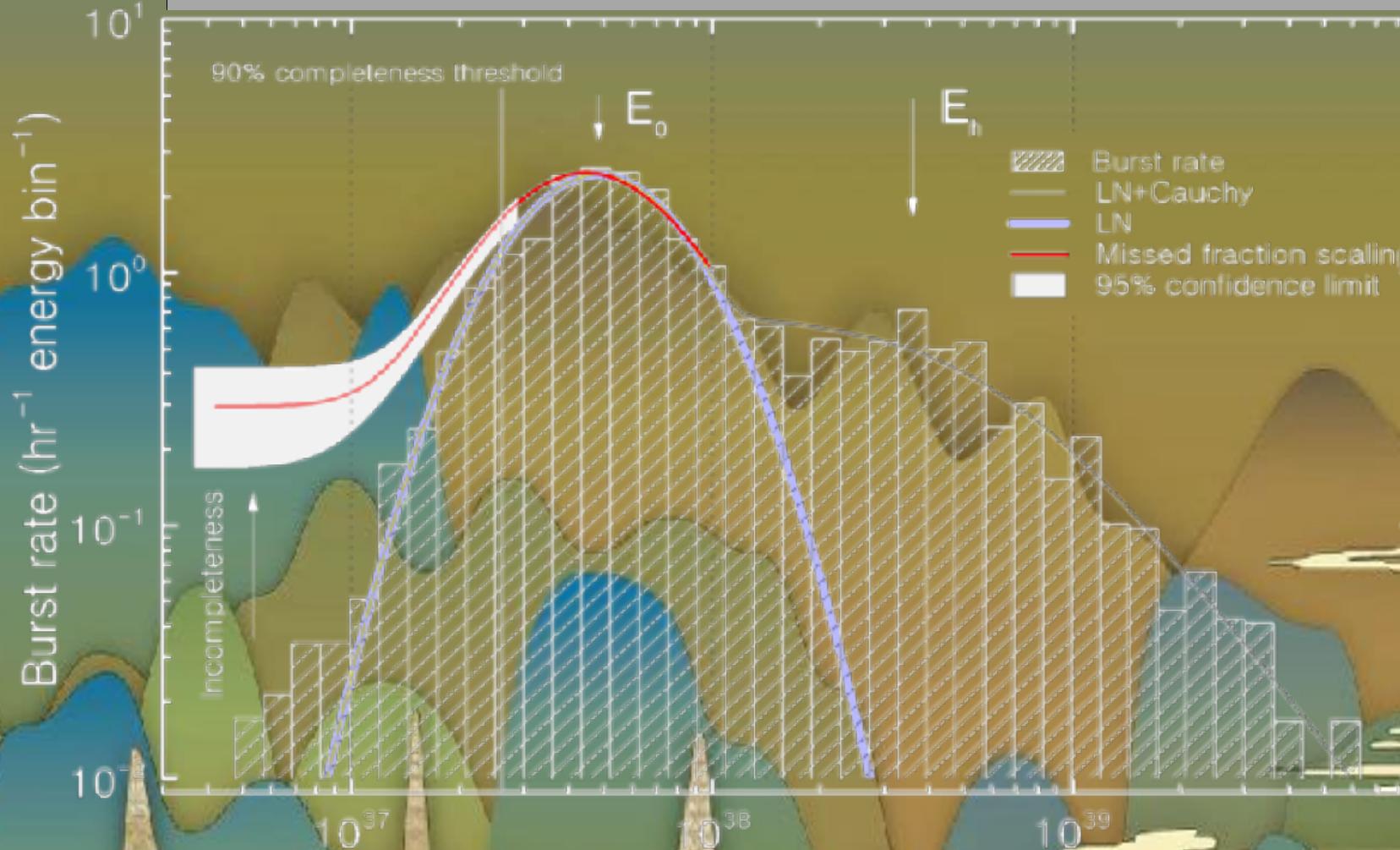
largest  
**DM<sub>host</sub>**

Only two  
**PRS**

1st & only  
**Persistently Active**



# 1st complete FRB burst-rate energy spectrum



“月半千辉”  
1652 bursts in 50 days

FRB 121102

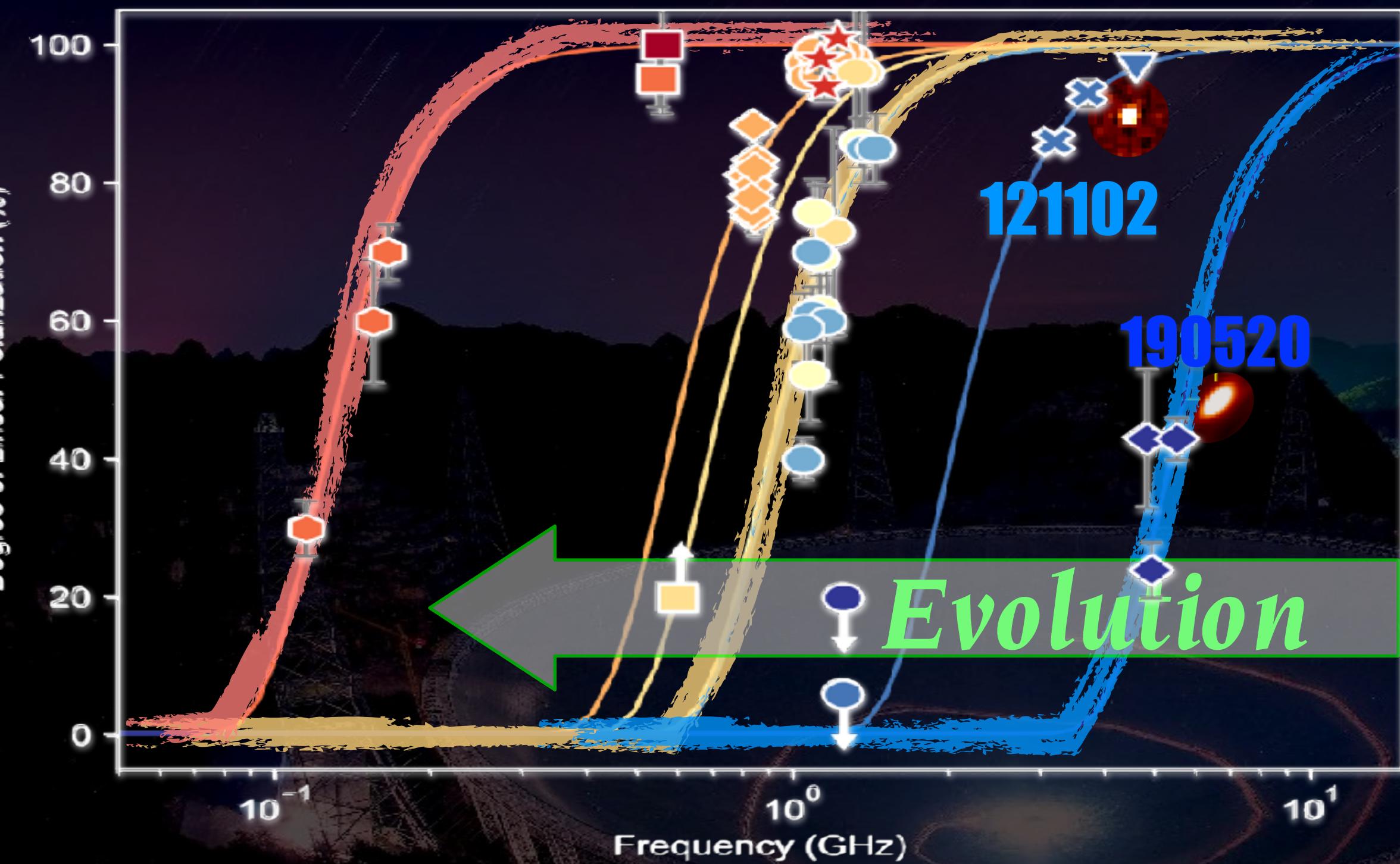


1113 A.D. 《Endless Rivers and Mountains》>>  
仿王希孟《千里江山图》

A bimodal burst energy distribution of a repeating fast radio burst source  
nature  
L. Wang, 2021 DOI: 10.1038/s41586-021-03878-5  
CRAFTS webpage: <https://crafts.bao.ac.cn/>  
CRAFTS



# FAST+GBT reveal FRB's environment



Feng, Li\* et al. 2022 Science, 375, 1266

## Unifying repeating fast radio bursts

- Research shows that both the Group IV repeating radio bursts are adaptive rapidly to a constantly changing environment in a phenomenon called “stop-the-trading.”
- By using five parallel changes in 30 repeating radio burst polarizations thousands of individual pulsations, 2019, suspending for groups of 100, then over a sequence average of >100 kHz, and mapping every few weeks, Riquelme et al. could detect temporal and parallel changes in the frequency of polarization, also known as frequency polarization evolution. By using a selection of specific frequencies, they found that frequency shifts changed the successive time intervals. The pulsar architecture underlying these changes indicates that many time slices of the genome respond to selective pressure. Because of pervasive associations, associations between sites under selection with those unrelated to the site of response, this might reflect the use of experimental populations with only four generations of genetic recombination (i.e., the process that isolates the genome); using far fewer than have been used to establish the population. Thus, because recombination of DNA in a lab requires only a break down of association, the study cannot resolve integrated changes at small genomic regions. Despite this, the marked parallelism of the response to fluctuating selection represents strong evidence for annual adaptation through adaptive trading. This research is especially timely considering climate change.
- An interesting aspect of the Riquelme et al. study is the lack of evidence for inversion—when a segment of a chromosome is reversed—like during genetic changes. This seems to not suffice to evidence for the importance of such rearrangements as a right source of adaptation, being only observed by Dohman et al. and their counterparts by many scientists (e.g., however, the frequency of chromosomal inversions can make low in nature. These will be populations at Pennsylvania, where the lines used by Riquelme et al. were from. This may help explain the lack of inversion rearrangements in their data. An open question is how do
- their genetic makeup, including the genome, affect evolution.
- Riquelme et al. establish that by polarizing radio signals in several directions, this might be expected on theoretical grounds. Pulsars’ populations are also very large with a wide genetic variation, and their evolution is not limited by non-randomness. Unlike with our them, even a slight mutation frequency strong and other factors that adaptive trading can be limited by. However, classical theory predicts that adaptive trading can be limited by the rate of evolution of the non-benefits of the time lag in adapting to environmental change, and other factors such as segregation load [3]. Interestingly, projects producing multi-directional polarization (radio telescopes simulating only elliptical polarization) and real-world data [1] show that these expectations are not borne out in real-world pulsar populations.
- A recent compilation of genetic and quantitative genetic data suggests that following selection, genetic linkage generally survives selection, except for mutations that increase genetic variation than previously thought [2]. In support of the underestimated importance of fluctuation selection, previous genomic studies have documented pervasive seasonal allele frequency changes in several fraternal populations [3, 4], and seasonal transitions may have been documented in like for cold resistance [5], among others. It suggests that fluctuations in breeding conditions, including cold fronts, can significantly affect the low-frequency seasonal [6]. The work by Riquelme et al. adds strong evidence to the feasibility of the mechanism and highlights the connection [2] of how genetic variability can be maintained.
- Rotation is a fundamental property of electromagnetic waves and is typically used to prove the presence of magnetism. The rotation measure [7] measures quantifies the scatter of the electromagnetic wave as it passes through material along its path, whereas the polarization rotation angle provides information about the magnetic field. Overall polarization rotation caused by RM would be minimalized around their origin as well as the immediate environment of the source producing them [8]. Repeating FRBs offer an unique opportunity to study the polarization properties of FRBs in magnetic field [9] with different frequencies and over various frequency ranges. Of all the known FRBs, the low and their polarization measured by observation. This is primarily because the data products are too large to be effectively stored and processed as a result of current computational limitations.
1. J. G. Simonetti. Radio astronomy in the plasma era. *Science*, 242:14–17, 1988.
  2. S. A. Lysenko. The role of selection in the evolution of quantitative traits. *Genetics*, 44:103–116, 1959.
  3. F. R. Dohman, C. H. Hart, M. A. Riquelme, J. A. Riquelme, and J. A. Riquelme. Seasonal allele frequency changes in a wild population of *Escherichia coli*. *Nature*, 432:102–105, 2004.
  4. K. M. Dohman, C. H. Hart, M. A. Riquelme, J. A. Riquelme, and J. A. Riquelme. Seasonal allele frequency changes in a wild population of *Escherichia coli*. *Nature*, 432:102–105, 2004.
  5. K. M. Dohman, C. H. Hart, M. A. Riquelme, J. A. Riquelme, and J. A. Riquelme. Seasonal allele frequency changes in a wild population of *Escherichia coli*. *Nature*, 432:102–105, 2004.
  6. J. A. Riquelme, C. H. Hart, M. A. Riquelme, J. A. Riquelme, and J. A. Riquelme. Seasonal allele frequency changes in a wild population of *Escherichia coli*. *Nature*, 432:102–105, 2004.
  7. J. D. Kraus. *Principles of Radio Astronomy*. University of California Press, Berkeley, CA, 1966.
  8. A. L. Ravi, C. H. Hart, M. A. Riquelme, J. A. Riquelme, and J. A. Riquelme. Seasonal allele frequency changes in a wild population of *Escherichia coli*. *Nature*, 432:102–105, 2004.
  9. E. Chittenden, J. Wilcock, C. S. Turner, S. S. Scott, and J. R. Bannister. Observing the polarization of repeating FRBs. *Science*, 375:1266, 2022.

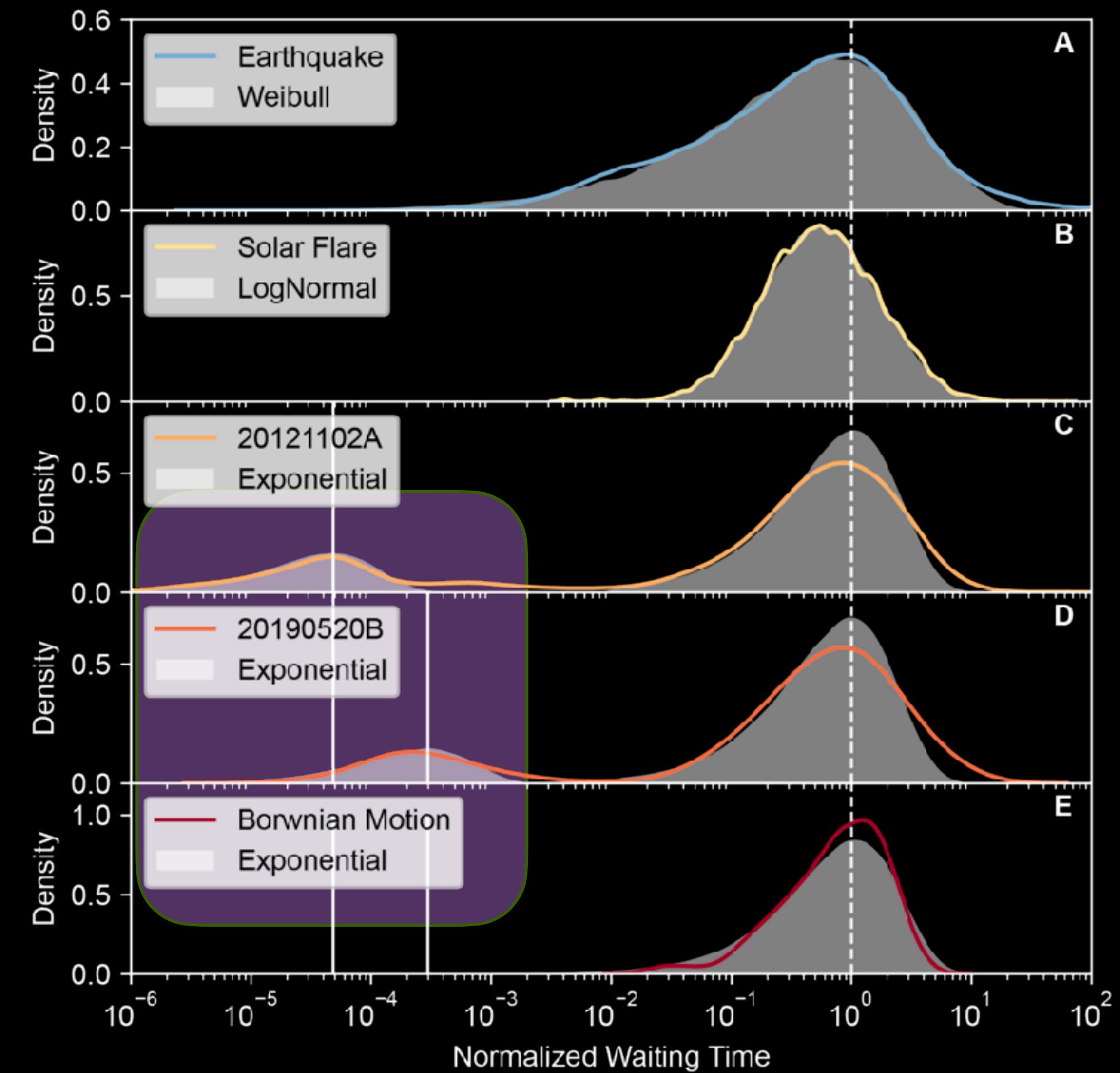
# FRB Waiting Time

**Normalization:** inverse of the average event rate; ~1 hour for earthquakes; 7 hours for flares; 88 s and 123 s for two FRBs

**Weibull** distribution: earthquakes have a higher rate of occurrence with short time intervals.

FRB emission seems to result from **two Poisson** processes.

Zhang, Li\* et al. 2024  
*Science-Bulletin*



# Randomness Pincus index

$$MaxApEn = \max_r \left( -\frac{1}{N-m} \sum_{i=1}^{N-m} \log \frac{\sum_{j=1}^{N-m} dist(x_j, x_i) < r}{N-m} \right)^{m+1}$$

**Random**  
constant unpredictability

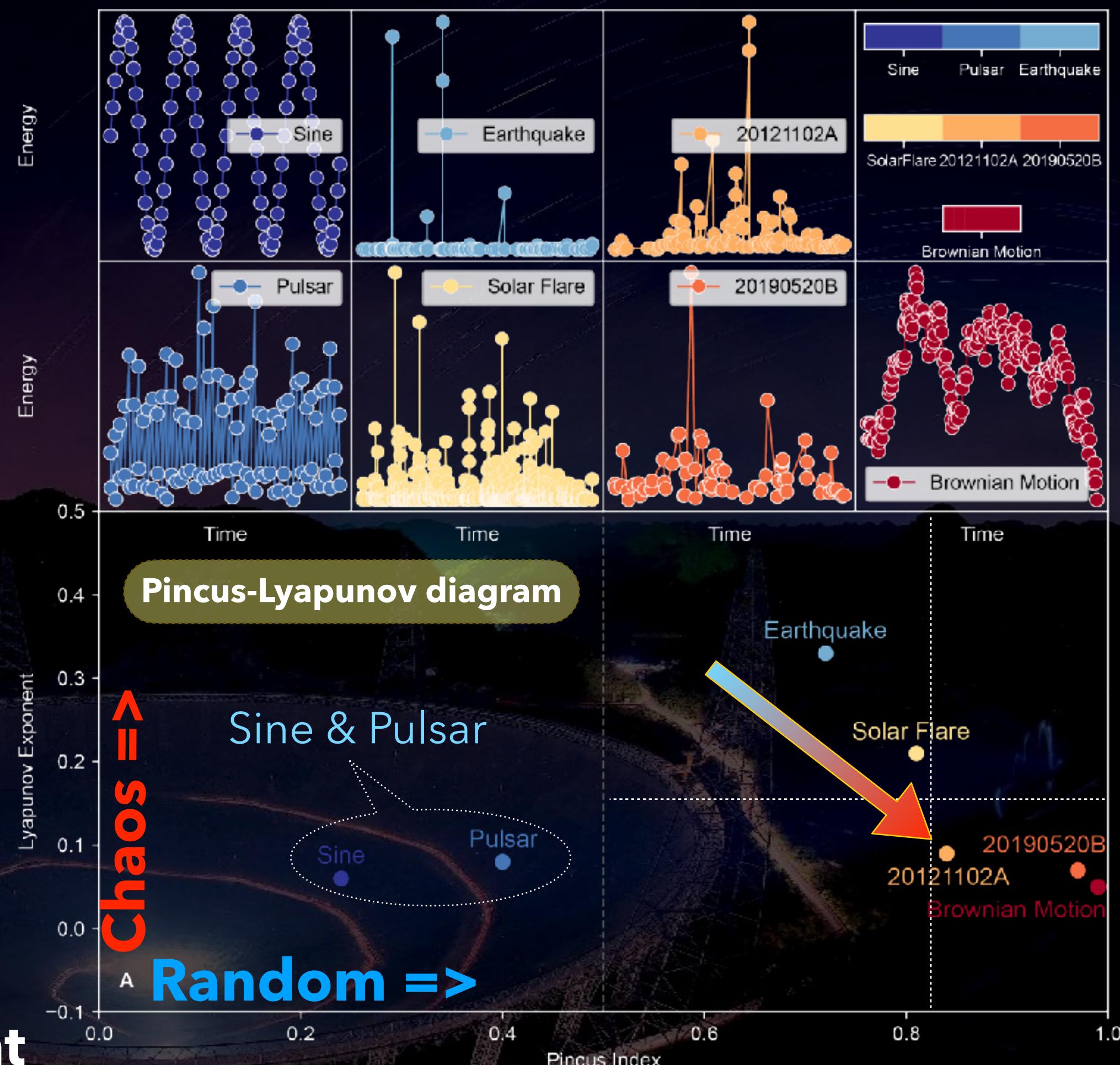
**PLD**  
**Pincus-Lyapunov Diagram**

dynamic events  
on Energy-Time phase space

**Chaos**  
exponential growth in unpredictability

$$\lambda(x_0) = \lim_{n \rightarrow \infty} \frac{1}{n} \sum_{i=0}^{n-1} \ln |f'(x_i)| \quad x_{n+1} = f(x_n)$$

**Chaos**      **Lyapunov exponent**



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# FRB

*God's dices in the E-t phase space?*

Pincus-Lyapunov diagram

- FRBs have **no spin-related periodicity!**
- FRBs' arrival times have **no dependence** on energy.
- FRBs events roam the energy-time space like a **Brownian motion**, much less chaotic than earthquakes, but more random.
- Spin trigger unlikely.

## «Science Bulletin»

- Multi-discipline journal
- IF ~20 (ranked #5 among all comprehensive journals)



Zhang, Y.K.

# Fast Radio Burst (FRB) 快速射电暴



Robustly Known  
确切知道

相干辐射 coherent emission

ECE = c · ct ... emission zone size scale

$$T = \frac{Se^2}{2k\omega_0 f^2} \sim 10^{38} - 10^{41} \text{ K}$$

重复 Repeat ( $\geq$  partial)

magneto-ionic 磁化等离子体

RM,  $\sigma_{RM}$ ,  $\Theta_{pol}$

radio loud  $E_x/E_R \sim 10^5; < 10^8$

Stochasticity  $\gg$  periodicity (ms  $\rightarrow$  ms)

Educated Guess  
合理推測

致密天体

compact object  
(stellar)

non-catastrophic

Source (swing...)

+ environment (persistent trends)

? PRS

Hypothesis  
假說

磁星

magnetar

repeat  $\neq$  non-repeat  
thus, diverse origin ?

VS

repeat  $\Rightarrow$  non-repeat  
evolution

MY-BET

SN  $\Rightarrow$  PRS  $\Rightarrow$  Repeater (Active)  
Single  $\Leftarrow$  Repeater (Sporadic)

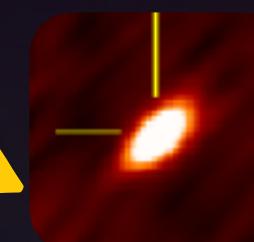
# *Fast Radio Bursts* unified picture



清华大学天文系  
Department of Astronomy, Tsinghua University

Chatterjee+ 2017 Nature  
Niu+ 2022 Nature

lights up the PRS

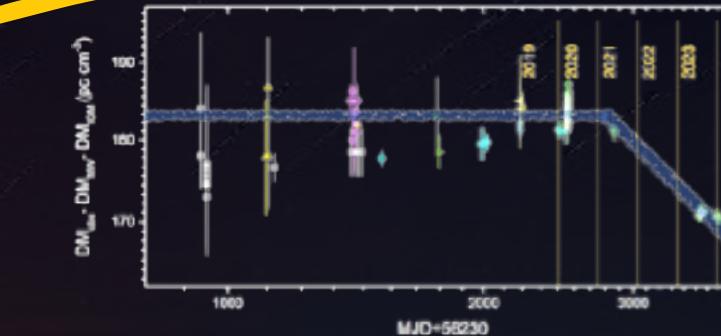


explosion  
hypernova?

compact binaries  
Reshma+ 2023 Science

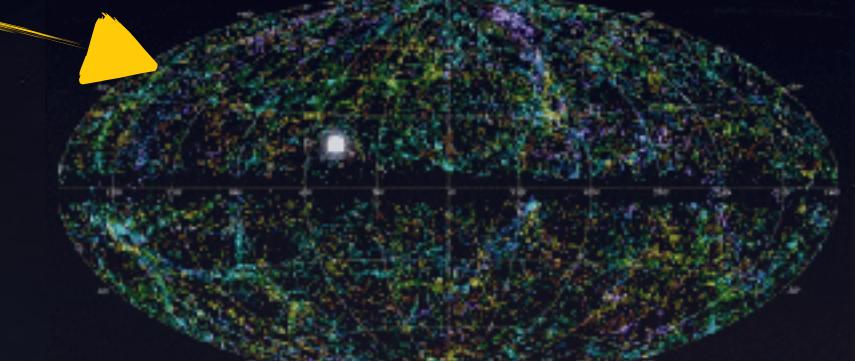
stochastic  
Li+ 2021 Nature  
Zhang+ 2024 Science Bull.

PRS fades/DM decreases



Wang+ NA under review

CHIME 2021 ApJS



Niu+ 2022 ApJ

Active Repeater



bursting through  
complex plasma

Feng+ 2022 Science

normal FRB  
Single/repeat?

rate drops  
pol. Stabilizes

**MARCEL GROSSMANN AWARDS**

PESCARA 2024

*Individual Awards*

Goes to

**DI LI**

*"For his groundbreaking contributions to the scientific definition of the most sensitive radio telescope and his numerous innovations in characterizing the dynamic universe, resulting in precise measurements of the interstellar magnetic field and advancing the field of fast radio bursts into a high-statistics era".*

*Goes to  
and* **TEST** *"For his groundbreaking contributions to the scientific definitions of the most sensitive radio telescope and his numerous innovations in characterizing the dynamic universe"*

*Institutional Awards*

*"For the innovative detection and comprehensive analysis of a large population of fast radio bursts, significantly increasing their statistic, including repeating sources, which have boosted our understanding of their origin and their application in mapping the universe structure and composition".*

Goes to:

**CHIME/FRB Team**

- presented to Professor Victoria Kaspi

**2024 Marcel Grossmann Awards**

Each recipient is presented with a silver casting of the TEST sculpture by the artist A. Pierelli. The original casting was presented to His Holiness Pope John Paul II on the first occasion of the Marcel Grossmann Awards.

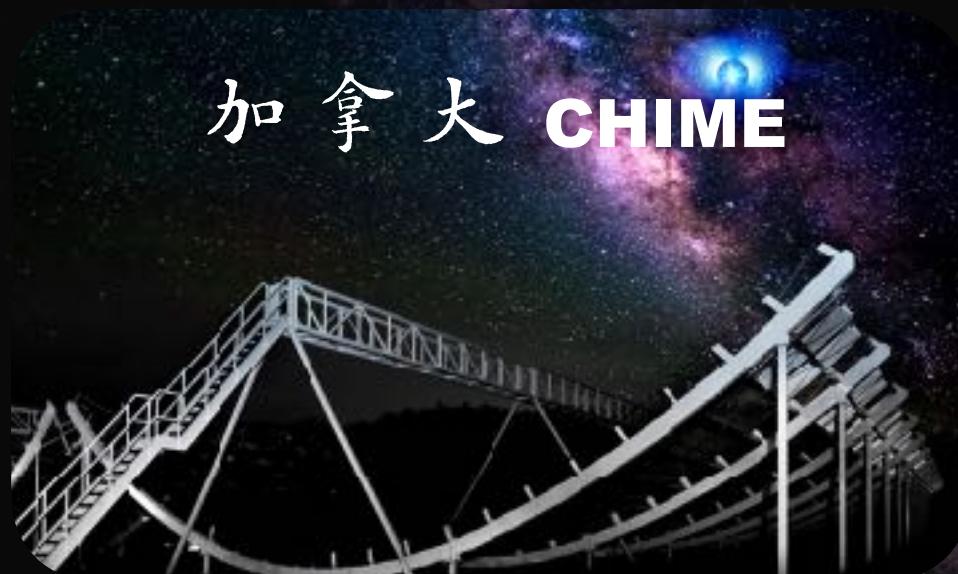


2024.07.08



+

# Breaking the detection limits

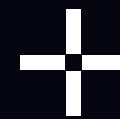


$$v = \frac{c}{\lambda}$$

$$\text{FOV 视场} = \lambda / D \quad \text{threshold 探测极限} = 1/D^2$$

望远镜	threshold	detection rate
中国天眼 FAST	0.01 Jy <b>x 21</b>	17/yr ↑
加拿大 CHIME	0.21 Jy ↓	1500/yr <b>x 88</b>

Bottleneck: detection rate



# from mirrors to field camera



Focusing-amplification

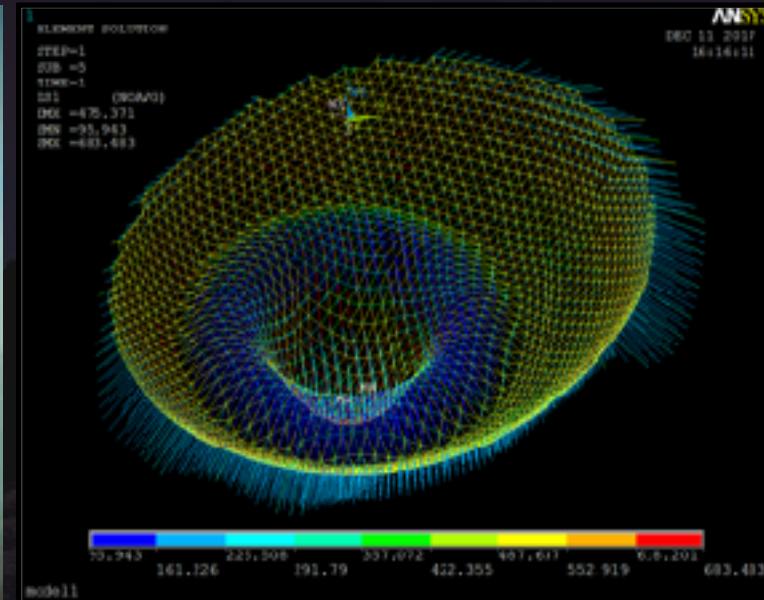
Field sensing + computation

FOCUS

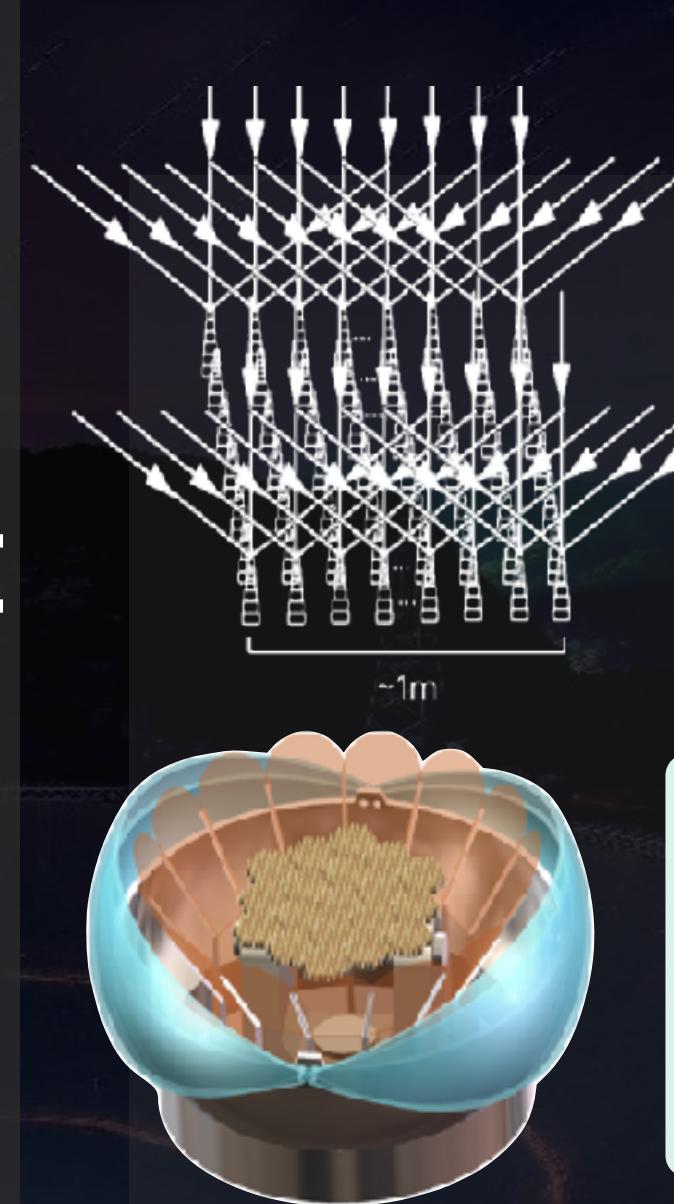
伽利略  
GALILEO



中国天眼 FAST  
Active Surface



C  
O  
M  
P  
U  
T  
E



2024.11.10



Wave => high throughput computing

Telescope - partial quantum computer

Field camera - digital quantum computer



Cosmic  
Antennae

Cosmic Antennae

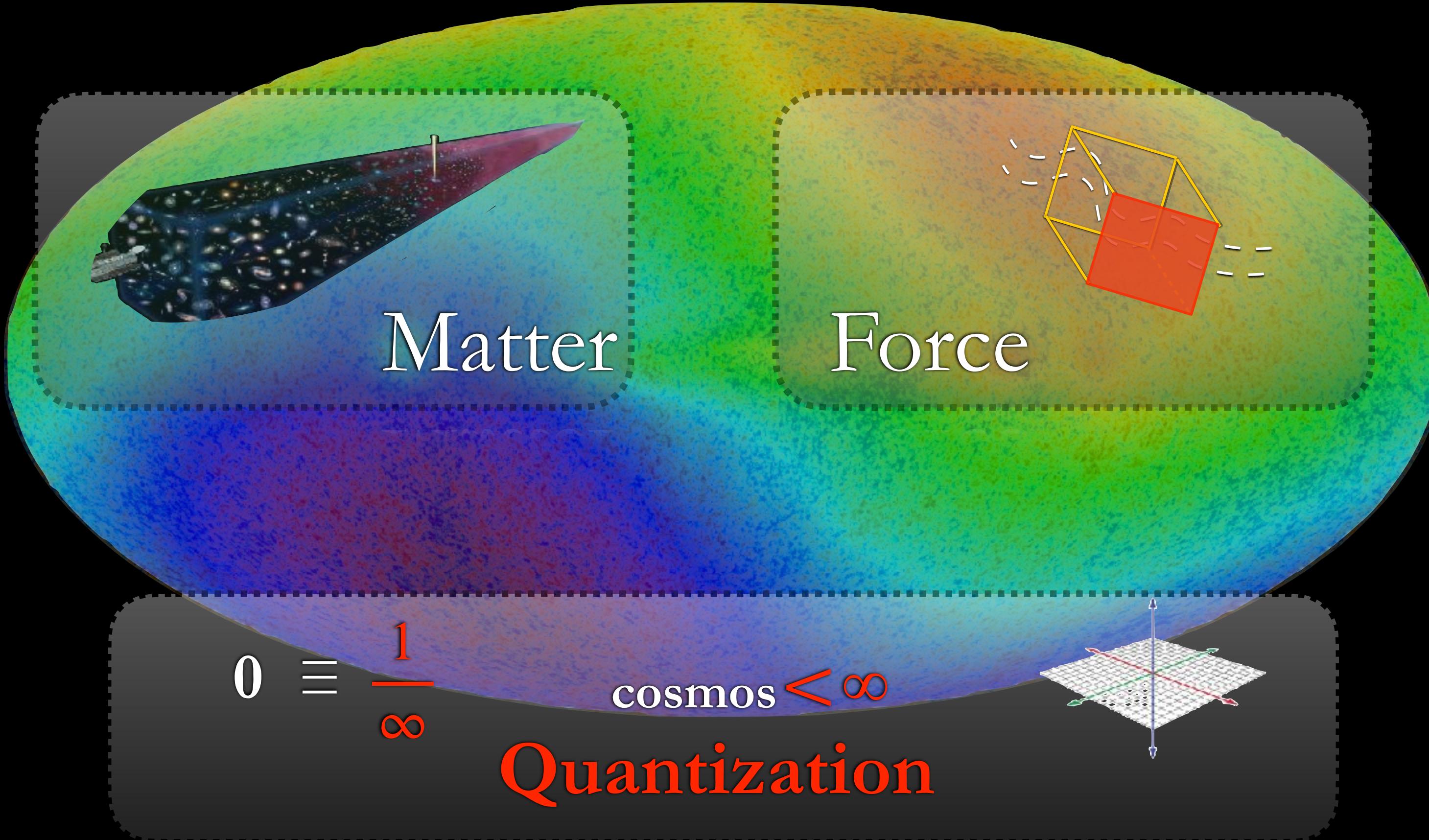
宇宙触角



清华大学天文系  
Department of Astronomy, Tsinghua University



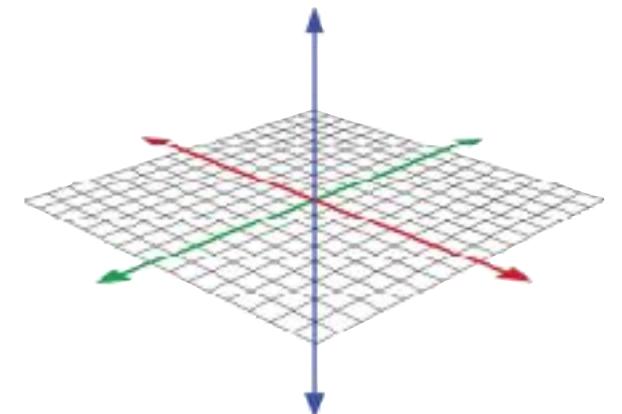
*13.7 billion yrs*



$$0 \equiv \frac{1}{\infty}$$

Universe  $< \infty \Rightarrow$  no singularity

$\Rightarrow$  no absolute symmetry / conservation



$\Rightarrow$  only “relative” relativity

# *Cosmic Time Frontier* “时间前沿”

“能量前沿”

The **Energy Frontier** Report:

the future of US particle physics (2021 US Community Study)

“时间前沿”

The Cosmic **Time Frontier**

2023-2024 weekend coffee discussion notes

$$E = h\nu$$

$$\nu = \frac{c}{\lambda}$$

$$\delta t < \frac{1}{2\nu}$$

$$\Delta t \quad \Delta E \geq \frac{\hbar}{4\pi}$$

?

*the finite Universe*

**$t = 13.7$  billion yrs**  $Z_{CMB} \sim 1100$

# Dynamic Universe

**FRB Discovery**

2007

*Lorimer et al.*

**Shaw Prize 2023**

**FRB Systematic**

2017-now

*FAST+CHIME  
ASKAP, SKA,  
Arecibo, etc.*

**Marcel Grossman  
Award 2024**

**FRB Origin/Physics**

*CHORD, DSA,  
Cosmic Antennae ...*

2030?

**New science**

*time frontier?*

2035 ?

*Computing senses cosmos*