

清華大學天文系
Department of Astronomy, Tsinghua University

Cosmic Antennae

# Time Frontier

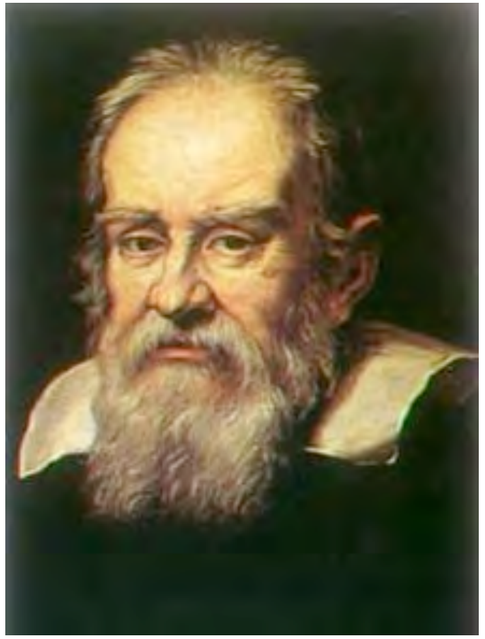
*from Galileo to Cosmic Antennae*




李荫 *Di Li*

# Galileo Galilei 伽利略

1564 – 1642 Italian astronomer, physicist and engineer, polymath










# 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, Zwicky invented a new type of telescope, the Schmidt telescope, which could photograph large areas of 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.



CALIFORNIA INSTITUTE OF TECHNOLOGY

Using the Schmidt telescope, Fritz Zwicky discovered dark matter.

Zwicky's discoveries led to conflict 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."

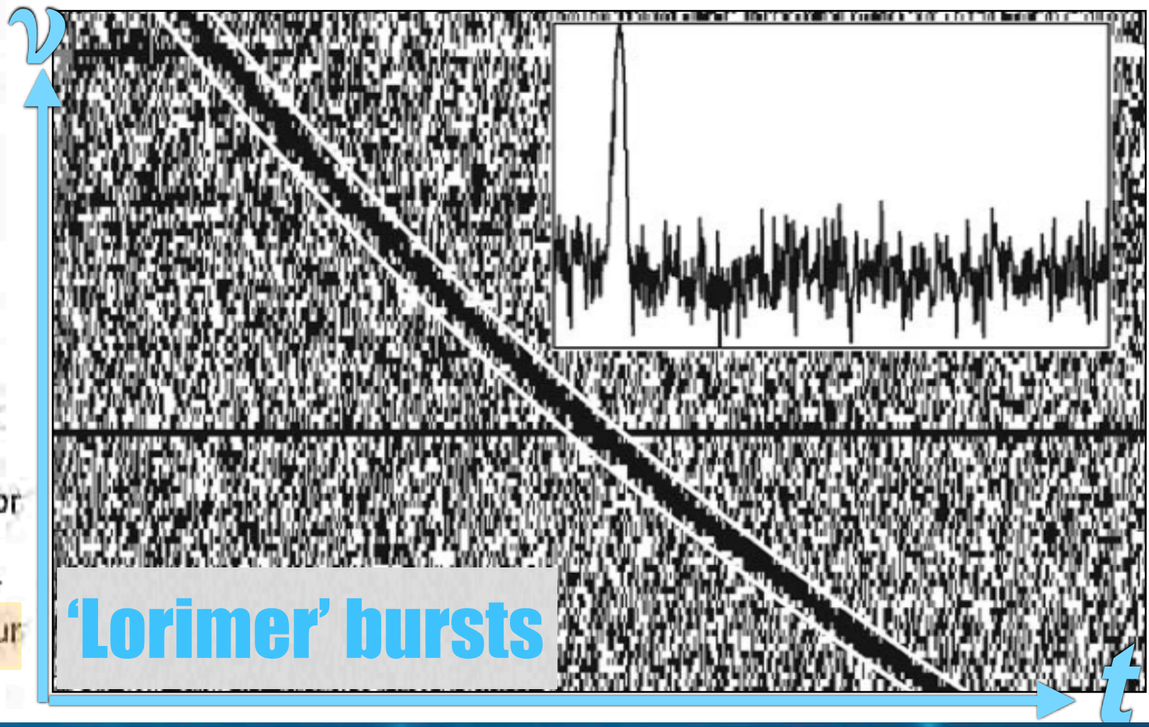
# A Bright Millisecond Radio Burst of Extragalactic Origin

2007

D. R. Lorimer,[1,2]* M. Bailes,[3] M. A. McLaughlin,[1,2] D. J. Narkevic,[1] F. Crawford[4]

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° from the Small Magellanic Cloud. The burst properties argue against a physical association with our Galaxy or the Small Magellanic Cloud. Current models for ... event such as a supernova or coalescence of relativistic objects. Hundreds of similar events could occur every day and, if detected, could serve as cosmological probes.

Hundreds of similar events could occur every day…




THE SHAW PRIZE 邵逸夫獎

# FRB Discovers





# SEARCHES FOR GIANT PULSES FROM EXTRAGALACTIC PULSARS

M. A. McLaughlin[1] and J. M. Cordes[2]

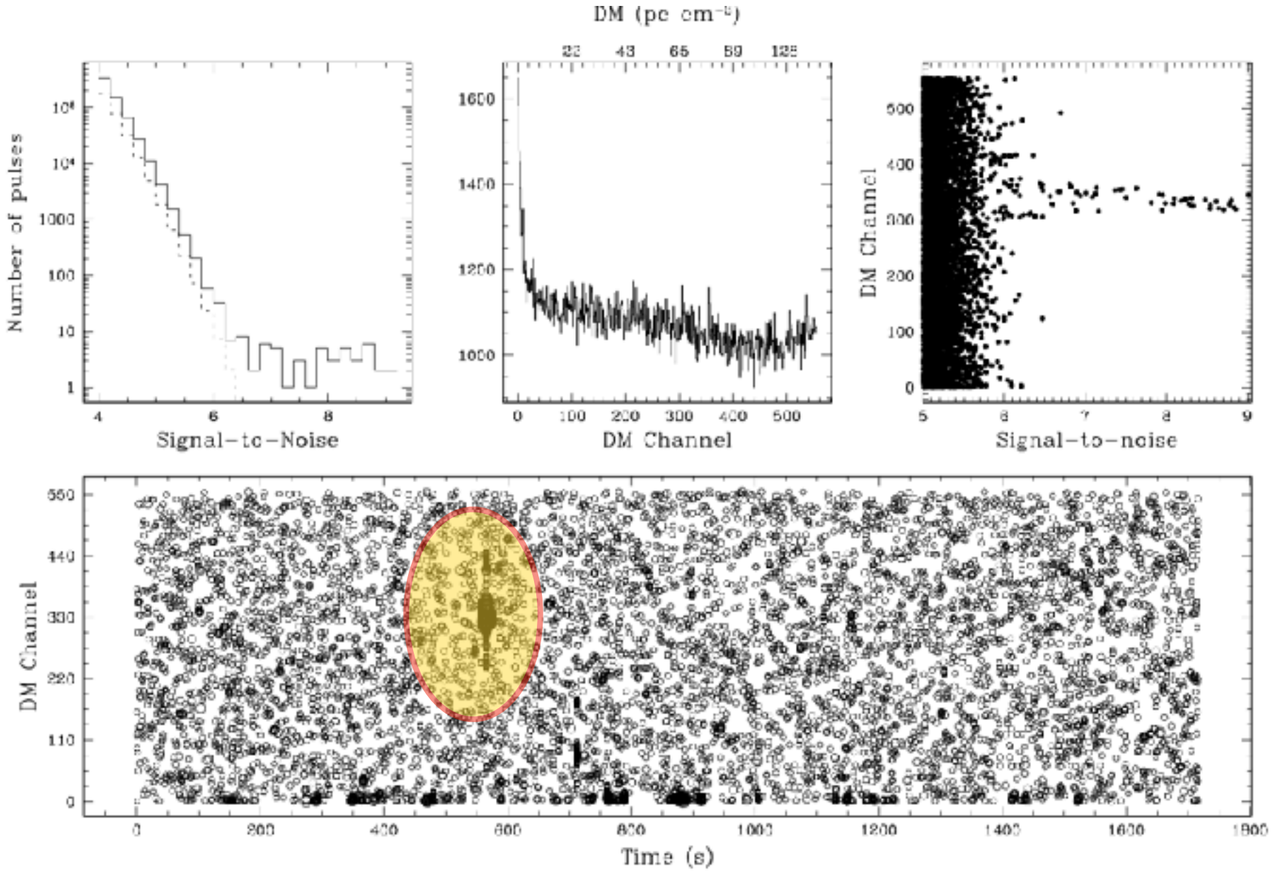
*Received 2003 April 21; accepted 2003 July 2*

## ABSTRACT

We discuss the giant-pulse phenomenon exhibited by pulsars and the distances to which giant pulses might be detected from extragalactic pulsars. We describe the conditions under which a single-pulse search is more sensitive than a standard periodicity search. We find that, for certain pulse-amplitude distribution power laws and time series lengths, single-pulse searches can be superior. We present the results of searches toward several extragalactic targets, including M33, the LMC (PSR B0540−69), and several other galaxies. While we have not conclusively detected giant pulses from any of these targets, these searches illustrate the methodology of, issues related to, and difficulties in these types of searches.

*Subject headings:* galaxies: individual (M33) pulsars: general pulsars: individual (B0540−69)

*On-line material:* color figures

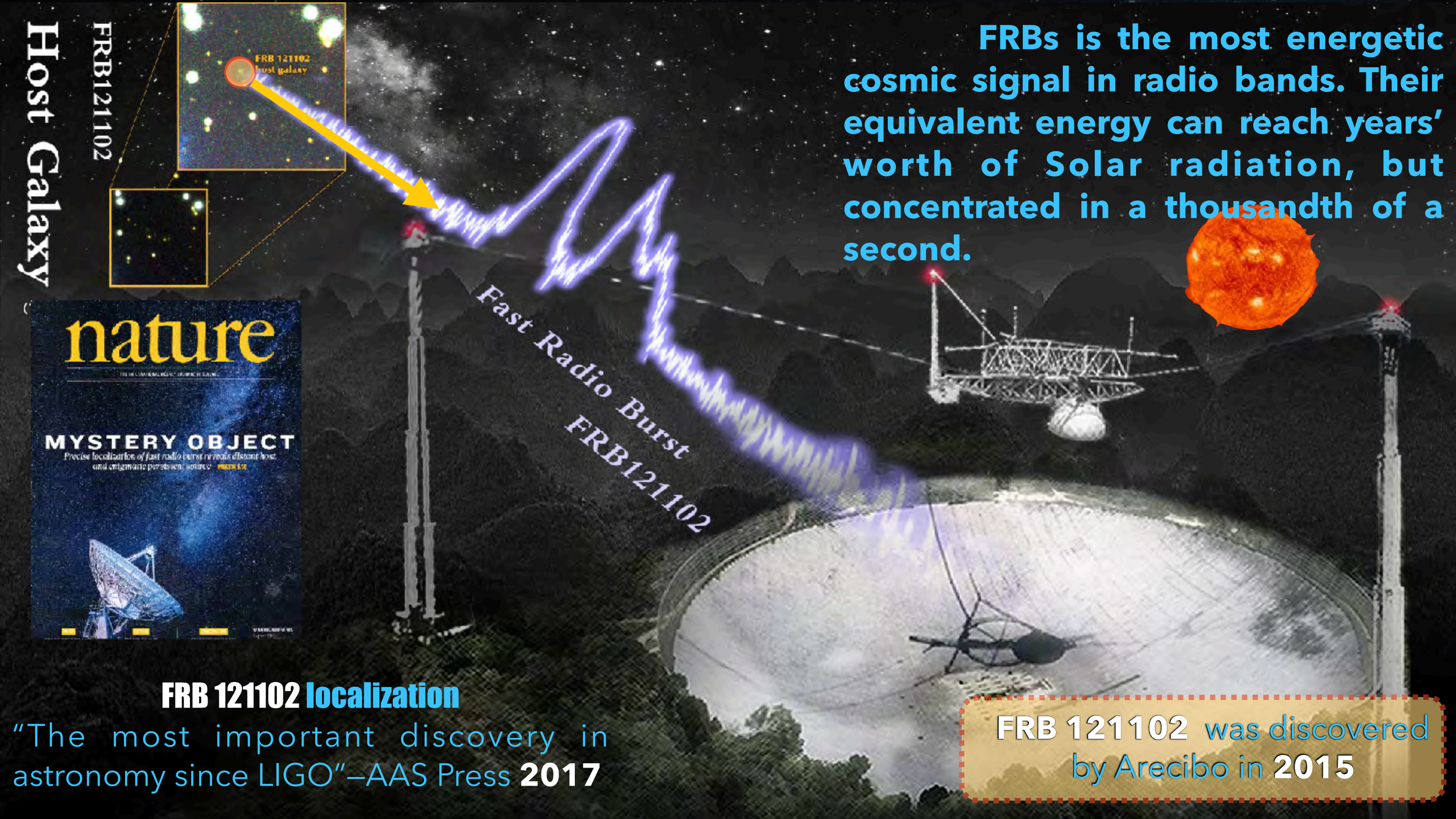










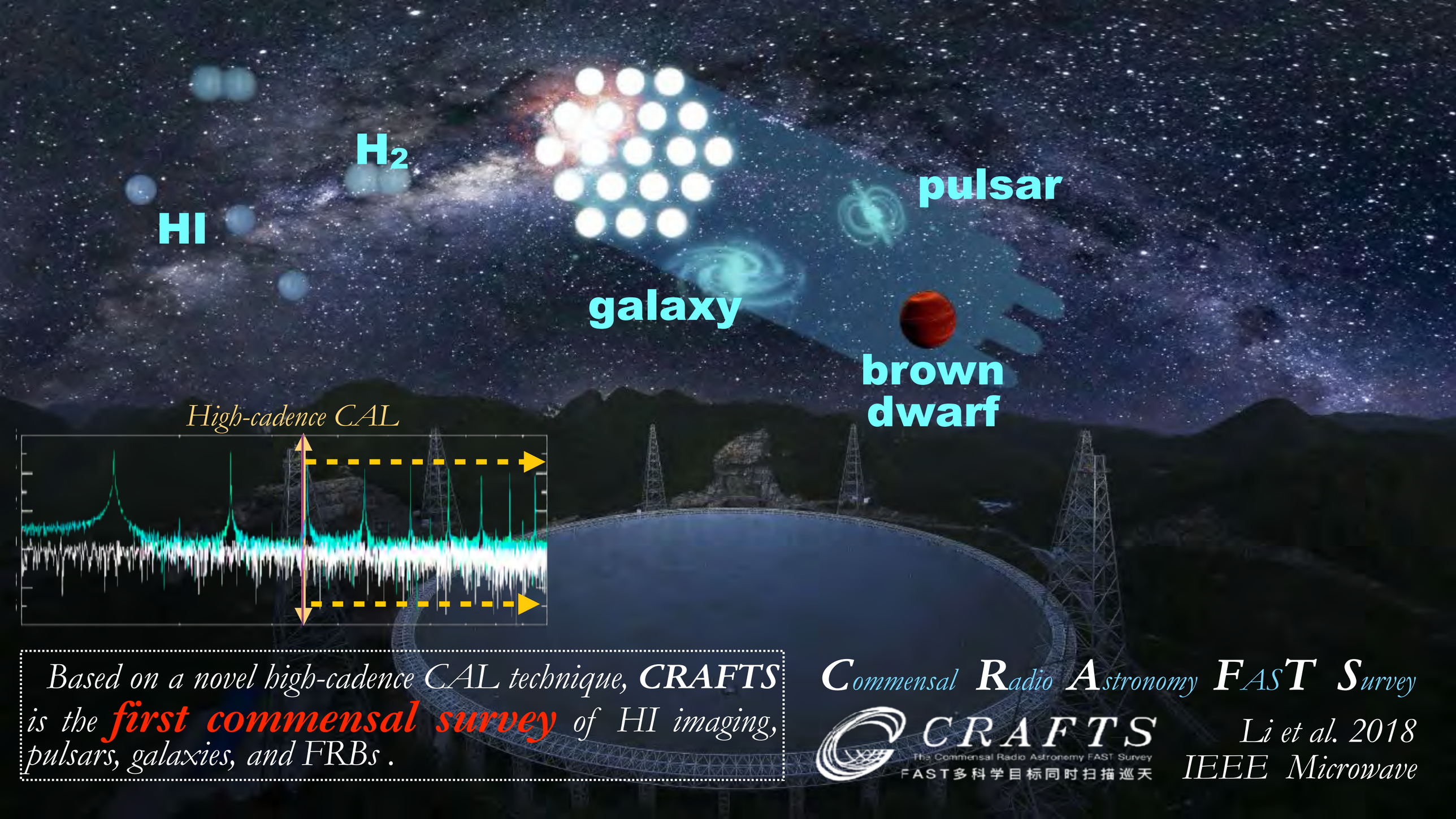

FRBs is the most energetic cosmic signal in radio bands. Their equivalent energy can reach years' worth of Solar radiation, but concentrated in a thousandth of a second.

**FRB 121102 localization**

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

**FRB 121102** was discovered by Arecibo in **2015**


Arecibo
(1963 - 2020)
FAST
(2020 - now)
300m
500m
1993
诺贝尔物理学奖
美国 Arecibo
中国天眼 FAST
人类建造的最大天线



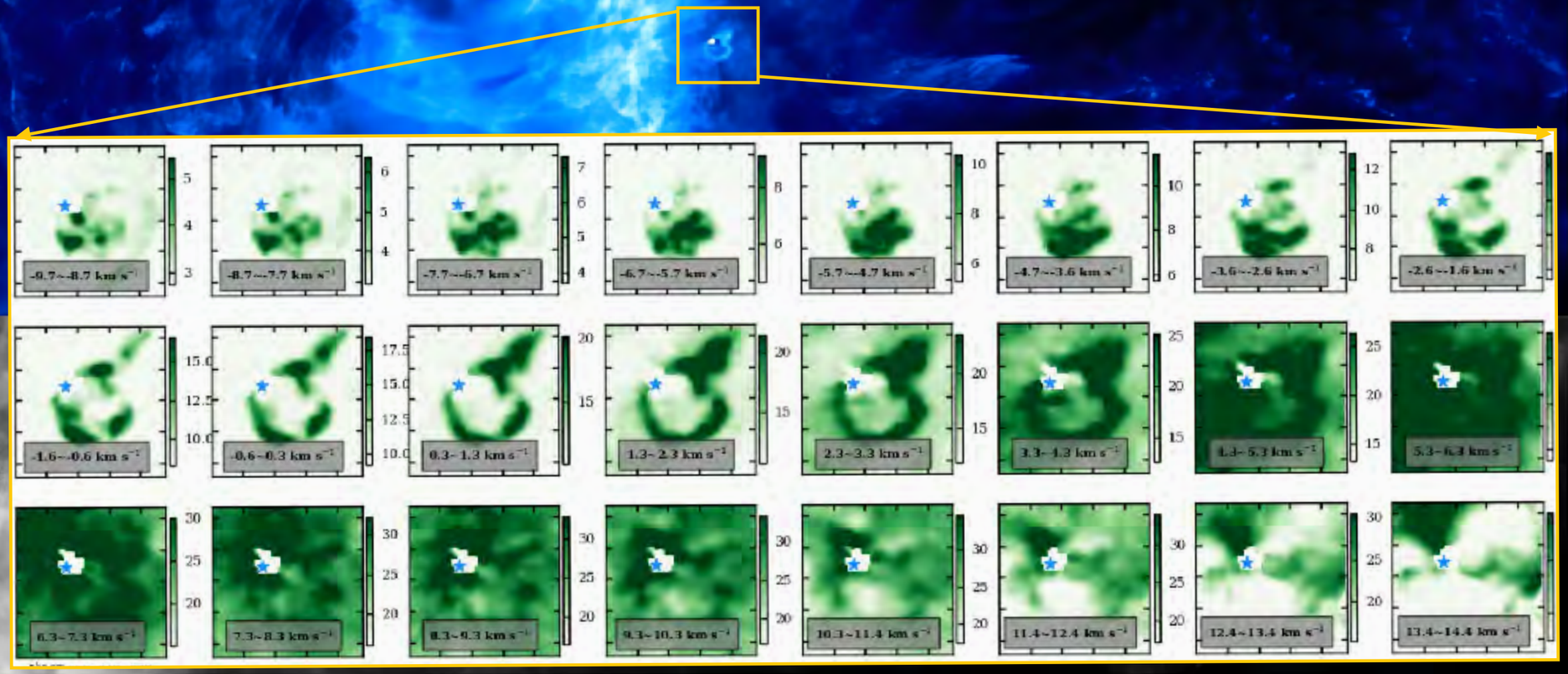

*Based on a novel high-cadence CAL technique,* ***CRAFTS*** *is the* ***first commensal survey*** *of HI imaging, pulsars, galaxies, and* FRBs .

***C****ommensal* ***R****adio* ***A****stronomy* ***F****A****S****T*** ***S****urvey*

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*

# CRAFTS HI images of Orion




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

*li & Qiu under review , Science Advances*

*("the Veil" in Orion: cf. Pabst et al. 2019 Nature)*

# CRAFTS

The Commersal Radio Astronomy FAST Survey

FAST多科学目标同时扫描巡天

# Welcome to CRAFTS

4738 $d^2$

publication quality

(dili@nao.cas.cn)

## Narrow band HI data releases

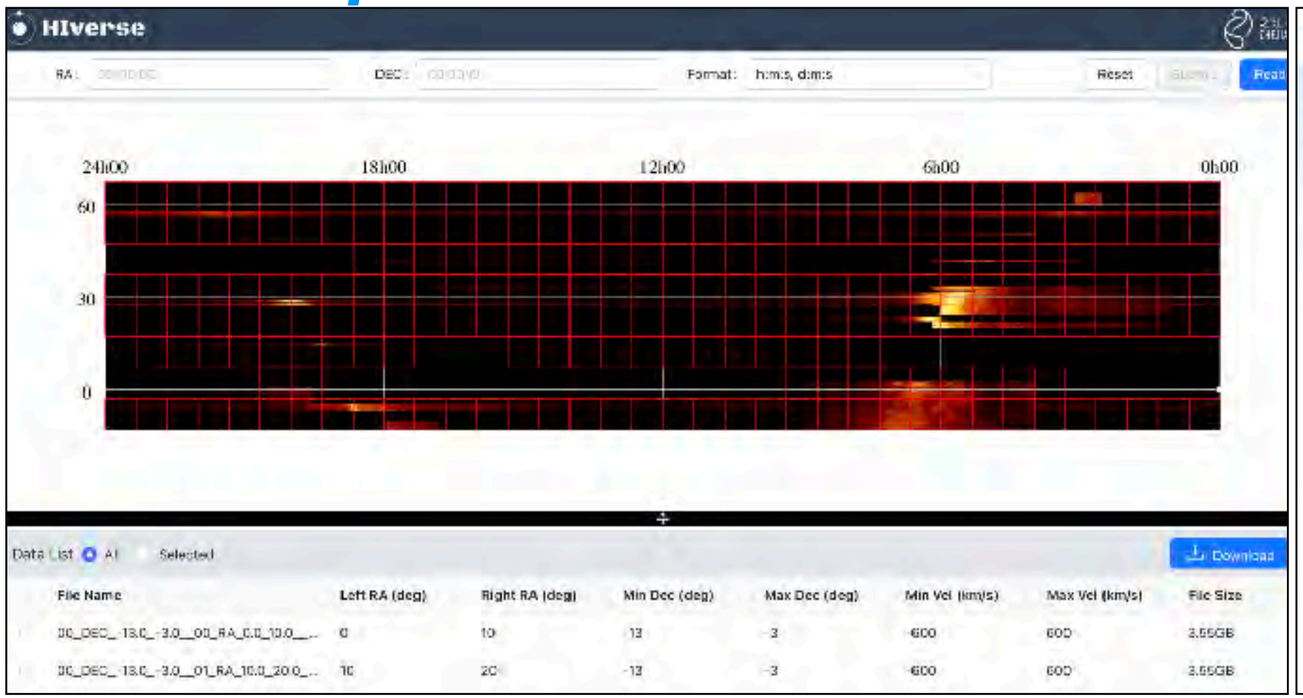
https://doi.org/10.57760/sciencedb.07779

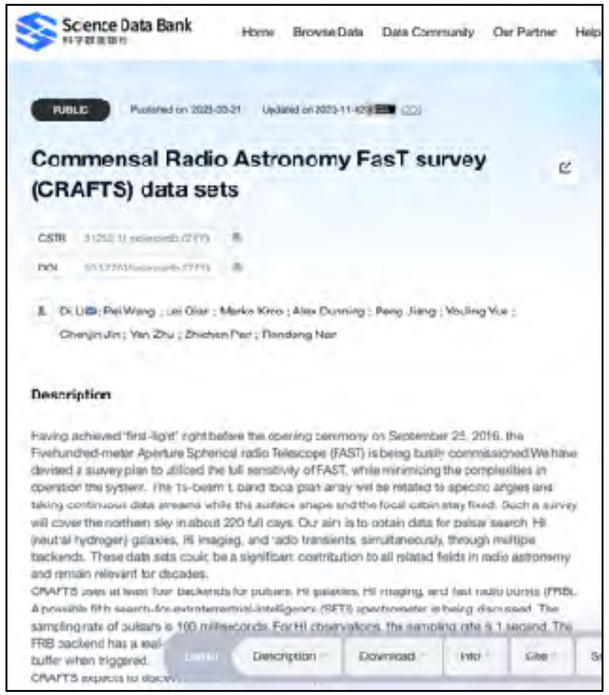
http://groups.bao.ac.cn/ism/english/CRAFTS

https://hiverse.alkaidos.cn/

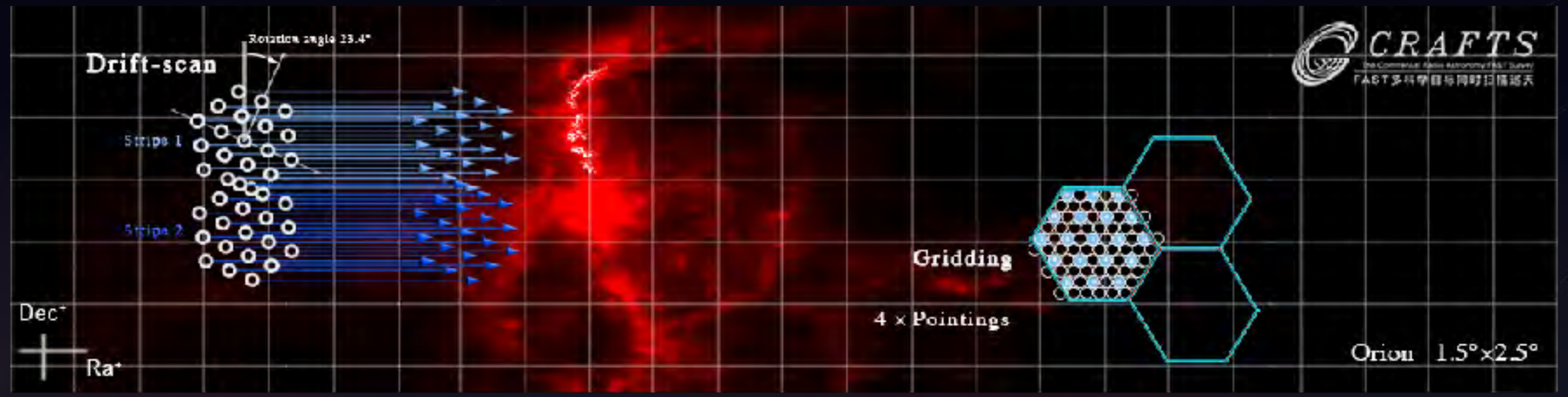
Li et al. 2018 IEEE MW



# Status of pulsar discoveries from CRAFTS



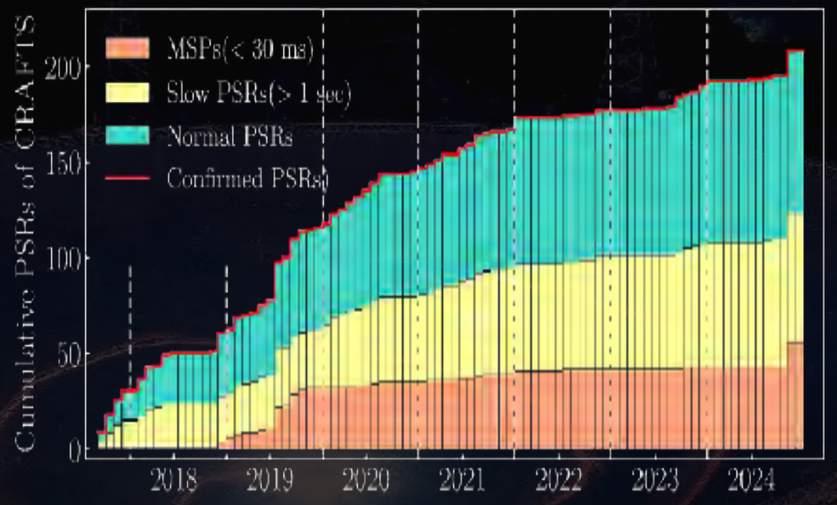

Confirmed
**222 New Pulsars**
Discovery

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

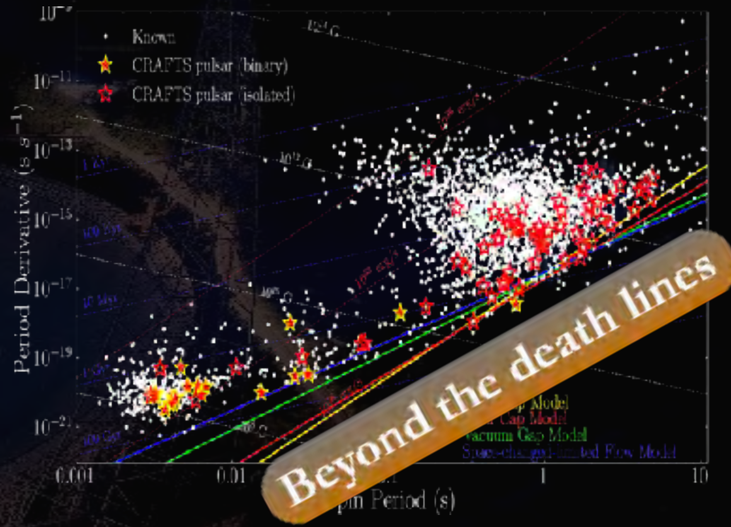
~90 Pulsars have full time solution
International collaborative pulsar timing

**CRAFTS** Catalog & Data Release
http://crafts.bao.ac.cn/pulsar/

https://fastro.scidb.cn/en
86GB+, 7 datasets
100,000 Views, 5200+ Downloads
>200 citations, from 20+ Countries



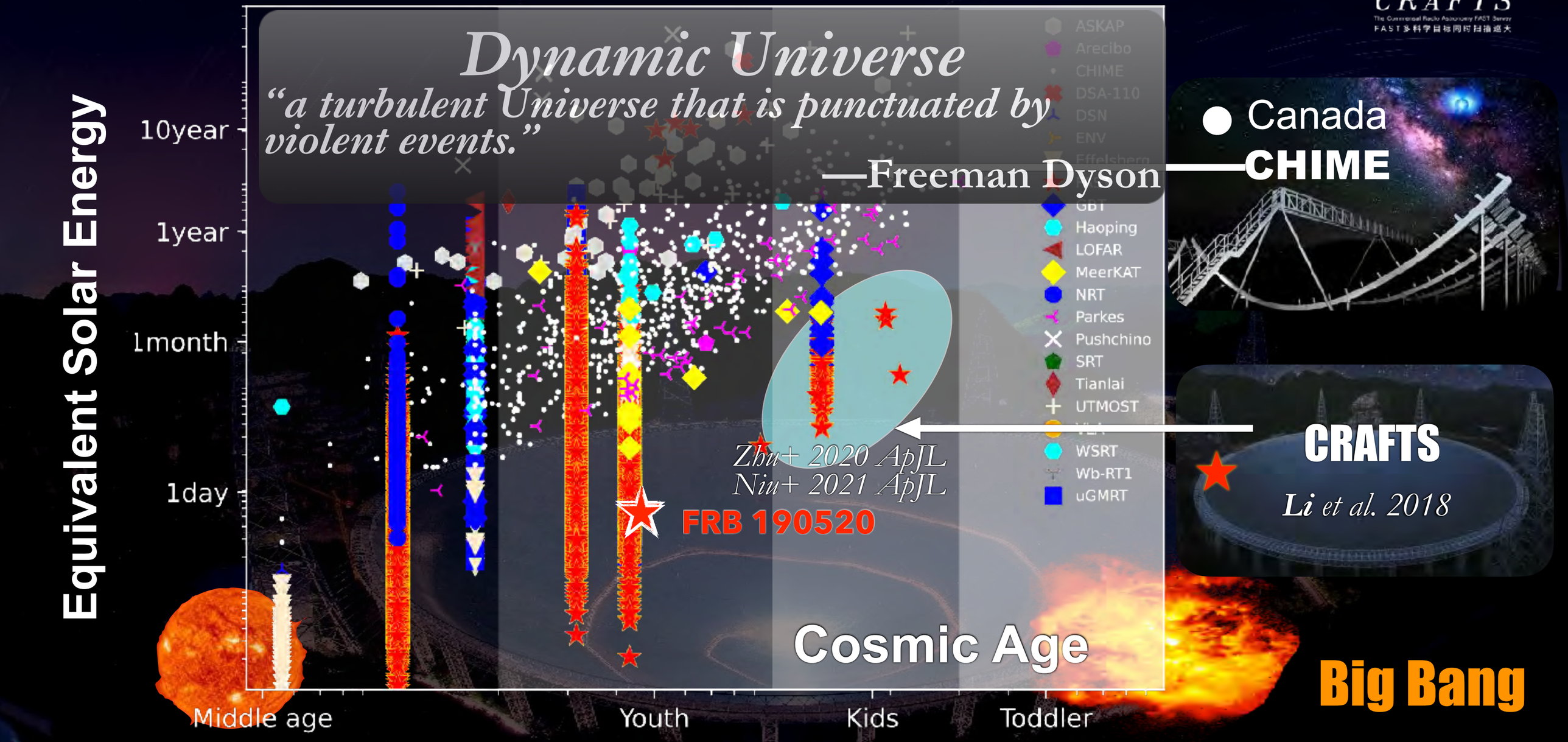

Date of discovery (Year)




P-Pdot Diagram

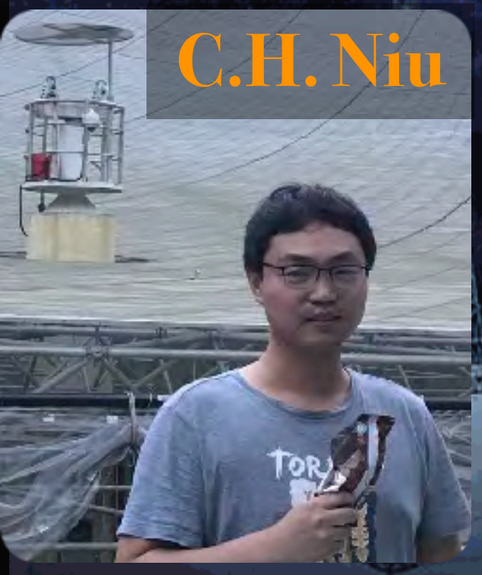
FRB event rate **>120K** ***day*$^{-1}$** ***4π*$^{-1}$** (Niu+ 2021)

CRAFTS
The Commensal Radio Astronomy FAST Survey
FAST多科学目标同时巡天



FRB 190520

CRAFTS



C.H. Niu

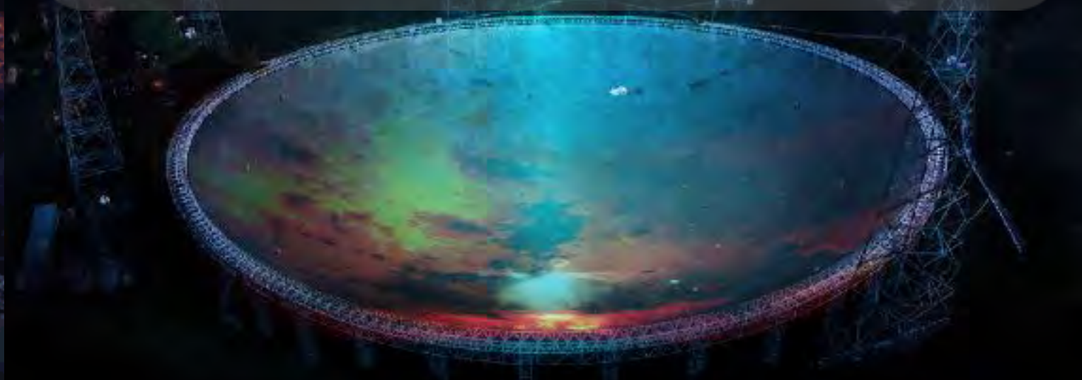
2019.5.20 **CRAFTS** scan: discovery

nature

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** 》

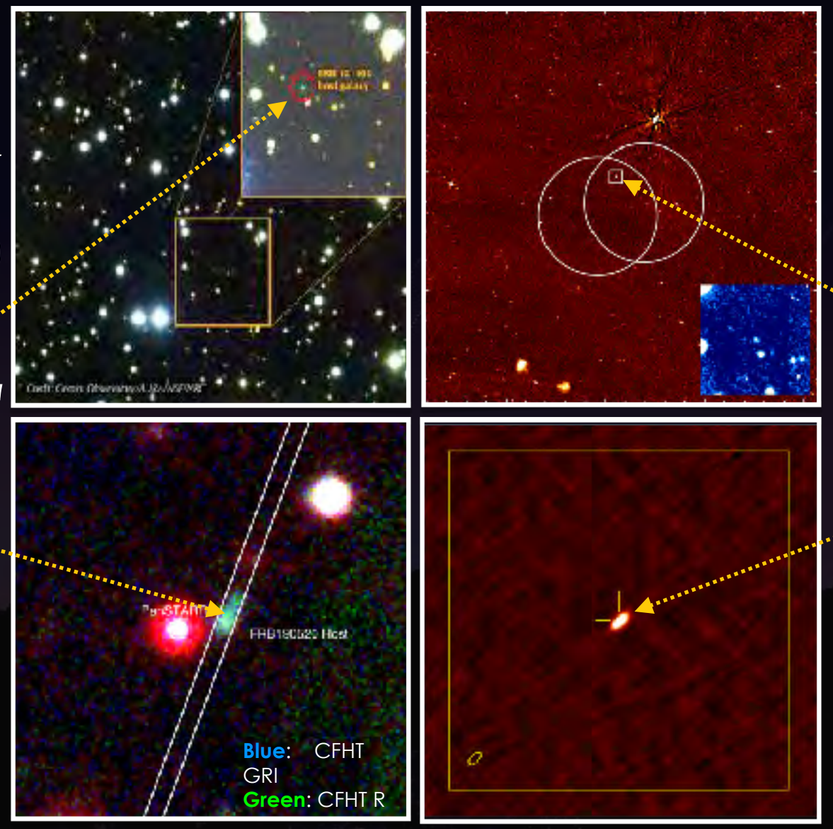



**Credit** Niu et al. 2022 / Saxton（NRAO）

FRB 121102

HOST GAL

PRS




FRB 190520

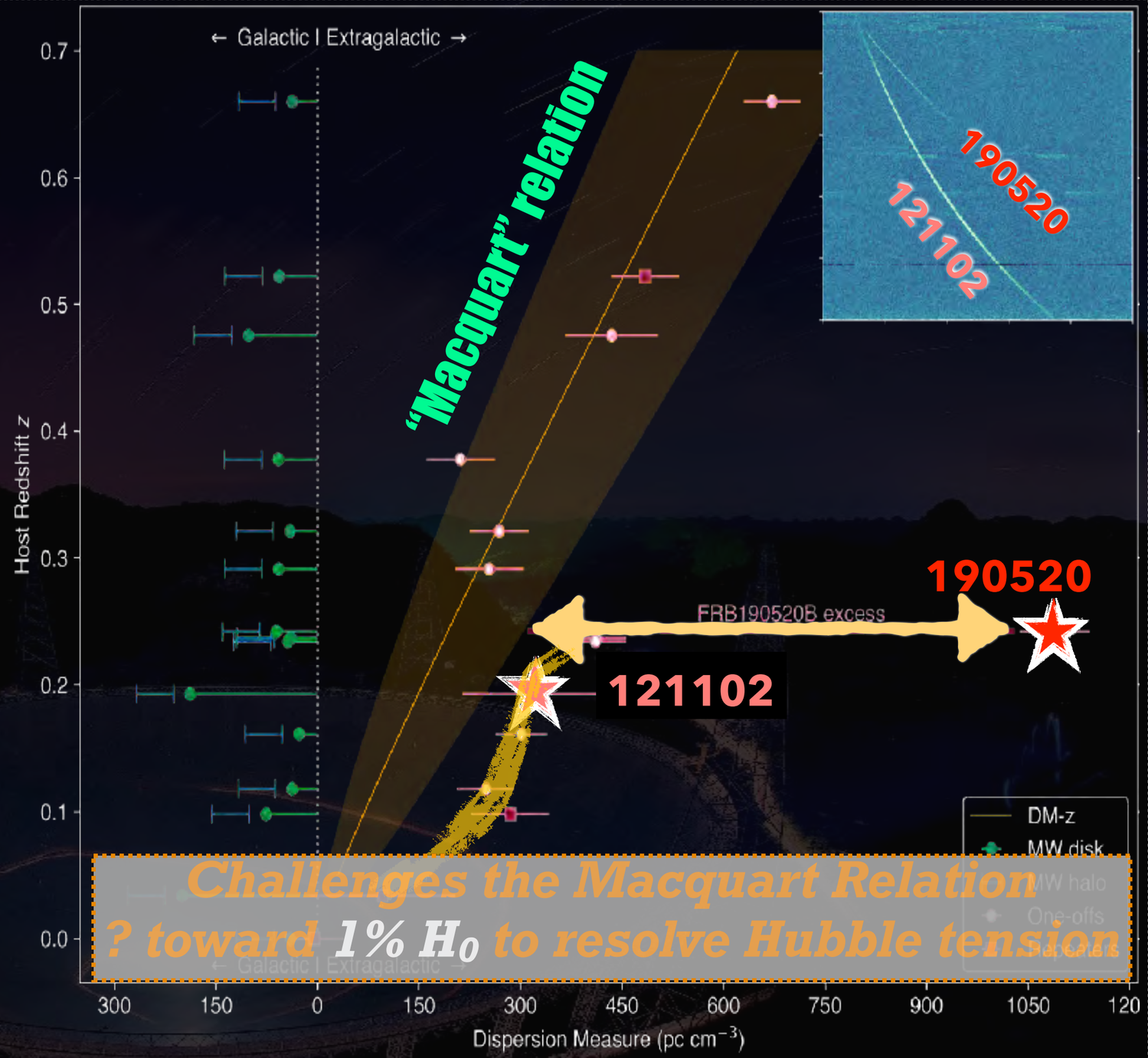
**190520**

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

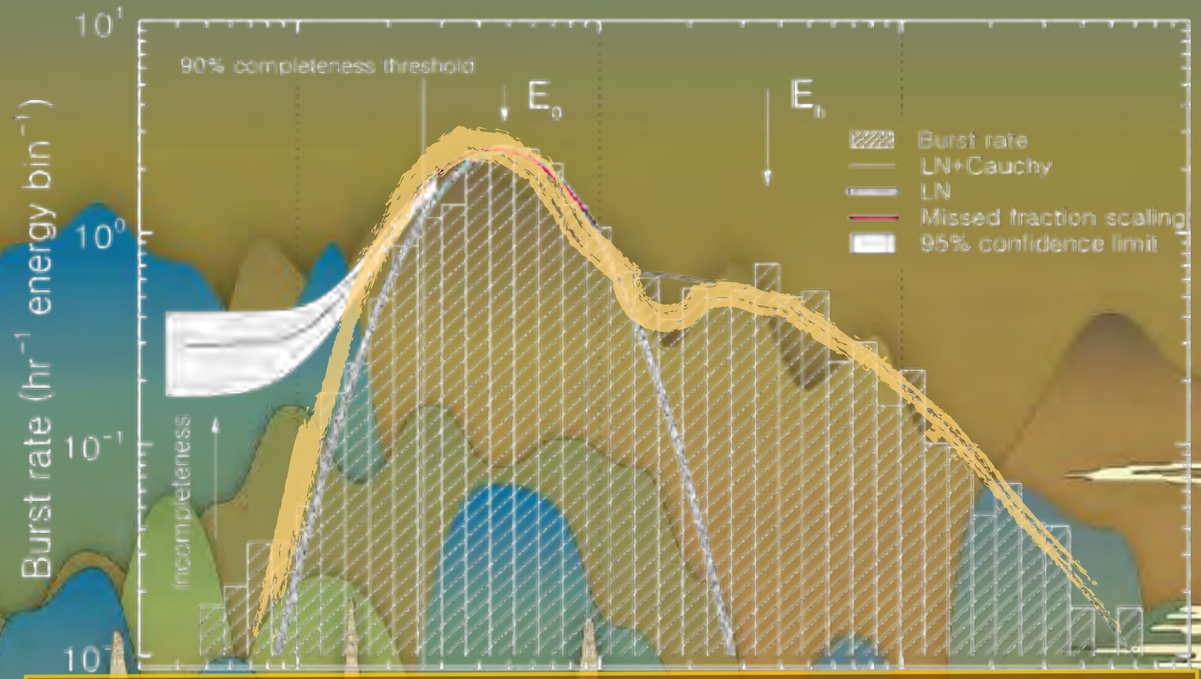
*largest* **DM$_{host}$**

*Only two* **PRS**

*1st & only* **Persistently Active**



*1st complete FRB burst-rate energy spectrum*




$$N(E) = \frac{N_0}{\sqrt{2\pi}\sigma_E E} \exp\left[\frac{-(\log E - \log E_0)^2}{2\sigma_E^2}\right] + \frac{\epsilon_E}{1+(\frac{E}{E_0})^{\alpha_E}}$$

“月半千辉”

1652 bursts in 50 days

**FRB 121102**

Universal $E_{FRB}$ : bimodal

*(Li+ 2021; Zhang+ 2024)*

**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

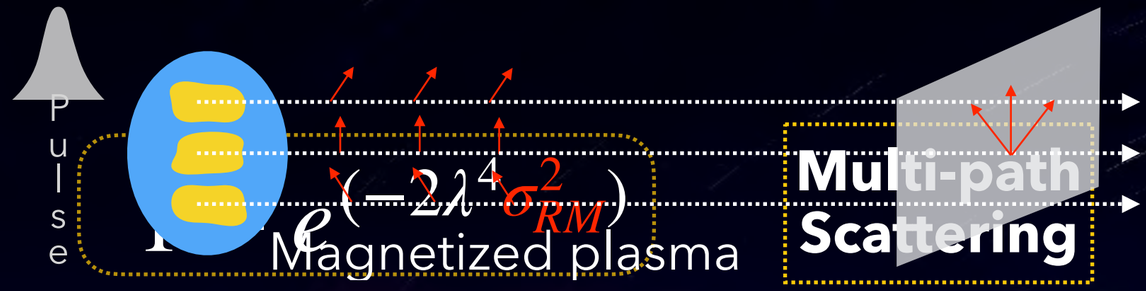
nature Li, Wang, 2021 DOI : 10.1038/s41586-021-03878-5

CRAFTS webpage: https://crafts.bao.ac.cn/

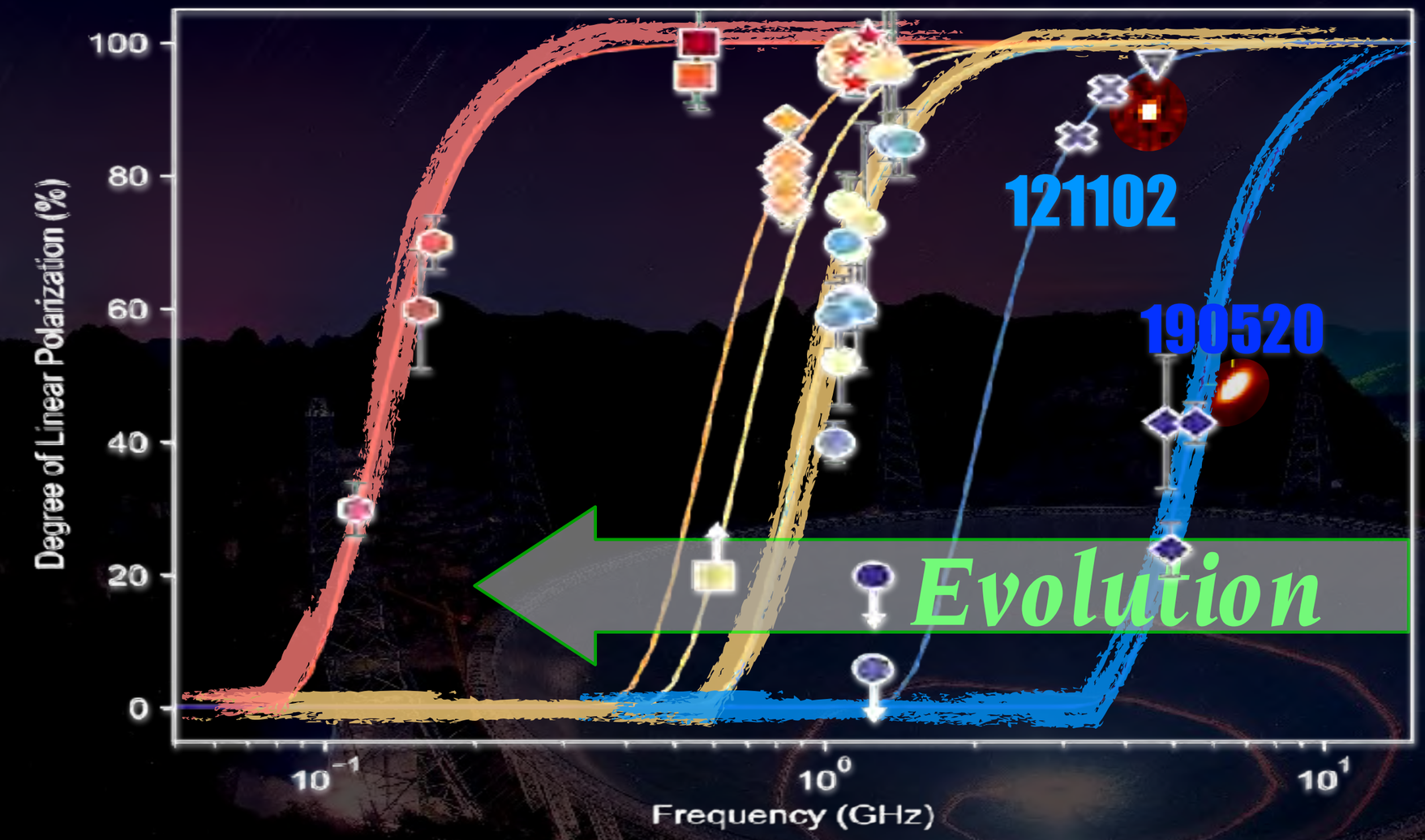
CRAFTS

# FAST+GBT

reveal FRB's environment




## Unifying repeating fast radio bursts





NATURE | NEWS

**Unifying repeating fast radio bursts**

Mysterious high-energy radio bursts are found to share certain characteristics

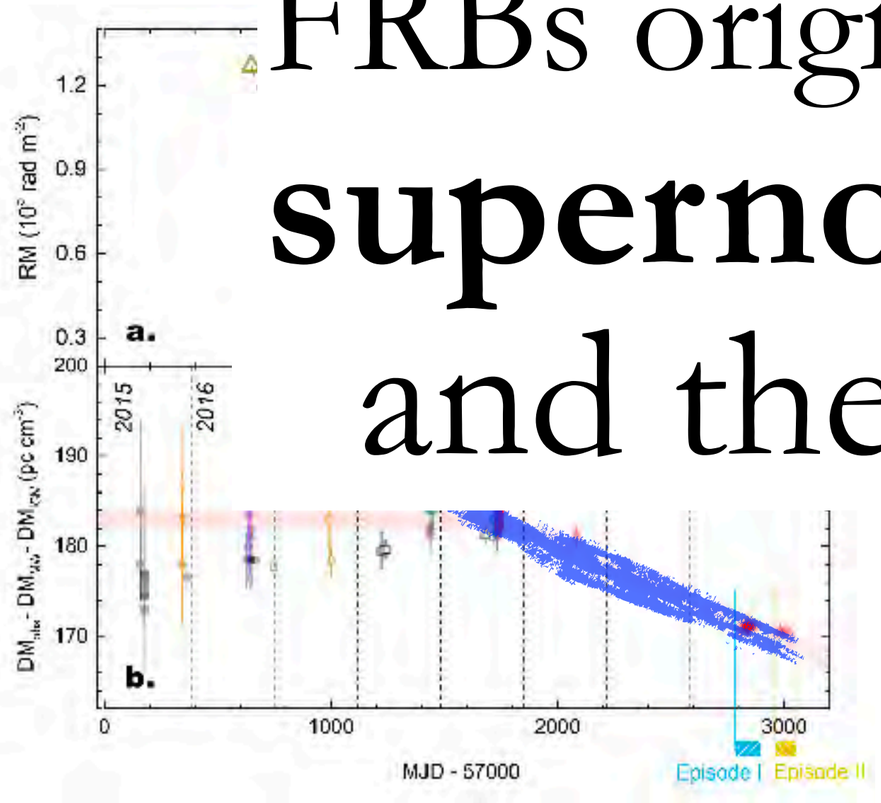
Feng, **Li*** et al. 2022 Science, 375, 1266

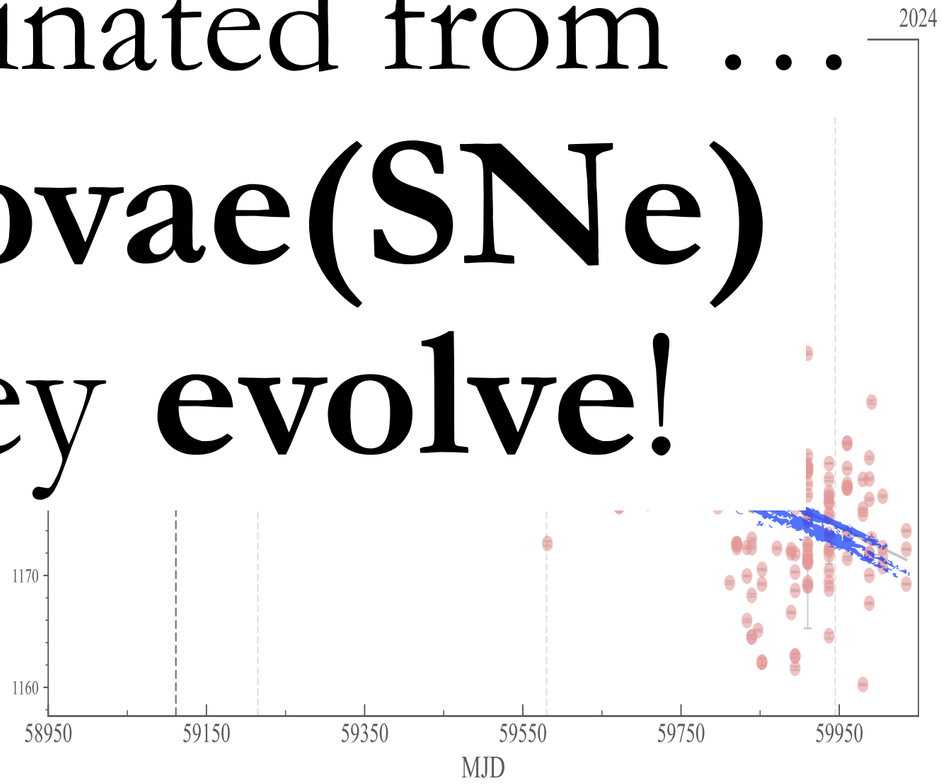
# Decadal evolution of repeating FRBs

FRBs originated from …

**supernovae(SNe)**

and they **evolve**!







$$\frac{d\mathrm{DM}}{dt} = -3.93 \pm 0.11 \ \mathrm{pc\ cm^{-3}\ yr^{-1}}$$

*Wang et al. 2025, Innovation under review*

$$\frac{d\mathrm{DM}}{dt} = -12.4 \pm 0.3 \ \mathrm{pc\ cm^{-3}\ yr^{-1}}$$

*Niu et al. 2026, Science Bulletin, Accepted*

# *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)

02

“时间前沿”

The Cosmic **Time Frontier**
2023-2024 weekend coffee discussion notes

$$E = h\nu \qquad \nu = \frac{c}{\lambda}$$

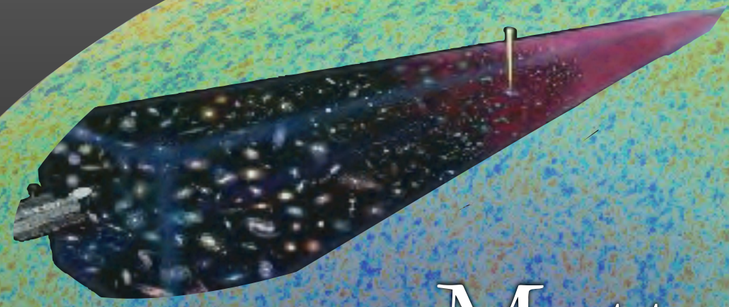
$$\delta t < \frac{1}{2\nu}$$

$$\Delta t \, \Delta E \geqslant \frac{h}{4\pi}$$

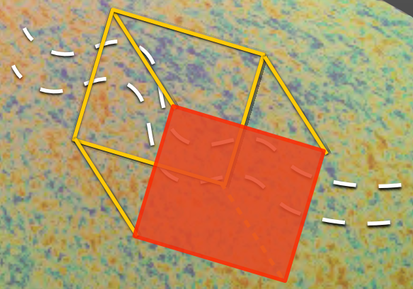
?

*the finite Universe*
$t$ = 13.7 billion yrs $z_{CMB} \sim 1100$

*13.7 billion yrs*



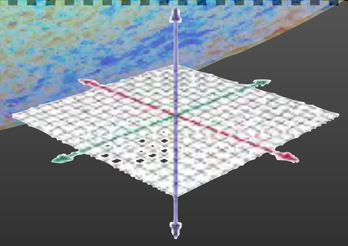
Matter



Force

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

cosmos $< \infty$



**Quantization**

# 宇宙触角
# Cosmic Antennae

计算感知宇宙




*1 TB/s; $10^4$ $d^2$ FoV*
*FRB localization: 1 $day^{-1}$*




清華大學天文系
Department of Astronomy, Tsinghua University

# Welcome to Tsinghua Astronomy















Joint **PhD** programs: (e.g. with U. of Manchester): 2+2 yrs, dual degrees

**SHUIMU Postdoctoral fellowships:** 2+1 yrs, ~$50K/yr, access to supercomputing, **FAST**, CSST, etc.