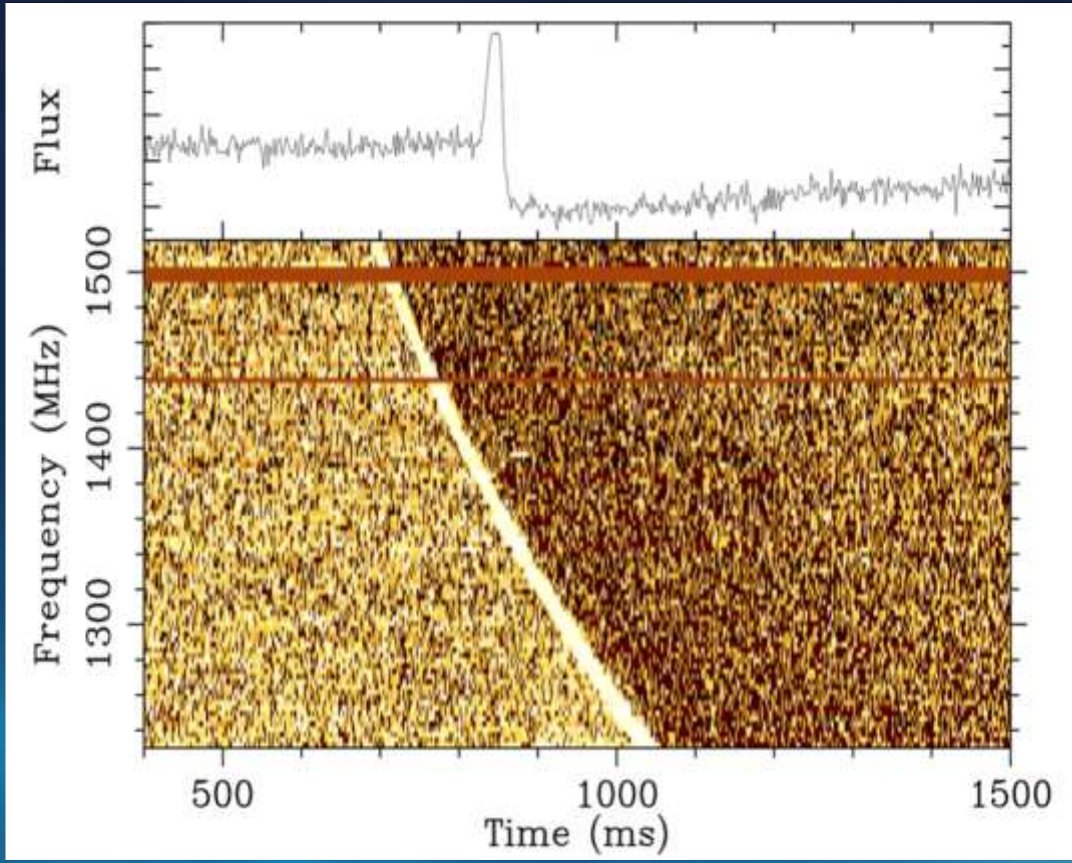
Exploring the blinking universe with FAST

Yi Feng
2023.11.30

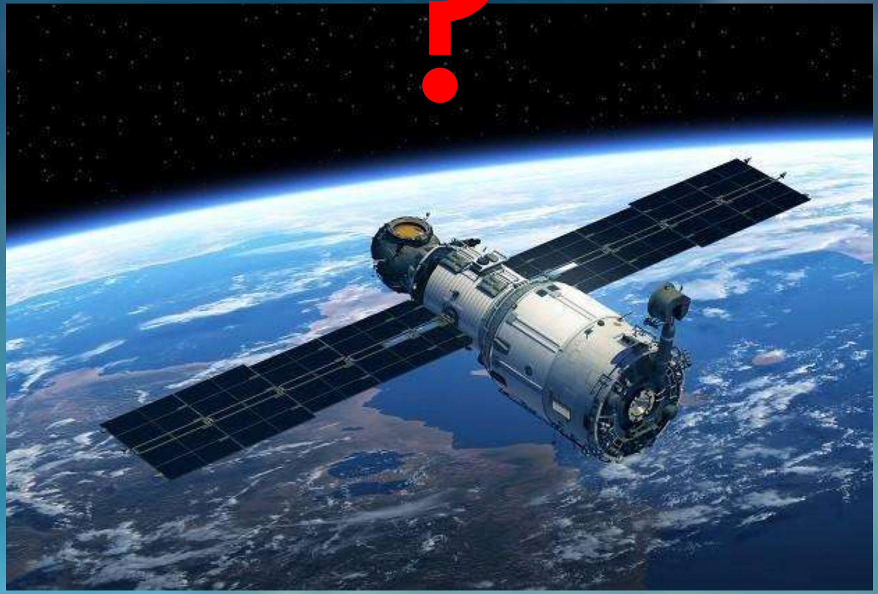
之江实验室
ZHEJIANG LAB

Introduction



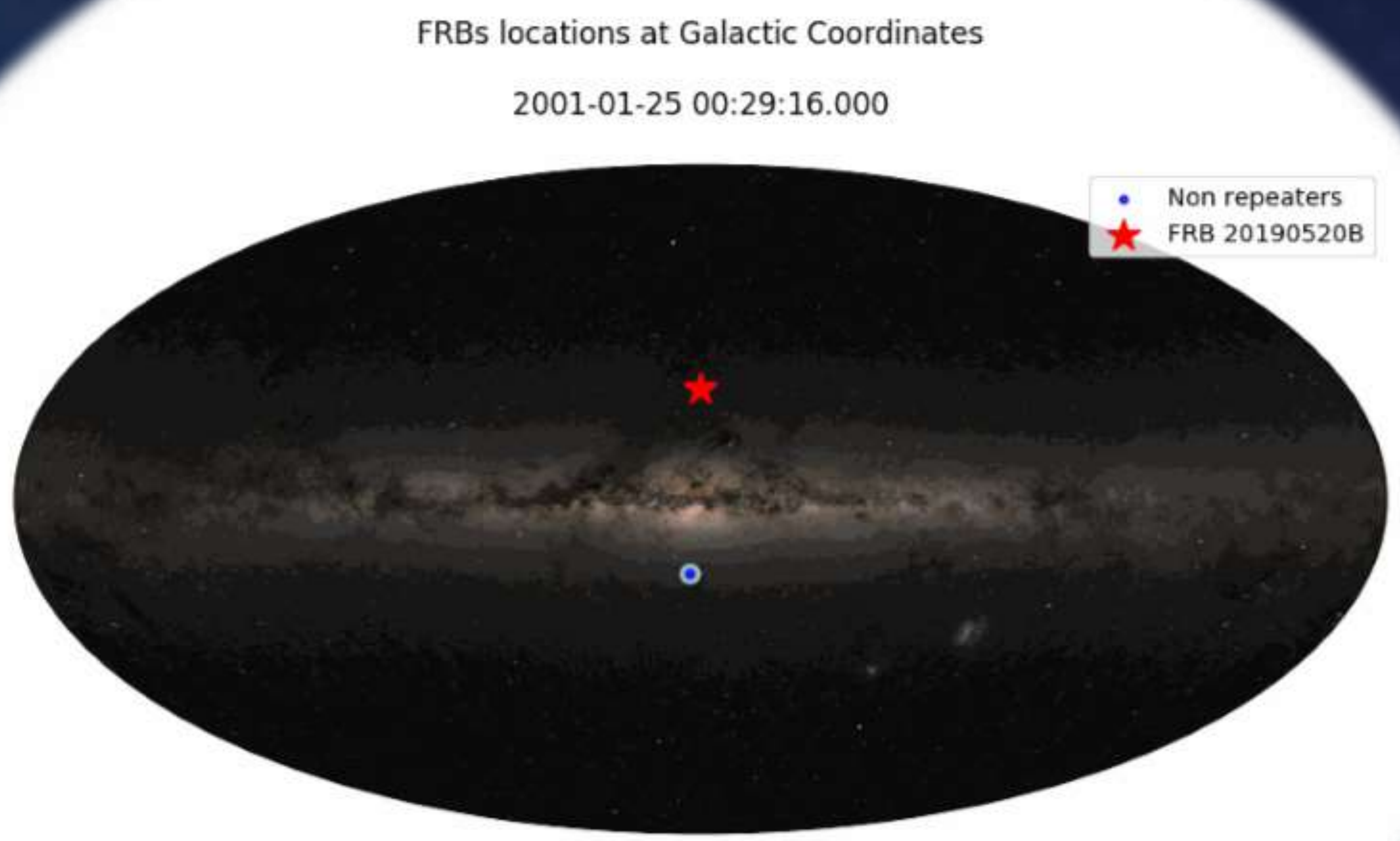
Lorimer Burst

Lorimer et al. 2007

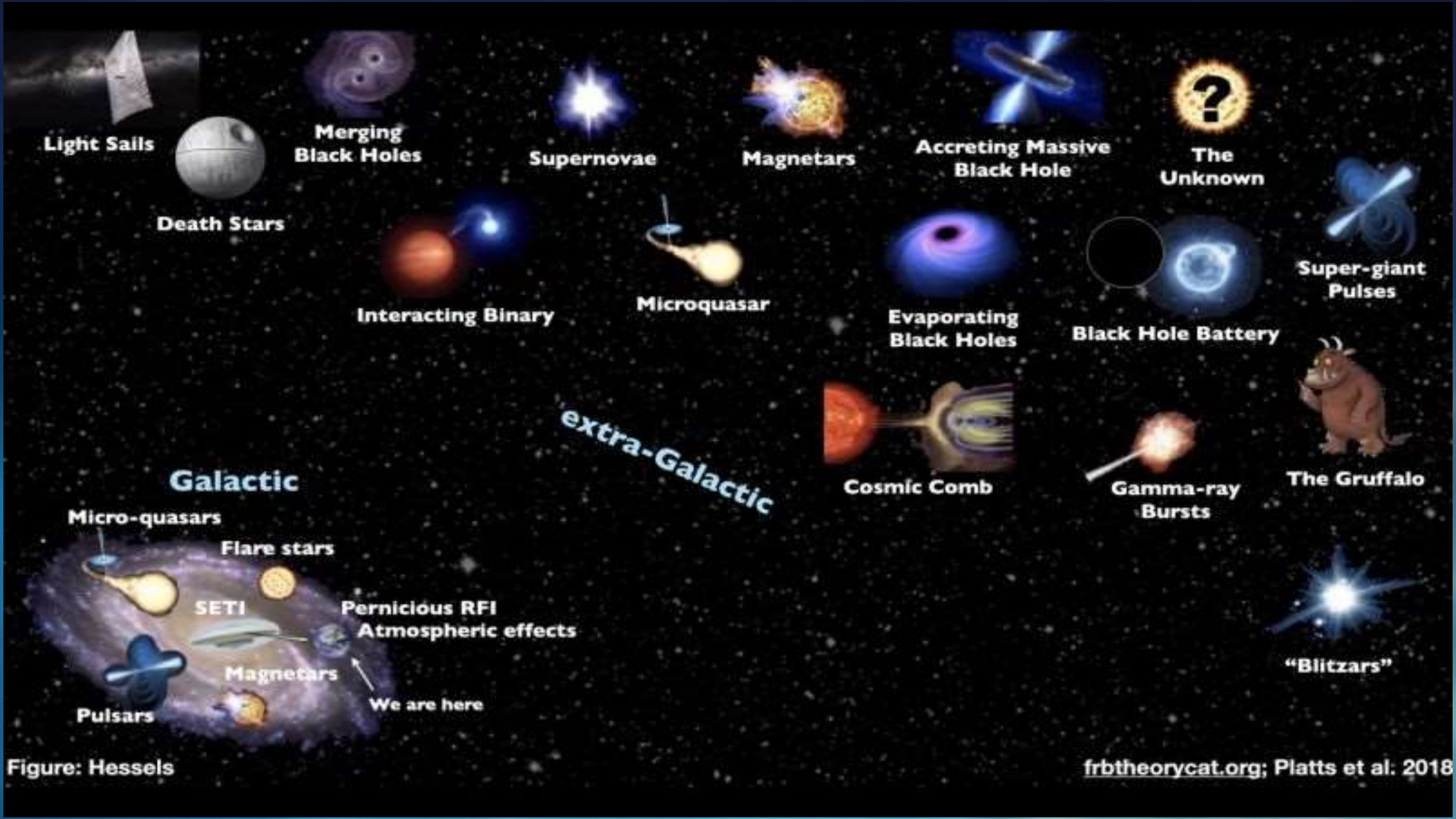


?

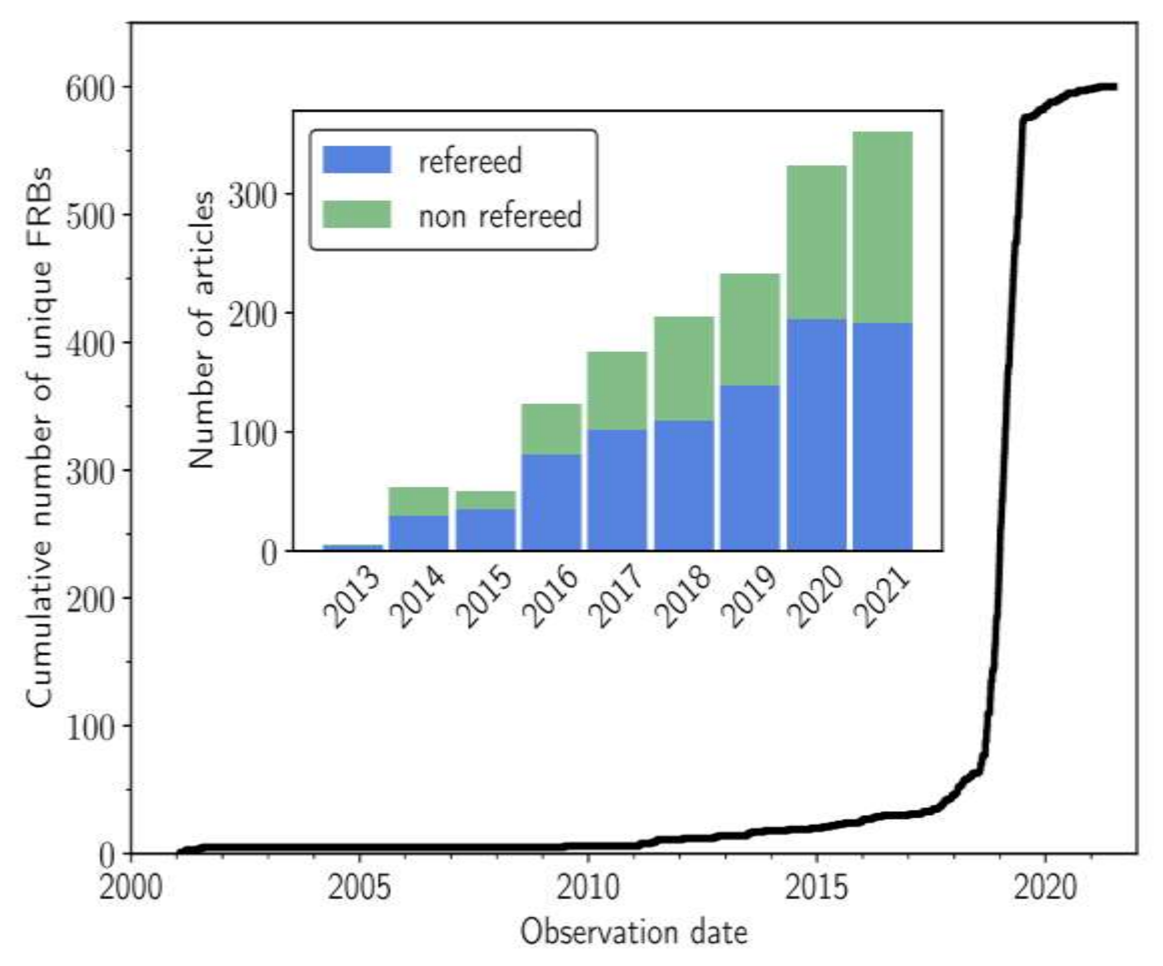
fast radio burst



Introduction



Introduction



Petroff et al. 2022

Flux: ~10 mJy to ~100 Jy

Width: ~100 us to ~10 ms

Frequency: 100 MHz to 8 GHz

FRBs: > 700

Repeating FRBs: 63

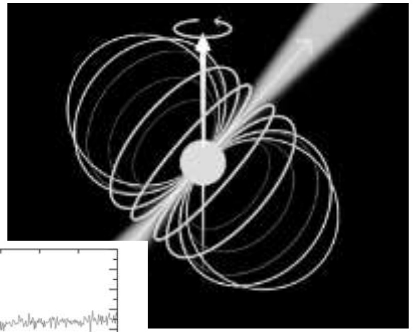
THE SHAW LAUREATES IN ASTRONOMY 2023

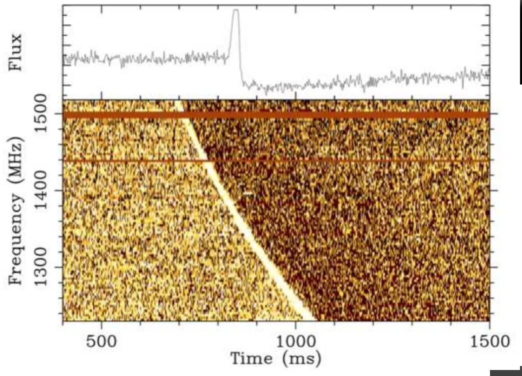
THE SHAW PRIZE 邵逸夫獎

Matthew Bailes,
Duncan Lorimer &
Maura McLaughlin

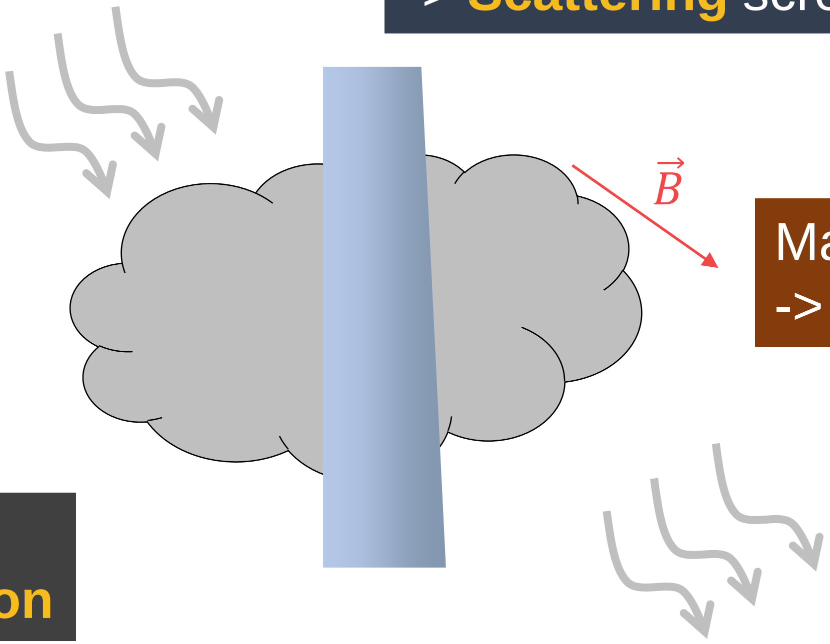
for the discovery of fast radio bursts (FRBs)

Propagation effects due to ISM

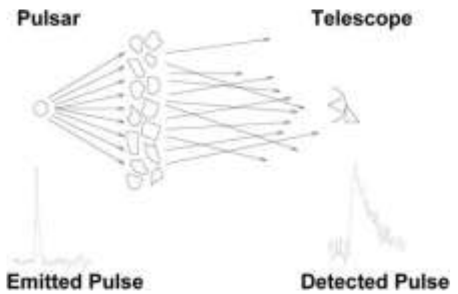




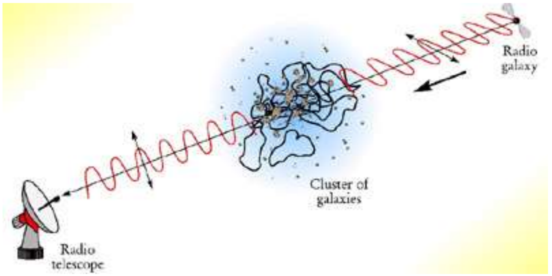
ionised ISM
-> **Dispersion**



Inhomogeneous ISM
-> **Scattering** screen



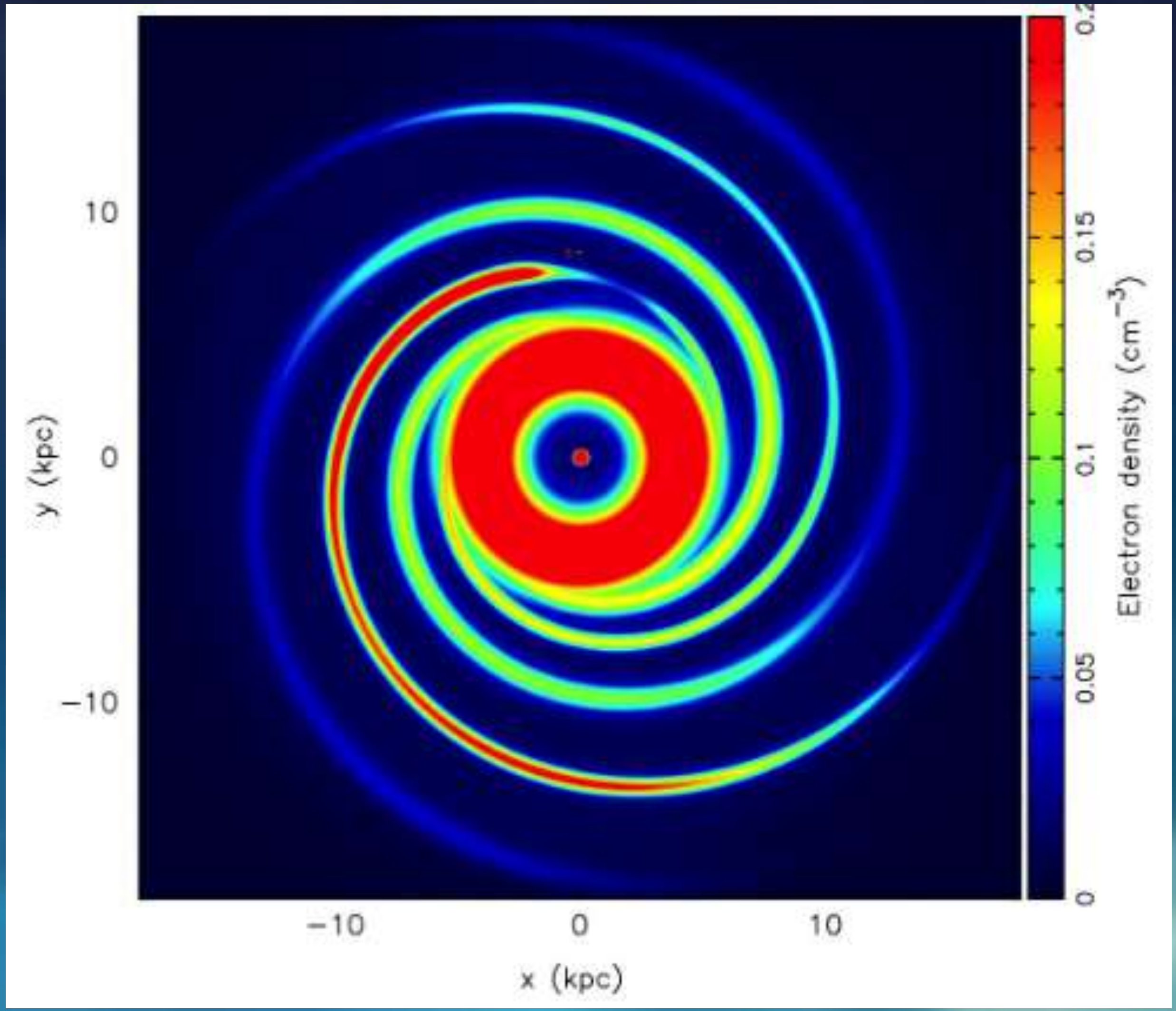
Magnetic field
-> **Faraday rotation**



All these effects are frequency dependent!

credit: Xue

Introduction



Electron density in the plane of the Galaxy for the YMW16 model

Introduction

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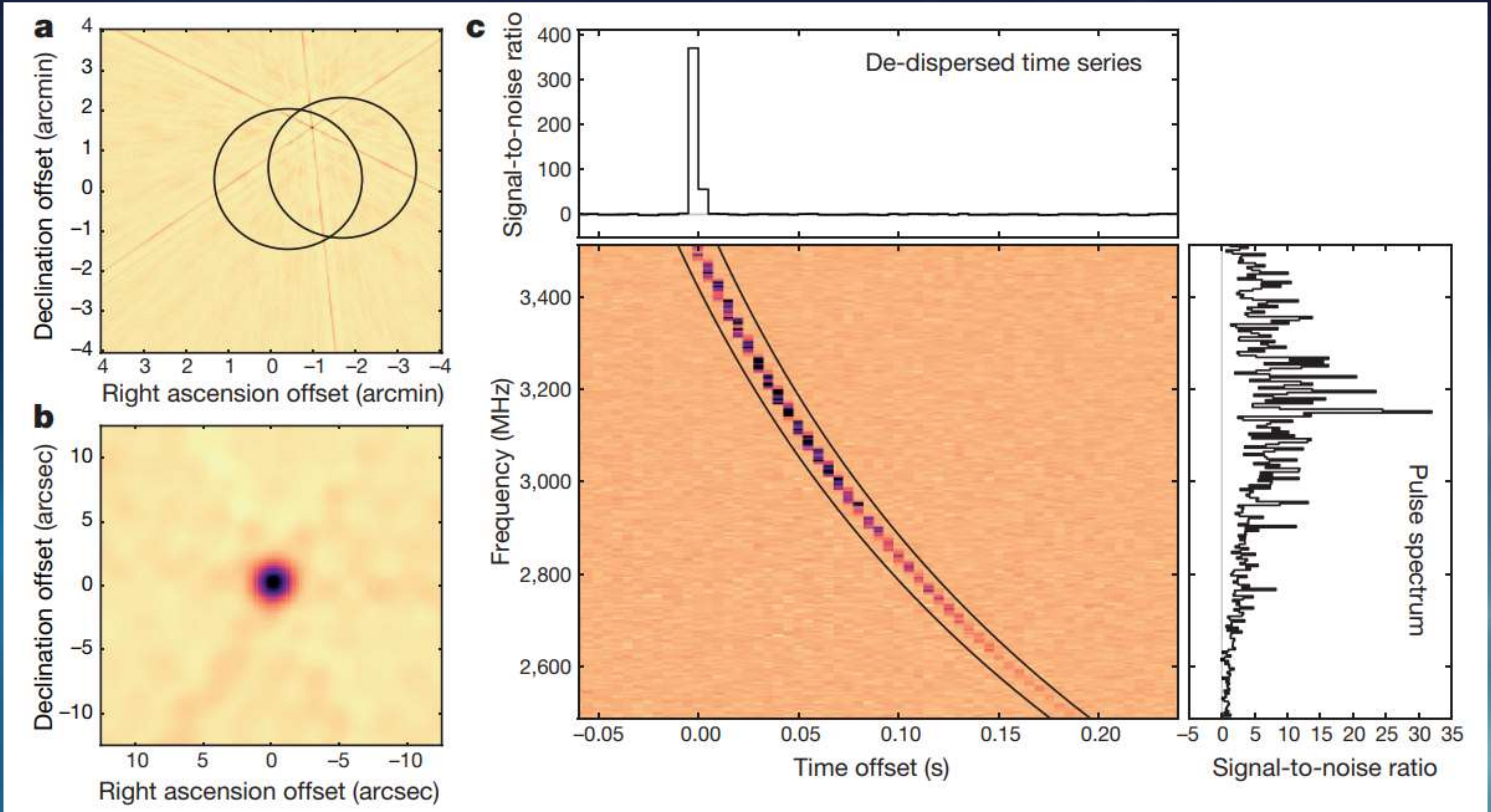


Chatterjee et al. 2017

Introduction

“The most important discovery in astronomy since LIGO”

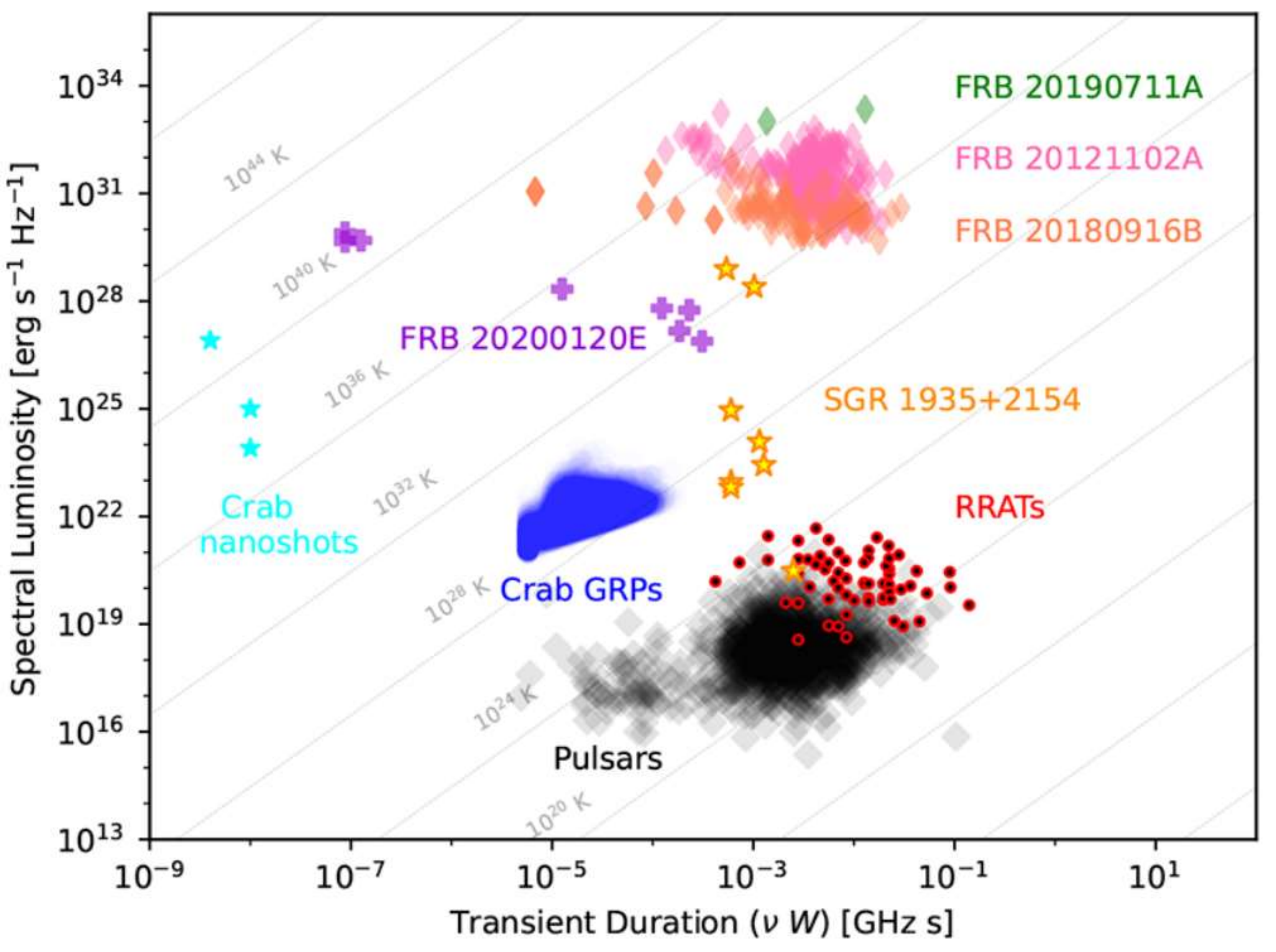
—AAS Press 2017

Introduction

Extremely powerful magnetic field ~10^9 to 10^{11} T

The strongest magnetic field created in the lab so far is a "mere" ~ 10^4 T!

Introduction



Petroff et al. 2022

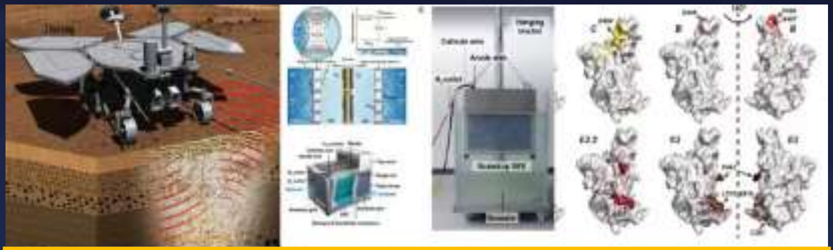
FAST

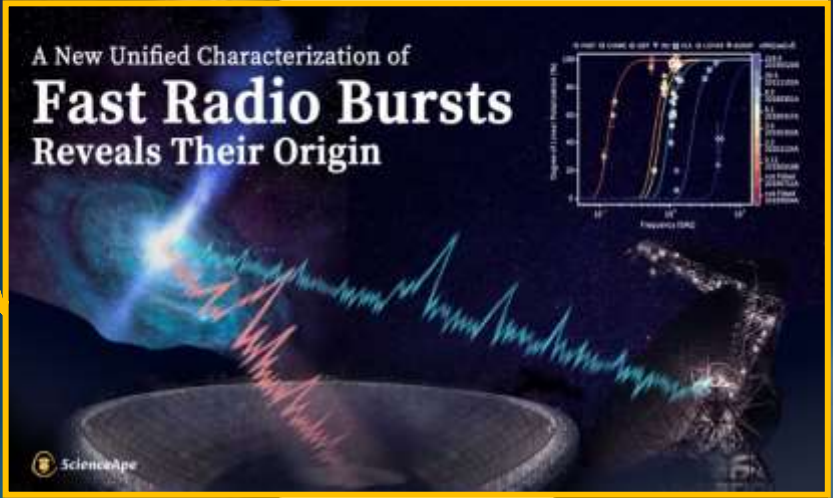
China's Top 10 scientific breakthroughs in 2021

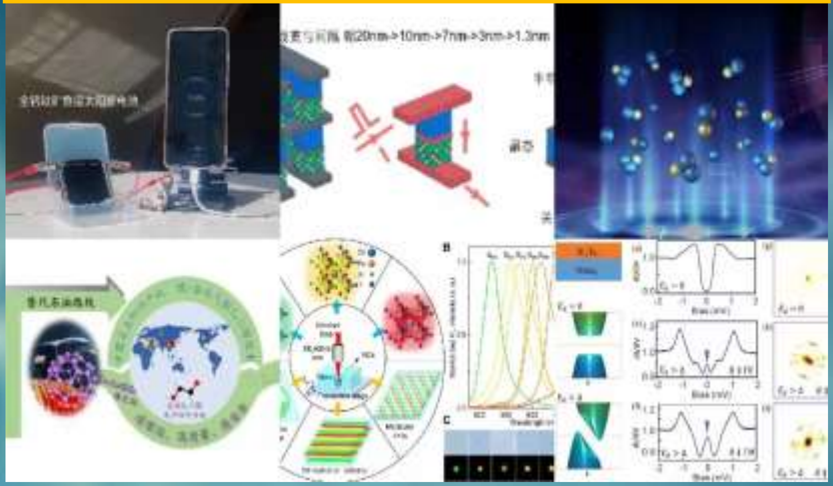
1. Tianwen 1 landed on Mars
2. China's space station core Tianhe in orbit
3. Synthesizing starch from carbon dioxide
4. Chang'e-5 returned with lunar rocks
5. Cryo-EM structure of an extended SARS-CoV-2
6. FAST caught largest set of fast radio bursts
7. High-performing woven lithium-ion fiber batteries
8. Programmable superconducting quantum processor
9. Soft robot 10,000 meters under the ocean's surface
10. Spatio-temporal dynamics of bird migration routes

China's Top 10 scientific breakthroughs in 2022

1. **Successful Revelation of Layered Subsurface of the *Utopia Plantitia* by *Zhurong***
2. **Characterization of Active Repeating Fast Radio Bursts by FAST**
3. **Splitting Seawater into Hydrogen Fuel Using New Mechanism**
4. **The Mutation Traits and Immune Evasion Mechanisms of Omicron Variants**
5. **Breakthrough in All-Perovskite Tandem Solar Cells**
6. **Single-Element Tellurium Switch Promises Denser Memory Chips**
7. **Quantum Coherent Synthesis of Ultracold Triatomic Molecules**
8. **Synthesis of Ethylene Glycol under Ambient Pressure**
9. **Direct 3D Lithography of Stable Perovskite Nanocrystals in Glass**
10. **Experimental Verification of Segmented Fermi Surface in Superconductivity**



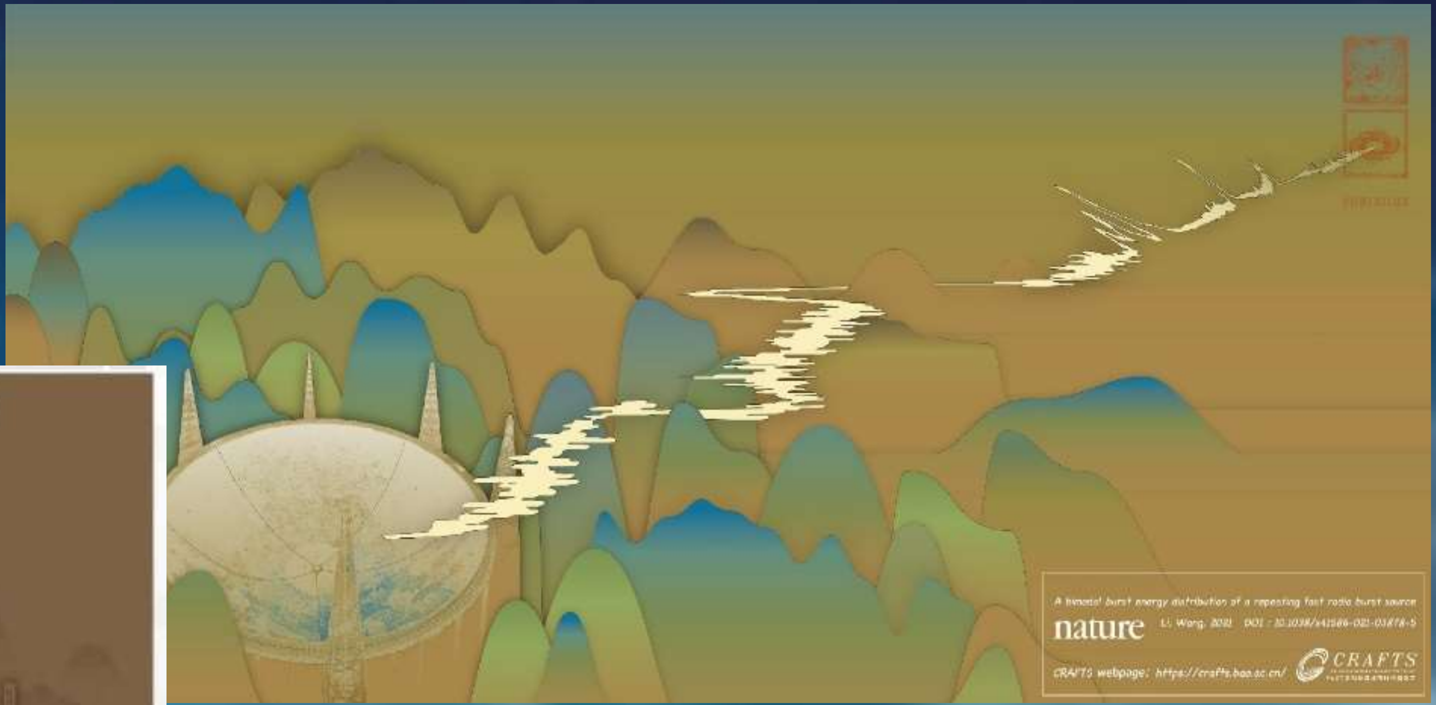




FAST

Li, Wang & Zhu et al. 2021, Nature, 598, 267

FAST caught largest set of fast radio bursts

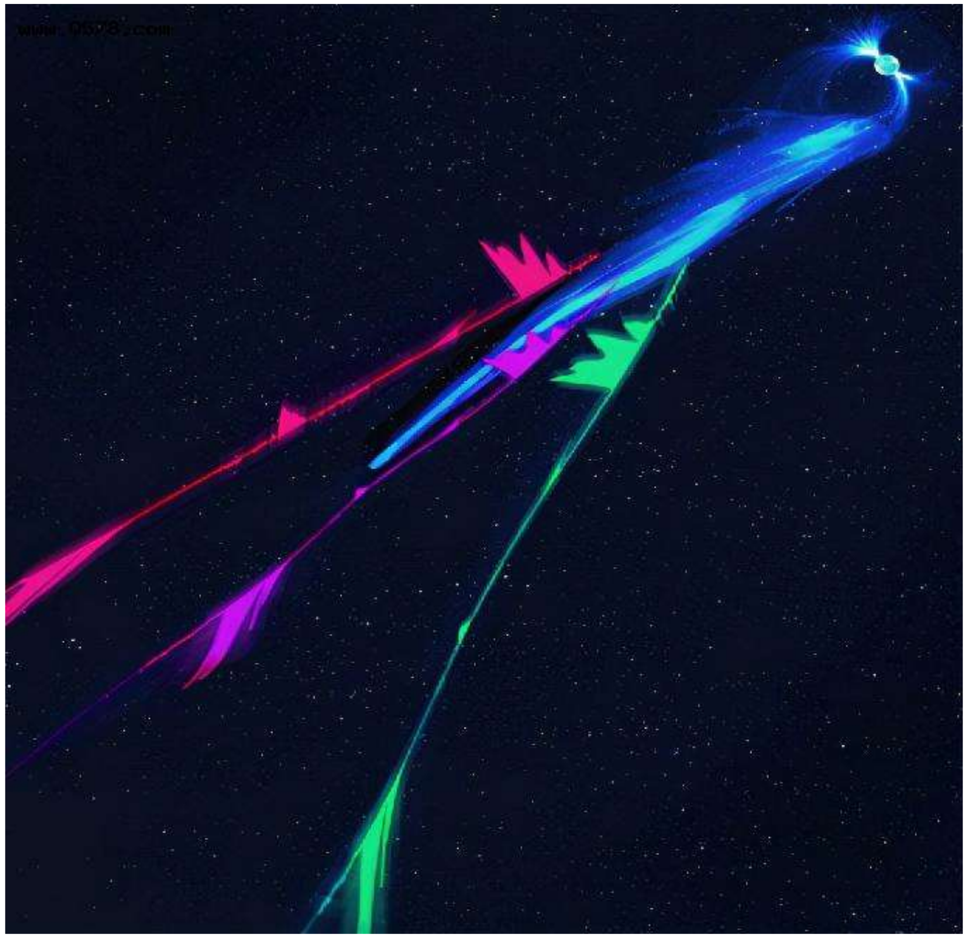


FAST discovers the world's first persistently active fast radio burst

Niu, Aggarwal & Li et al. 2022, Nature, 606, 873

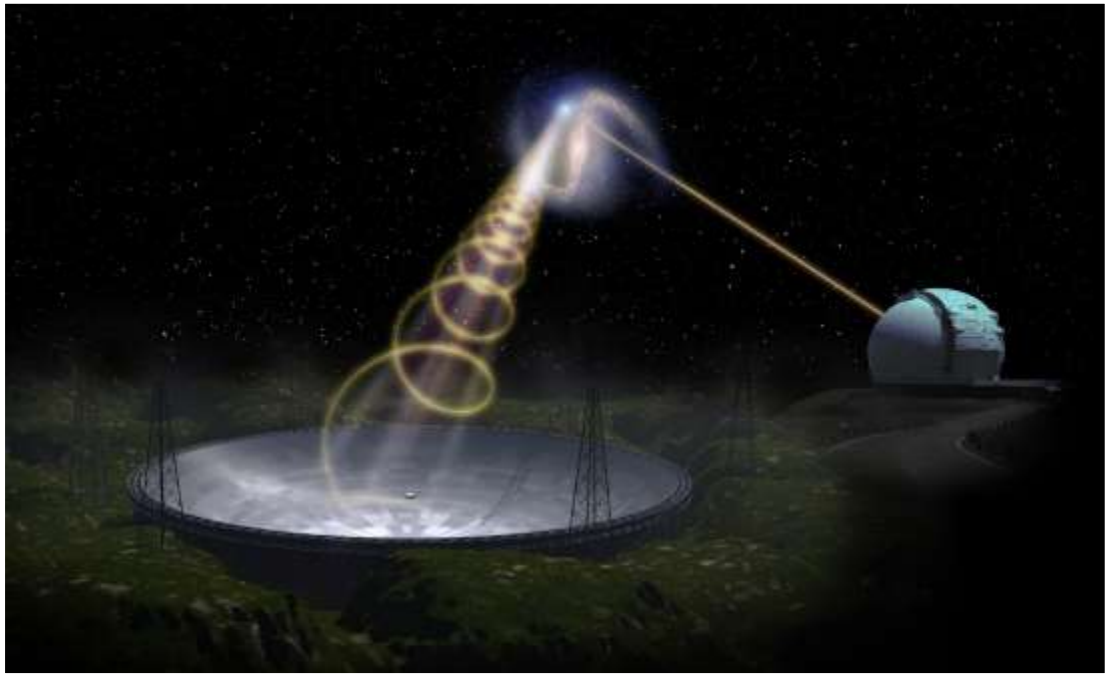
FAST

Various polarization angle swings



Luo et al. 2020, Nature, 586,693

Oscillations in fractional linear and circular polarizations

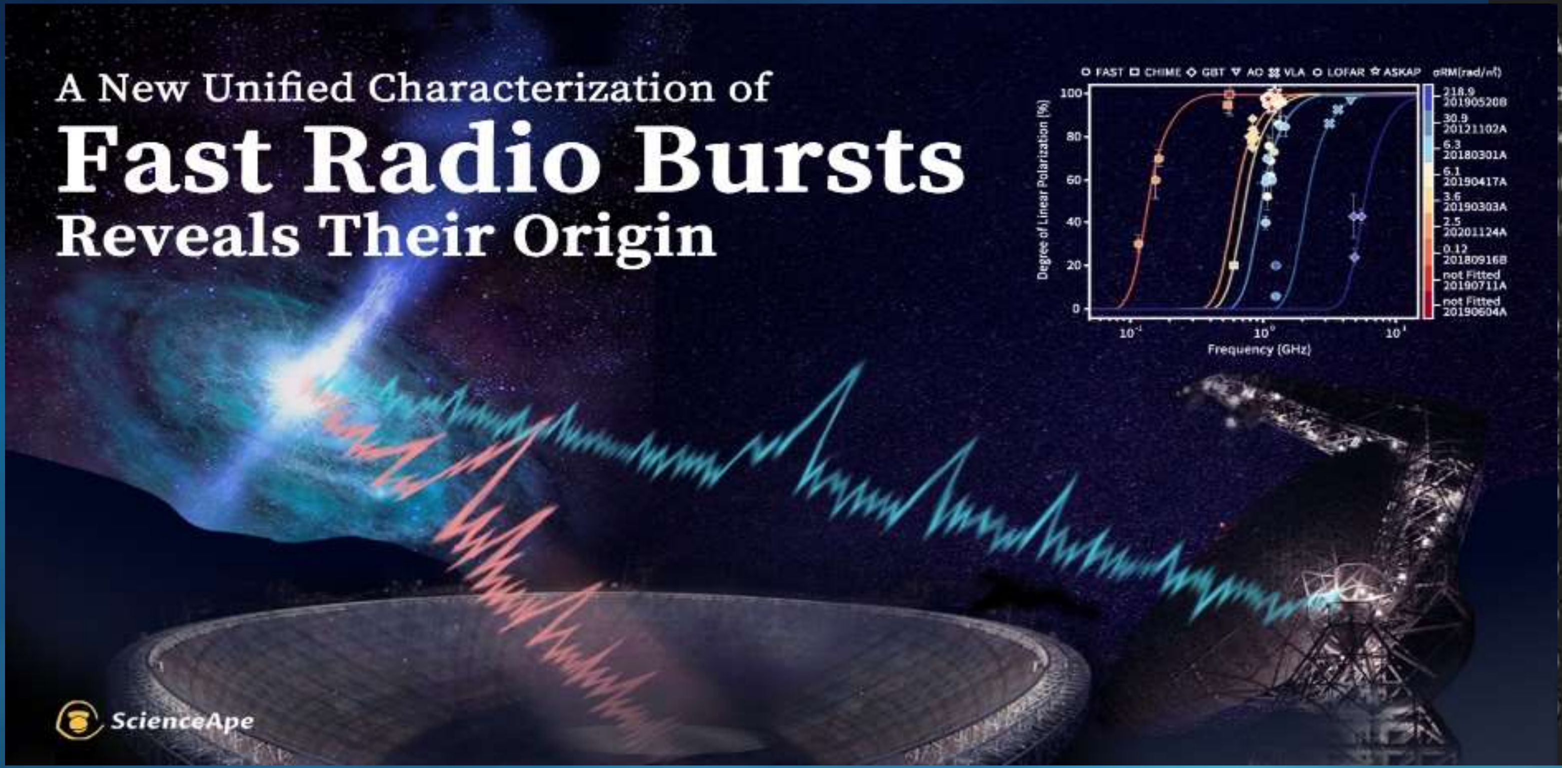


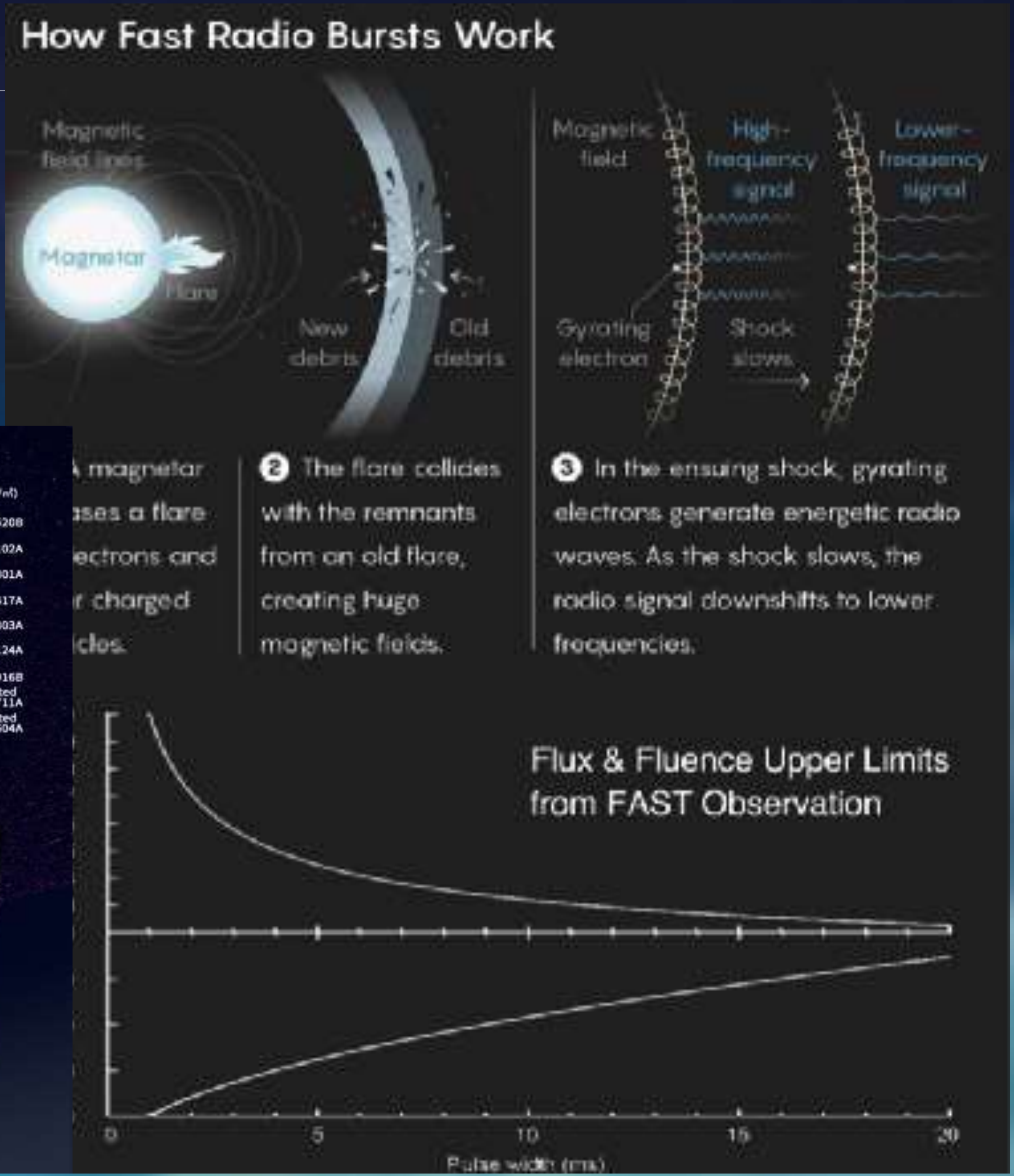
Xu et al. 2022, Nature, 609, 685

Lin et al. 2020, Nature, 587,63

FAST

Unified characterization of frequency evolution of repeating FRBs’ polarization

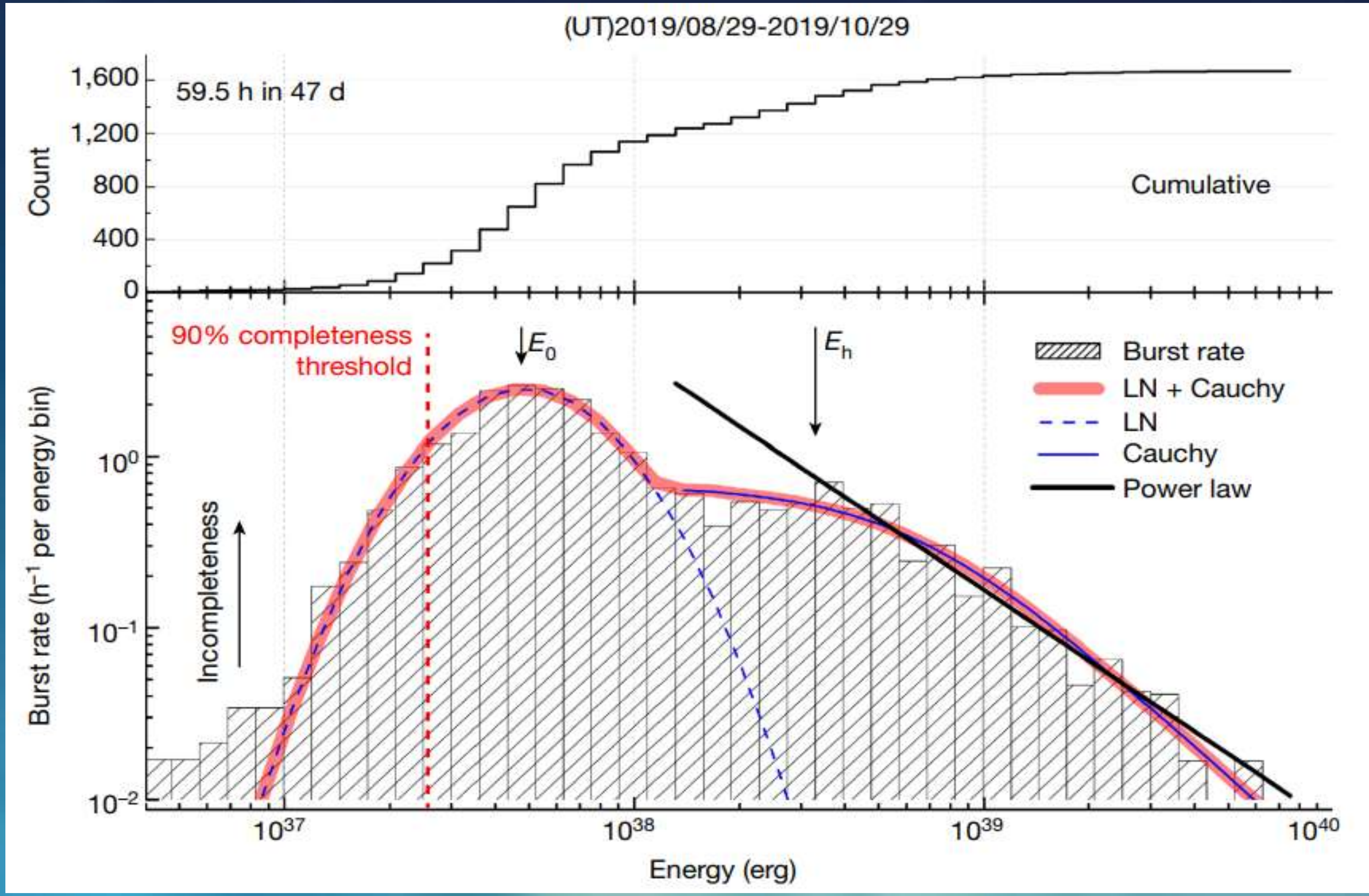




Feng & Li et al. 2022, Science, 375, 1266

FAST

1652 bursts!

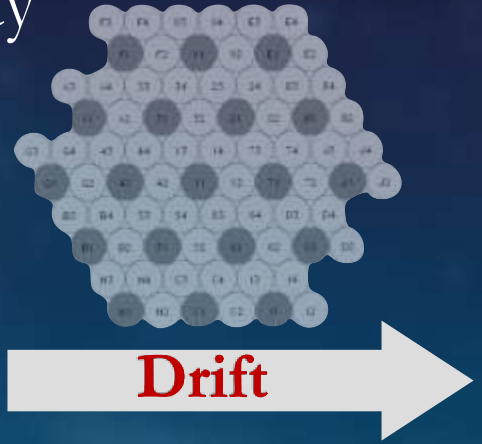


Li & Wang et al. 2021, Nature, 598, 267

Commensal Radio Astronomy FAST Survey

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

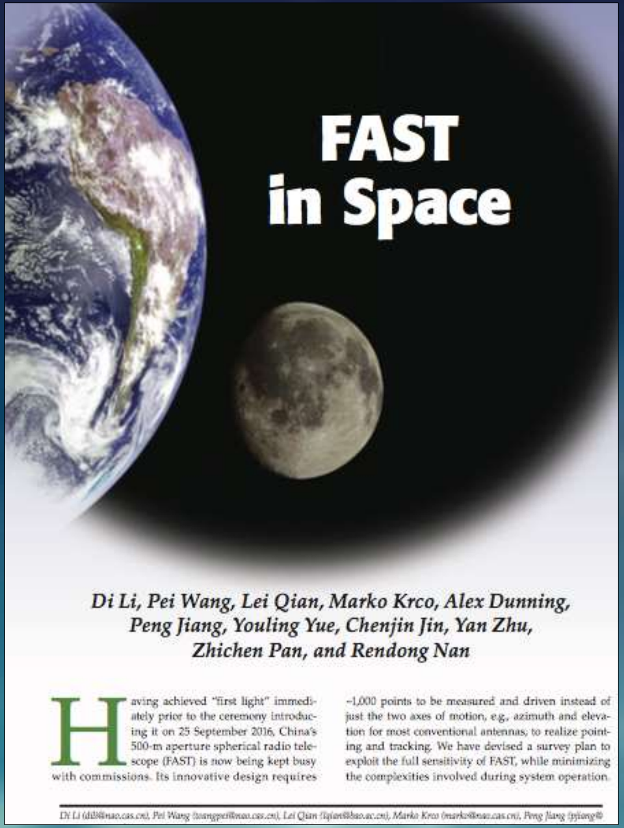
unprecedented commensality
pulsar, galaxy, imaging, and FRB



Proprietary high-cadence CAL injection

FAST **'big data'** stream
pulsar: 19 x 8bit x 4 x 4k x 2x10^4 per second
HI: 19 x 8bit x 4 x 1M x 2 /s

- 6 GB/s
- 25TB/h
- 550TB/day
- 10 PB/ year



FAST in Space

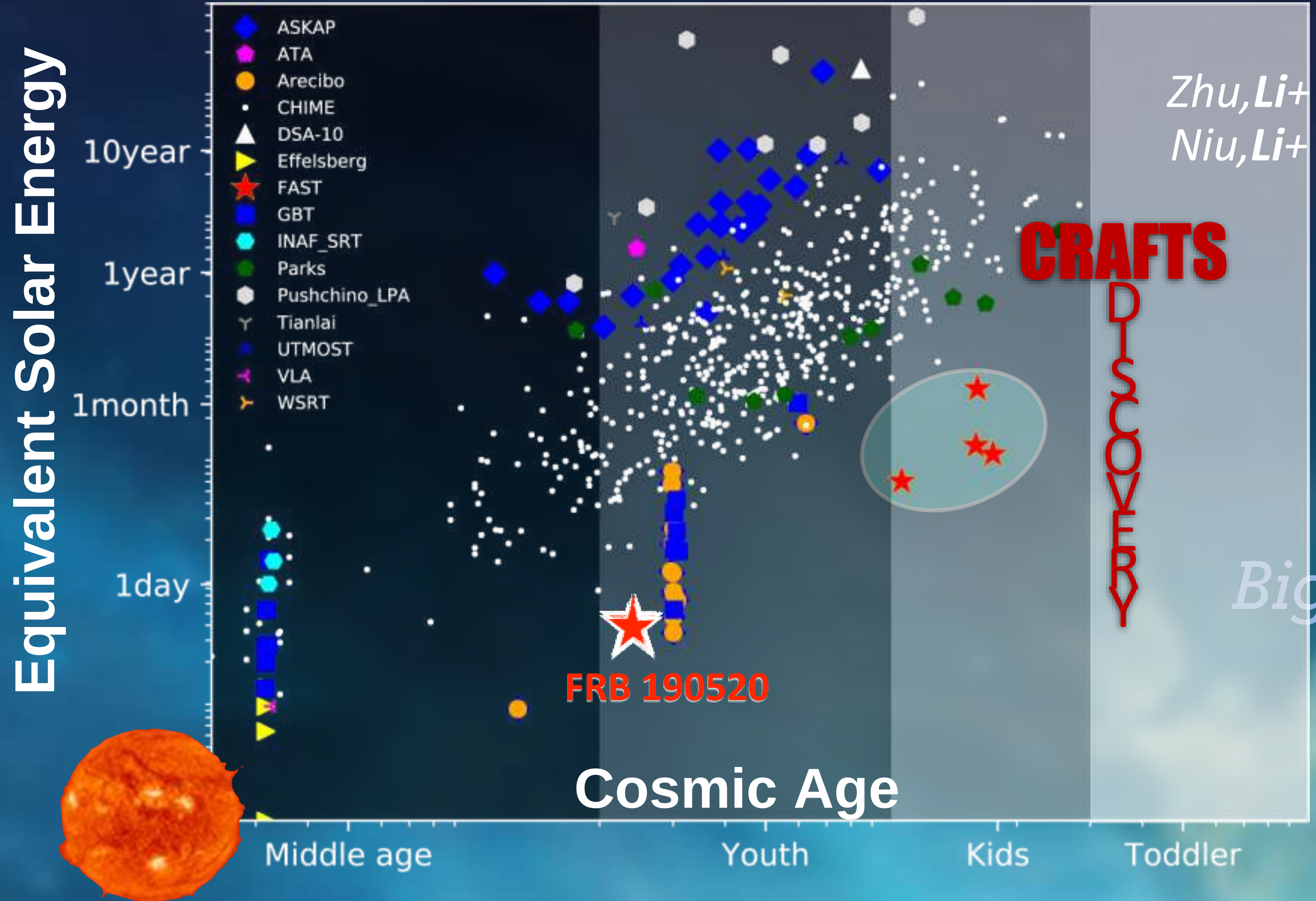
Di Li, Pei Wang, Lei Qian, Marko Krco, Alex Dunning, Peng Jiang, Youling Yue, Chenjin Jin, Yan Zhu, Zhichen Pan, and Rendong Nan

Having achieved "first light" immediately prior to the ceremony introducing it on 25 September 2016, China's 500-m aperture spherical radio telescope (FAST) is now being kept busy with commissions. Its innovative design requires ~1,000 points to be measured and driven instead of just the two axes of motion, e.g., azimuth and elevation for most conventional antennas, to realize pointing and tracking. We have devised a survey plan to exploit the full sensitivity of FAST, while minimizing the complexities involved during system operation.

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

Li et al. 2018, Invited Review
IEEE Microwave, Vol 19, Issue 3, p112

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



*Zhu,**Li**+ 2020 ApJL*
*Niu,**Li**+ 2021 ApJL*

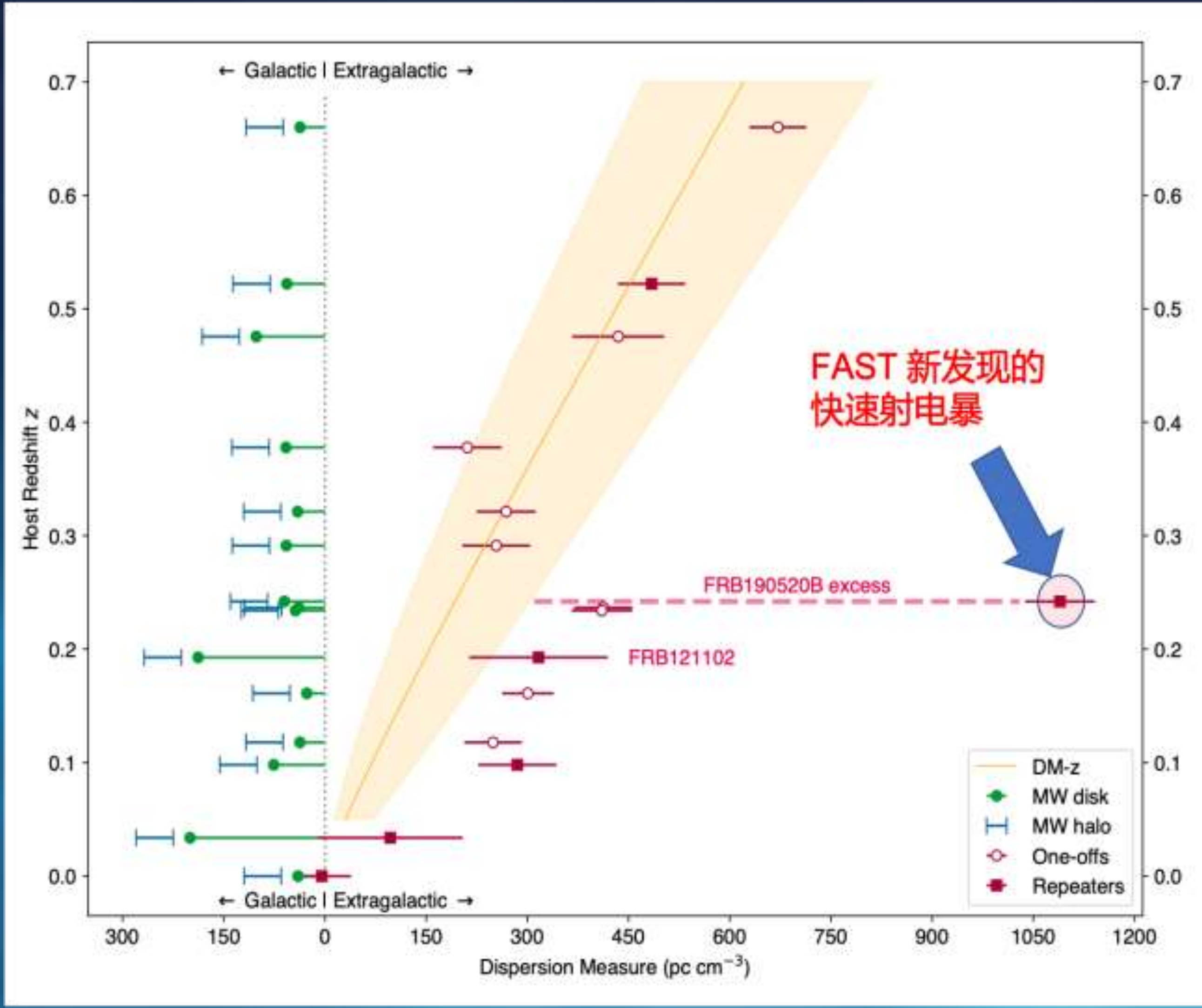
Big Bang

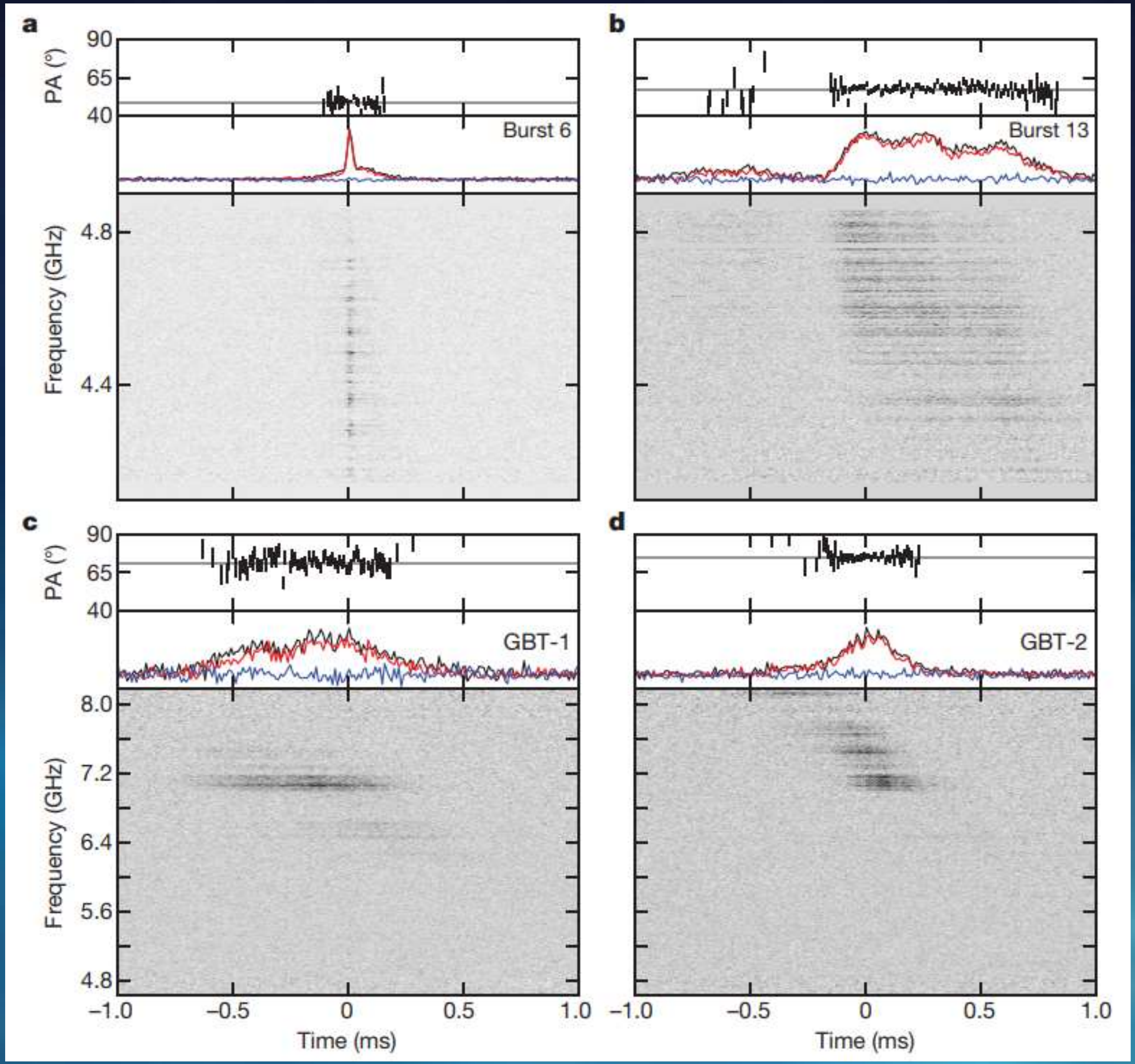
C R A F T S


FRB 190520
2019.5.20 CRAFTS scan


nature
2022.6.30 Nature

FAST discovers the world's first persistently active fast radio burst

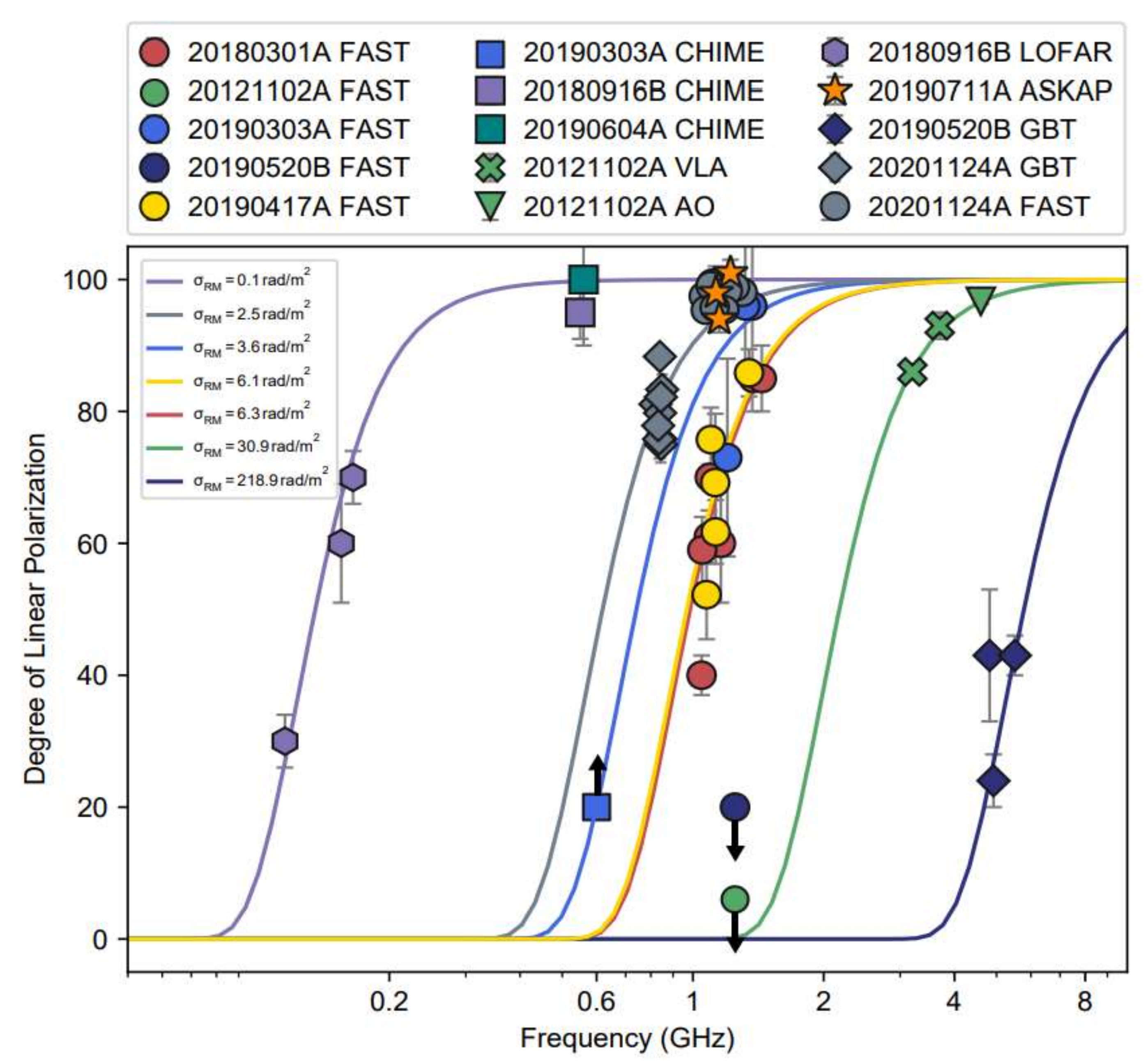




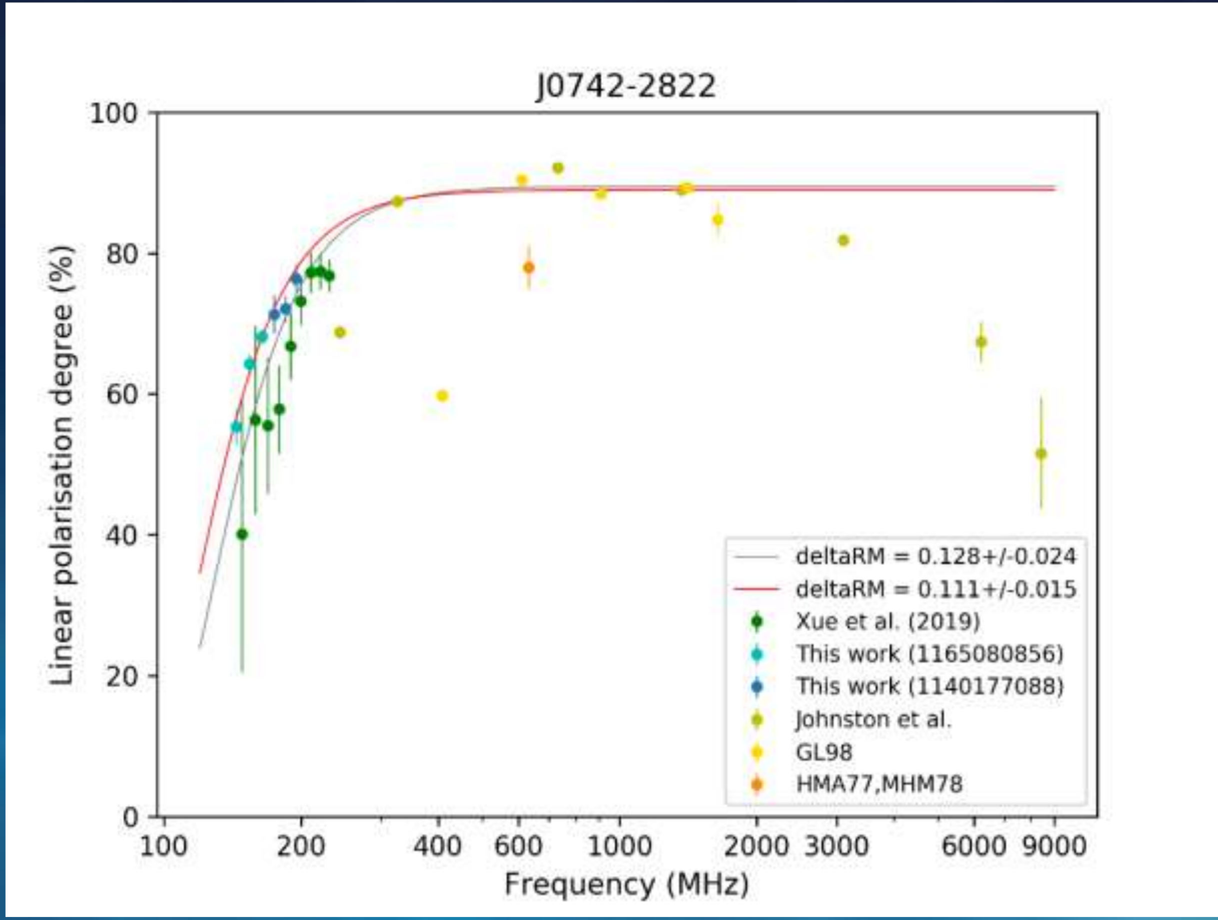
No linear polarization at FAST!

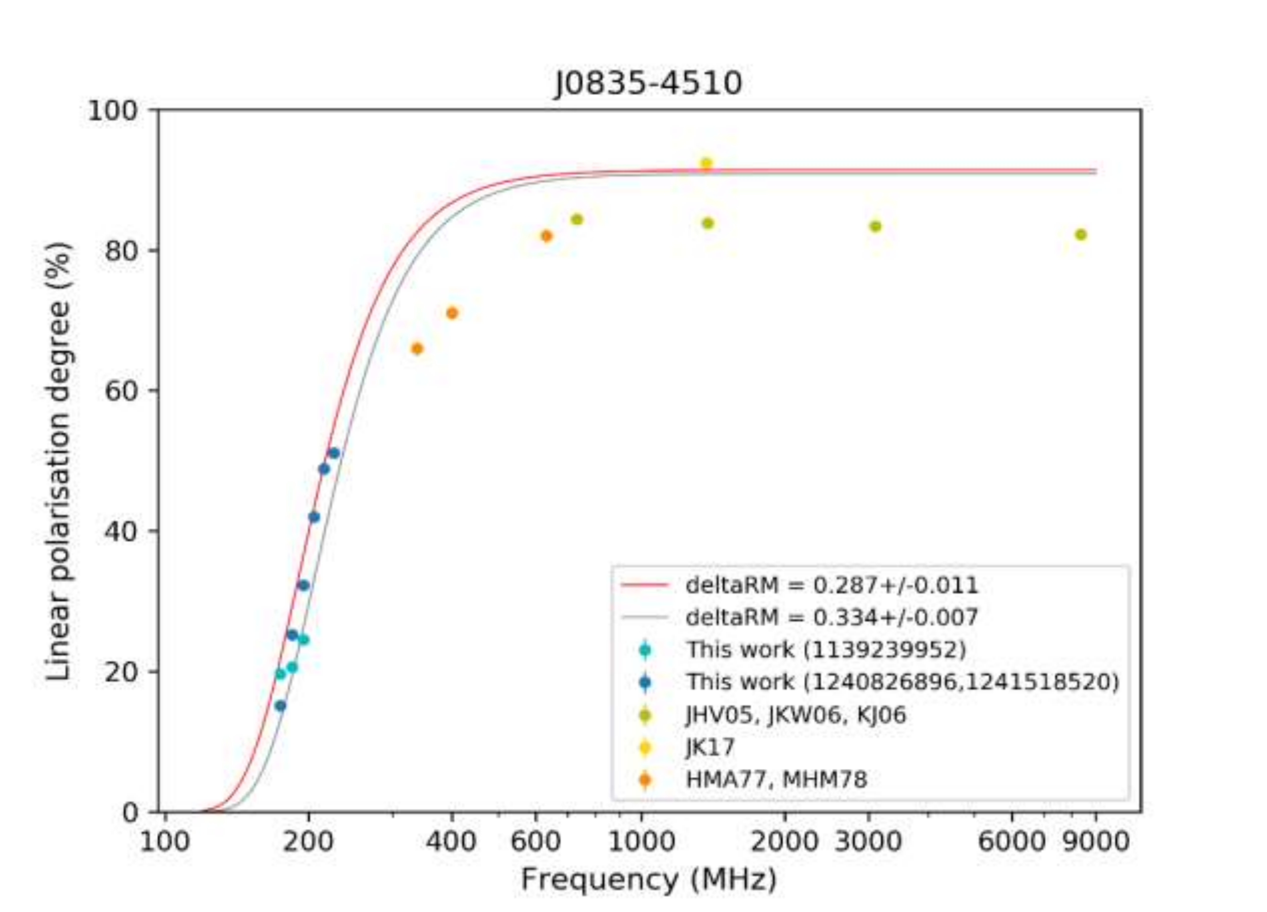
Michilli et al. 2018

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

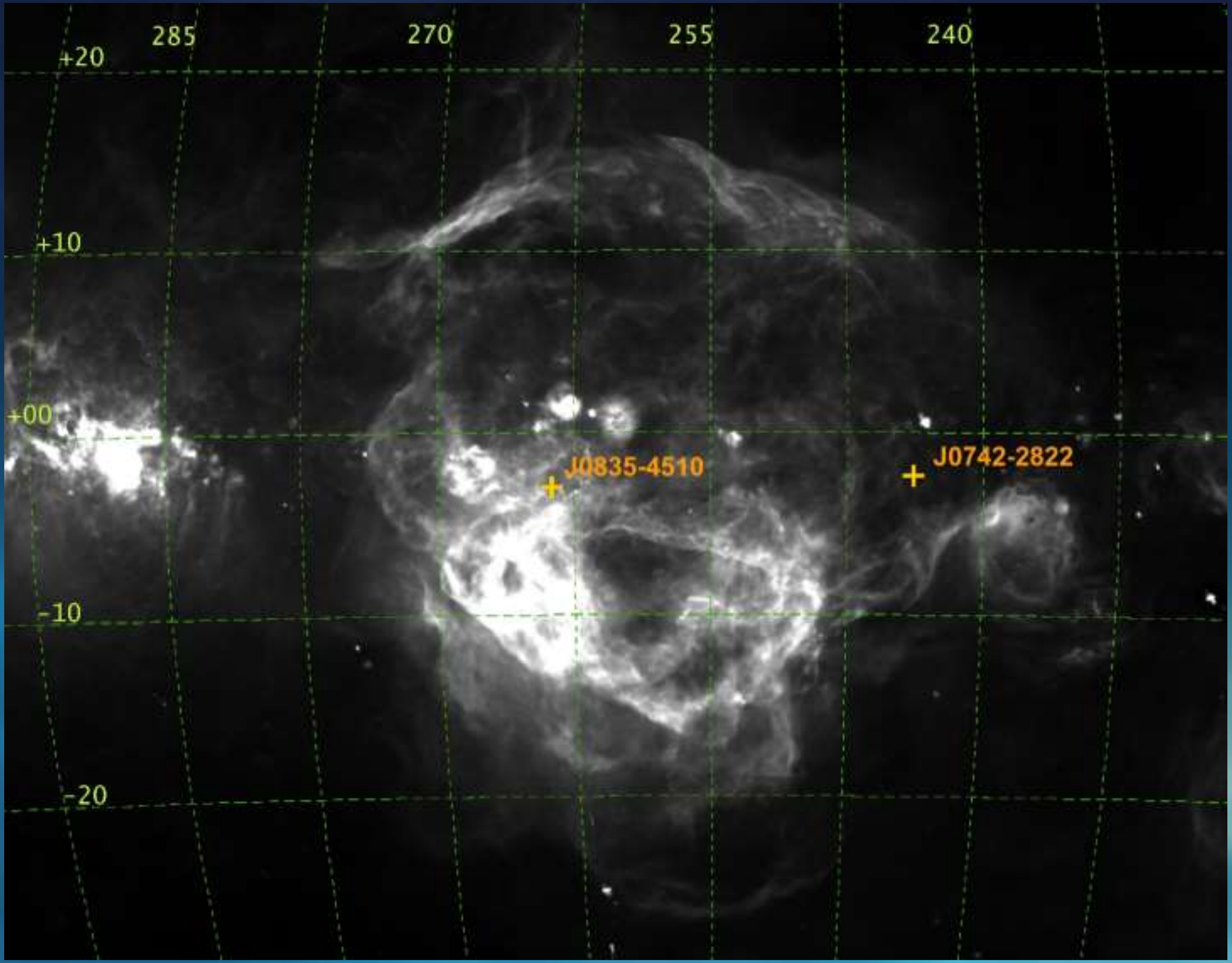


Feng & Li et al. 2022, Science, 375, 1266


J0742-2822
100
80
60
40
20
0
Linear polarisation degree (%)
100
200
400
600
1000
2000
3000
6000
9000
Frequency (MHz)
deltaRM = 0.128+/-0.024
deltaRM = 0.111+/-0.015
Xue et al. (2019)
This work (1165080856)
This work (1140177088)
Johnston et al.
GL98
HMA77,MHM78


J0835-4510
100
80
60
40
20
0
Linear polarisation degree (%)
100
200
400
600
1000
2000
3000
6000
9000
Frequency (MHz)
deltaRM = 0.287+/-0.011
deltaRM = 0.334+/-0.007
This work (1139239952)
This work (1240826896,1241518520)
JHV05, JKW06, KJ06
JK17
HMA77, MHM78

credit： Xue

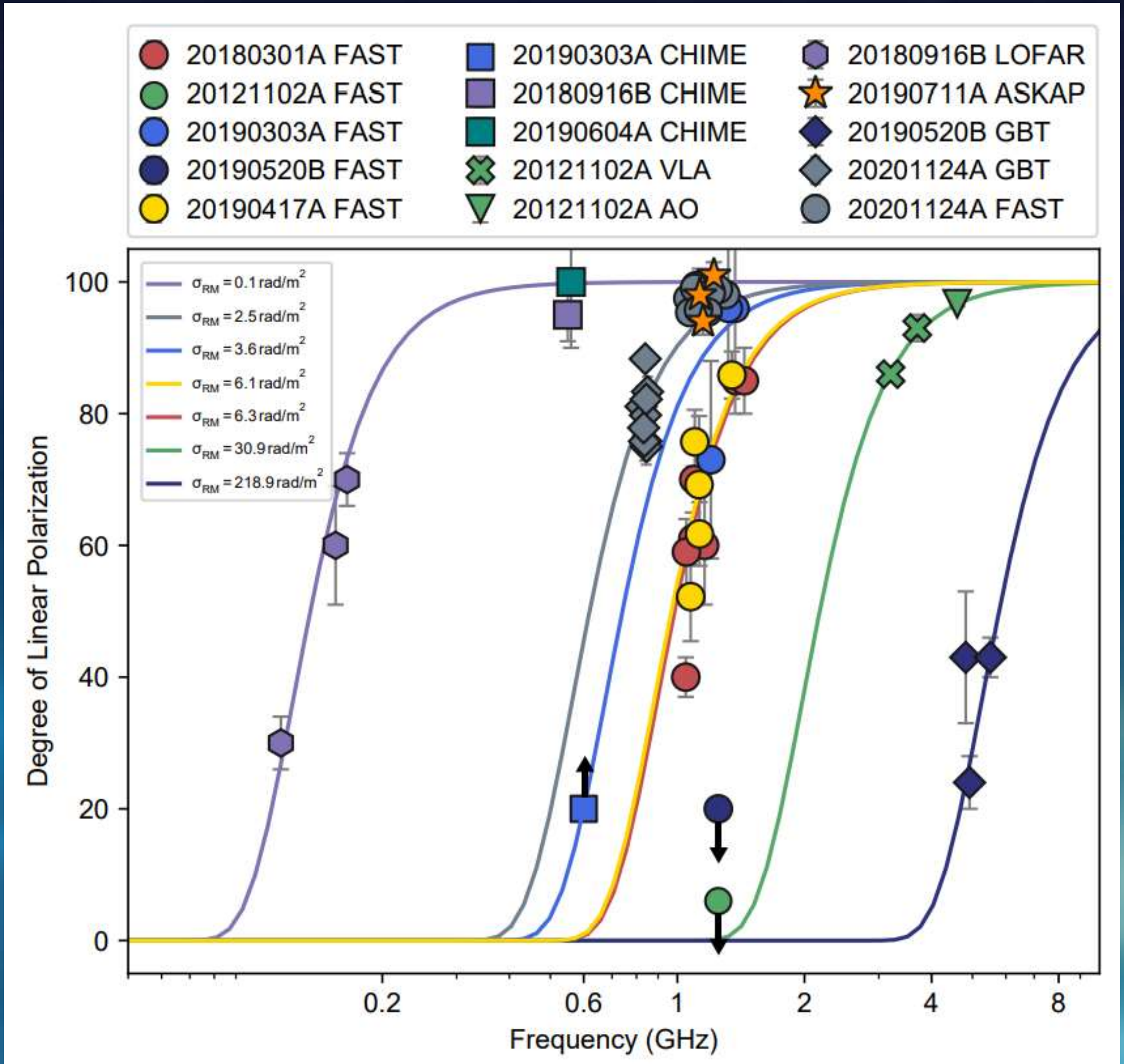


The Gum Nebula

Another well-known pulsar, the Vela pulsar (J0835-4510)

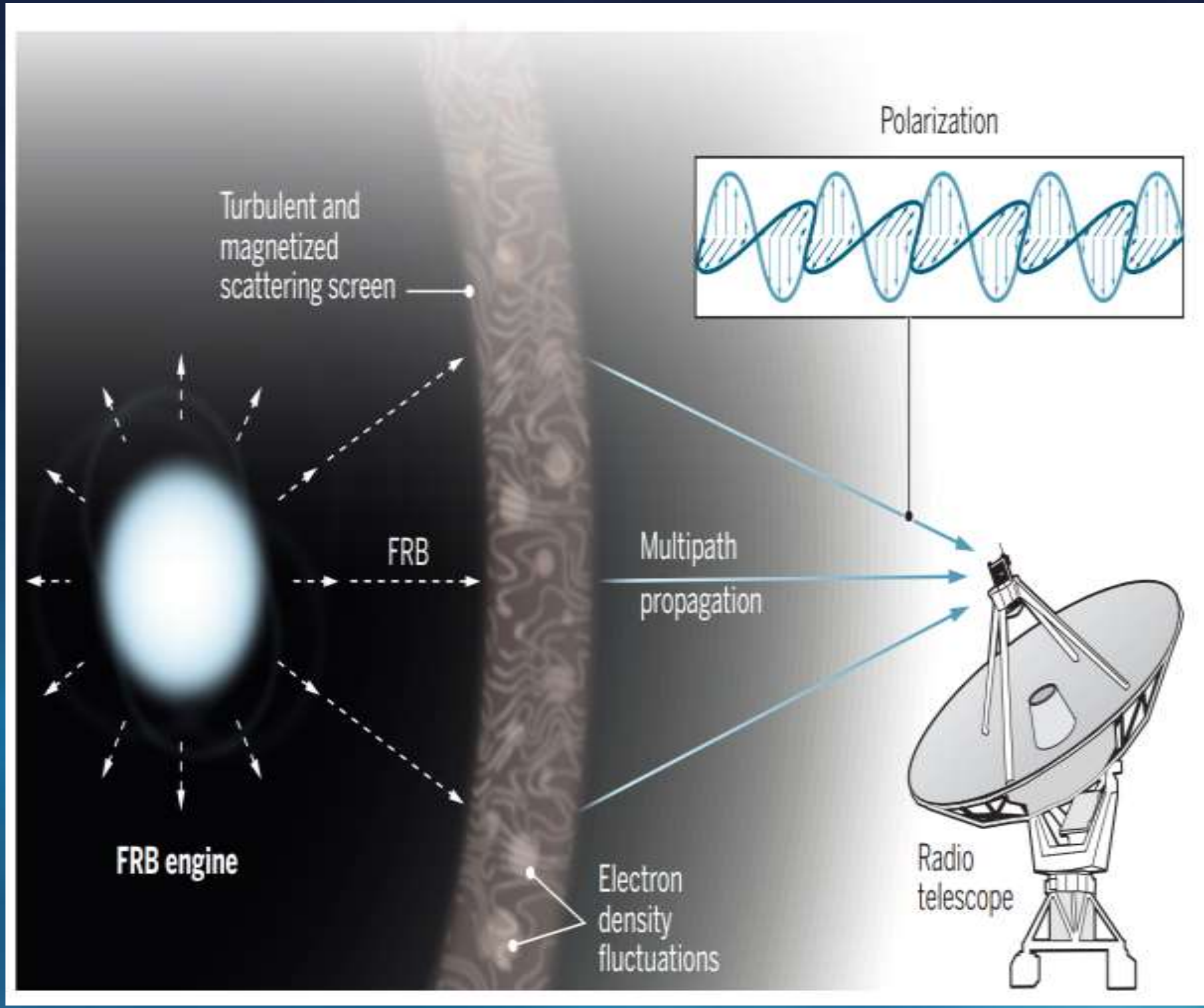
Finkbeiner (2003)
Powered with Aladin

credit： Xue

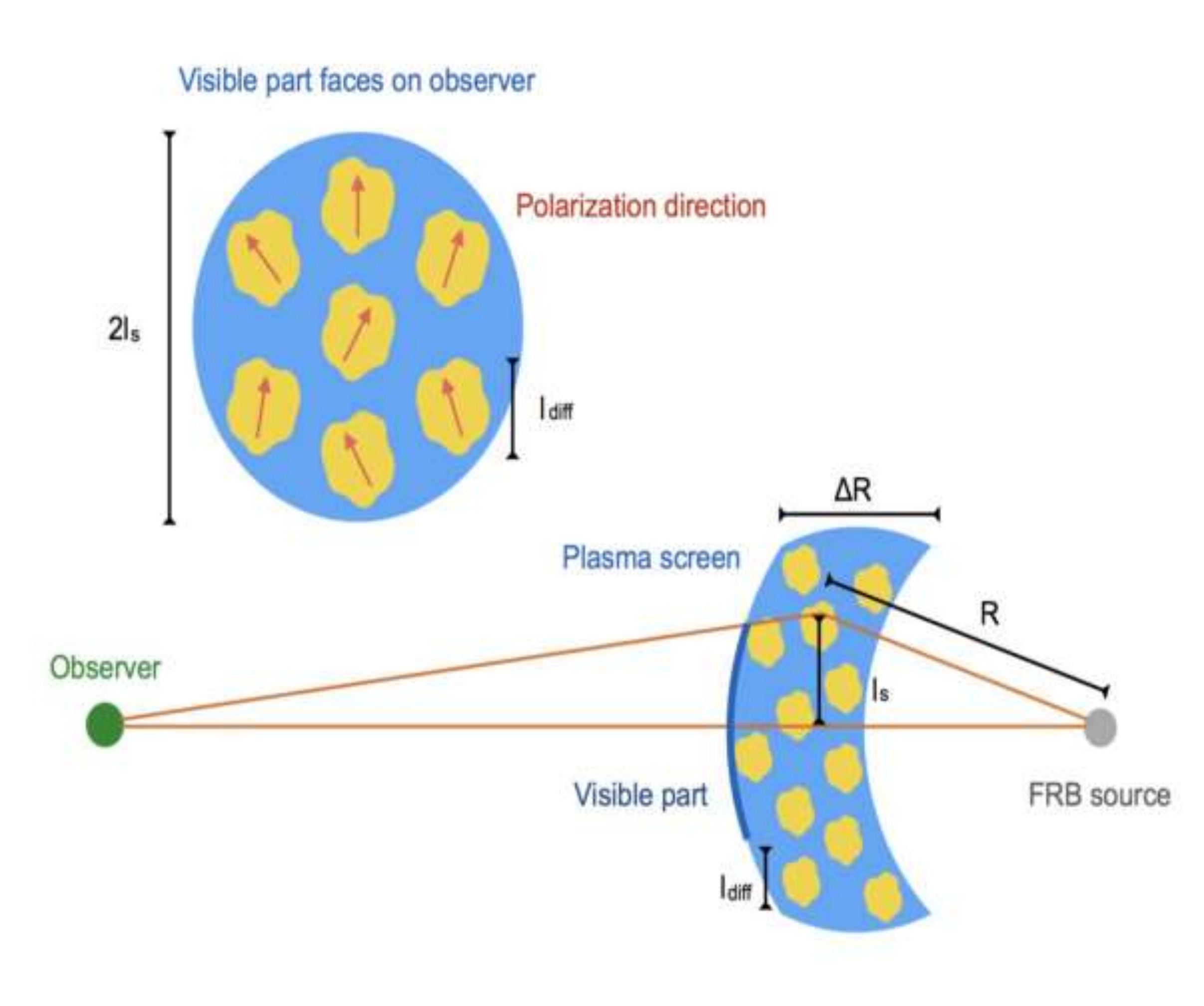


$$\%L \propto \exp(-2\lambda^4 \sigma_{RM}^2)$$

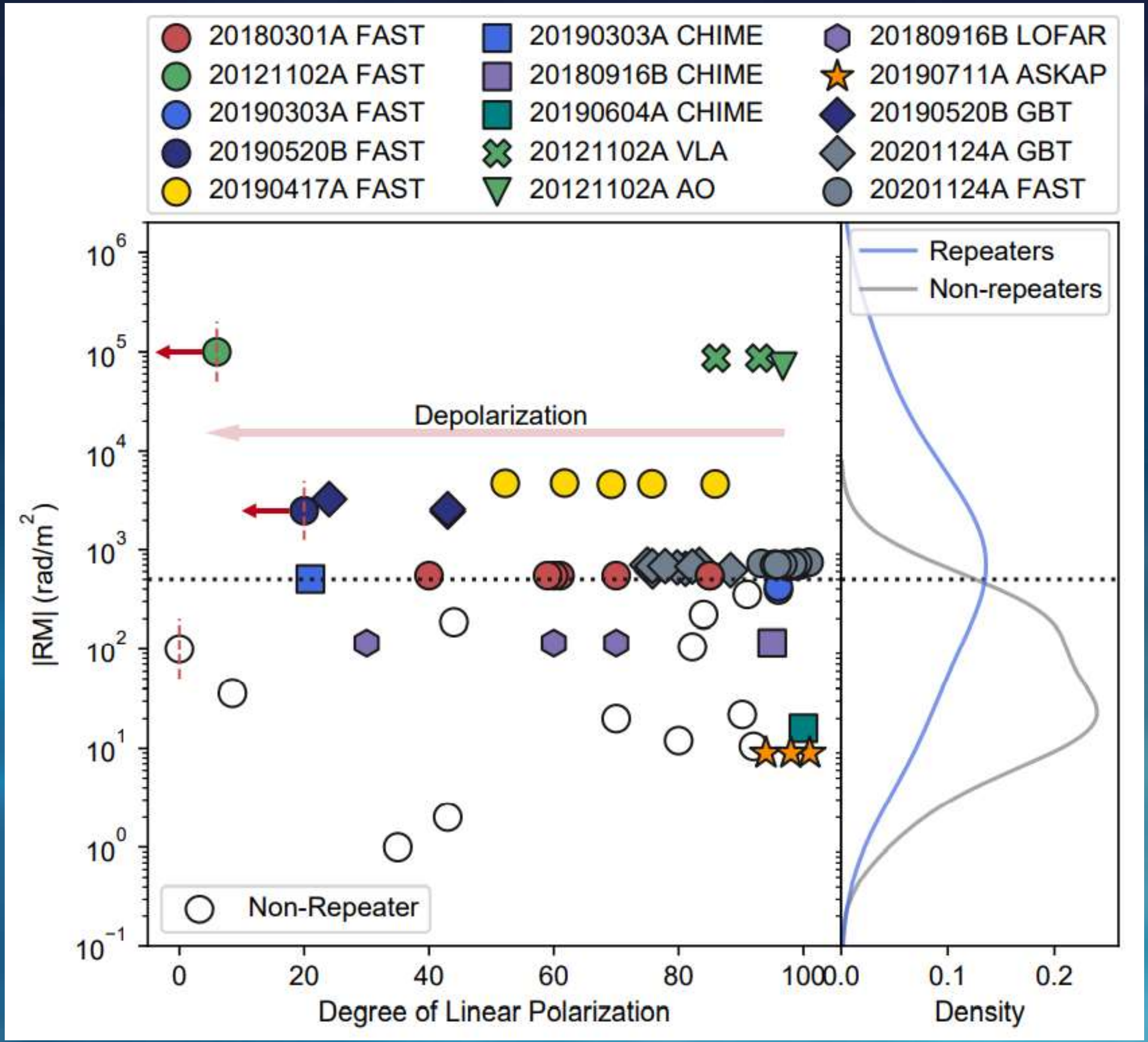
Feng & Li et al. 2022, Science, 375, 1266



Caleb et al. 2022

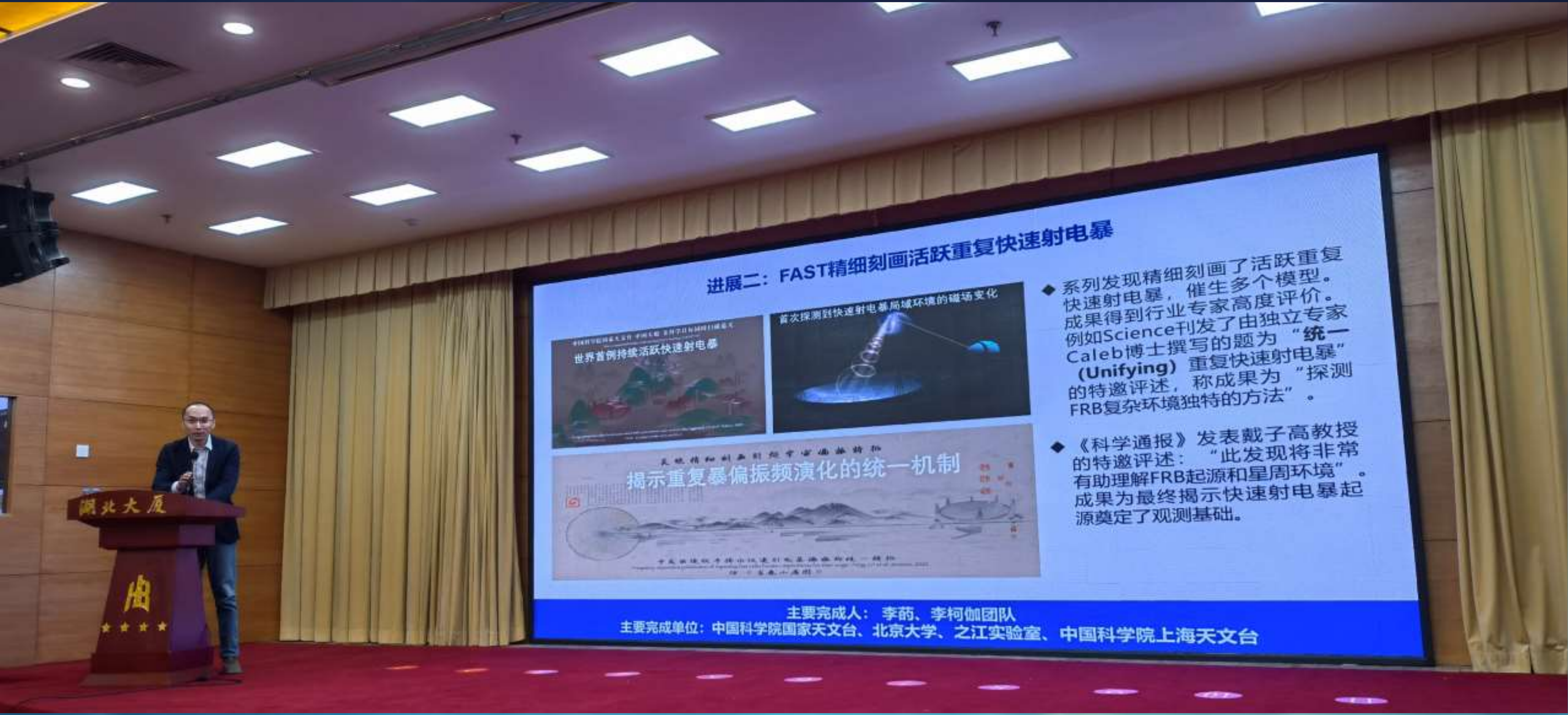


Yang et al. 2022



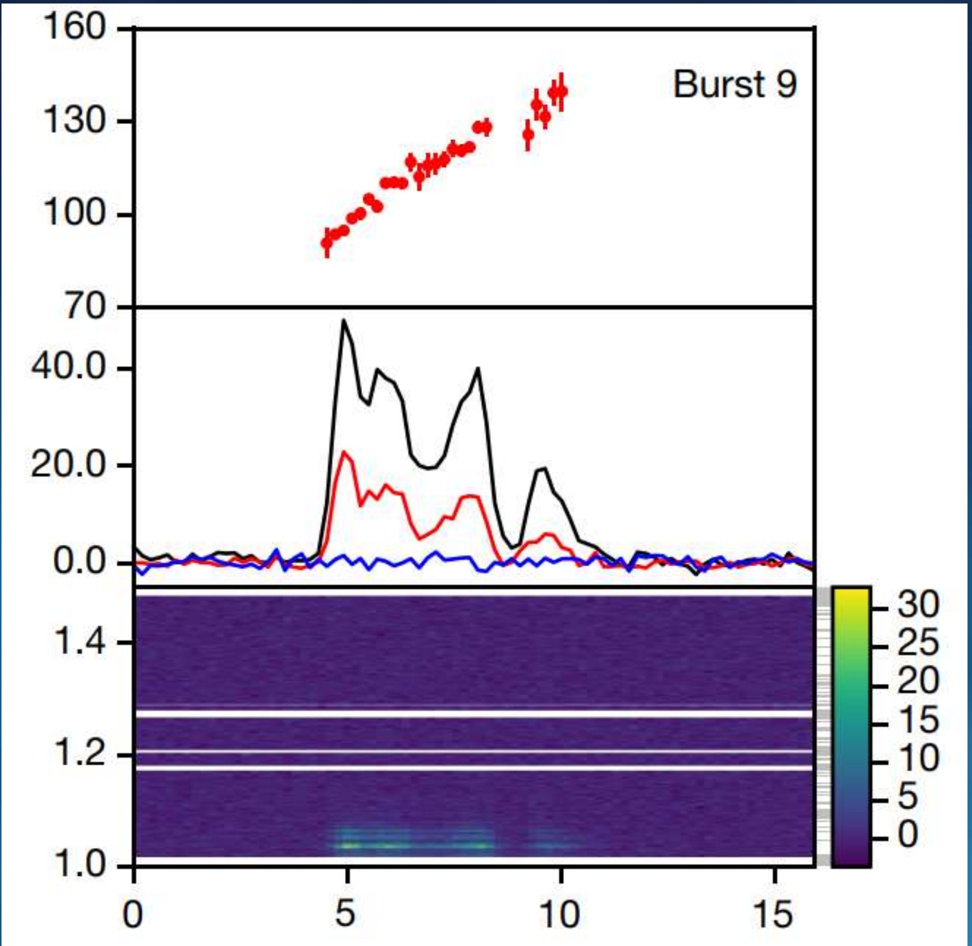
It is possible to classify FRBs using polarization properties!

Feng & Li et al. 2022


进展二：FAST精细刻画活跃重复快速射电暴
世界首例持续活跃快速射电暴
首次探测到快速射电暴局域环境的磁场变化
揭示重复暴偏振频演化的统一机制
系列发现精细刻画了活跃重复快速射电暴，催生多个模型。成果得到行业专家高度评价。例如Science刊发了由独立专家Caleb博士撰写的题为“统一（Unifying）重复快速射电暴”的特邀评述，称成果为“探测FRB复杂环境独特的方法”。
《科学通报》发表戴子高教授的特邀评述：“此发现将非常有助理解FRB起源和星周环境”。成果为最终揭示快速射电暴起源奠定了观测基础。
主要完成人：李菂、李柯伽团队
主要完成单位：中国科学院国家天文台、北京大学、之江实验室、中国科学院上海天文台
湖北大厦

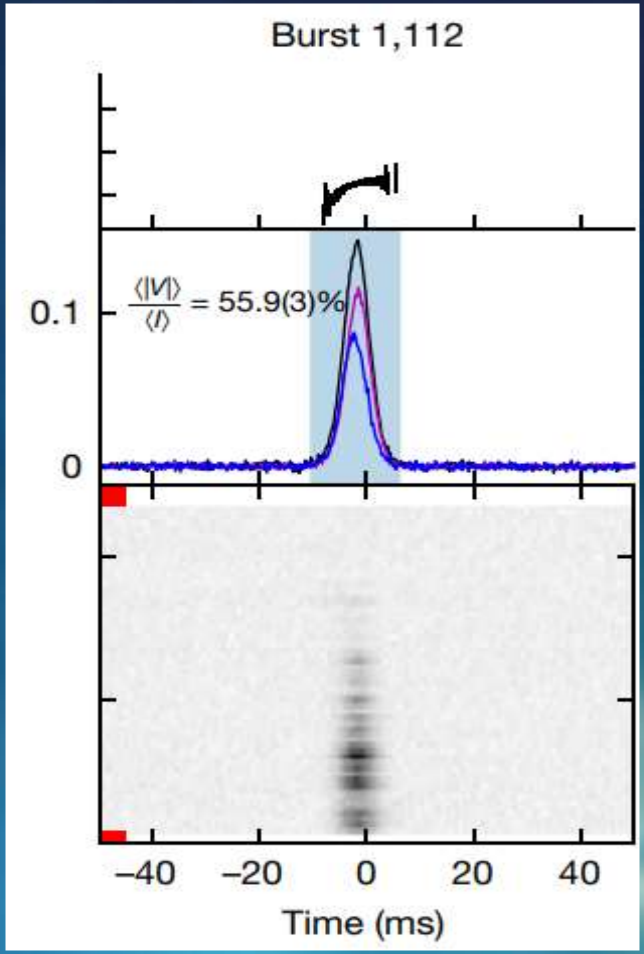
Polarization angle

FRB 20180301A



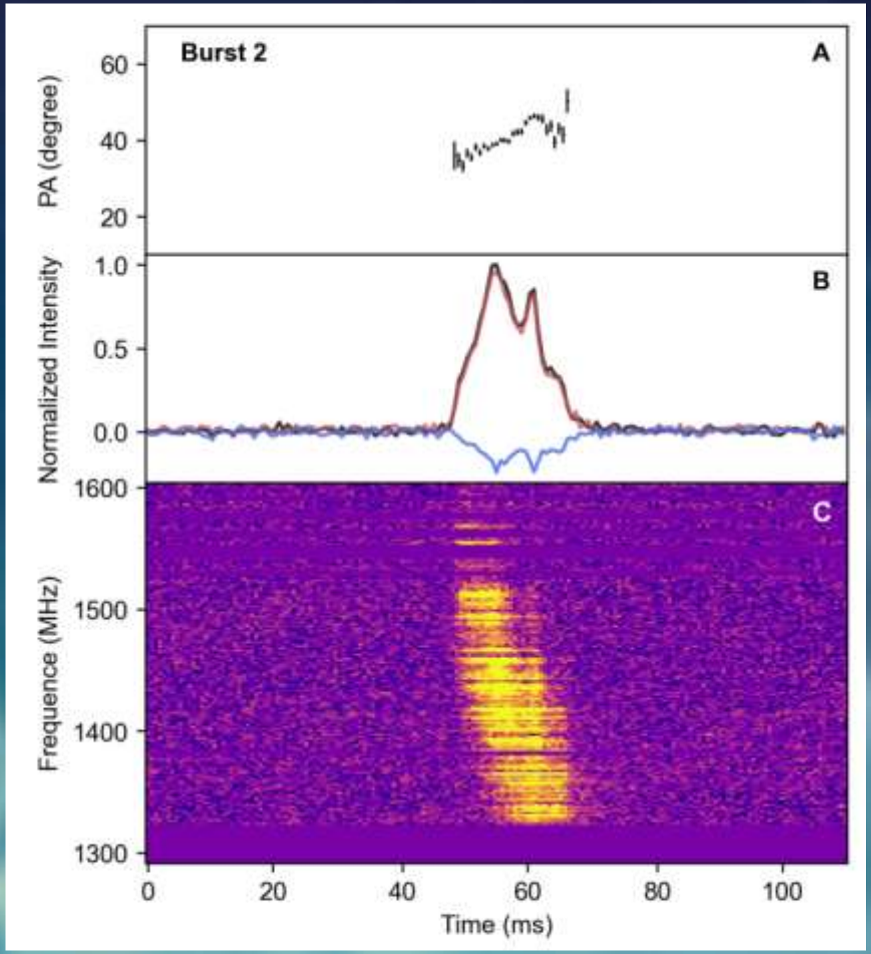
Luo et al. 2020, Nature, 586,693

FRB 20201124A



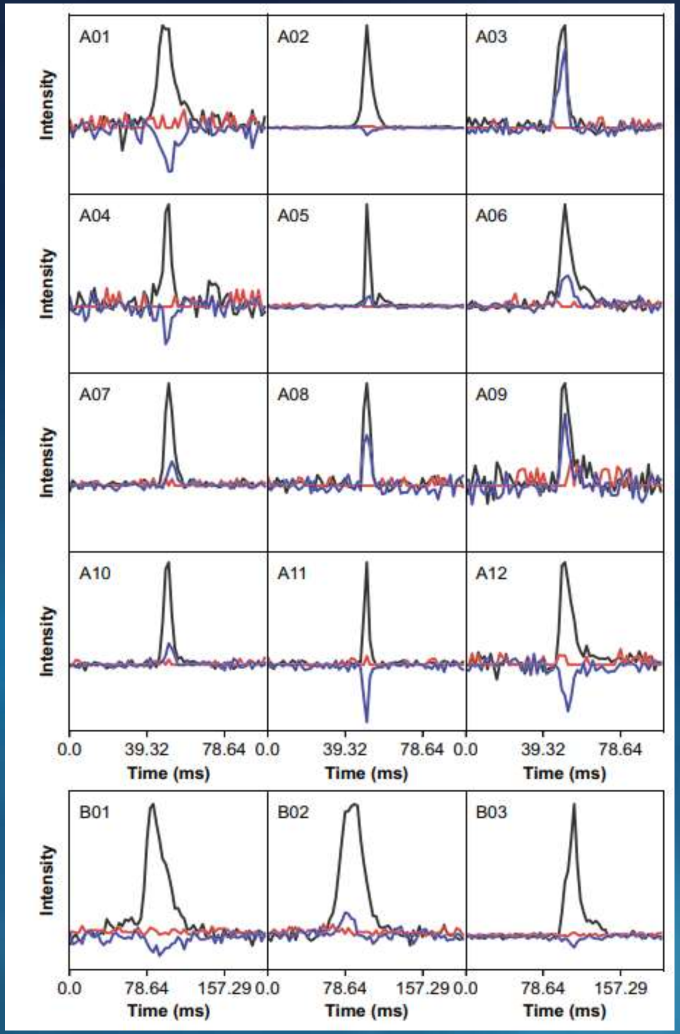
Xu et al. 2022, Nature, 609,685

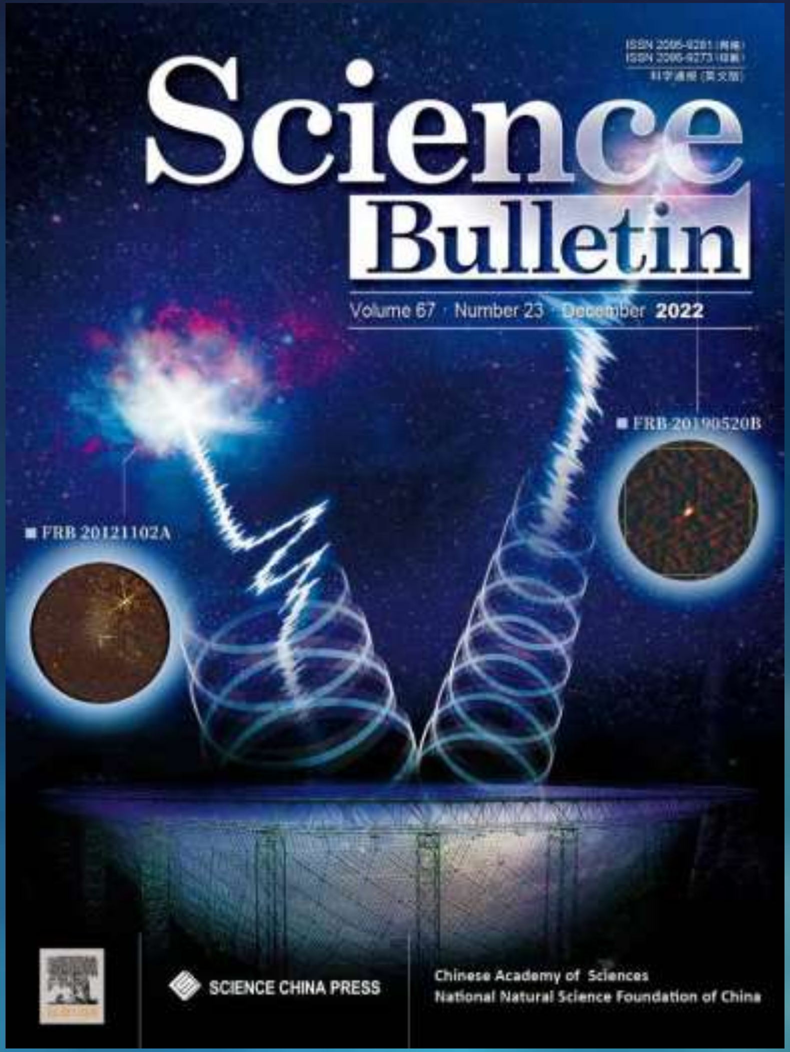
FRB 20220912A



Feng et al. submitted

Circular polarization





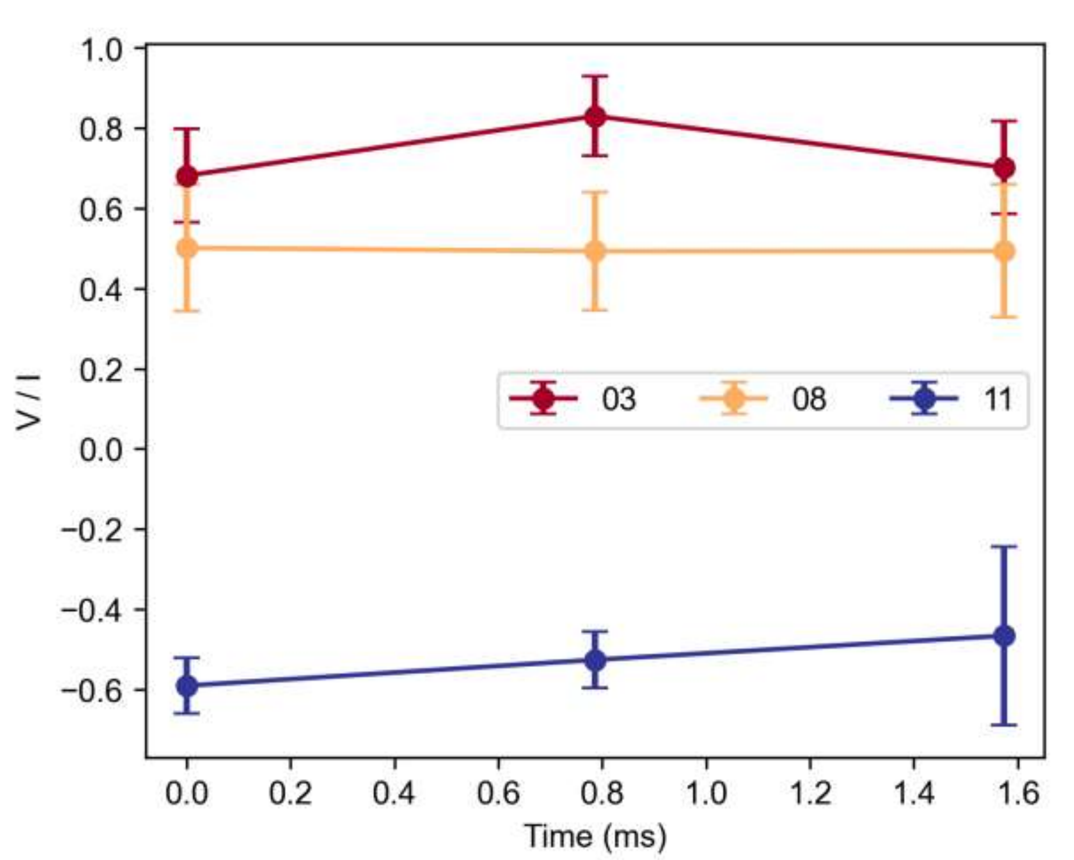
Feng, Zhang & Li et al. 2022

The observed circular polarization is unlikely induced by multipath propagation.

Favor circular polarization induced by Faraday conversion or radiation mechanism intrinsic to the FRB source.

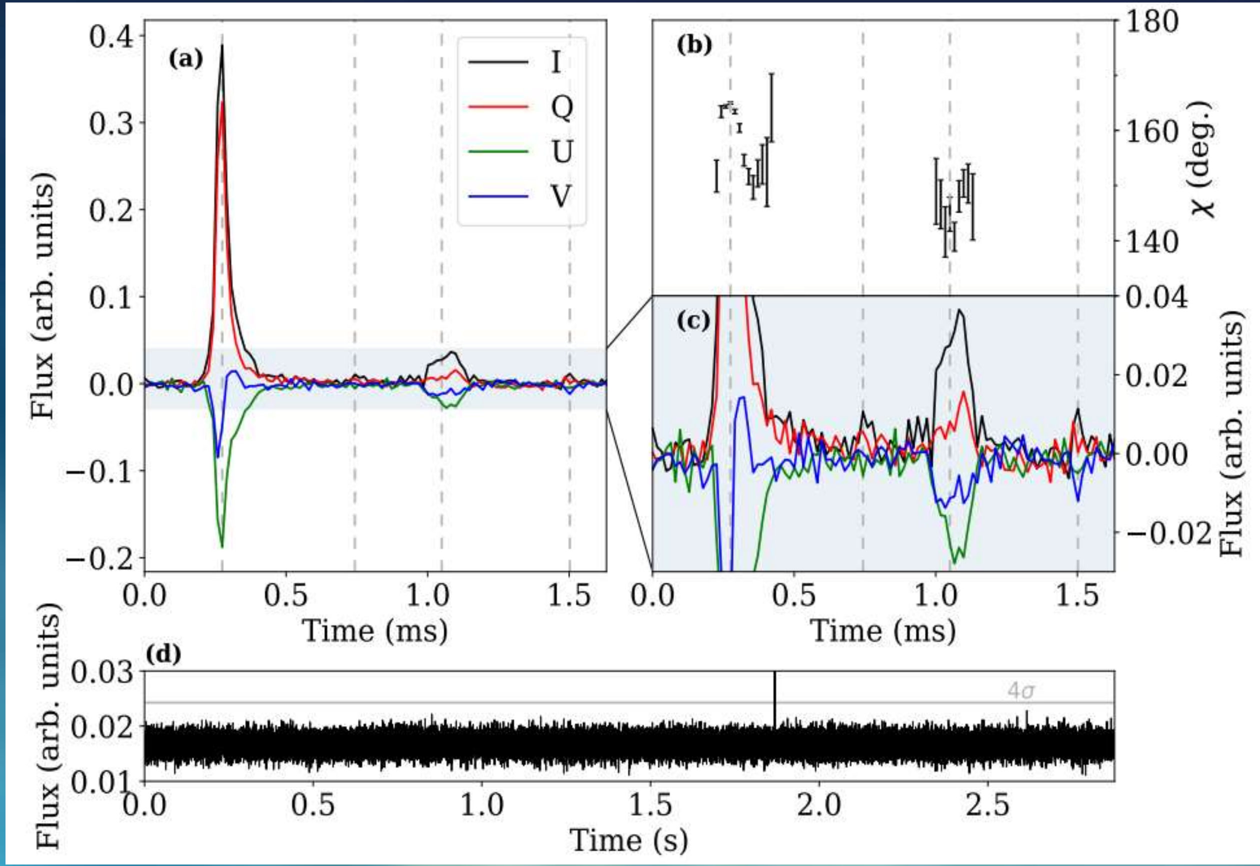
Variation time-scale of circular polarization

Repeater :FRB 20121102A



Feng, Zhang & Li et al. 2022

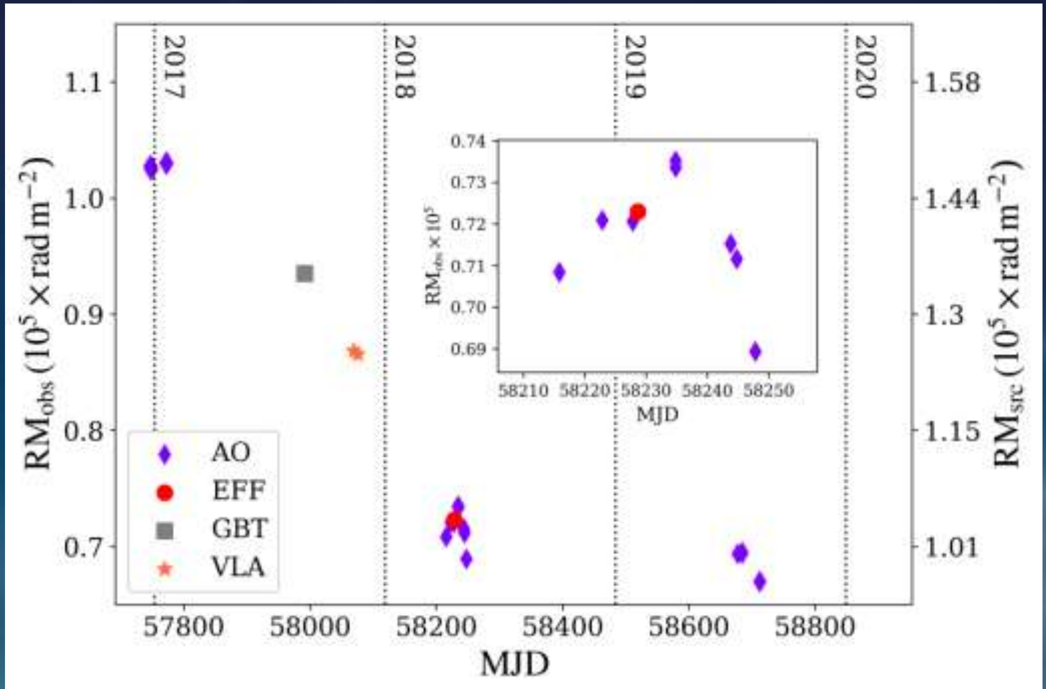
Non Repeater :FRB 20181112A



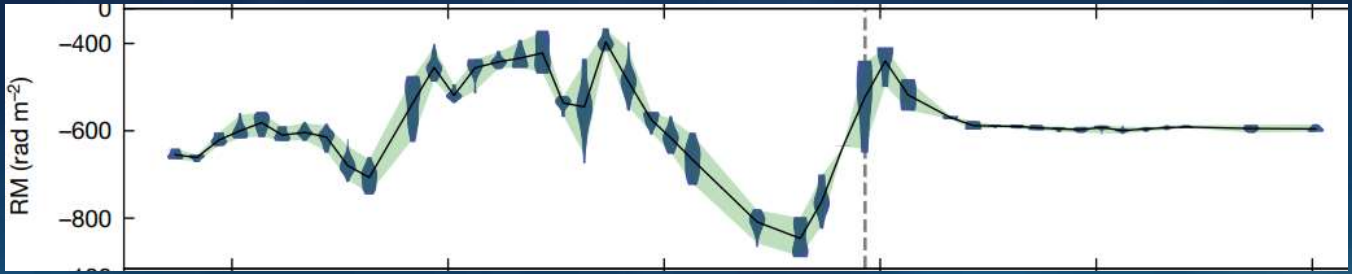
Cho et al. 2020

Rotation measure

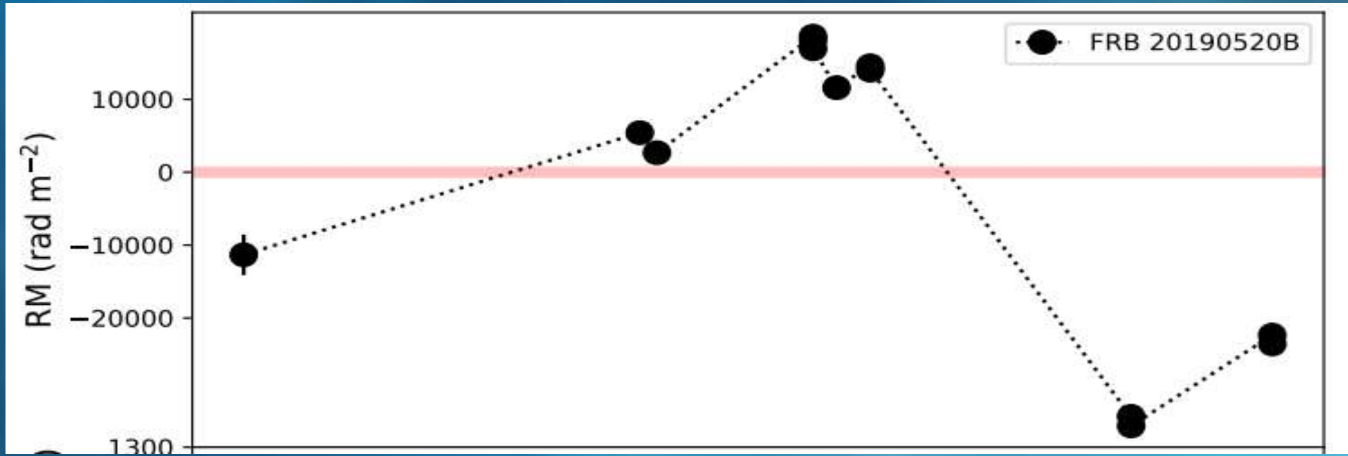
FRB 20121102A Hilmarsson et al. 2021



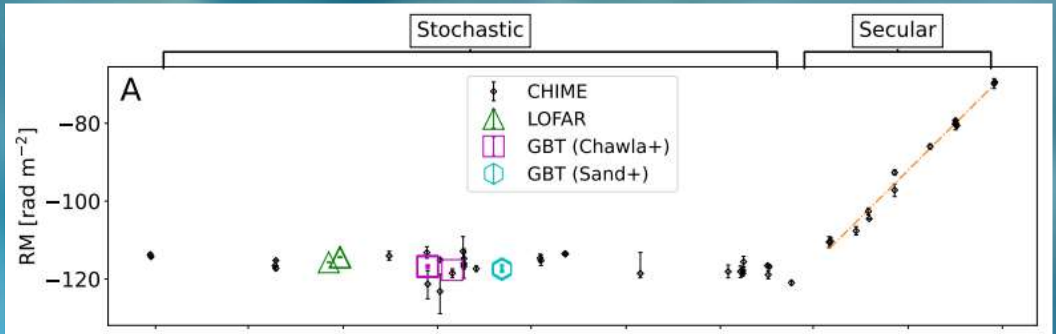
FRB 20201124A Xu et al. 2022, Nature, 609,685



FRB 20190520B Anna-Thomas, Dai, Feng & Li et al. Science, 380,599

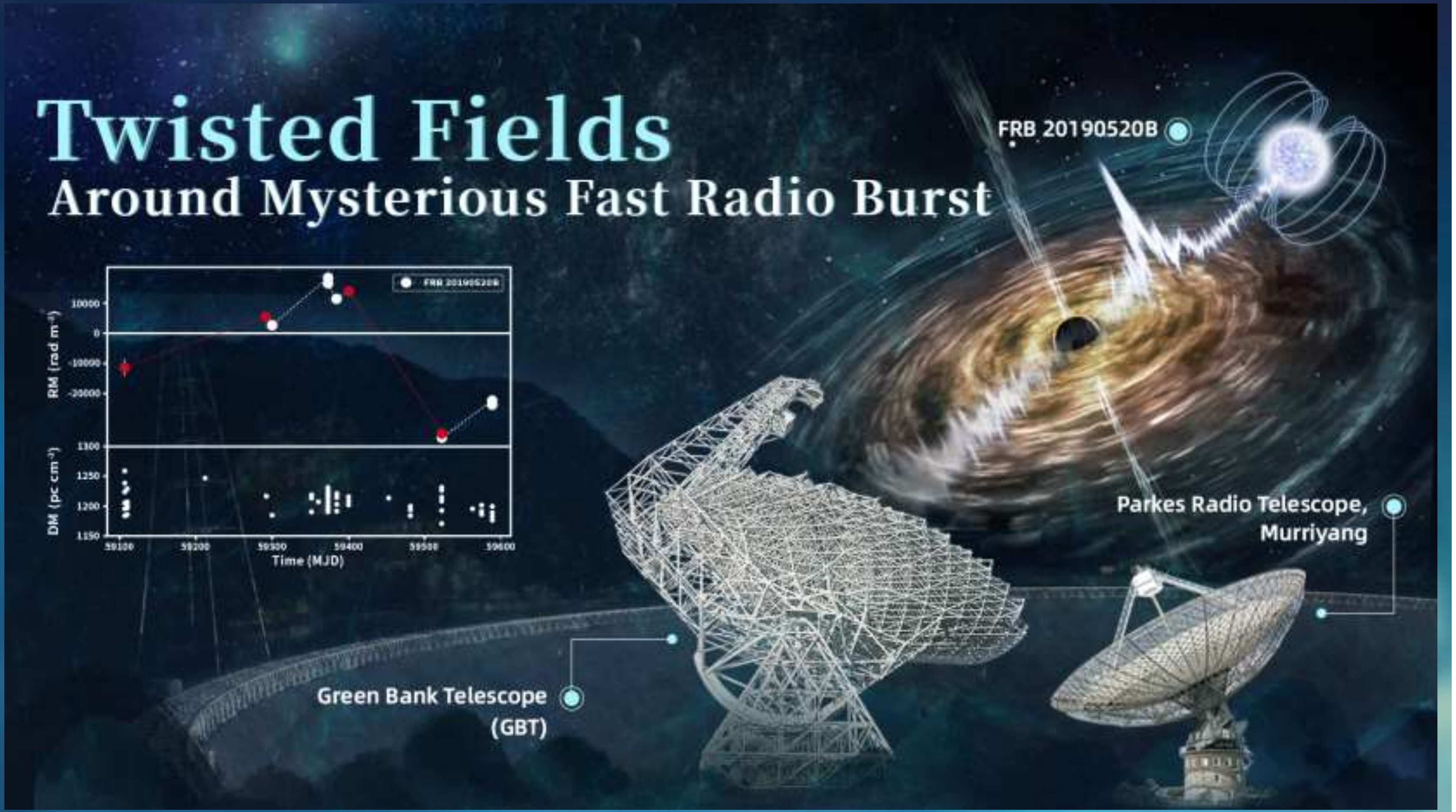


FRB 20180916B Mckinven et al. 2022



Rotation measure

Magnetic field reversal of world's first persistently active fast radio burst



ASTRONOMY

An origin scenario for a fast radio burst

Never-before-observed behavior of a repeating burst suggests its possible origin

By Zsolt Paragi

In just a tiny fraction of a second, a fast radio burst (FRB) in the distant cosmos can emit as much energy as the Sun does in several days. The sources of these intense bursts, observed only as radio waves, have been elusive. Studies on FRBs that repeat indicate that their progenitors reside in diverse environments within far-away galaxies. Some "repeaters" also appear to have an associated persistent source, likely a radio nebula, that may be powered by a magnetar (highly magnetized neutron star) or a black hole. The nature of these sources might provide information about the origin of FRBs. On page 599 of this issue, Anna-Thomas et al. (1) report a highly variable medium with turbulent magnetic fields surrounding a repeating FRB. This observation suggests that the pulses of radio wave emission may come from a compact object accompanied by a binary companion with strong stellar winds.

Magnetars have long been a prime suspect as FRB progenitors because of their similarities to pulsars, strong magnetic fields, and small emitting regions. However, their exact process of formation channel is not known, and there are still viable alternative FRB progenitors. Localizing the sources of FRBs within a host galaxy has been a powerful tool to constrain various progenitor formation models. Radio interferometric methods—especially those involving very long baselines—have shown that FRBs exist in different environments (2, 3). Sometimes an FRB appears near a site of active star formation, but a repeating FRB was also found in a globular cluster (a luminous, nearly spherical collection of hundreds of thousands of stars) containing a very old stellar population (4). Precise localization could provide clues about the nature of the environment and constrain the channels of FRB progenitor formation but so far has not provided a conclusive answer. Turning attention to the properties of the bursts themselves may offer clues.

As radio waves travel through plasma in space, their properties change. Dispersion slows down the radio waves at longer wavelengths, and Faraday rotation (a magneto-optical phenomenon) changes their polarization properties. FRB pulses thus have a full history of plasma distribution in space imprinted on them and can provide information about the amount of baryonic matter (atomic matter) in between galaxies (5). However, this only works if the effects on radio wave propagation are dominated by this intergalactic matter. Substantial local dispersion and Faraday rotation effects from the immediate environment can constrain FRB progenitor formation models (6), but the benefits of this information go beyond just improving models. Understanding individual sources will ultimately allow the applications of FRBs to broader questions in cosmology (such as constraining the distribution of ionized gas in the universe) because we can minimize systematic errors in the data.

"Understanding individual sources will ultimately allow the applications of fast radio bursts to broader questions in cosmology..."

The repeating FRB 20190520B studied by Anna-Thomas et al. stands out in that its local environment contributes more to altering the burst emission than the intergalactic plasma and the interstellar gas in the Milky Way combined, resulting in a very large excess dispersion (7). It has an associated persistent radio source and resides in a dwarf galaxy—just like the first-ever discovered repeater FRB 20121102A (8). Therefore, these two FRBs are sometimes referred to as twins. FRB 20121102A already provided some insight into the nature of its source and its associated persistent radio source: The observed Faraday rotation in this system is particularly high and variable, which may point to an environment around a massive black hole, or in a young supernova remnant (9). However, neither interpretation gave a coherent picture of a formation channel for this FRB when considering the data. There was a hint about possible nonuniformities in the environment or in the emitting region, evidenced from the frequency dependence of the burst polarization properties (10).

Anna-Thomas et al. used some of the largest radio telescopes available to study the bursts seen from FRB 20190520B, and especially to see variations in propagation effects. What the authors found was rather surprising: The Faraday rotation was highly variable and also changing sign, which indicates a rather turbulent environment. A possible scenario is that there is a binary system in which the radio waves travel through the dense and variable stellar wind of a companion star.

Whether the above interpretation holds is still to be seen. The 16.3-day periodicity observed in FRB 20180916B may also support a binary interaction model for repeating FRBs (11). Compact objects such as neutron stars or black holes have certainly been found in binary systems, also with companions having massive stellar winds. Perhaps the best known such example is SS433, which is associated with a supernova-like radio nebula, W50. It was proposed that nebulae surrounding hyperaccreting x-ray binaries, similar to the SS433-W50 system, may be the precursors and persistent counterparts to FRBs (12).

It has also been proposed that the burst properties are not solely determined by the nature of the progenitor and in some cases can be dominated by interactions with the external medium (13). In any case, understanding the effect of the local environment on propagation effects will greatly increase the potentials of using FRBs for precision cosmology. Future monitoring of the time evolution of burst properties, as well as high-spatial-resolution studies of nebulae associated with FRB sources, may provide further clues. These studies will also reveal whether there is only a single FRB population, or if there are different FRB progenitors with various formation channels. ■

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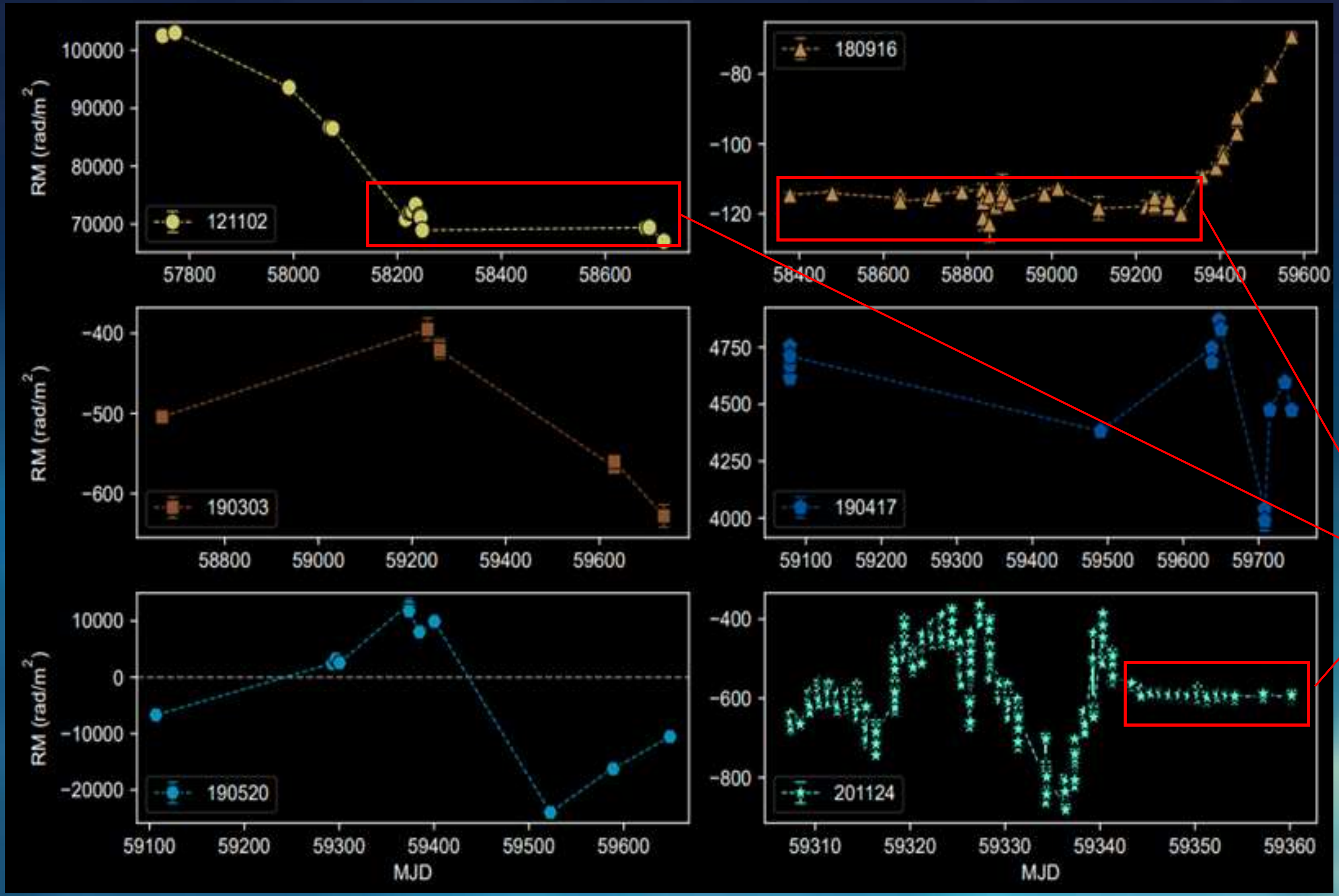
Rotation measure



A significant fraction show RM variations

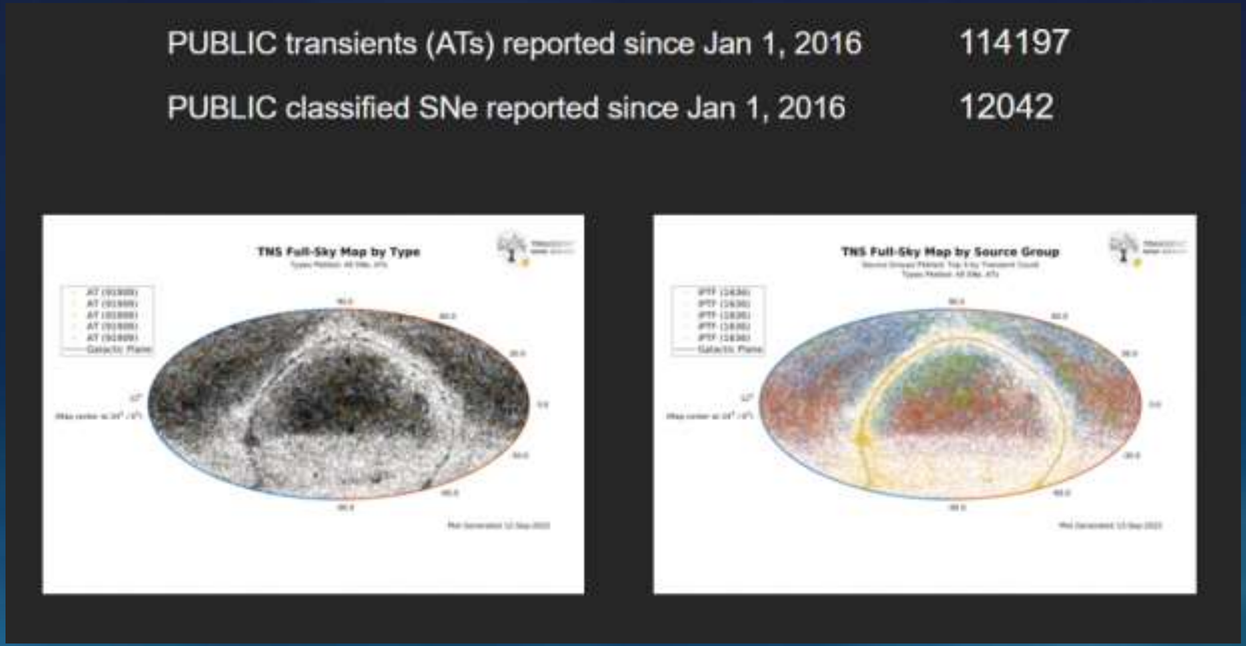
Some have sign change

Sometimes are relatively

stable

Feng et al. in prep

FRB database



Transient Name Server

CHIME/FRB

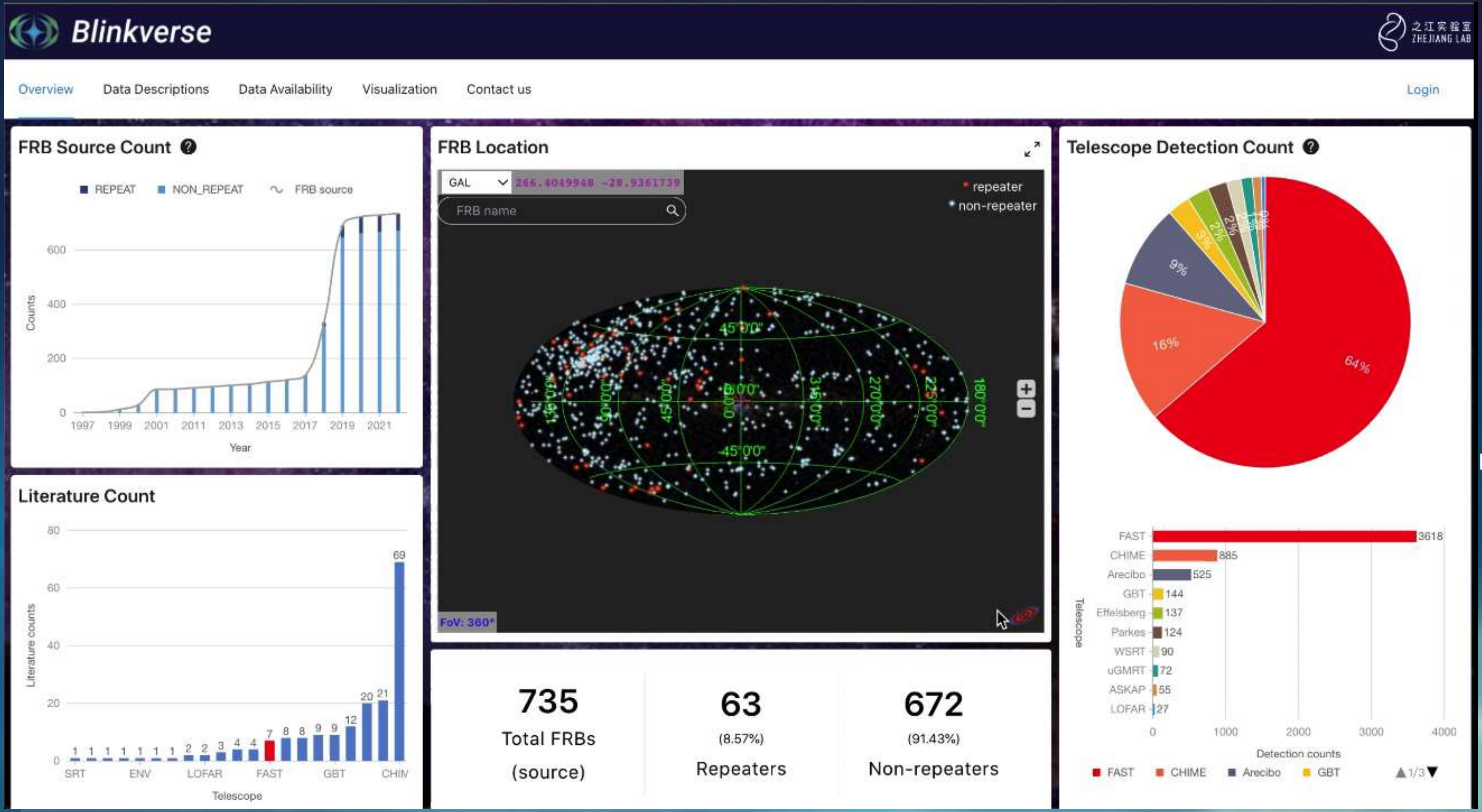
Current status of FRB database

- Transient Name Server (TNS)
- FRB Catalogue (FRBcat)
- CHIME/FRB

The Australia Telescope National Facility (ATNF)

- The world's largest pulsar database
- 3000+ pulsars recorded
- Number of citations: 2100+

BlinkVerse

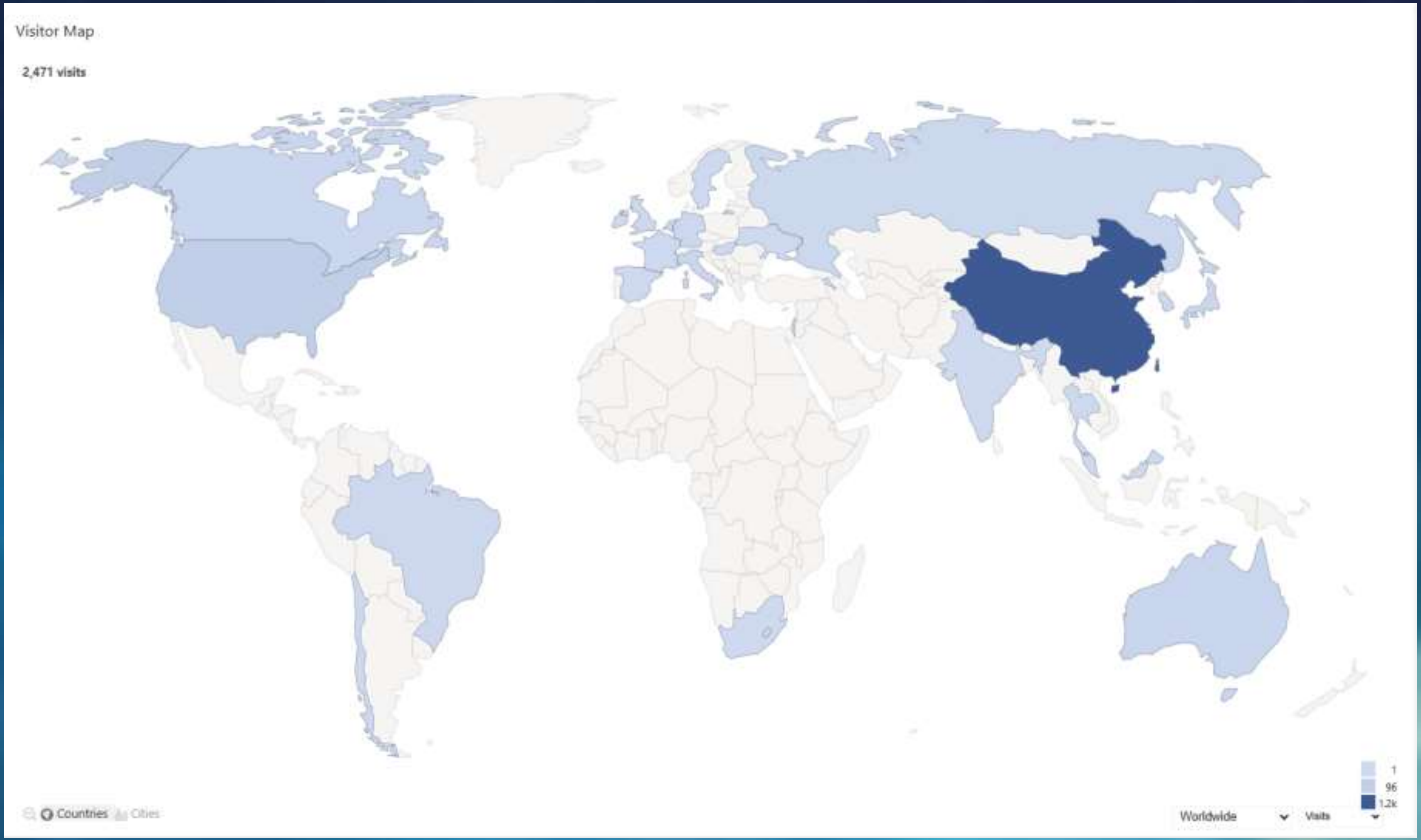


- ✓ ~800 sources
- ✓ 5700+ bursts
- ✓ 30+ parameters
- ✓ Dynamic spectrum
- ✓ Interactive Celestial sphere

Xu et al. 2023, Universe, 9(7), 330
https://doi.org/10.3390/universe9070330

https://blinkverse.alkaidos.cn

BlinkVerse



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- ✓ Until September 20
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- Energy Analysis
- Temporal distribution
- Periods Analysis
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- decut
- Heimdall
- regrid
- ripple
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- calibrate
- ODFSearch
- DSPSR

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Exploring the blinking universe

THANK YOU