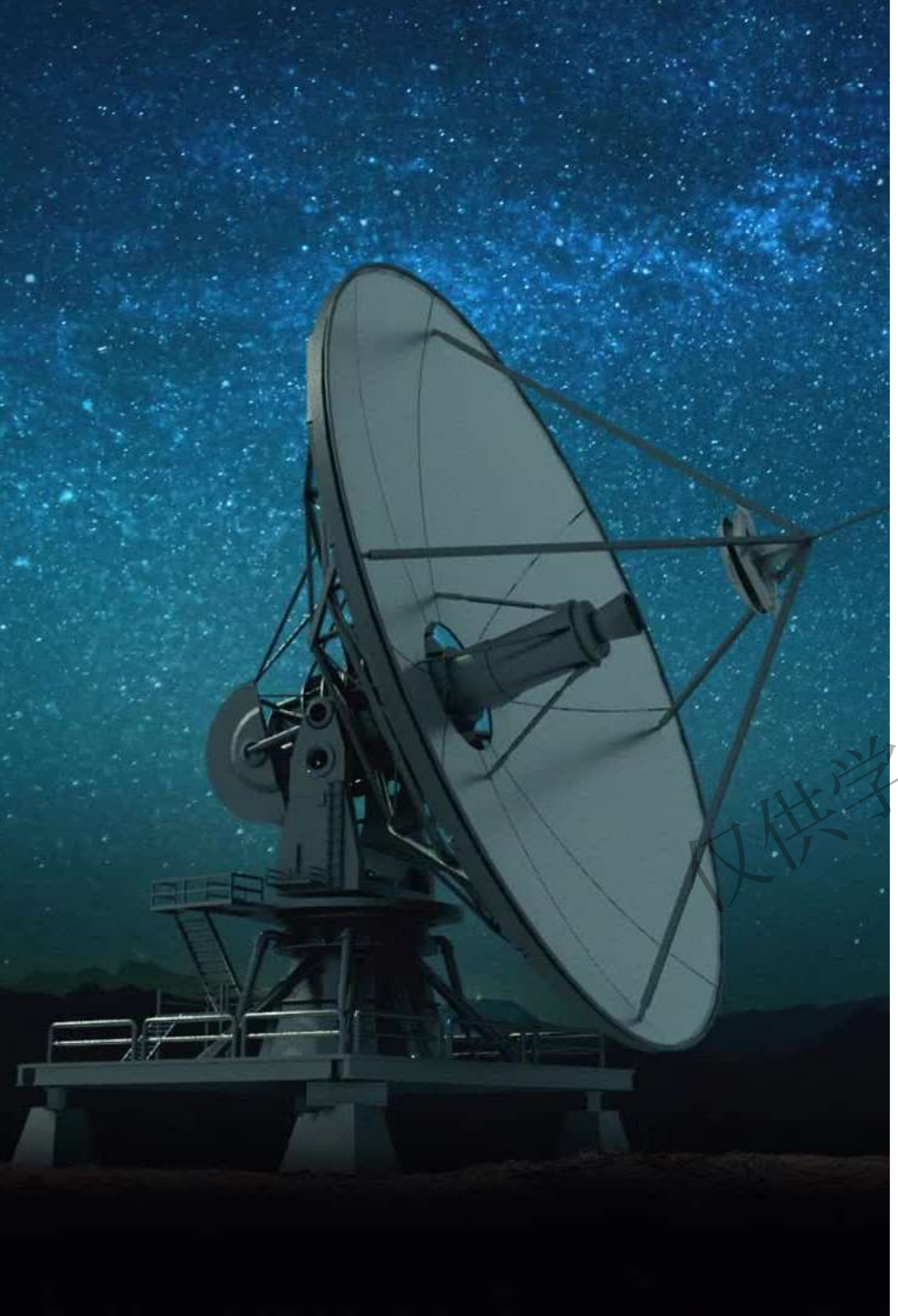
Pulsar and FRB study using FAST

Weiwei Zhu (朱炜玮)
National Astronomical Observatories, CAS (国家天文台)

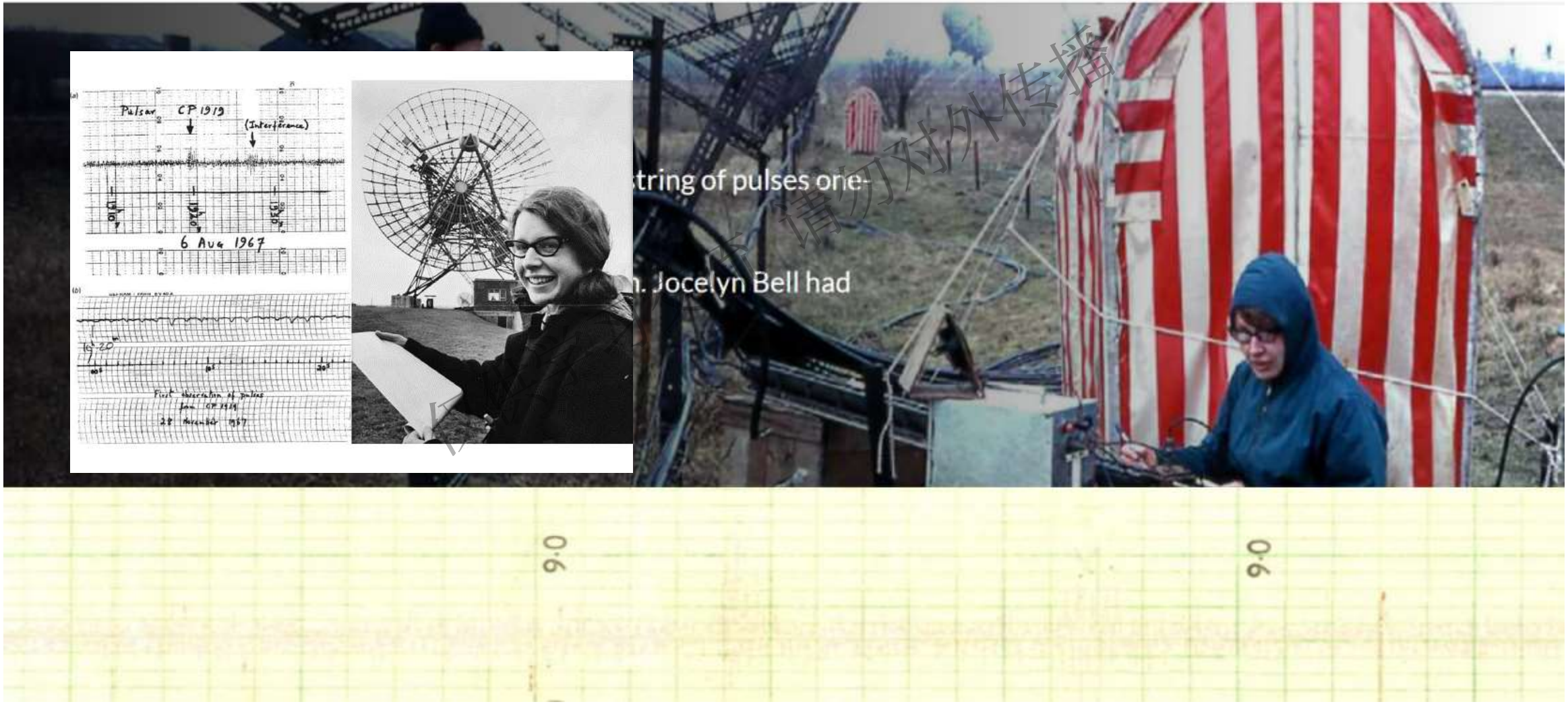
NAOC Colloquium-2023-3-22



Outline

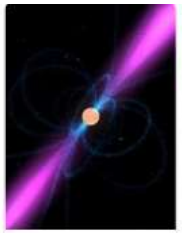
- **Pulsars**
- **Fast Radio Bursts** (FAST FRB KSP)
- Future Prospect

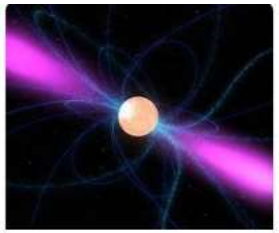
What are Pulsars



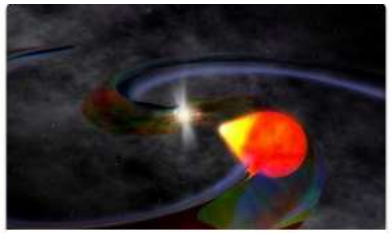
Pulsars are discovered by J. Bell in 1967; Nobel Prize in 1974

What are Pulsars


Smallest speed jump of pulsar cau...

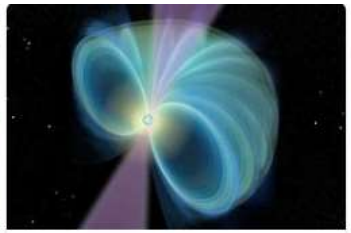

A Pulsar Eases Off the Brakes

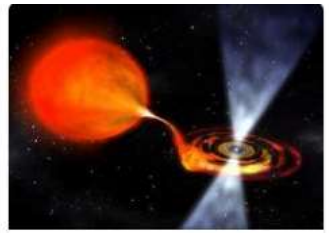

We've found a pulsar spinning so slowly that it shouldn't exist | New ...

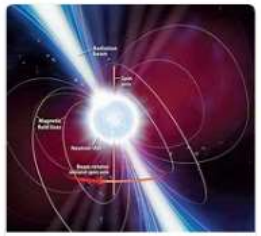

Astronomers find six new millisecond pulsars

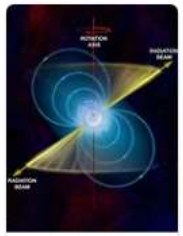

Images of 2 pulsars could clear up geometry debate - Futurity


Images of 2 pulsars could clear up geometry debate - Futurity


Researchers find a new way to weigh pulsars – Astronomy Now


Amateur astronomer helps uncover secrets of unique pulsar binary system


Atmospheres can protect exoplanets from pulsars | Ast...


Parts of a Pulsar – National Radio Ast...

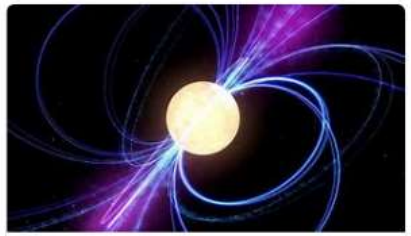

Pulsars at 50: Still going strong | Astronomy Magazine

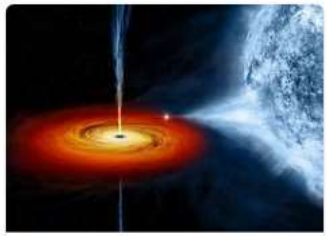

Pulsar_2r Kesque

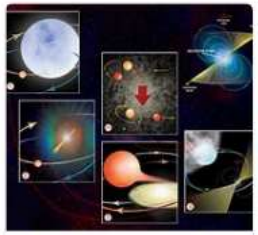

1: One of the most famous pulsars is the Crab pulsar...


Pulsars

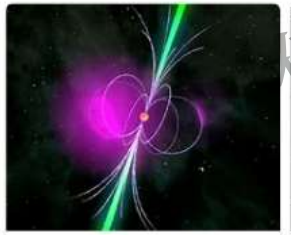

Pulsars as Nature's own GP...


Neutron Stars | Max Planck Institute for Radio Astronomy

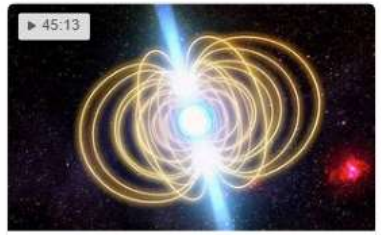

An Aging Pulsar has Captured a new Companion, and it's Spinning back up ...


How to Make a Millisecond Pulsar – National Radio Astr...

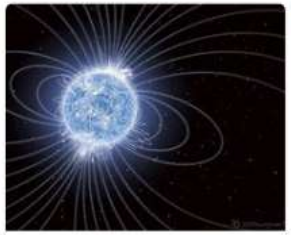

Challenge theoretical models, Crab pulsar be...

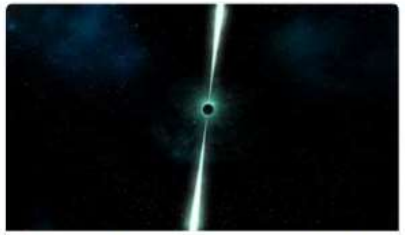

Spin! Crab Pulsar Speed Jumps Linked To Billions Of Tiny Vortice...

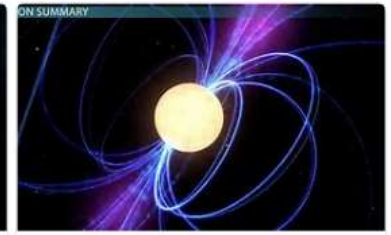

Pulsar: Pulsars zijn de snelheidsduivels van het heelal | wibnet.nl



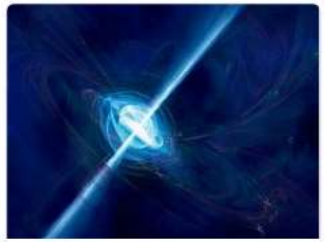
Watch The Universe Season 4 Episode 10 | HISTORY Channel

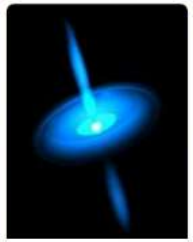

Researchers find 'missing link' between magnetars and rotation ...

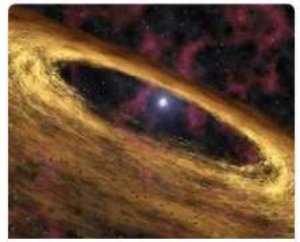

Astronomers Detected The Slowest-Spinning Radio Pulsar Ever - Great ...

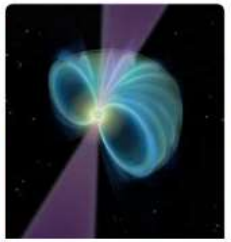


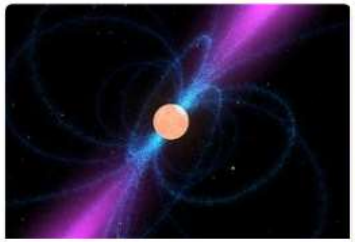
Binary Pulsars & Pulsar Planets - Video & Lesson Transcript | Study.com

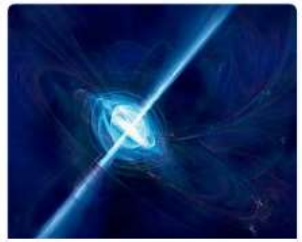




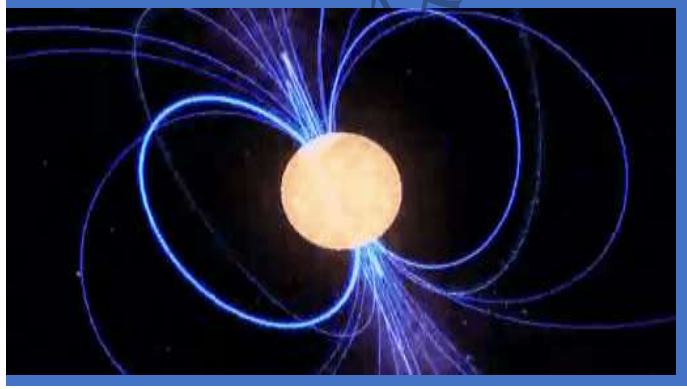








What are Pulsars?



- Spin faster than blender
- Weighs more than the Sun, but only size of a city
- Its gravity bends the light and spacetime around it

Pulsar Sciences

- Can gravity crush atoms? (discovery of neutron stars, 1974 Nobel Prize)
- Existence of GW (1993 Nobel Prize)
- Can neutron star crush neutrons and protons into quarks?
- Is GR correct?
- Are there GW from massive galaxy mergers?

FAST优先和重大项目　　科学院建制化科研平台等项目

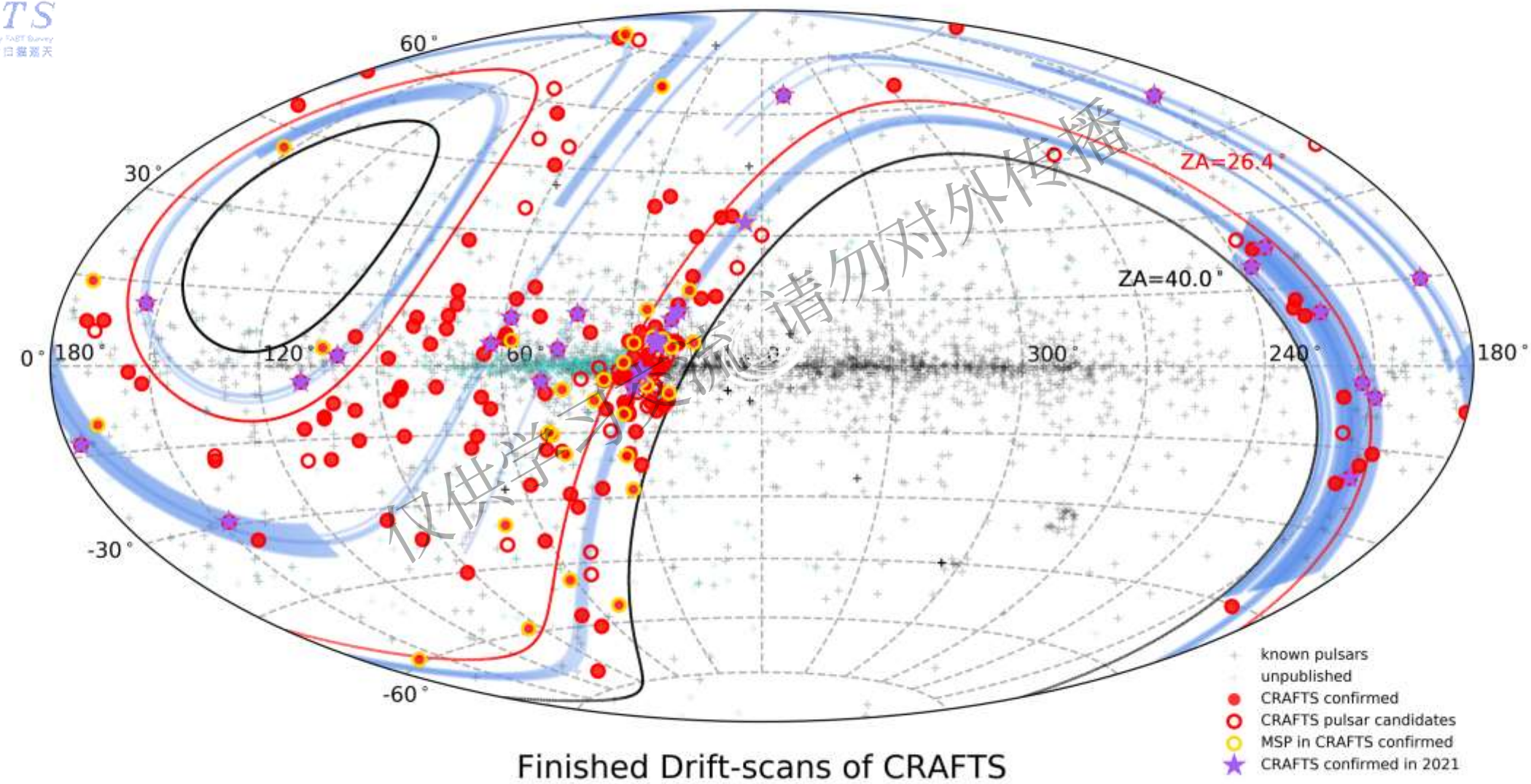
2020-04-11

经FAST科学委员会讨论，决定设立五个优先和重大项目，见下表。

序号	项目名称		项目负责人	联系方式
一	FAST漂移扫描多科学目标同时巡天（CRAFTS）		李菂	dili@nao.cas.cn
二	快速射电暴的搜寻和多波段观测		朱炜玮	zhuww@nao.cas.cn
三	银道面脉冲星巡天		韩金林	hjl@bao.ac.cn
四	M31中性氢成像与脉冲星搜寻		王杰	jie.wang@nao.cas.cn
五	脉冲星测时	1.中国脉冲星测时阵列	李柯伽	kjlee@pku.edu.cn
		2.脉冲星物理和演化	王娜	na.wang@xao.ac.cn

Commensal Radio Astronomy FAST Survey

CRAFTS

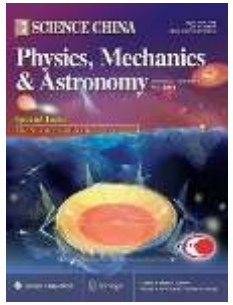


Finished Drift-scans of CRAFTS

Credit: Pei Wang

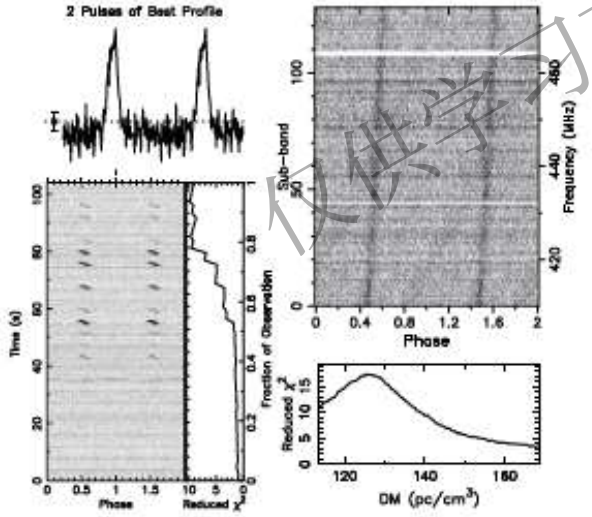
PI: Di Li

Pulsar candidate selection using ensemble networks for FAST drift-scan survey



HongFeng Wang[1,2,3*], WeiWei Zhu[2*], Ping Guo[4*], Di Li[2,5], SiBo Feng[1], Qian Yin[1], ChenChen Miao[5,2], ZhenZhao Tao[7,2], ZhiChen Pan[2], Pei Wang[2], Xin Zheng[1], XiaoDan Deng[4], ZhiJie Liu[6], XiaoYao Xie[6], XuHong Yu[6], ShanPing You[6], Hui Zhang[6], and FAST Collaboration

- ResNet deep learning AI
- Customized for FAST drift scan pulsar survey



Real FAST pulsar signals

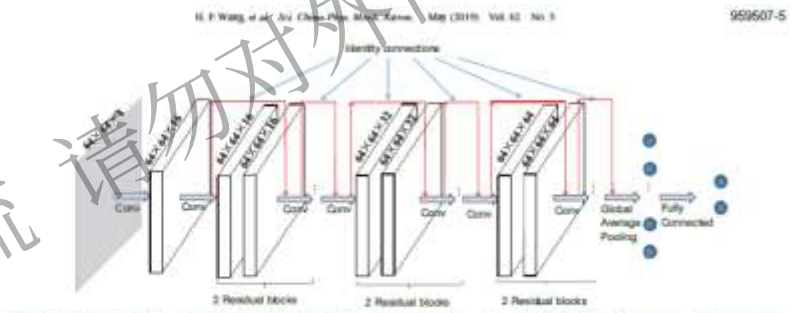


Figure 4 (Color online) Diagram of a 15 layered ResNet model. Conv refers to convolutional operation. The "2 Residual Blocks" component contains two building blocks that possess an identical architecture. The input image is $64 \times 64 \times 1$, and the output sizes are $H \times W \times N$, where H and W denote the height and width of the tensor, and N denotes the number of features.

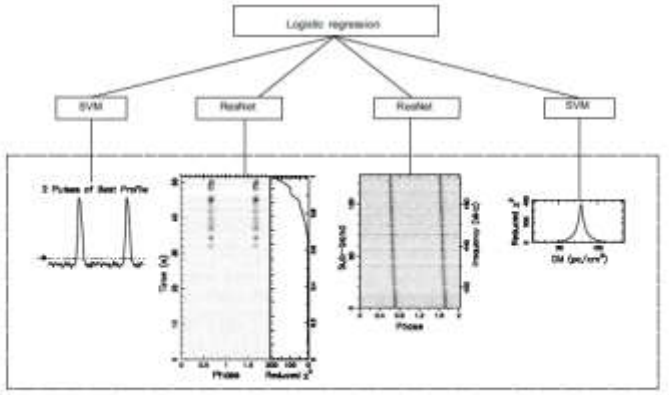
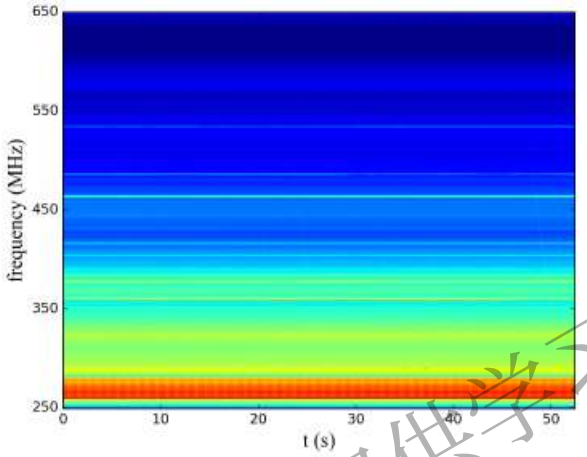


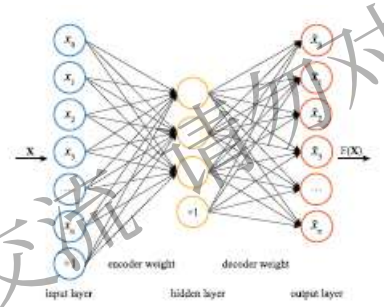
Figure 5 Diagram of the PICS-ResNet model. The first layer classifies the individual features (the pulse profile, time versus phase plot, frequency versus phase plot, and DM curve), whereas the second layer classifies the candidates based on the results of the first layer. The SVM components represent the support vector machine model, while the ResNet components represent the residual network model. See Figure 4 for a schematic of the ResNet model.

Wang Zhu Guo et al. 2019 SCPMA

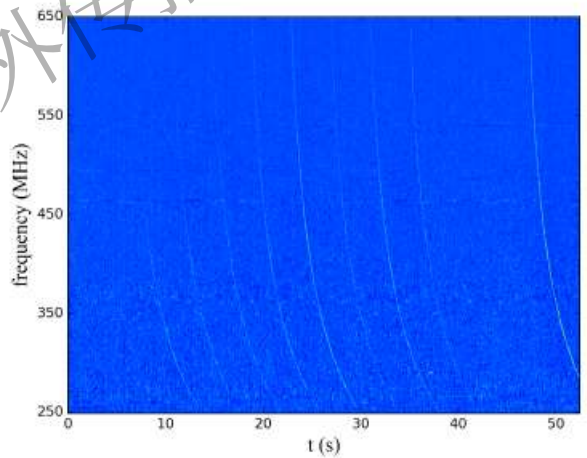
Removing Radio Interferences using AI



Original data



PIL AutoEncoder



After RFI removal

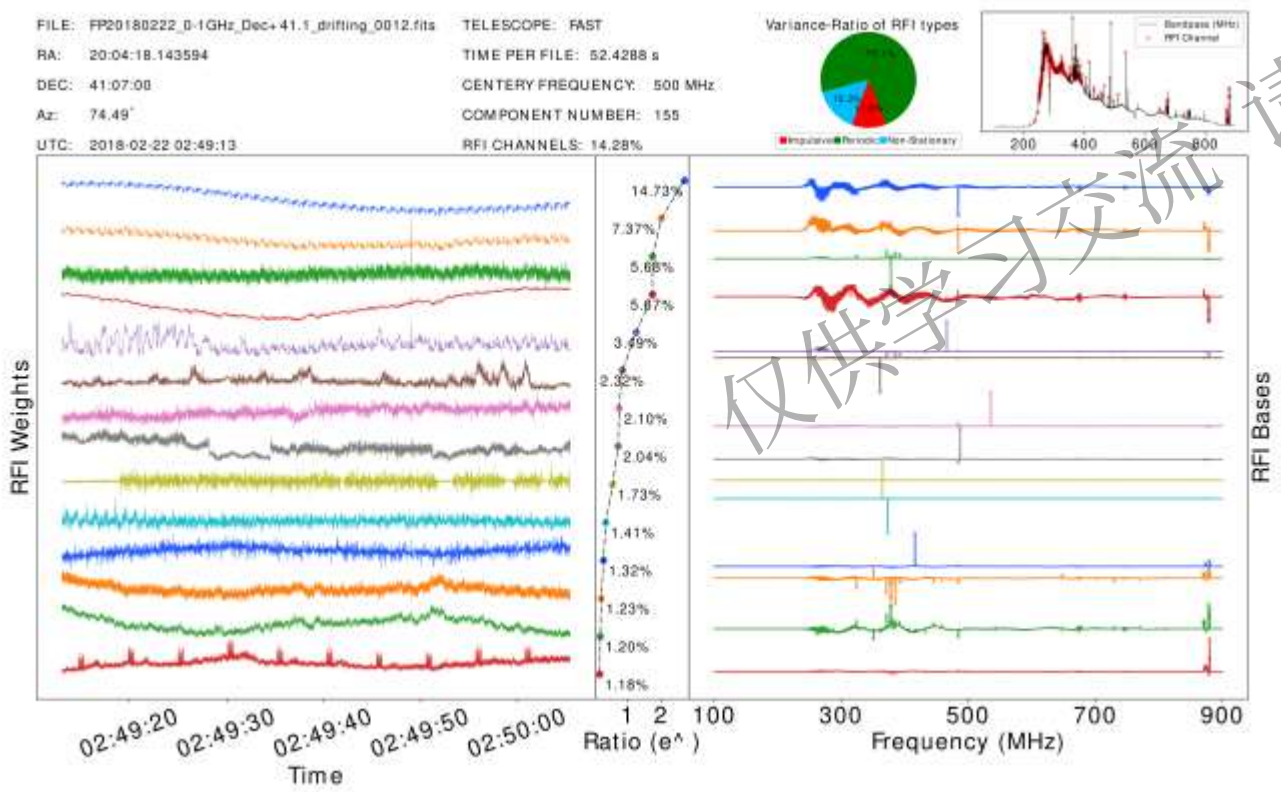
Radio Frequency Interference Mitigation using Pseudoinverse Learning AutoEncoders *

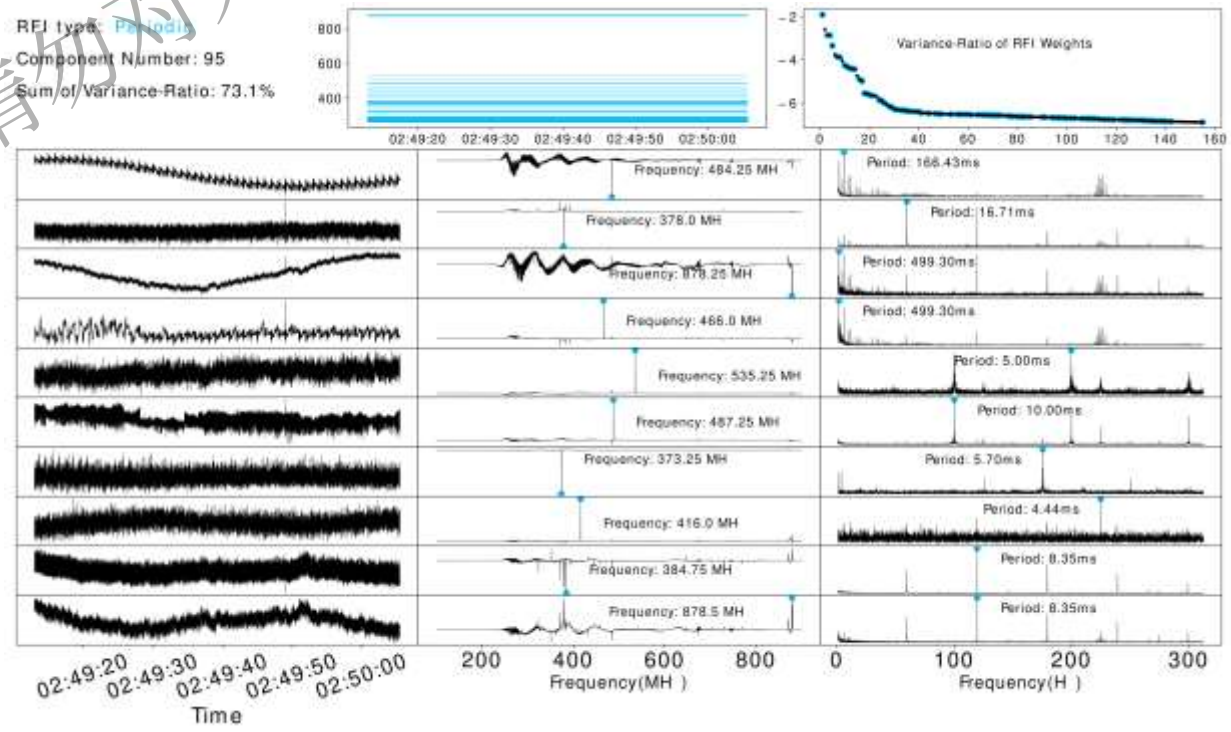
Hongfeng Wang[1,2,3,5], Mao Yuan[2,6], Sibo Feng[7], Ping Guo[4], Weiwei Zhu[2], Di Li[2,6]

Wang H. F. et al. RAA 2020

Classifying and cataloging RFIs

- RFI identification with wavelets
- RFI classification with ML
- Long-term monitoring and cataloging RFIs



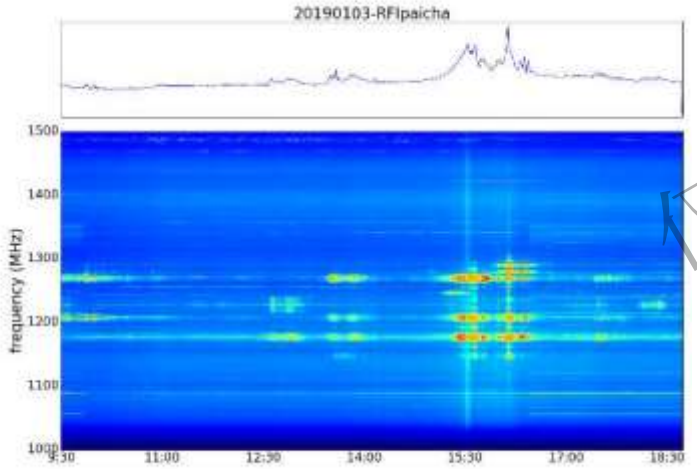


RFI成分分析和时间变化

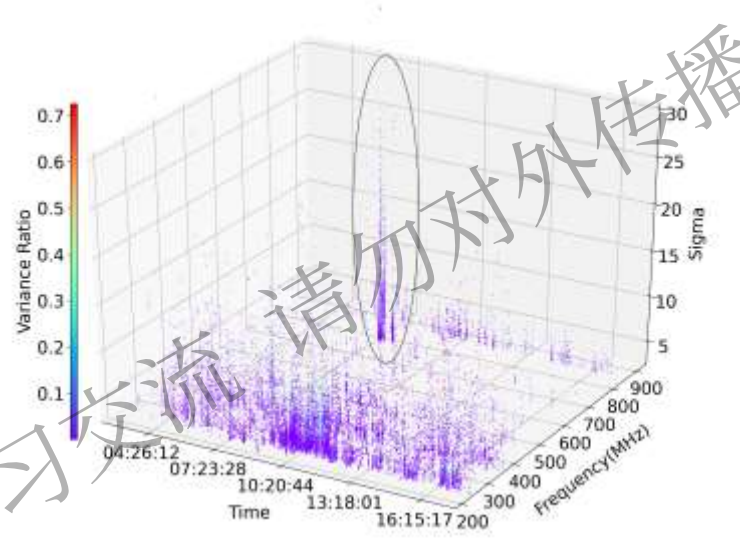
Yuan M, Zhu W. W., Zhang H. Y. et al. MNRAS 2022

Classifying and cataloging RFIs

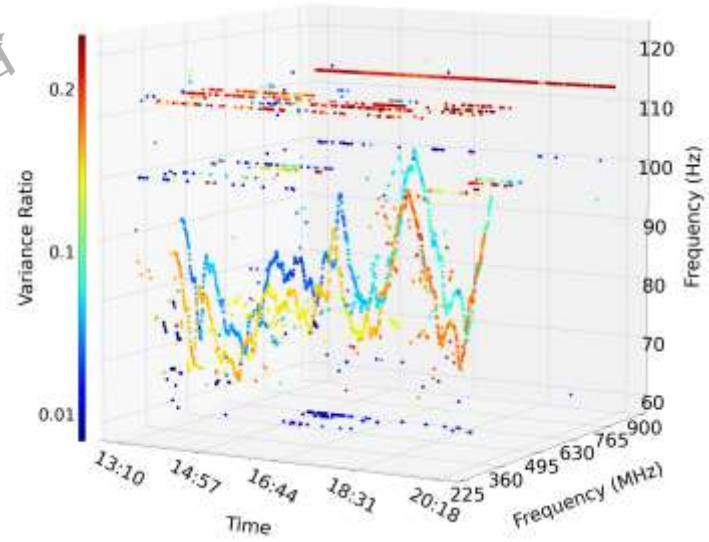
- RFI identification with wavelets
- RFI classification with ML
- Long-term monitoring and cataloging RFIs



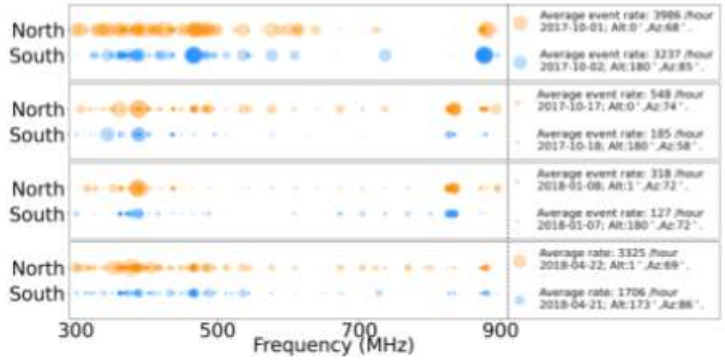
脉冲星数据中的RFI情况



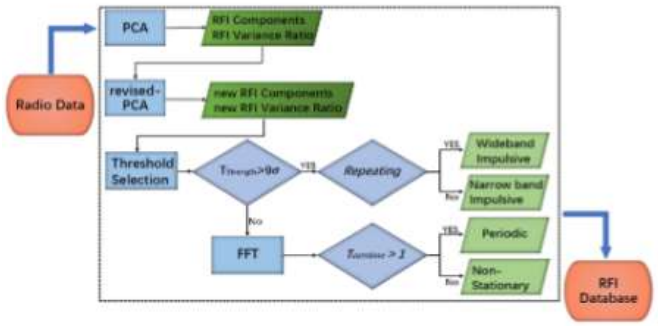
Impulsive RFI



Periodic RFI



Direction dependance and Time Evolution

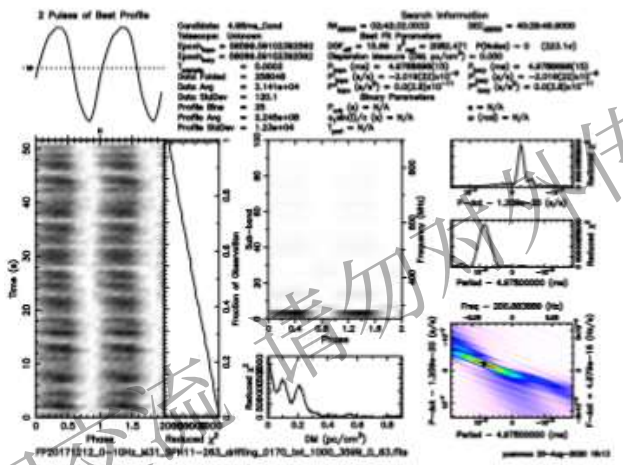


Yuan M, Zhu W. W., Zhang H. Y. et al. MNRAS 2022

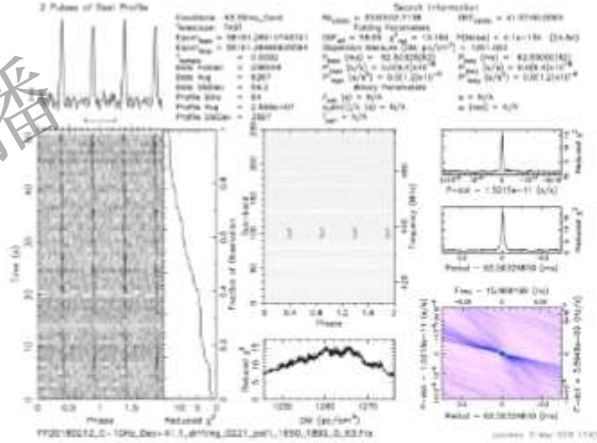
Classifying and cataloging RFIs

- RFI identification with wavelets
- RFI classification with ML
- Long-term monitoring and cataloging RFIs

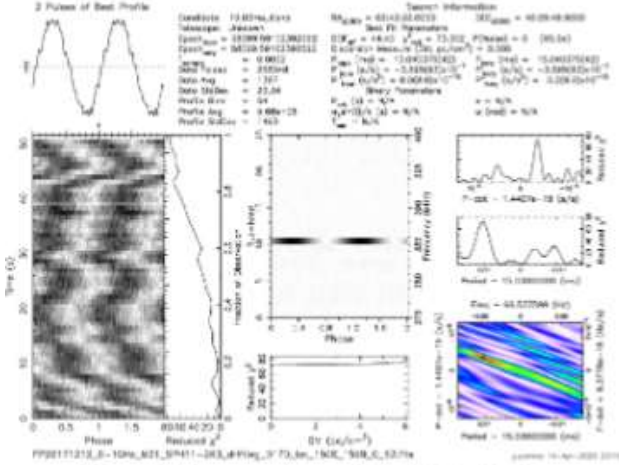
- Remove RFI candidate in Pulsar Search



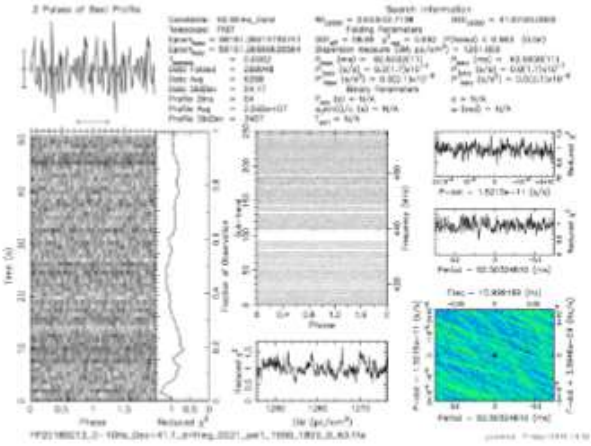
(a) candidate caused by period-stable birdy



(a) *rfifind*.



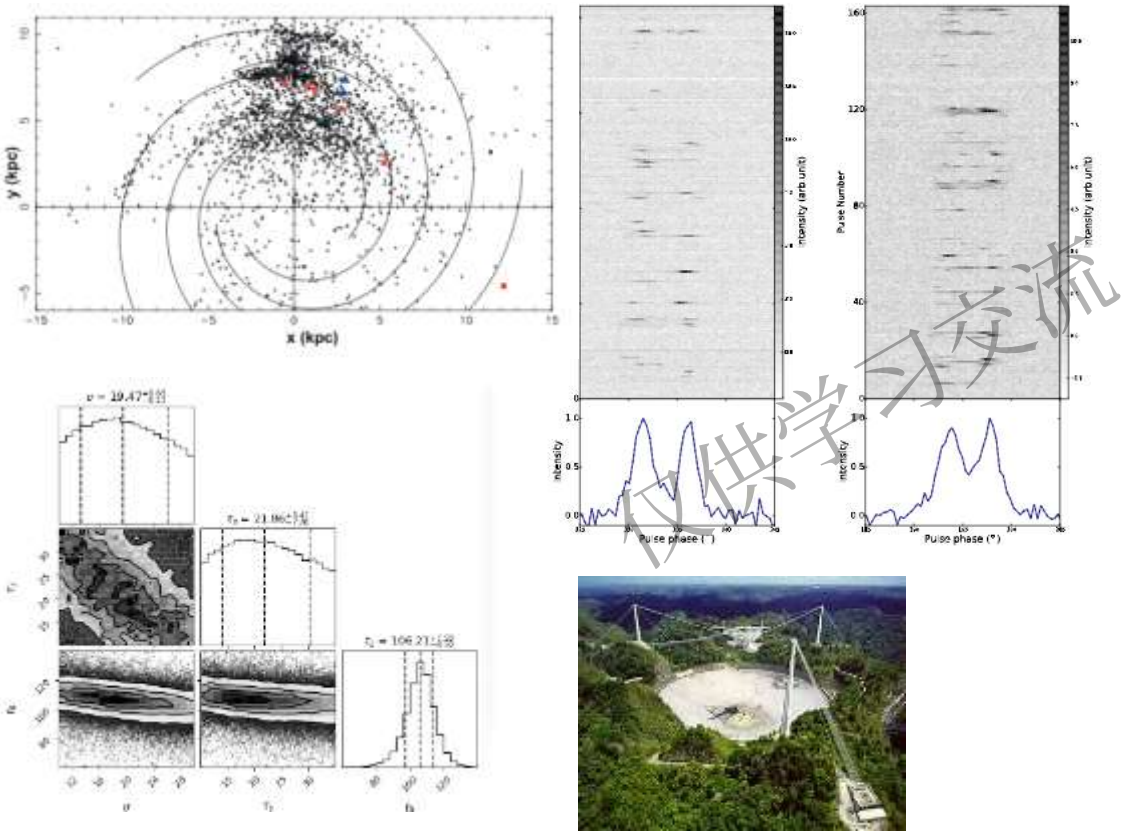
(b) candidate caused by period-drifting birdy



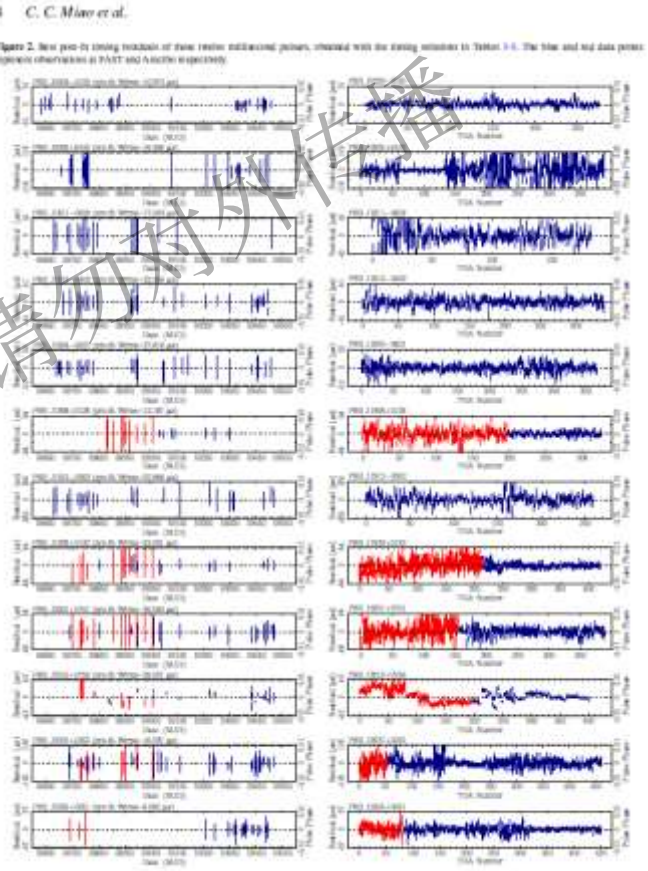
(b) *rfifind* & PCA.

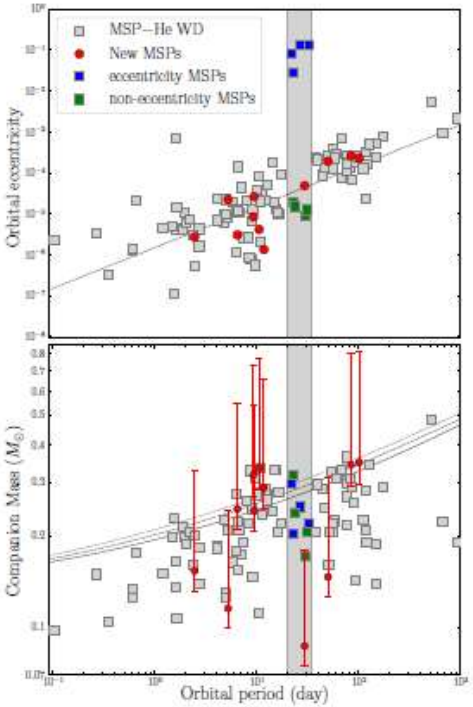
Yuan M, Zhu W. W., Zhang H. Y. et al. MNRAS 2022

Follow up new discoveries



7 FAST pulsar followed up with Arecibo
Wang S. Zhu W. W. Li D. et al. 2021 RAA

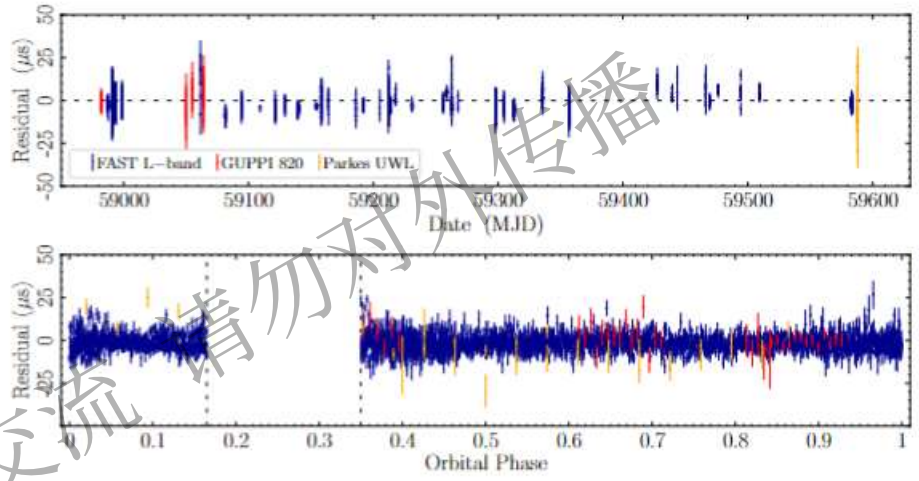


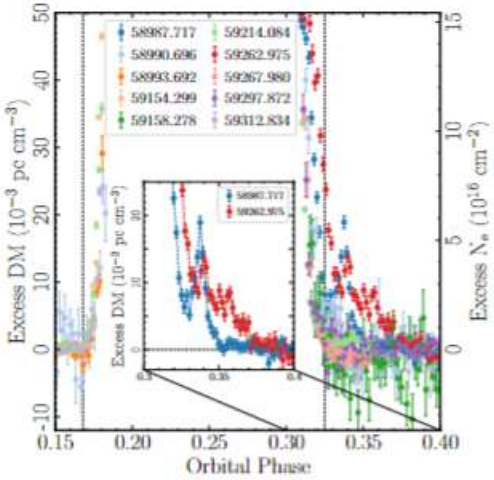


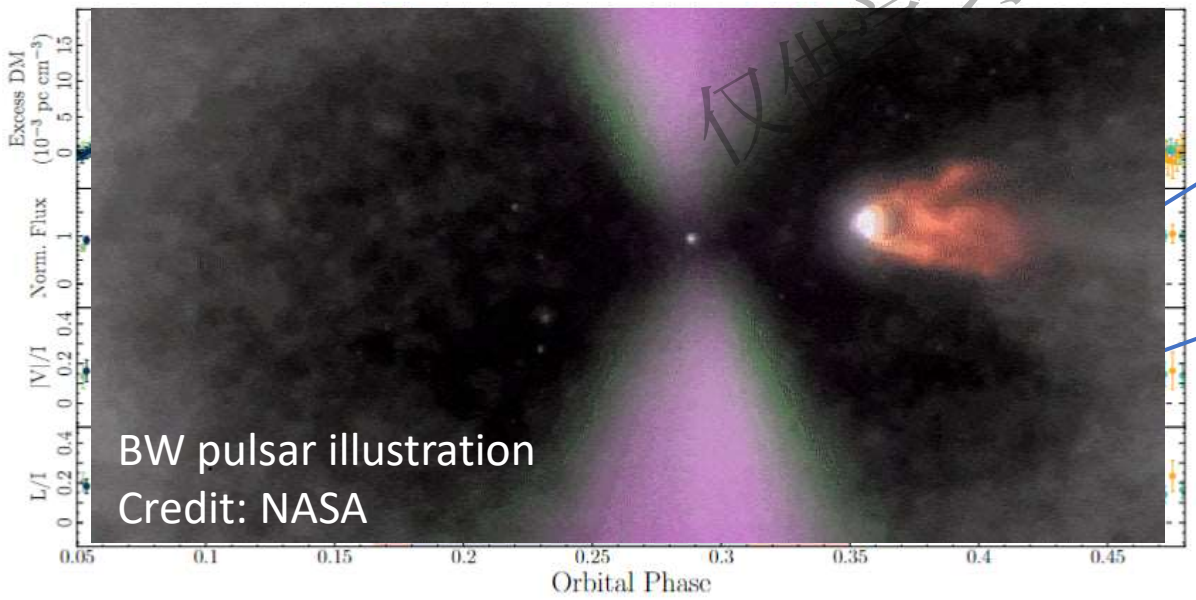
Timing of 11 millisecond pulsars discovered in CRAFTS
Miao C. C. Zhu W. W. Li D. et al. 2022 MNRAS

Follow up new discoveries

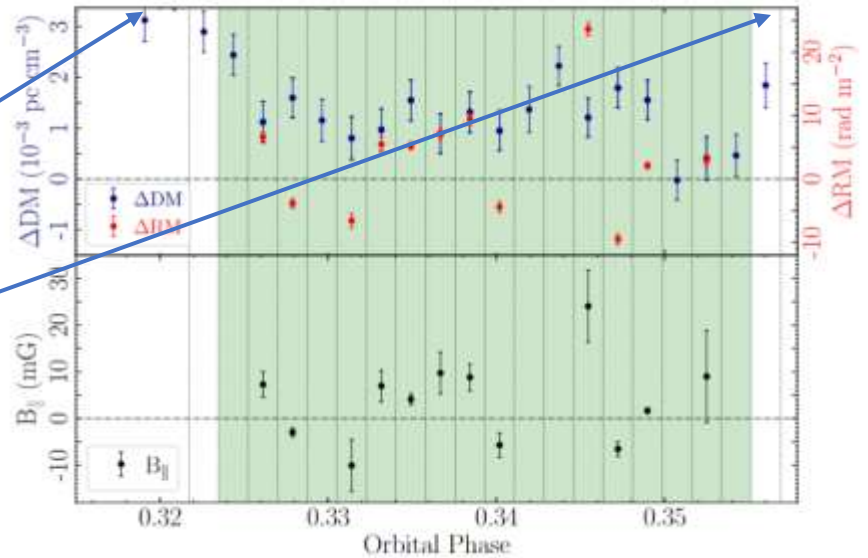
- Timing of PSR J1720−0534
- Measuring the eclipses
- Polarization eclipse > Intensity eclipse
- Faraday rotation oscillations in egress
- Sign changes in Faraday rotation oscillations after egress





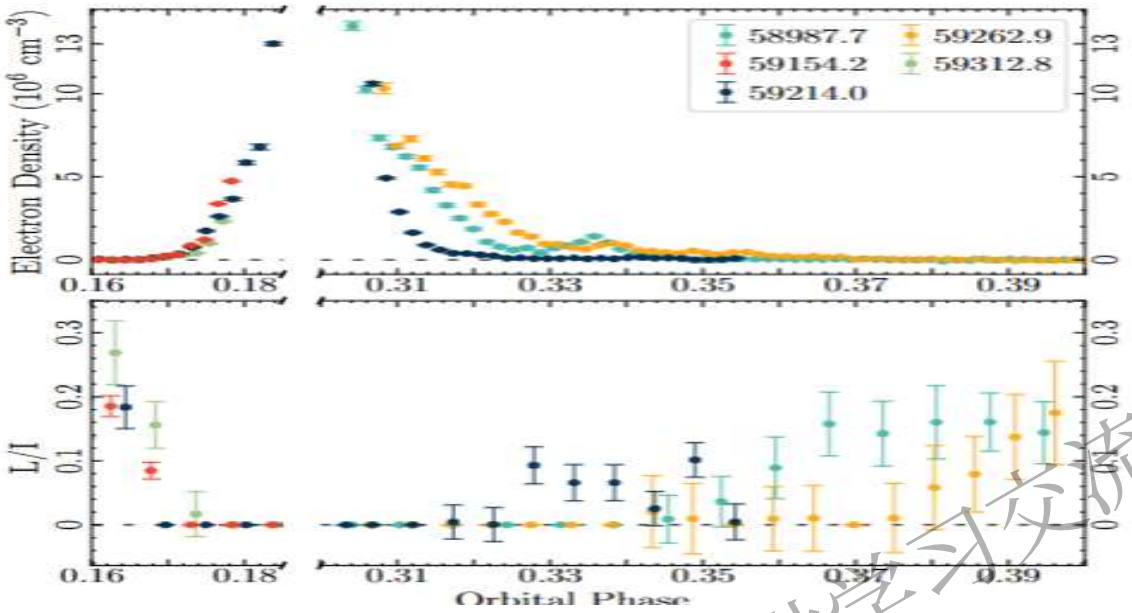


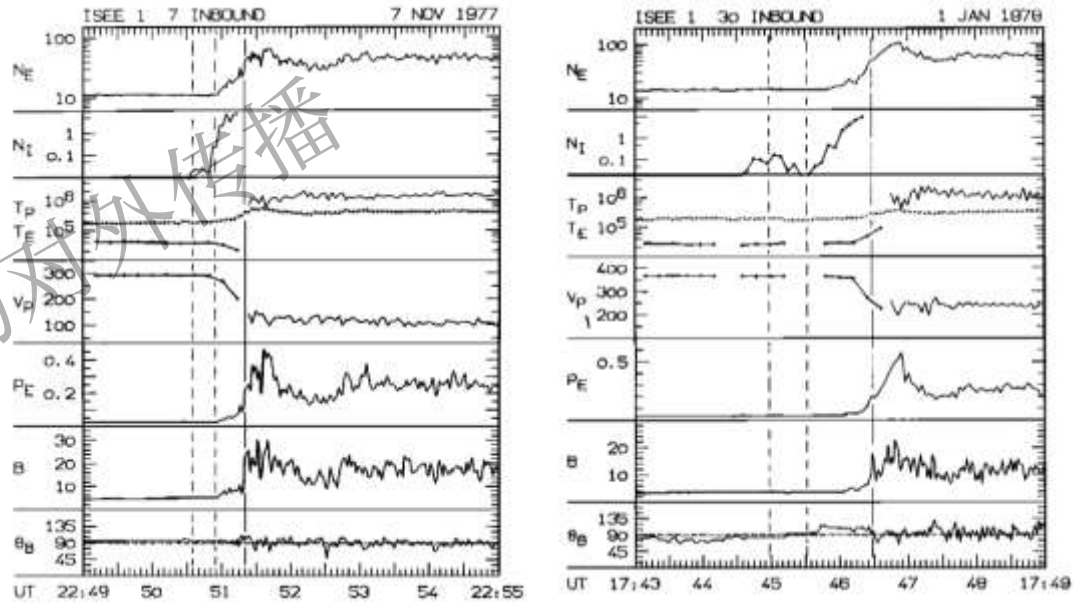
BW pulsar illustration
Credit: NASA



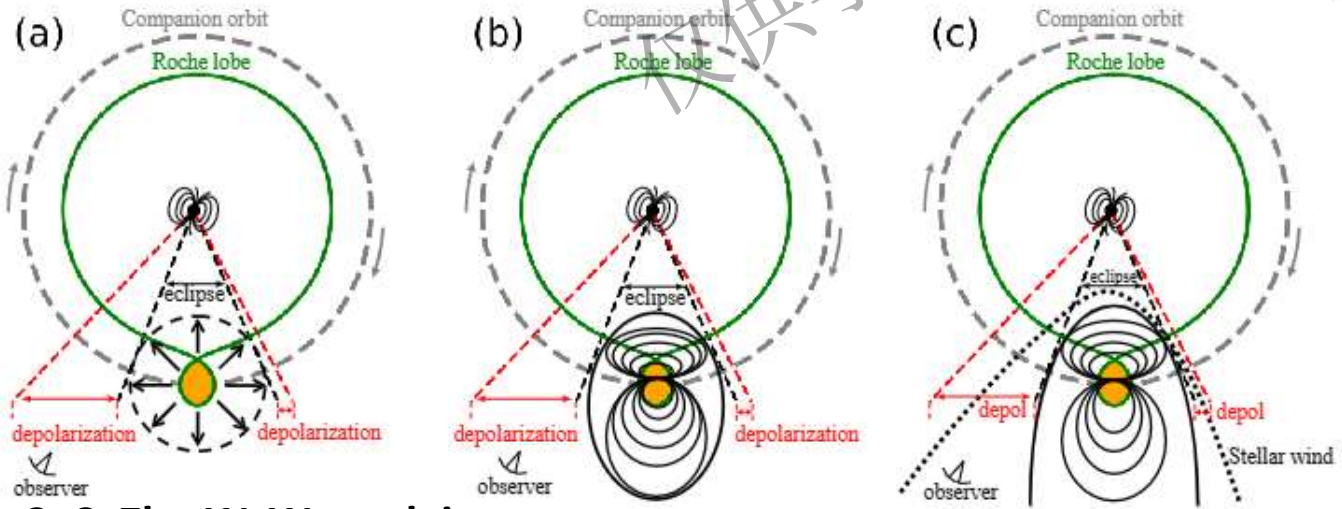
Miao C. C. Zhu W. W. et al. in prep.

Follow up new discoveries

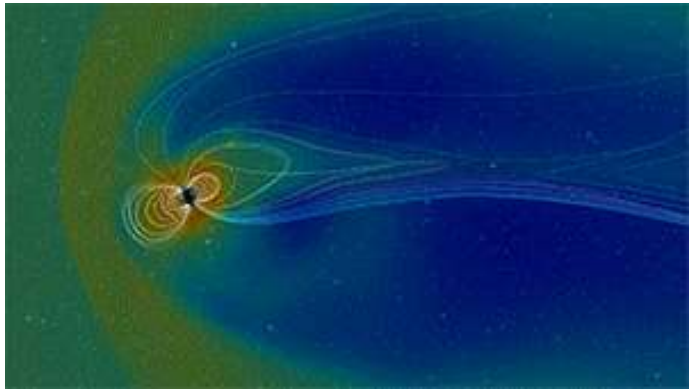




Sckopke et al. 1983 Journal of Geophysical Research



Miao C. C. Zhu W. W. et al. in prep.



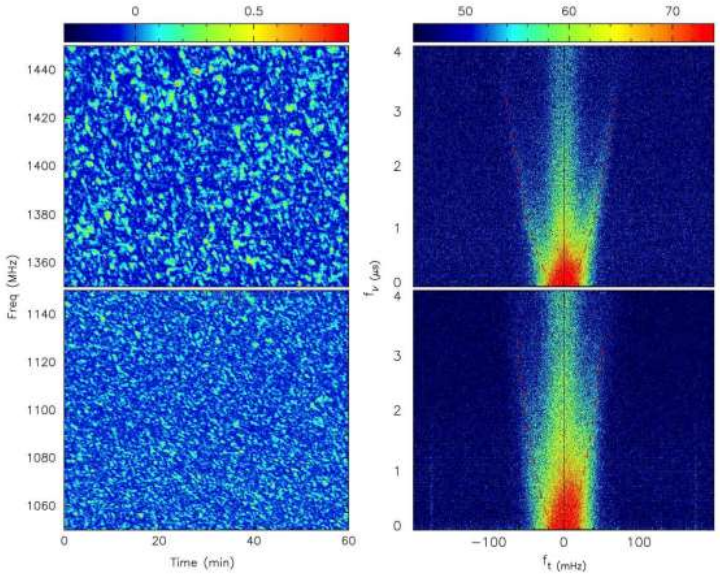
Earth Magnetosphere (NASA)

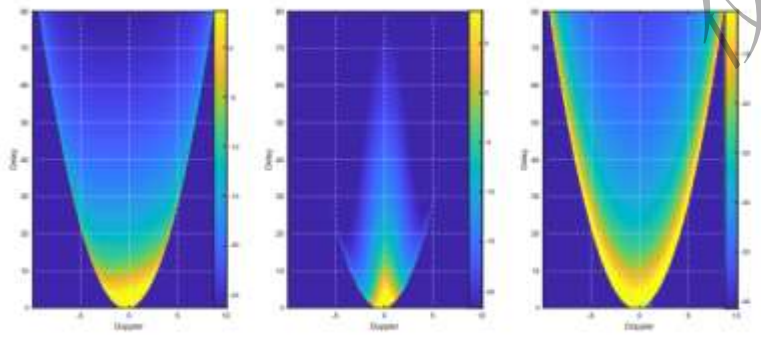
How are pulsars formed?

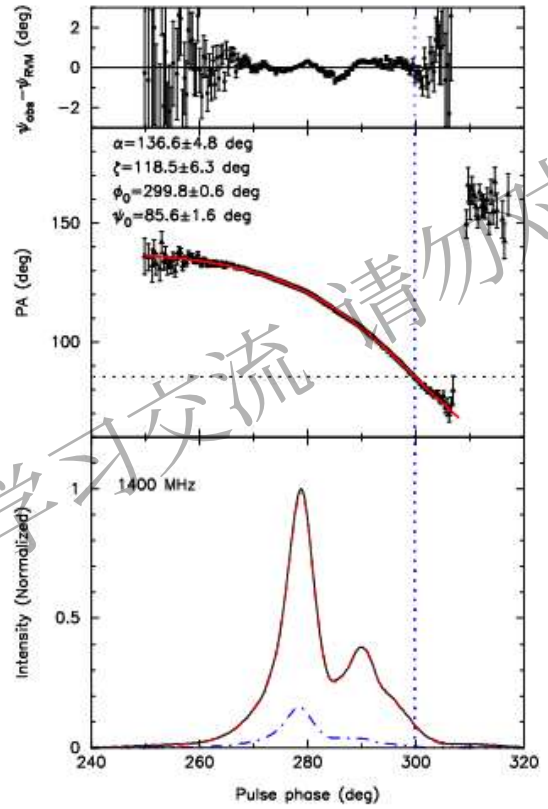
- B0355+54 (NASA Chandra Observatory)

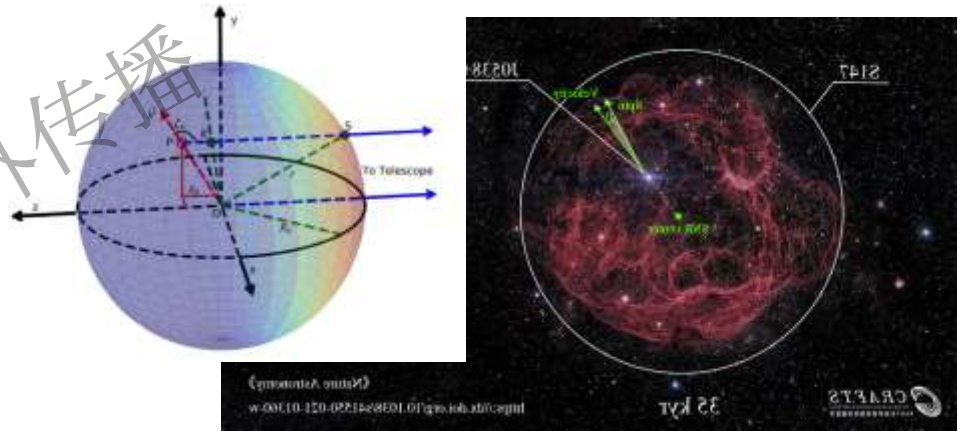
- One of《Science》125 most important scientific problems
- How did pulsars gain its speed?
- Is pulsar kick velocity aligned with its spin?

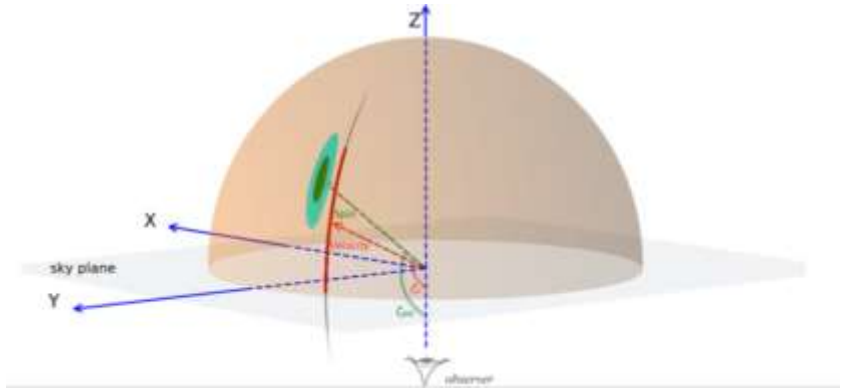
The pulsar birth mystery











Yao J. M.*, Zhu W. W.*, Manchester R. N. et al. 2021 **Nature Astronomy**

Pulsar scintillation reveal high altitude ISM structures

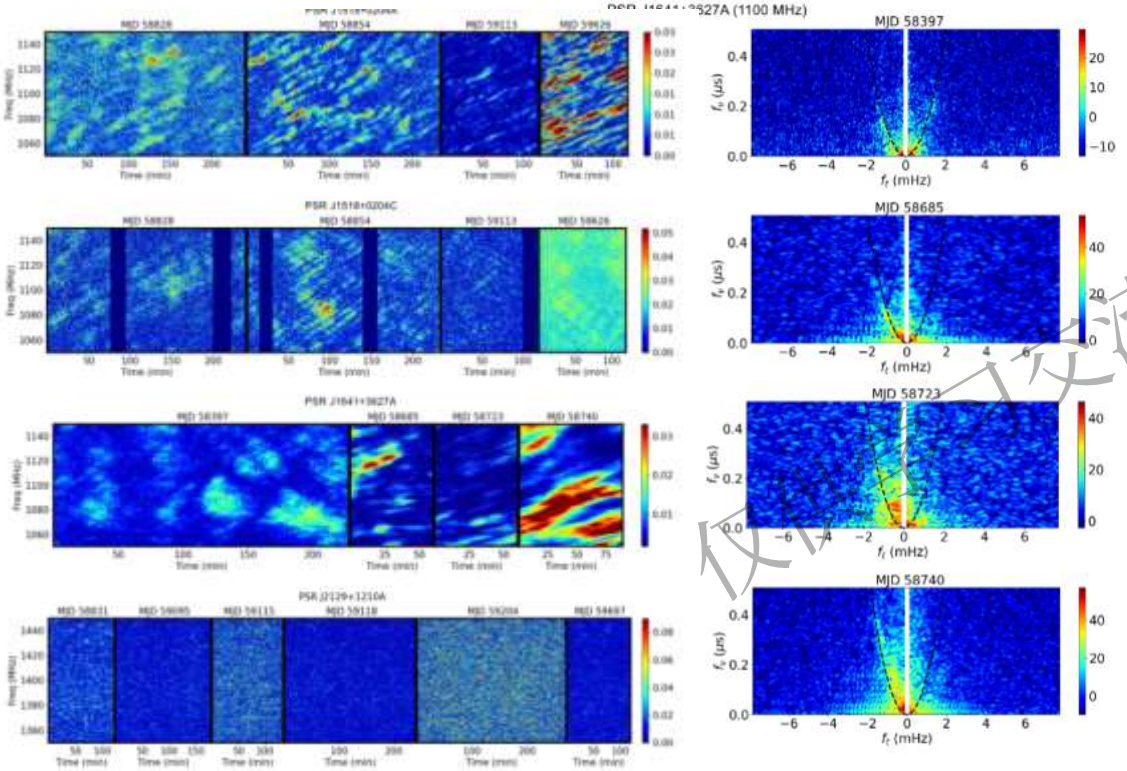
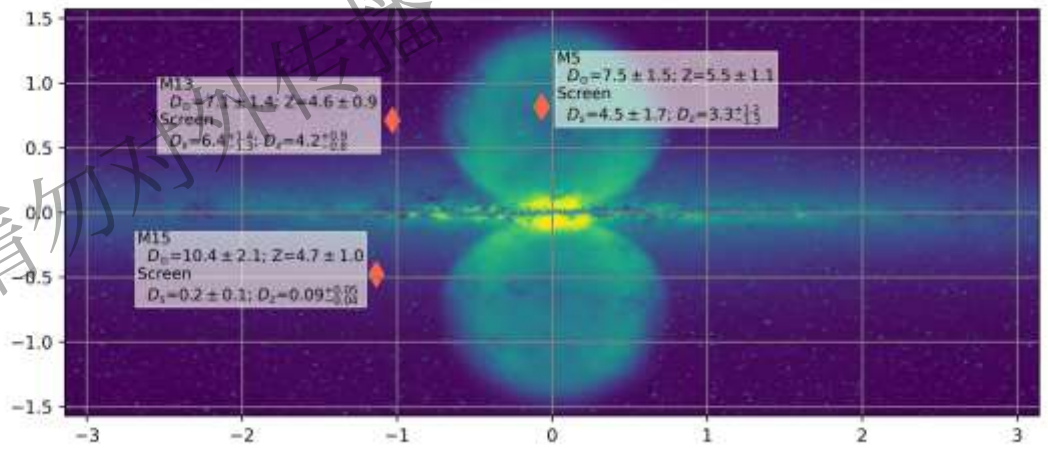
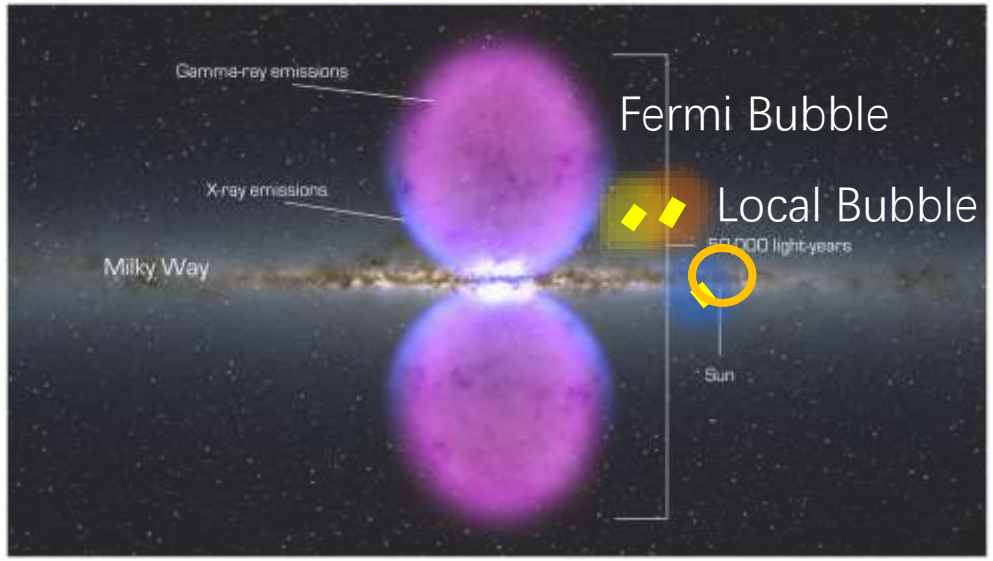


Figure A11 As in FigureA6, results of arc curvature fittings and secondary spectra for PSR J1641+3627A at 1100 MHz.

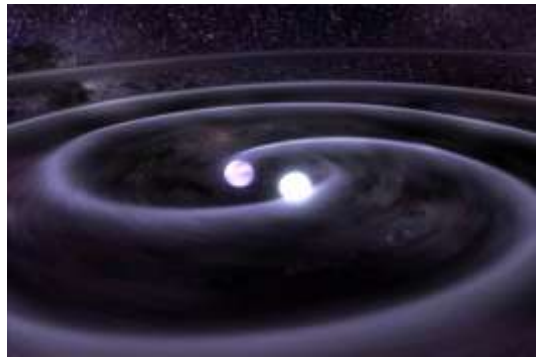


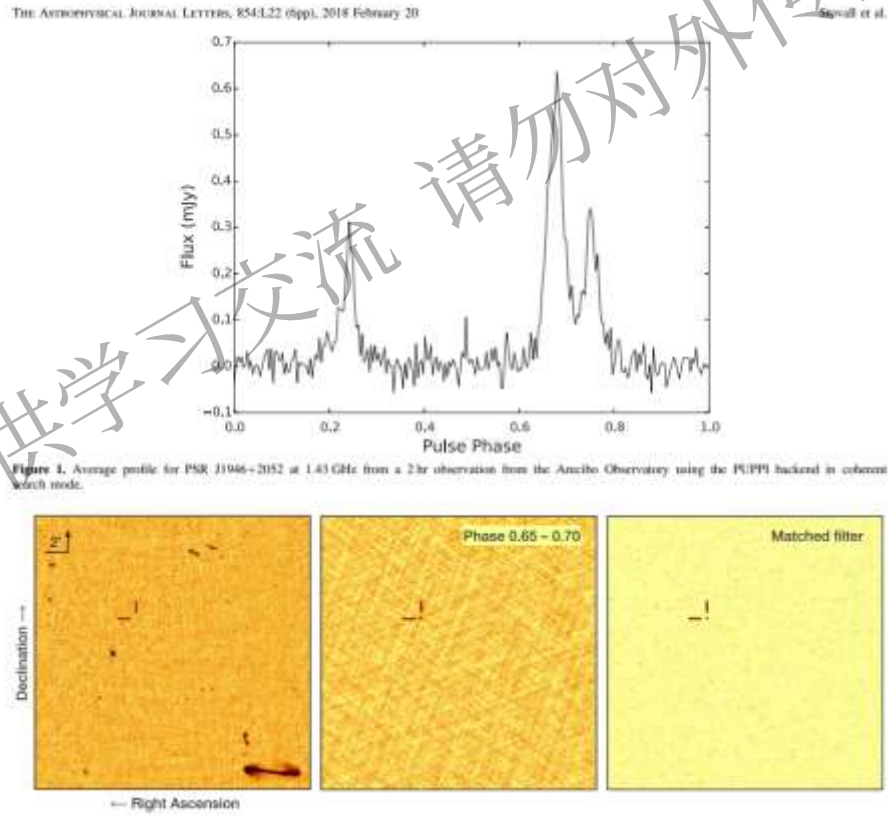


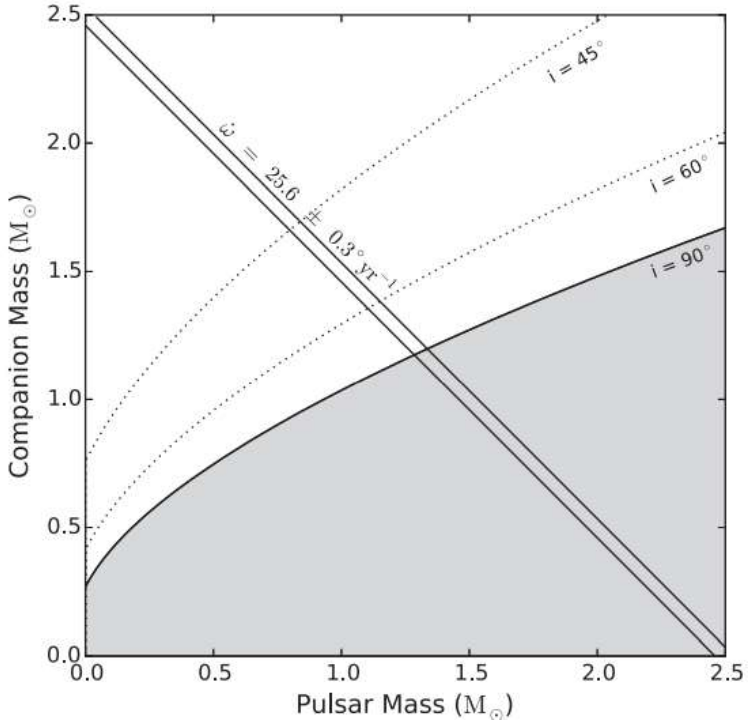
Zhang D. D. et al. submitted

The closest DNS – directly measuring relativistic spin precession

PSR J1946+2052
Closest DNS
Pb=1.8 hr

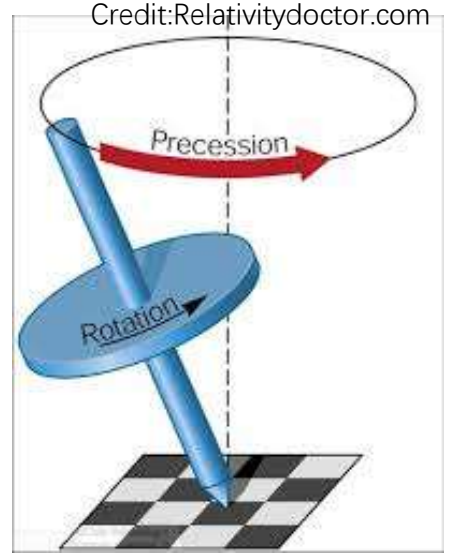


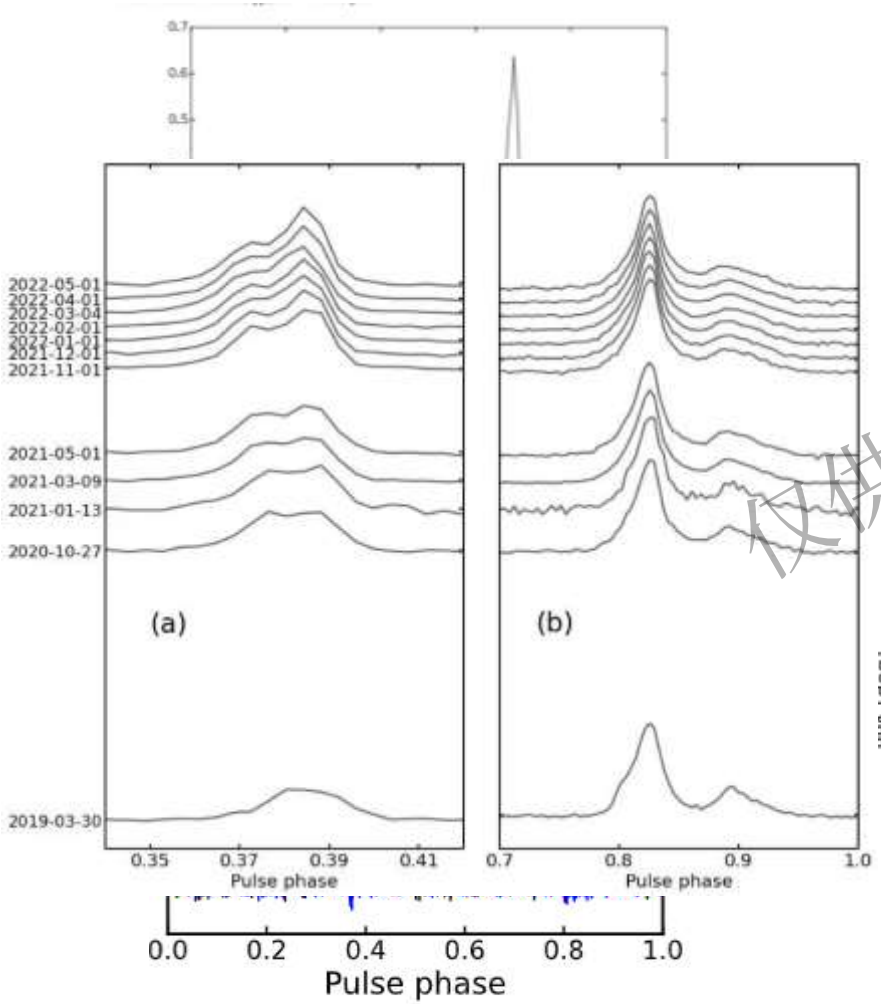


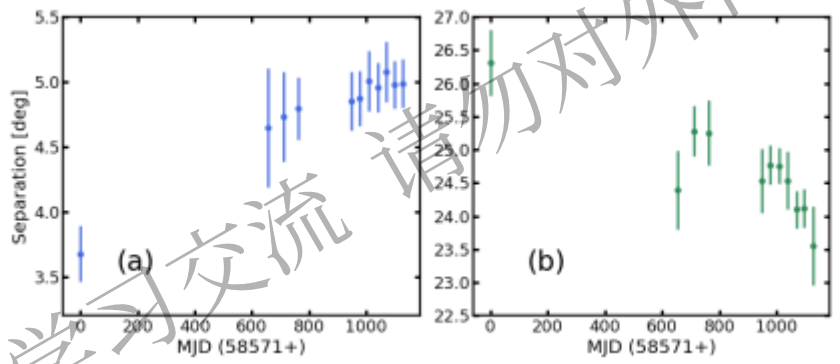


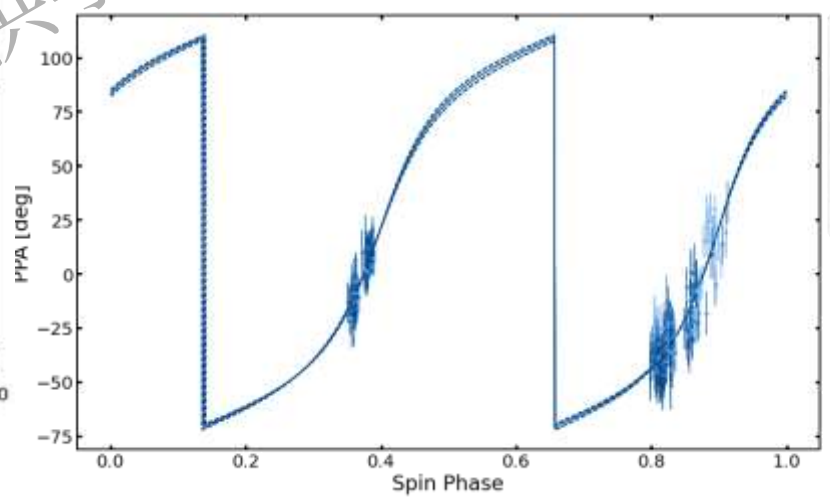
Stovell et al. 2018 ApJ

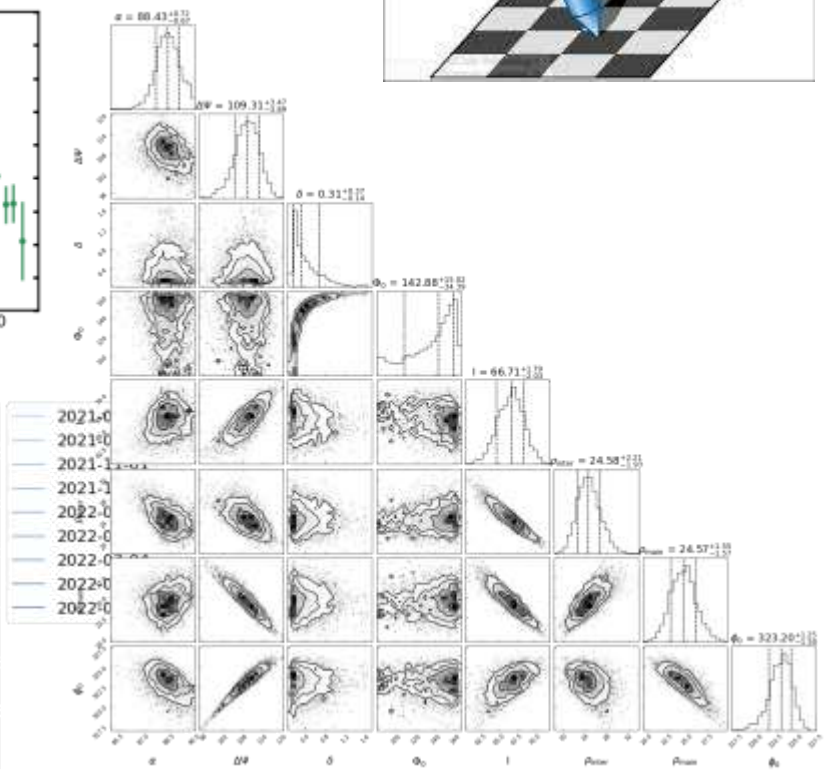
The most compact DNS – relativistic spin precession





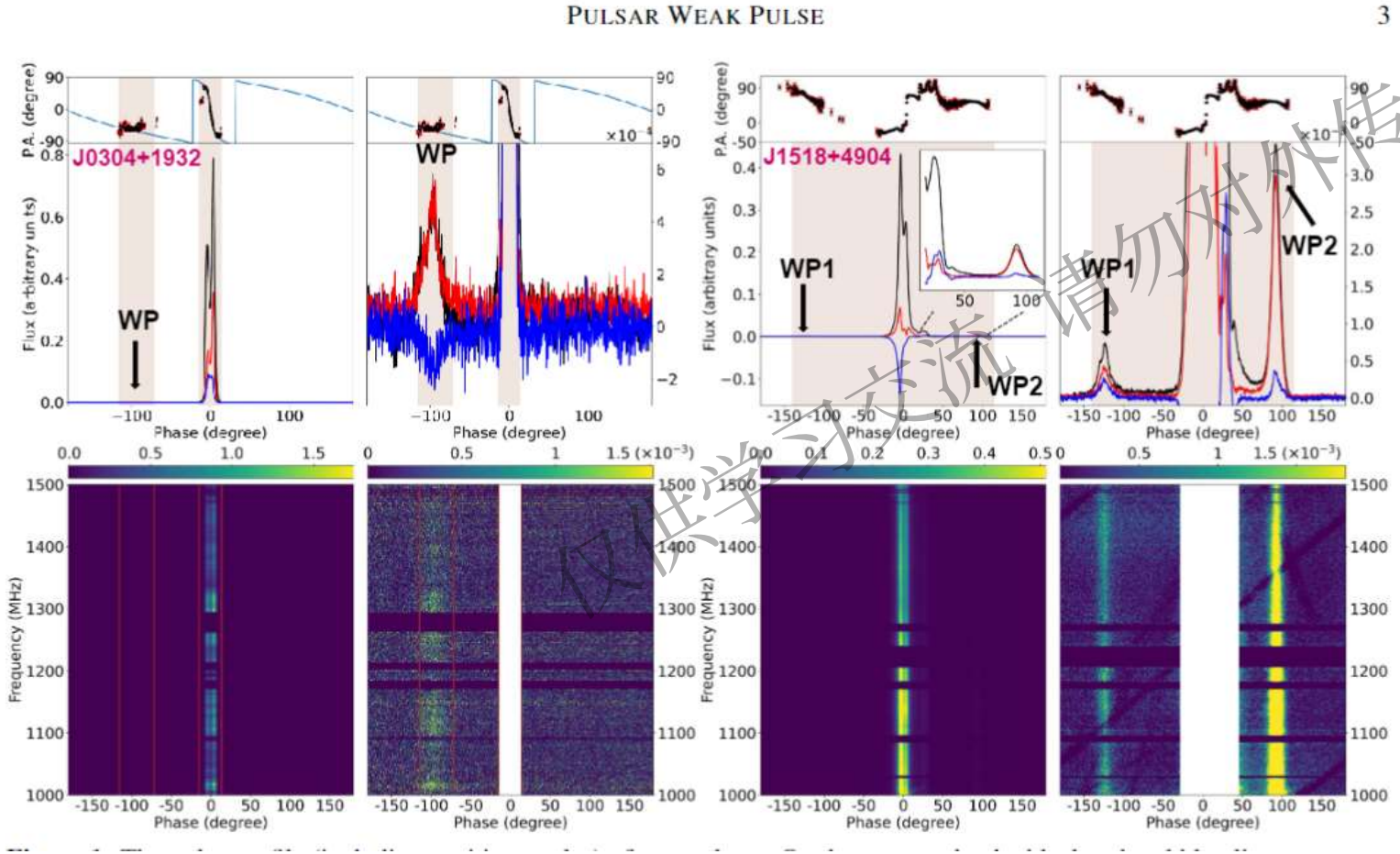


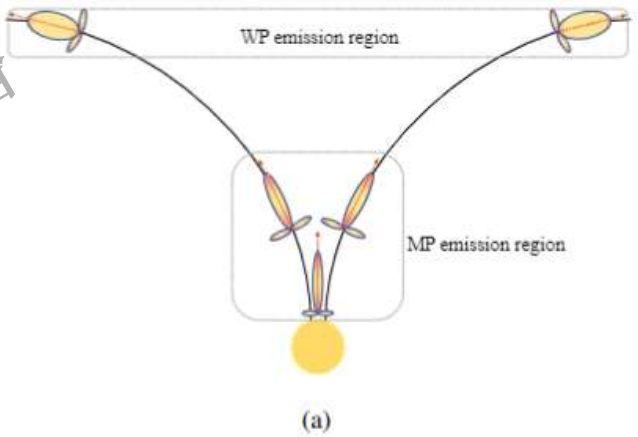


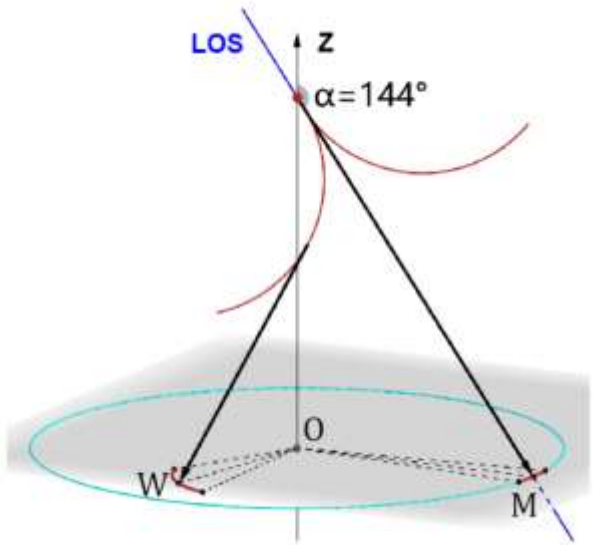


Meng et al. 2022 in prep.

Discover new pulsar emission component -emissions from very high altitudes



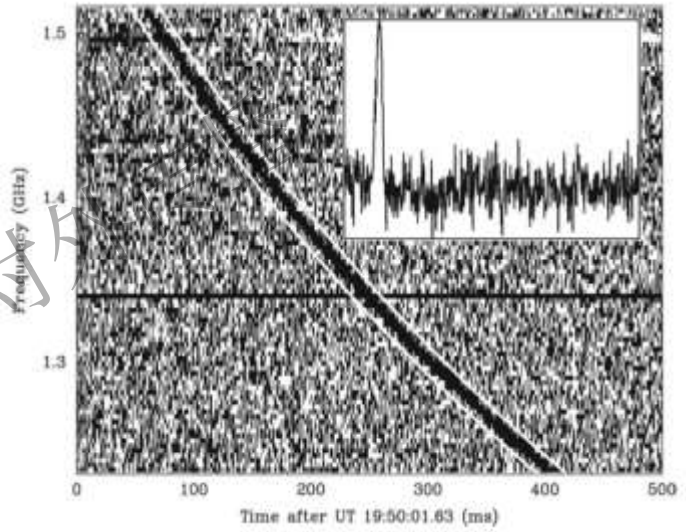




Yuan, Zhu et al. submitted 2023

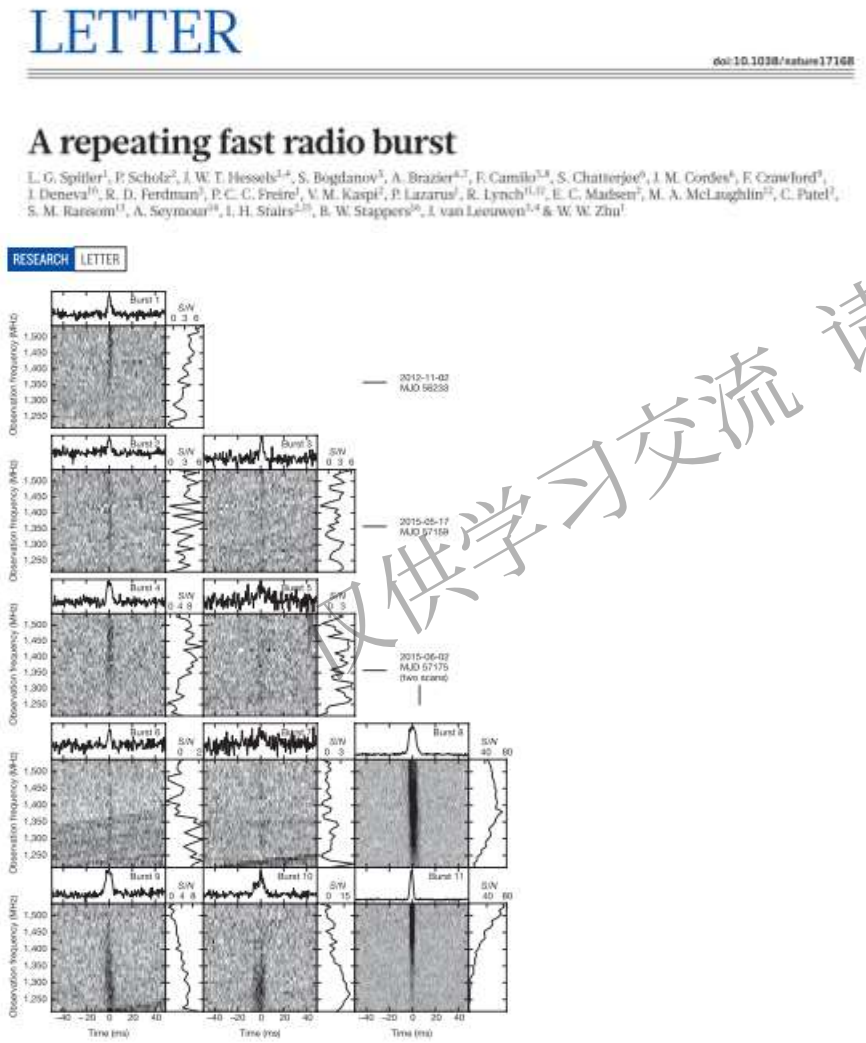
Fast Radio Burst (FRB)

- Initially discovered in A Multi-beam pulsar survey using the **Parkes Observatory**
- Thousands of isolated events + dozens repeaters
- One of the hottest astronomical mysteries today



Lorimer et al. Nature 2007

The Repeater and Arecibo FRBs


LETTER

doi:10.1038/nature17168

A repeating fast radio burst

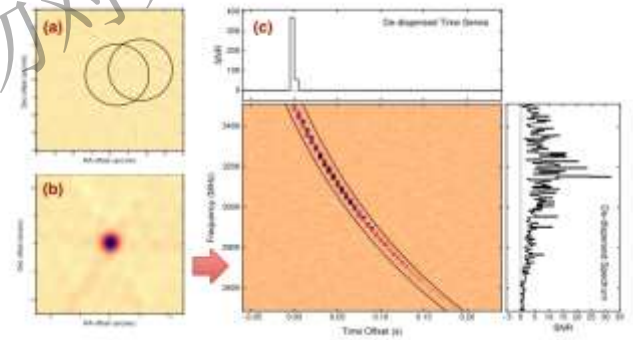
L. G. Spitler[1], P. Scholz[2], J. W. T. Hessels[3,4], S. Bogdanov[5], A. Brazier[6,7], F. Camilo[5,8], S. Chatterjee[6], J. M. Cordes[6], F. Crawford[9], J. Deneva[10], R. D. Ferdman[3], P. C. C. Freire[1], V. M. Kaspi[2], P. Lazarus[1], R. Lynch[11,12], E. C. Madsen[2], M. A. McLaughlin[12], C. Patel[2], S. M. Ransom[13], A. Seymour[14], I. H. Stairs[2,15], B. W. Stappers[16], J. van Leeuwen[3,4] & W. W. Zhu[1]

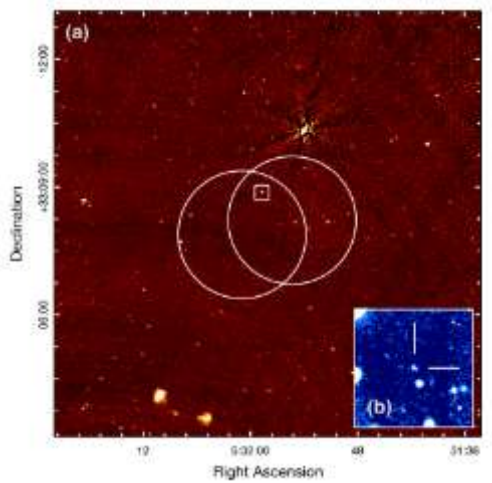
RESEARCH LETTER

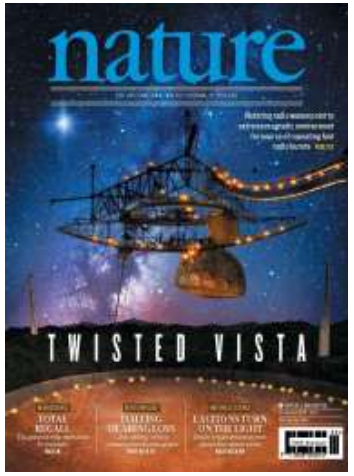
Spitler et al. 2016 Nature

The direct localization of a fast radio burst and its host

S. Chatterjee[1], C. J. Law[2], R. S. Wharton[1], S. Burke-Spolaor[3,4,5], J. W. T. Hessels[6,7], G. C. Bower[8], J. M. Cordes[1], S. P. Tendulkar[9], C. G. Bassa[6], P. Demorest[3], B. J. Butler[3], A. Seymour[10], P. Scholz[11], M. W. Abruzzo[12], S. Bogdanov[13], V. M. Kaspi[9], A. Keimpema[14], T. J. W. Lazio[15], B. Marcote[14], M. A. McLaughlin[4,5], Z. Paragi[14], S. M. Ransom[16], M. Rupen[11], L. G. Spitler[17], & H. J. van Langevelde[14,18]







Chatterjee et al. 2017 Nature

FAST优先和重大项目

科学院建制化科研平台等项目

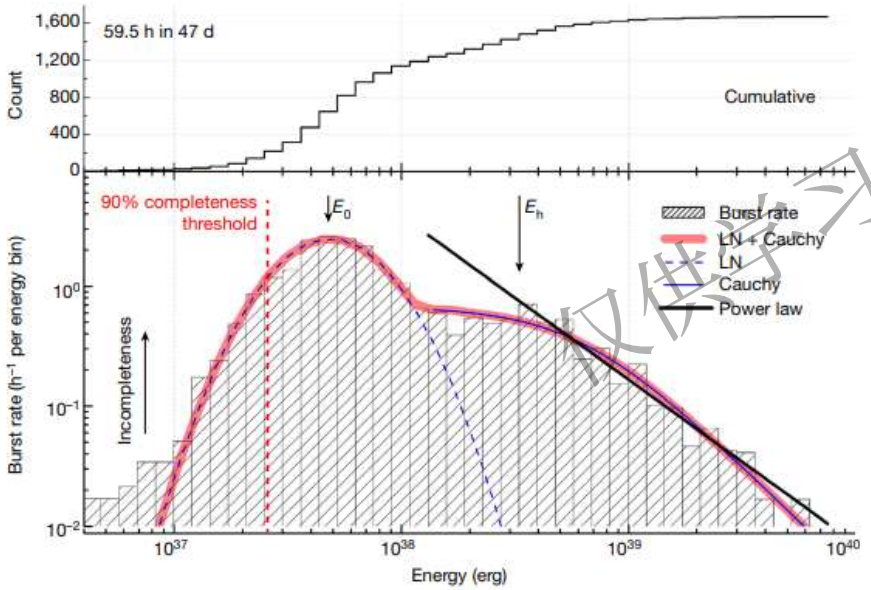
2020-04-11

经FAST科学委员会讨论，决定设立五个优先和重大项目，见下表。

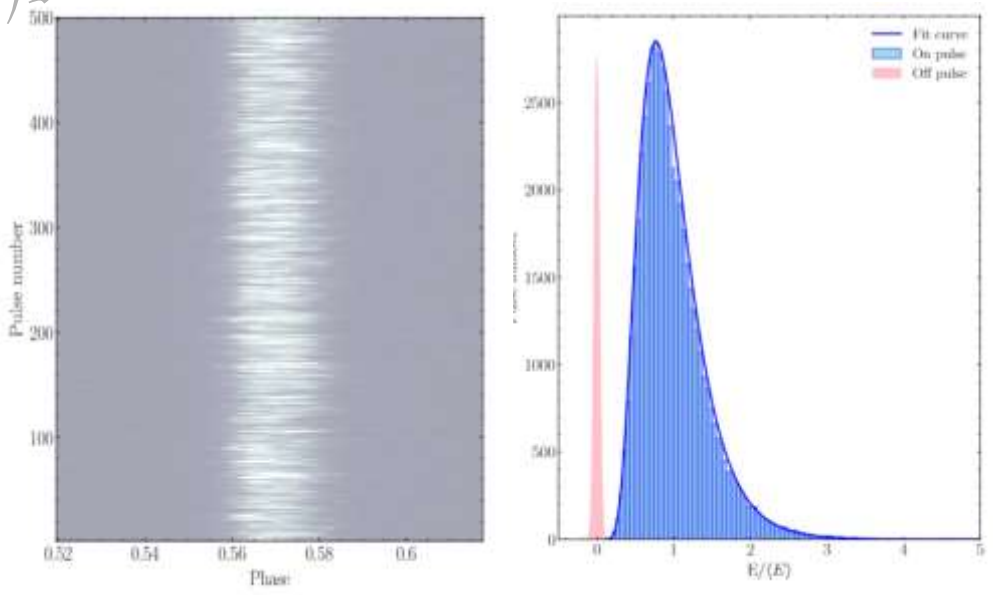
序号	项目名称		项目负责人	联系方式
一	FAST漂移扫描多科学目标同时巡天（CRAFTS）		李菂	dili@nao.cas.cn
二	快速射电暴的搜寻和多波段观测		朱炜玮	zhuww@nao.cas.cn
三	银道面脉冲星巡天			
四	M31中性氢成像与脉冲星搜寻			
五	脉冲星测时	1. 中国脉冲星测时阵列		
		2. 脉冲星物理和演化		

The FAST FRB Key Science Project

- Large sample repeating bursts
- Bi-model energy distribution



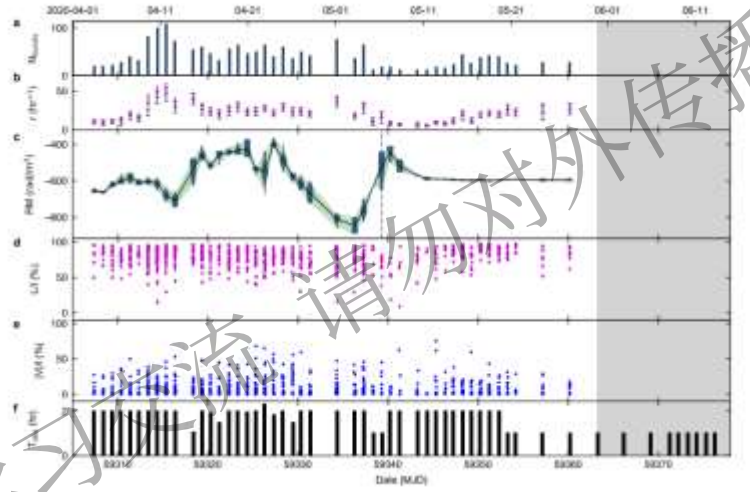
A bimodal burst energy distribution for FRB121102
Li D., Wang P., Zhu W. W. et al. **Nature** 2021

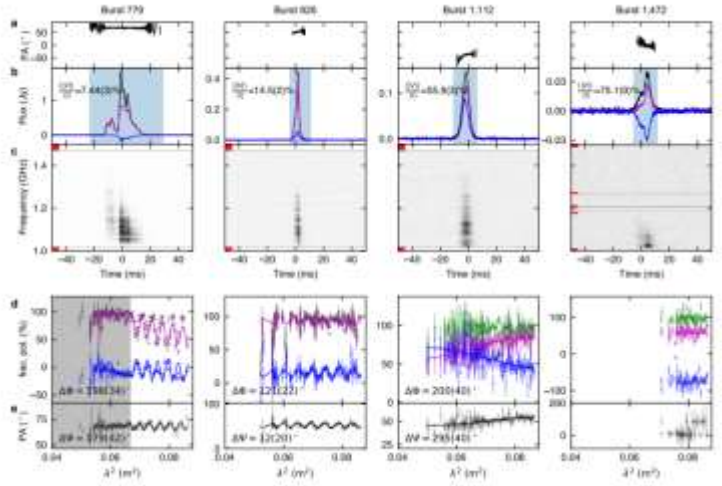


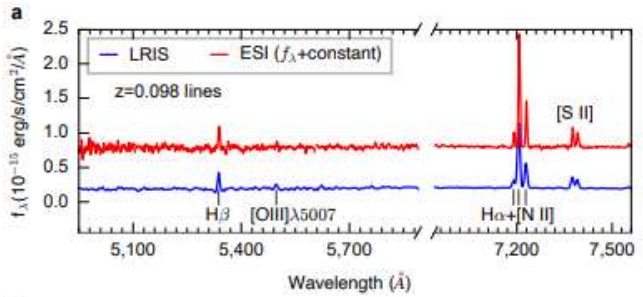
Single pulse energy distribution of J2222-0137
Miao X. L. Zhu W. W. et al. in prep.

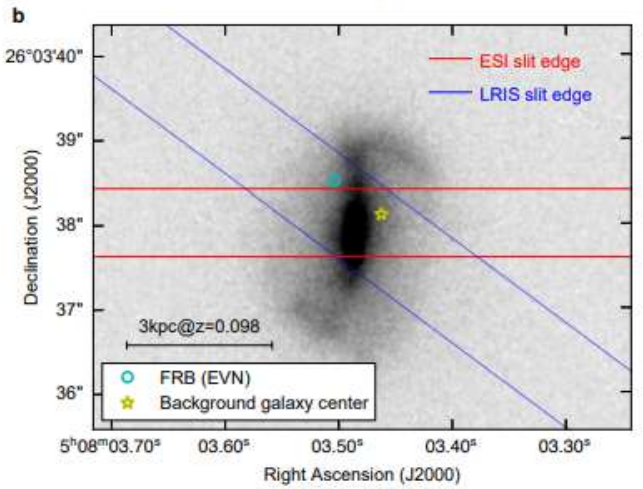
The FAST FRB Key Science Project

- FRB20201124A
- Largest RFRB Polarization sample
- Strong Faraday Rotation variation
- Magnetic environment ~AU from the source
- Optical observation of the host





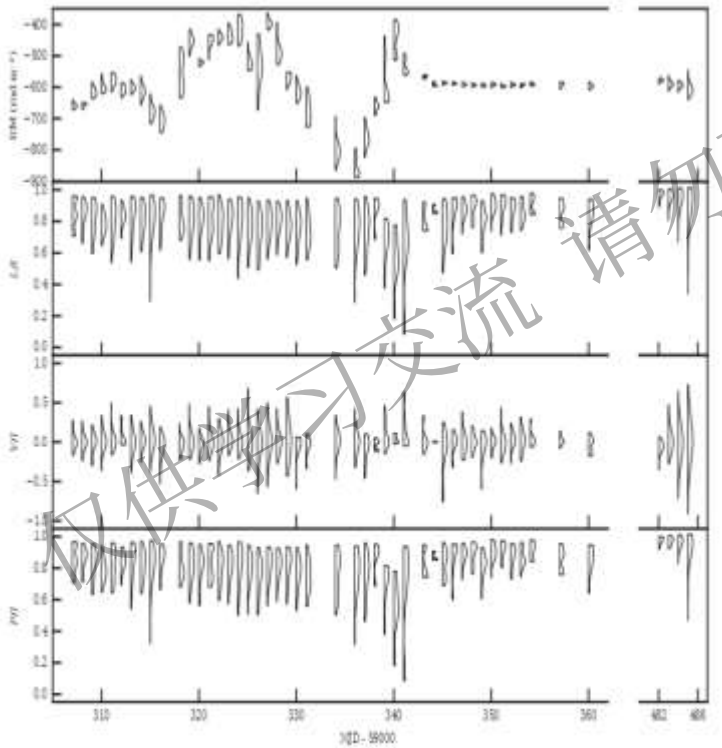




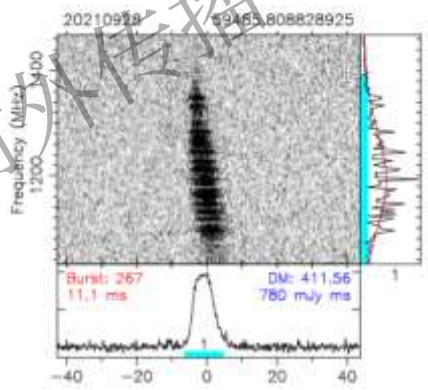
Xu et al. 2022 Nature

The FAST FRB Key Science Project

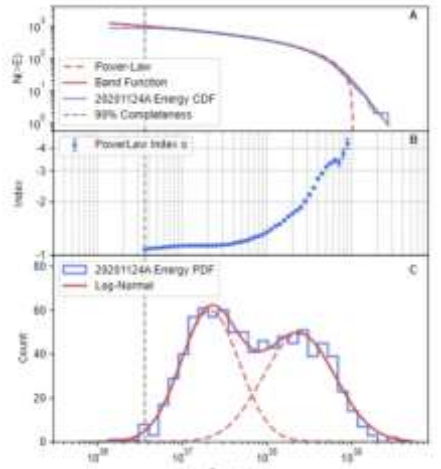
- FRB20201124A
  2021.09
- 4 papers series
  - Energy distribution
  - Burst Morphology
  - Polarization
  - Spin period search



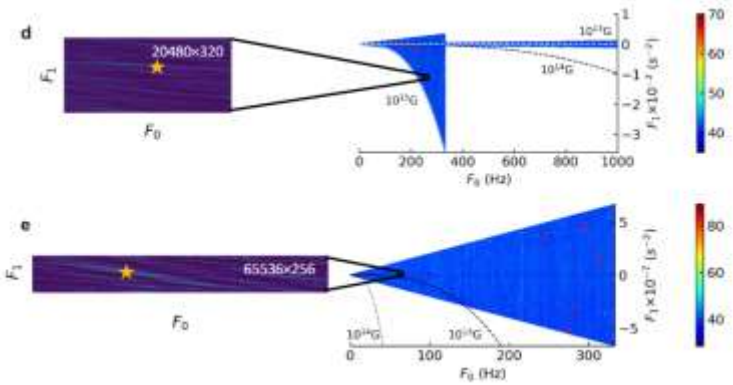
Jiang J. C. et al. 2022 RAA in press



Zhou D. J. et al. 2022 RAA



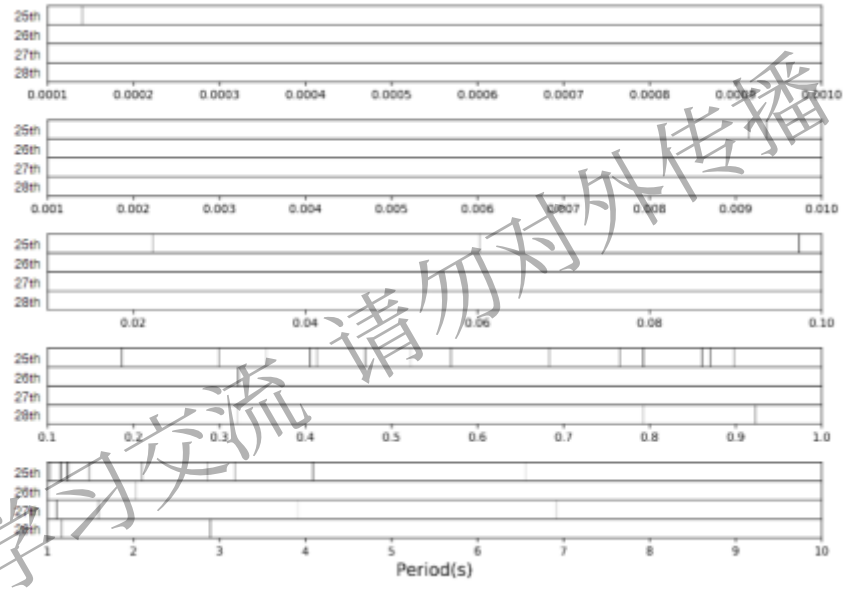
Zhang Y. K. 2022 RAA



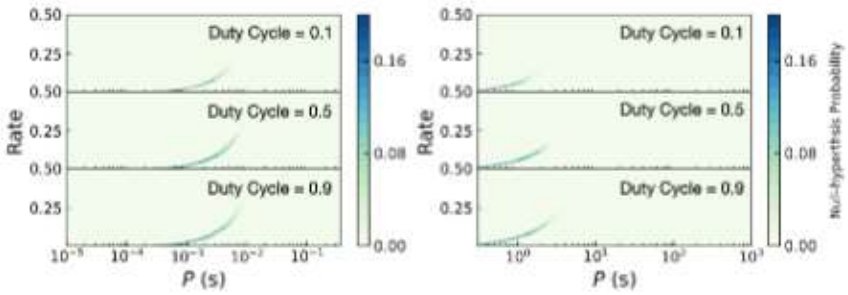
Niu J. R. et al. 2022 RAA

The FAST FRB Key Science Project

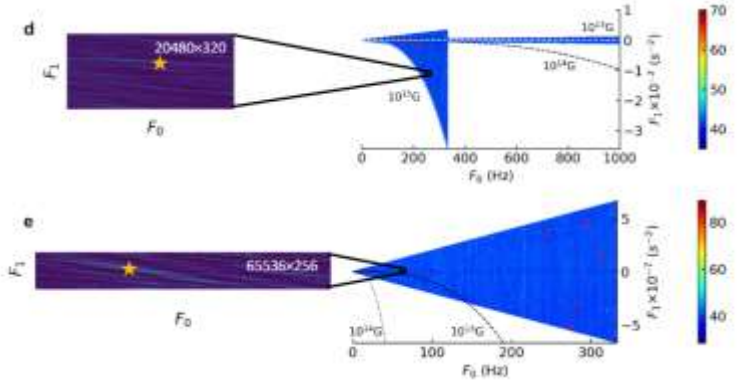
- FRB20201124A in one of its most active episode
- Highest burst rate **~400 bursts/hr**
- **P-Pdot search – Null result**
- Burst fine structure study



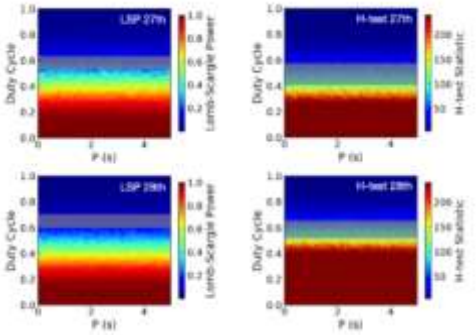
Compare Lomb-Scargle Periodogram from 4 days



Ranges of possible period



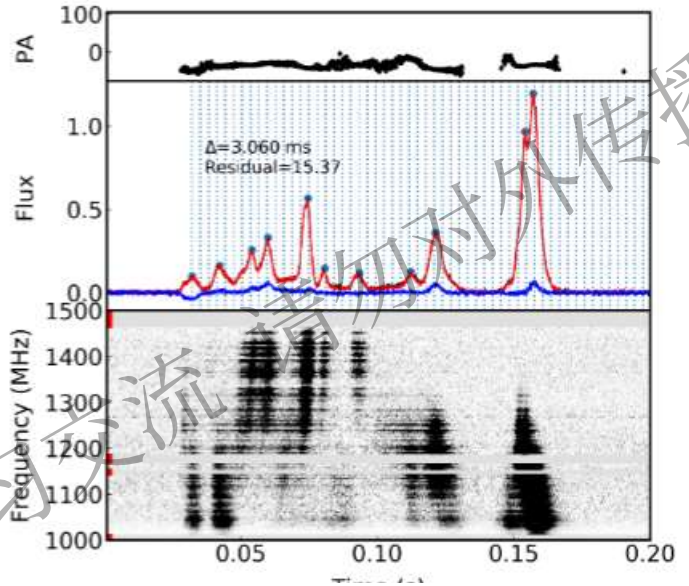
P-Pdot search for a large range
Cover B up to 10^{15} G
And a large range of binaries

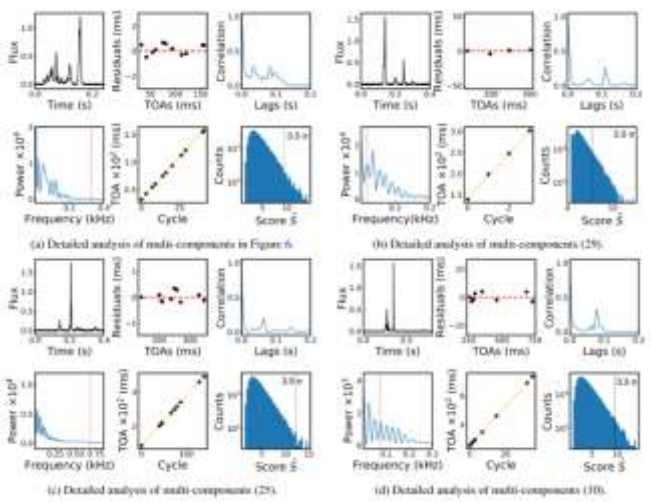


Niu J. R. et al. 2022 RAA

The FAST FRB Key Science Project

- FRB20201124A in one of its most active episode
- Highest burst rate ~400 bursts/hr
- P-Pdot search – Null result
- **Burst fine structure study**
- **Random 3.9σ period of few ms ✗**





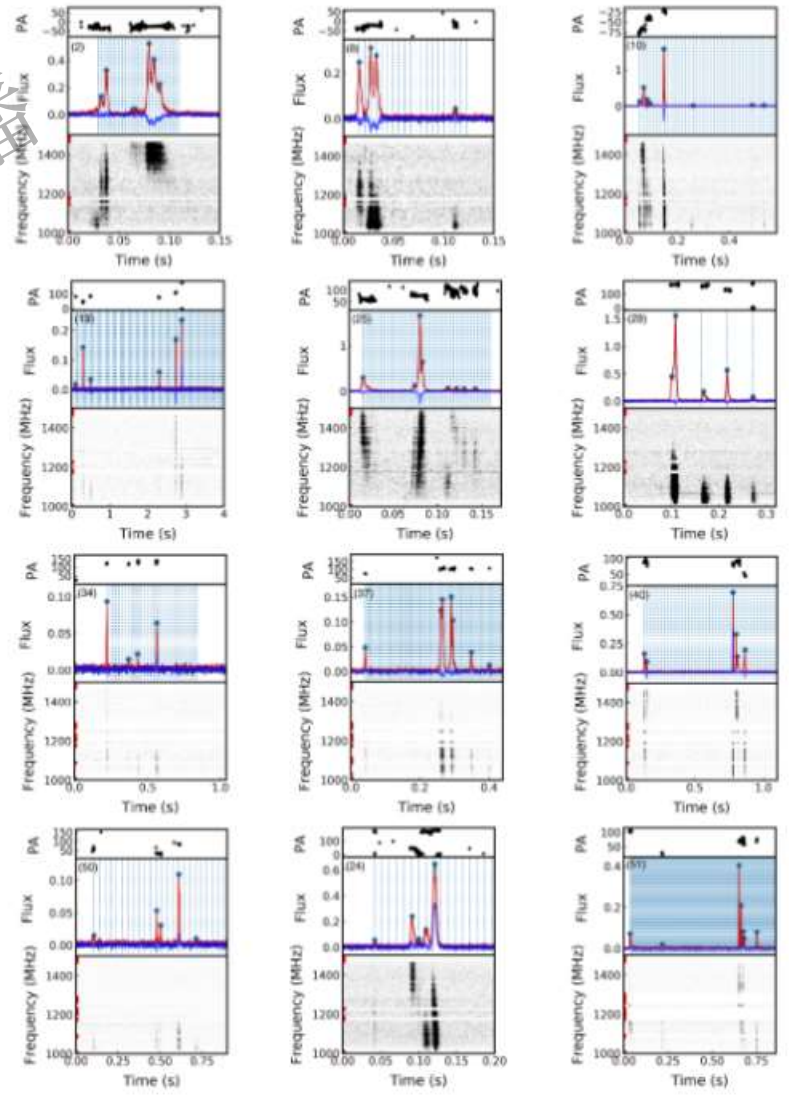
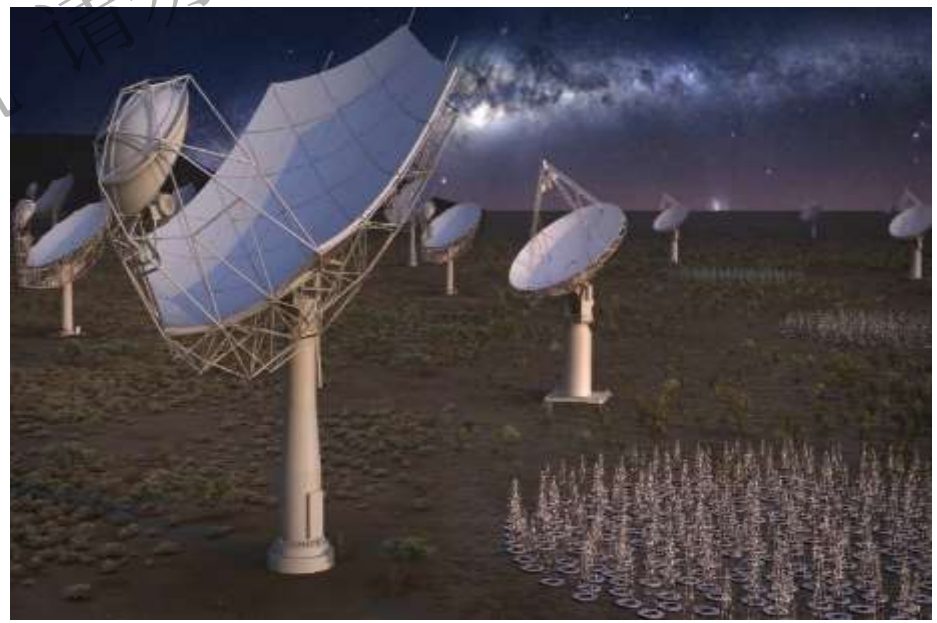


Fig. 15: Examples of multi-components.

Niu J. R. et al. 2022 RAA

Future Prospects

- 科技部SKA专项“SKA脉冲星搜寻预研”项目（2021-2025）项目启动




Thank You
We are looking forward to more collaborations