中国科学院国家天文台
NATIONAL ASTRONOMICAL OBSERVATORIES, CAS

FAST 快速射电暴优先及重大项目
FAST Fast Radio Burst (FRB) Key Science Project

# FRB 20201124A的周期分析与偏振位置角跳变

## Period search and polarization position Angle jump of FRB 20201124A

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**FAST/Future Pulsar Symposium 13**

**Yunnan**

**2024.07.15**

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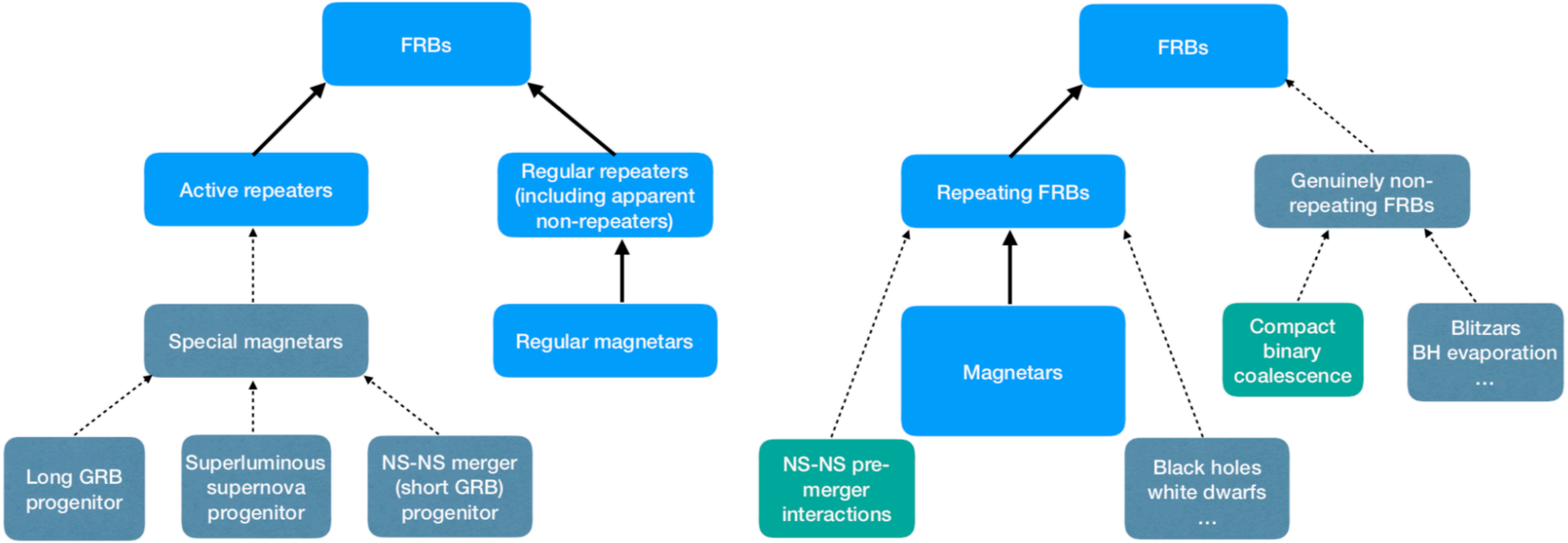
# Possible origins of FRBs

Bing Zhang, Nature 2020



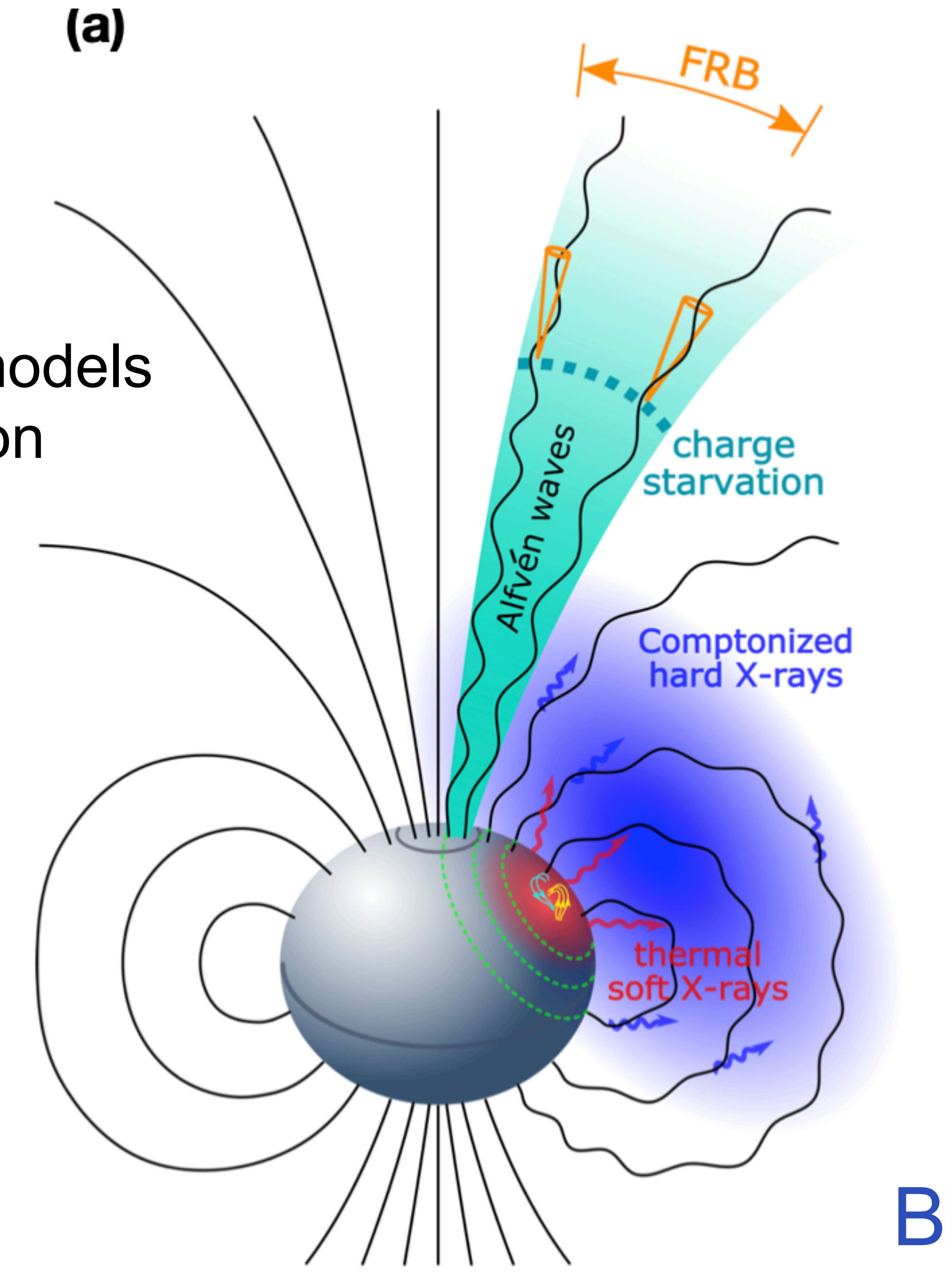

light blue boxes—observational facts grey boxes —speculations green boxes —multi-messenger connections

**The magnetar path is clearly the only channel that can produce FRBs at present**

# Radiation mechanisms

## Pulsar-like models
Radiation in the magnetosphere

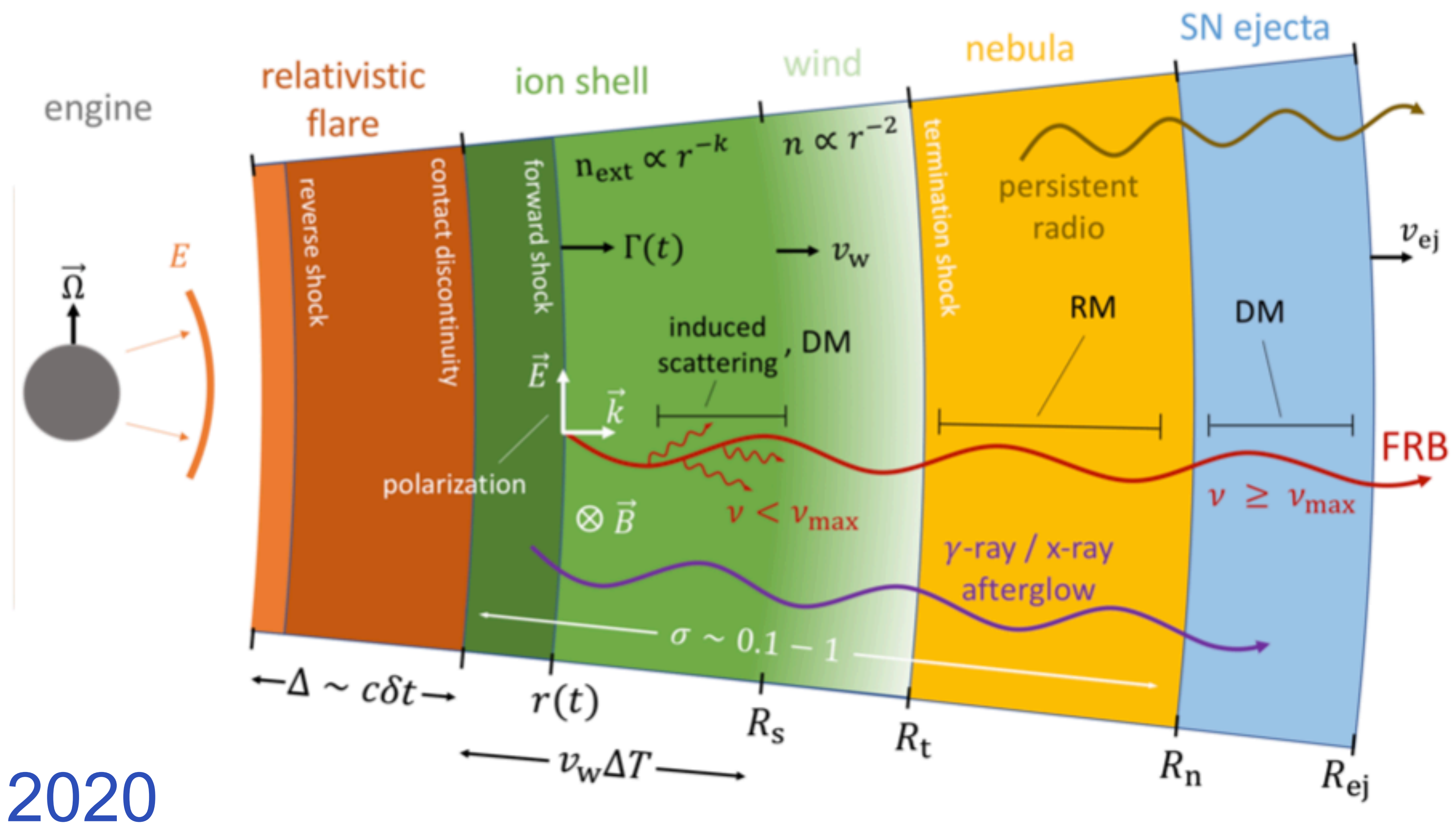
plasma maser models
coherent radiation




Bing Zhang, Nature 2020

## GRB-like models
Relativistic shocks outside the magnetosphere

Relativistic shock waves of vacuum maser radiation




- Swing of the polarization angle（Luo et al，2020）
- Highly circular polarization（Hilmarsson et al，2021；Xu et al，2022）
- Isolated burst time intervals in a single source are as short as milliseconds（Li et al，2021b）

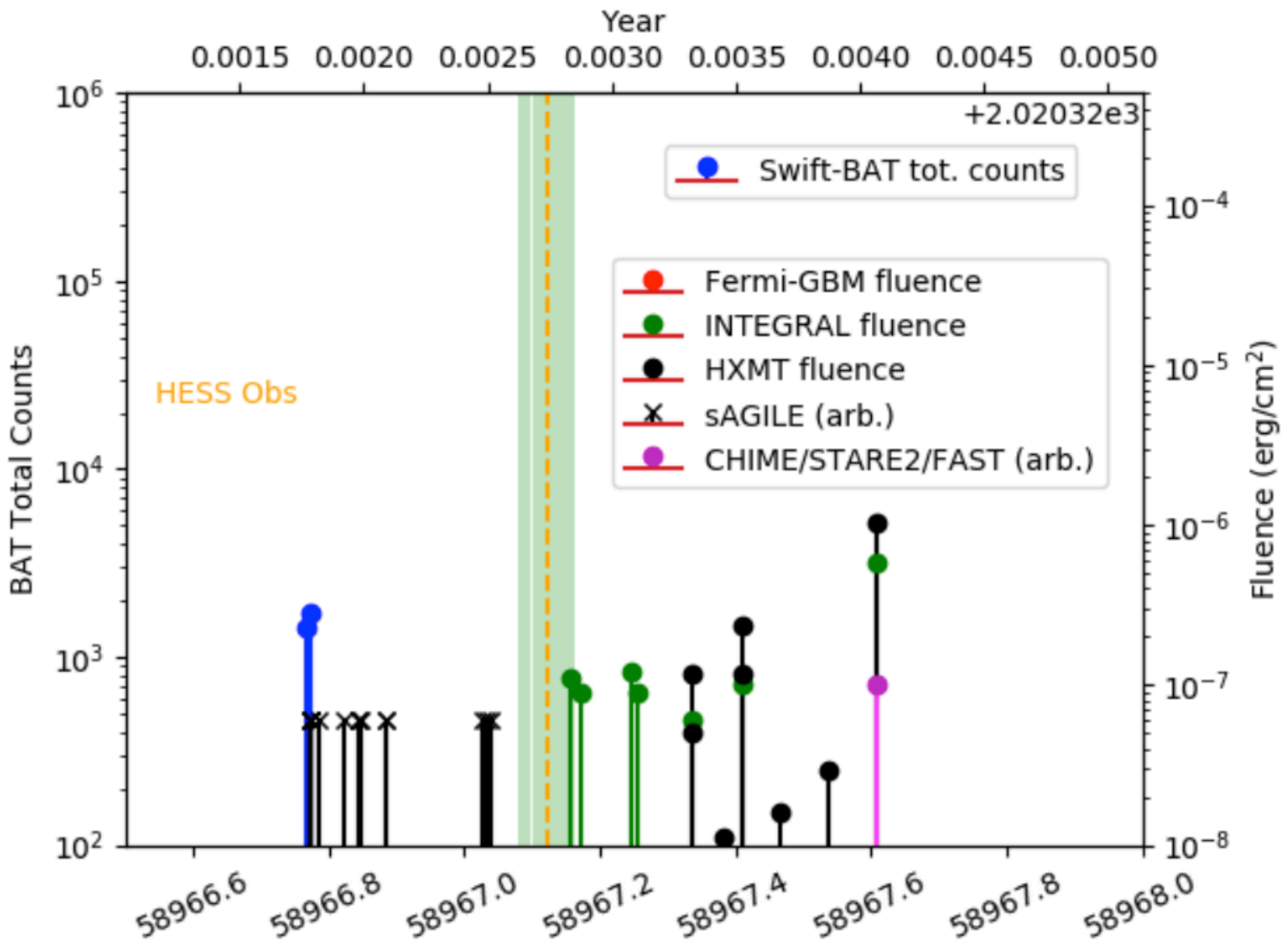
Beloborodov（2021）：

- The cross section of electron scattering waves is very large.

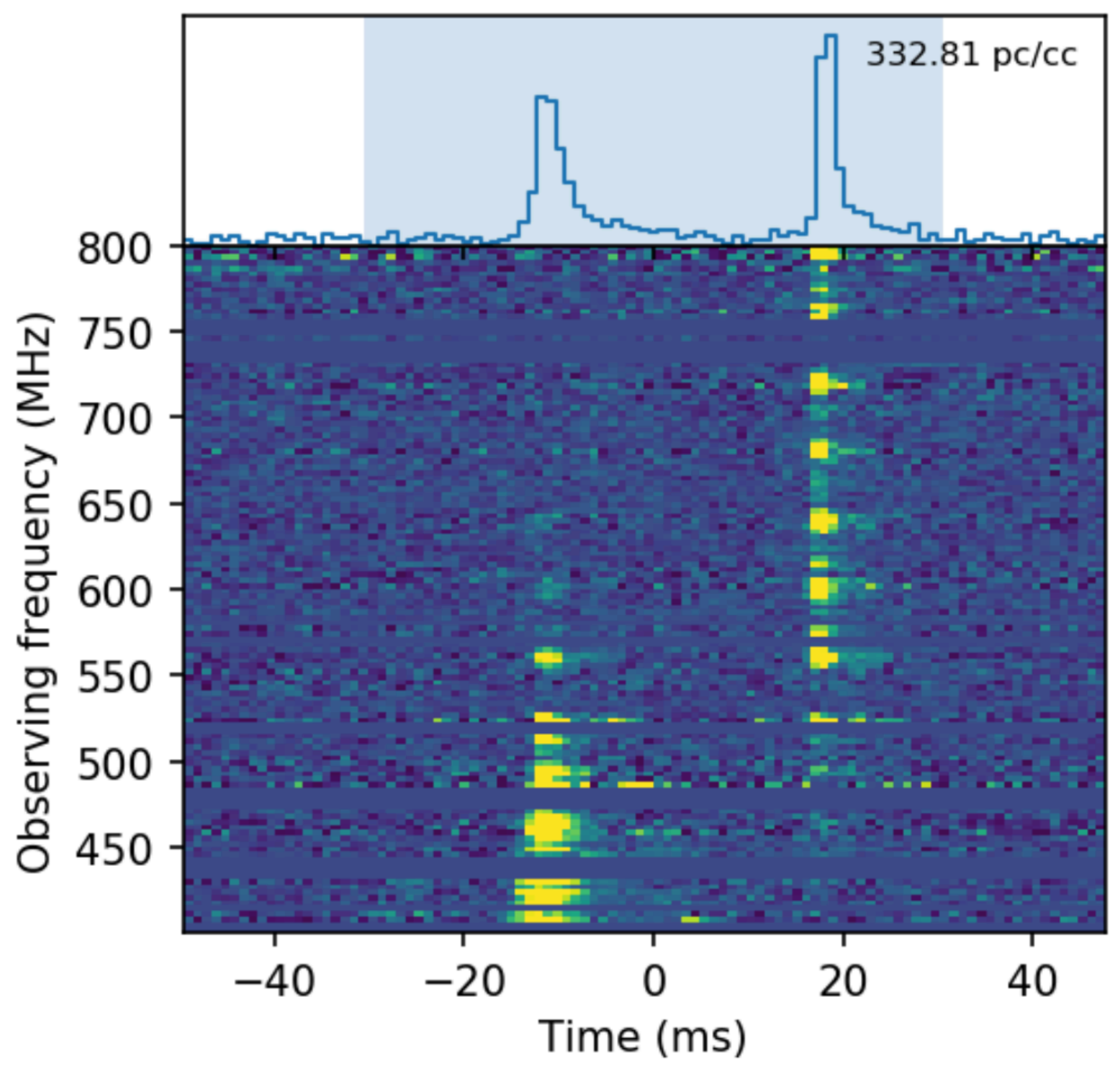
# Possible origins of FRBs

## SGR 1935+2154 and FRB 200428

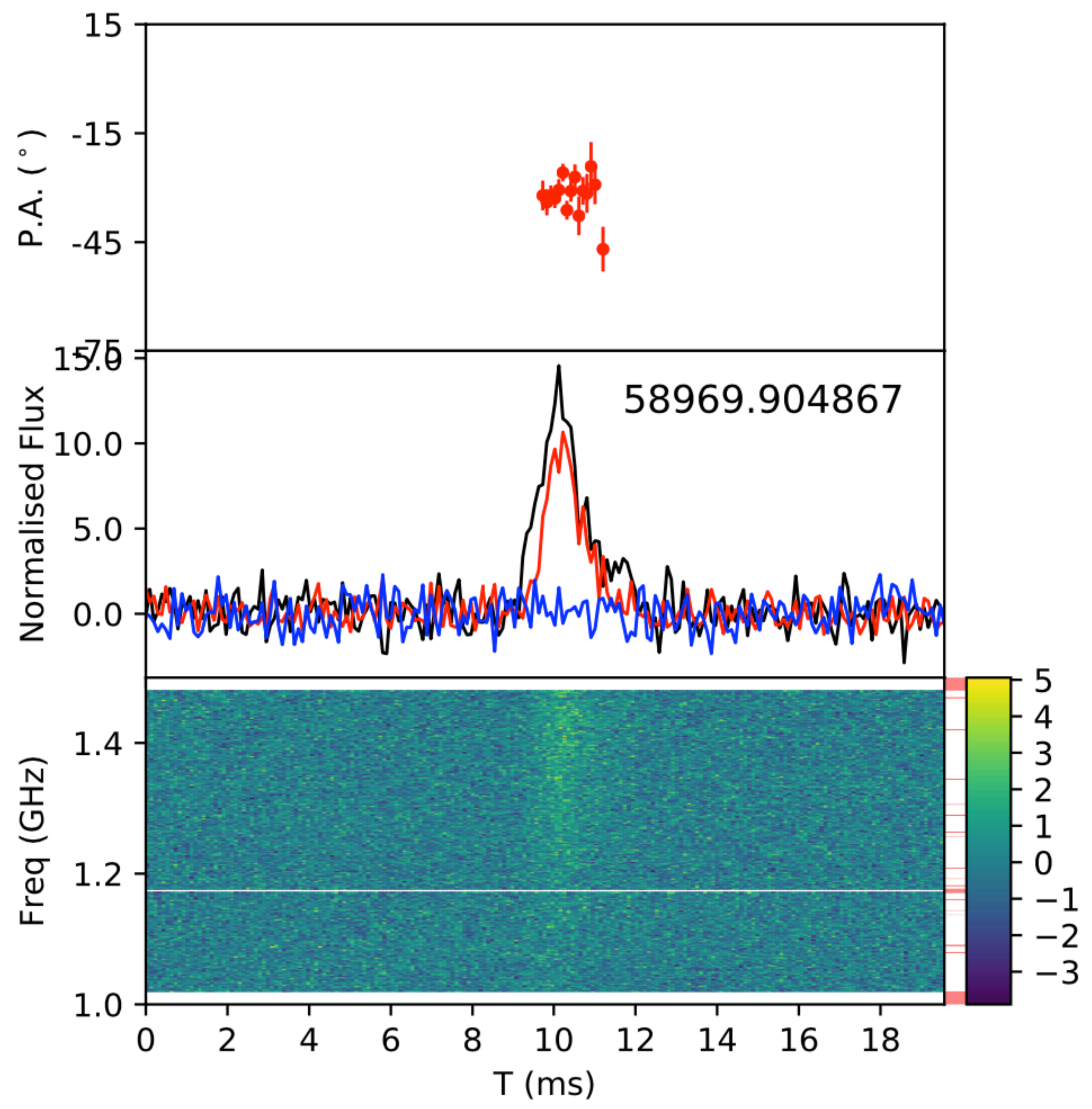
Magnetars are highly magnetized neutron stars with surface magnetic fields $10^{15}$ Gauss gamma-ray bursts, superluminous supernovae, and the merger of neutron star-neutron star binaries may produce rapidly rotating magnetars.




https://www.mpi-hd.mpg.de/HESS



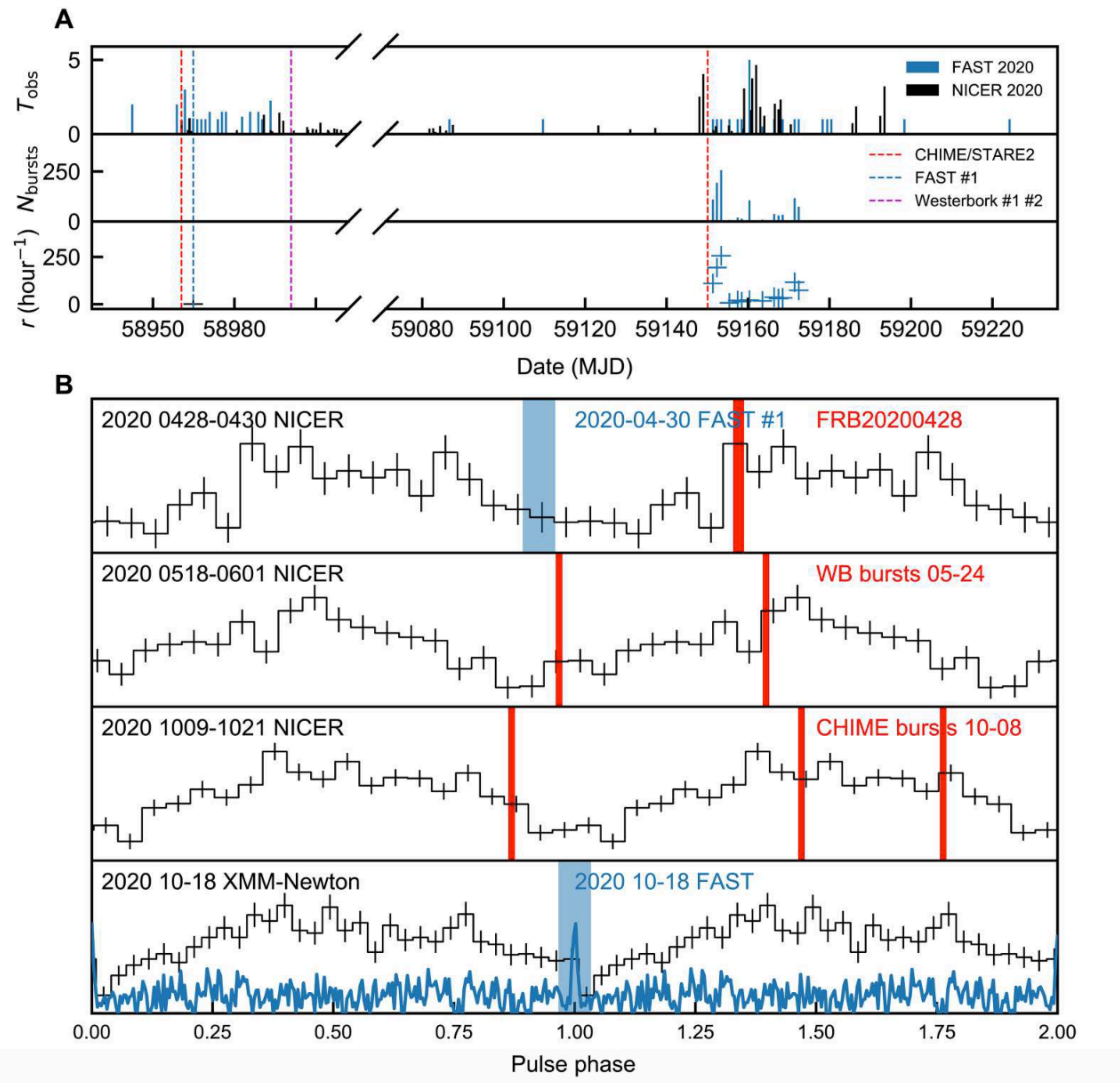

CHIME/FRB Collab. 2020



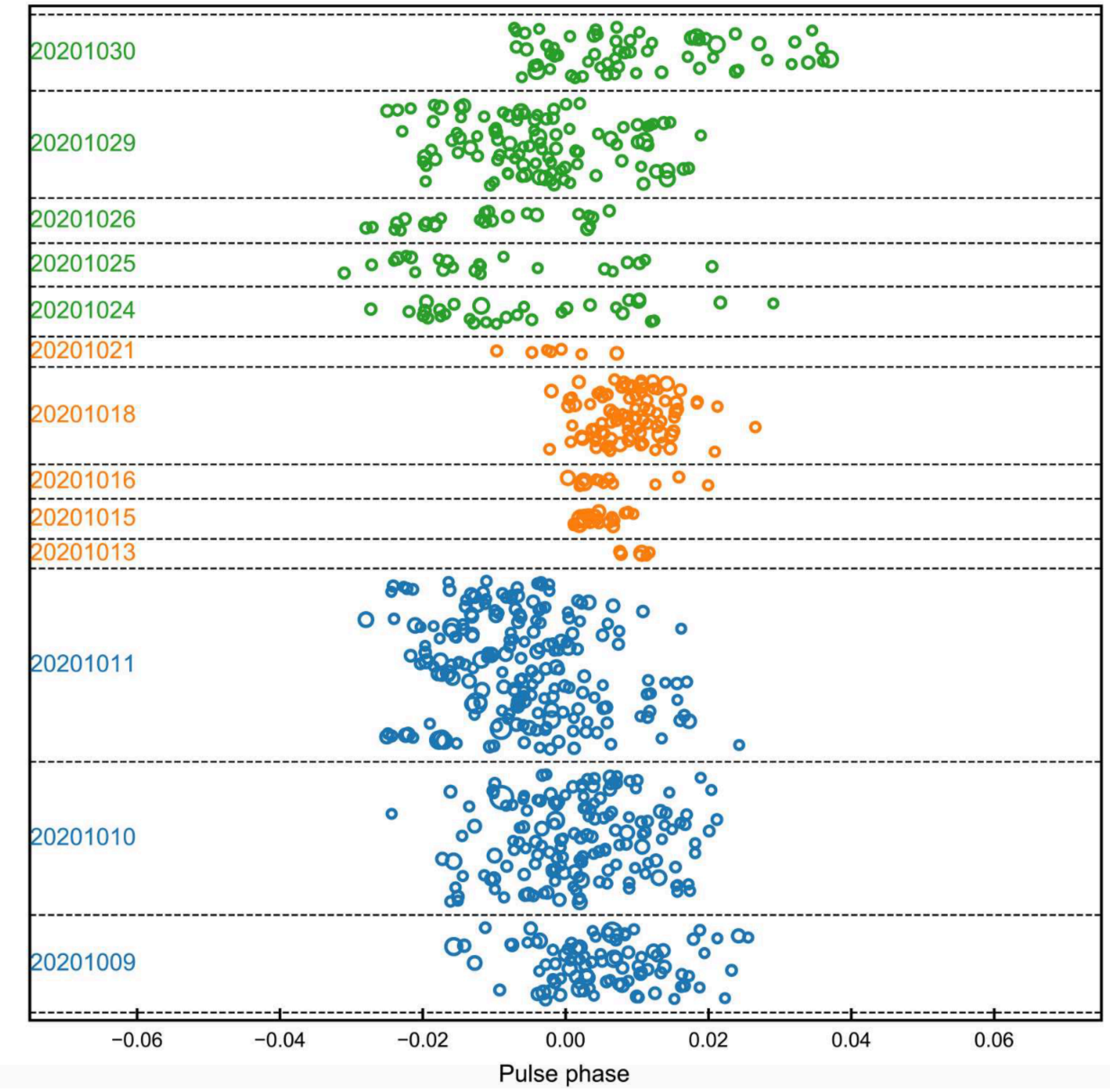

Atel.13699 FAST 2020

# Possible origins of FRBs

SGR 1935+2154 and FRB 200428

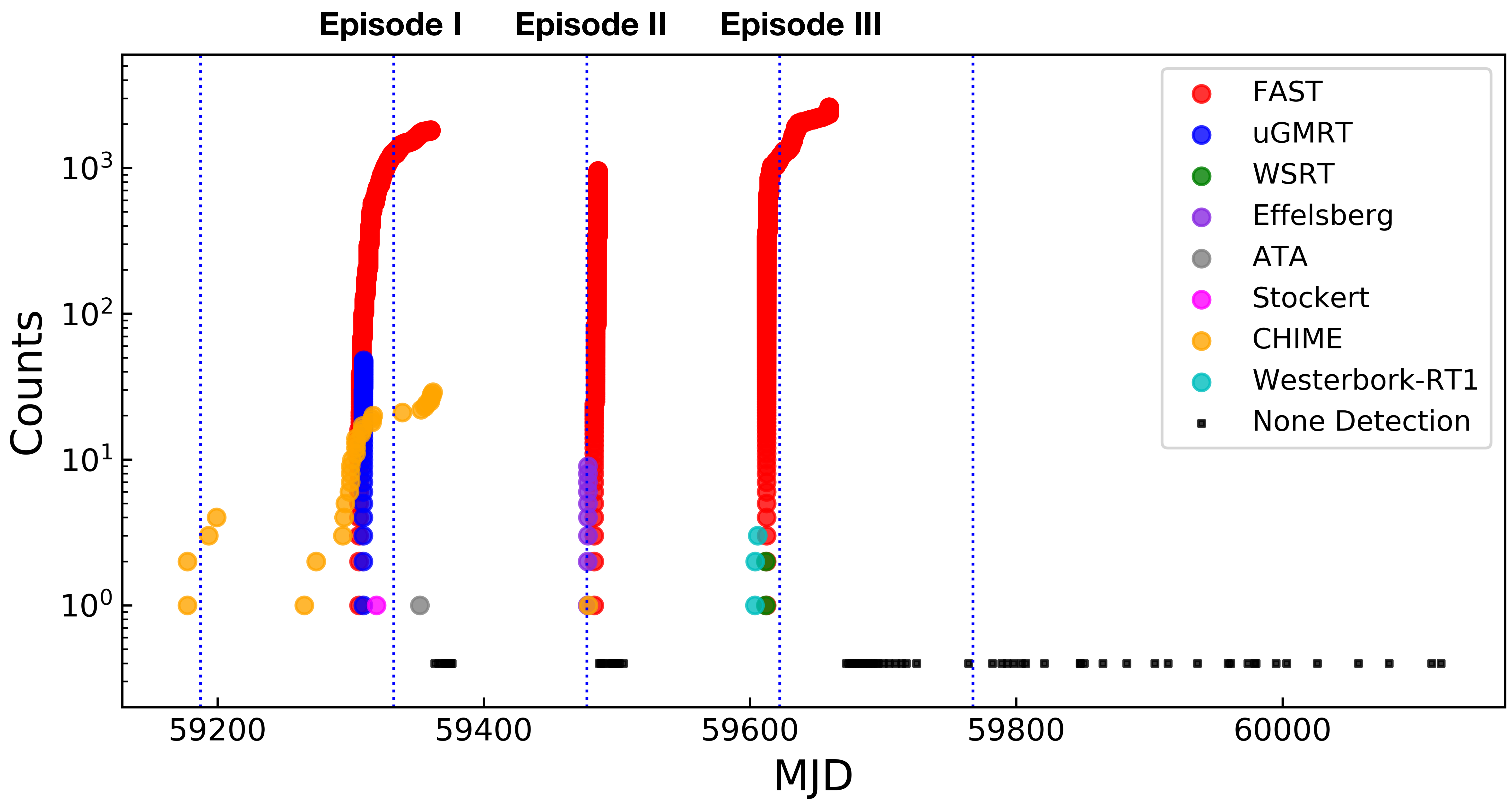



Weiwei Zhu, et al 2023




Weiwei Zhu, et al 2023

# FAST Observation of FRB 20201124A



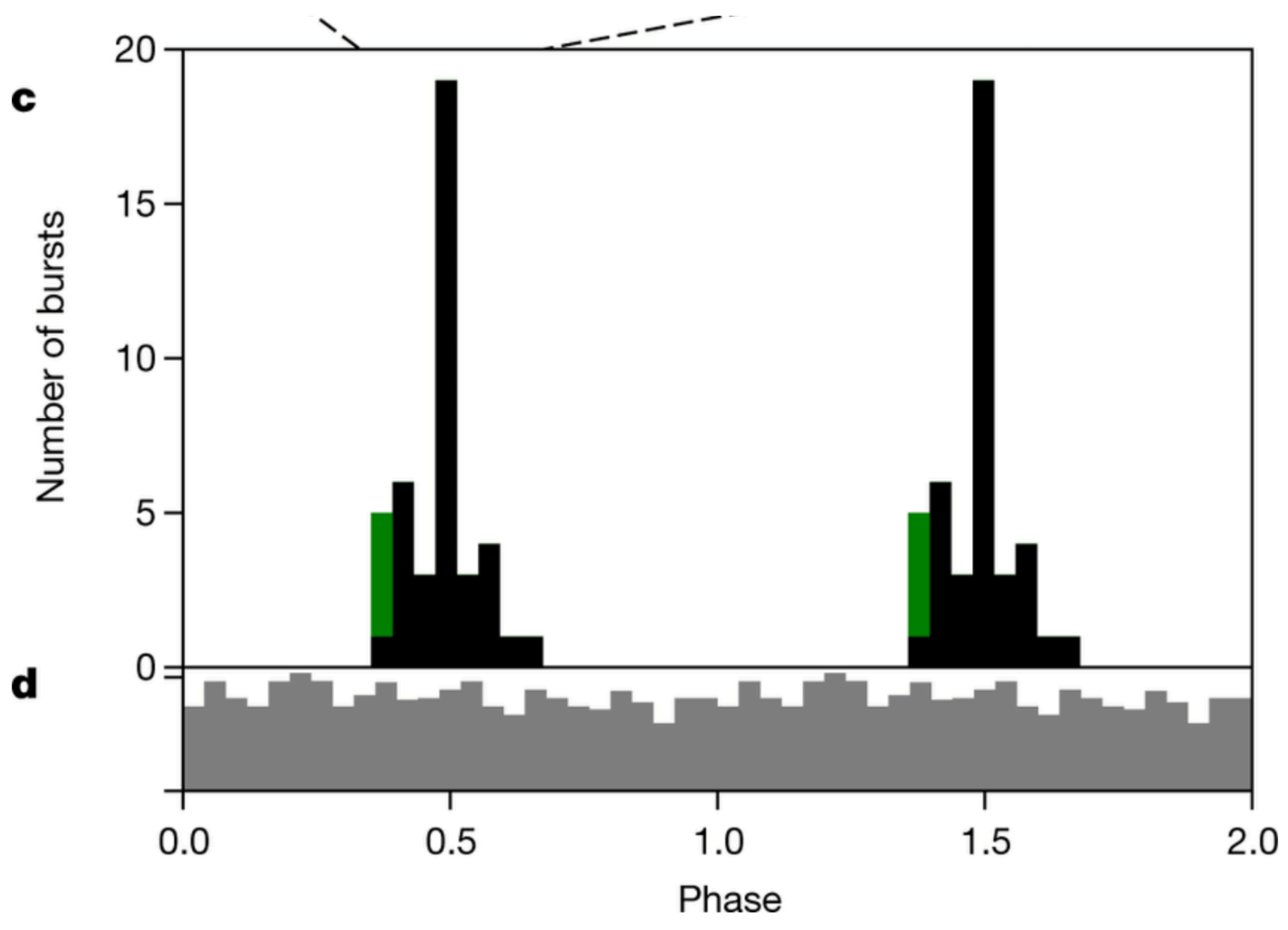

Episode I: Xu et al. 2022

Episode II:

I. Burst Morphology (Zhou Dejiang et al.2022)
II. Energy Distribution (Zhang Yongkun et al.2022)
III. Polarimetry (Jiang Jinchen et al.2022)
IV. Spin Period Search (Niu Jiarui et al.2022)

Episode III: Xu et al. in prep.

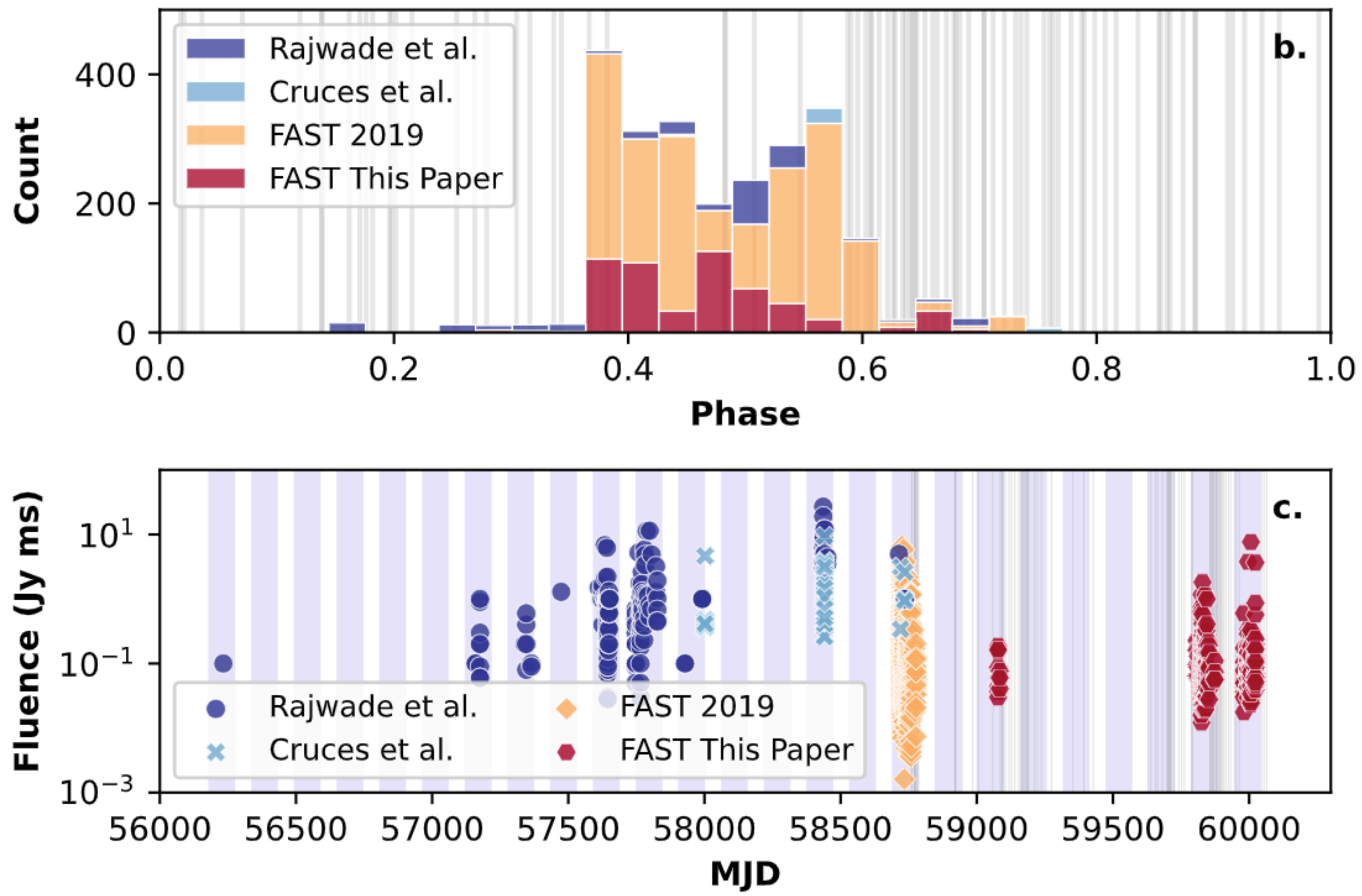
# Active-window (cycle)




(Chime/Frb Collaboration et al. 2020)

**FRB 20180916B**

**period 16.35 ± 0.15 day**




**FRB 20121102A —period 161 ± 5 day (165-hr Effelsberg)**

**—period 160 day； duty cycle 60%( 59.5-hr in 47 days FAST)**

**—period 4.605 day ; 1145 bursts Phase folding analysis**

(Cruces et al. 2021) (Wang et al. in prep.) (Li et al. 2024 )

Binary system (Ioka & Zhang 2020; Zhang & Gao 2020; Sridhar et al. 2021)

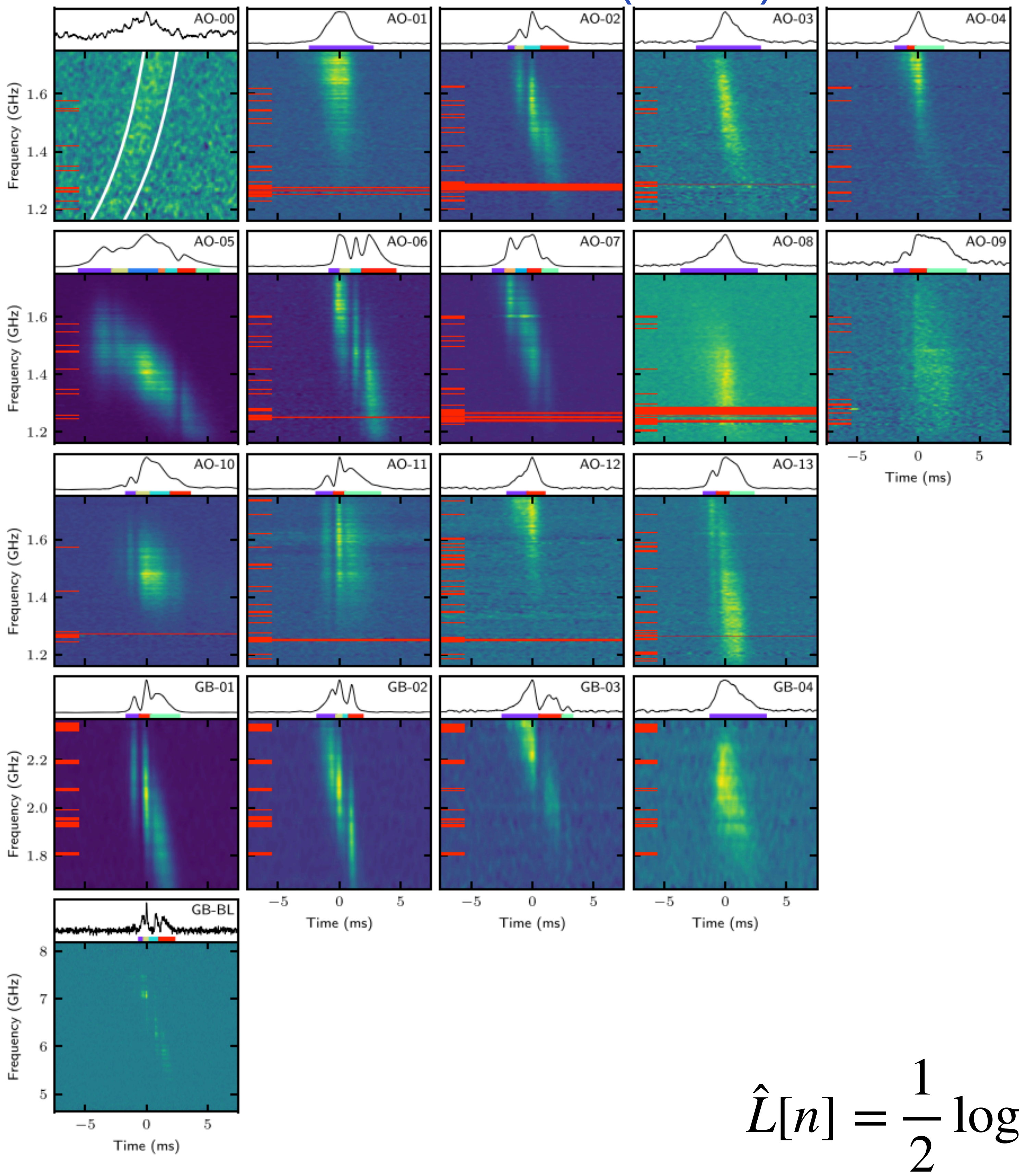
Magnetar precession (Yang & Zou 2020; Levin et al. 2020; Zanazzi & Lai 2020; Sob’yanin 2020)

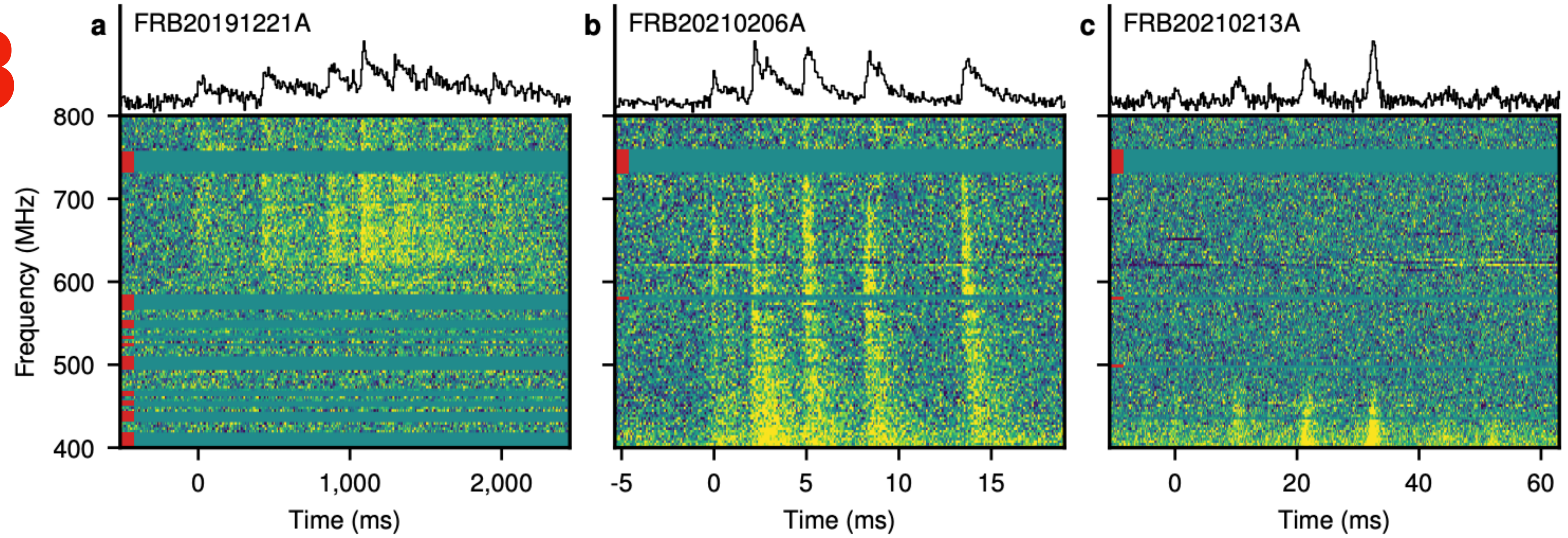
Asteroid Interactions (Dai & Zhong 2020; Voisin et al. 2021; Du et al. 2021)

Slowly rotating magnetar (Beniamini et al. 2020).

# Multi-components in FRB

Hessels et al. (2019)



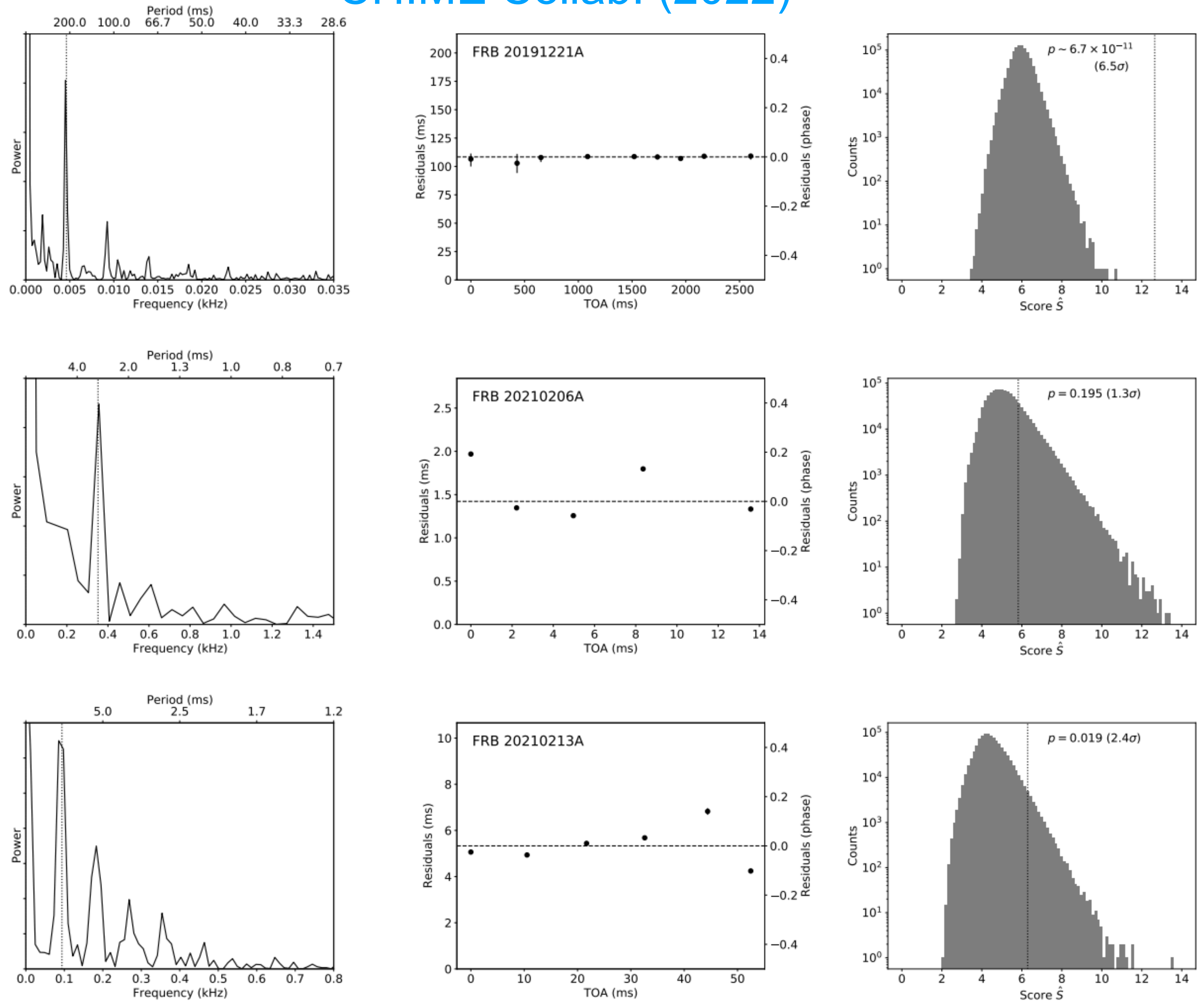




CHIME Collab. (2022)

216.8 ms
6.5 σ
Spin period?

2.8 ms
1.3 σ

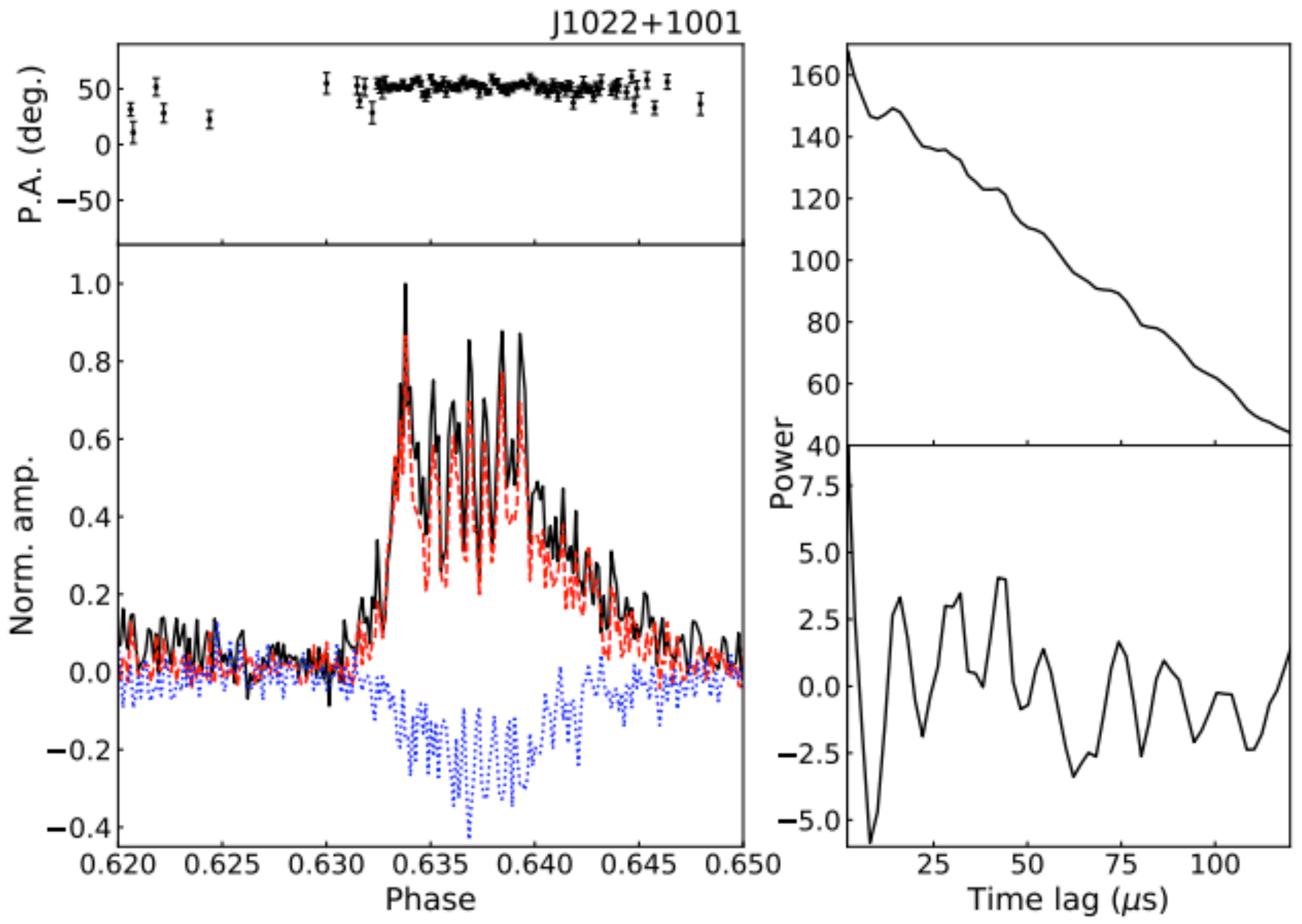
10.7 ms
2.4 σ

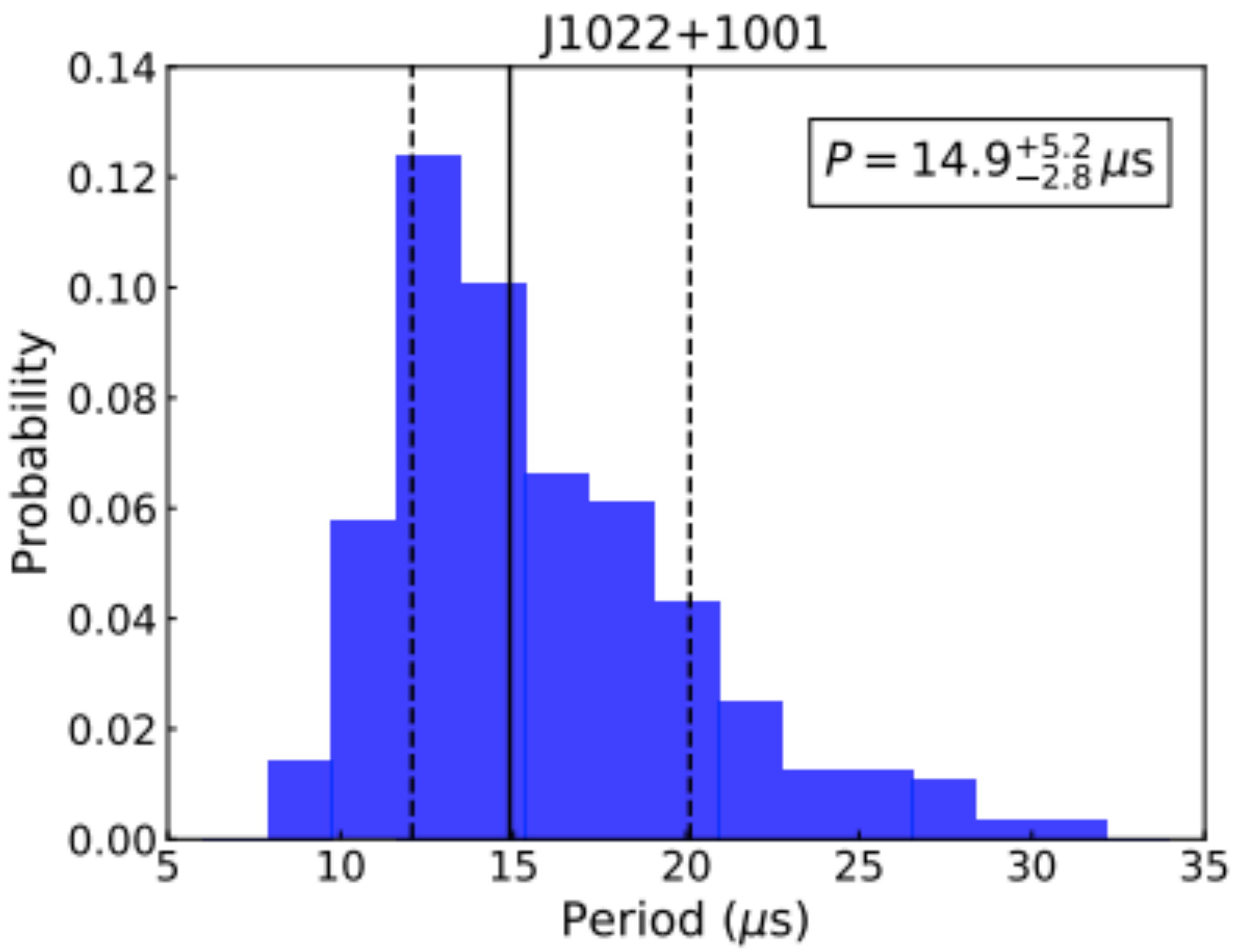



$$\hat{L}[n] = \frac{1}{2}\log\left(\sum_i \frac{(t_i - \bar{t}_i)^2}{r_i^2}\right)$$

$$\hat{S} = \max_n(\hat{L}[n])$$

# Multi-components in FRB

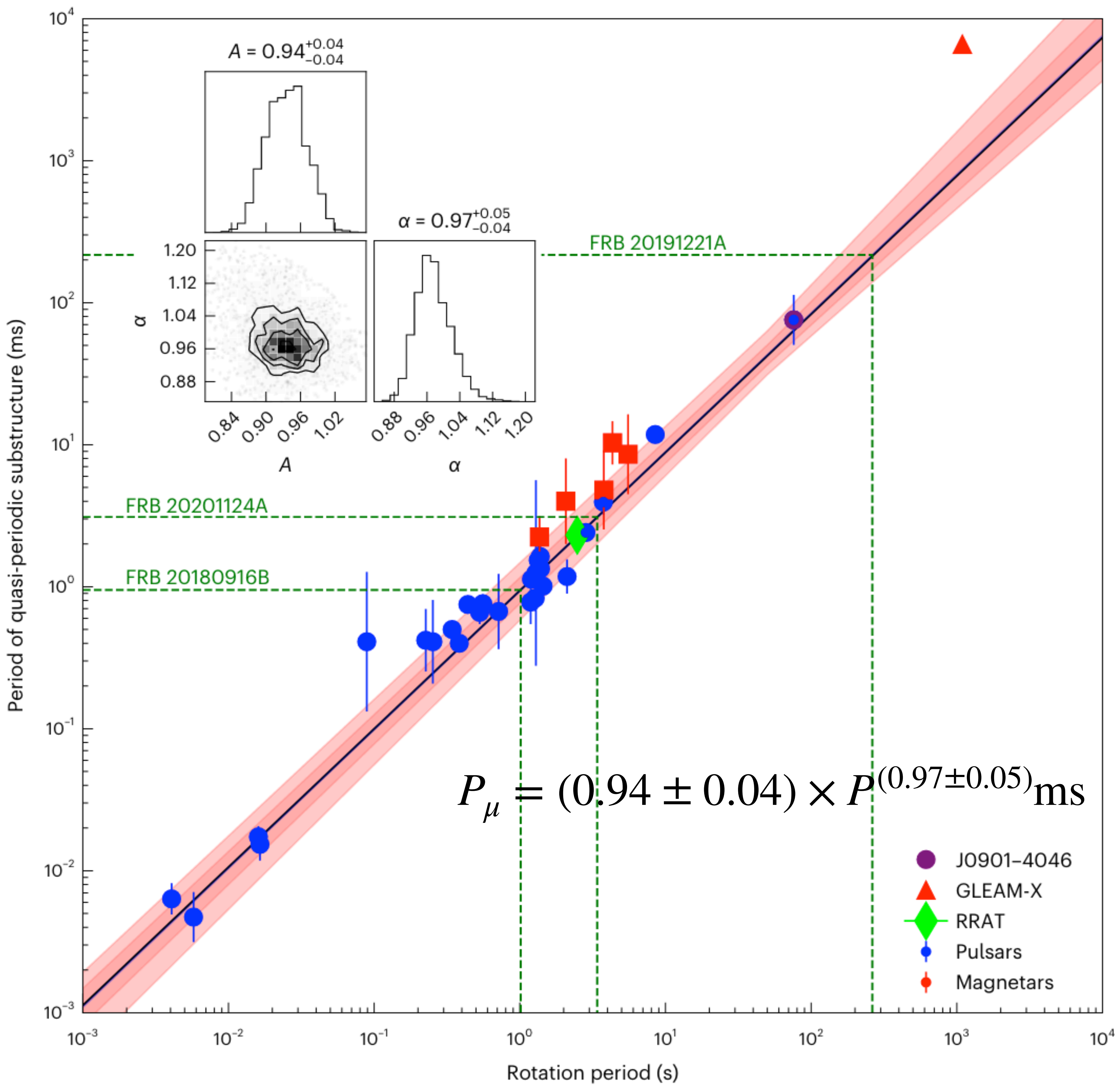



Liu, K. et al. 2022

## Quasi-periodic sub-pulse structure as a unifying feature for radio-emitting neutron stars

Michael Kramer & Kuo Liu 2023



# FRB 20201124A: Spin Period Search

**Criterion**

1)It has a high statistical significance;

2)It appears in multiple epochs of observations either as identical, close or harmonically related signals.

**Method**

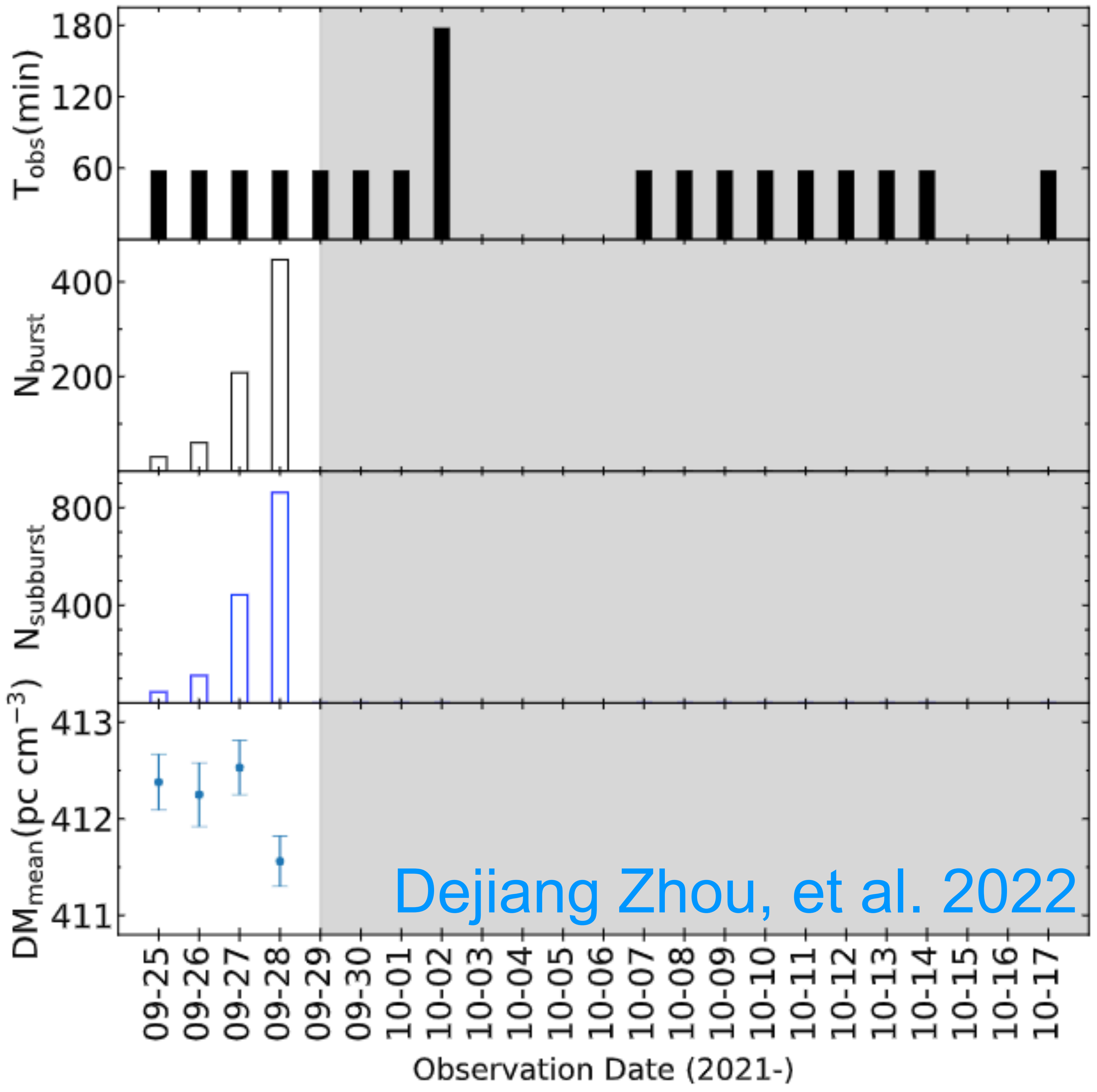
1)Periodicity search with raw data (FFT, FFA);

2) Lomb-Scargle Periodicity search with TOAs;

3) Period and acceleration search with TOAs (H-test);

4) Periodicity analysis of multi-components (53 unrelated millisecond-timescale "periods" in multi-components with the highest significance of 3.9 σ);

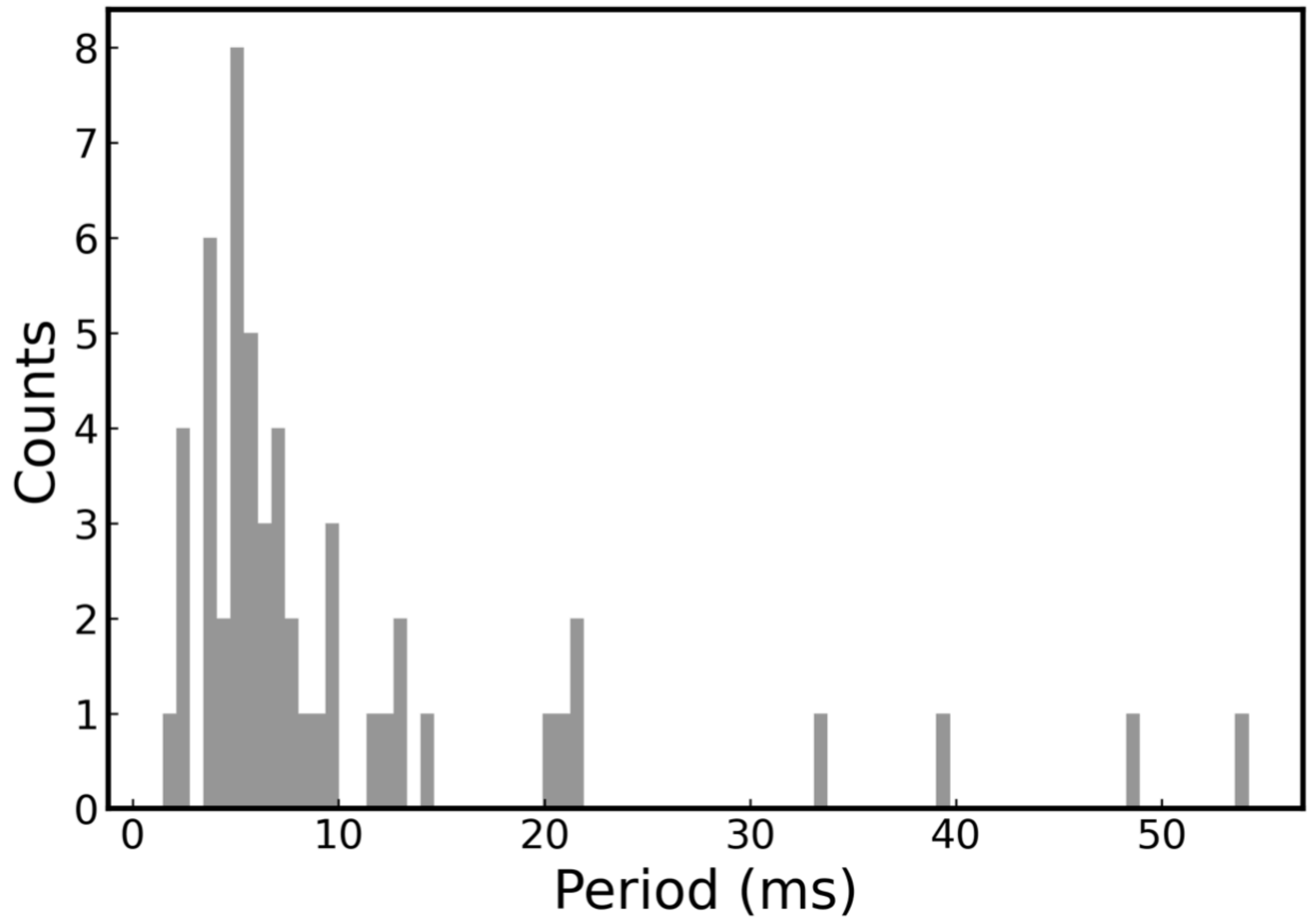
5) Test putative periods using waiting times.



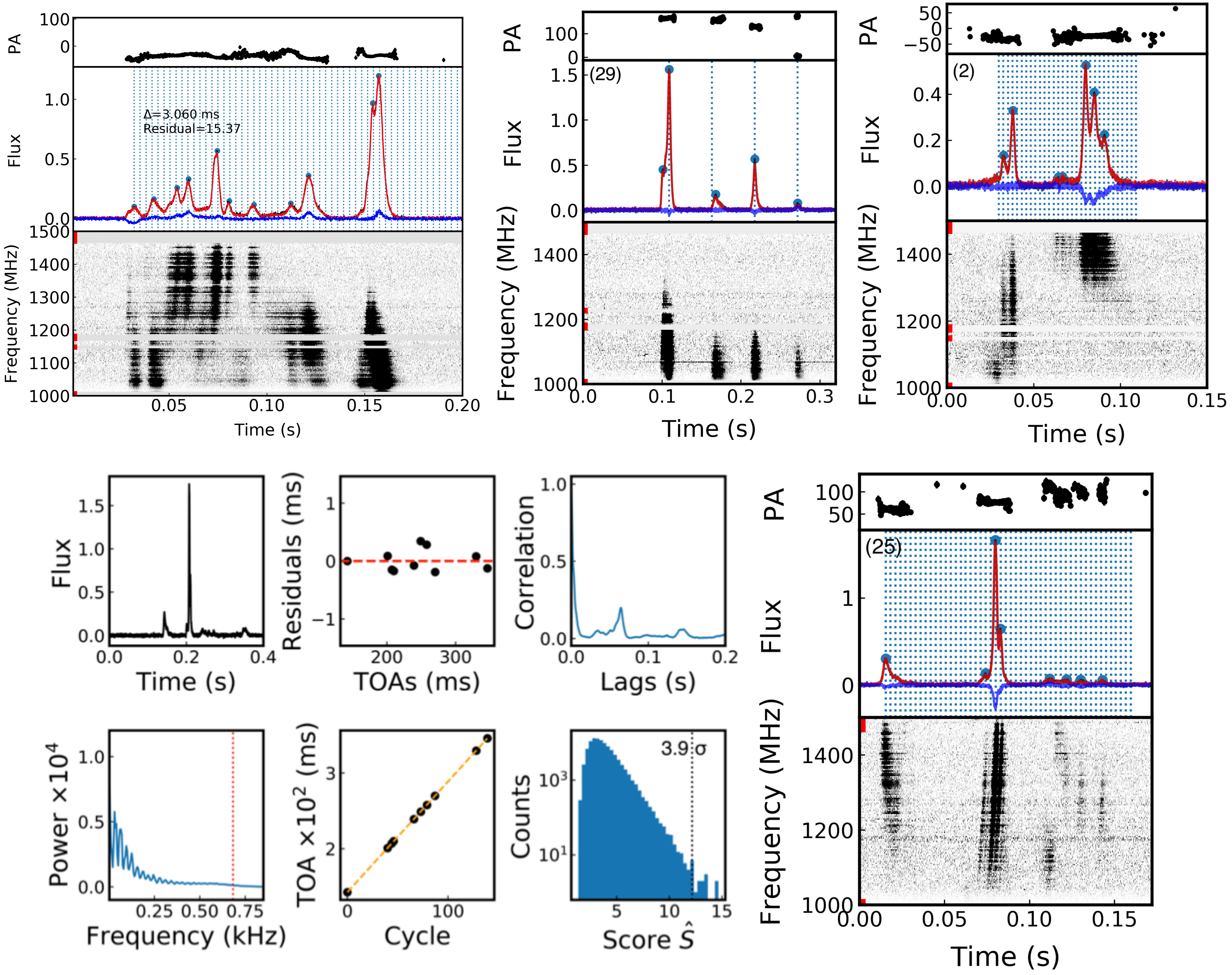

**We rule out the presence of significant periodicity in the range between 1 ms to 600 s with a pulse duty cycle < 0.49 ± 0.08 and linear acceleration up to 300 m $s^{-2}$ in each of the four one-hour observing sessions, and up to 0.6 m $s^{-2}$ in all 4 days.**

# Multi-components

## Total 53 multi-components




We should be cautious when linking quasi-periodicity in FRB micro-components to the rotation of the source object for signals with significance below ~ 4 σ.

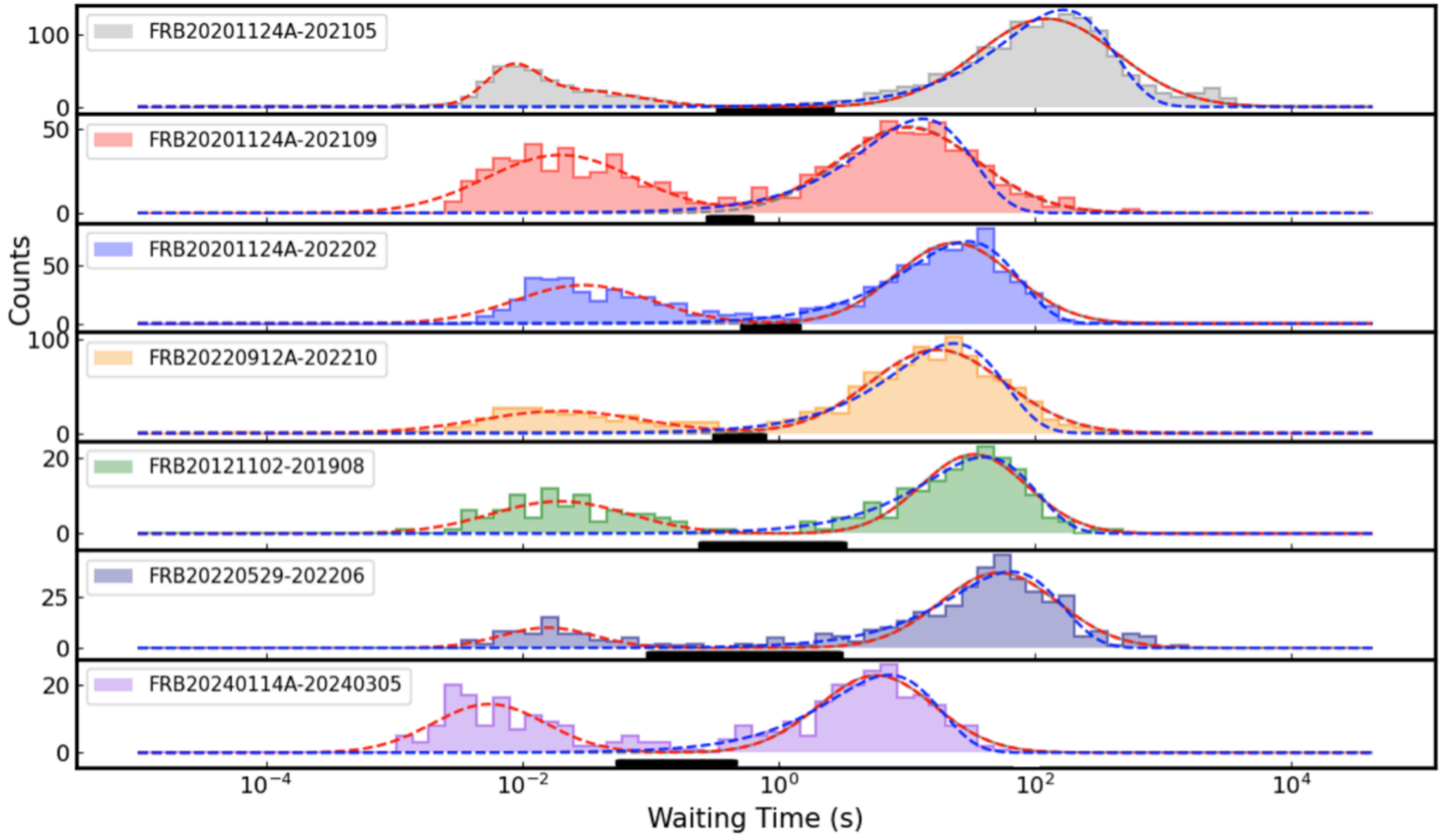



(c) Detailed analysis of multi-components (25).

Jiarui Niu, et al. 2022

# Waiting Time of FRB

The waiting time refers to the time interval between two FRB bursts.



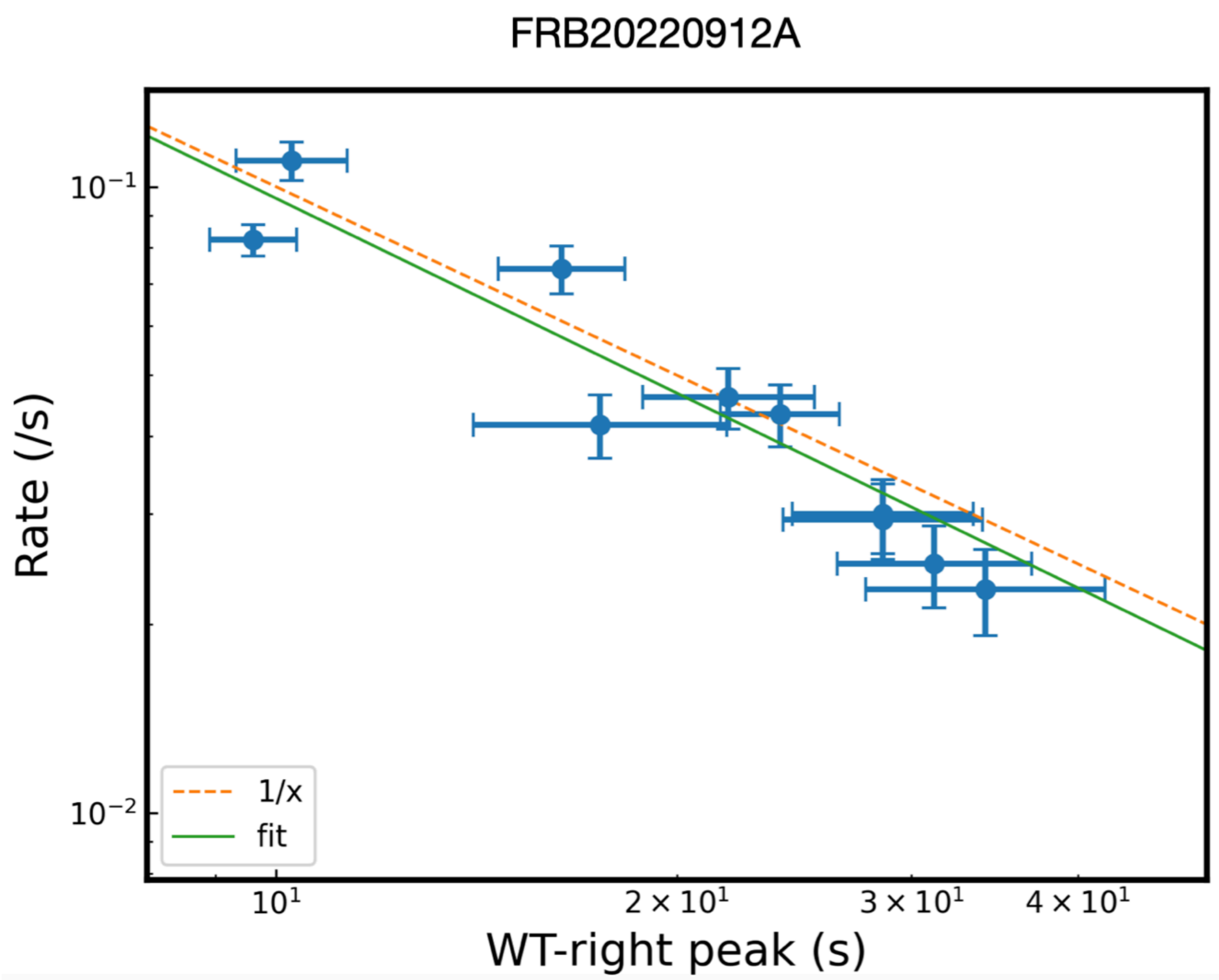

Jiarui Niu, et al. In prep.

**Waiting time has the following characteristics:**

1. The waiting time distribution has two significant peaks, one in milliseconds and the other in seconds.

2. The left waiting time peak may be caused by intrinsic physics that are not affected by burst rate.

3. The peak on the right side is dominated by the event rate.




Jiarui Niu, et al. In prep.

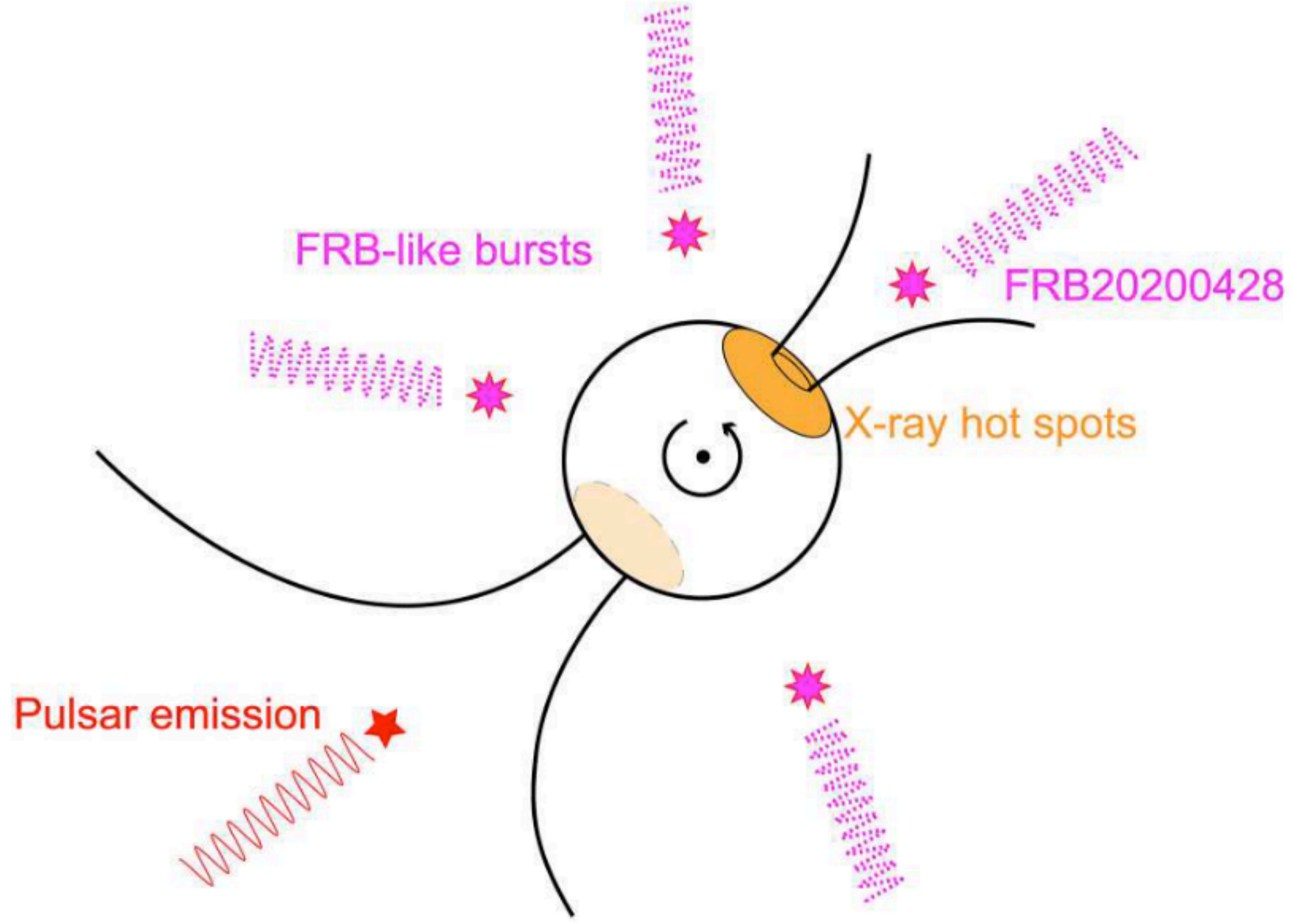
# Inspiration from the fast radio burst period search

**Observational explanation:**

- Large duty cycle, corresponding to special geometry.
- In an extreme binary system. The search parameter space is insufficient. (Chunfeng Zhang in prep.)
- Spin slowly or even no rotation (low GJ charge density)

**Theoretical explanation:**

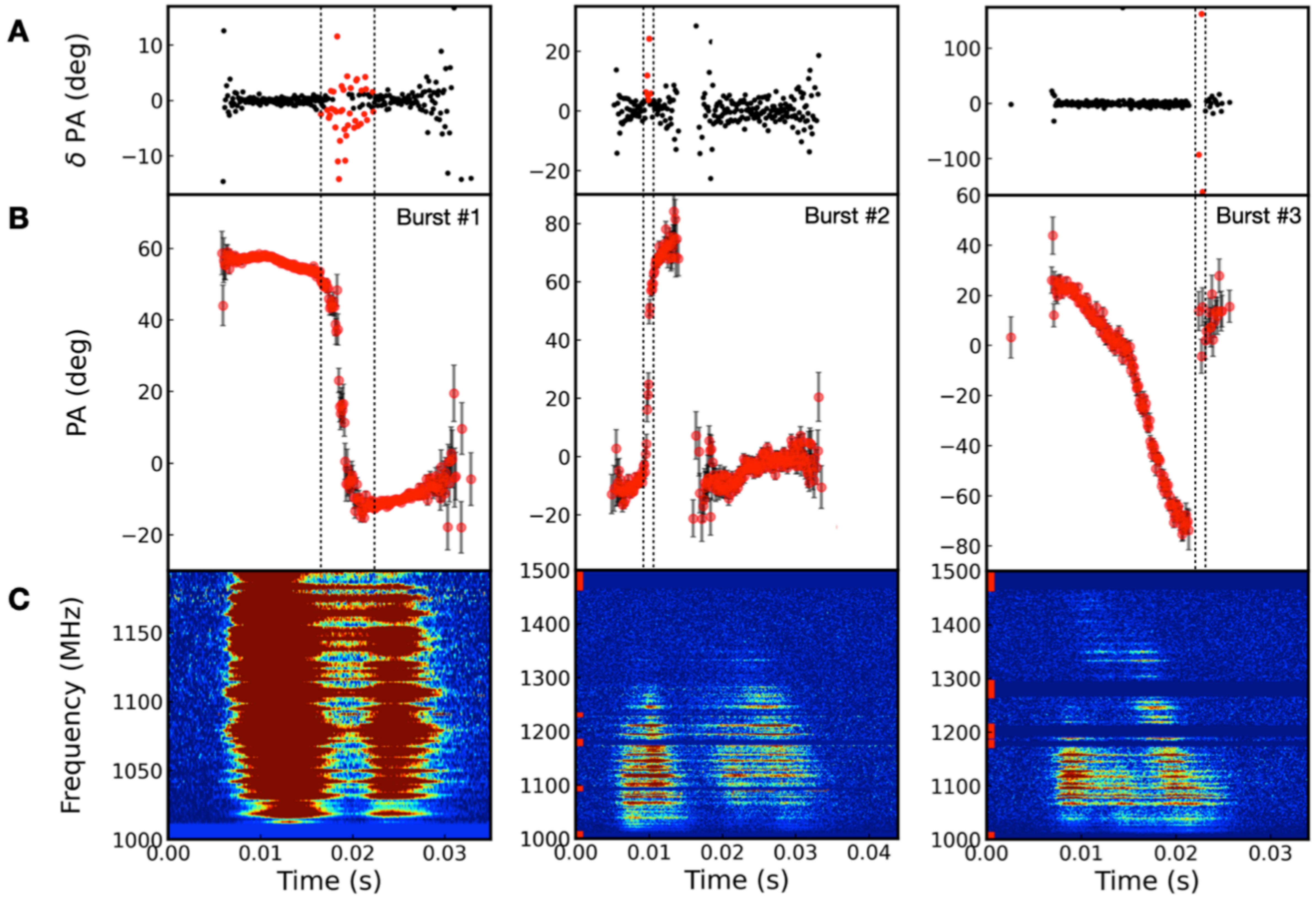
- For FRBs, the areas of open magnetic field lines can be distorted and enlarged, matching observations of FRB-like bursts from SGR J1935+2154 (Zhu et al., 2023).
- The absence period of FRB may have a strong relationship with the triggering mechanism. Charged emission particles can be triggered by point discharges from "hills" on the star's surface, and bright bursts are prone to periodic bursts. ( Wang et al, 2024)
- There is an extra torque during releases energy, similar to multiple Glitch.




Weiwei Zhu, et al 2023

# Energy of FRB 20201124A PA Jump Bursts

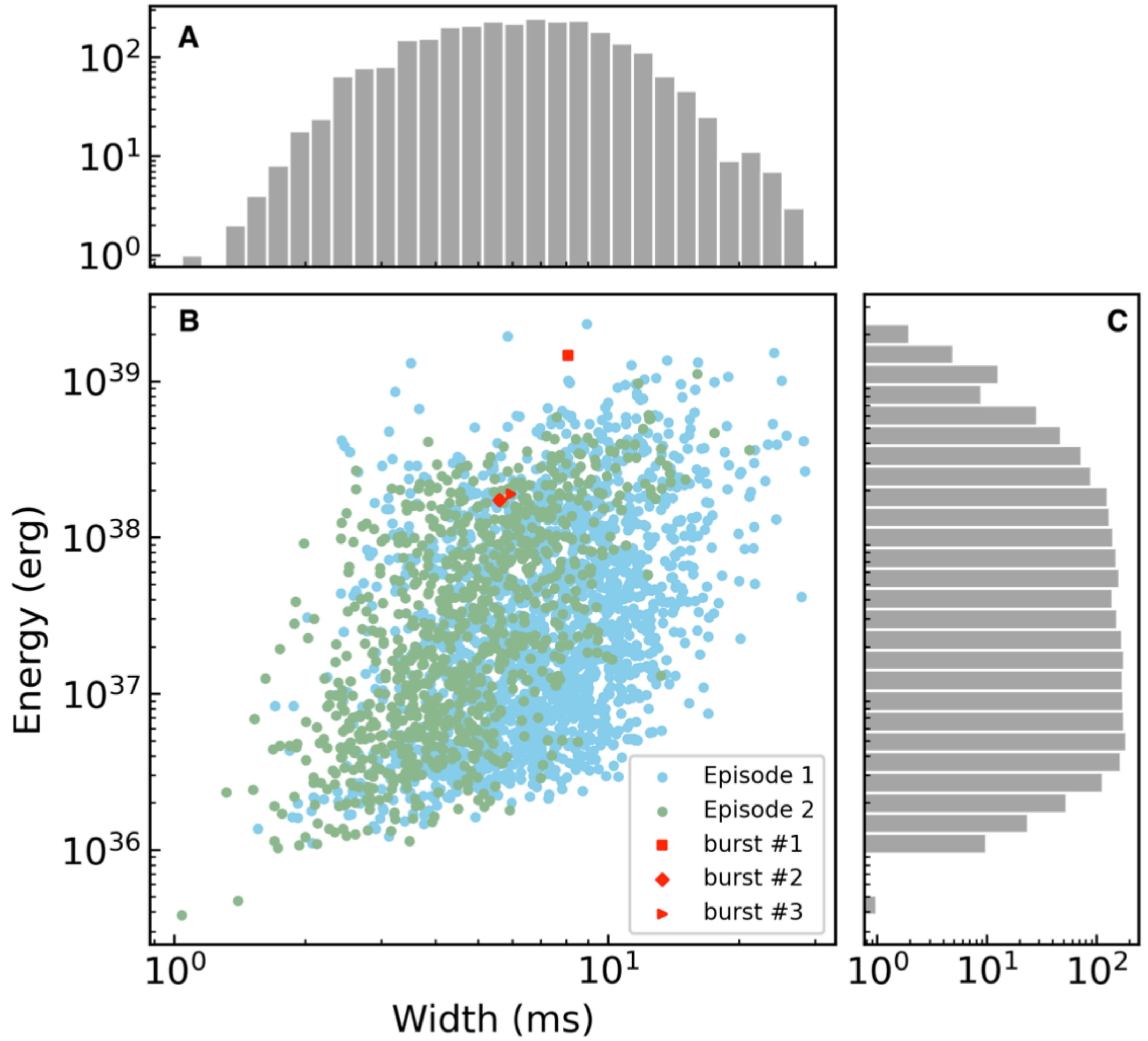
**The detection of sudden polarization angle jumps from a fast radio burst unveils its radiation mechanism.**




Burst#1 65.9 ± 1.1 degree in 4.1ms

Burst#2 97.7 ± 23.9 degree in 1.2ms

Burst#3 88.7 ± 30.0 degree in 1.4ms



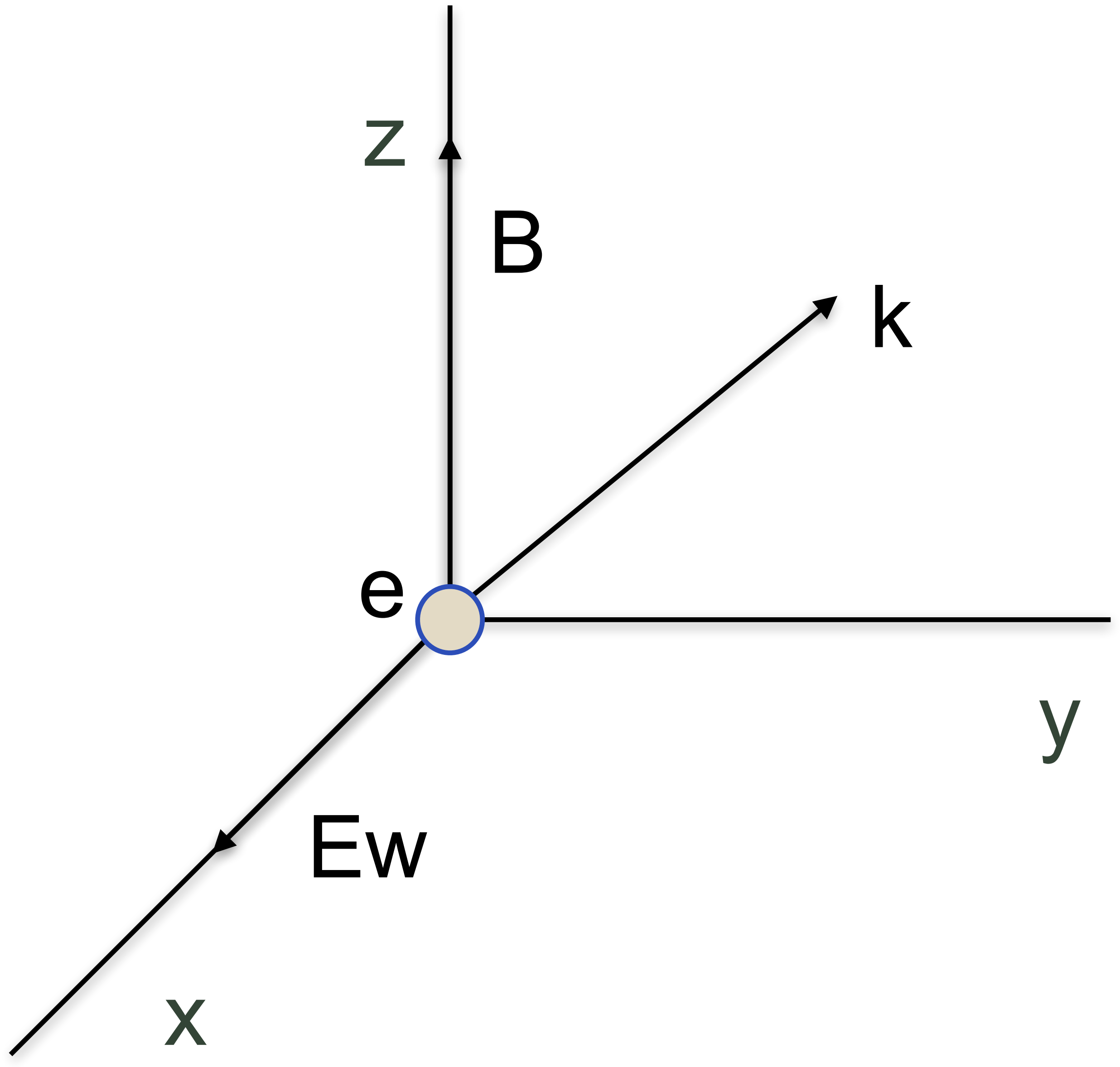

| Number | TOA (BC) | RM (rad $m^{-2}$) | DM (pc $cm^{-3}$) | Fluence (mJy ms) |
|---|---|---|---|---|
| Burst#1 | 59314.337398370 | -654.9 ± 0.8 rad $m^{-2}$ | 413.5 ± 0.7 pc $cm^{-3}$ | 13554.4 mJy ms |
| Burst#2 | 59485.809688968 | -610.9 ± 0.4 rad $m^{-2}$ | 410.2 ± 1.8 pc $cm^{-3}$ | 3928 mJy ms |
| Burst#3 | 59485.821414110 | -565.1 ± 2.6 rad $m^{-2}$ | 411.8 ± 3.7 pc $cm^{-3}$ | 1344 mJy ms |

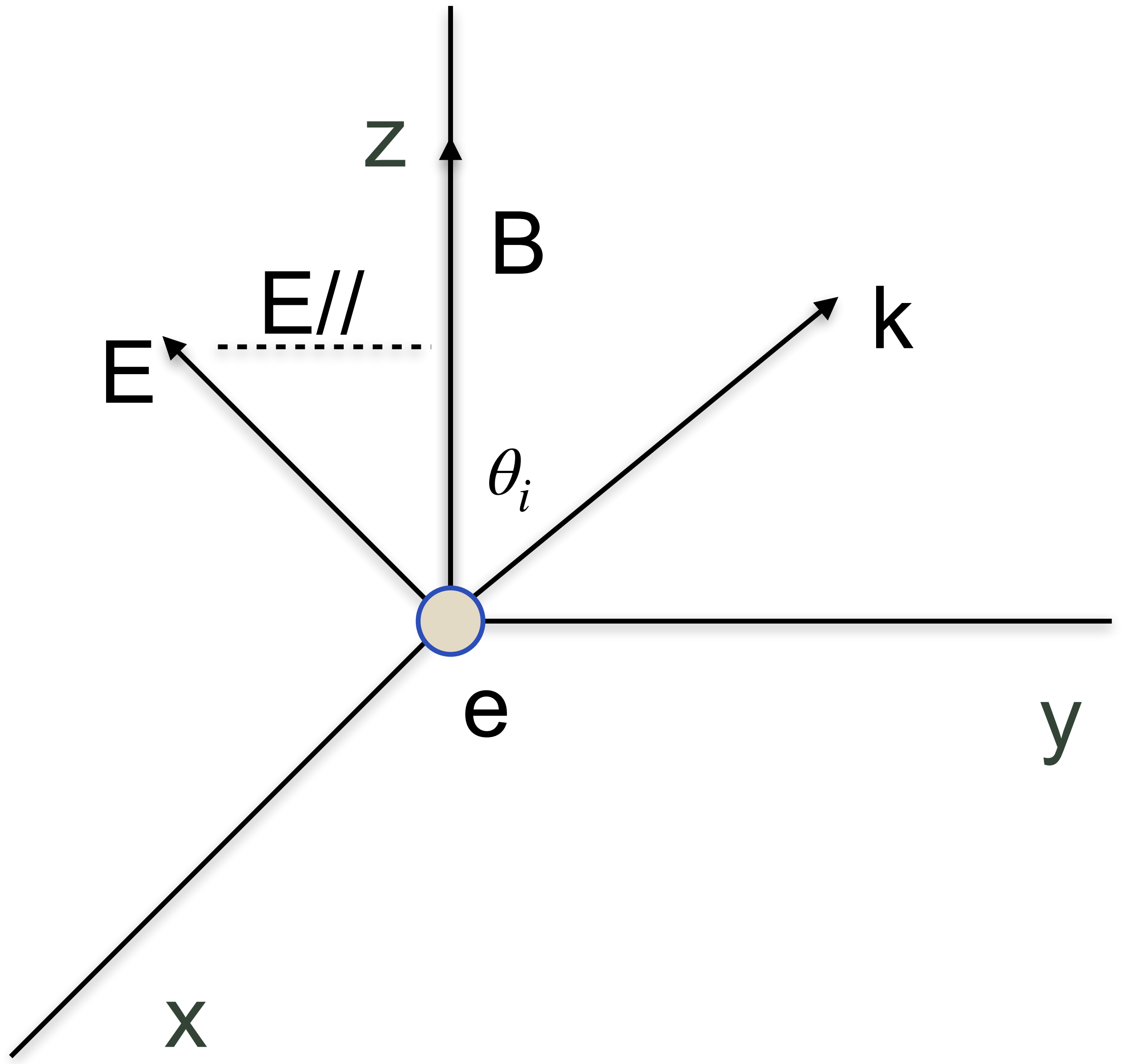
Jiarui Niu, et al. submitted

# O-mode and X-mode in Plasma

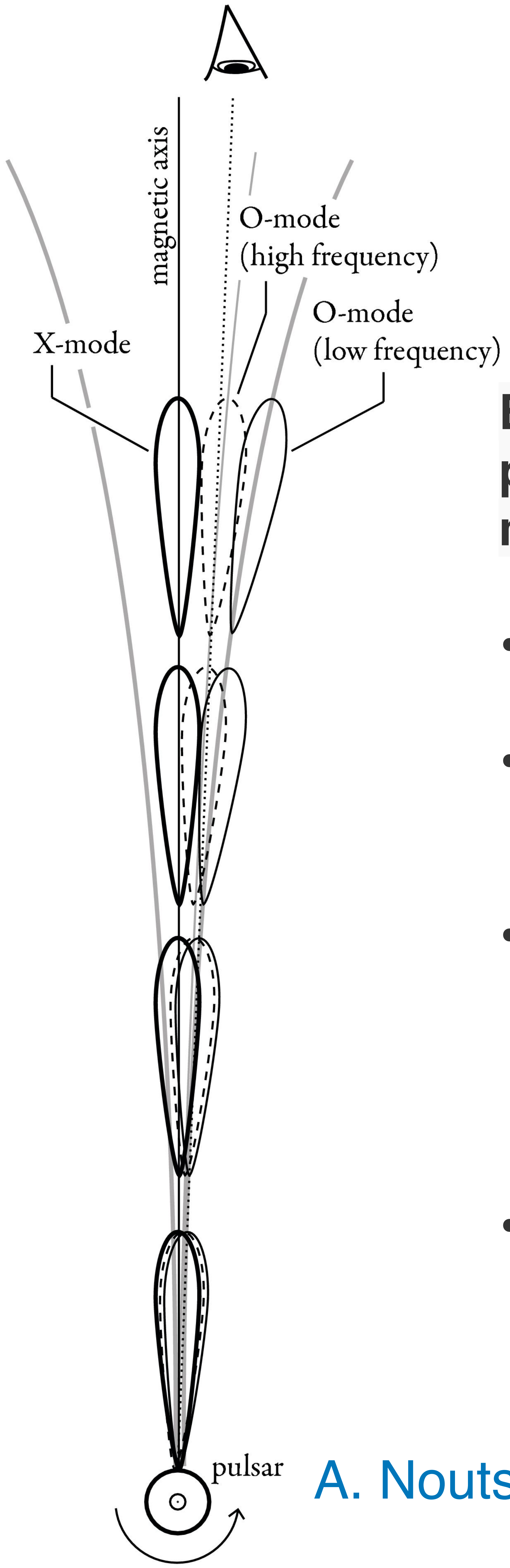
X-mode $\vec{E}_w \perp (\vec{k} - \vec{B}_{bg})$

O-mode $\vec{E}_w \parallel (\vec{k} - \vec{B}_{bg})$




In pulsars, the 90-degree PA jump is a manifestation of two orthogonal polarization modes (OPM) that reflect the characteristic pattern of the plasma.




# Birefringence

**Birefringence in radio-wave propagation through pulsar magnetospheres**

- X mode —parallel to the magnetic axis
- O mode —follows the magnetic-field line
- The ordinary (O-mode) and extraordinary (X-mode), are beamed towards different directions.
- The degree of mode separation depends on the frequency of the emission.

A. Noutsos et al.2015

# PA Jump in Pulsar and FRB

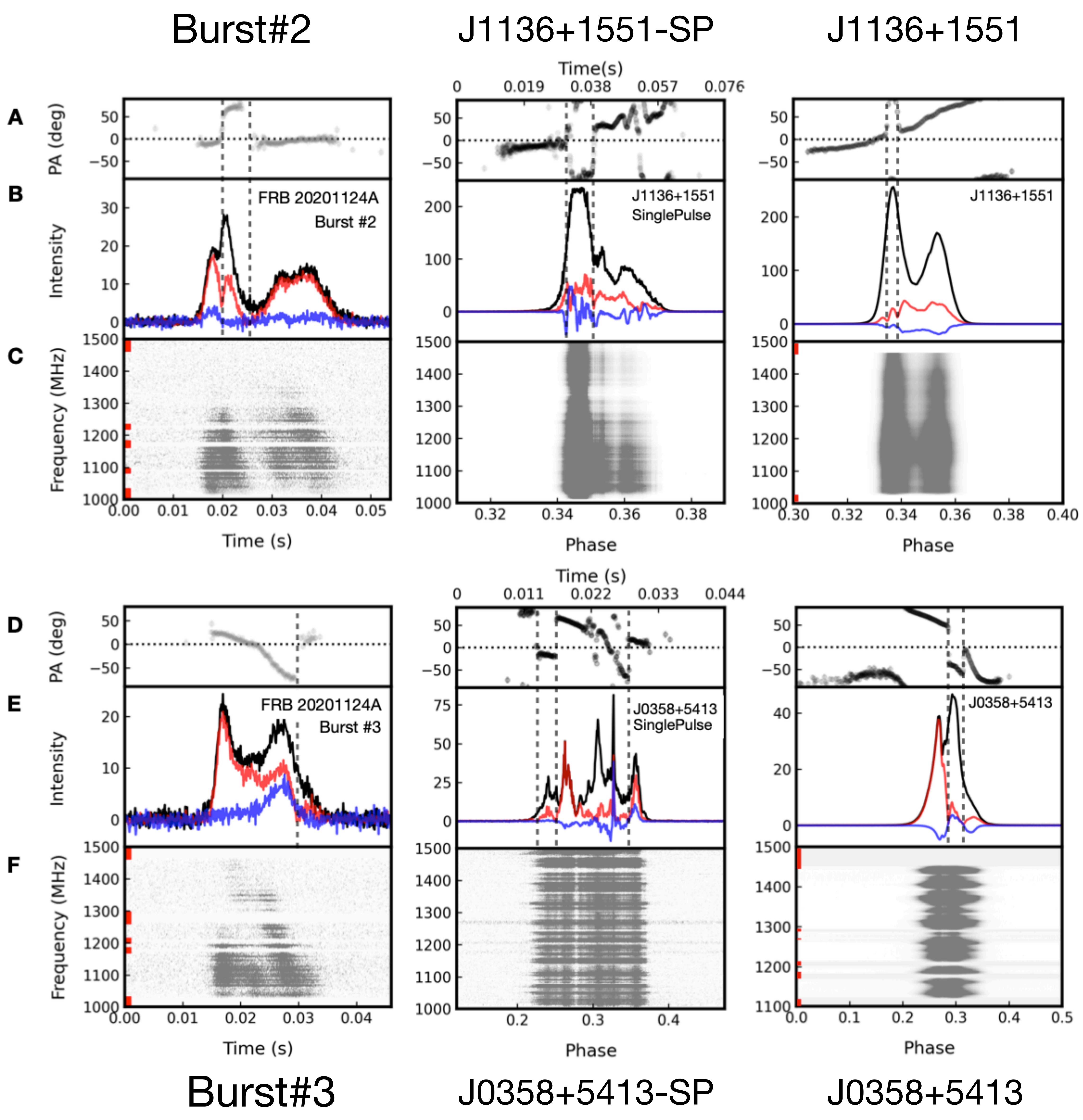
**Similarities:**

- Can occur in different phases (times).
- Occurs at circular polarization sign changes or minima linear polarization.
- It could be 90 degrees or not 90 degrees.

**Difference:**

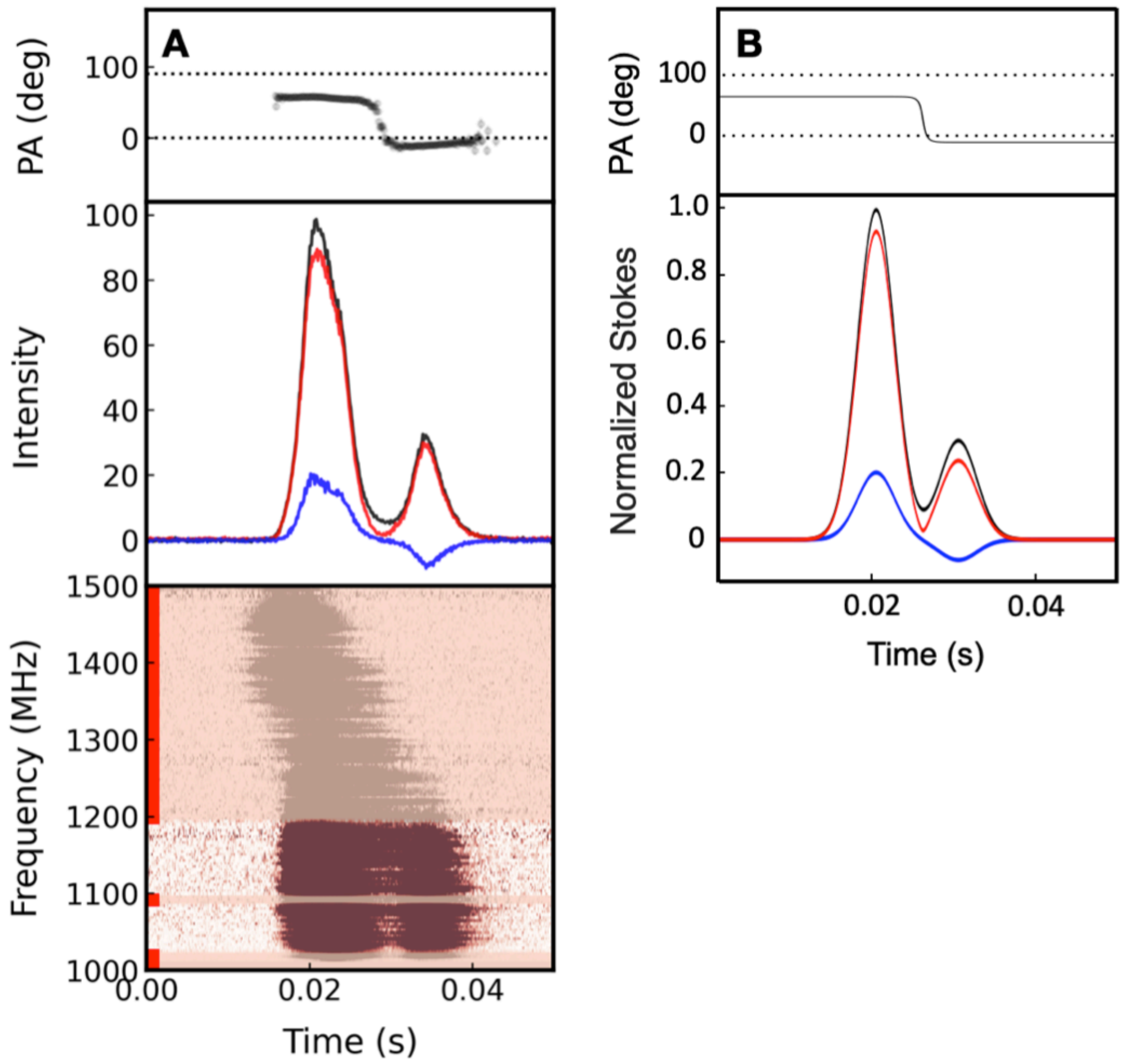
- Radiation bandwidth
- Radiation energy

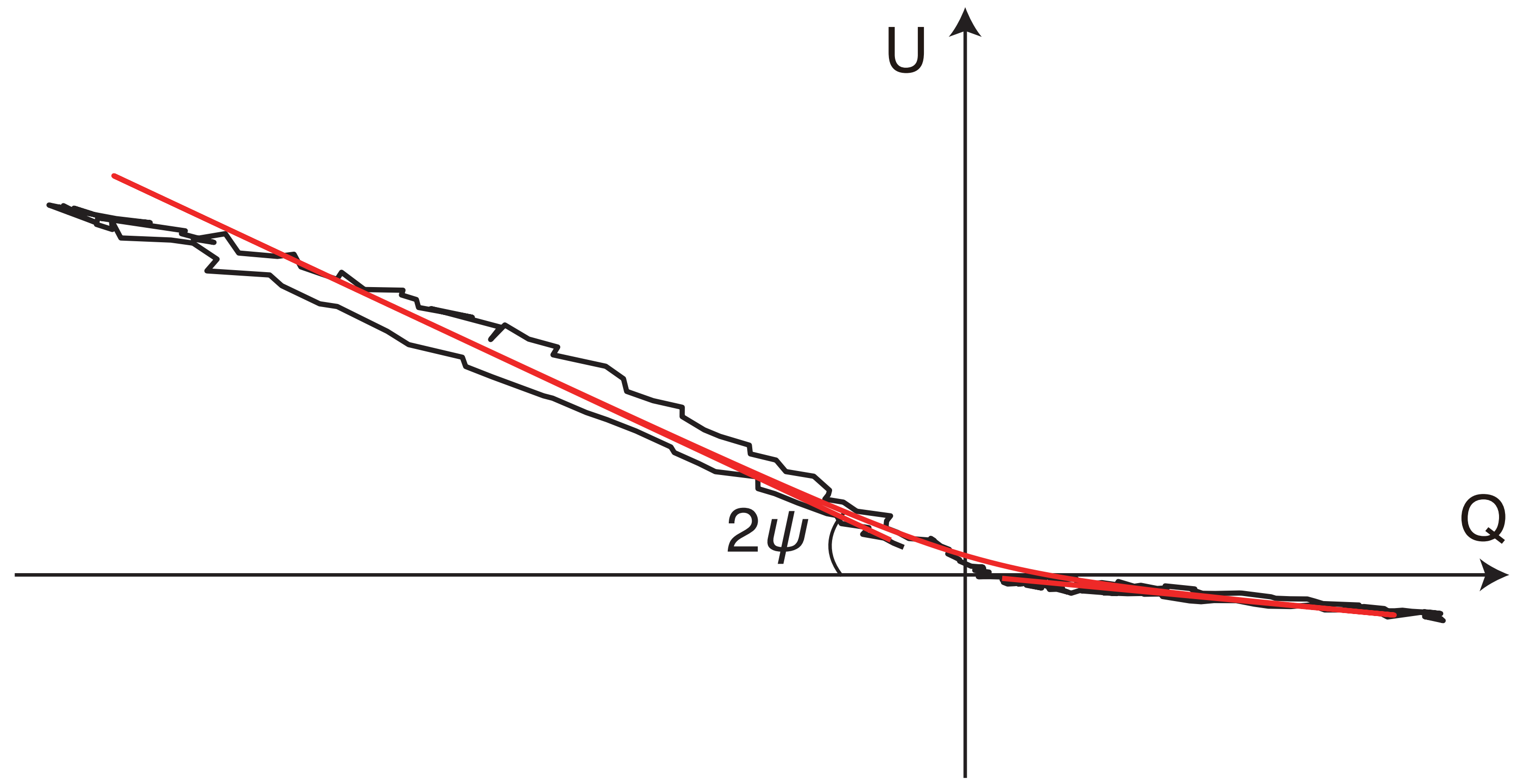
**The OPM-jump bursts are quite rare indicates that very special conditions, likely special geometry, are required to cause the OPM-jump phenomenon.**




Jiarui Niu, et al. submitted

# Possible explanation
# O-mode and X-mode superposition




$$I = \exp(-[(t-0.02)/\sigma_w]^2) + 0.3\exp(-[(t-0.03)/\sigma_w]^2),$$

$$Q = -0.4\exp(-[(t-0.02)/\sigma_w]^2) + 0.2\exp(-[(t-0.03)/\sigma_w]^2),$$

$$U = -0.8\exp(-[(t-0.02)/\sigma_w]^2) - 0.08\exp(-[(t-0.03)/\sigma_w]^2),$$

$$V = 0.2\exp(-[(t-0.02)/\sigma_w]^2) - 0.06\exp(-[(t-0.03)/\sigma_w]^2),$$

Jiarui Niu, et al. submitted

**The polarization position Angle jump may come from the superposition of different modes in the magnetosphere**

# Sudden polarization angle jumps of FRB 20201124A

Why inside the magnetosphere:

1. The two modes come from different but close emission regions.

2. There is no known mechanism that can cause a sudden change in the dominant polarization pattern at some time, and no distant coherent mechanism that can achieve this in shock model.

3. The extremely short ~ 1ms PA jump time corresponds to ~ 300km. The scale is smaller than the light cylinder radius of a typical magnetar.

# Summary

- No spin period in linear acceleration search and possible reason
- Radiation mechanisms—inside the magnetosphere

# Thank you !