青年学者学术报告

基于FAST观测的两个快速射电暴
FRB 121102、SGR 1935+2154研究

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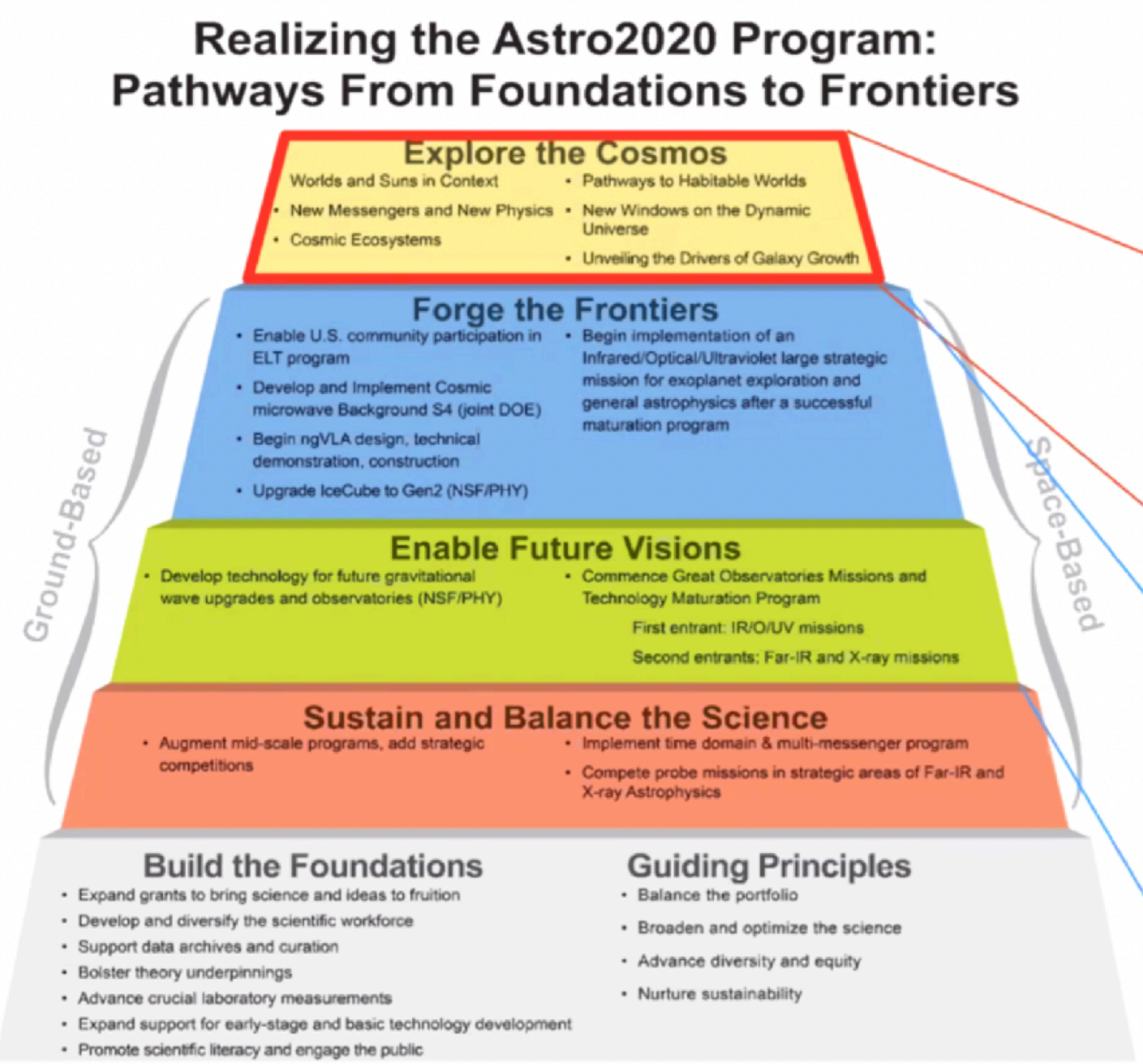
研究工作的重要意义

重大问题 —— 探索动态宇宙

- 天文学的基本问题
- 孕育基础物理重大突破机遇



《美国天文十年规划》

- ❖ 探索宜居世界
- ❖ **动态宇宙**
- ❖ 星系成长及其他天文

THz+新兴前沿

- ❖ IceCube Gen2
- ❖ ELT + IR/Opt/UV
- ❖ **CMB S4 (THz)**
- ❖ ngVLA (radio)
- ❖ Far-IR and X-ray

快速射电暴(FRB)是重要宇宙瞬变源

- 已知宇宙中射电波段最明亮的爆发现象，起源至今未知
- 问题本质：尚不清楚FRB的能量来源和辐射机制，新兴的热点前沿

研究背景

- 数百例FRB发现：迄今没有广泛认可的普适物理图像，涉及宇宙各种致密天体活动
- 问题本质：尚不清楚FRB的能量来源和辐射机制

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研究背景

- 难点分析

  - 可能有多种起源机制和族群分类
  - 时标短，数量少，需大量观测

  样本少

  - 源对应体，周边环境复杂，能量跨度大
  - 难以同时测量，设备选择性影响大

  精度低

- 解决方法

  - 新FRB及重复暴发现
  - FAST深度观测已知重复暴
  - 多波段多信使协同观测

重要的源，理解FRB切入点

FRB 121102

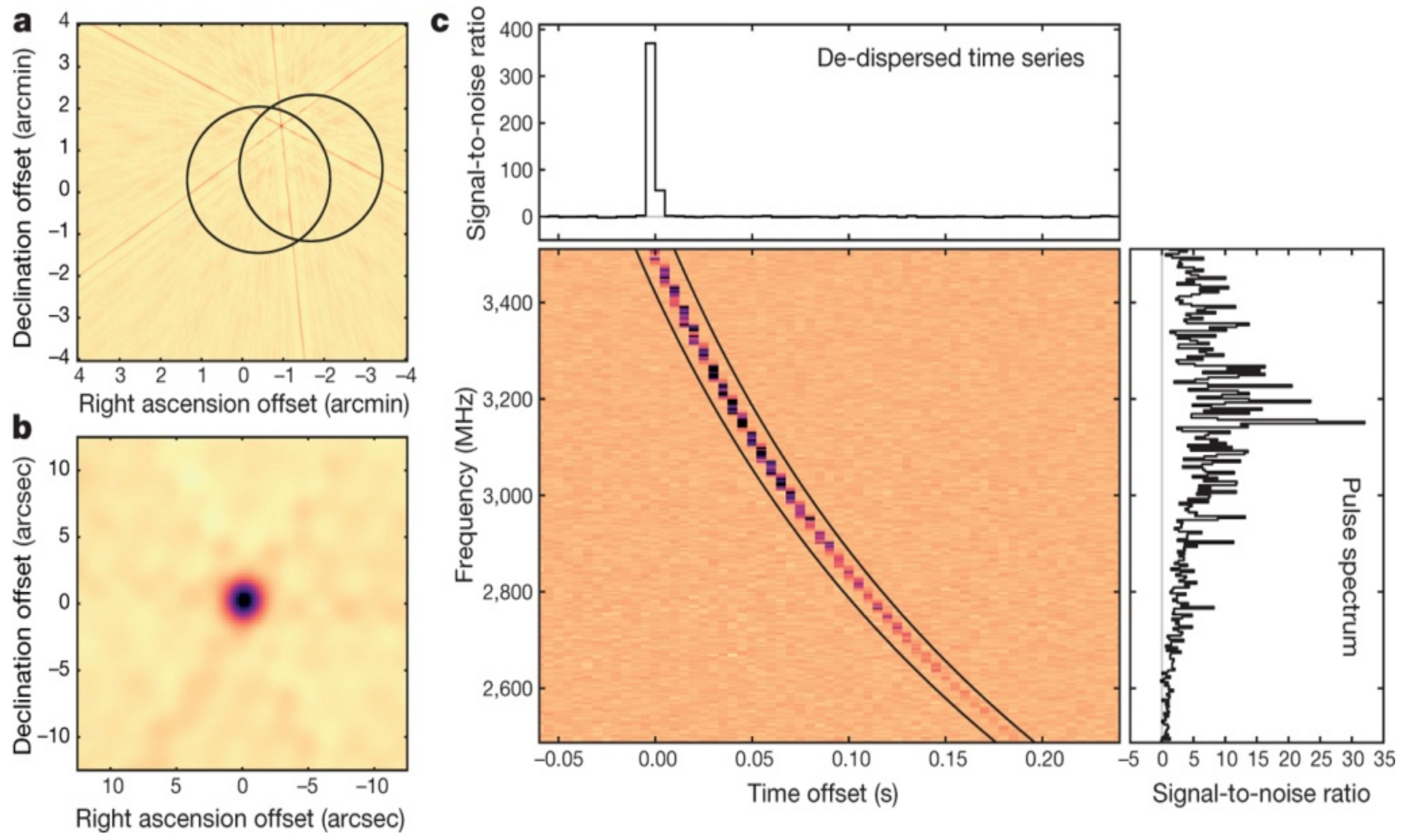
人类所知的第一个重复暴

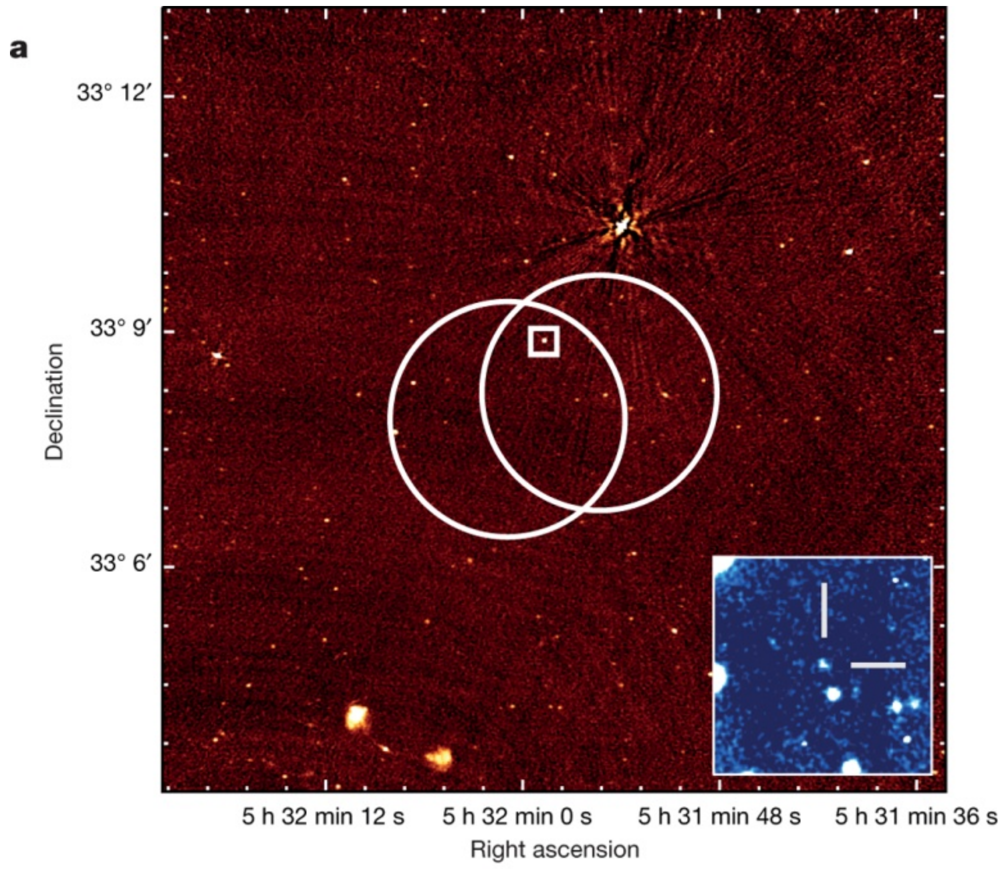
SGR J1935+2154

首个河内磁陀星爆发产生FRB

FRB 121102：获得爆发事件大样本集

- 2017年，成为首个精确定位宿主星系的FRB





S Chatterjee *et al.* *Nature* **541,** 58–61 (2017) doi:10.1038/nature20797

"The most important discovery in astronomy since LIGO"

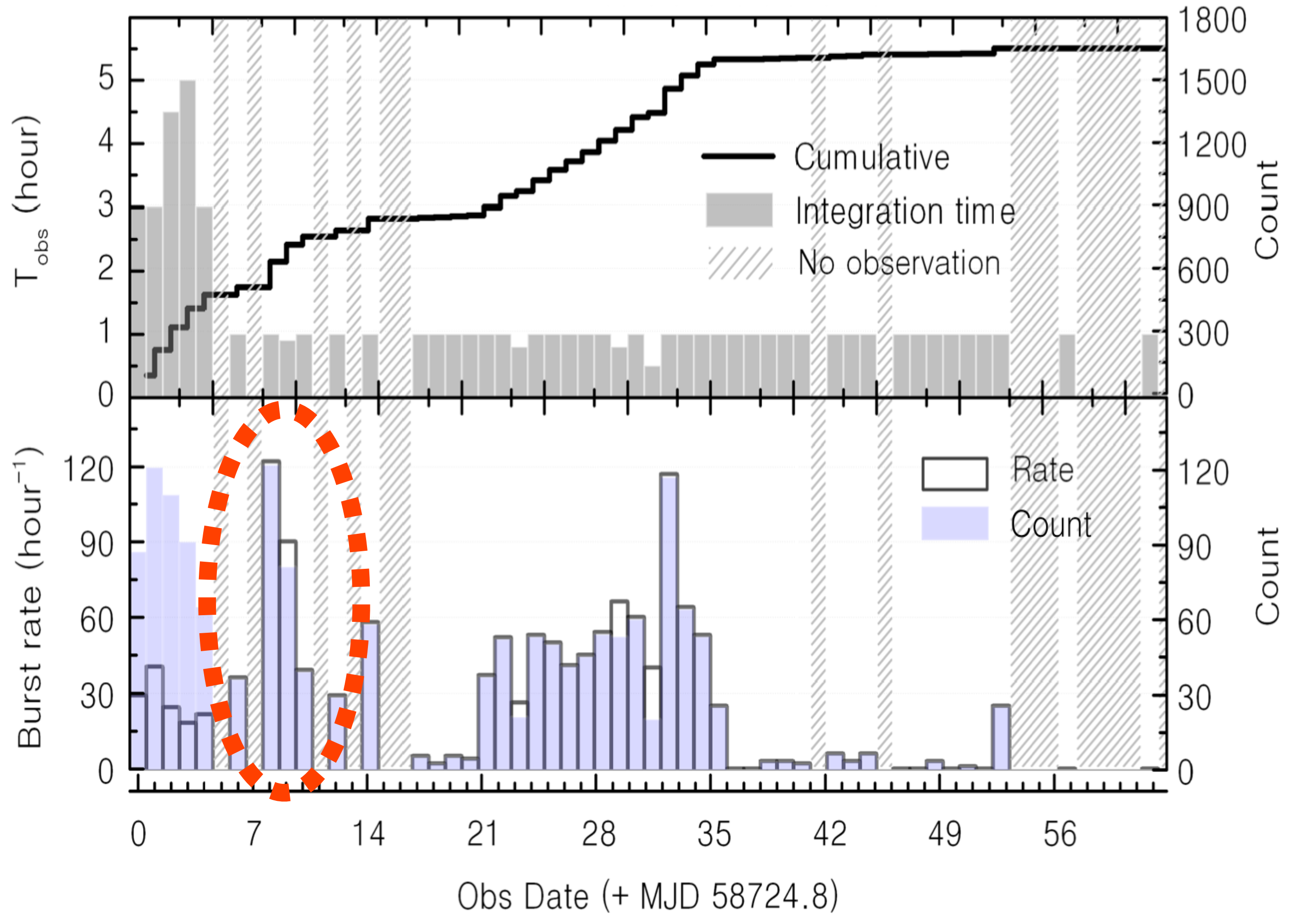
—AAS Press 2017

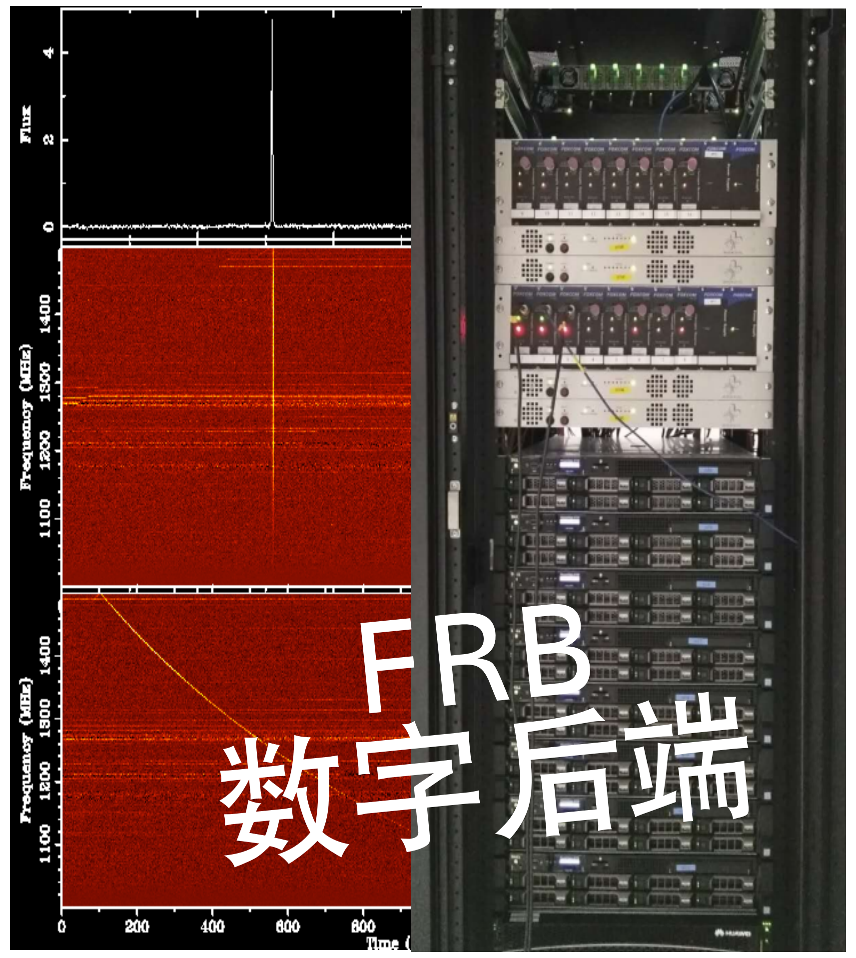
- 2019年8-10月，FAST 捕捉到极端活跃期

47天连续监测累积捕捉**1652**个高信噪比爆发事件

超过此前14年所有FRBs探测**样本量总和**

最高达到每小时**122**的超高爆发率





FRB 121102: 完整揭示快速射电暴爆发率能谱

重复暴大样本是理解切入点:
推动FRB研究进入高统计性时代

- 能量跨越**3**个数量级
- **完整揭示**FRB爆发率能谱
- 首次发现**双峰结构**，测得**特征能量**E_0
- 辐射等效总能量占磁星总能量38%
- 排除了ms-hr具有稳定自转，**严格限制**FRB物理起源


nature 598, 267 (2021)
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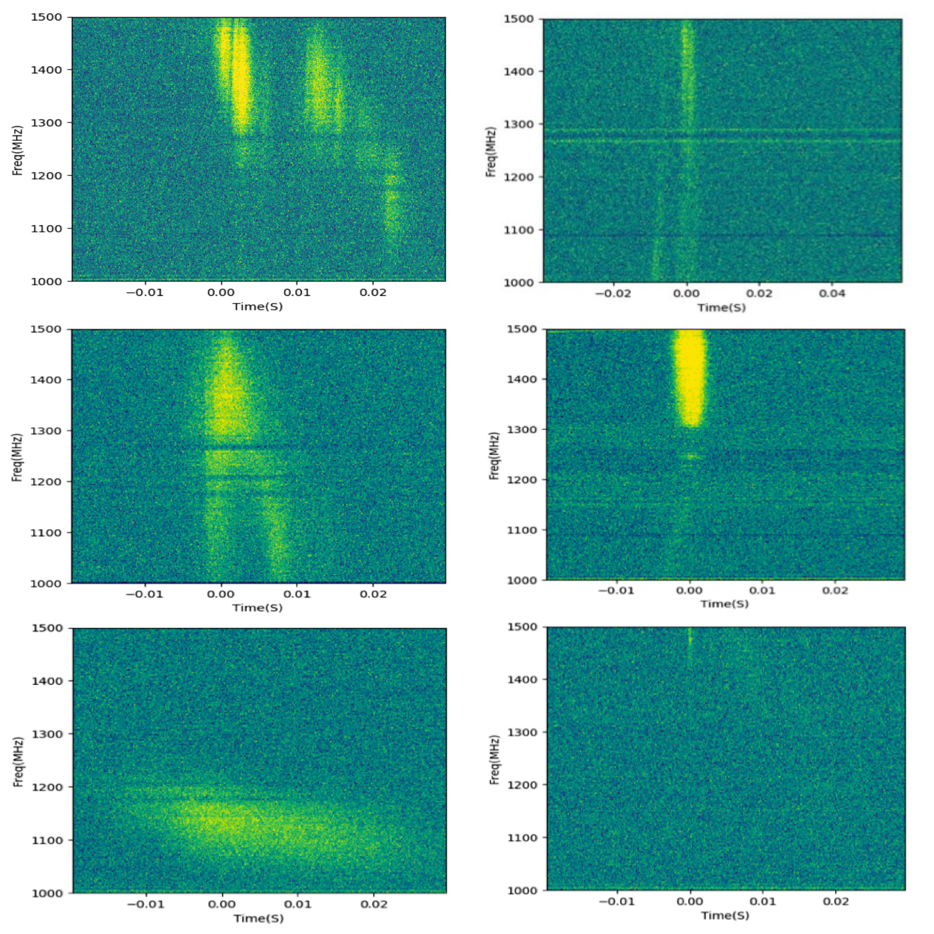
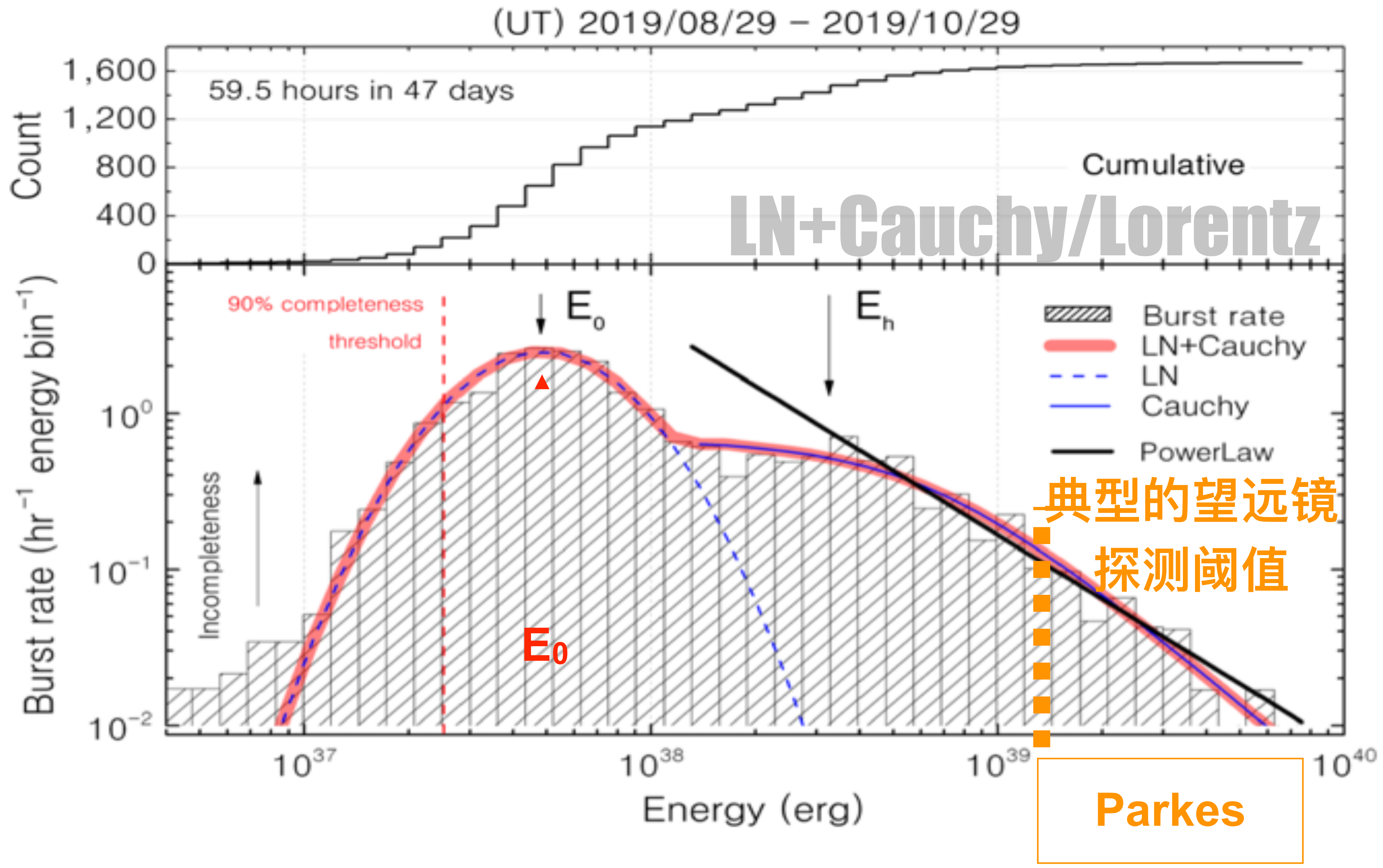
nature > articles > article
Article | Published: 13 October 2021
A bimodal burst energy distribution of a repeating fast radio burst source
D. Li, P. Wang, ... Y. Zhu + Show authors

Li, Wang, Zhu et al. Nature, 2021





FRB 121102：成果影响

FRB综述文章正面评价

Astron Astrophys Rev (2022)
Fast radio bursts at the dawn of the 2020s   Page 9 of 49   2

2021). This shows that repeaters can produce multiple types of bursts, some of which arguably appear more similar to those seen from one-off FRBs. The large sample of bursts found by FAST (Li et al. 2021) and Arecibo (Hewitt et al. 2021) has yet to demonstrate any strict or quasi-periodicity in the burst arrival times, like

FRB发现者 Duncan Lorimer：

"等效能量低能端发现的明确峰值分布表明FRB重复暴可具有**多种模态**的爆发"

2022年度科学院级新闻发布会特邀专家点评

荷兰射电天文台首席科学家、阿姆斯特丹大学教授 Hessels：

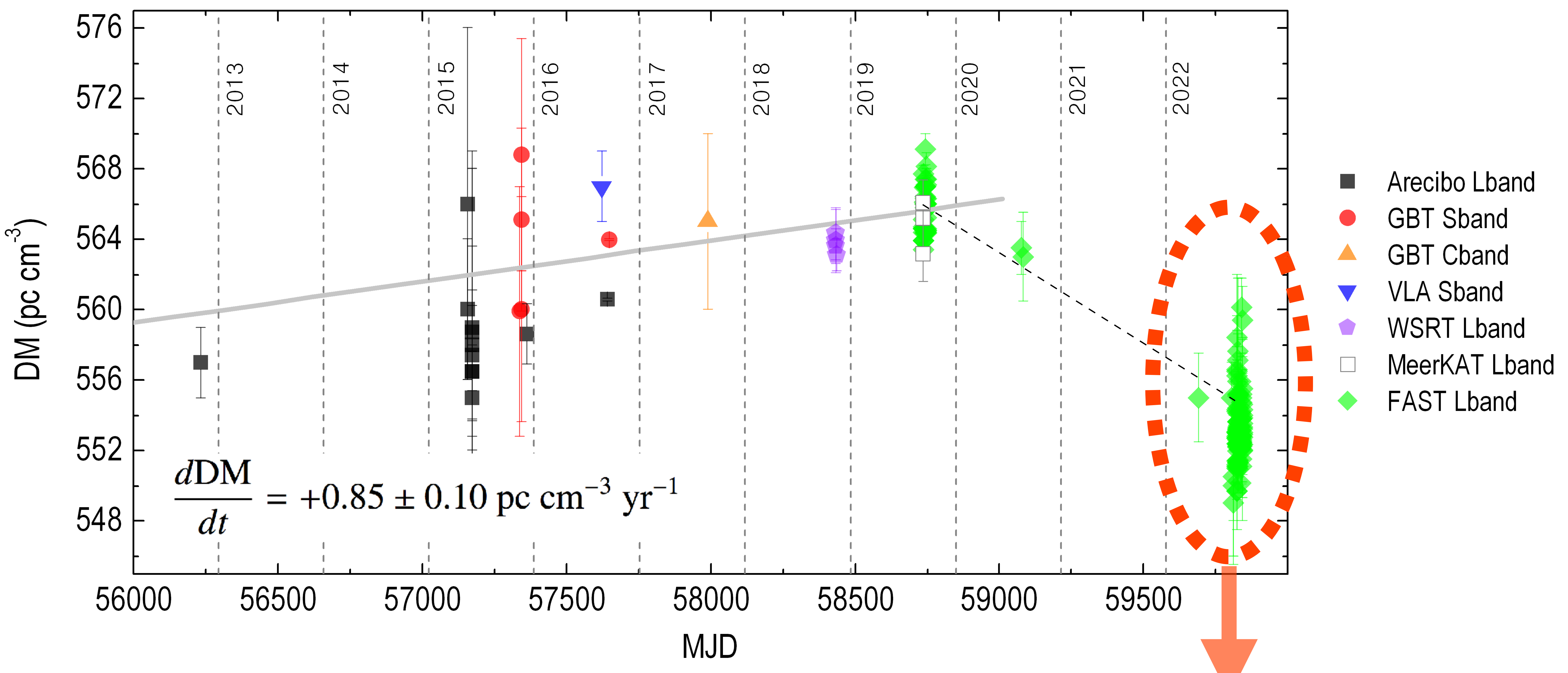
"FAST给我们带来**令人震撼**的来自该天体前所未有的新观测结果。

成果已**催生**FRB起源**系列模型**，例如FRB相干辐射机制、中子星磁层曲率辐射模型等

入选2021年度"中国科学十大进展"

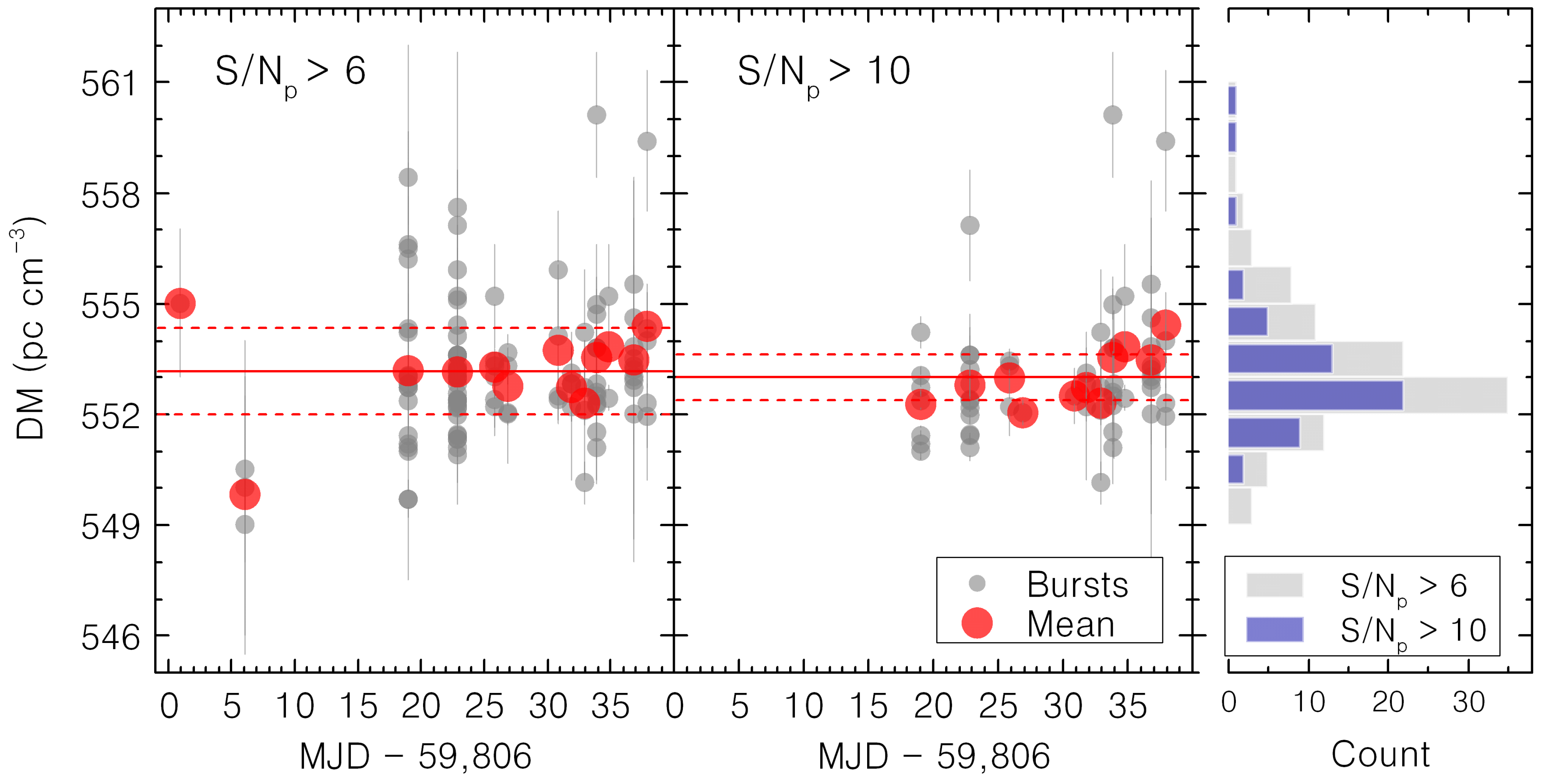
1. 火星探测天问一号探测器成功着陆火星
2. 中国空间站天和核心舱成功发射、对接
3. 从二氧化碳到淀粉的人工合成
4. 嫦娥五号月球样品揭示月球演化奥秘
5. 揭示SARS-CoV-2逃逸抗病毒药物机制
6. **FAST捕获世界最大快速射电暴样本**
7. 实现高性能纤维锂离子电池规模化制备
8. 可编程超导处理器"祖冲之号"的量子行走
9. 自供电软机器人成功挑战马里亚纳海沟
10. 揭示鸟类迁徙路线成因和长距离关键基因

FRB 121102：熄灭2年后，色散发生演化



- 熄灭2年再度活跃，爆发率以年为时标演化
- 色散系统性降低 ~2%

提供了源周围环境介质的重要信息



Wang et al. in preparation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19 Sep 2022; 04:10 UT

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[Previous]

FRB 20121102A is active again with significantly smaller DM as revealed by FAST

ATel #15619; *Pei Wang(NAOC), Yongkun Zhang(NAOC), Weiwei Zhu(NAOC), Bing Zhang(UNLV), Di Li(NAOC), Junshuo Zhang(NAOC), Jinhuang Cao(NAOC), Yi Feng(Zhejiang Lab), Jinlin Han(NAOC), Kejia Lee(PKU&NAOC), Yuan-Pei Yang(YNU), Chenhui Niu(NAOC), Jiarui Niu(NAOC), Weiyang Wang(PKU), Chenchen Miao(NAOC), Rui Luo(CSIRO), Ye Li(PMO), Bojun Wang(PKU), Fayin Wang(NJU), Xuefeng Wu(PMO), Heng Xu(PKU), Jinchen Jiang(PKU), Jiangwei Xu(PKU), Yunpeng Men(PKU), Dejiang Zhou(NAOC), Jumei Yao(NAOC), Wenfei Yu(SHAO), Chunfeng Zhang(PKU), Songbo Zhang(PMO)*
on 19 Sep 2022; 04:09 UT
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Subjects: Radio, Request for Observations, Transient, Fast Radio Burst

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FAST has been monitoring FRB 20121102A for 0.5 to 1 hour daily to weekly since February of 2022, with the central beam of the FAST 19-beams L-band Array pointing to RA = 05h31m58.70s, DEC = +33d08m52.5s (Chatterjee et al. 2017; Marcote et al. 2017), taking pulsar-searching data with a 49.152 microsecond sampling and 4096 frequency channels in between 1.0 GHz and 1.5 GHz. Following non-detections until August 1st, 2022 (between UTC 2022-08- 01 03:59:00 and UTC 2022-08-01 04:29:00), FAST detected at least 300 bursts from FRB 20121102A with a peak burst rate of 200/hr and estimated fluence between 0.03 and 0.3 Jy ms from the following dates: (UTC) 16th Aug., 21st Aug., 3rd Sep., 7th Sep. and 10-17th Sep., suggesting that this repeater is likely in another active episode. This recent activation of FRB 20121102A is generally consistent with the proposed periodicity of Rajwade et al. (2020) and Cruces et al. (2020), even though in several previous projected active windows no burst was detected by FAST. By combining the bursts collected in Raiwade et al. (2020) and Cruces et al. (2020) and the newly detected by FAST in 2019 and 2022, the projected turn-off date is around 17th Oct. - 1st Dec. 2022. If the source is continuously on after the projected turning-off time, it suggests that the putative period of the source becomes less robust or has evolution.

The optimal dispersion measure (DM) of the bursts is constrained to 552.5 +/- 0.9 pc cm^{-3} which is measured using the method in Seymour et al. (2019), from MJD 59806 till now. This indicates that the DM of FRB 20121102A has decreased by about 10 pc cm^{-3} (i.e. 2%) compared to earlier detections in Li et al. (2020), suggesting a previously unseen temporal DM variation over 10 years. We encourage more follow-up monitoring efforts with multi-band facilities.

FAST is a Chinese national mega-science facility, built and operated by the National Astronomical Observatories, Chinese Academy of Sciences (NAOC). We appreciate all the members in the FAST FRB key science project collaboration for their support and assistance during the observations.

[1] Chatterjee, S.; Law, C. J.; Wharton, R. S. et al. 2017, Nature, 541, 58
[2] Rajwade, K. M.; Mickaliger, M. B.; Stappers, B. W. et al. 2020, MNRAS, 495, 3551
[3] Cruces, M.; Spitler, L. G.; Scholz, P. et al. 2021, MNRAS, 500, 448
[4] Marcote, B.; Paragi, Z.; Hessels, J. W. I. et al., 2017, ApJL, 834, L8
[5] Seymour, A.; Michilli, D.; Pleunis, Z. et al., 2019, Astrophys. Source Code Lib. ascl:1910.004
[6] Li, D.; Wang, P.; Zhu, W. W. et al., 2021, Nature, 598, 267

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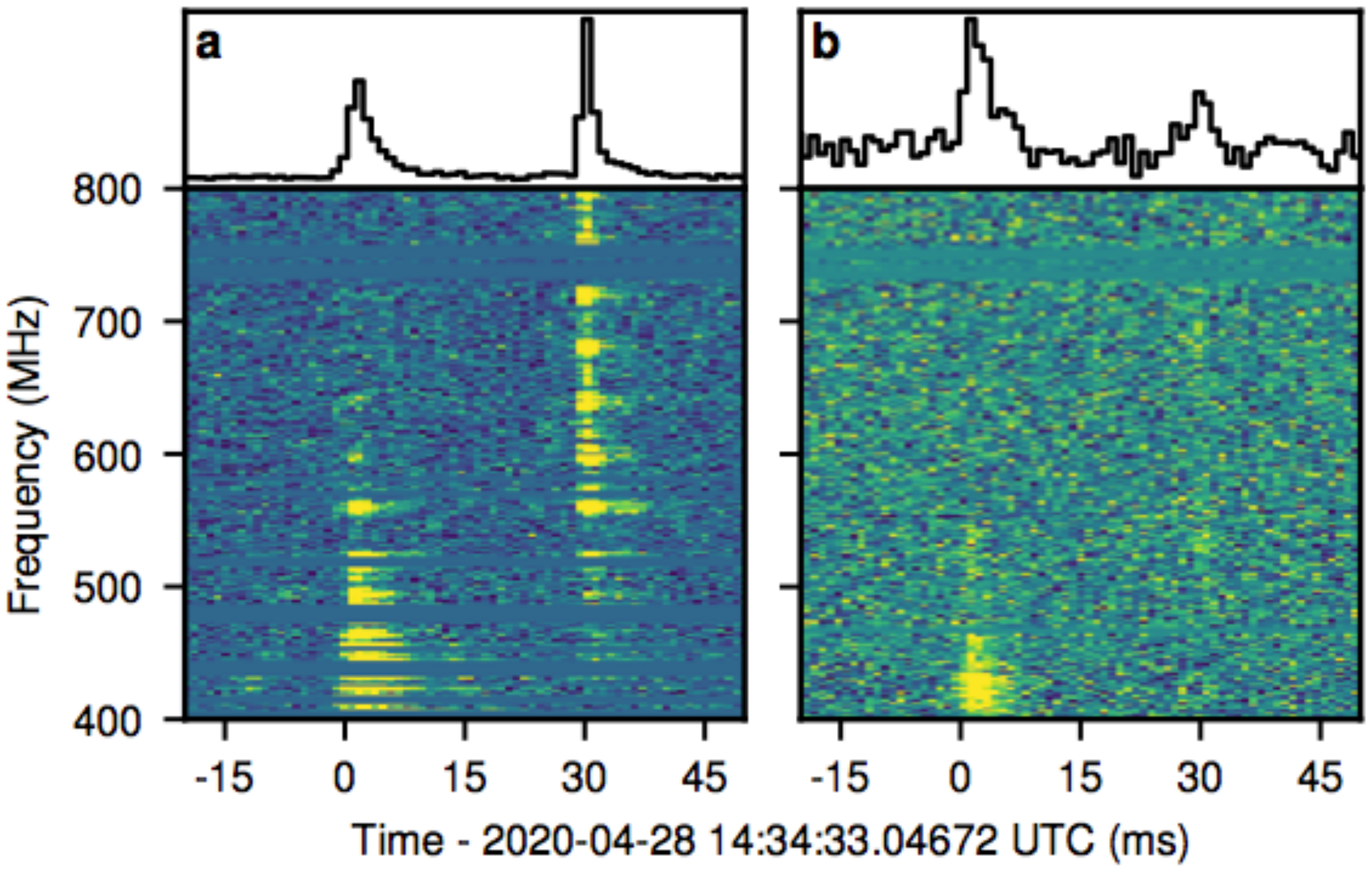
Wang et al. 2022 Atel#15619

SGR J1935+2154: 首次追踪到磁陀星与FRB的联系

CHIME/FRB Collaboration et al. 2020, Nature
STARE2: Bochenek et al. 2020, Nature

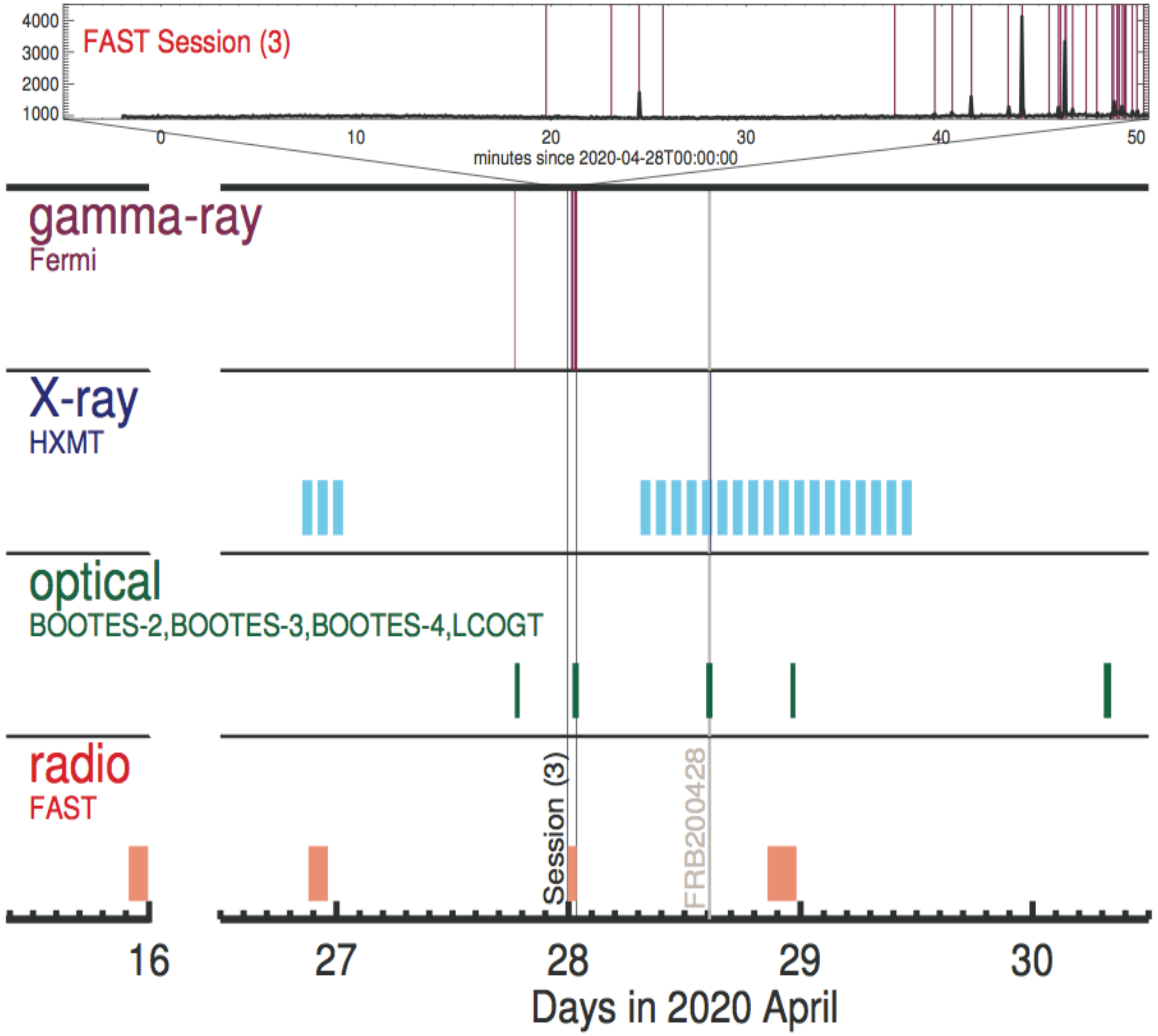


$$E_{\rm CHIME} = 3^{+3.0}_{-1.6} \times 10^{34}\ {\rm erg}$$

$$E_{\rm STARE2} = (2.2 \pm 0.4) \times 10^{35}\ {\rm erg}$$

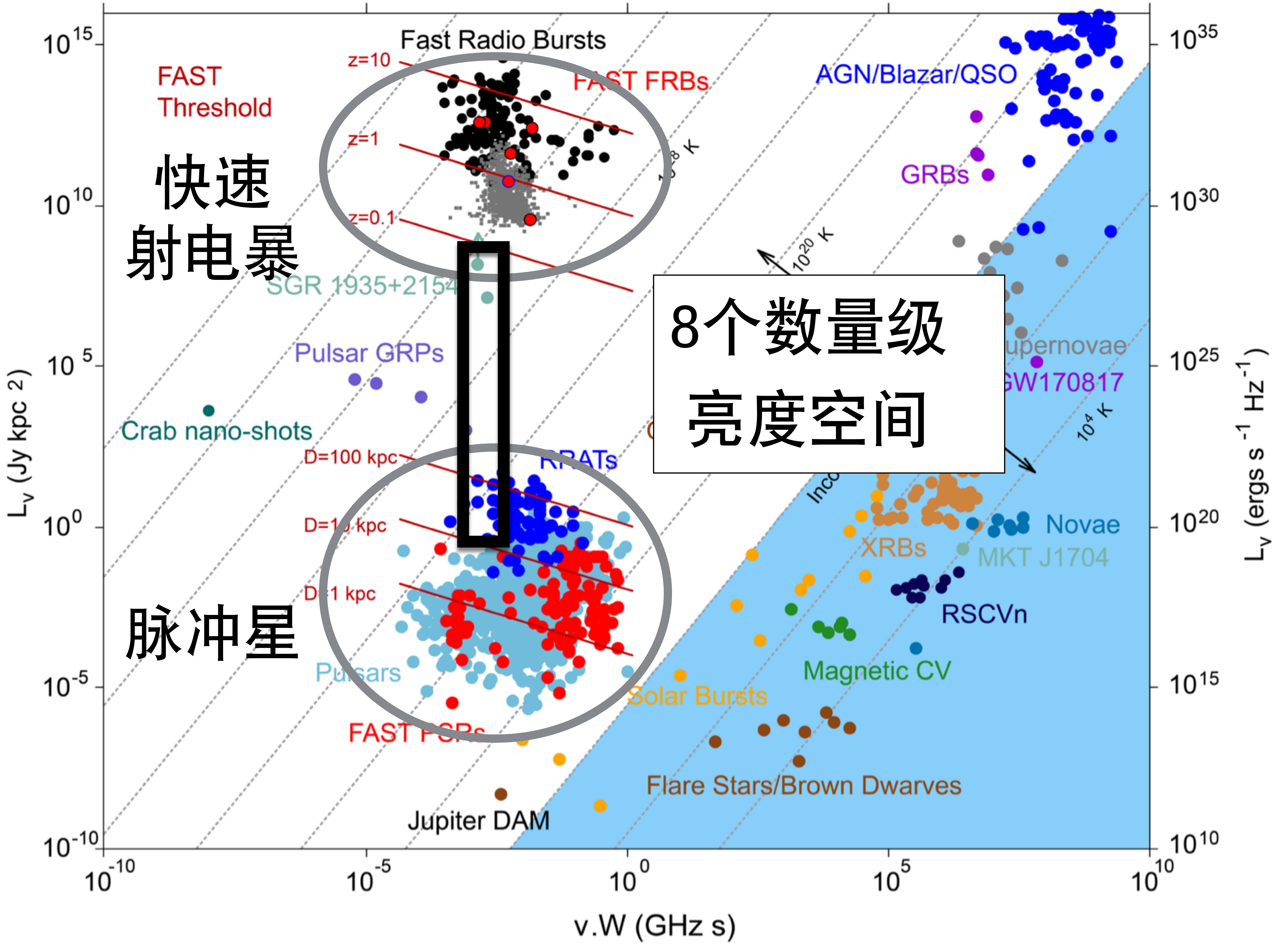
FRB200428 比FRB特征能量低 ~3个数量级

29个软伽马射线暴



FAST开展SGR J1935+2154集中观测
没有探测到任何射电辐射

SGR J1935+2154: 最严格限制磁陀星爆发射电流量



光度 ↑

爆发时标 →

nature 587，63–65（2020）

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Article | Published: 04 November 2020

No pulsed radio emission during a bursting phase of a Galactic magnetar

FAST: Lin, Zhang, Wang et al. 2020, Nature

获得最深射电流量限制，
给出最强物理约束

- FRB与SGR具有较弱的相关性
- 磁星可能是大部分FRB起源

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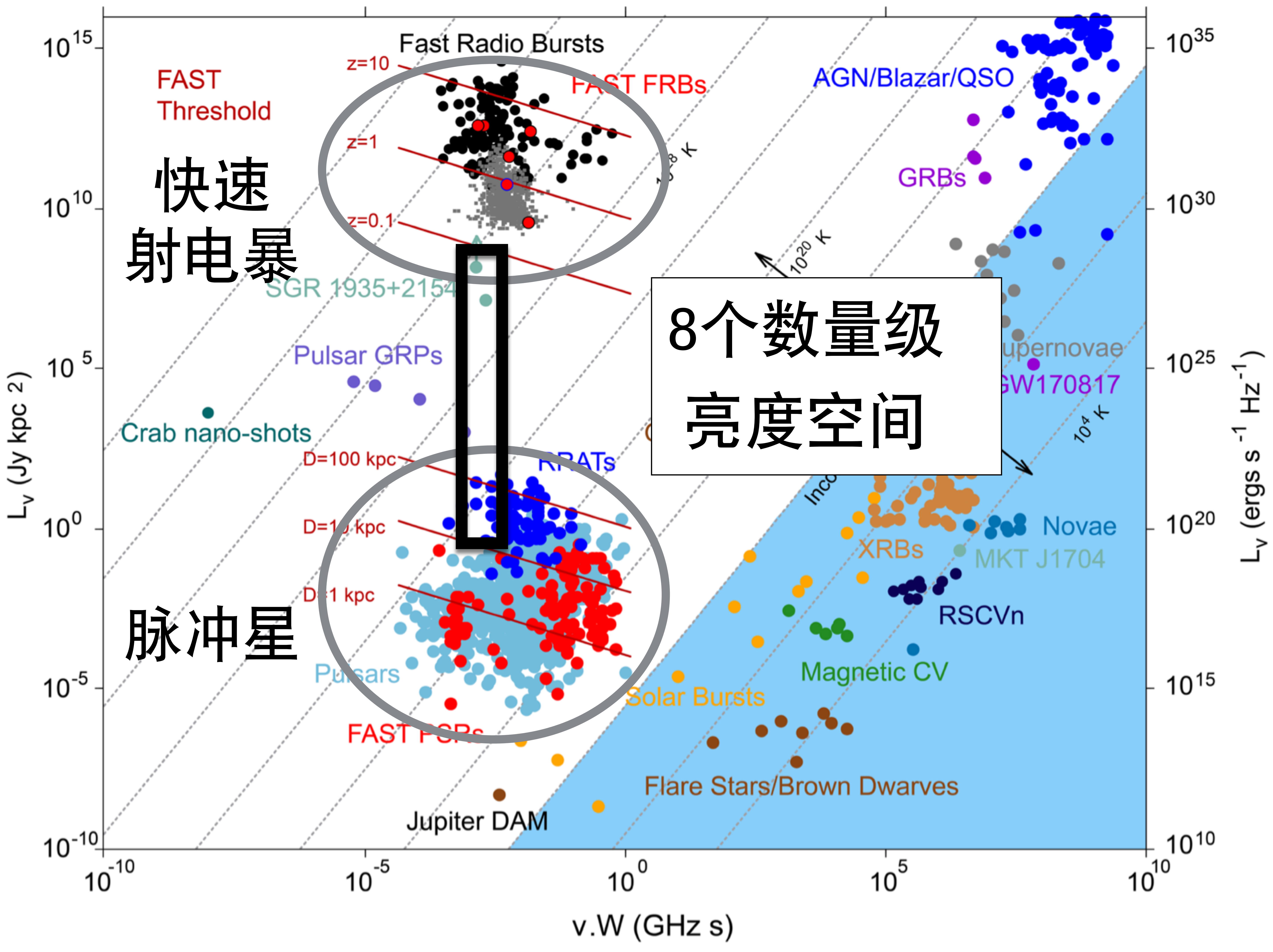
光度



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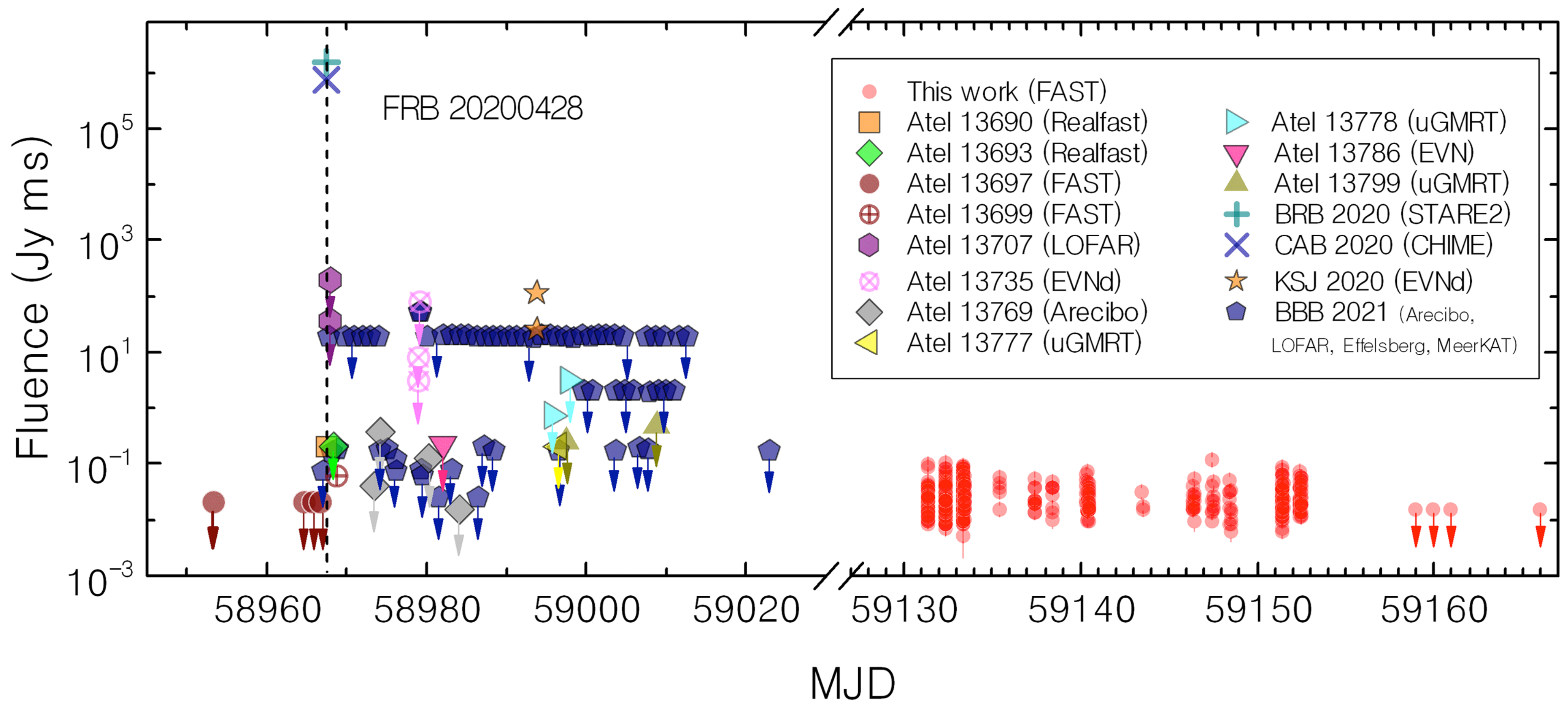
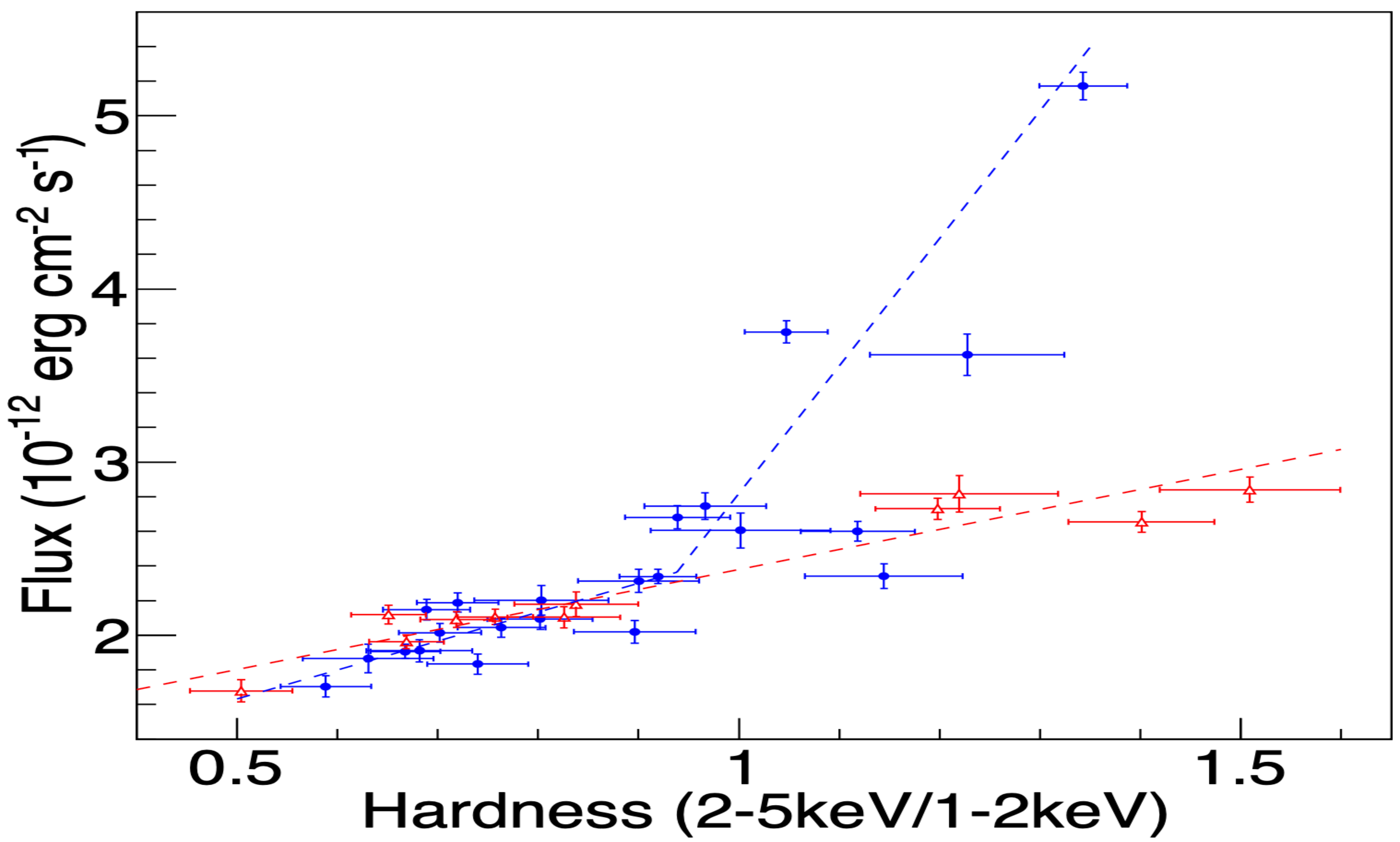
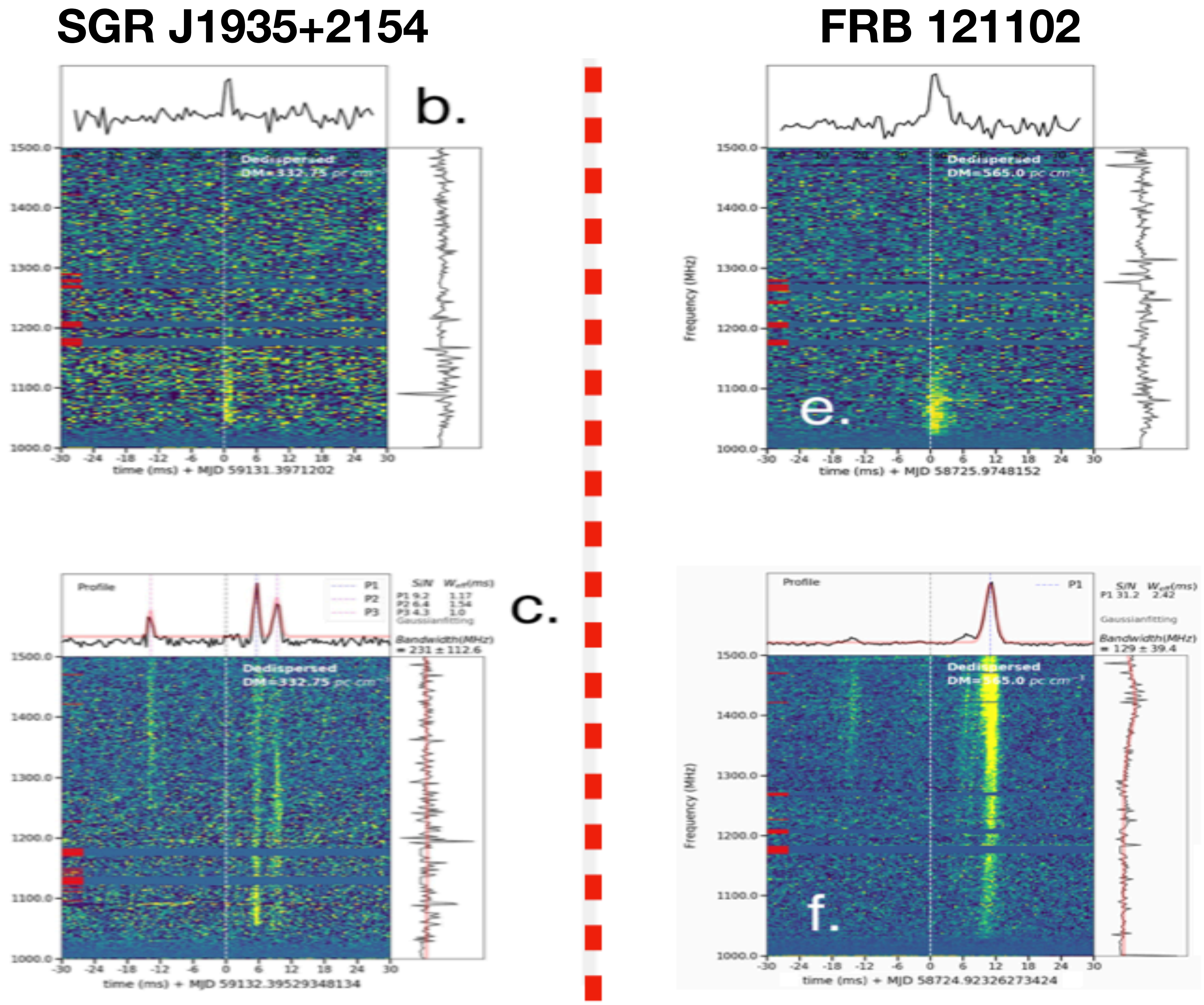
入选《自然》、《科学》分别评选2020年度世界科学十大发现及十大科技进展

入选 2020 年“中国十大天文科技进展”（“中国天眼确定快速射电暴起源”排名第一）

SGR J1935+2154: 转换为射电脉冲星







- 5个月后出现与自转周期一致的射电脉冲辐射
- 脉冲星辐射出现稀有的窄带及频漂FRB特征
- 射电脉冲时间窗口内外，Xray硬度bimodel分布

FAST + X射线 多波段多设备观测

以更好理解磁陀星和FRB之间的潜在关系

总 结

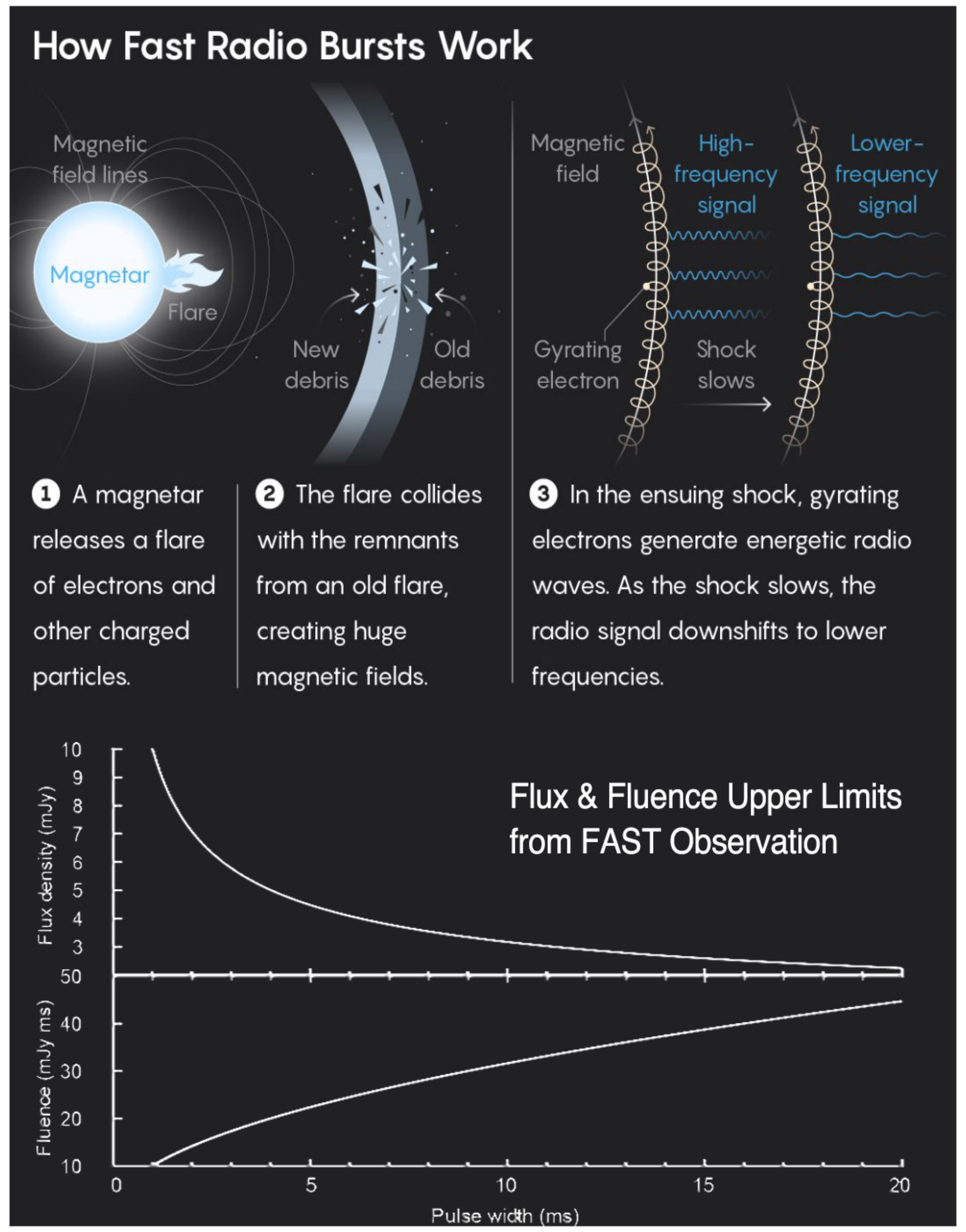
FRB研究前沿在于新样本和特殊样本发现，高精度物理量测量和细致分析

依托FAST为核心的国内外设备优势，正在揭示FRB起源、本质、分类、演化、源区环境

FRB 121102

- 大样本集，揭示FRB爆发率能谱
- 色散改变，体现源周围环境介质演化

SGR J1935+2154



- 最严格限制磁陀星高能爆发对应射电流量
- 多模态辐射：磁陀星－FRB－射电脉冲星

“Fast radio bursts at the dawn of the 2020s”
Petroff et al. 2022
Astron Astrophys Rev (2022)30:2

Open Questions:

- What’s the FRB redshift distribution?
- Are all FRBs repeating? One-off FRBs?
- What is the coherent mechanism (curvature or maser)?
- All FRBs have period? Physical mechanisms (precession or binary)?
- Are there engines other than magnetars that power FRBs?
- FRB, GRB, SLSNe and GW associations?

Instruments:

Current: FAST, CHIME, ASKAP, VLA, EVN, ~~Arecibo~~, GBT, MeerKAT…
Future: FASTA, SKA, QTT,…

随着FRB研究深入，不断有问题解决，又有新问题出现，看似混乱
正是探索充满活力的迷人之处

FAST 正在为揭示这一宇宙中神秘现象的机制、推进快速射电暴的天文学全新领域做出独特贡献！

谢 谢

敬请批评指正

FRB 121102 obs favors SNR scenarios ?

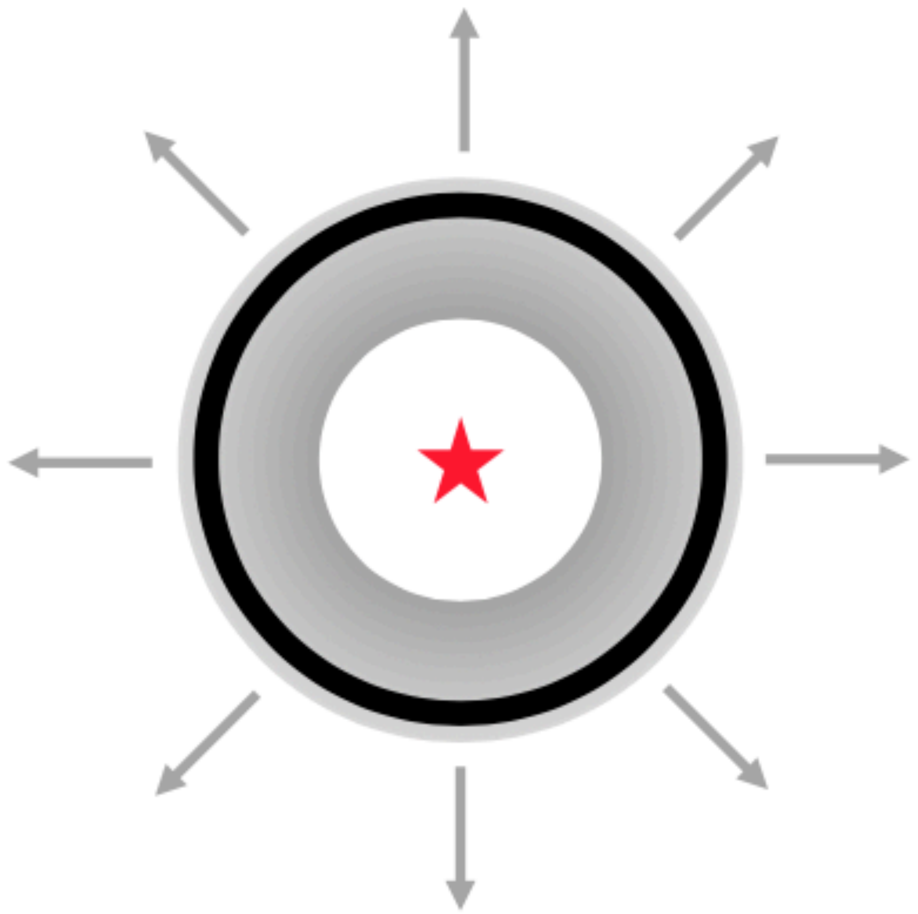
two origins ?

- **FRB repeater： complex environment**
- **non-repeater： simple environment**

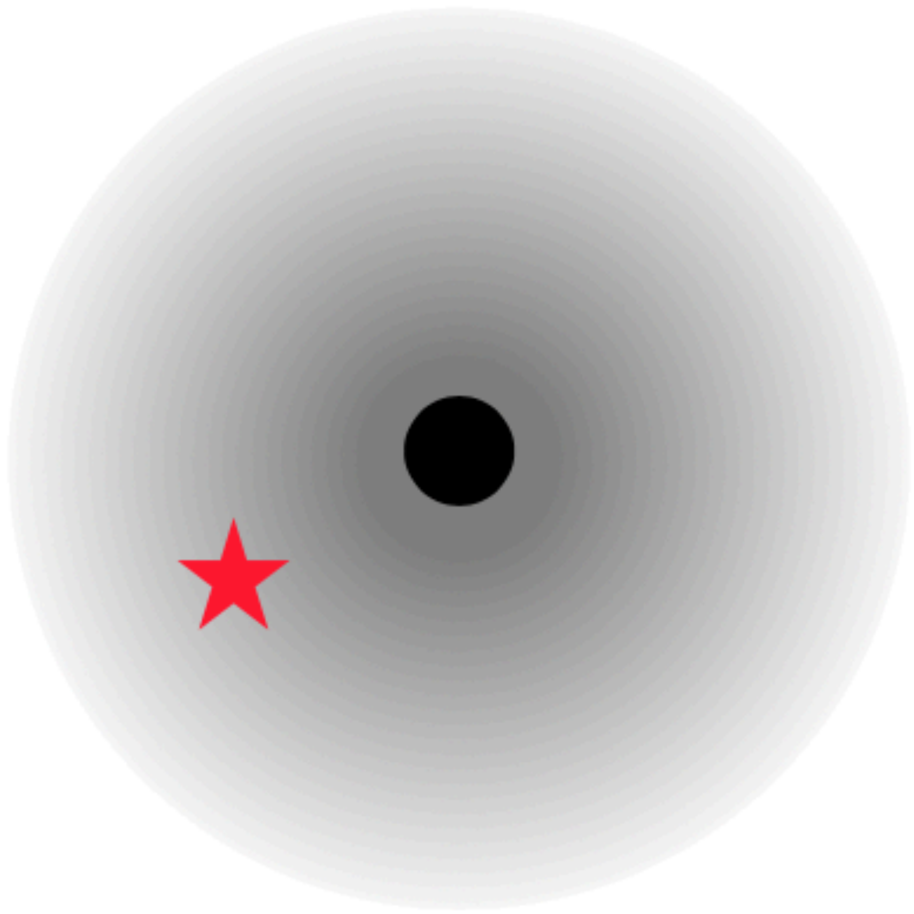
massive black holes or binary systems

- **No spin/orbital periodicity are found.**
- **Why no FRB is found in galactic binary systems?**

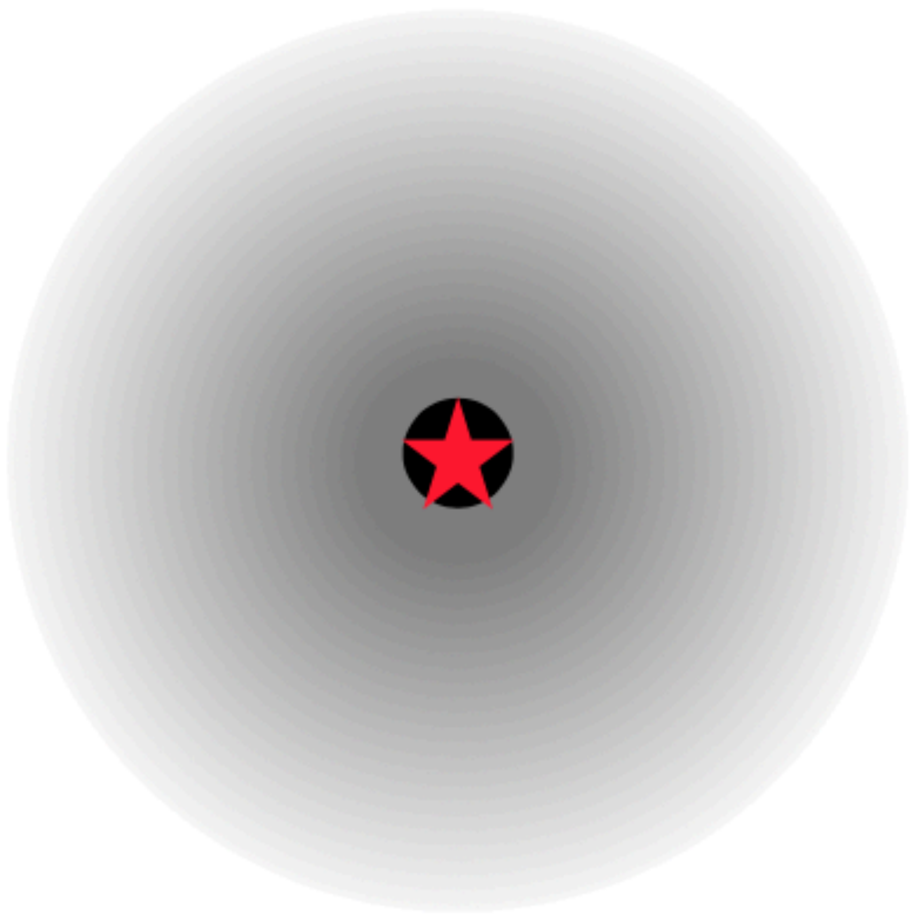
SNR or Magnetar Nebula



Galactic Center (unrelated)



Galactic Center (related)



FRB Source

Persistent Radio Source

Magnetized Plasma