FRBs searching stories

K. J. Lee (李柯伽)

Kavli institute for astronomy and astrophysics, Peking Univ.

NAOC, CAS

I am the speaker, but work is done by many others

Students, PKU-XAO-YNAO FRB searching team

FAST FRB collaboration and …

@NAOC 2020 Dec.

Outline

- What is FRB
- What we are doing
- Four stories

What is FRB?

- Fast radio bursts

A Bright Millisecond Radio Burst of Extragalactic Origin

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
nd a 30-jansky dispersed burst, less
ellanic Cloud. The burst properties
Magellanic Cloud. Current models for
less than 1 gigaparsec distant. No
which implies that it was a singular
hundreds of similar events could occur

Preliminary Statistical Analysis of Fast Radio Bursts at 3 Wavelengthes Observed at Yunnan Observatory

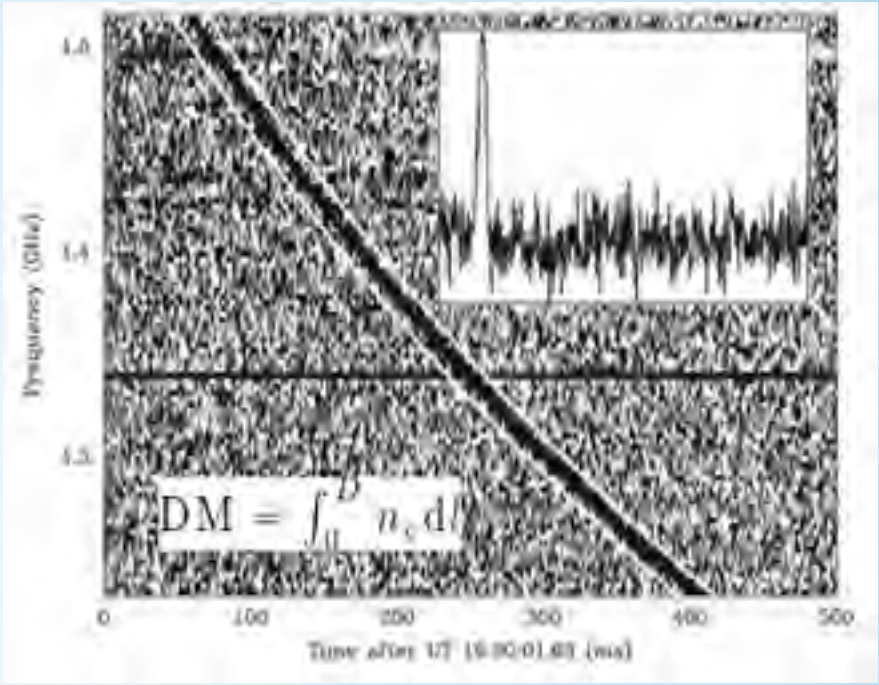
Ma Yuan, Xie Ruixuan, Yang Kaiping
(Yunnan Observatory, Academia Sinica)

Abstract

In this paper the statistics of the fast solar radio spike events at 7.5cm, 10.6 cm and 21 cm wavelengths observed at the Yunnan Observatory from February 1987 to April 3, 1988 are presented. These events are compared with the corresponding optical observations. Two spike events obtained on March 29 and April 2, 1988, are also preliminarily analysed in this article.

FRBs

- High DM (Greater than local Galaxy values)
- Short duration (ms) --> must be compact
- Bright --> 1E38 erg/s
- Mostly found around 1GHz (recently detected around 100MHz)
- Spectrum now known
- Maybe two types
  - repetitive vs non repetitive
- **Unknown** origins



Lorimer et al. 2007

FRB catalog (Petroff et al. 2016)

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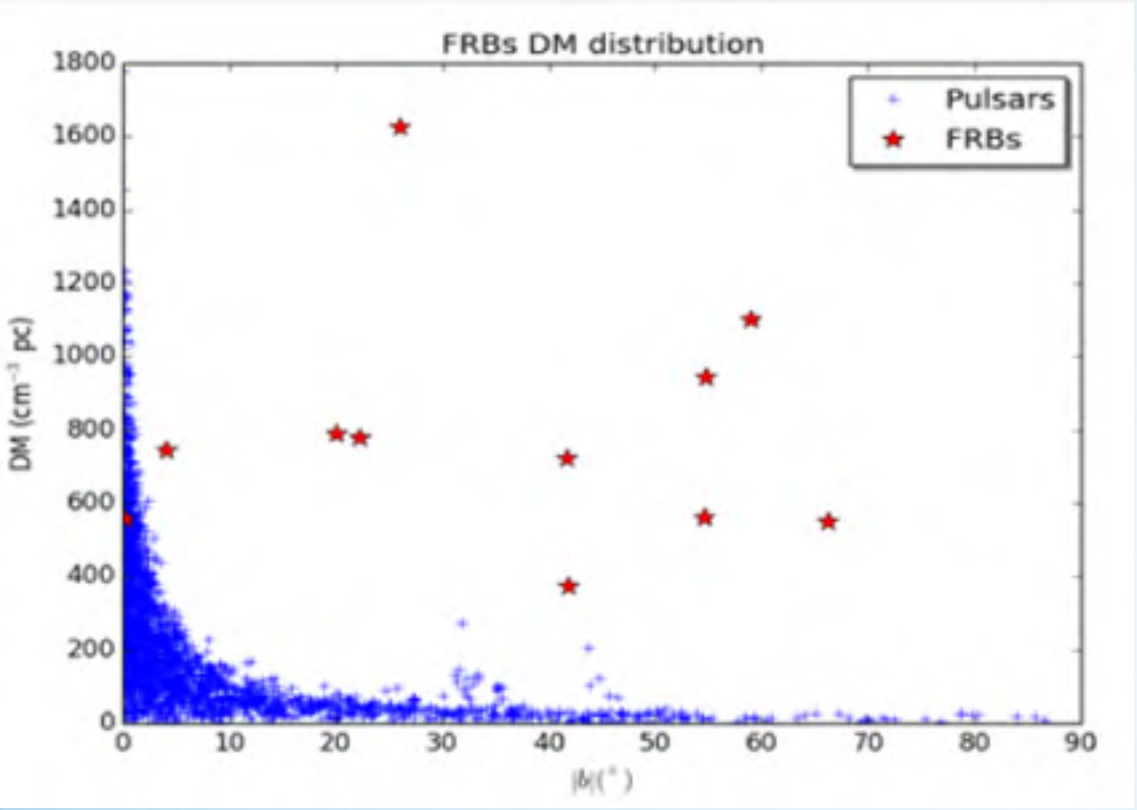
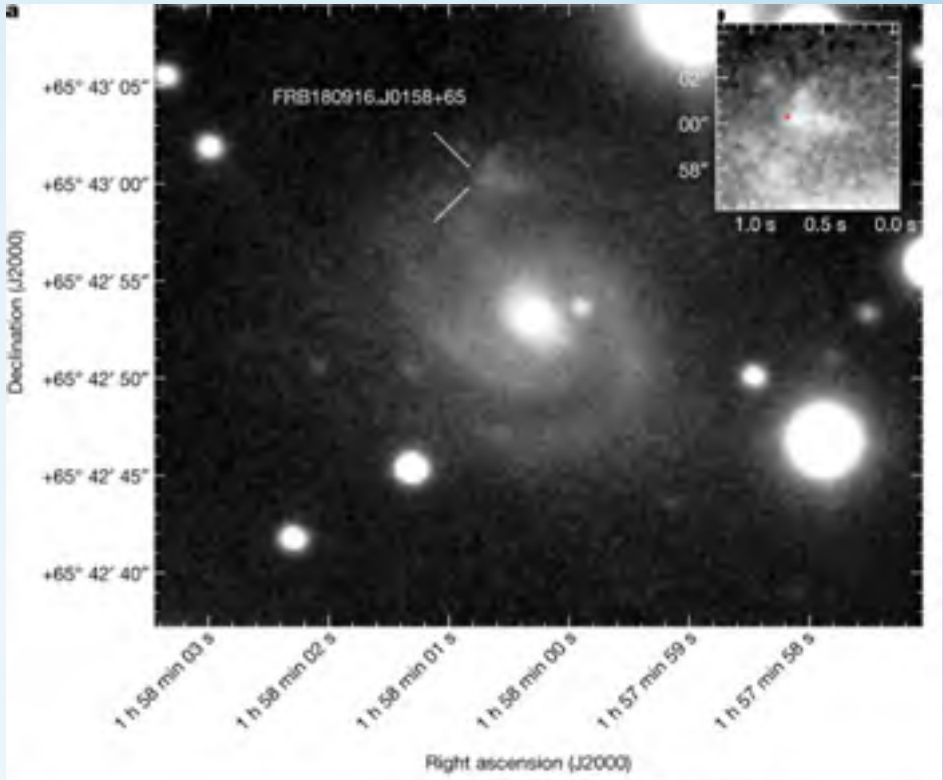
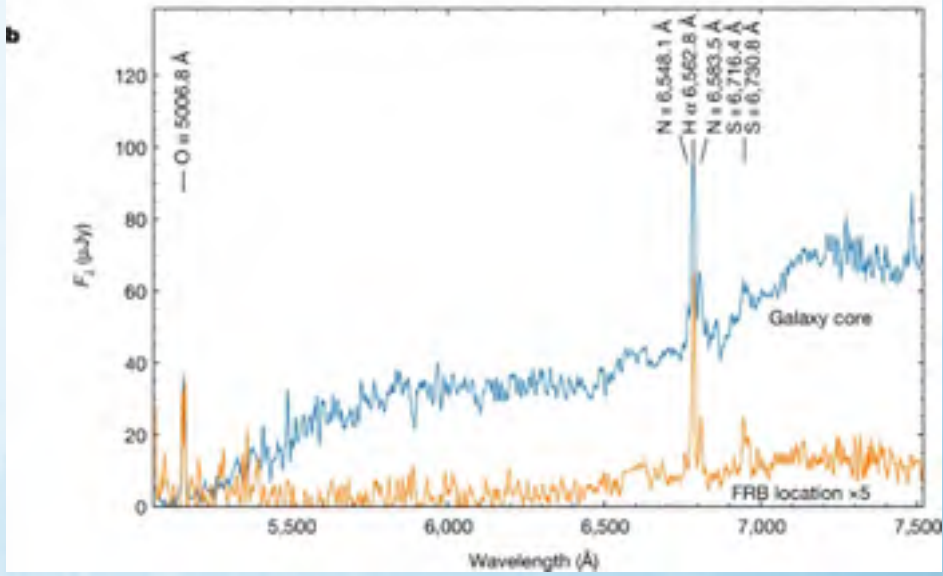
Observational facts







FRB is extragalactic

Marcote et al., 2020

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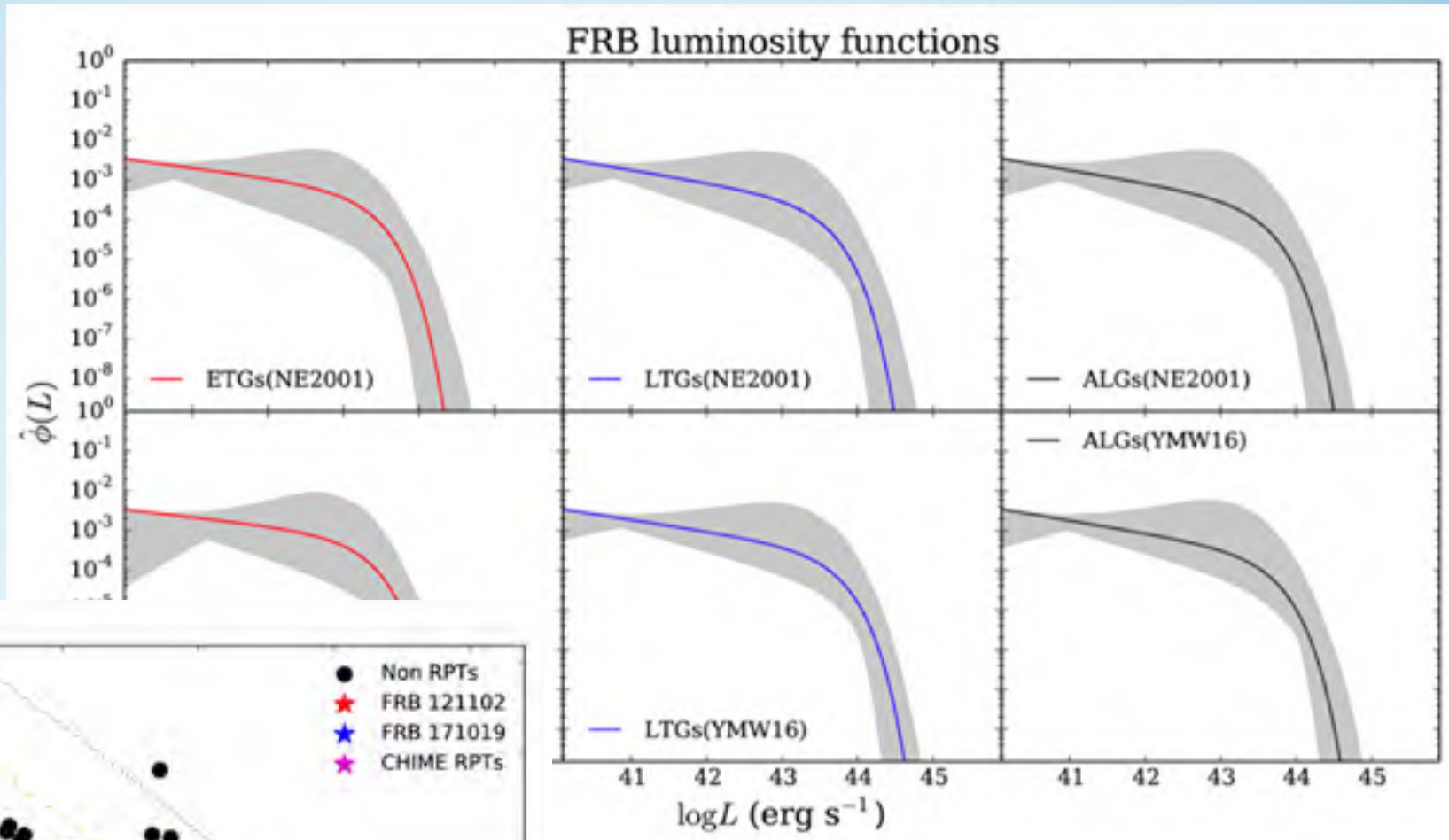
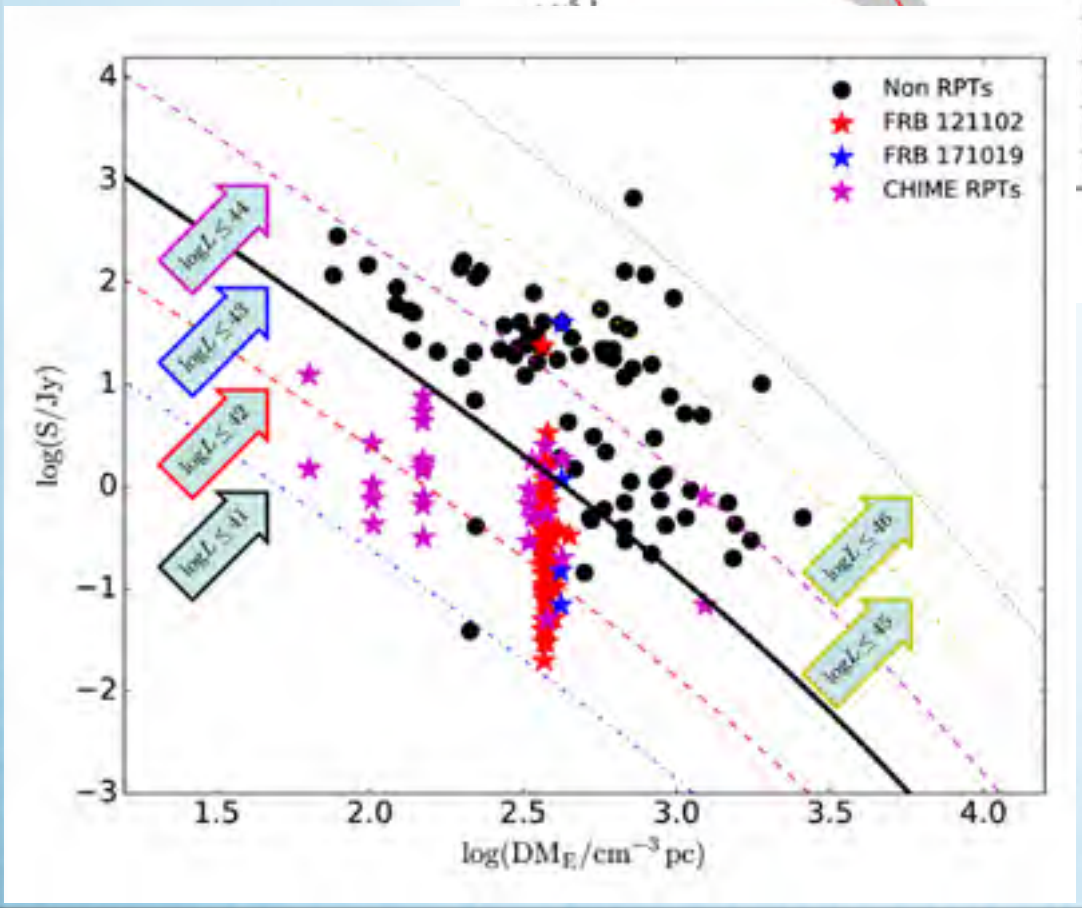




Luo et al., 2018

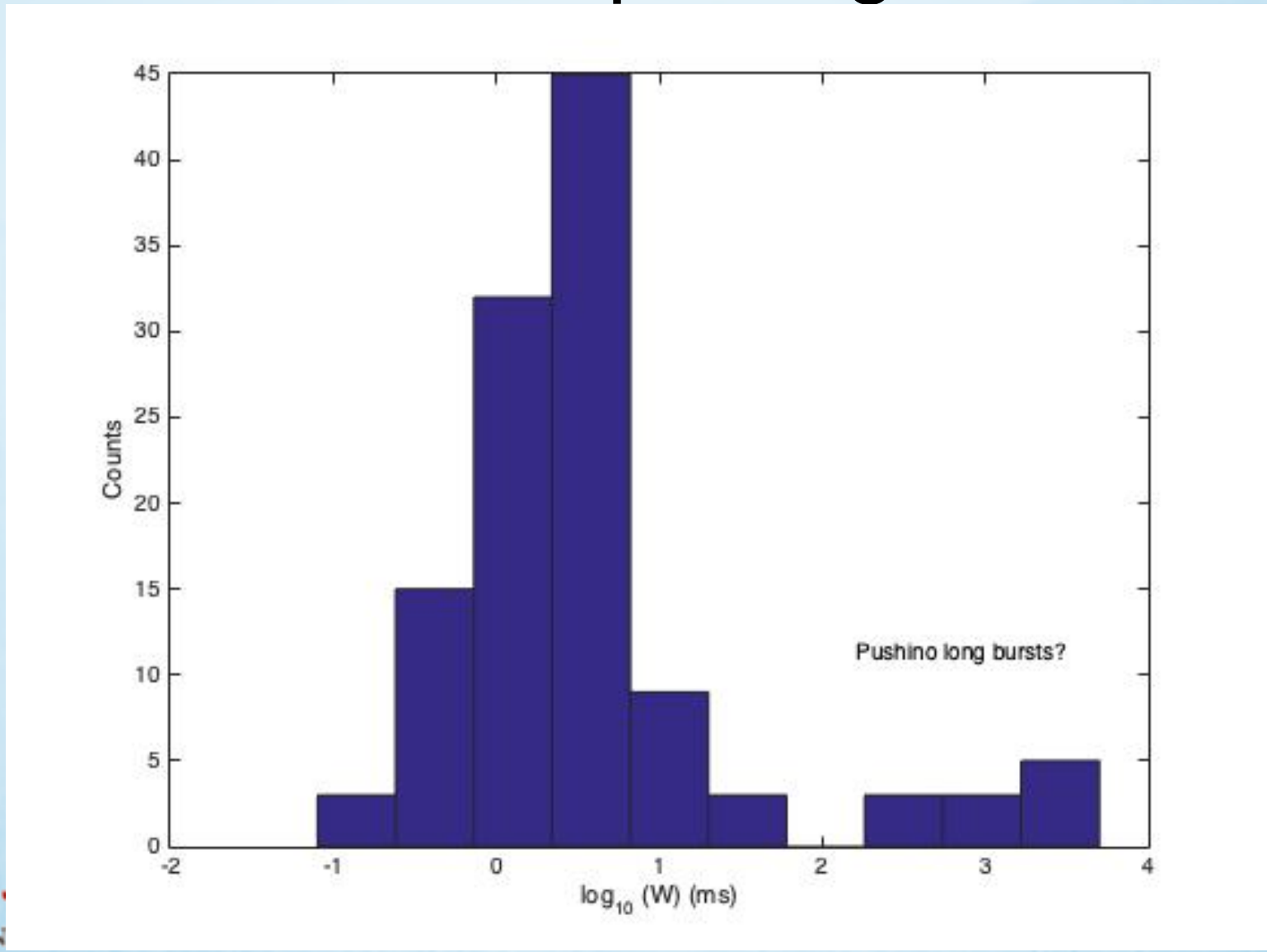
Peak flux of 1E42 erg/s
Cut-off around 1E44 erg/s

Luo et al., 2019

http://frbcat.org/

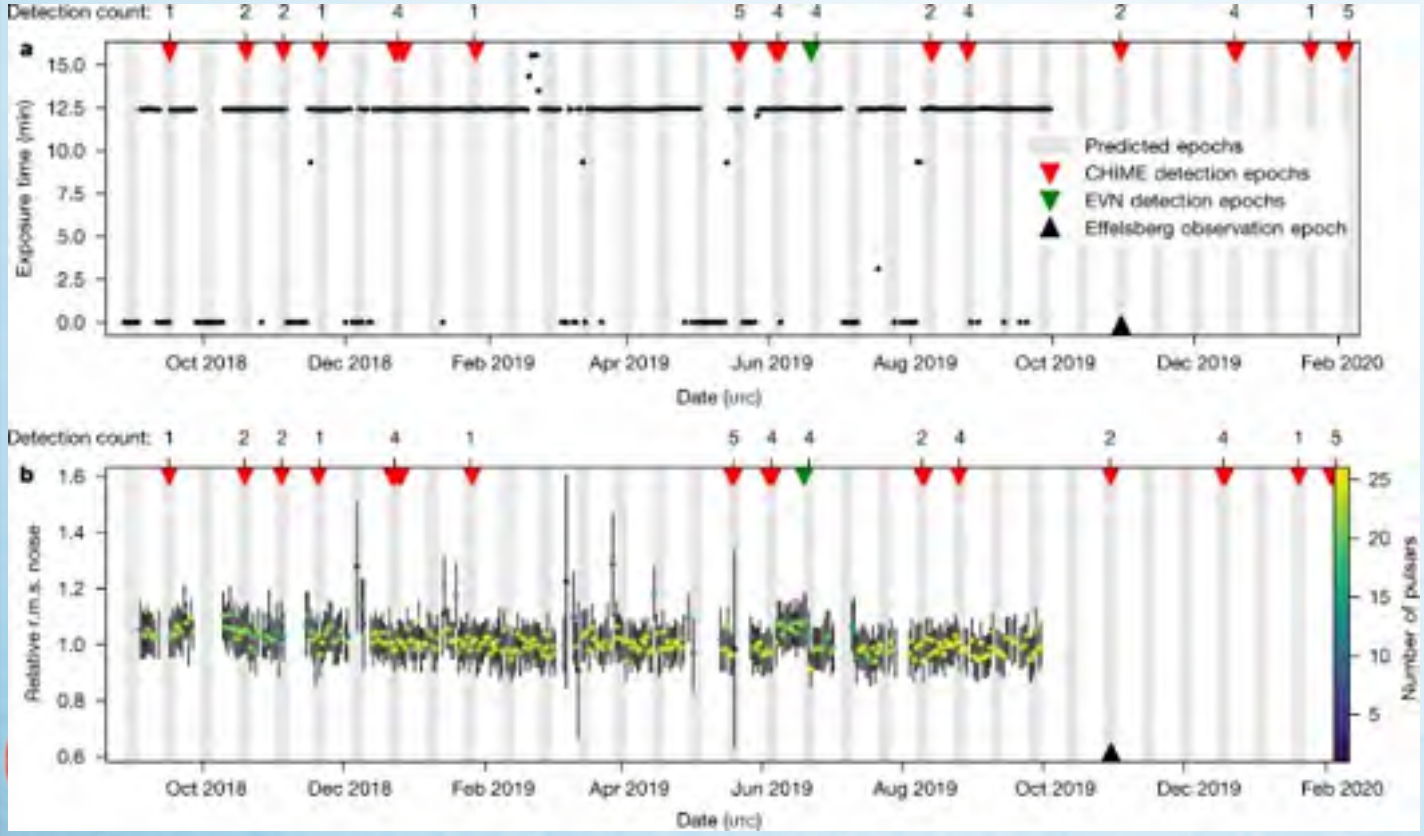
FRB pulse width

119 in total, 23 repeating ones.



Possible period

CHIME 2020



Key breakthrough in the past

- Discovery 2007
- Repeater 2012
- Host galaxy identification 2017
- High magnetic field 2018
- 16-day period 2019

One sentence conclusion

- FRB, repeating or not, is a ms-duration radio burst with about 1E42 erg/s peak flux.
- No spin-like period detected yet, but longer period may be discovered.

Models

- radio pulses from black hole evaporation (Rees 1977; Keane et al. 2012)
- superconducting cosmic strings (Cai et al. 2012a,b; Yu et al. 2014)
- flaring stars (Loeb et al. 2014) or magnetars (Popov & Postnov 2010, 2013);
- mergers of white dwarfs (Kashiyama et al. 2013);
- mergers of double neutron stars (Totani 2013; Wang et al. 2016);
- collapses of neutron stars into black holes (Falcke & Rezzolla 2014; Zhang 2014);
- synchrotron masers (Lyubarsky 2014; Ghisellini 2017; Lu & Kumar 2018)
- binary model of white dwarf and black hole (Gu et al. 2016);
- super-giant pulses from pulsars (Cordes & Wasserman 2016; Connor et al. 2016)
- radio emissions from soft gamma-ray repeaters (Pen & Connor 2015; Katz 2016);
- axion stars (Iwazaki 2015);
- quark nova (Shand et al. 2016);
- mergers of charged black holes (Liu et al. 2016; Zhang 2016b
- collisions between pulsar and asteroids (Geng & Huang 2015; Dai et al. 2016);
- Inspiral DNS(Wang et al., 2016)
- relativistic jet – cloud interactions (Romero et al. 2016; Vieyro et al. 2017;
- births of millisecond magnetars (Metzger et al. 2017);
- 'cosmic comb', i.e. magnetosphere – environment interactions(Zhang 2017, 2018);
- accretion of black holes (Katz 2017);
- star-quakes of compact stars (Wang et al. 2018).
-

Story 1 Searching FRB with NS26m and KM 40m, Peryton detection

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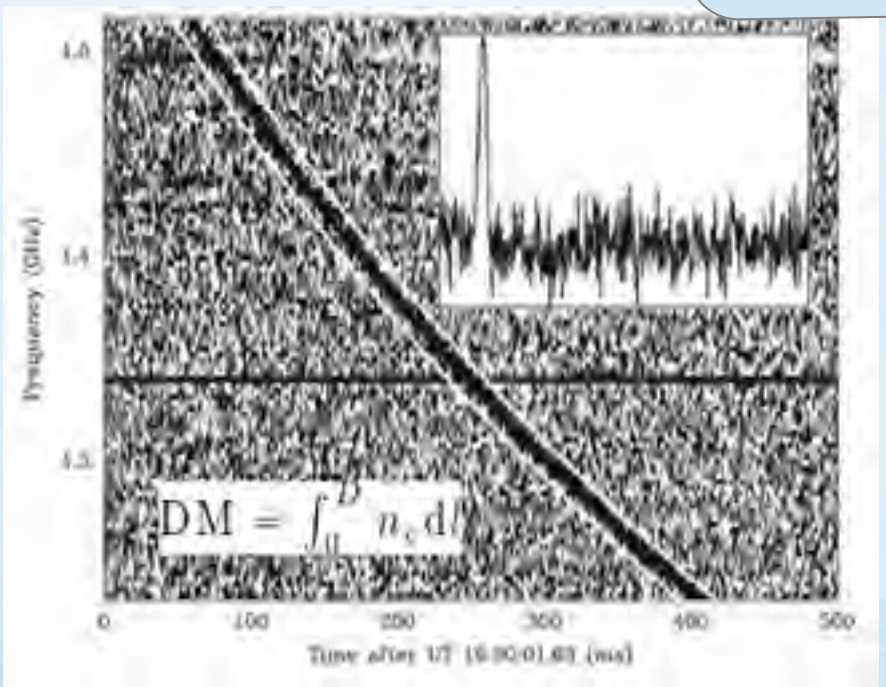
In 2007, Prof. Qiao told us about this paper in the group meeting.

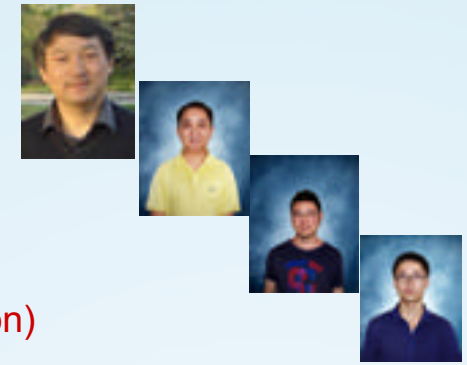
May be RFIs,
but it is interesting.

How so?



2015, we decide to try to search for FRBs

Peking University



K. J. Lee (PI)

R. X. Xu (theory)

R. Luo (theory)

Y. P. Men (data processing, instrumentation)

C. F. Zhang (AI, data reduction)

Xinjiang Observatory

X. Pei (data processing, instrumentation, observation)
Z. Y. Liu (instrumentation)

Z. G. Wen (data processing, observation)

J. P. Yuan (Data, observation)

Yunnan Observatory

L.F. Hao (observation, data processing)

Y.H. Xu (observation, data processing)

Z.X. LI (Observation, data processing)

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Supported by U1531243 and 天山创新团队

Story line around 2015

- Discovery 2007
- Repeater 2012
- Host galaxy identification 2017
- High magnetic field 2018
- 16-day period 2019

项目批准号	U1531243
申请代码	A03
归口管理部门	
依托单位代码	10087108A0031-0054

U15312431008151

国家自然科学基金委员会

资助项目计划书

资助类别：联合基金项目

亚类说明：重点支持项目

附注说明：天文联合基金

项目名称：云南台40米和新疆台25米脉冲星和快速射电暴观测研究

直接费用：210万元　　间接费用：29.6万元

项目资金：239.6万元　　执行年限：2016.01-2019.12

1， 建立和完善云南 40 米脉冲星观测系统以获取可
工程”任务的同时，云南 40 米（S、X 波段）每年可以保证 2000

2， 脉冲轮廓多波段观测研究以检验脉冲星磁层辐射模型。这一研究不仅能够检验脉冲星射电辐射模型（Lee et al., 2009），而且有助于国内新建望远镜的良好运行、获取可靠

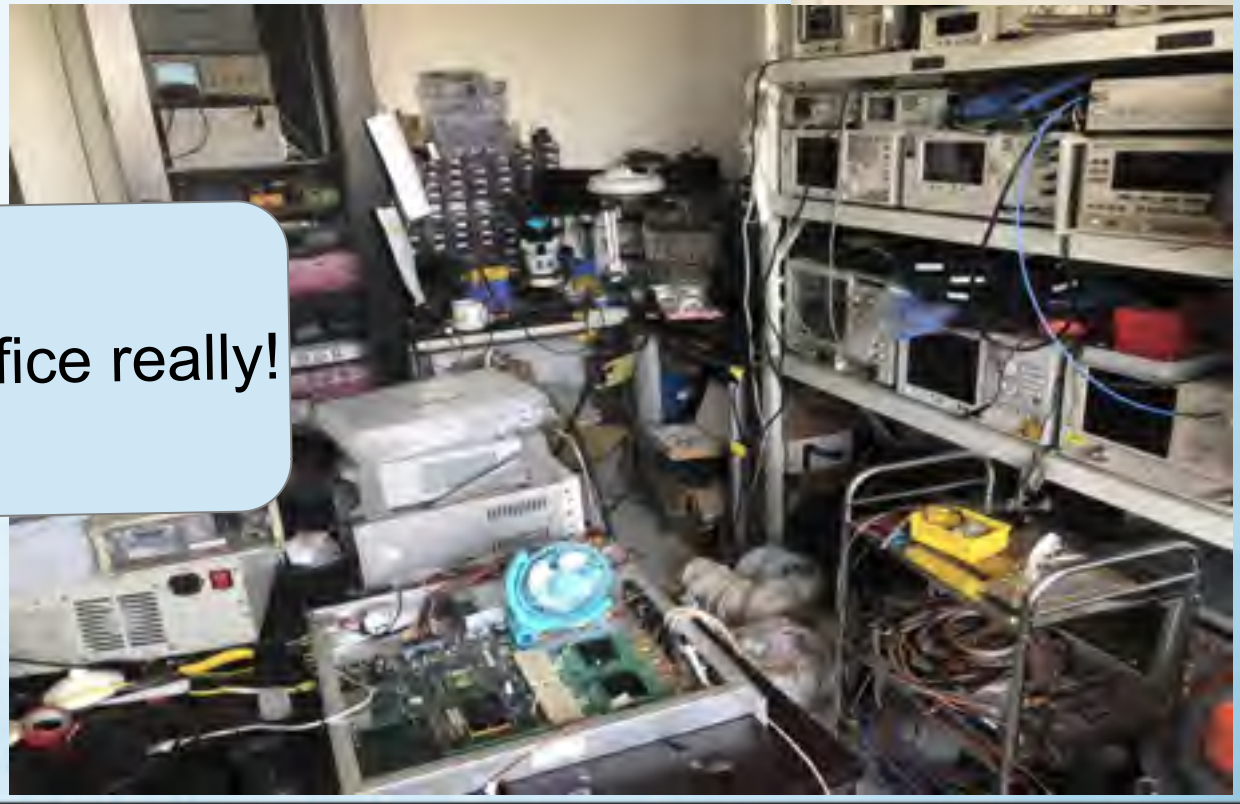
3， 发展国内脉冲星和爆发类射电天体的搜寻技术。过去 20 年中，脉冲星相关科学的前沿无不与发现新类型的脉冲星息息相关。发现新的脉冲星不仅仅为脉冲星测时阵列提

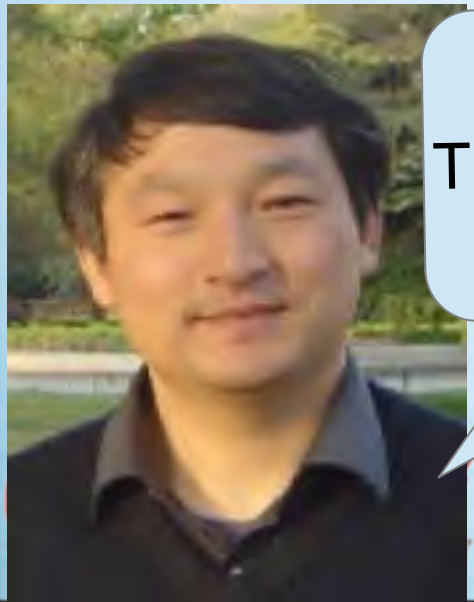
4， 常规计时监测若干脉冲星以获取自转、轮廓演变、消零等方面的信息。脉冲星自转行为的变化以及脉冲缺失现象反映了磁层的动力学过程和星体内部结构；近期的研究还发现

5， 反常 X 射线脉冲星和软伽玛射线重复暴（AXP/SGR）的射电监测。目前在约 30 颗 AXP/SGR 中发现几颗是射电暂现源；这对于人们了解 AXP/SGR 的本质是关键的。根据云台 40 米

First, let there be a lab

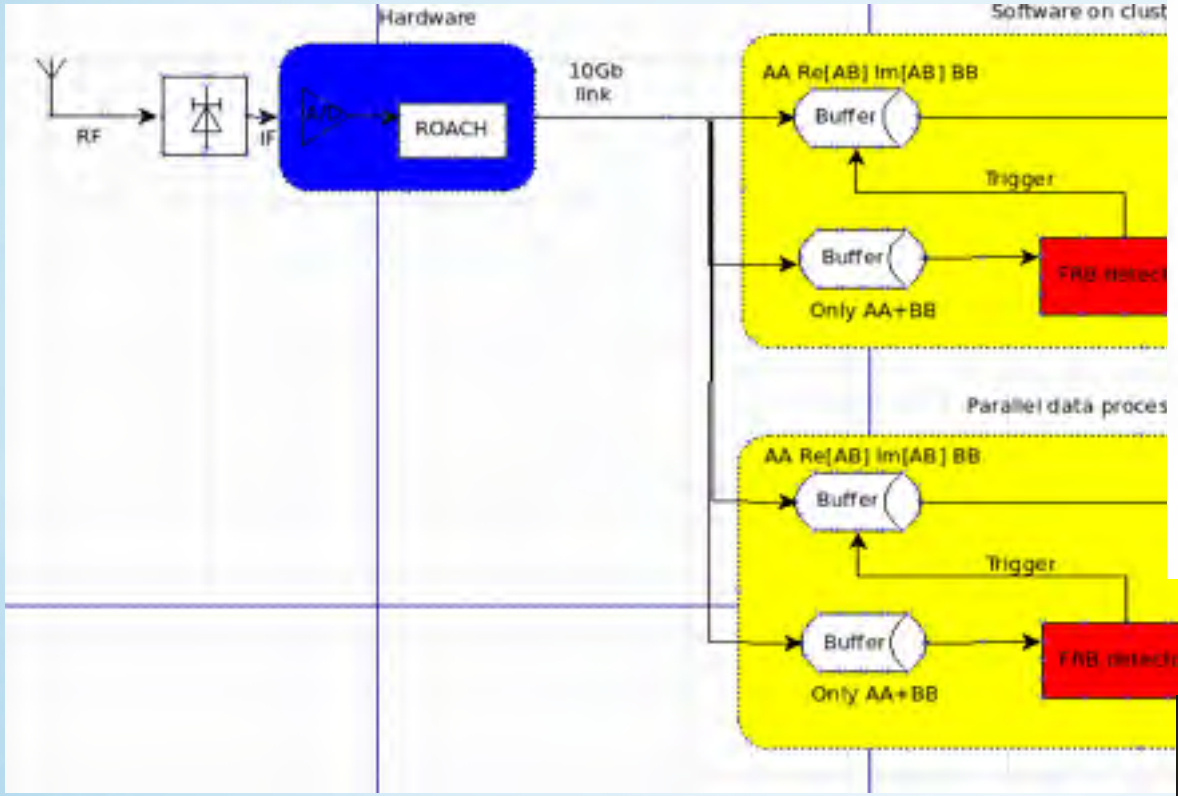
- We spend three minutes to convince Prof. Xu to convert his office to be a lab for 6 month. We then spend a few months to do so, and then we sneakily and gradually installed those noisy things such as miller and driller there.

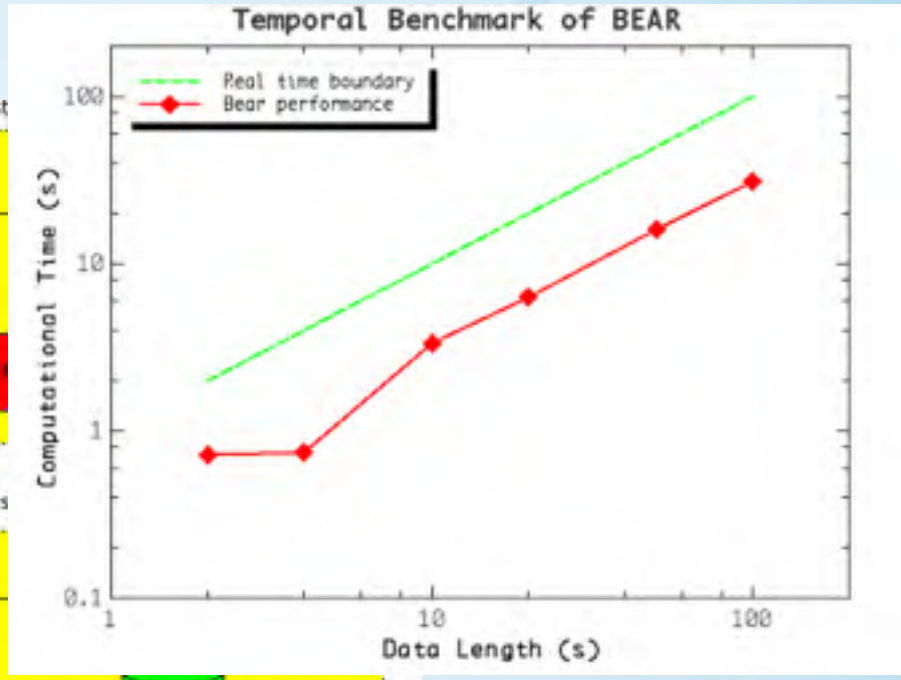




That was my office really!

While waiting for the things to arrive, we code the software





500MHz BW, 3000 DM tries

Developed Software BEAR. Optimize the memory-cache access that we can real time processing with one cpu core. Also we get the match filter runs with O(N+m) complexity instead of Nlog(m) .

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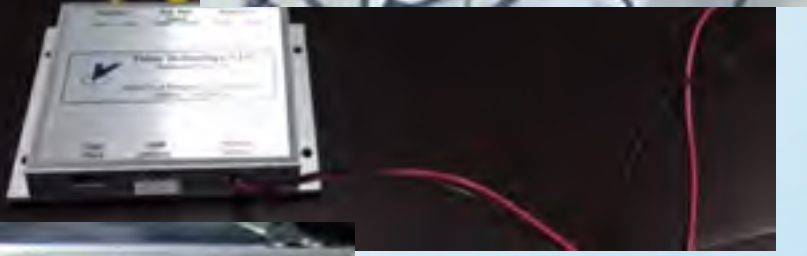
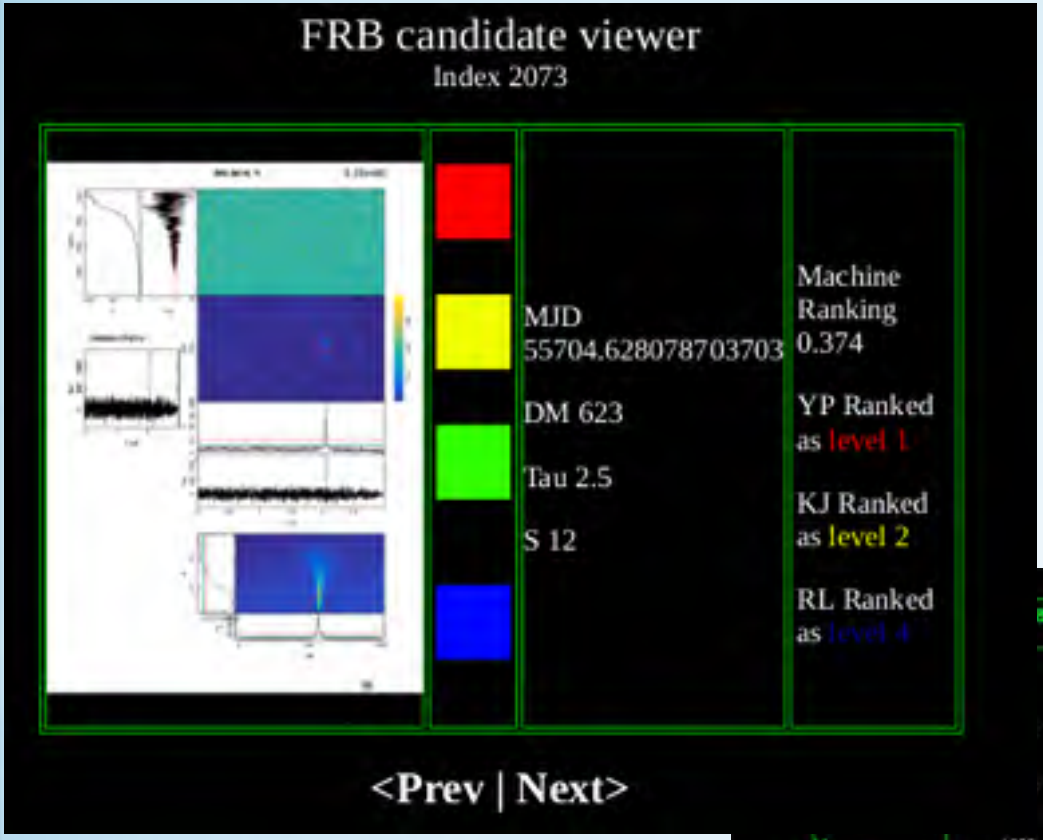
After we have the lab, Hardware developing

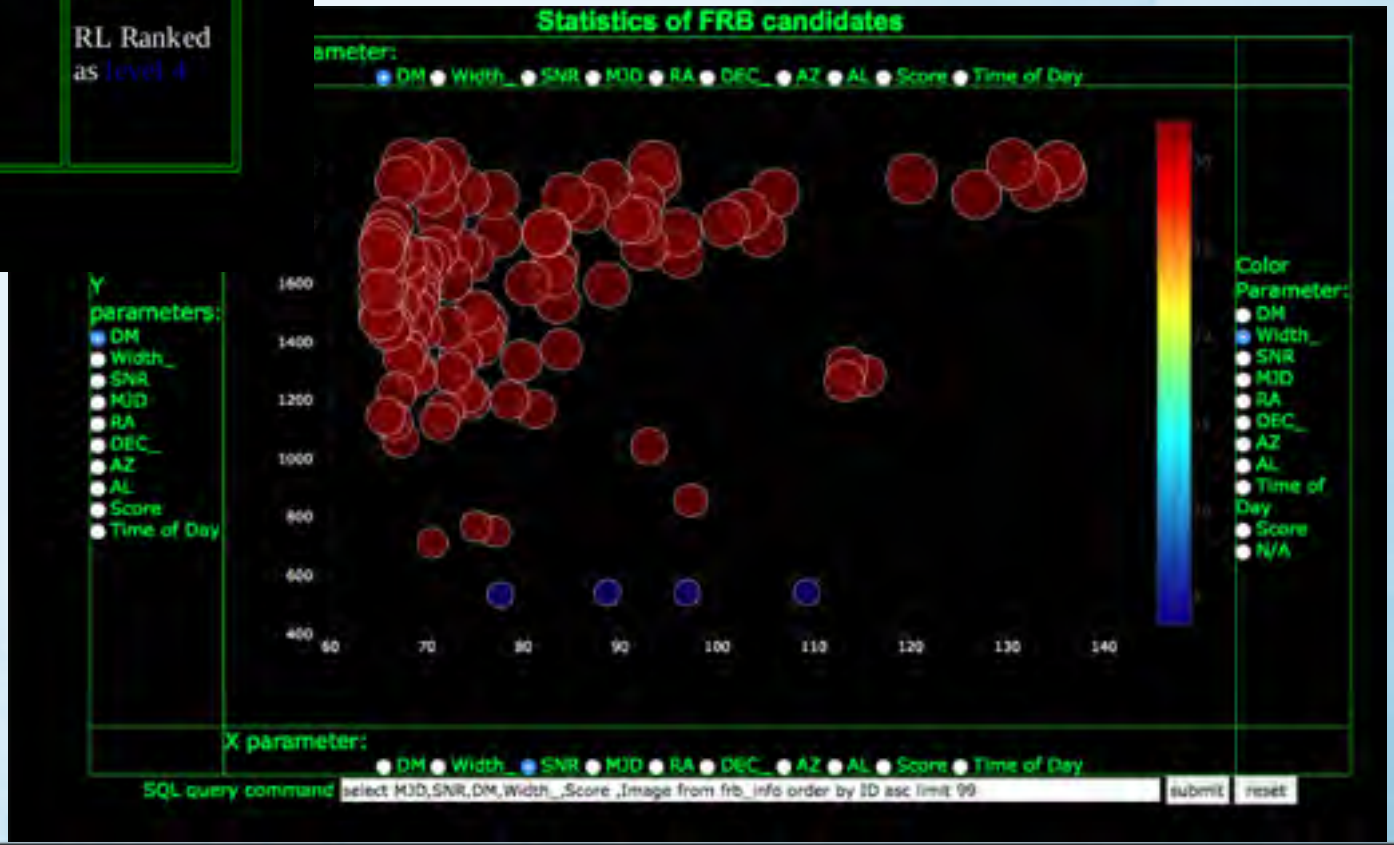
Roach 2 system



Web framework for sifting



We are trying to put the data online even before we saw the results. In this way, everyone can help and contribute.



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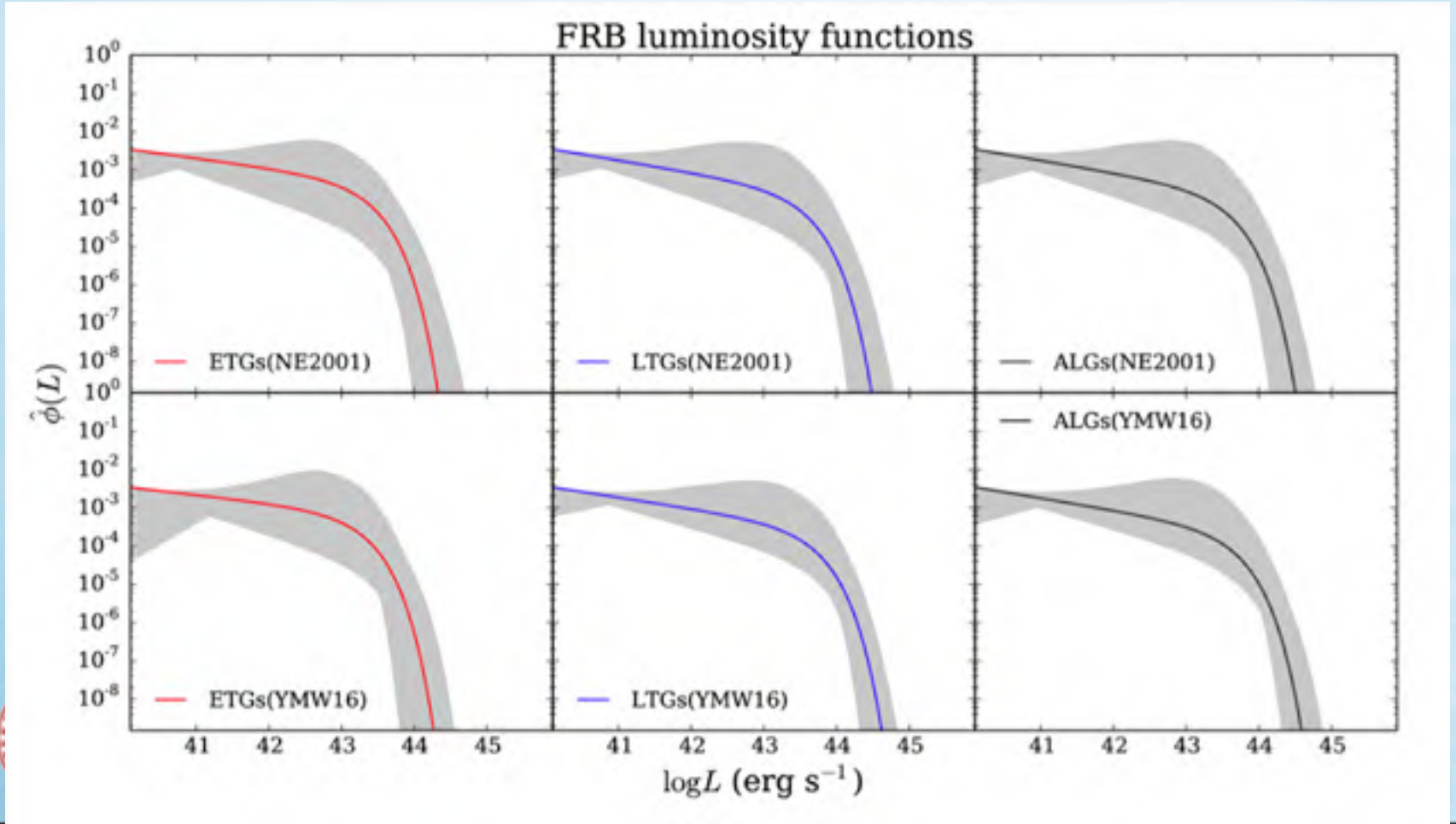
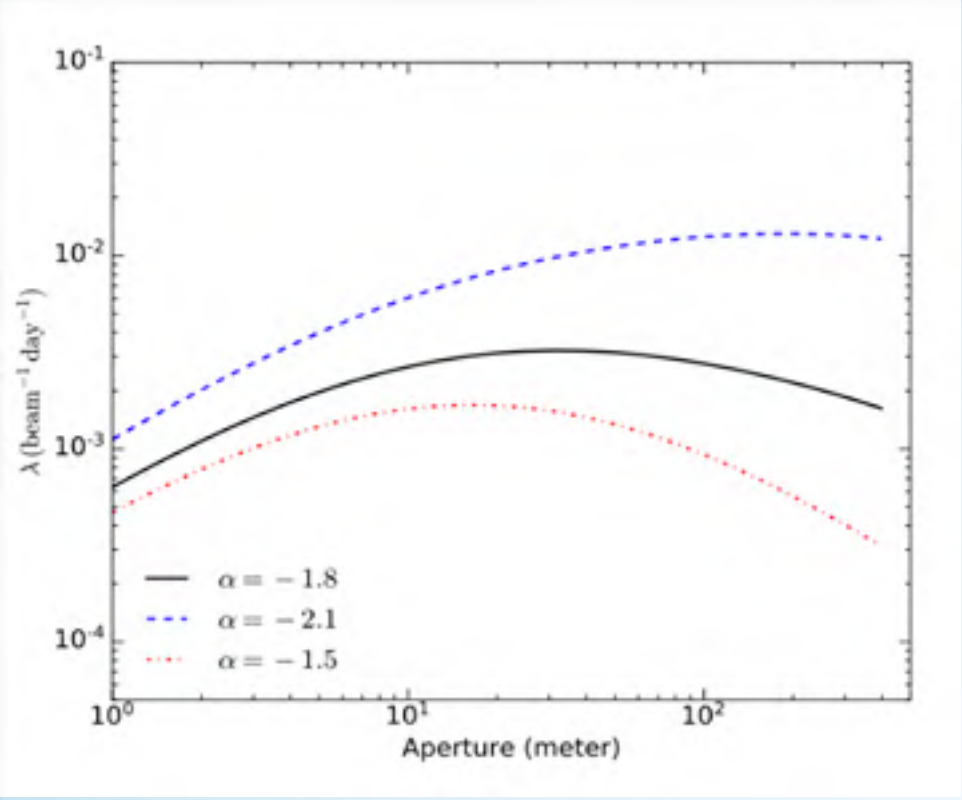
Search scheme and instruments

After including host galaxy DM modeling, cosmic DM modeling, Galaxy contribution, volume effects, antenna response etc. We have



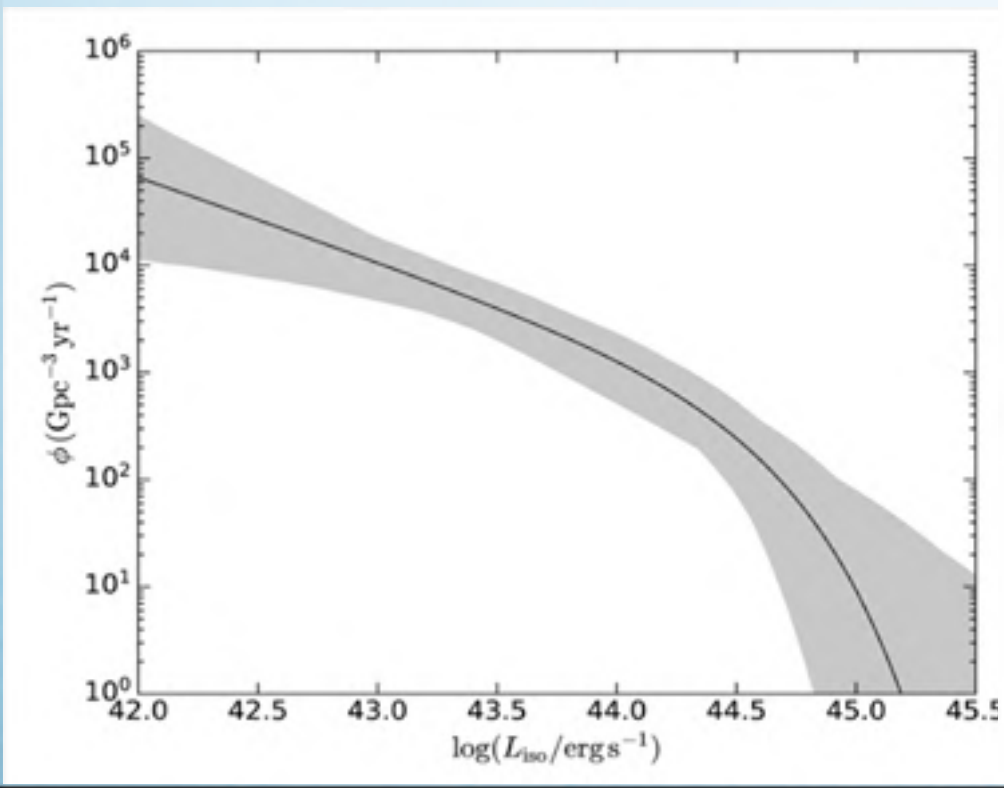
Luo et al, 2019

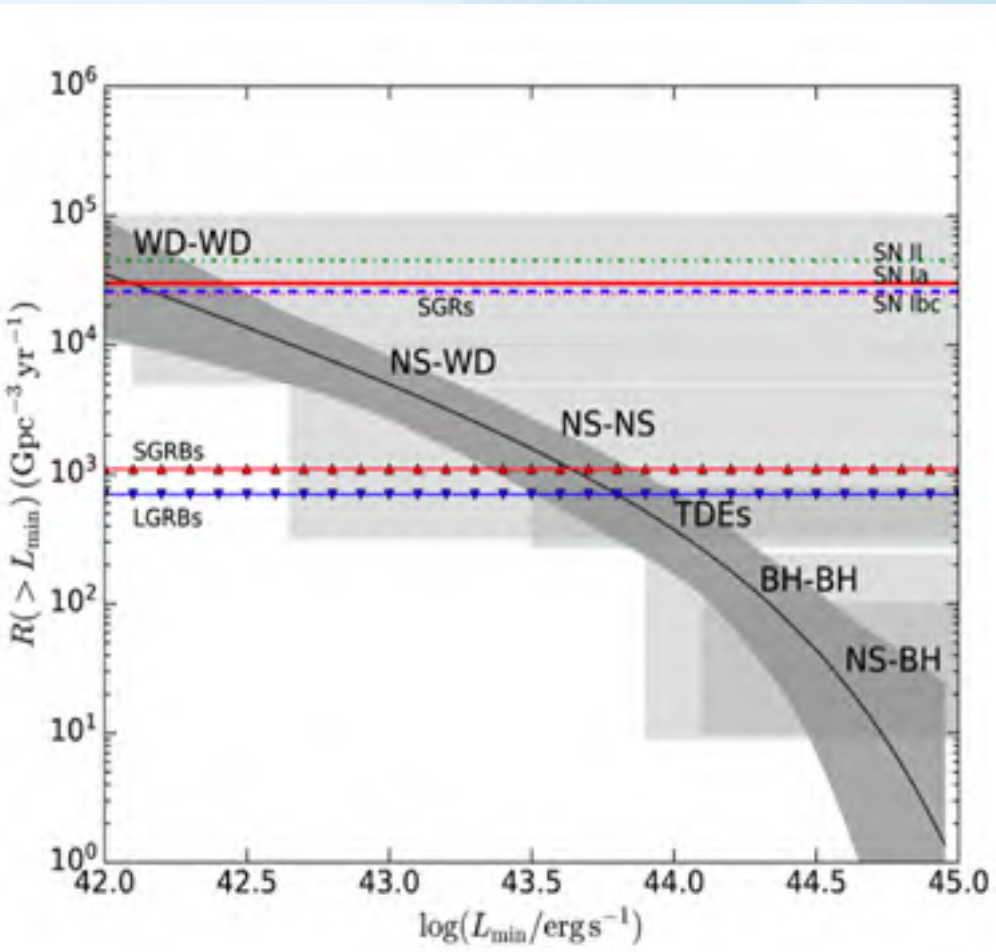


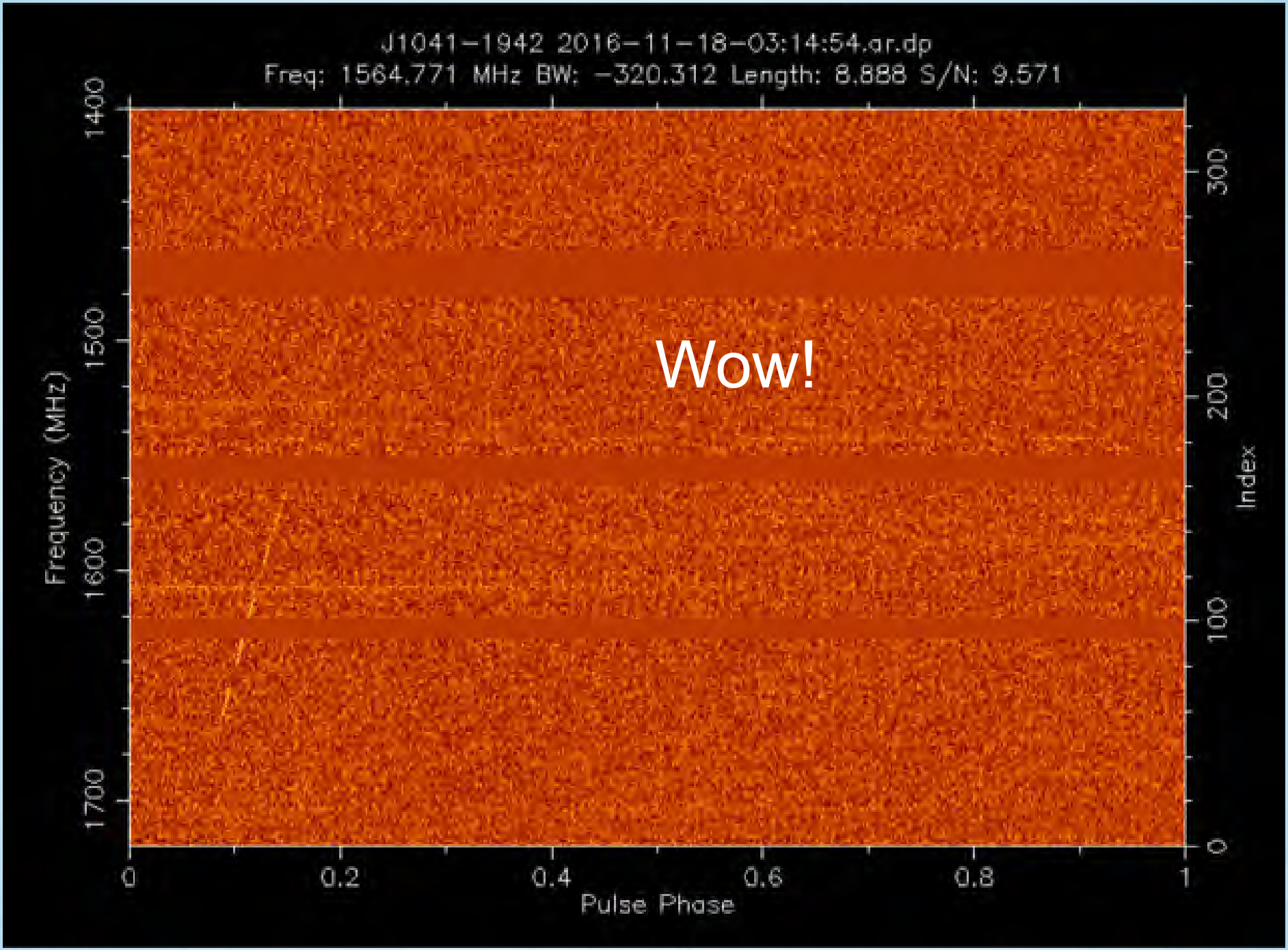
We get the luminosity density function, and can check if using 40m and 25m is reasonable.

Things looked very good at beginning, but….

Luo et al, 2019







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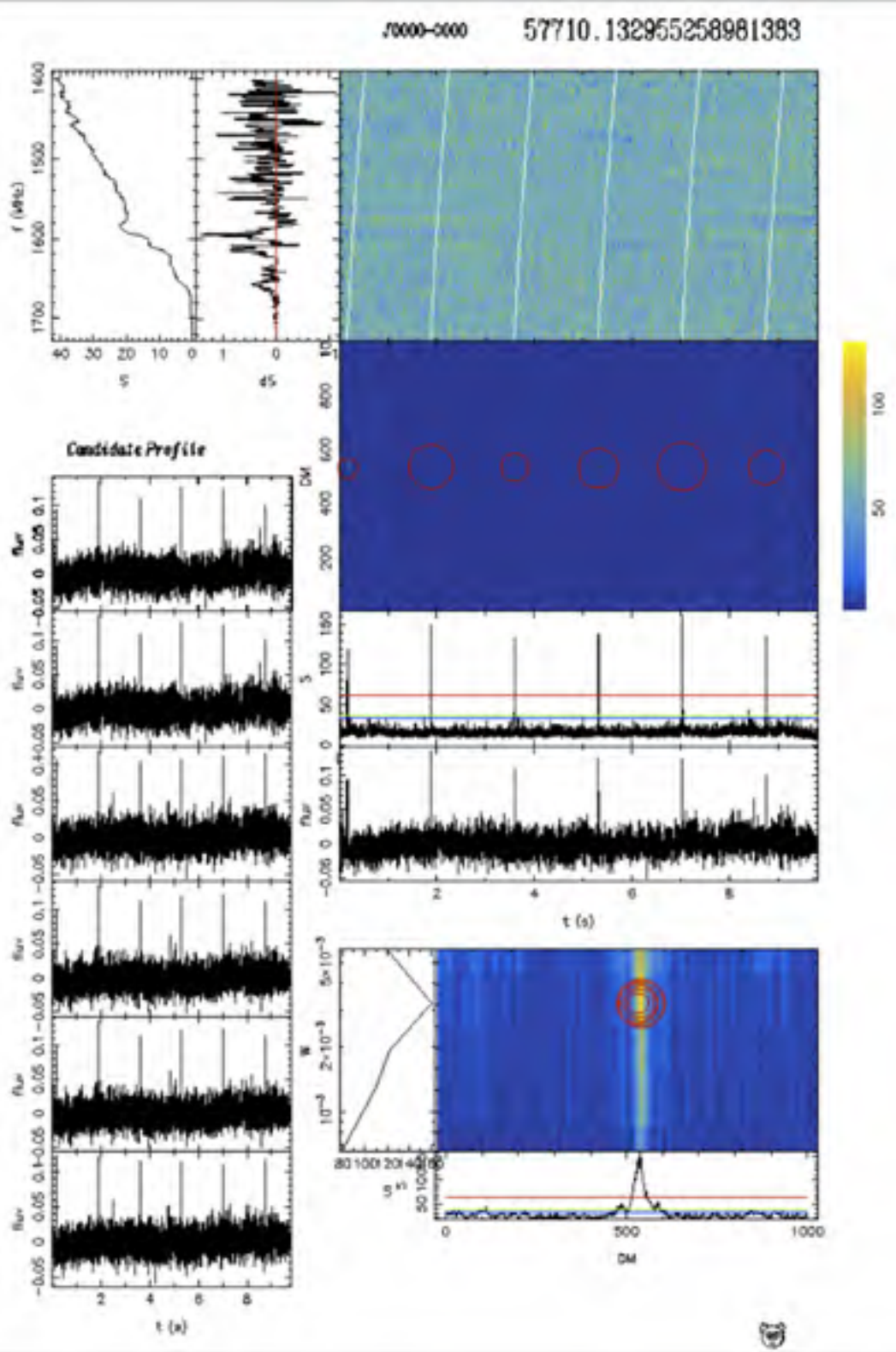
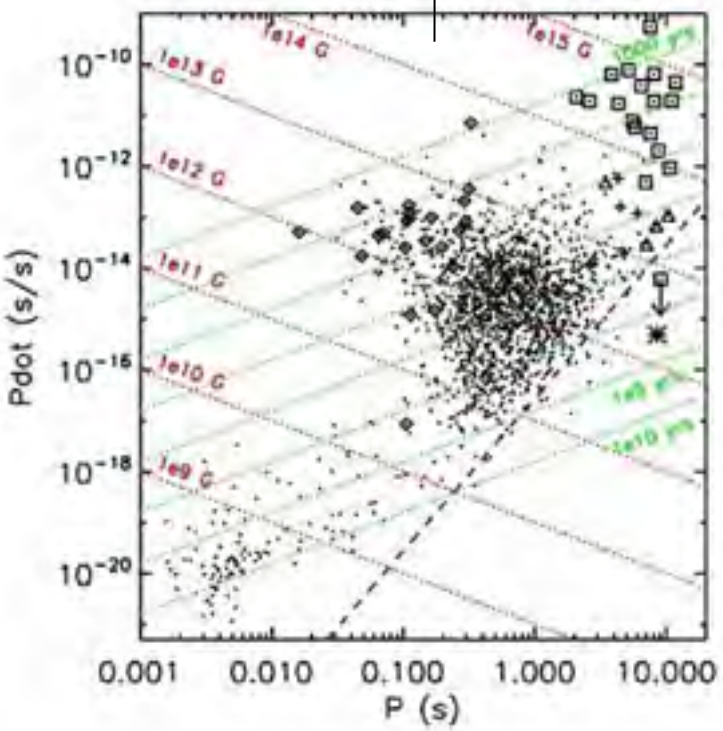
Men et al., 2018



DM ~ 530 pc cm^-3

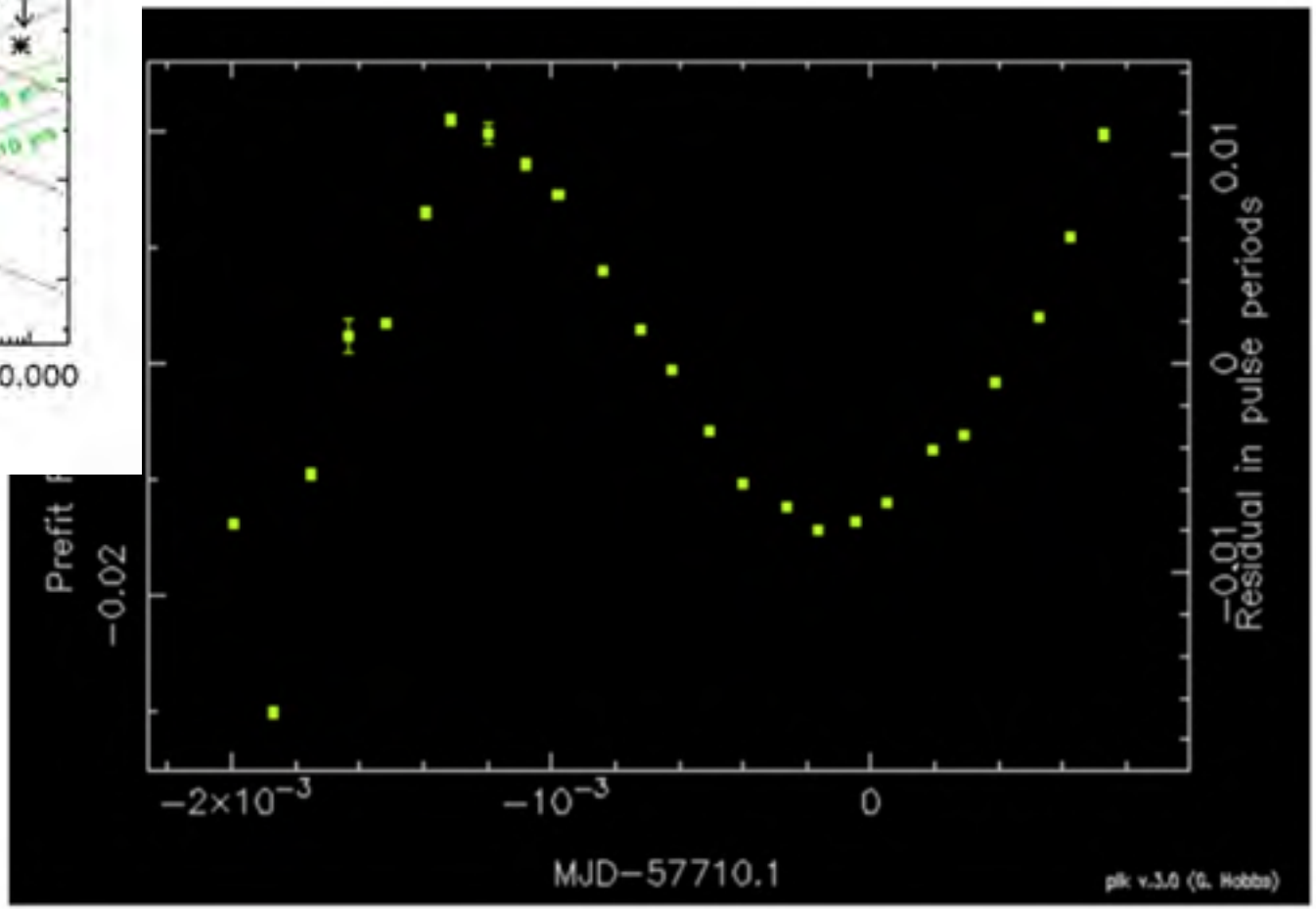
P0 ~ 1.7s

Not found in ATNF Pulsar Catalog!



$F0 \sim 0.58$ Hz $F1 \sim 1e^{-6}$ s^{-2}

Normal pulsars: $F1 \sim 1e^{-15}$ s^{-2}



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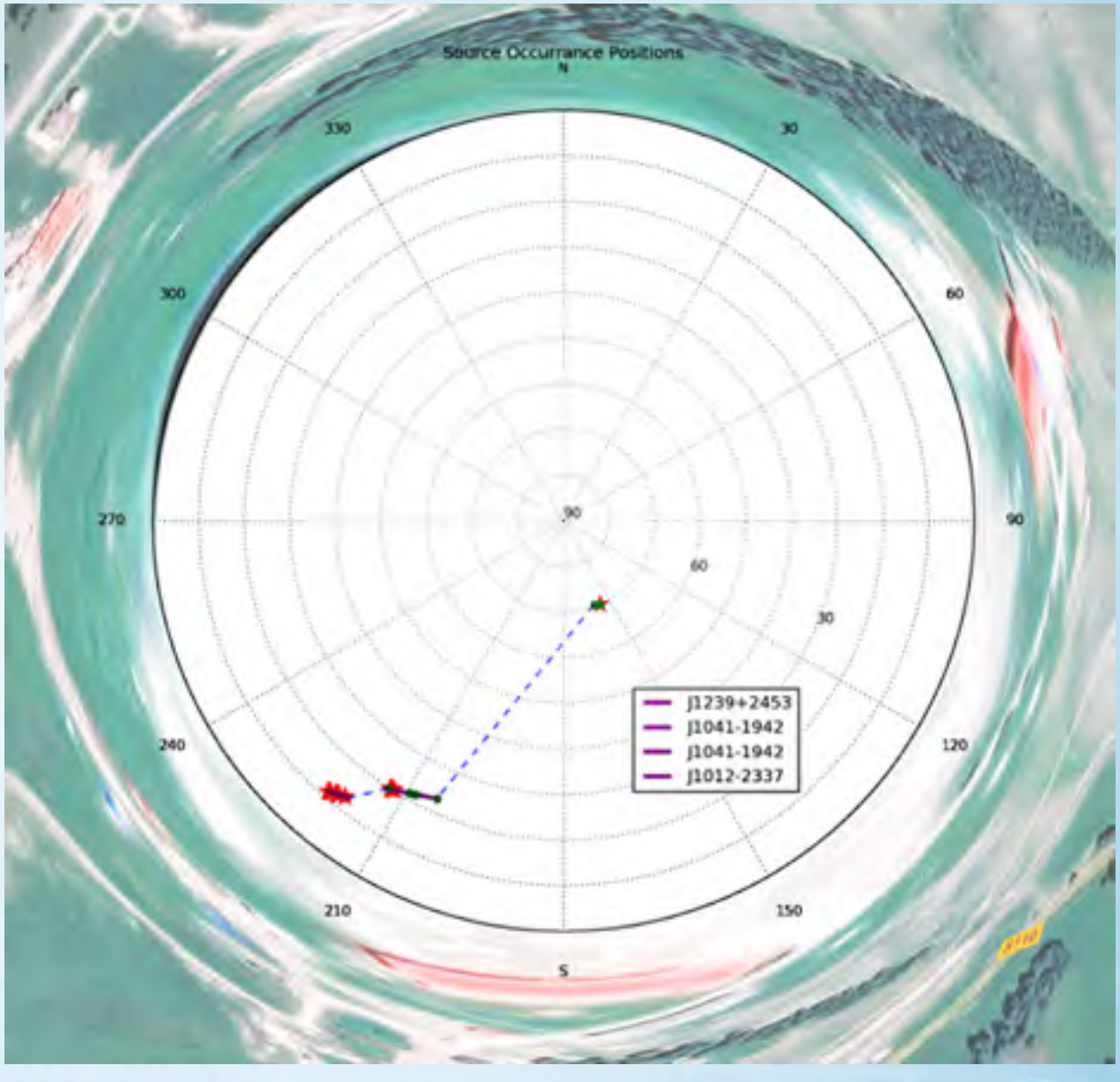
- EM simulation using the telescope structure does not support reflection
- No record of airplane
- Not seen before and afterwards
- No record of car activities on site
- No record of new electronics installation.



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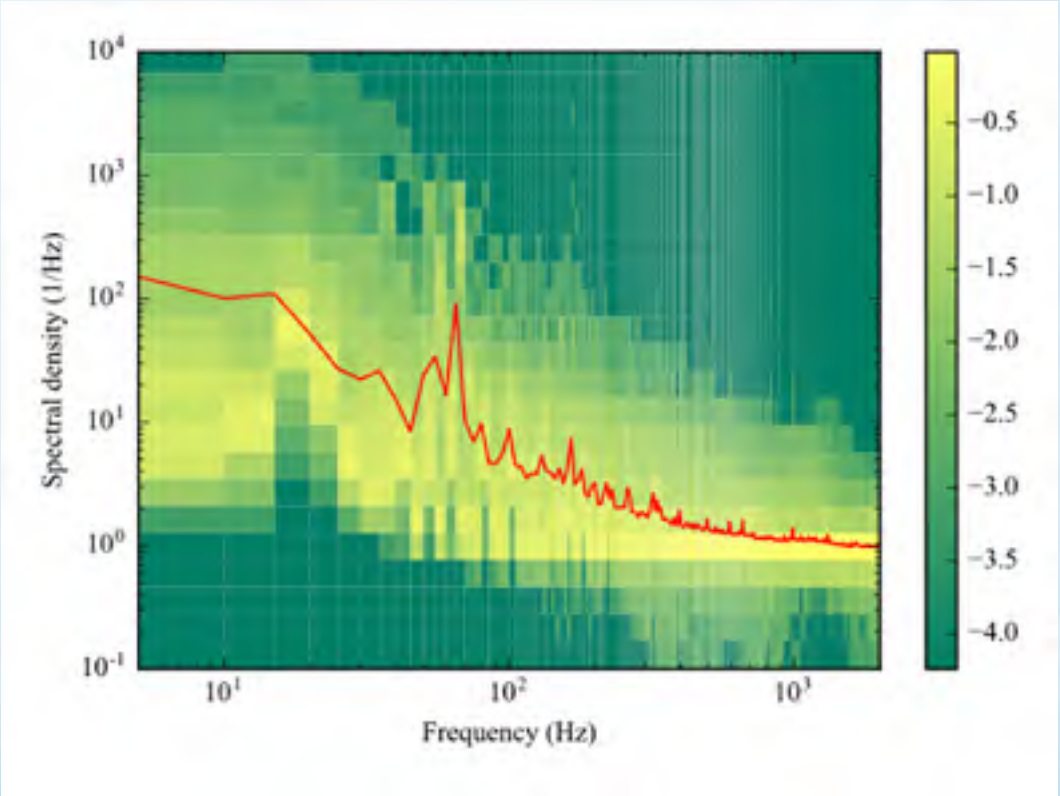
	Pros	Cons
Communication	• Narrow channel	• No information flow • One detection only • Wideband
Radar	• Structured spectrum • Wideband	• One detection only
Microwave oven	• Wideband • DM-like dispersion	• **Timing precision**
Airplane/sat.	• One detection only	• **Will not see over one hour** • Wideband • DM-like dispersion
Local natural processes	• One detection only	• **Narrow channel feature** • DM-like dispersion
astronomical	• Event rate agree with FRBs • Dispersed curve	• **Narrow channel** • **Multiple sky position**

Lesson learnt:

1. It is very hard for single telescope without miultibeam system to confirm FRB detection.
2. Really need to understand RFIs.

Story 2: M82 FRB candidates



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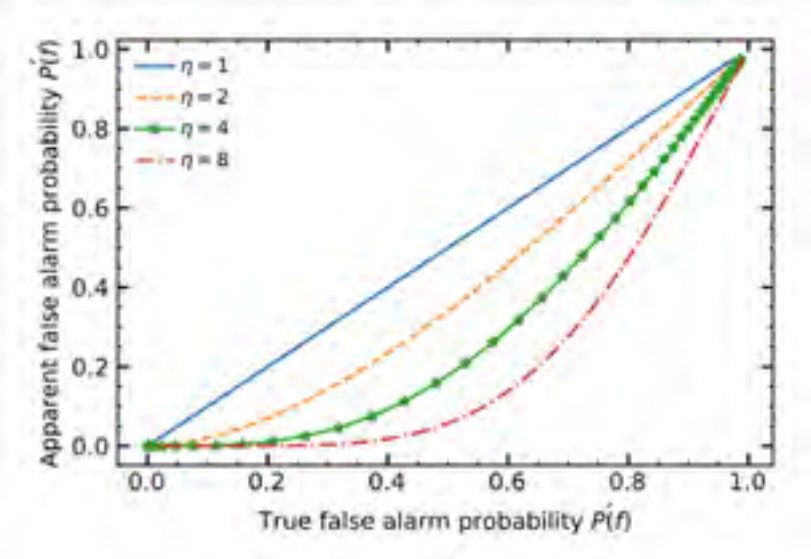
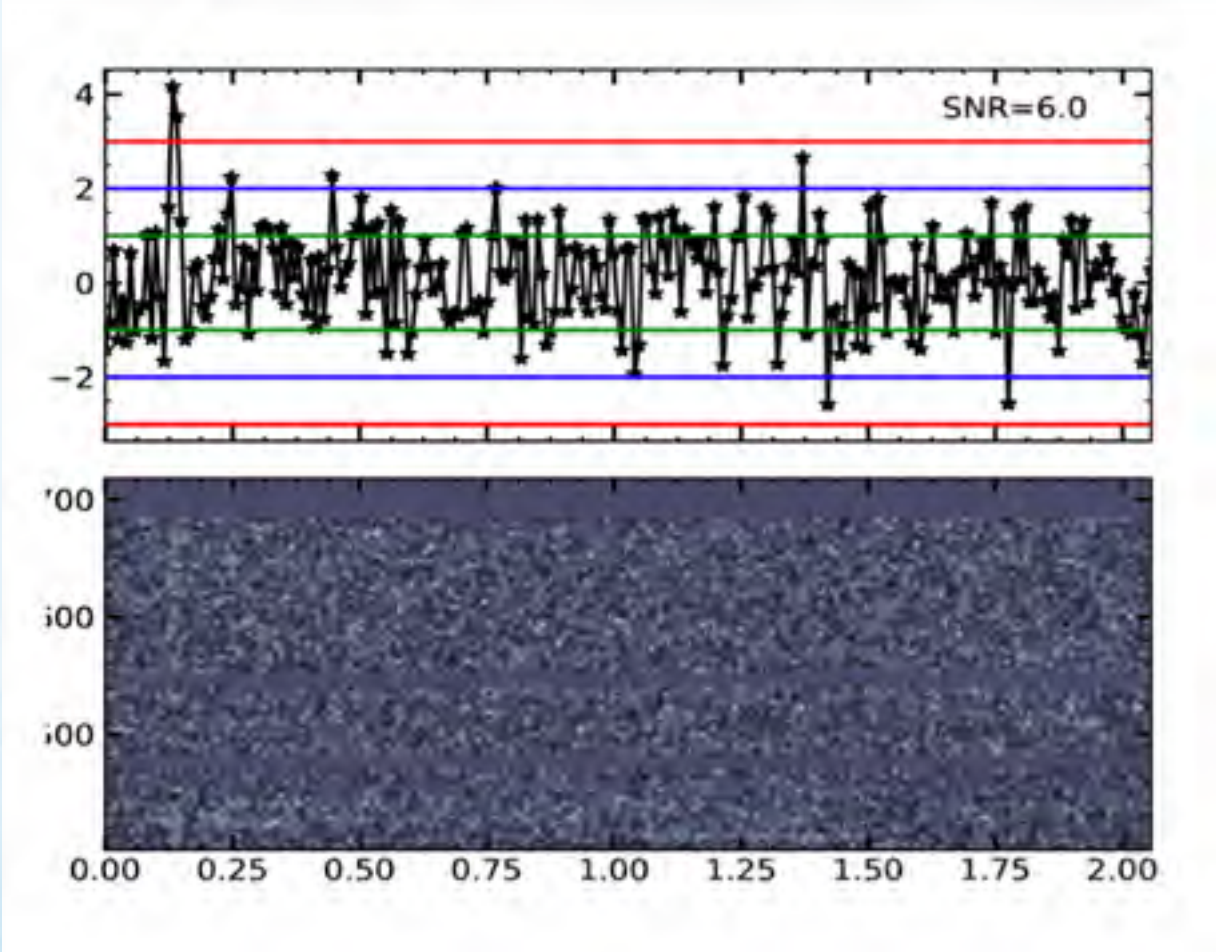
Observe M82 for 55 hours with NS26m. We get one event with low SNR. We performed follow ups with KM40m and HRT, but get no further bursts.

The source can be real, and we studied the red noise impact. We find out that this burst can be also induced by low level (6% RMS amplitude) red noise.

DM 1523
F=0.6 Jy
Fluence 7Jy ms



Zhang et al., in prep



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Lesson learnt:

It is very hard for small telescope to study FRB even with detection. The SNR is too low to confirm, even we have a lot of candidates.

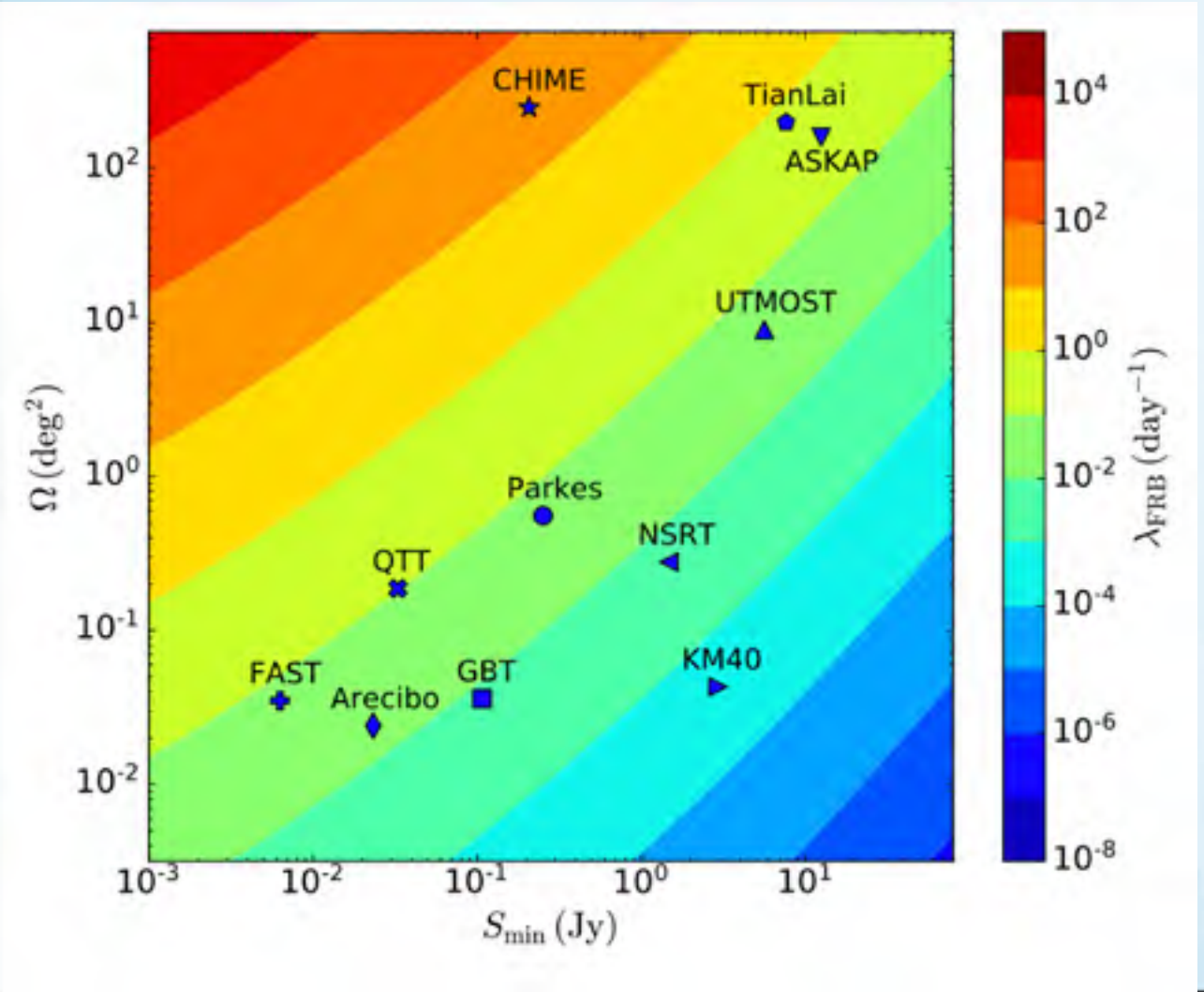
We need some larger telescopes with multi-beam receiver
Or multiple telescopes to form an array.

When FAST made the open calls, we start to apply time.

Story 3: FAST observations

At 2019, the two key problems left on the table are

1. Where the radiation comes from?
2. How the radiation was generated?



Luo et al., 2020

Intrinsic (magnetosphere) or propagation amplification(maser)

Polarisation as a probe for radiation mechanism

Polarisation is a statistical quantity describing the spin of photon or oscillating electric field direction of radio wave

High temprature radio wave is generated via

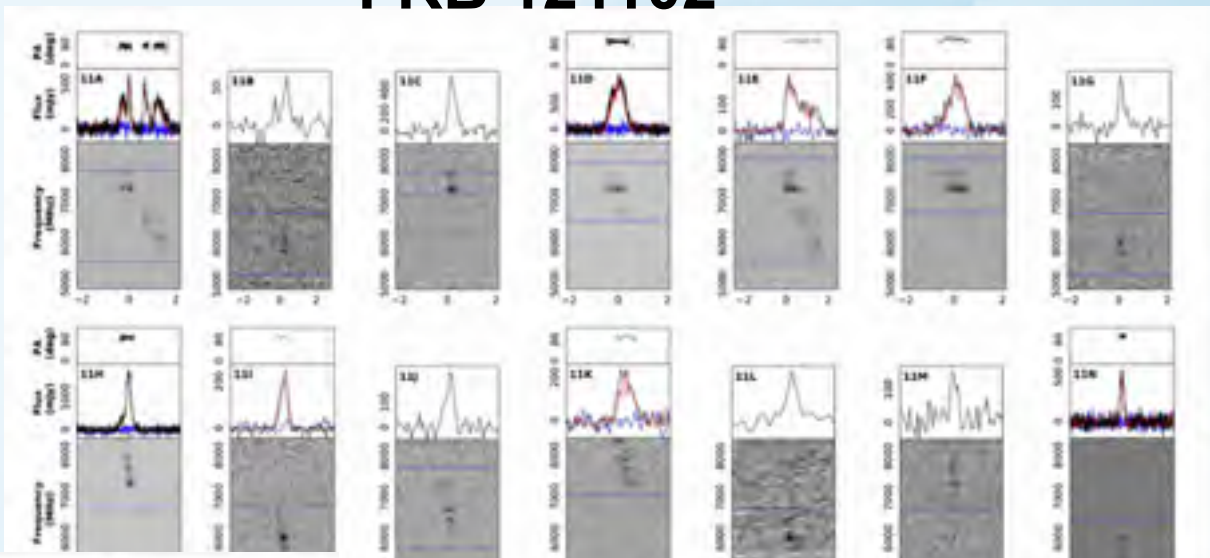
- Intrinsic coherent radiation --- radiating electron is in coherent state
- maser mechanism --- propagation leads to coherency

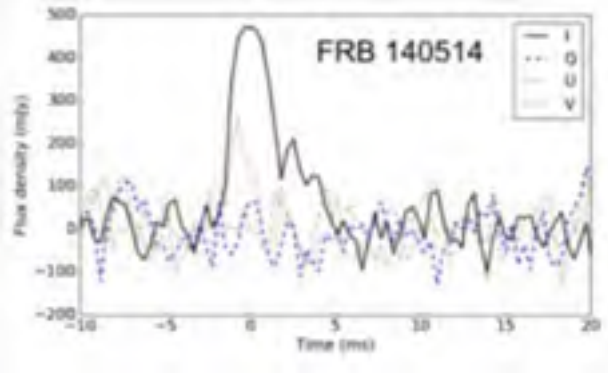
Over ms timescale, it is hard to change the maser enviroment, if we see polarsiation changes over such a short time scale, we know the radiation mechanism must be coherent radiation.

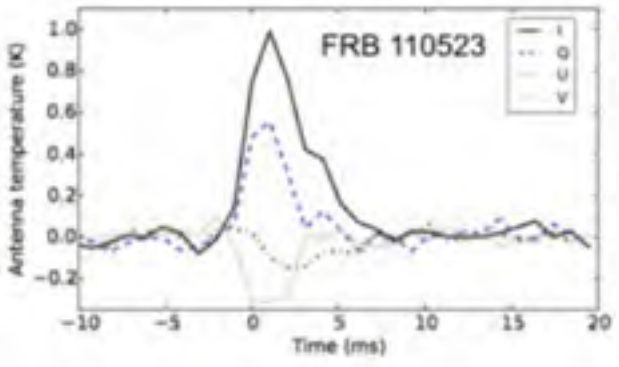
FRB polarisation was inconclusive

- Flat PA
- high linear polarisaiton
- low circular polarisation
- Repeating/non-repeating can be different

FRB 121102

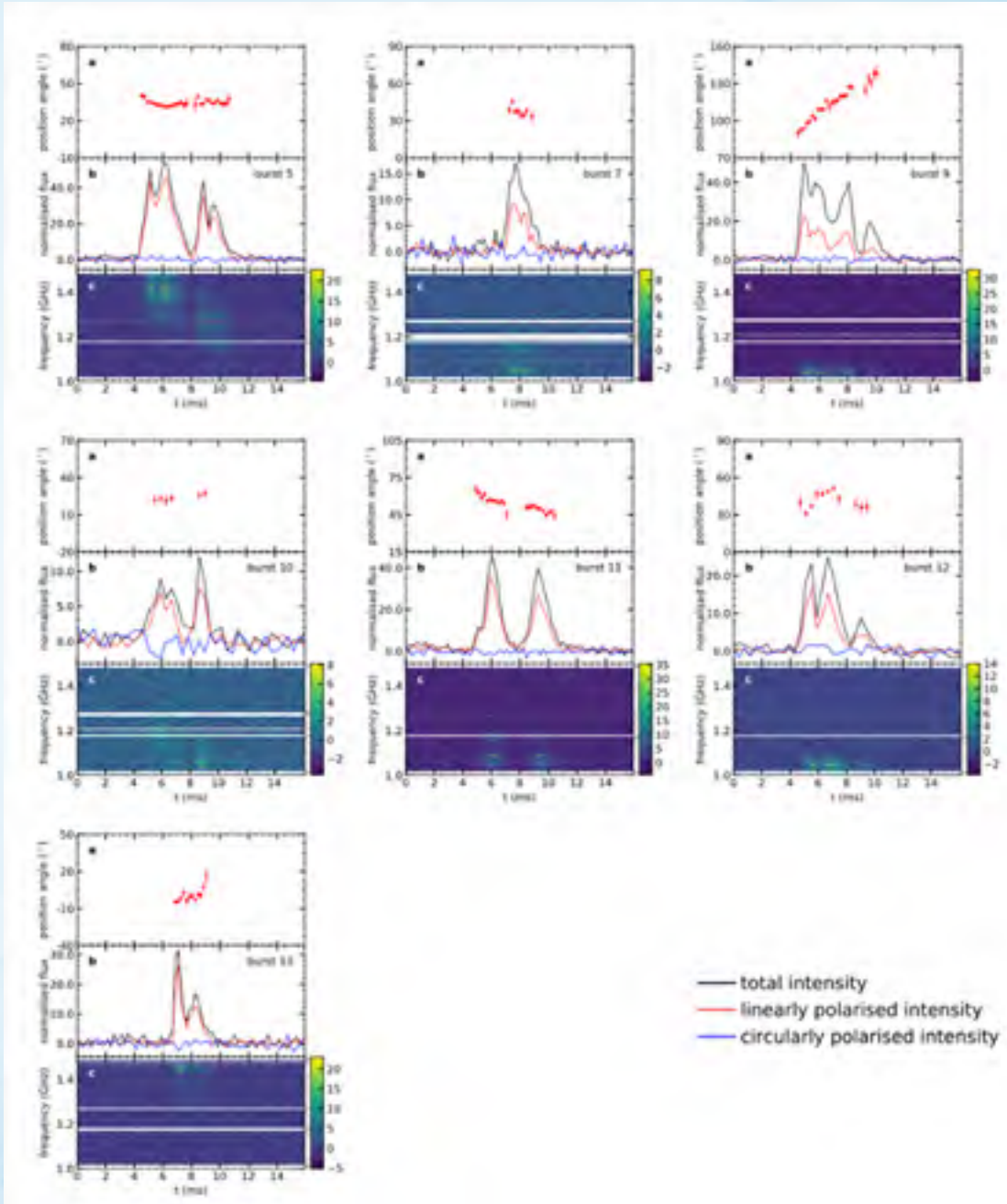






Polarisation

- FRB 180301 has very diverse morphology of polarisation.
- Not seen in any other repeater.
- Such morphology complexity tells that FRB radiation mechanism should not be maser mechanism.
- Polarisation does not look like a magnetar



Luo et al., 2020

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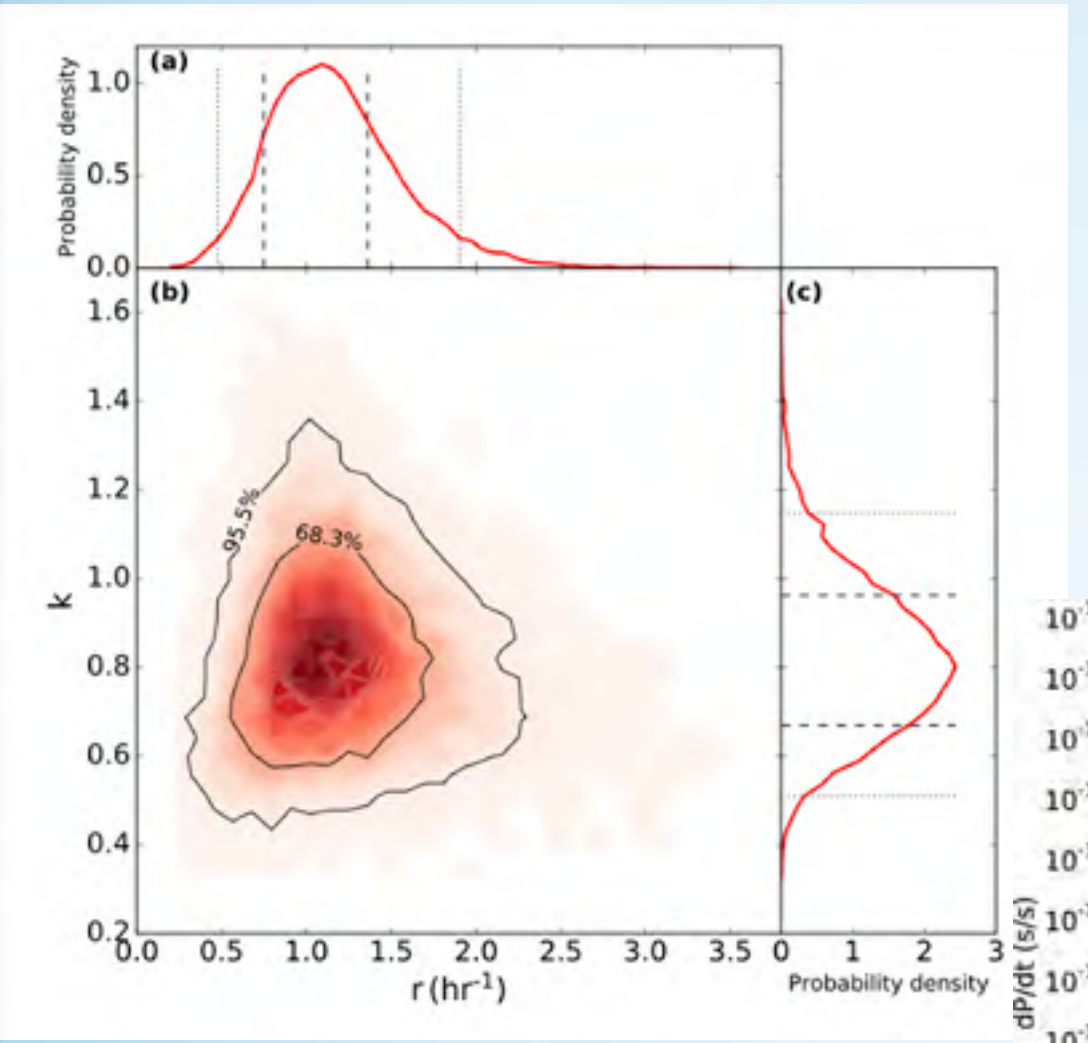
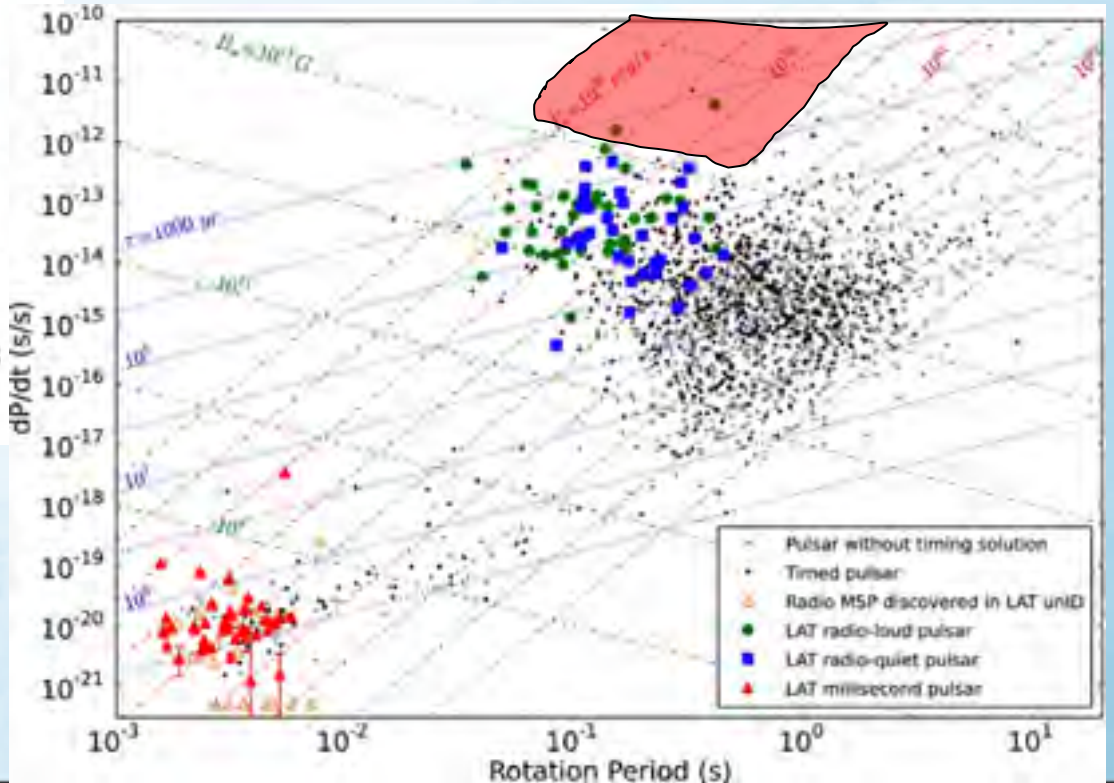
Event rate



The average active phase energy loss rate is 1E35 erg/s.



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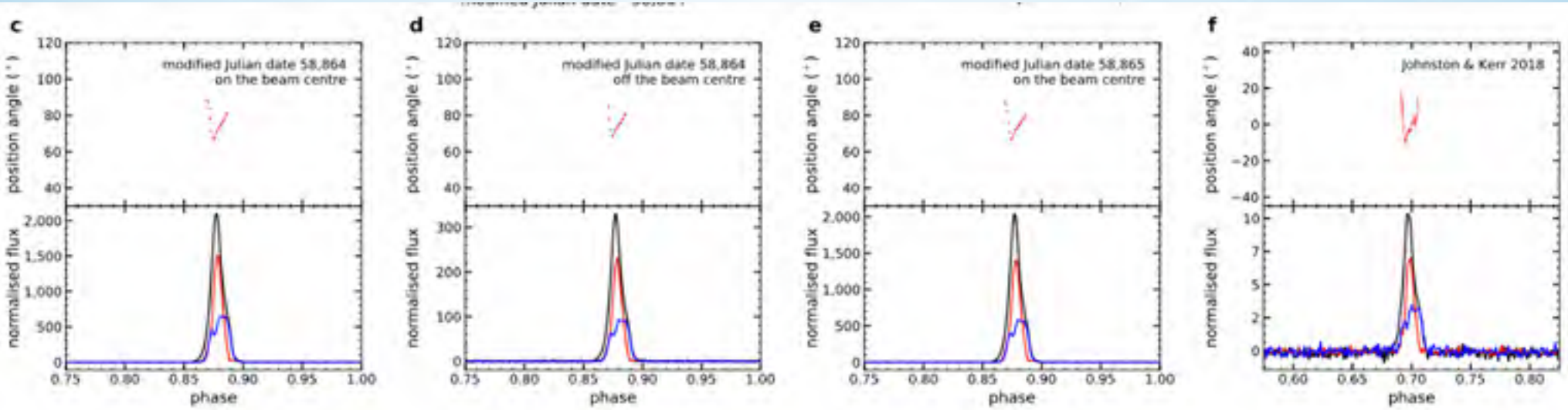
By product: FAST poalrisation is superb!

- The diverse polarisation is not due to systematics
- We crossed checked with pular observation, turns out FAST polarisaiton, if calibrated can reach 0.5% level precision as indicated by the lab test of feed.
- FAST polarimetry fidelity is excellent and stable.

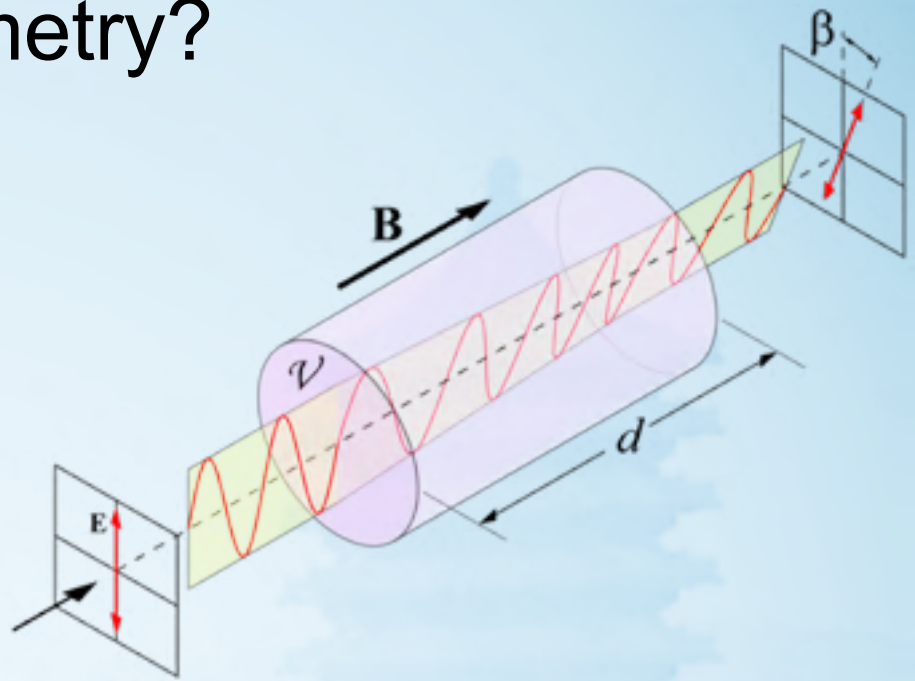
Luo et al., 2020

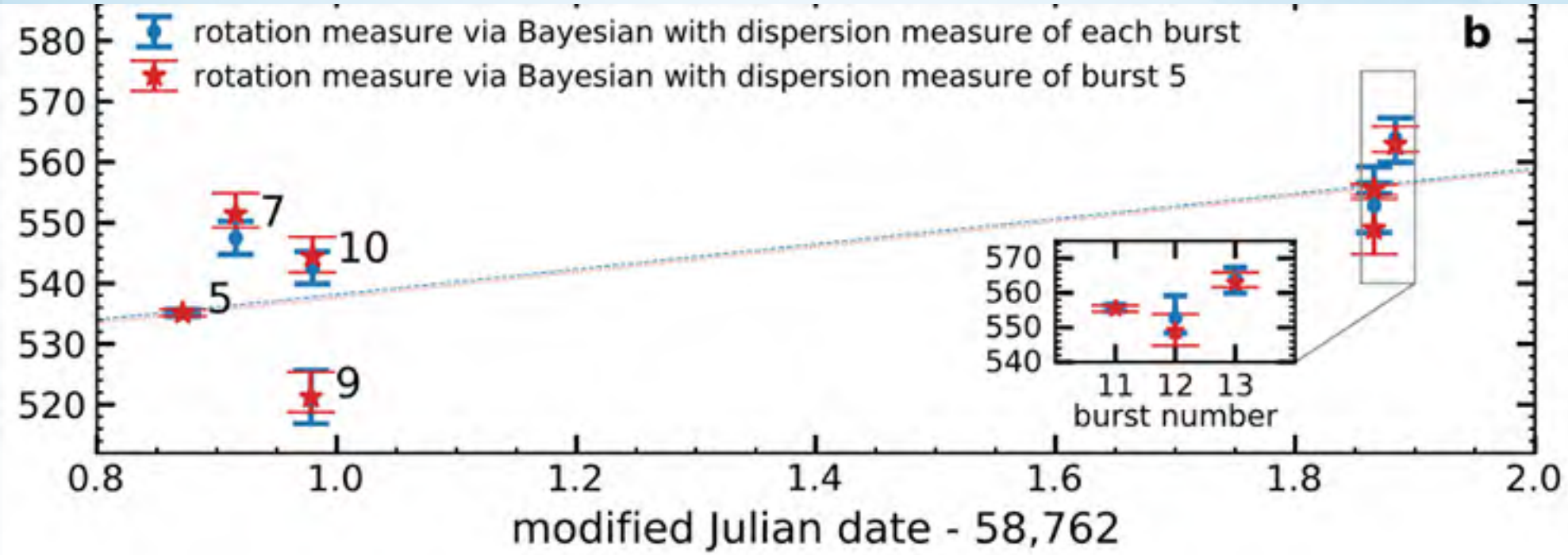


Magnetic field variation or geometry?

We saw pulse to pulse RM variaiton, indicating
the radiation is generated in a highly magnetoionic enviroment.

$$\mathrm{RM} = 0.810 \int_{path} n_e \boldsymbol{B} \bullet \mathrm{d}\boldsymbol{l}$$





Magnetosphere? What kind of magnetosphere?

Story 4 No detection at FAST

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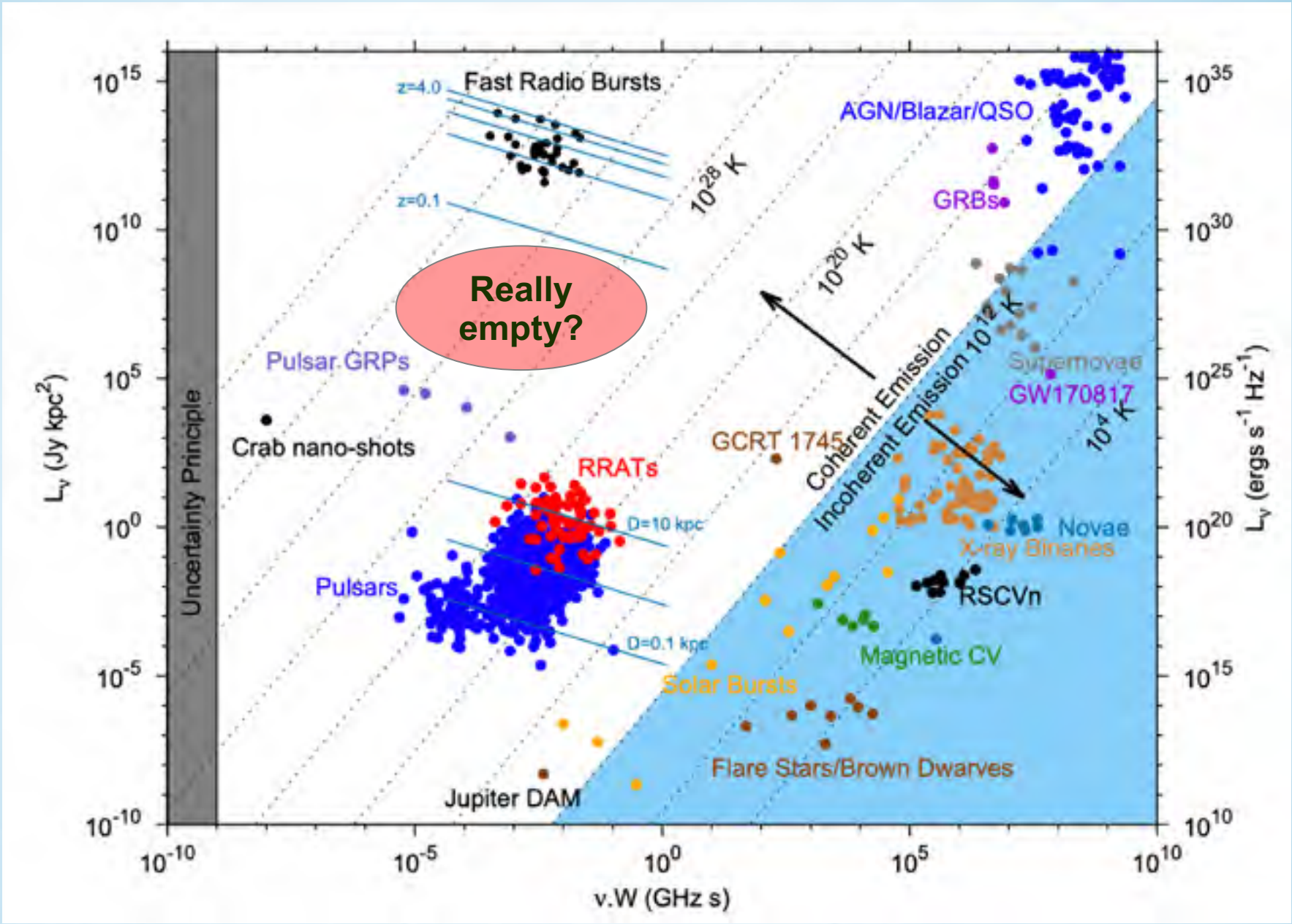

What type of magnetosphere radiation?

Keane 2019

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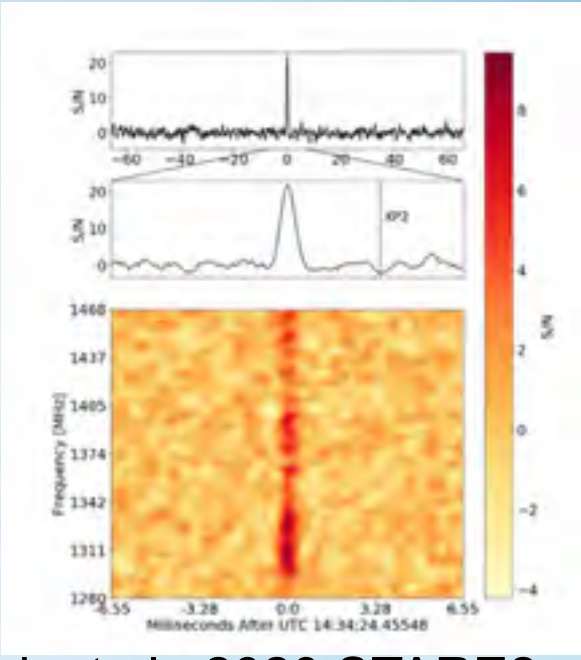
SGR 1935+2154

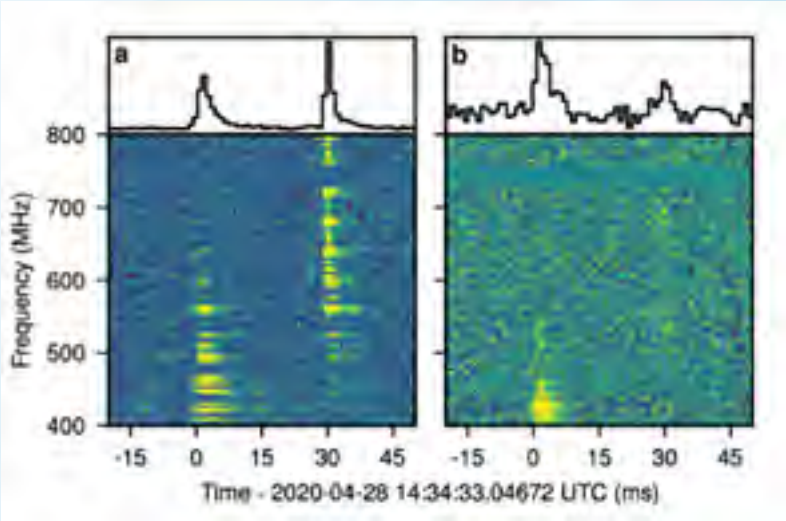
April. 2020，Swift/BAT team noted high energy activities.

CHIME and STARE2 found MJy level radiation.

We performed FAST observation



Bochenek et al., 2020 STARE2



CHIME/FRB coll. 2020

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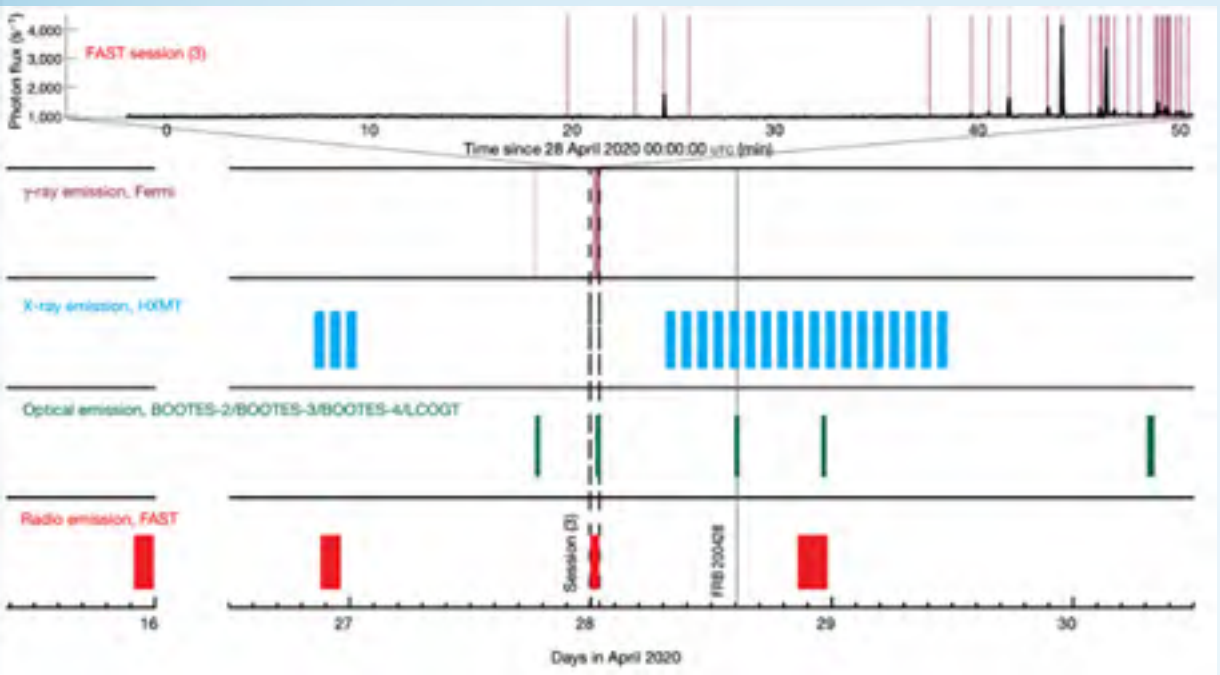
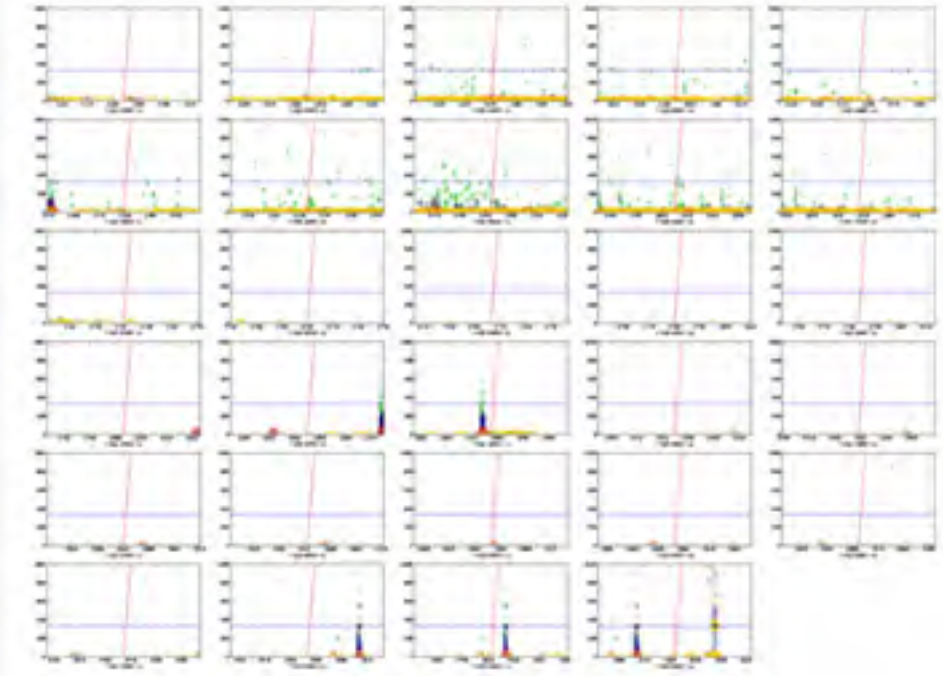
SGR J1935+2154



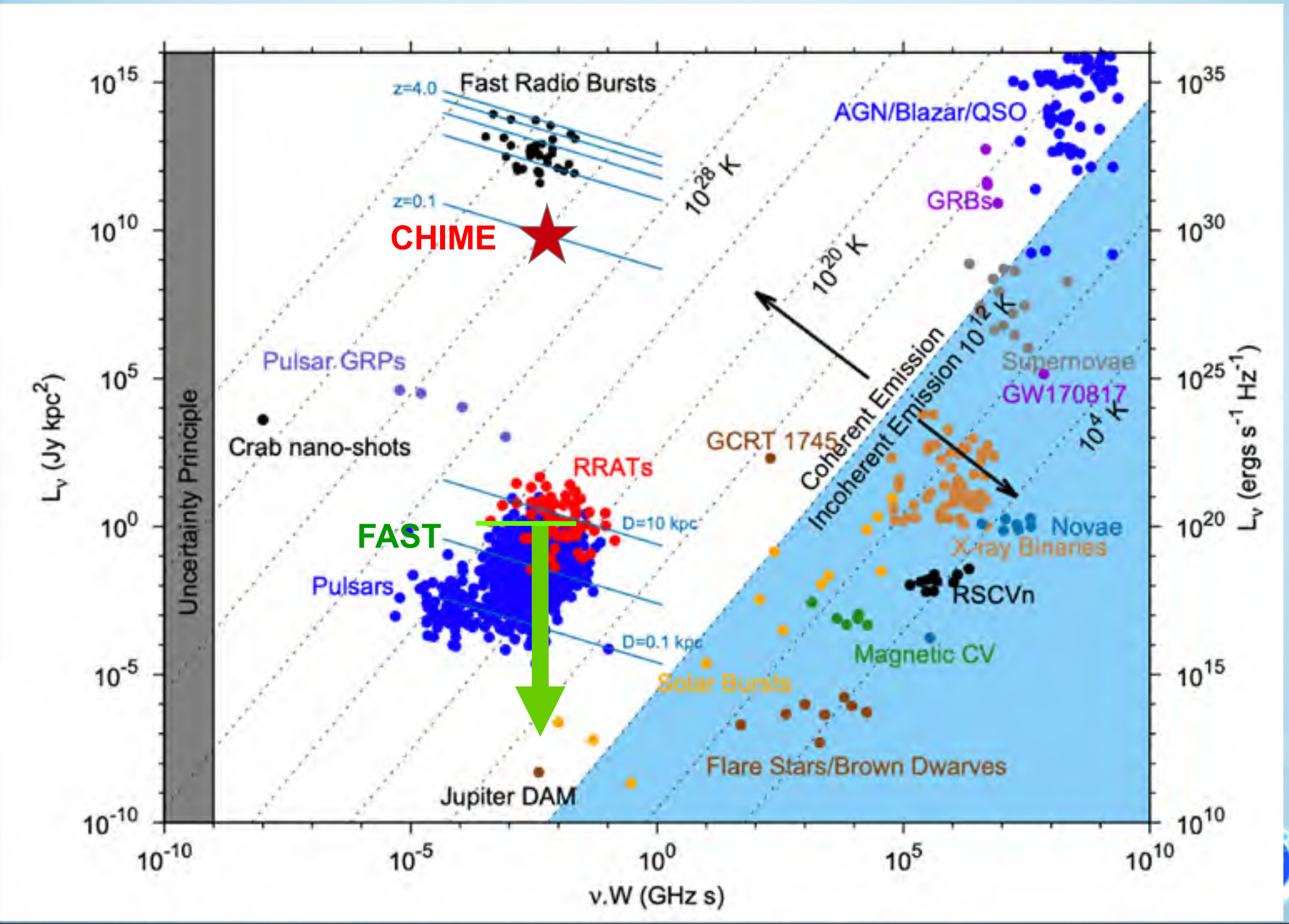
Lin et al., 2020



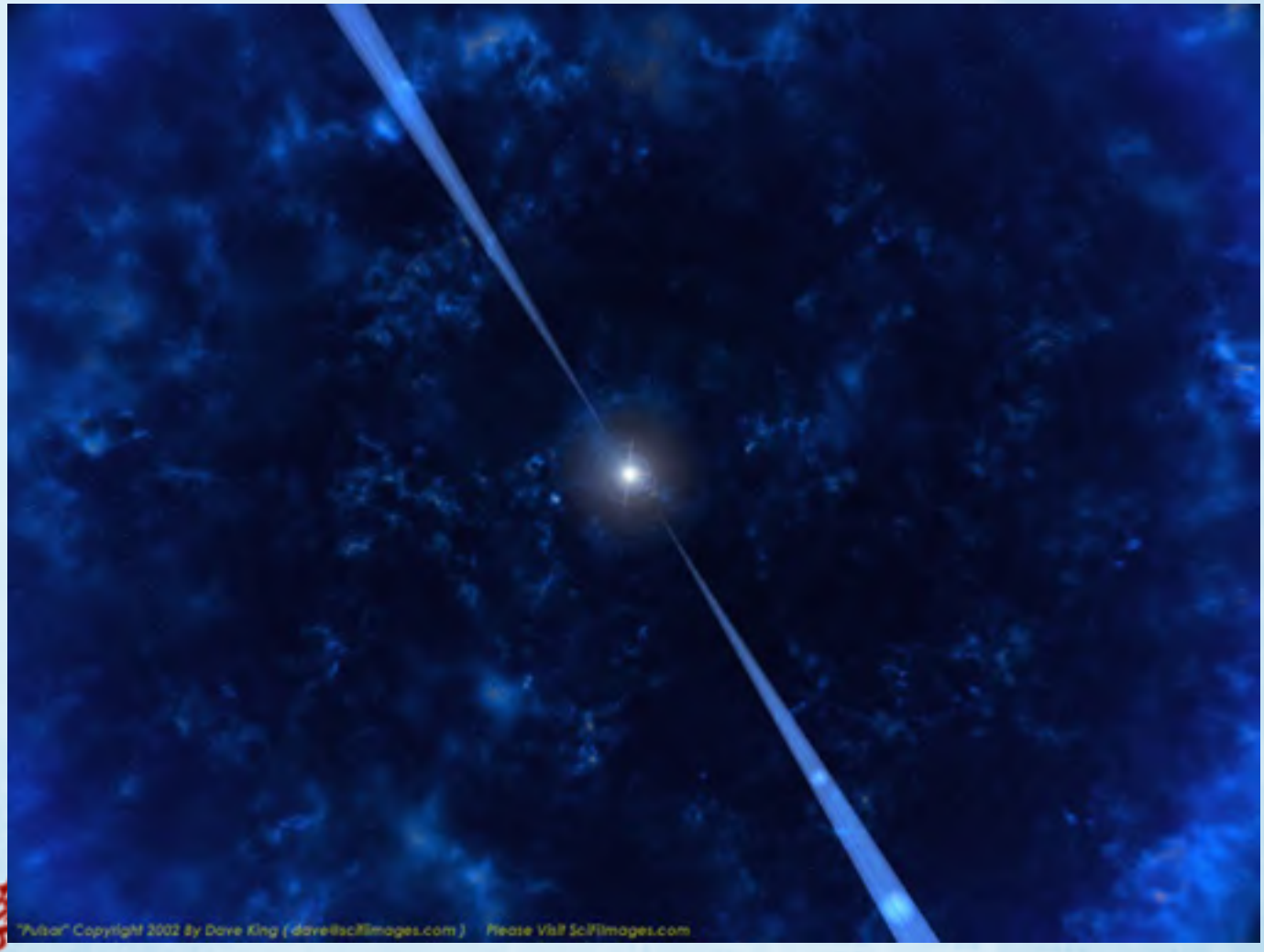
1. Not all high energy burst associating with radio bursts. FRB is generated in an extreme condition.

2. We detected normal radio pulse from SGR J1935+2154 and measured its polarisaiton property. The SGR indeed share common features with AXPs in radio band.

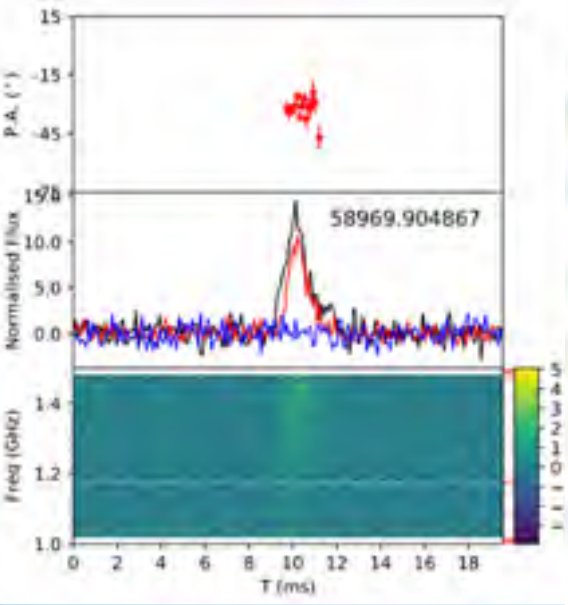
Lin et al., 2020, Nature.

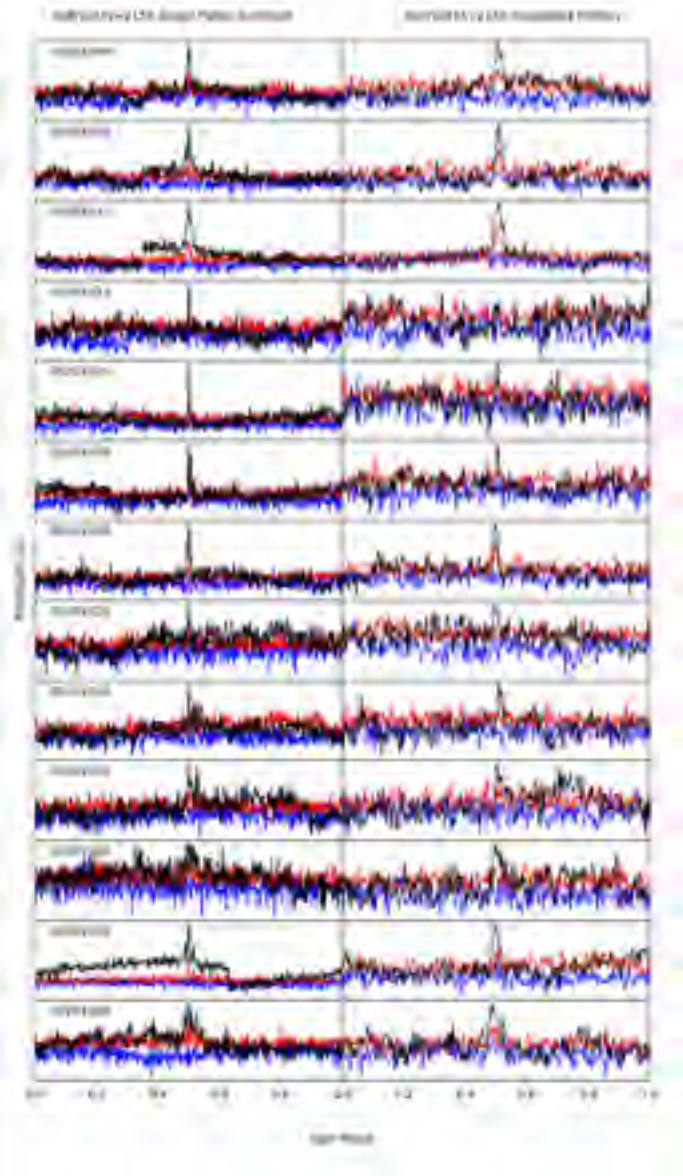

Fast Radio Bursts
z=4.0
z=0.1
CHIME
FAST
Pulsar GRPs
Crab nano-shots
RRATs
Pulsars
D=10 kpc
D=0.1 kpc
Jupiter DAM
Uncertainty Principle
AGN/Blazar/QSO
GRBs
Supernovae
GW170817
GCRT 1745
Novae
X-ray Binaries
RSCVn
Magnetic CV
Solar Bursts
Flare Stars/Brown Dwarves
Coherent Emission
Incoherent Emission
10^{28} K
10^{20} K
10^{12} K
10^{4} K
L_ν (Jy kpc^2)
L_ν (ergs s^{-1} Hz^{-1})
$\nu.W$ (GHz s)

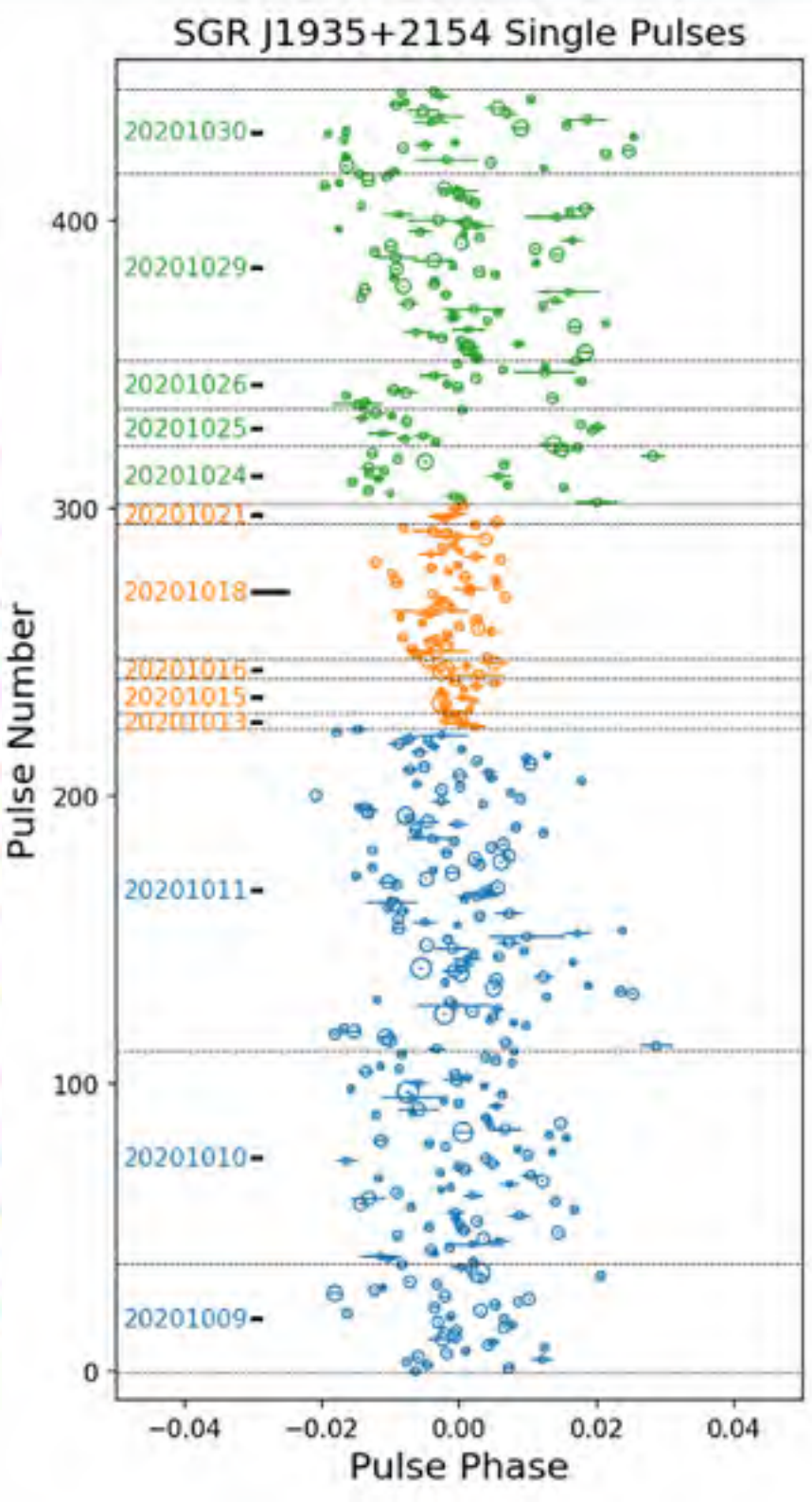
Story 4.5: SGR1935 become a radio pulsar



Story 4.5: SGR1935 become a radio pulsar







In prep

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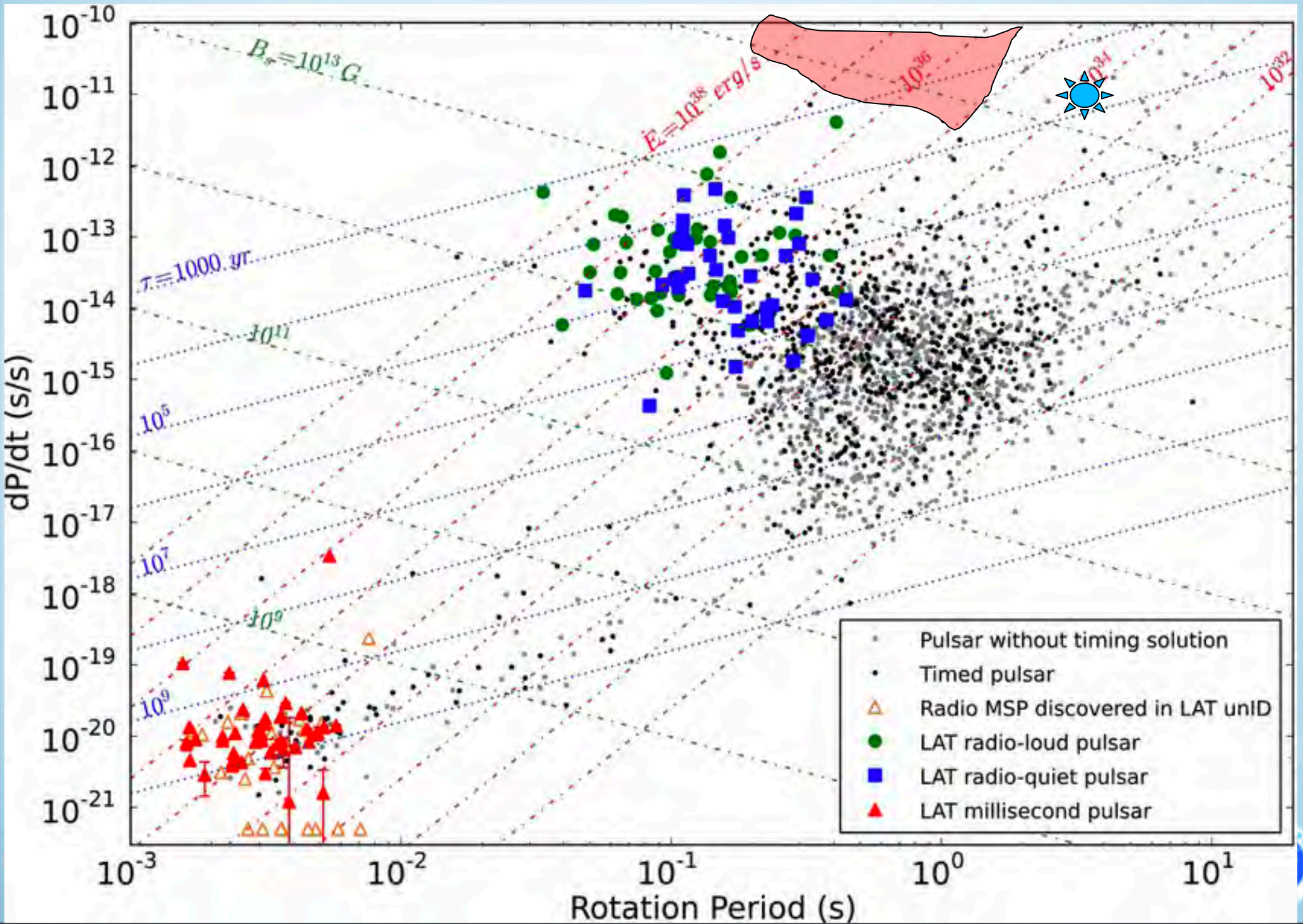
$B_*=10^{13}$ G
$\dot{E}=10^{38}$ erg/s
10^{36}
10^{34}
10^{32}
$\tau=1000$ yr
10^{11}
10^{5}
10^{7}
10^{9}
10^{9}
dP/dt (s/s)
Rotation Period (s)
Pulsar without timing solution
Timed pulsar
Radio MSP discovered in LAT unID
LAT radio-loud pulsar
LAT radio-quiet pulsar
LAT millisecond pulsar

Conclusion after 5-year work:

1. FRBs are real.
2. Big telescope or telescope array are needed for FRB bussiness.
3. FAST is fantastic for follow up observation.
4. FRB should come from magnetosphere type of enviroment
5. FRB radiation mechanism for magnetar is indeed very special
6. We may facing a new population of new pulsars!

Advs: We are hiring post-doc and searching for project hired scientist, If you do not mind to get hand dirty (We have glooves, but…).

如果你不怕把手搞脏，我们在招博士后和项目科学家。（我们有手套但是…）

Thanks!

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