FPS7, Guangzhou 07 / 2018

Pulsar searches of Fermi sources with FAST

Pei Wang (王培)

Di Li, Weiwei Zhu, Youling Yue, Lei Qian, Zhichen Pan, et al.

- On behalf of all contributions from FAST team and FAST - Fermi_LAT collaboration group
- With great help from Guizhou normal university

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

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

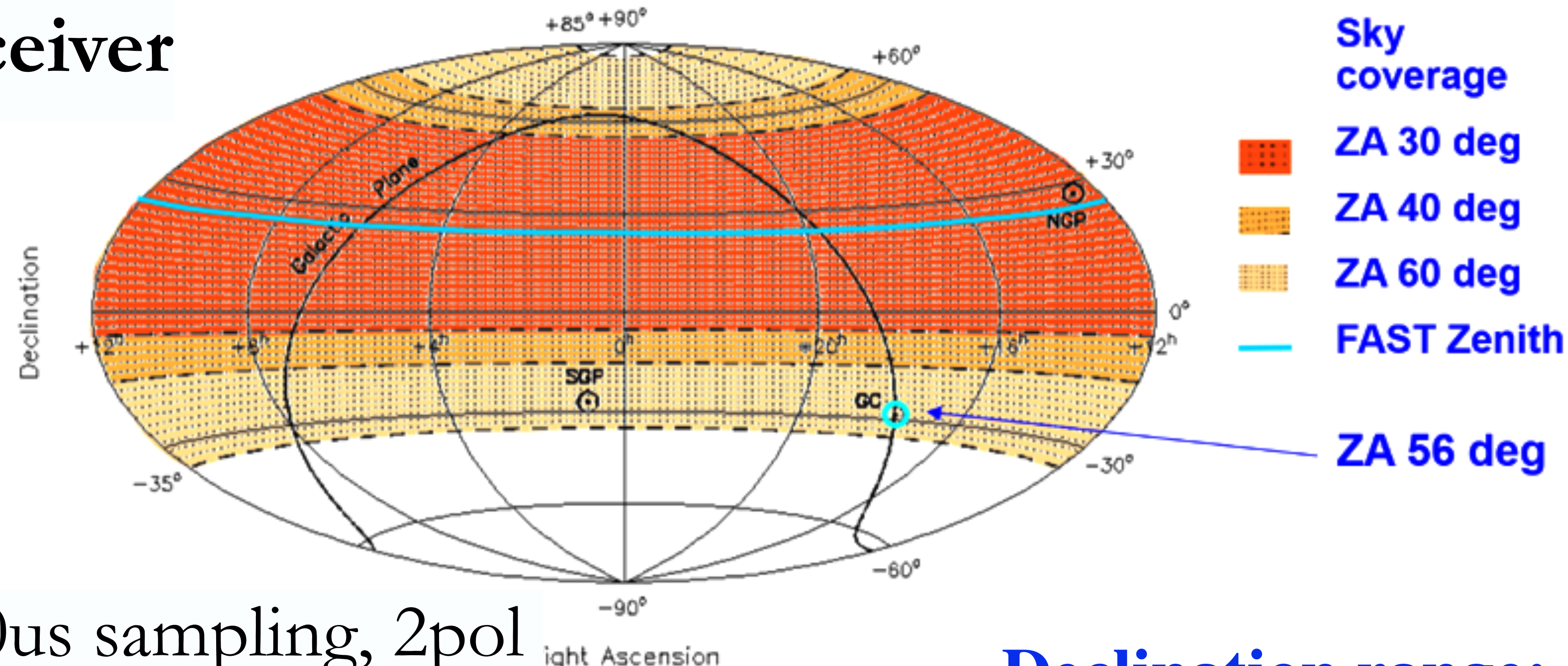
Outline

- Basic Parameters for FAST
- Targets and Pulsar Data Processing
- Initial Result
- Multi-messenger International Collaboration

The Basic Parameters for FAST and Initial Pulsar Observing System

- **Ultra wide-band receiver**

  Tsys = 65K + Tsky
  270 -> 900MHz
  900 -> 1600MHz



- **Digital Backend**

  8-bit, 8192 channels, 50us sampling, 2pol
  Roach2, Spectrometer
  CRANE (Spectral line, Pulsar, Baseband)

Declination range: (–14° to +66°)

- **Observing modes**

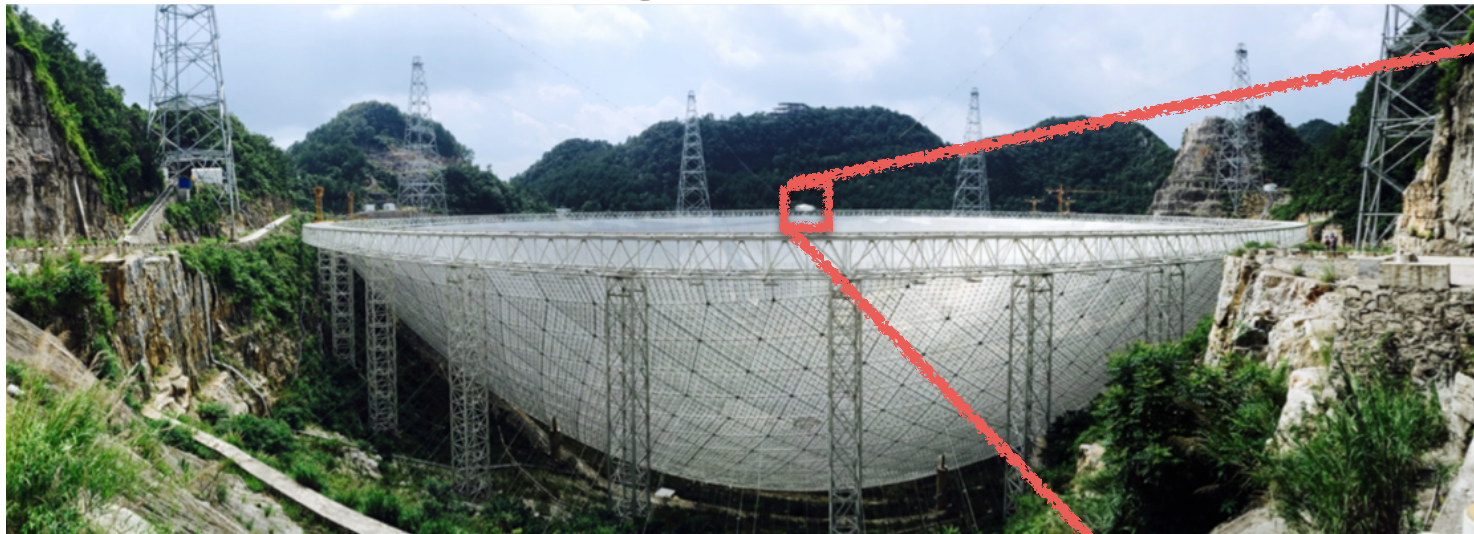
  Tracking + Drift-scan over primary beam + side-lobes (~40sec @500MHz)

- **Pipelines of data processing**

  RFI monitor and mitigation, Pulsar searches, Pulsar timing, Spectral line

L-band 19 Beam Receiver

is a highly efficient pulsar-finding machine



FAST 'big data' stream

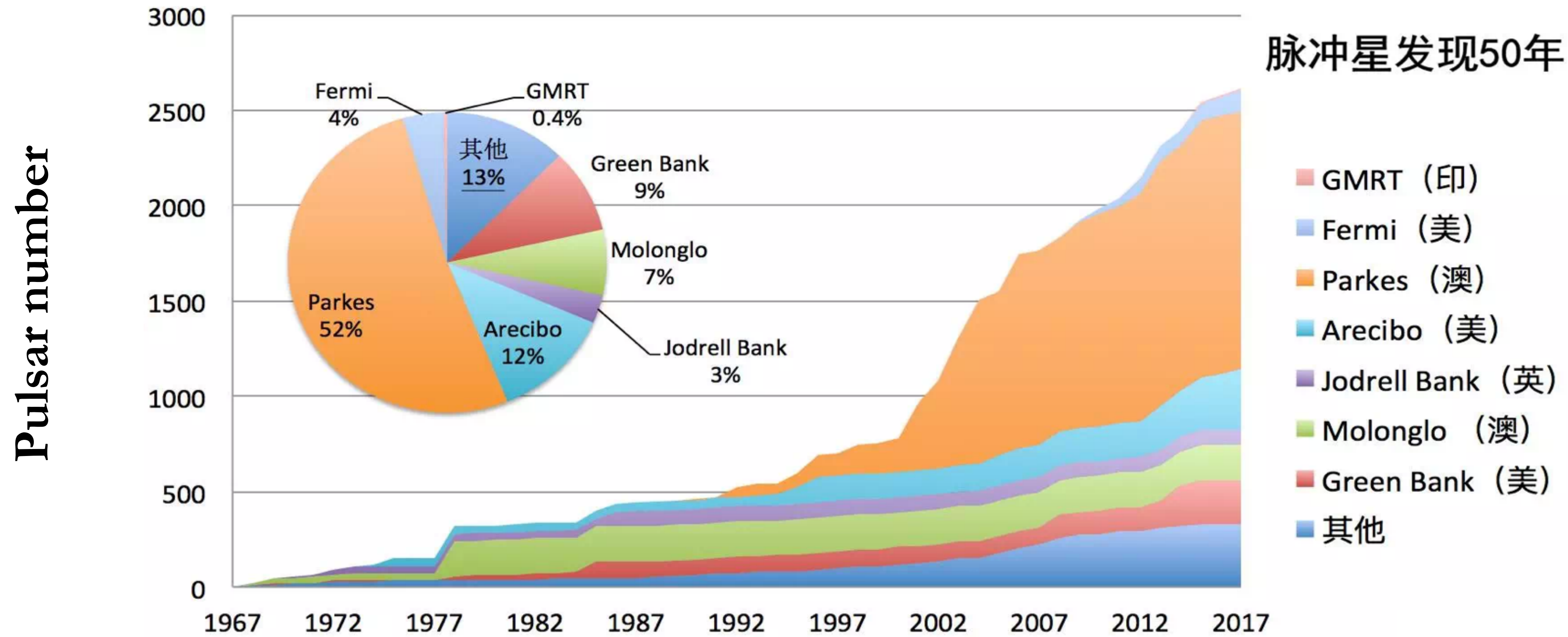
<u>8bit x 10^4 x 2 x 4k x 19 per second</u>

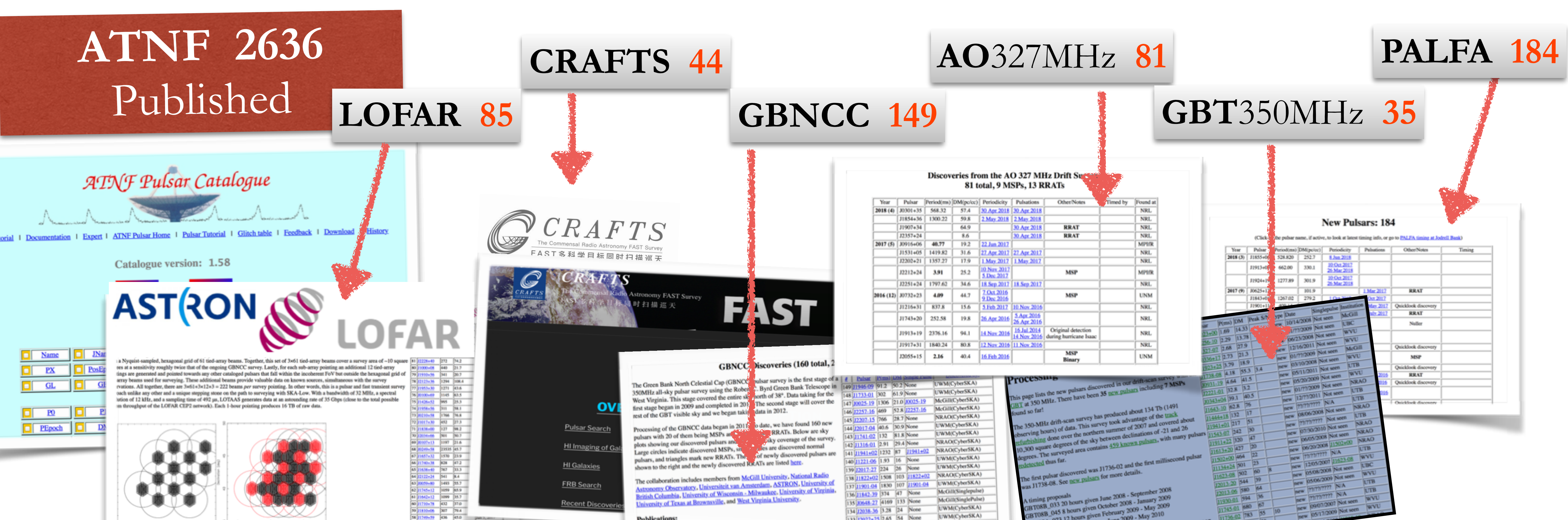
- 1.6 GB/s
- 5.8 TB/h
- 144 TB/day
- 10-20 PB/yr

1.05 – 1.45 GHz, 25K Tsys
>3 times sensitivity than UWB

The FAST commissioning phase is expected to last until **Spring 2019**, during which time the critical specifications of the FAST system, e.g. pointing, gain, system temperature, etc., are still being calibrated.

Pulsar Survey Competition (partial list)





Targets & Observing Modes < Drift-scan / Tracking

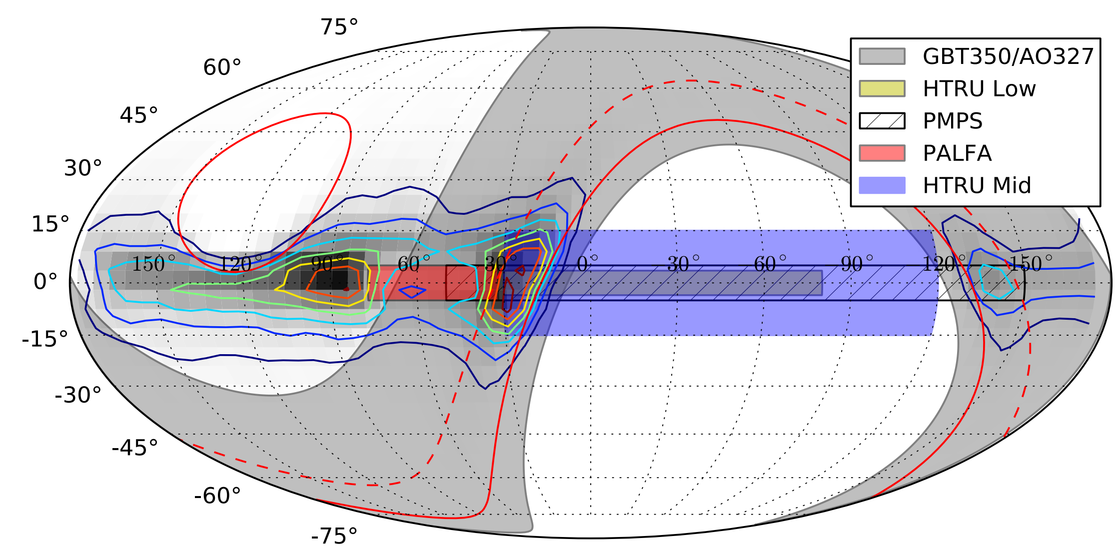
(A) Periodicity search (account for beam shape) — Pulsars

(B) Single pulse search — Giant pulses from pulsars, RRATS, FRBs, ...

Tracking for depth integral observation

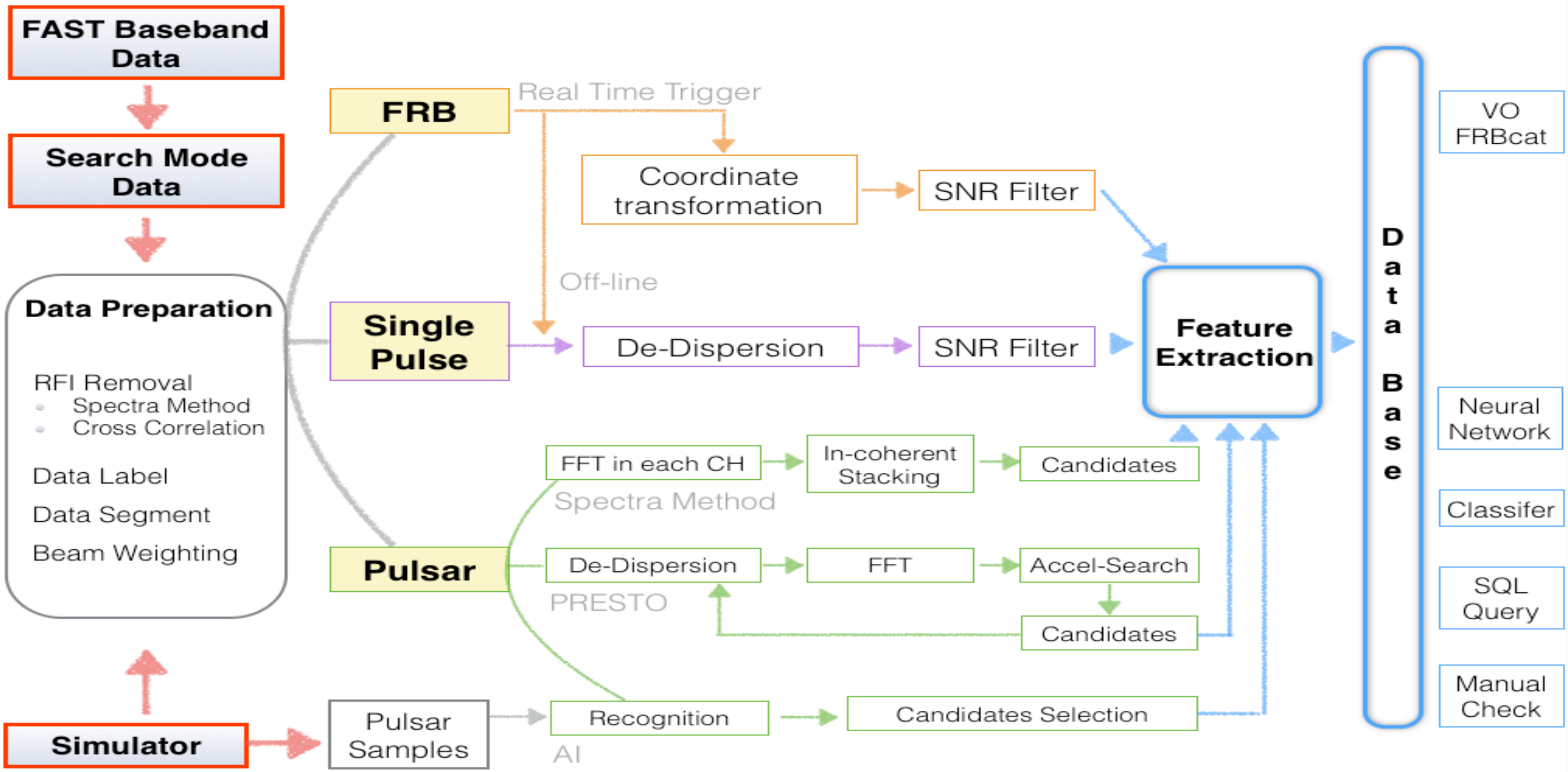
- Globular clusters
- Close-by galaxies (e.g., M31)
- Fermi radio-quiet pulsars
- Unidentified Fermi gamma-ray sources
- Repeated FRBs
- X-ray point sources in (or near) supernova
- Candidate pulsars from other (e.g., Parkes) surveys

Optimized drift-scan pulsar survey



Dai & Zhu et al.

Data Processing for Pulsar Search (3 Pipelines)



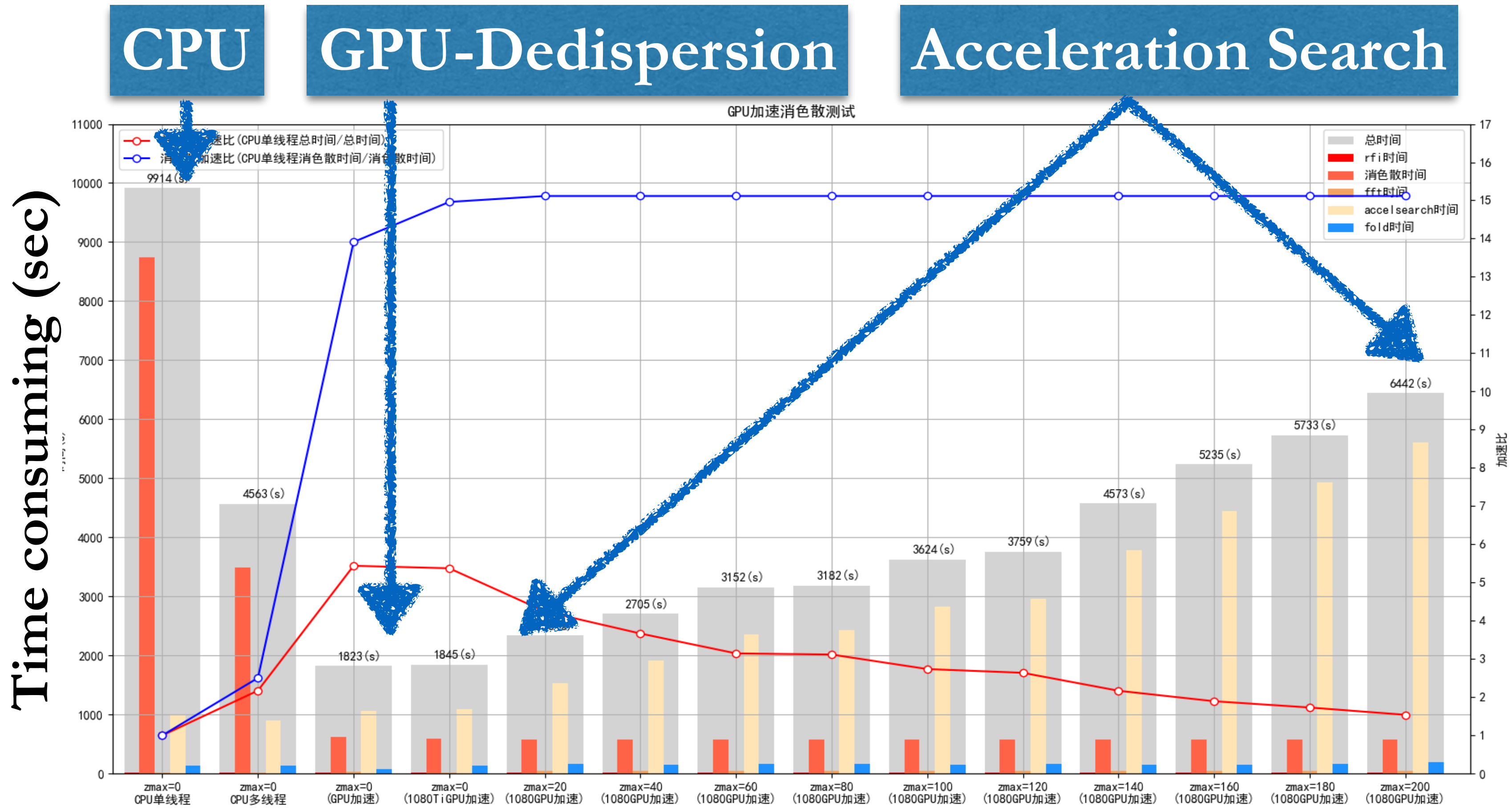
Data preparation

Distributed computing architecture + GPU

Real time for Periodicity & Single pulse Searches

Database

Higher computing ability for greater parameter space



>2000 CPU cores
>350 GPU cards
~7PB Disk storage
~3PB Tape library

What SQL databases do

- Combine multi sorting algorithms, e.g. image recognition, deep learning, etc.
- Characteristics can be flexibly formulated
- Radio Frequency Interference extraction
- Multi-beams cross validation of pulsar candidate, improve positioning
- Correlation and statistics of signals with multiple observations
- Data file backtracking.

Online interactive automatic FAST pulsar search

Known pulsars **matching**

Pulsar Match Tool

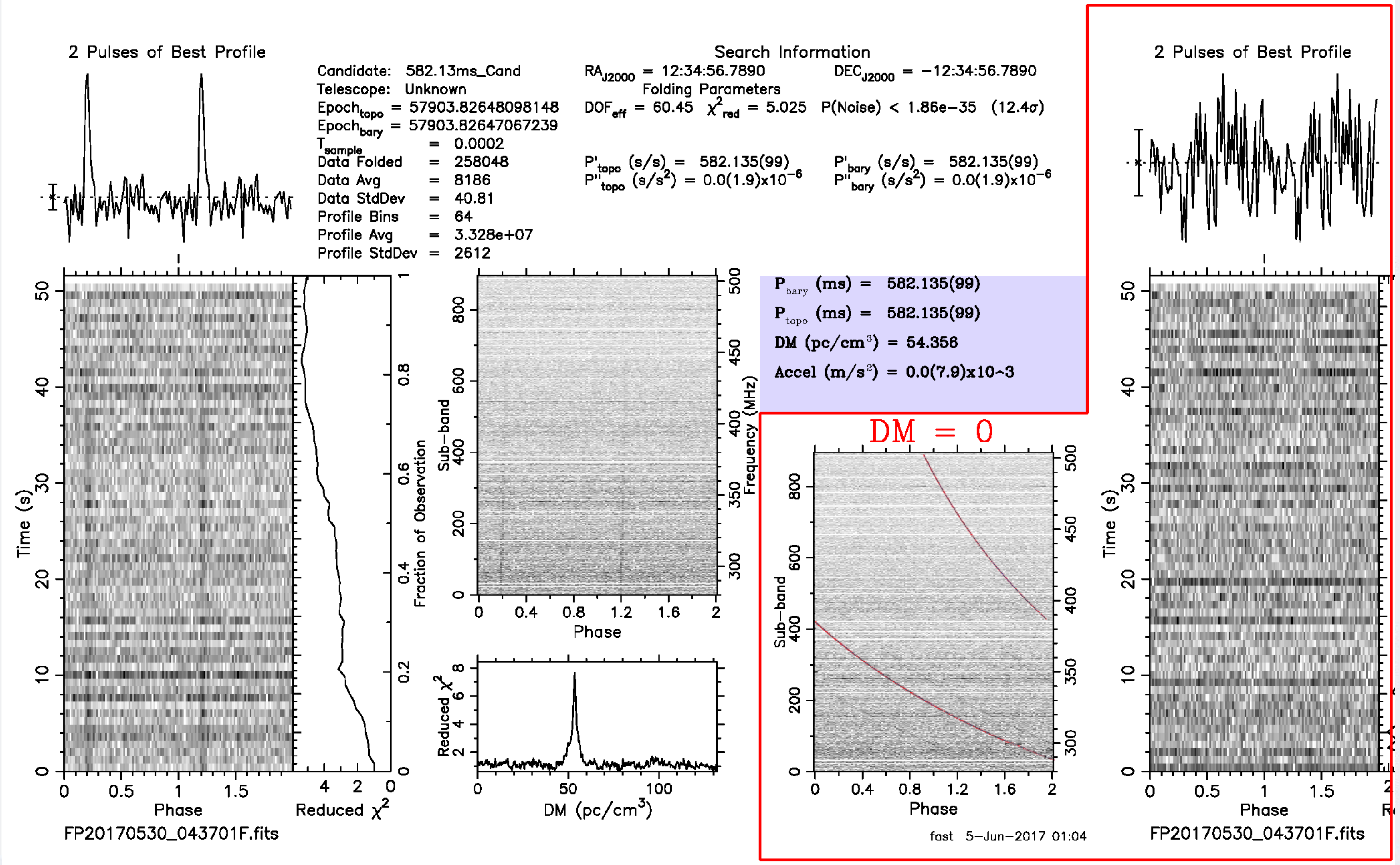
Ra(J2000) range(deg): 0.5 Dec(J2000) range(deg): .5
DM range: 10 P0 range(‰): 20
Harmonics: 16

order	Jname	P0(ms)	DM(pc/cm^3)	RA(deg)	DEC(deg)	Delta_P0(%)	Delta_DM	RA_DEC_D	Harmonics	OPT
1	B0950+08	253.065	2.97	148.28879	7.926597	0.0081(0.0032%)	0.13	0.26822778273126663	11/2	

SQL database
Feature extraction

```
select picname, picdm, ptopo, pic_1_peaknum, score, file_id, task_id, dm, cut_id, cand from t_pic_info where PIC_2_BARPERCENT <0.92 and PIC_3_BARPERCENT <0.94 and MAXVATDM <> 0 and dm < ptopo and score <1 and file_id in (select file_id from t_fits_info where file_name like 'FP20180109%') order by dm
```

Query Clear



第1页 共2页 共31条记录

matchChecked	picdm	ptopo	pic1Peaknum	score	fileId	taskId	dm	cand
0	30.1	5.553199	10	0.945664217	104295	1	30.1	3
0	30.1	5.553234	7	0.905505399	104369	1	30.1	2
0	30.1	5.553234	11	0.885745313	104299	1	30.1	3
0	30.1	5.553234	6	0.861617207	104370	1	30.1	4
0	30.1	5.553234	6	0.854888685	104360	1	30.1	2
0	30.1	5.553199	5	0.85246256	104357	1	30.1	2
0	30.1	5.553199	8	0.82054772	104390	1	30.1	1
0	30.1	5.553234	10	0.818480389	104393	1	30.1	2
0	30.1	5.553199	8	0.789452391	104365	1	30.1	5
0	30.1	5.553163	7	0.780848902	104377	1	30.1	3
0	30.1	5.553234	4	0.777707122	104342	1	30.1	2
0	30.1	5.553163	3	0.776937609	104267	1	30.1	2
0	30.1	5.553163	9	0.758784468	104378	1	30.1	3
0	30.1	5.553234	10	0.719380851	104356	1	30.1	1
0	30.1	5.553163	6	0.705921735	104361	1	30.1	3

CRAFTS

The Commensal Radio Astronomy FAST Survey

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http://crafts.bao.ac.cn/pulsar/

No.	Name	RA (J2000)	DEC (J2000)	Period (ms)	DM	Type	Plots	Discovery date	Confirmation	Notes
1	J1859-01	18 59	-01	1832	188	PSR	FFT	2017-08-22	2017-09-10(Parkes)	
2	J2338+48	23 38	+48	119	34	PSR	FFT	2017-08-04	2017-10-06(Effelsberg)	
3	J1931-02	19 31	-02	593	36	PSR	FFT	2017-08-22	2017-09-10(Parkes)	Coincide with GBT drift 350-MHz search result J1930-01
								2017-08-	2017-10-	

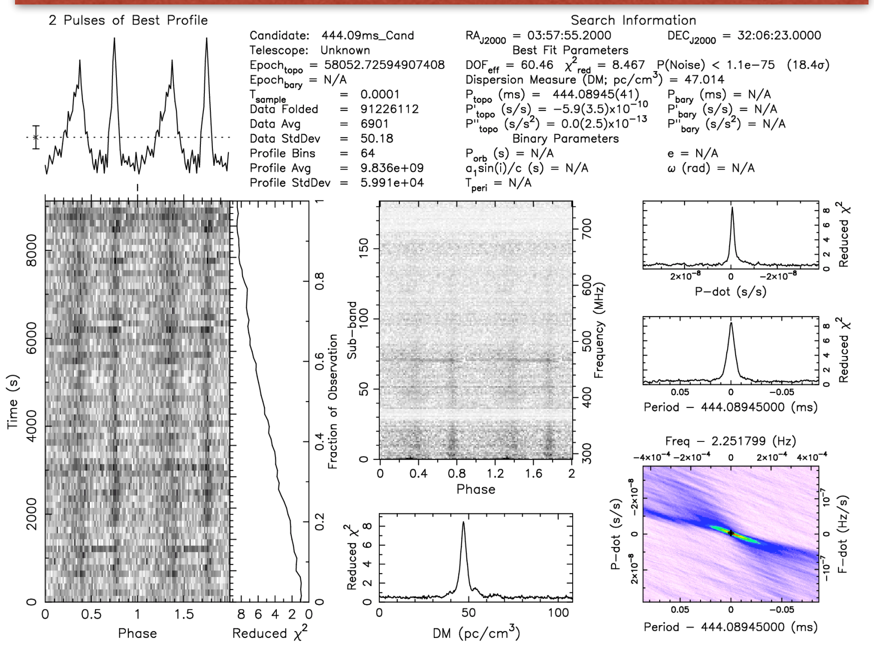
18 **FAST pulsar candidates are confirmed by Parkes and Effelsberg**

25 **FAST pulsar candidates are confirmed by FAST self**

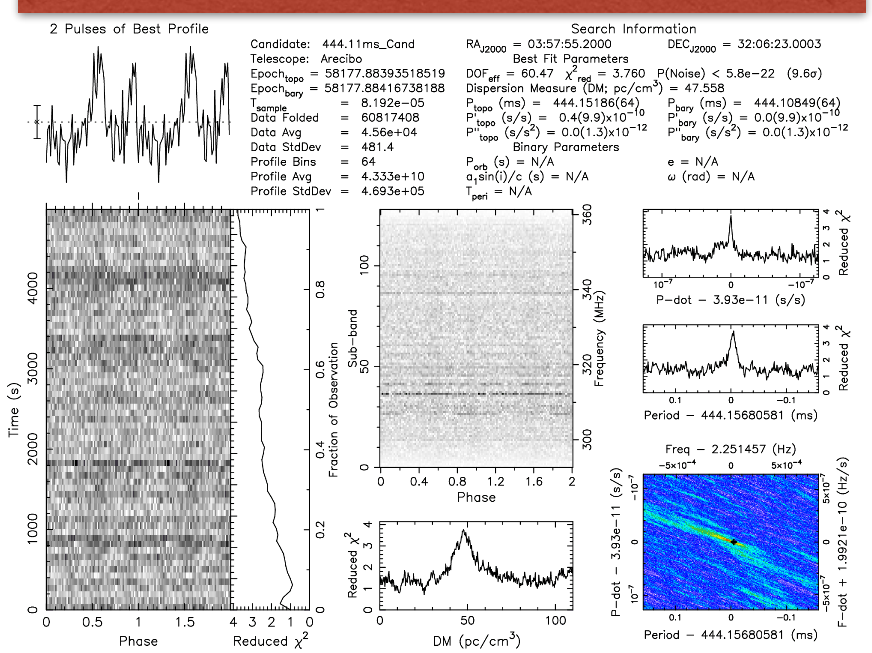
1 **of the weakest radio Millisecond Pulsar (MSP) with gramma ray radiation is confirmed by the Fermi-LAT team**

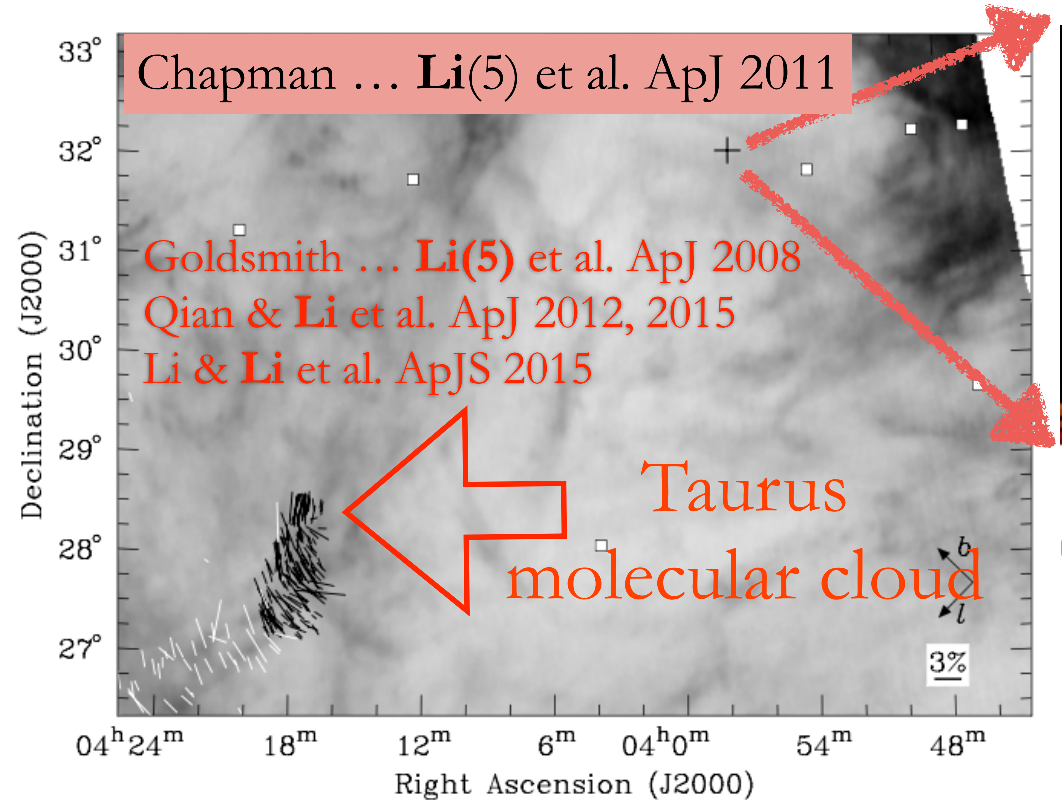
Detect radio counterpart of Taurus Fermi γ-ray PSR J0357.8+3205

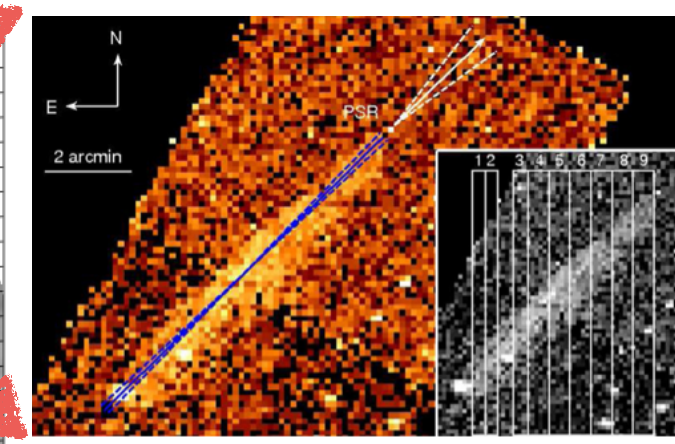
2017.10 Discovered by FAST



2018.3.1 Confirmed by Arecibo DDT

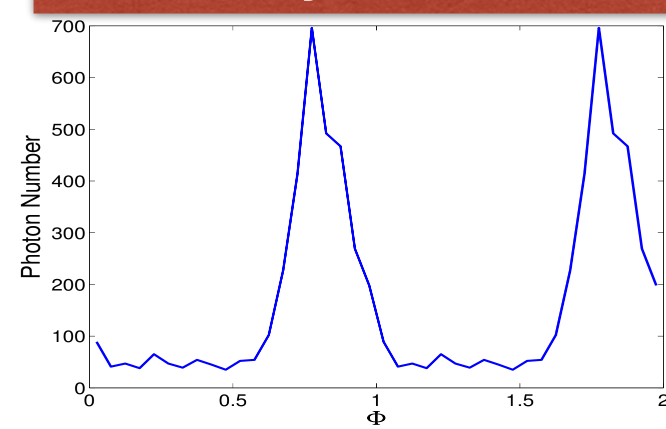


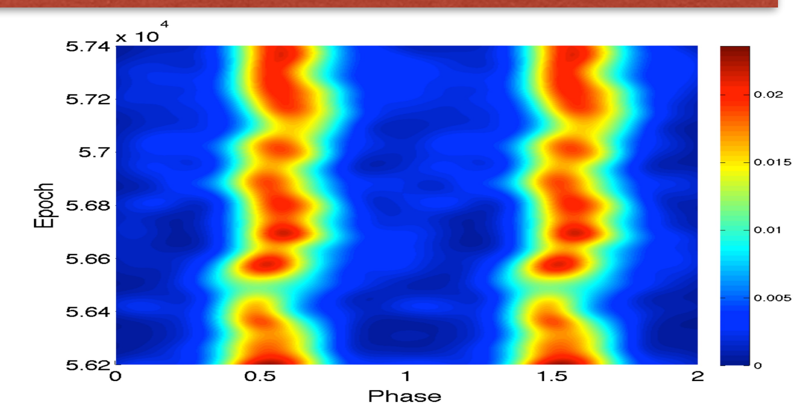




Chandra X-ray Image
De Luca et al. 2011

> 8 years of Fermi-LAT Gamma ray data





Had submitted AO, Chandra proposals

- Upper limite < 43uJy for Arecibo 327MHz
- Upper limite < 134uJy for GBT 350MHz
- ~ 40uJy for FAST low band

FAST's Discovery of MSP J0318+0253

coincident with the unassociated gamma-ray source 3FGL J0318.1+0252

• Dec. 19, 2017	**MoU signed between the FAST team and Fermi-LAT team**
• Feb. 18 - Mar. 08, 2018	**Sources selection and Joint-research funding proposal**
• Feb. 27, 2018	**1 hour tracking observation with the FAST ultra-wide band receiver, the radio pulses toward 3FGL J0318.1+0252 were detected.**
• Apr. 18, 2018	**Confirmed by the Fermi-LAT team in reprocessing of Fermi data**

Spin period is 5.19 milliseconds, an estimated distance of about 4 thousand light-years, and as potentially one of the faintest radio MSPs. No X-ray counterpart is detected at the pulsar position.

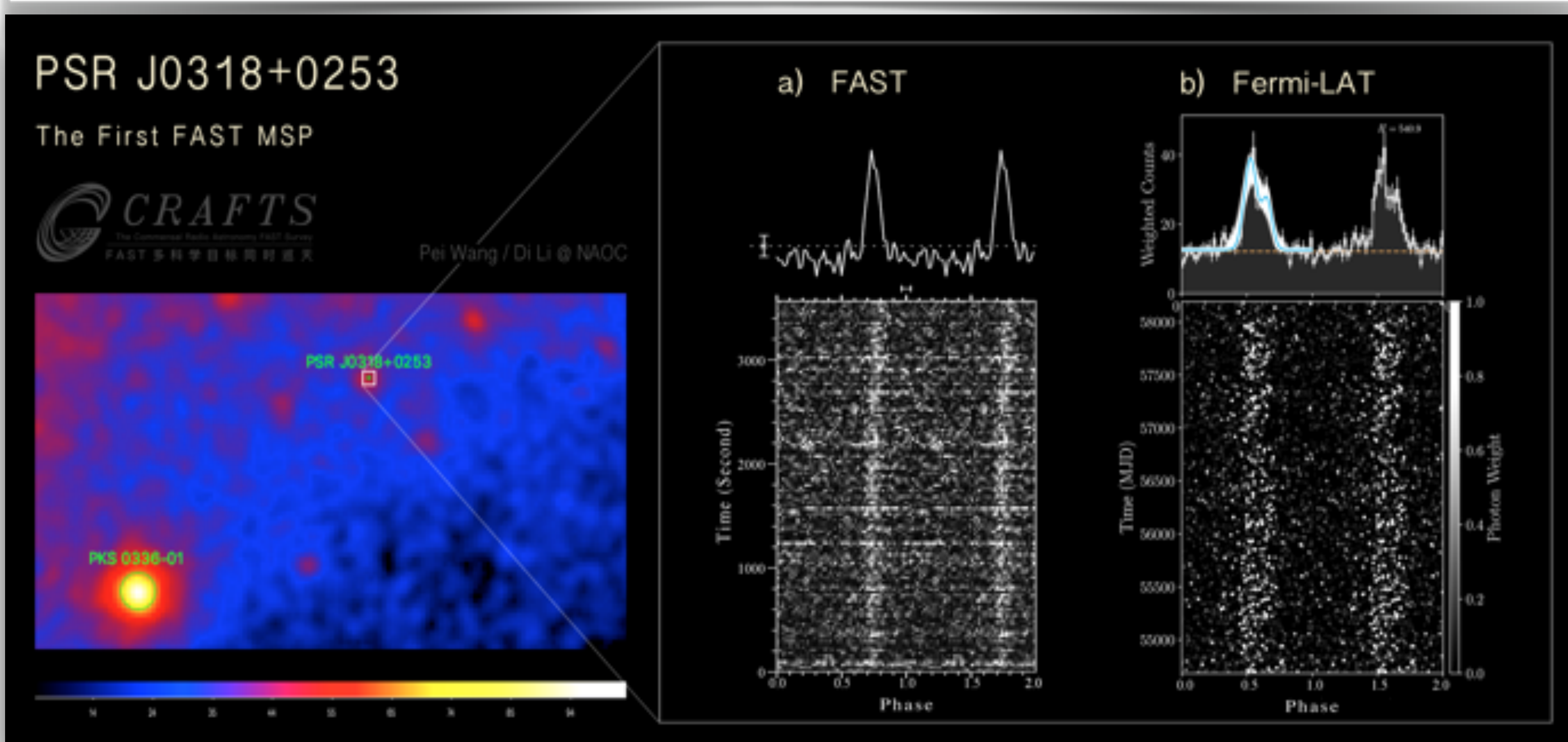
First MSP discovered by FAST!

Deeper multi-wavelength follow-up observations are strongly encouraged.

ATel #11584; *Pei Wang, Di Li, Weiwei Zhu, Chengmin Zhang, Jun Yan (National Astronomical Observatories, Chinese Academy of Sciences), Xian Hou (YunNan Observatories, Chinese Academy of Sciences), Colin J. Clark (Jodrell Bank Centre for Astrophysics, School of Physics and Astronomy, University of Manchester), Pablo M. Saz Parkinson (Department of Physics and Laboratory for Space Research, University of Hong Kong & Santa Cruz Institute for Particle Physics), Peter F. Michelson (Stanford University), Elizabeth C. Ferrara (UMCP/CRESST/GSFC), David J. Thompson, (NASA/GSFC), David A. Smith (Universite ? Bordeaux 1, CNRS/IN2P3/CENBG), Paul S. Ray, Matthew Kerr (Space Science Division, Naval Research Laboratory), Zhiqiang Shen (Shanghai Astronomical Observatory), Na Wang (Xinjiang Astronomical Observatory), on behalf of FAST and the Fermi-LAT Collaboration Â*

on 28 Apr 2018; 04:43 UT

Credential Certification: Di Li (dili@nao.cas.cn)



Atel #11584

First of many result from the FAST-Fermi LAT collaboration

Upper limit of **Swift XRT (3.4ks)** observations in 0.3-10 keV is **2.8e-13 erg cm^{-2}s^{-1}** in the direction of the MSP.

(Pablo et al.)

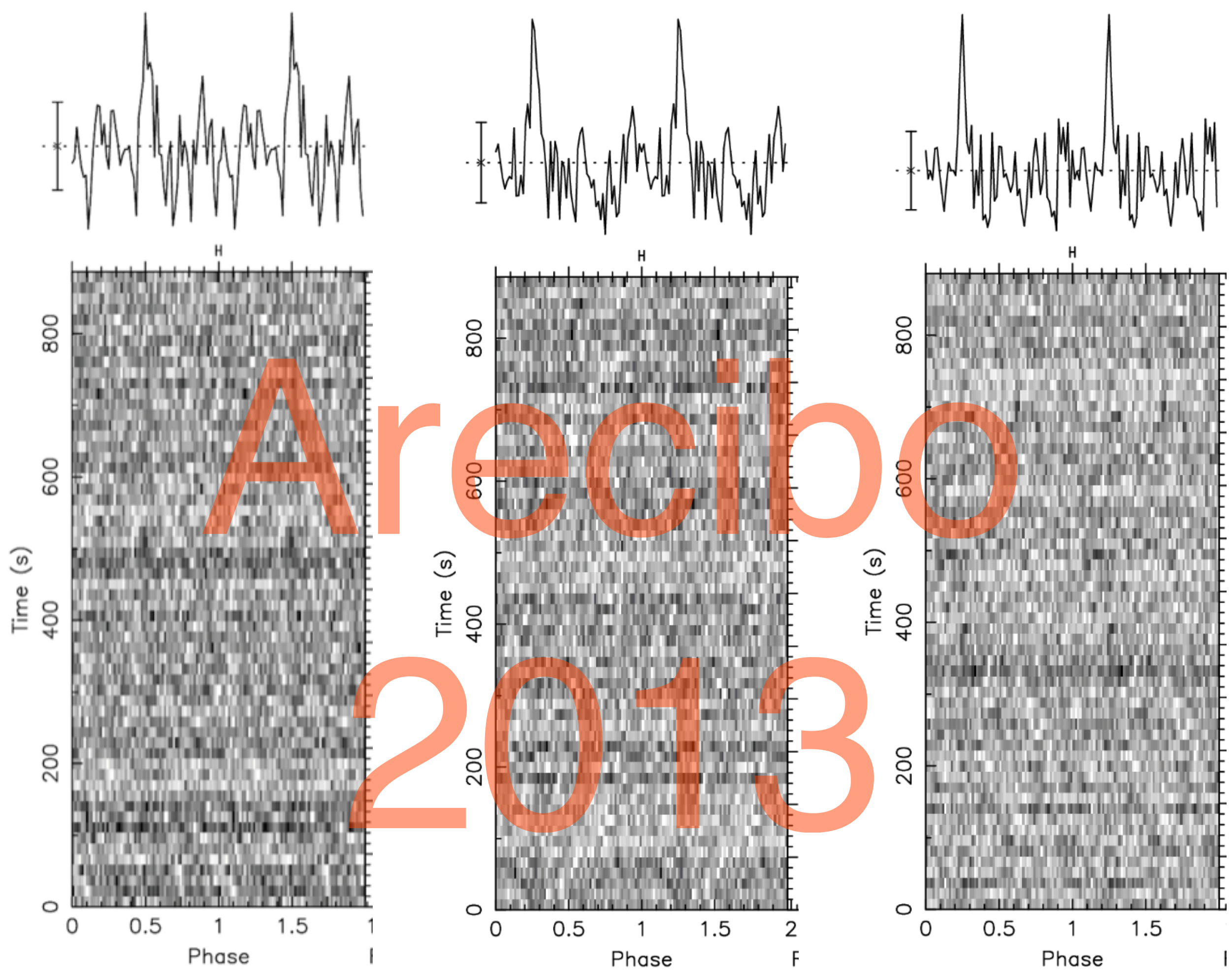
Radio Flux Density

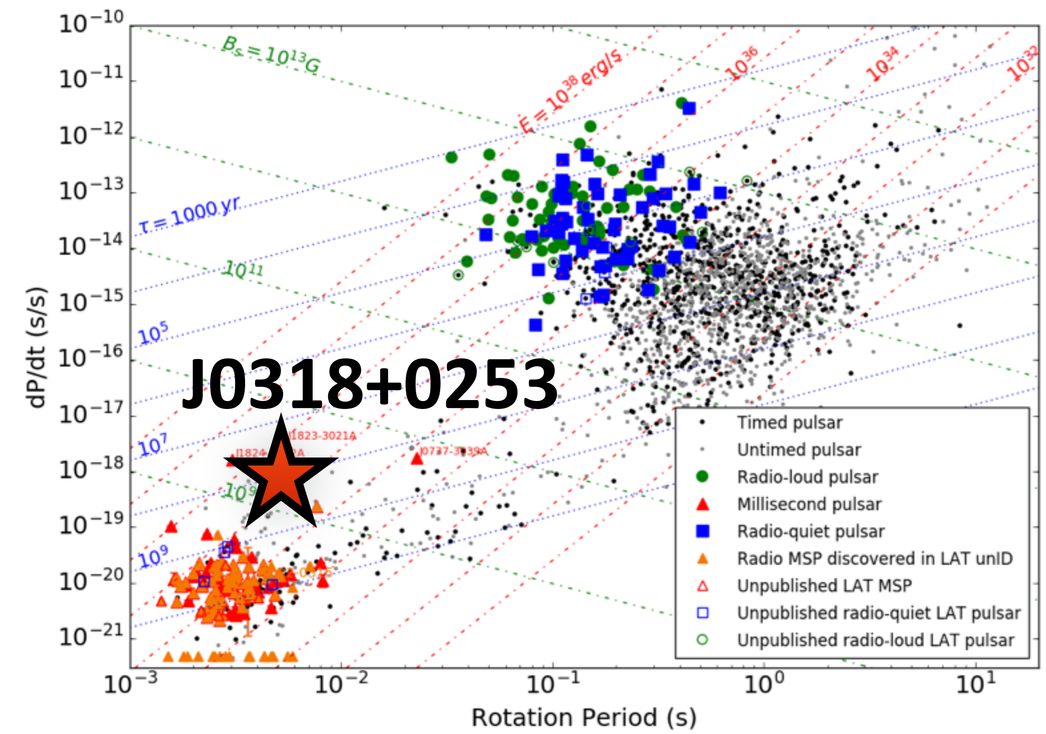
(290-802MHz) 1 Sigma ~ 20-30micro-Jy

~100 micro-Jy, corresponding to <u>less than 20 micro-Jy in L-band</u> assuming a canonical spectral index of 1.7

$$\sigma = \frac{T_{sys}}{\sqrt{\tau * \Delta\upsilon}} = \frac{70}{\sqrt{60*60*512*10^6}} K \approx 10^{-4} K \qquad \frac{T_A}{S} = \frac{\eta_A A_g}{2k} = 10.22K/Jy$$

$$\sigma = \frac{10^{-4}K}{10.22K/Jy}\sqrt{\frac{P-W_{eff}}{W_{eff}}} = 9.8\mu Jy\sqrt{\frac{5.19-0.93}{0.93}} = 21\mu Jy$$





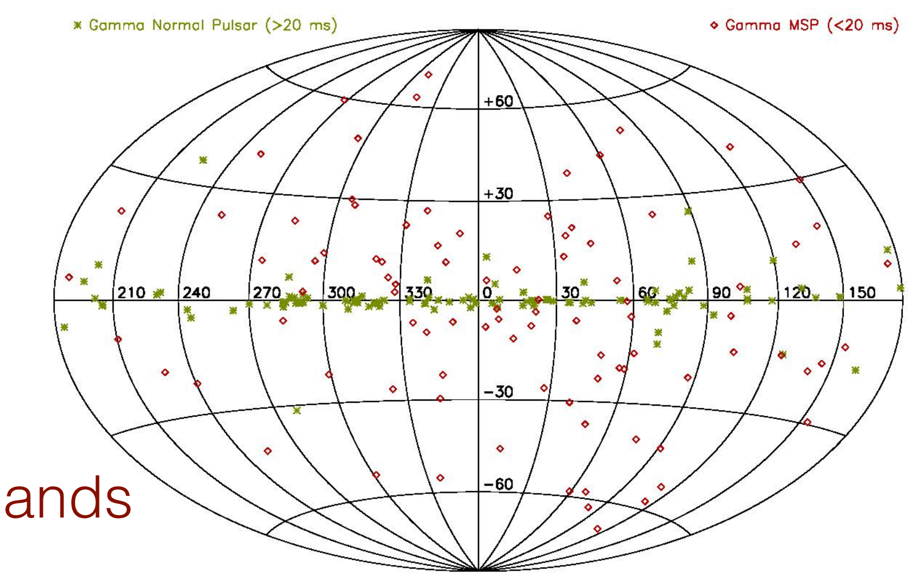
Ephemeris from Colin

PSRJ	J0318+0253
RAJ	03:18:15.5408
DECJ	+02:53:01.5138
F0	192.68371552268
F1	-6.5493039411933e-16
PEPOCH	56437
START	54681.0
FINISH	58194.0
POSEPOCH	56437
CLK	TT(TAI)
UNITS	TDB

Actually visible in each observation, but always at a significance much too low to have any chance of being found in a blind search. This is a testament to the huge collecting area of FAST.

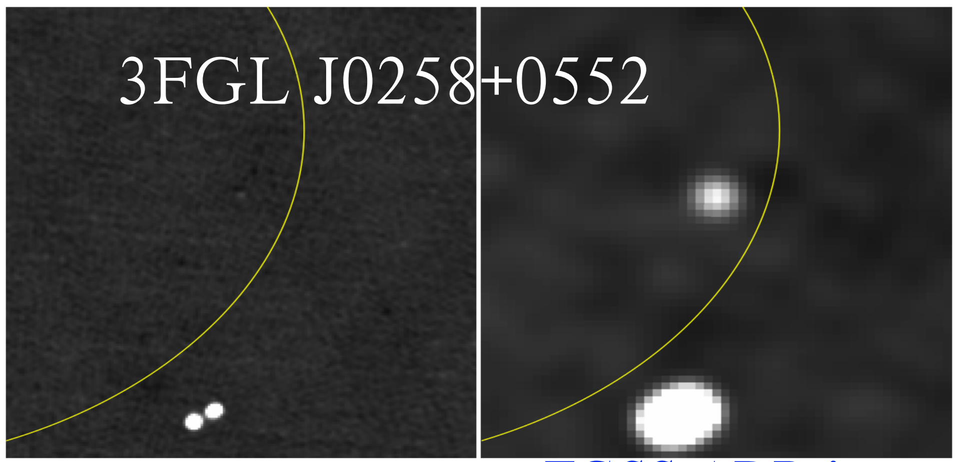
Pulsar candidates in Fermi unconfirmed soures

< 20ms MSP —> Bulge distribution
> 20ms Nomal pulsar —> Galactic disc



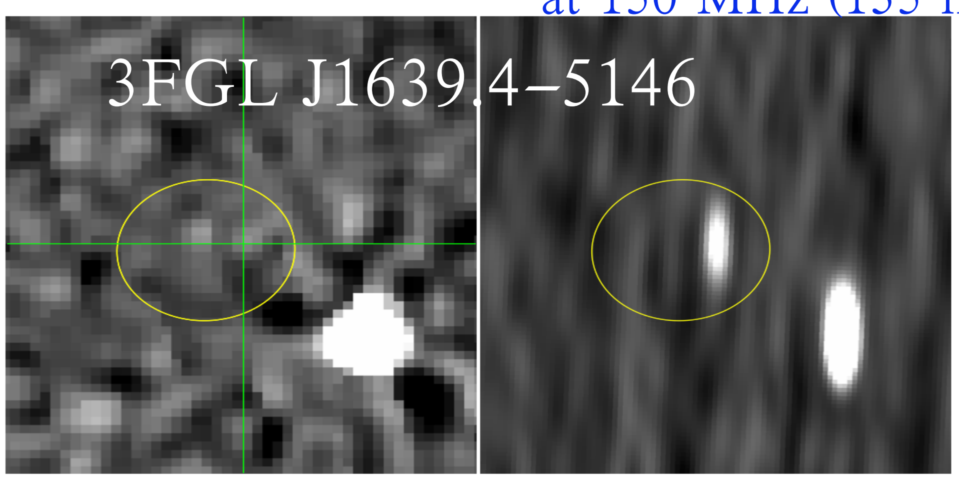
In FAST sky：

41 MSP Cands
39 Nomal_PSR Cands



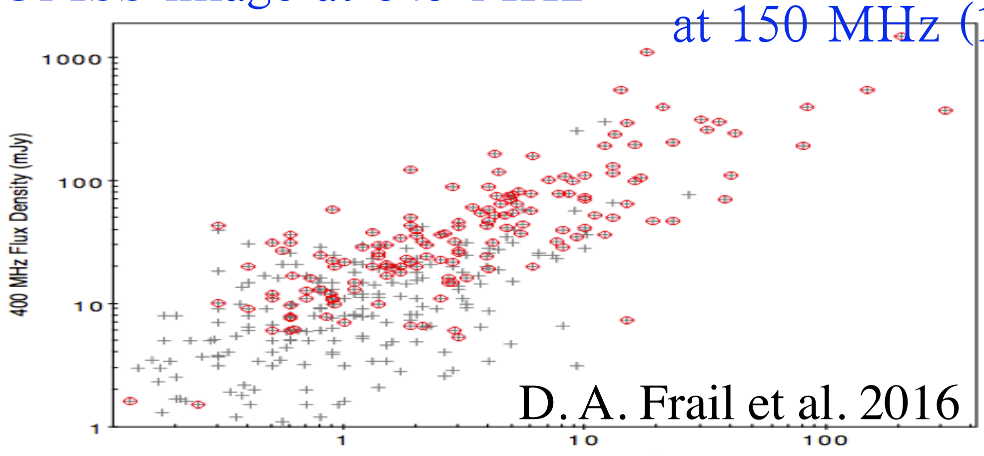
FIRST image at 1.4GHz

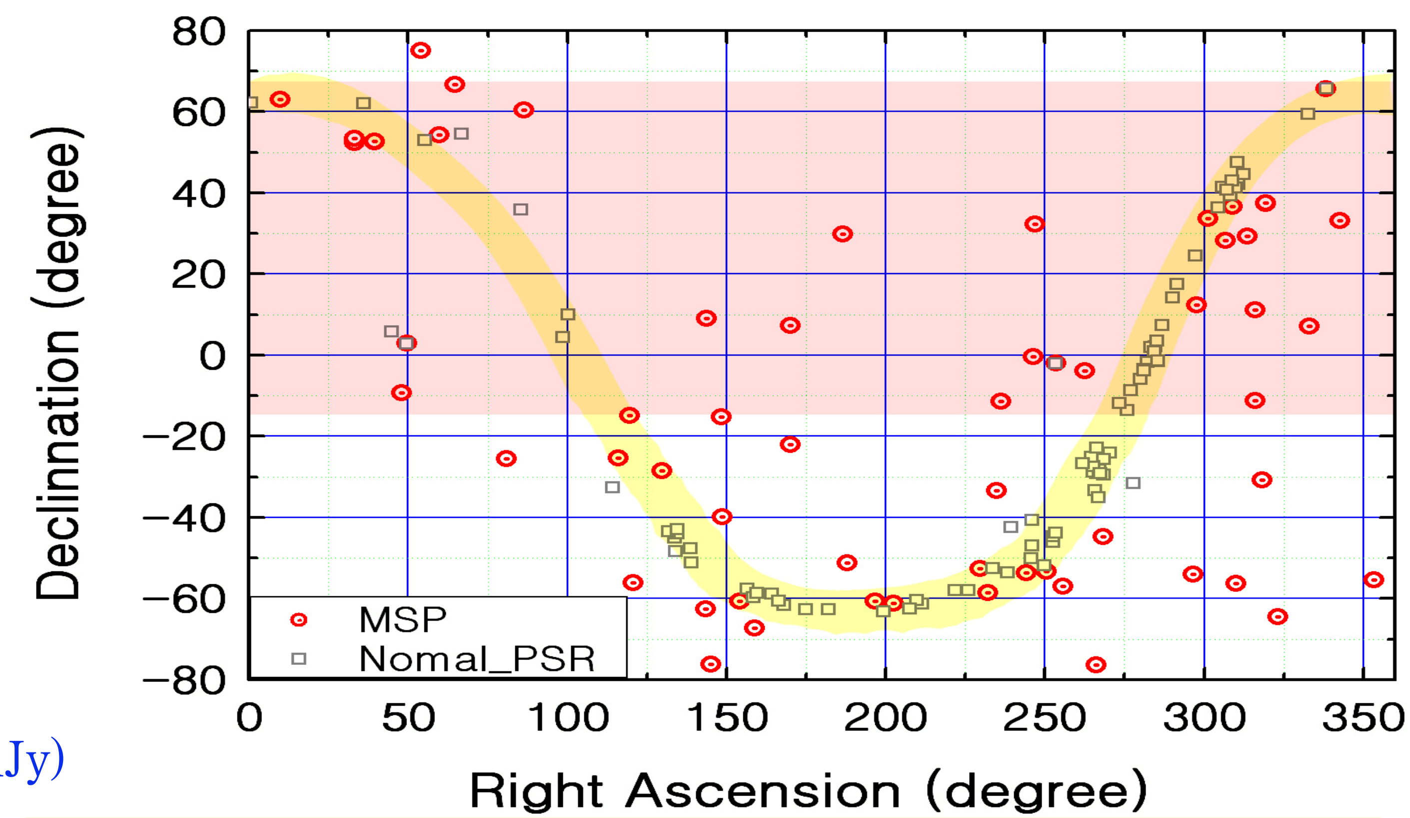
TGSS ADR image at 150 MHz (135 mJy)



SUMSS image at 843 MHz

TGSS ADR image at 150 MHz (175 mJy)





High efficient discover MSPs at high latitude

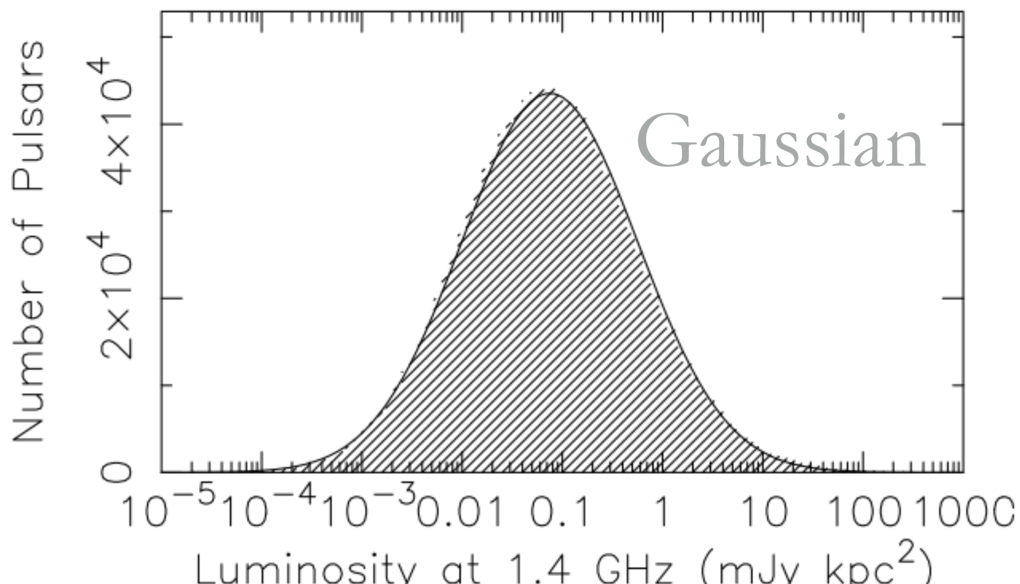
- Mapping from interferometer + Spectral index
- Machine learning method (Saz. Parkinson et al. 2016)

Statistical Model for Galactic Pulsar Population

Set up model by using 1008 isolated pulsars of Parkes survey result， fitting distribution, Monte-Carlo method.

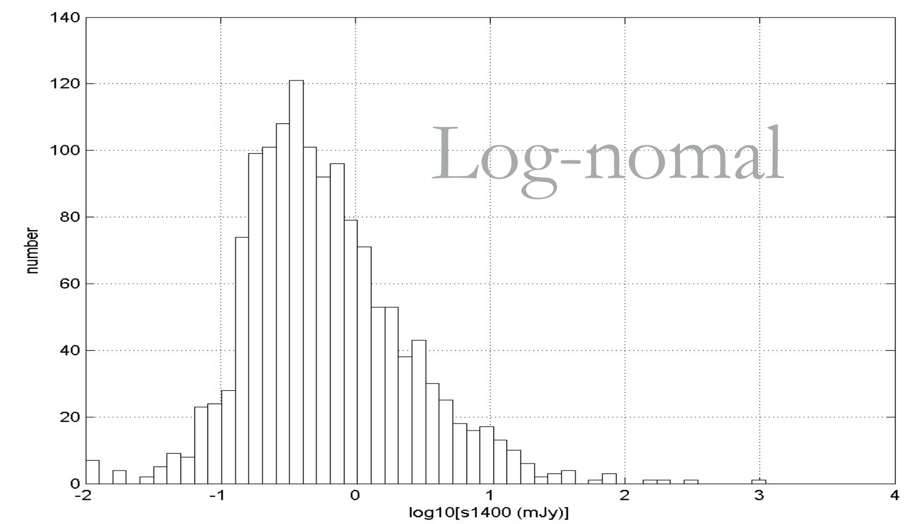
PALFA、HTRU pulsar survey (Lazarus, 2012)： Underestimate pulsar number in low-luminosity.

PsrPop



Lorimer et al., Statistical Model

PsrPopPy



https://github.com/samb8s/PsrPopPy, 2015

FAST pulsar search with a wider range of flux will be extremely helpful. Shed light on the evolution of neutron stars and contribute towards a unified picture of the neutron star zoo.

Multi-messenger International Collaboration

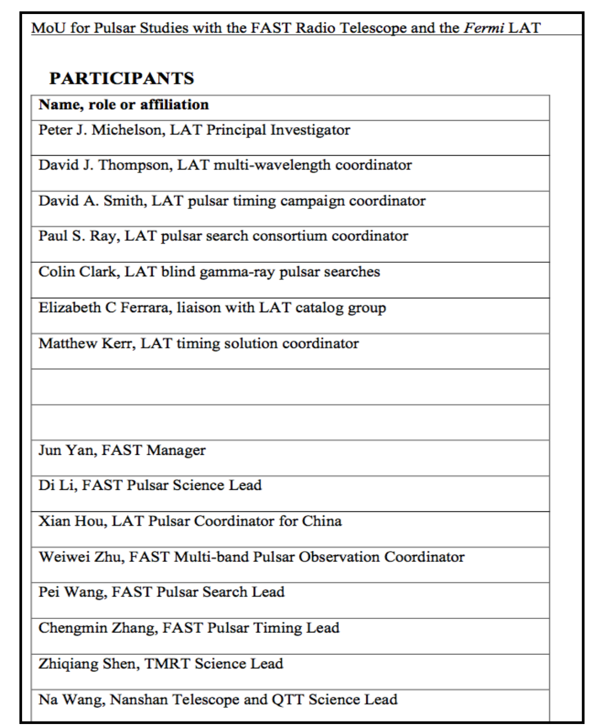
FAST is not only a highly efficient pulsar-finding machine

Revolutionary technique upgrading

- Gravitational wave: LIGO
- Fast Radio Brust
- Phased Array Feed technology
- Time domain astronomy
- Artificial intelligence
- Multi-wavelength observations are crucial: radio, soft and hard X-rays, MeV,TeV, etc

LIGO-M1600222, VIR-0417A-16
Memorandum of Understanding between FAST and LIGO and VIRGO ...

FAST - HXMT



MoU for Pulsar Studies with the FAST Radio Telescope and the *Fermi* LAT

PARTICIPANTS

Name, role or affiliation
Peter J. Michelson, LAT Principal Investigator
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David A. Smith, LAT pulsar timing campaign coordinator
Paul S. Ray, LAT pulsar search consortium coordinator
Colin Clark, LAT blind gamma-ray pulsar searches
Elizabeth C Ferrara, liaison with LAT catalog group
Matthew Kerr, LAT timing solution coordinator
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Weiwei Zhu, FAST Multi-band Pulsar Observation Coordinator
Pei Wang, FAST Pulsar Search Lead
Chengmin Zhang, FAST Pulsar Timing Lead
Zhiqiang Shen, TMRT Science Lead
Na Wang, Nanshan Telescope and QTT Science Lead

MoU between FAST and Fermi-LAT

http://adsabs.harvard.edu/abs/2018IMMag..19..112L

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 **original "busily commissioned" is not clear in context.>** 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

Li et al. 2018
IEEE Microwave Invited Review

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