Discovery of new pulsars in Globular Clusters NGC6517, M13 and M92 with FAST

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OUTLINE

- New Pulsars in NGC 6517 discovered with FAST
- Galactic Globular Cluster pulsar population simulation
- Newly binary pulsars from M13 and M92 using segmented search

NGC 6517

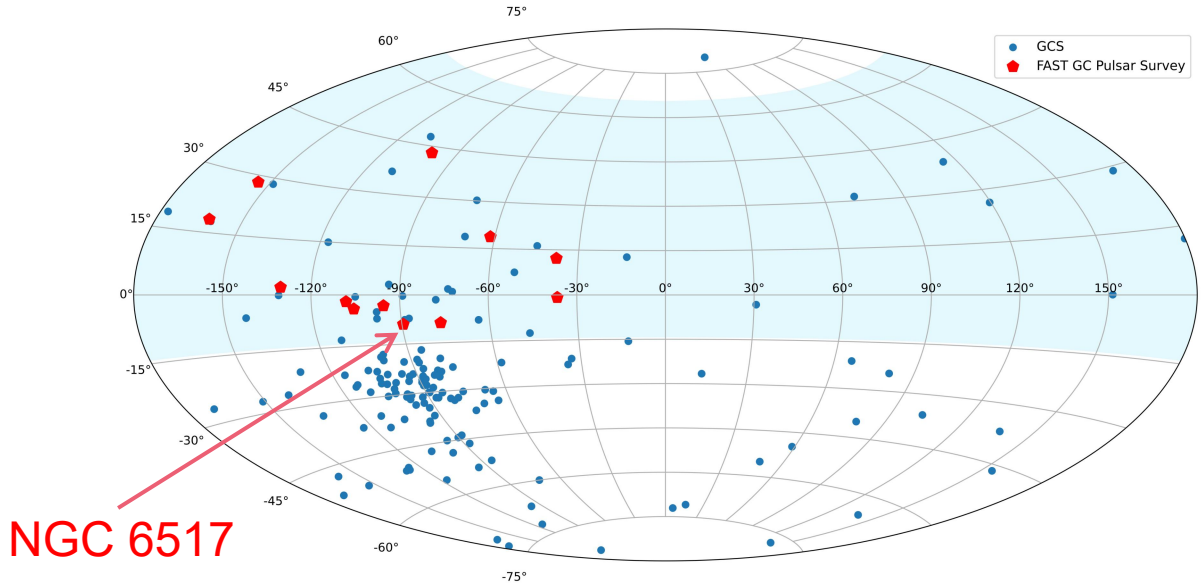


Image Credit: PanSTARRS DR1, PS1 Science Consortium

Ra: 18:01:50.52, Dec: -08:57:31.6;

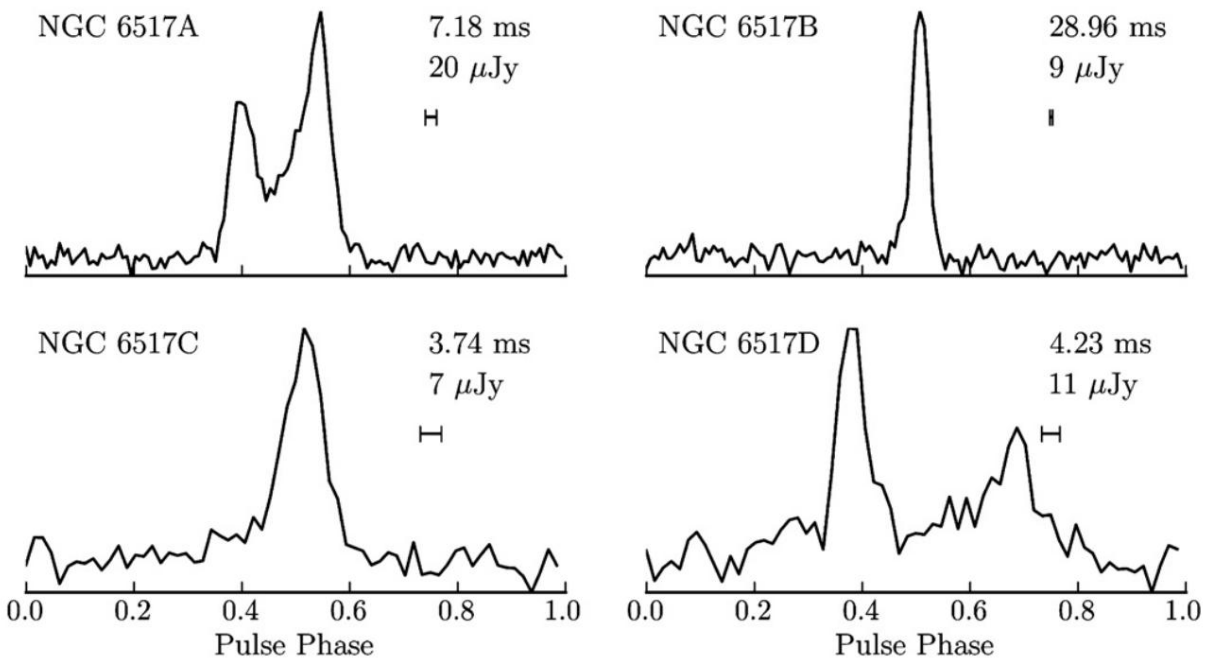
R_sun: 10.6 kpc; Mass: $2.16 \pm 0.24 * 10^5 M_\odot$; T = 12 Gyr

(Baumgardt et al. 2023) ;

The densest cluster in FAST sky, $\rho_0 = 10^{5.29} L_\odot\ pc^{-3}$ (13 in all GCs,

Harris. 2010).

The first pulsars in NGC 6517



Average pulse profiles of the newly discovered pulsars in NGC 6517 with Green Bank Telescope (Lynch et al. 2011).

1. Dispersion Measures (DM) range:

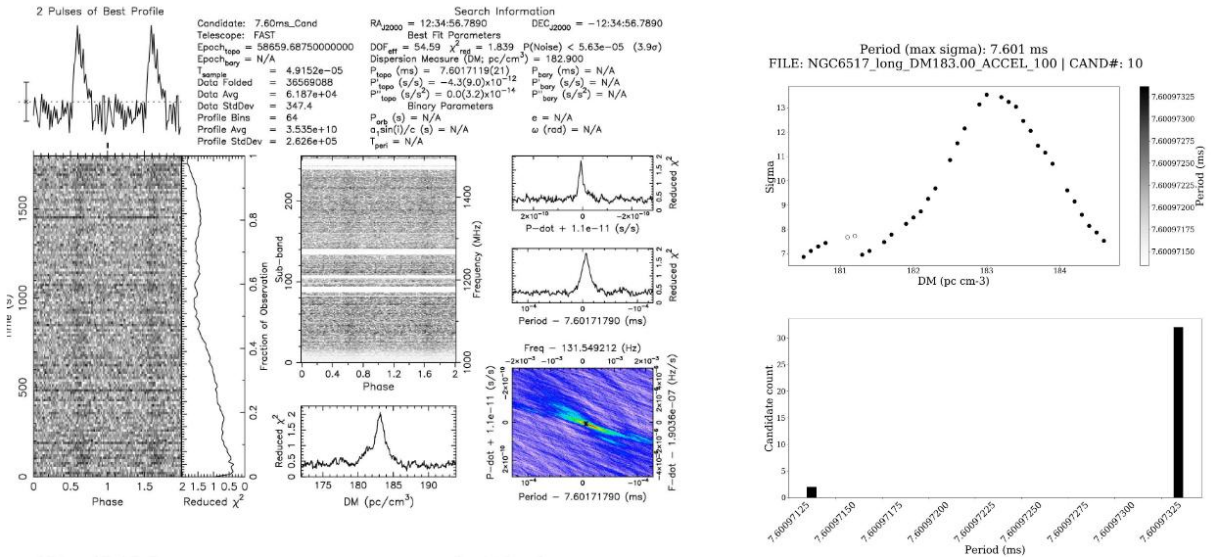
J1801−0857A to C (NGC 6517A to C): ~182.4 cm^{-3} pc

NGC 6517D: ~174.7 cm^{-3} pc.

2. Only NGC 6517B is in binary system (~59.9 days PB).

3. By analyzing the luminosity function of the pulsars in NGC 6517, NGC 6517 was predicted to harbor roughly 12-17 pulsars (Lynch et al. 2011).

More pulsars in NGC 6517 with FAST



The discovery plot of NGC6517E. Left panel is the PRESTO folding result and right panel is the DM to SNR plot from **JinglePulsar code** (Pan et al. 2021).

8 new pusars NGC 6517E, F, G, H, I, ~~J~~, K, L with FAST

(Pan et al. 2021a,b)

New Pulsars:

1. NGC 6517E to I, K and L are isolated.

2. These new pulsars are faint with DM range of 177.8 to 185.6 cm^{-3} pc.

Why?

1. The high sensitivity of FAST.

2. New algorithm used to check and sifting possible candidates.

FAST observation data of NGC 6517

Table 1. The information of 19 FAST archival data of NGC 6517 processed in this paper.

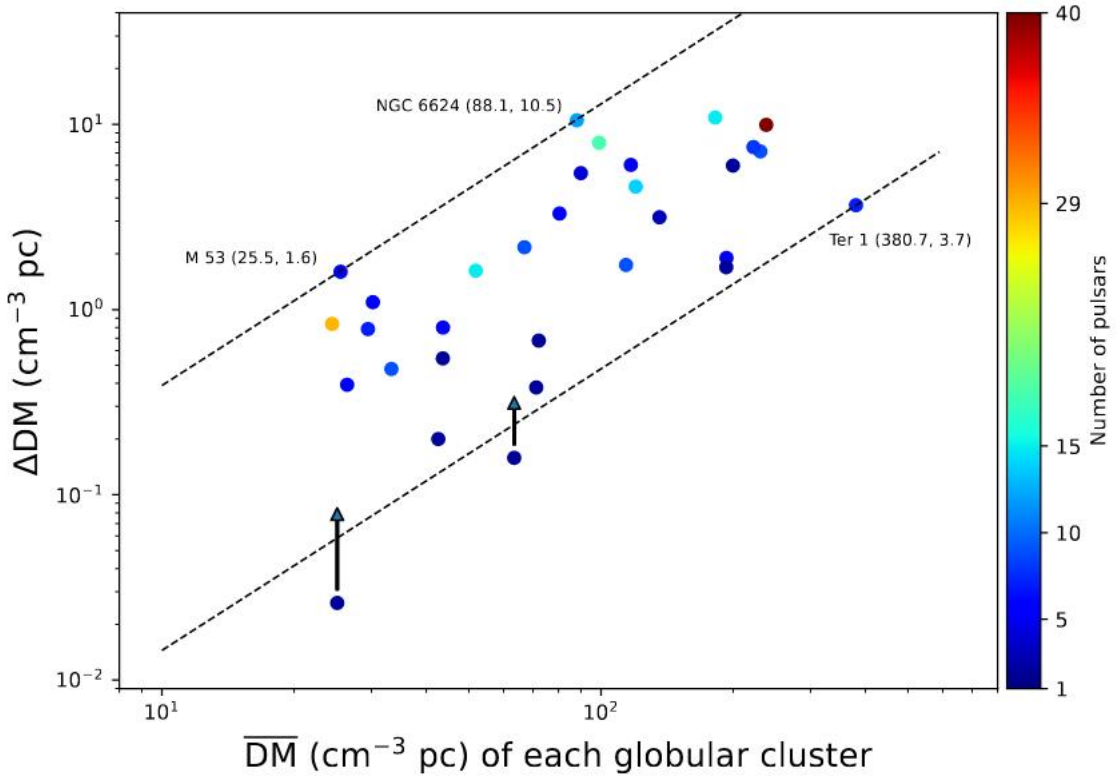
Epoch of observation YYYY/MM/DD (MJD)	α J2000	δ J2000	Observation Length (seconds)	Number of polns	Sample time (us)
2019/06/25 (58659)	18:01:50.52	-08:57:31.6	1800	2	49.152
2019/07/24 (58688)	18:01:50.52	-08:57:31.6	2513	2	49.152
2019/07/25 (58689)	18:01:50.52	-08:57:31.6	3600	2	49.152
2019/07/26 (58690)	18:01:50.52	-08:57:31.6	1417	2	49.152
2019/10/17 (58773)	18:01:50.52	-08:57:31.6	1800	2	49.152
2020/01/08 (58856)	18:01:50.52	-08:57:31.6	3368	2	49.152
2020/01/19 (58867)	18:01:50.52	-08:57:31.6	7200	2	49.152
2020/01/20 (58868)	18:01:50.52	-08:57:31.6	7200	2	49.152
2020/01/21 (58869)	18:01:50.52	-08:57:31.6	7200	2	49.152
2020/01/22 (58870)	18:01:50.52	-08:57:31.6	4800	2	49.152
2020/01/23 (58871)	18:01:50.52	-08:57:31.6	9000	2	49.152
2020/03/22 (58929)	18:01:50.52	-08:57:31.6	3720	2	98.304
2020/03/23 (58930)	18:01:50.52	-08:57:31.6	3720	2	98.304
2020/04/26 (58964)	18:01:50.52	-08:57:31.6	1365	2	98.304
2020/04/27 (58965)	18:01:50.52	-08:57:31.6	2340	2	98.304
2020/09/13 (59105)	18:01:50.52	-08:57:31.6	7200	4	49.152
2022/04/30 (59698)	18:01:50.52	-08:57:31.6	7200	2	49.152
2022/12/28 (59941)	18:01:50.52	-08:57:31.6	8400	4	49.152
2022/12/31 (59944)	18:01:50.52	-08:57:31.6	8400	4	49.152

.....

1. Observation span: 2019/06/25 - 2022/12/31

2. The longest observation : 9000 s

The plan of data processing



$\Delta DM \equiv DM_{max} - DM_{min}$ in each GC (Yin et al. 2023).

M 53 (5 psr, Lian et al. 2023); NGC 6624 (12 psr, Abbate et al. 2022). The upper bound:

$$\lg(\Delta DM) = 1.52 \times \lg(\overline{DM}) - 1.93$$

1. The time delay between two frequencies :

$$\Delta t = 4.15\ \mathrm{ms} \times \left[\left(\frac{\nu_{\mathrm{lo}}}{\mathrm{GHz}}\right)^{-2} - \left(\frac{\nu_{\mathrm{hi}}}{\mathrm{GHz}}\right)^{-2}\right] \times \left(\frac{\mathrm{DM}}{\mathrm{cm}^{-3}\ \mathrm{pc}}\right)$$

$$\mathrm{DM} = \int_0^d n_e\, dl,$$

2. For NGC 6517:

(181.3) ± 16 cm^{-3} pc (165 -198 cm^{-3} pc)

DM step: DDplan.py routine of PRESTO (0.05 cm^{-3} pc)

3. Candidates sifting and diagnose

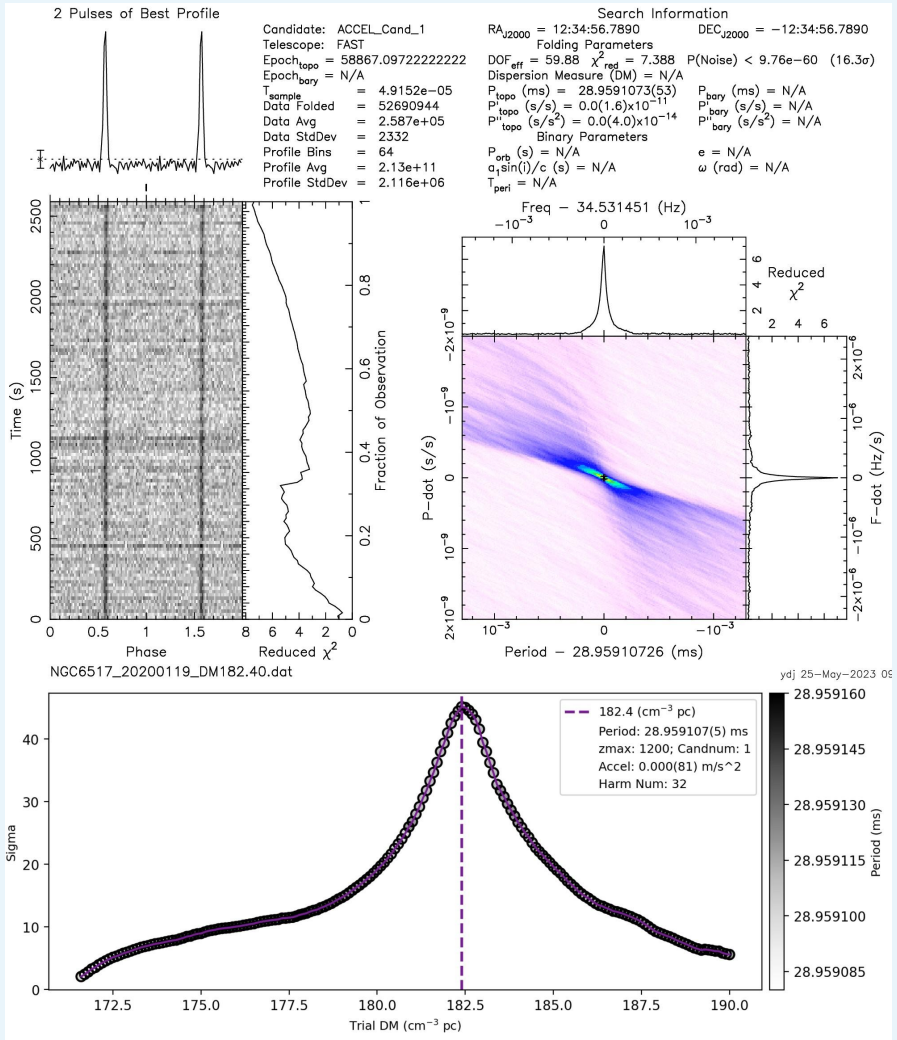
3.1. **ACCEL_sift.py** routine in PRESTO

3.2. **JinglePulsar code**

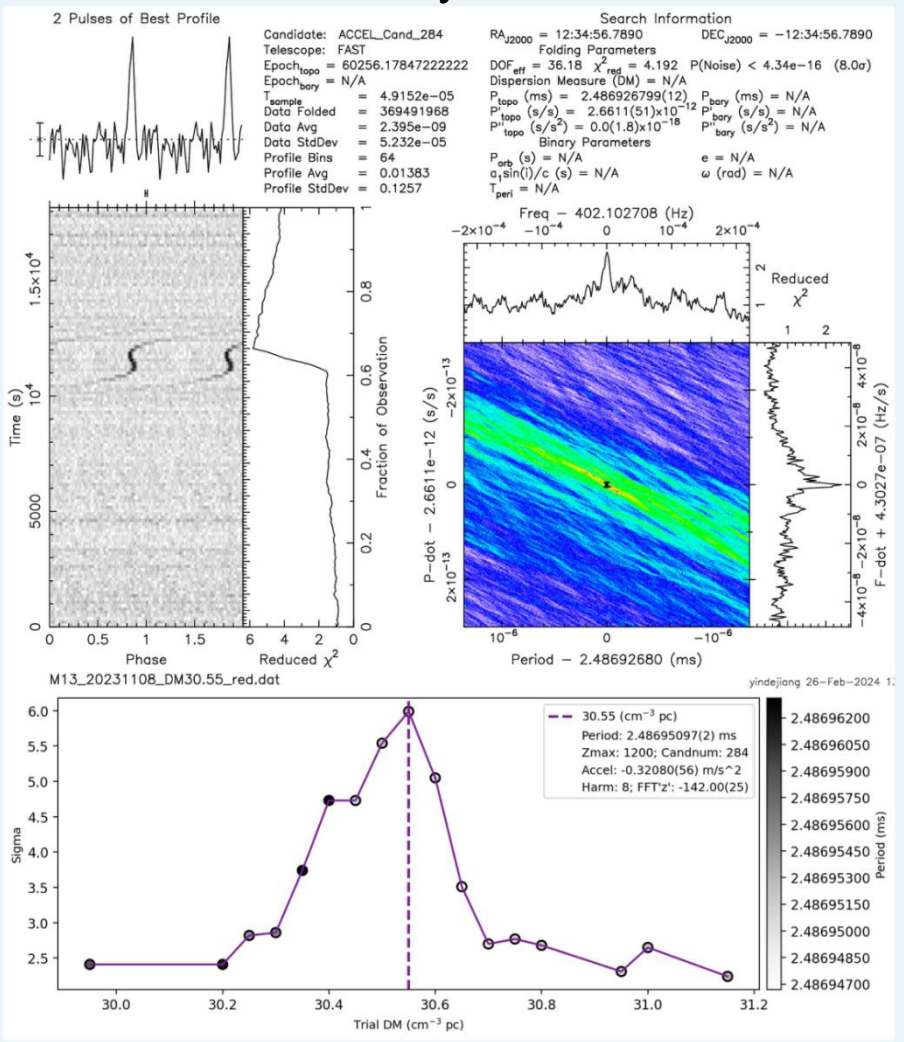
3.3. **New pipeline**

Pulsar Candidate Sifting and Synthesis Pipeline

NGC 6517B, PB ~ 60 days



M13E, PB ~ 0.11 days

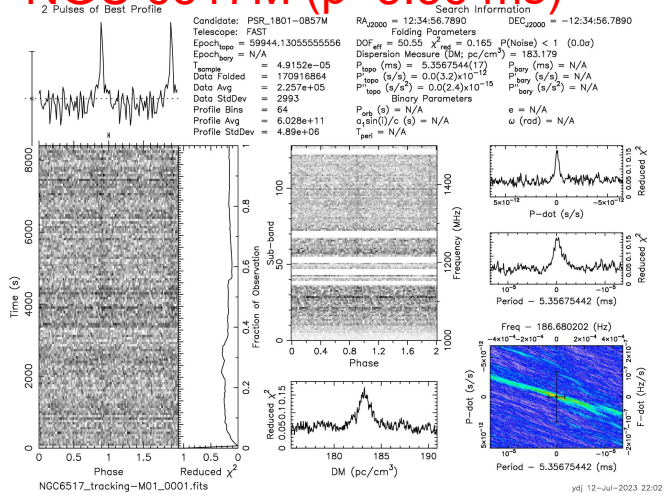


(Yin et al. in prep)

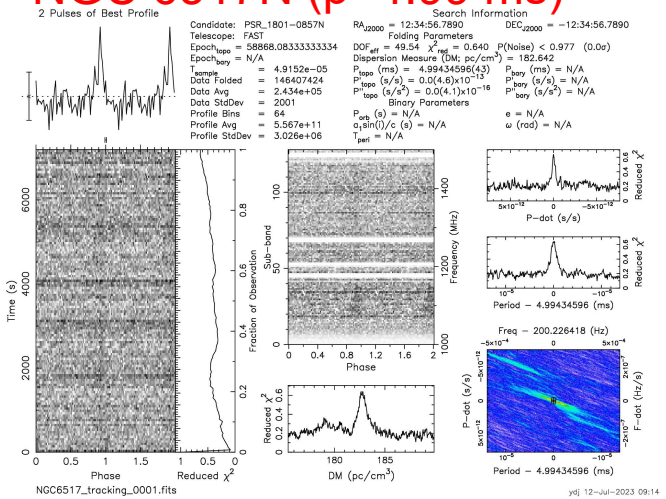
More new pulsars

The raw data folding plots of NGC 6517M to R from PRESTO

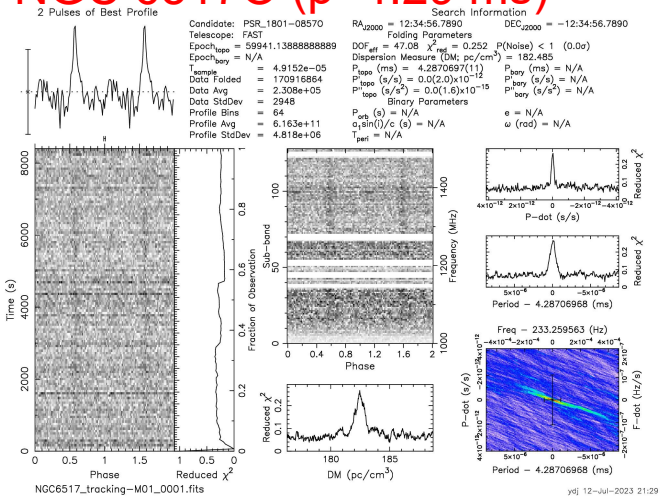
NGC 6517M (p~5.36 ms)



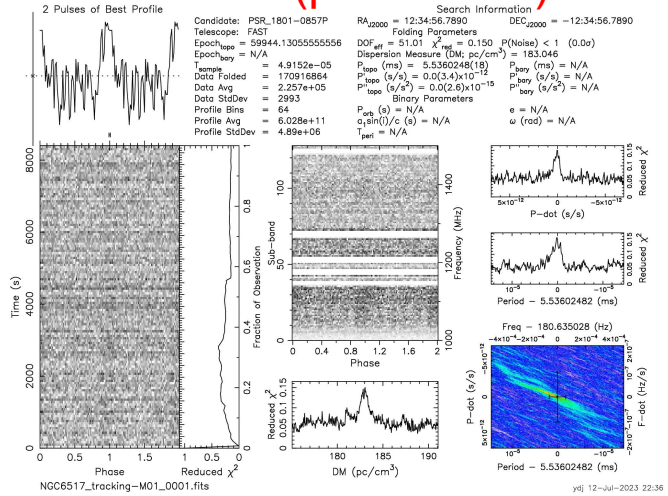
NGC 6517N (p~4.99 ms)



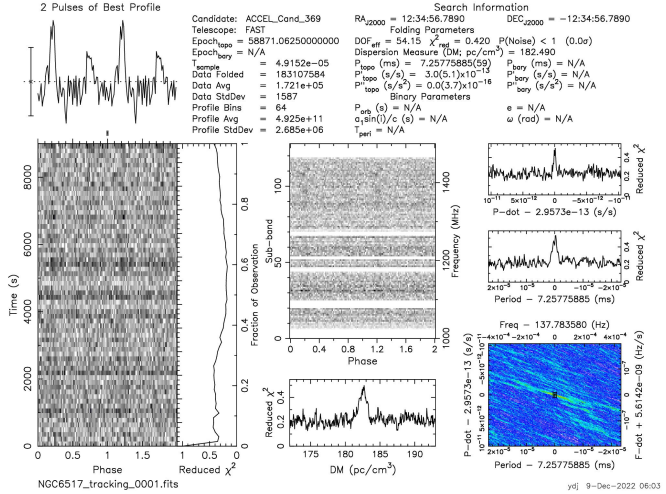
NGC 6517O (p~4.29 ms)



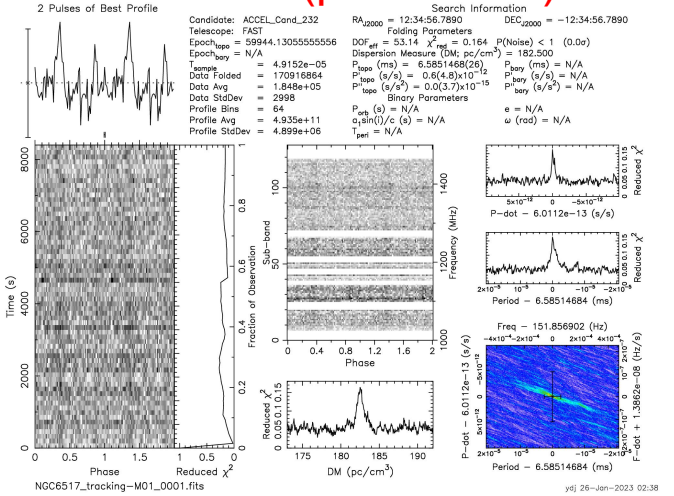
NGC 6517P (p~5.53 ms)



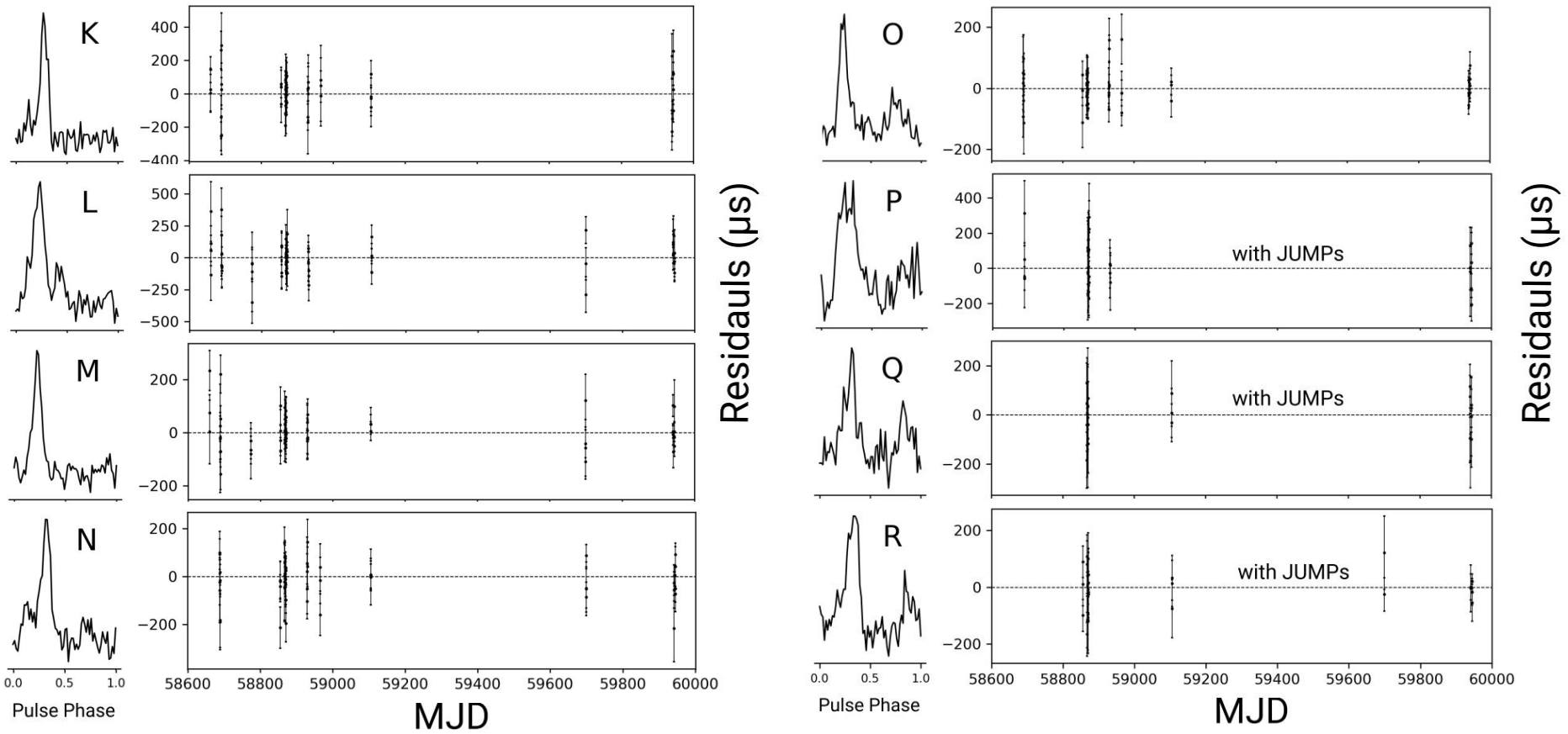
NGC 6517Q (p~7.26 ms)



NGC 6517R (p~6.58 ms)



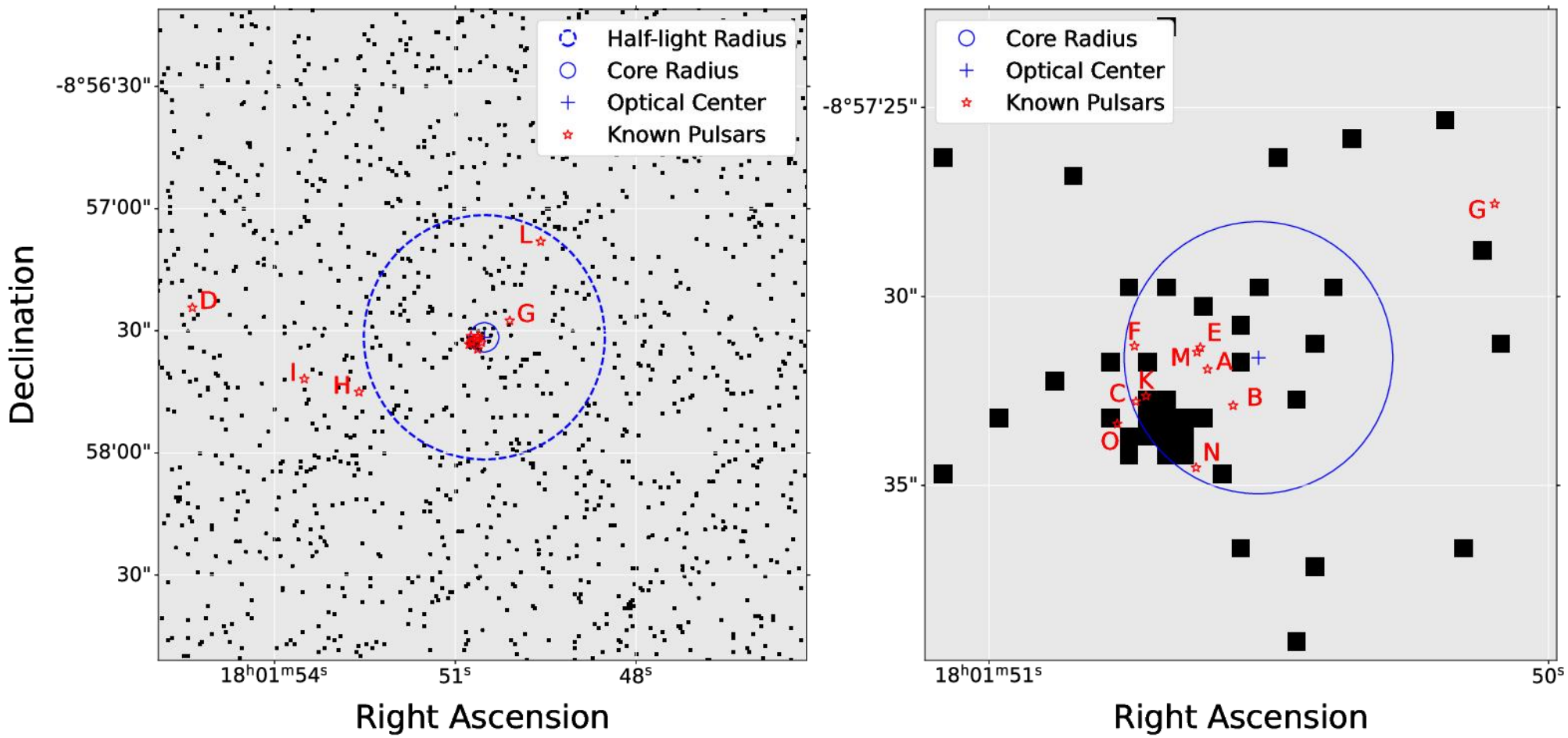
Timing solutions of new pulsars



1、17 pulsars in NGC 6517, Only NGC 6517B is in binary system.

2、Their are almost isolated, consistent with the expectation of core-collapse clusters (e.g., Verbunt & Freire 2014).

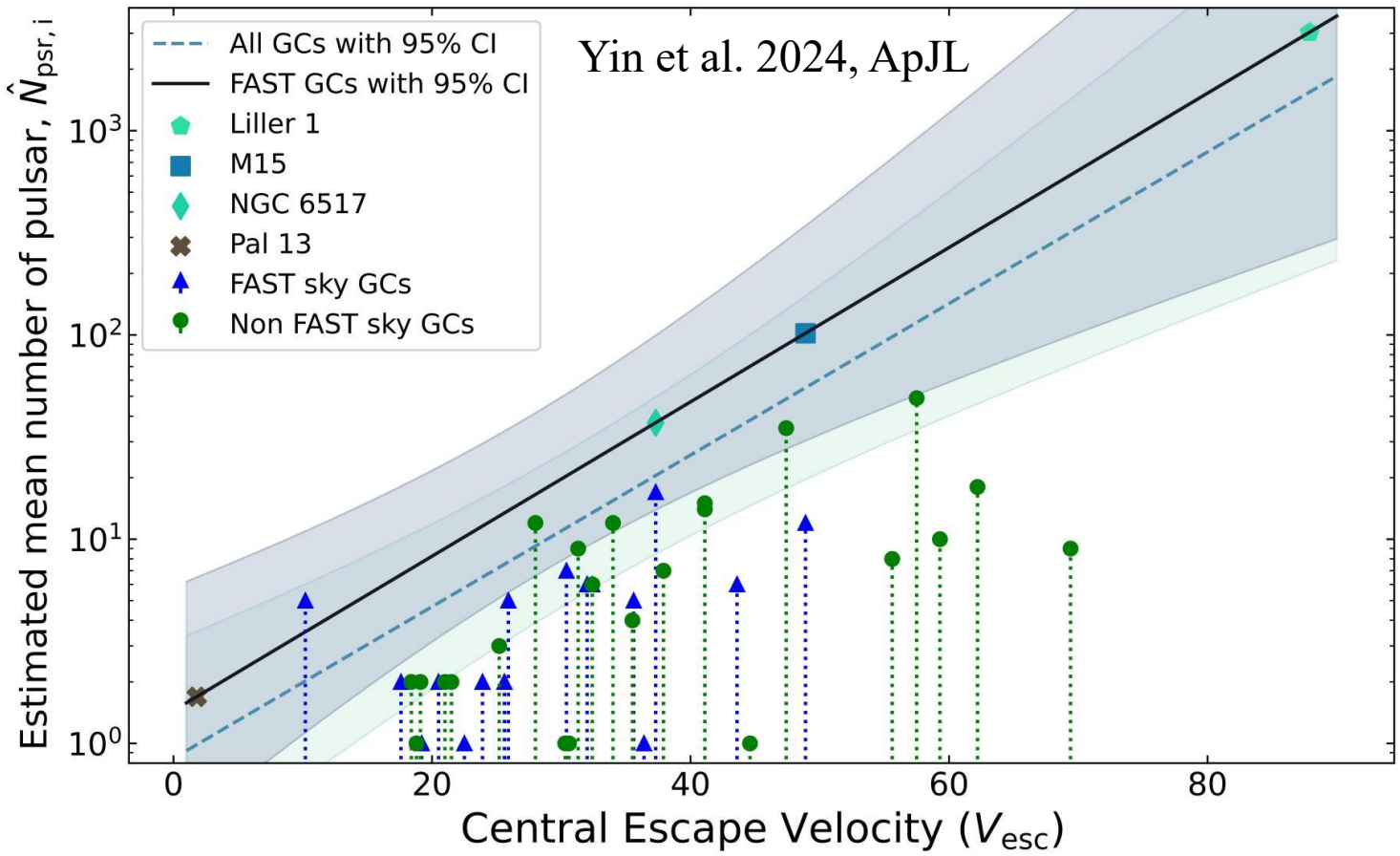
The positions

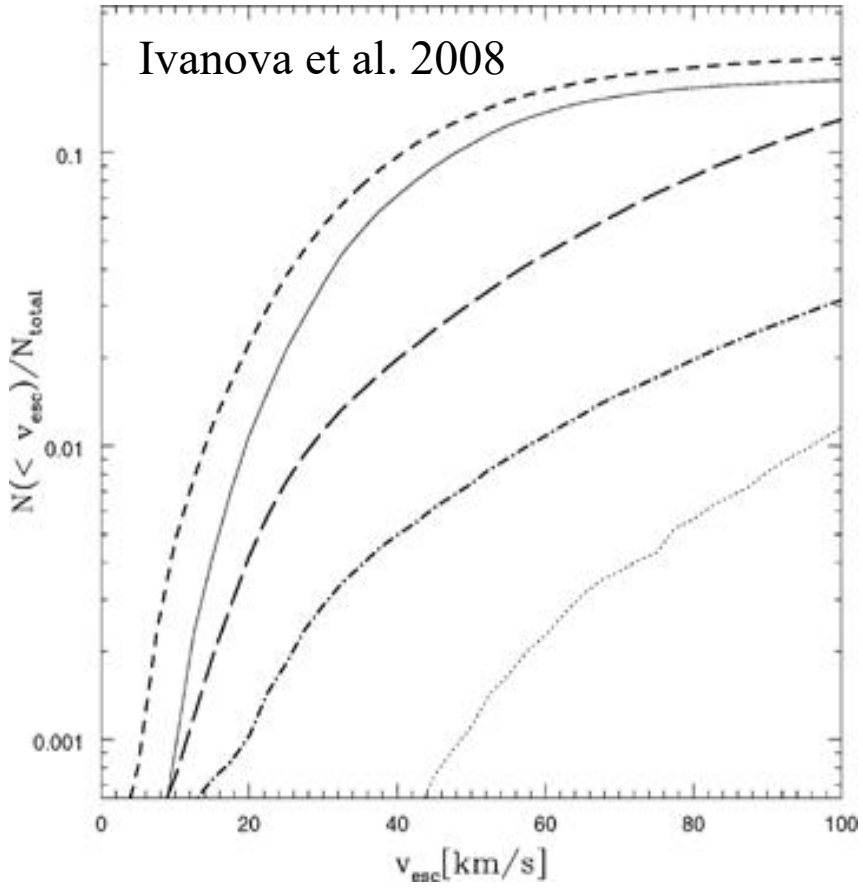


(Lian et al. in prep)

Globular Cluster pulsar population simulation

Method: empirical Bayesian from Turk & Lorimer 2013





FAST sky: M2 (M2G,H,I,J), M92 (M92B) and M15 (M15J,K,L,M,N)

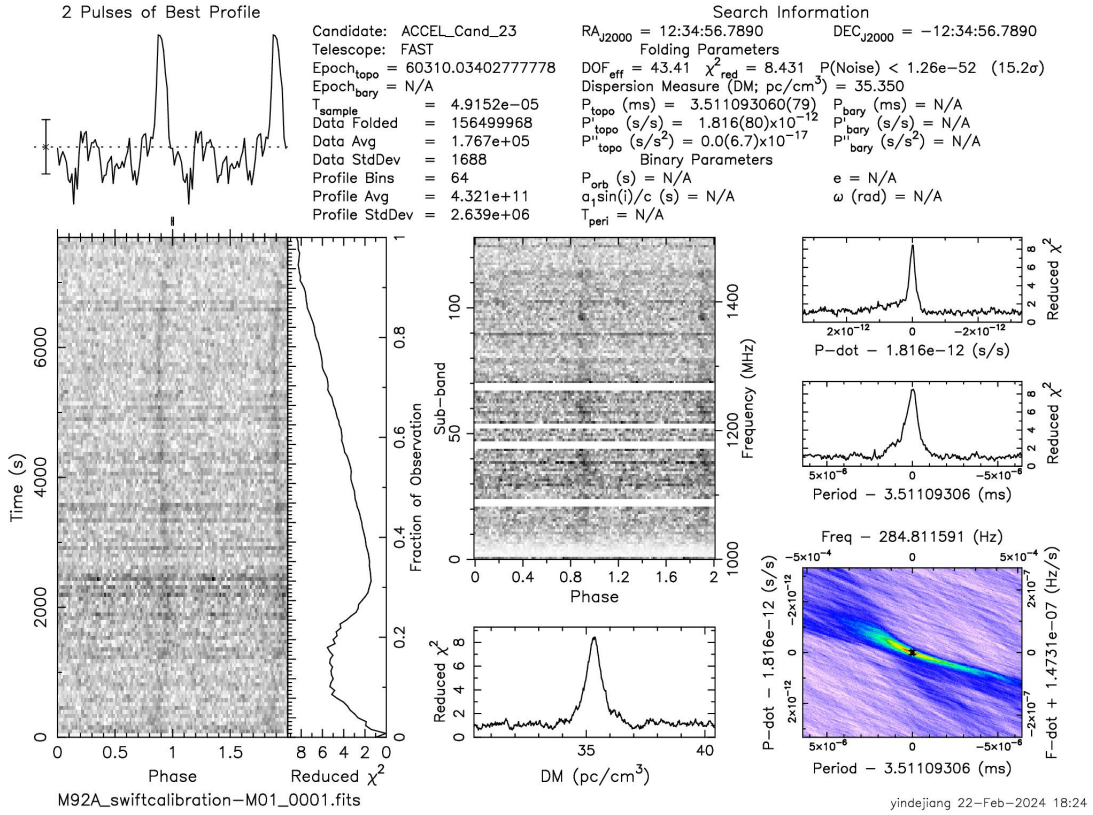
Outside FAST sky: Liller 1, NGC 6441(9 psrs), M54 (NGC 6715), and ω-Cen (NGC 5139, 18 psrs), etc..

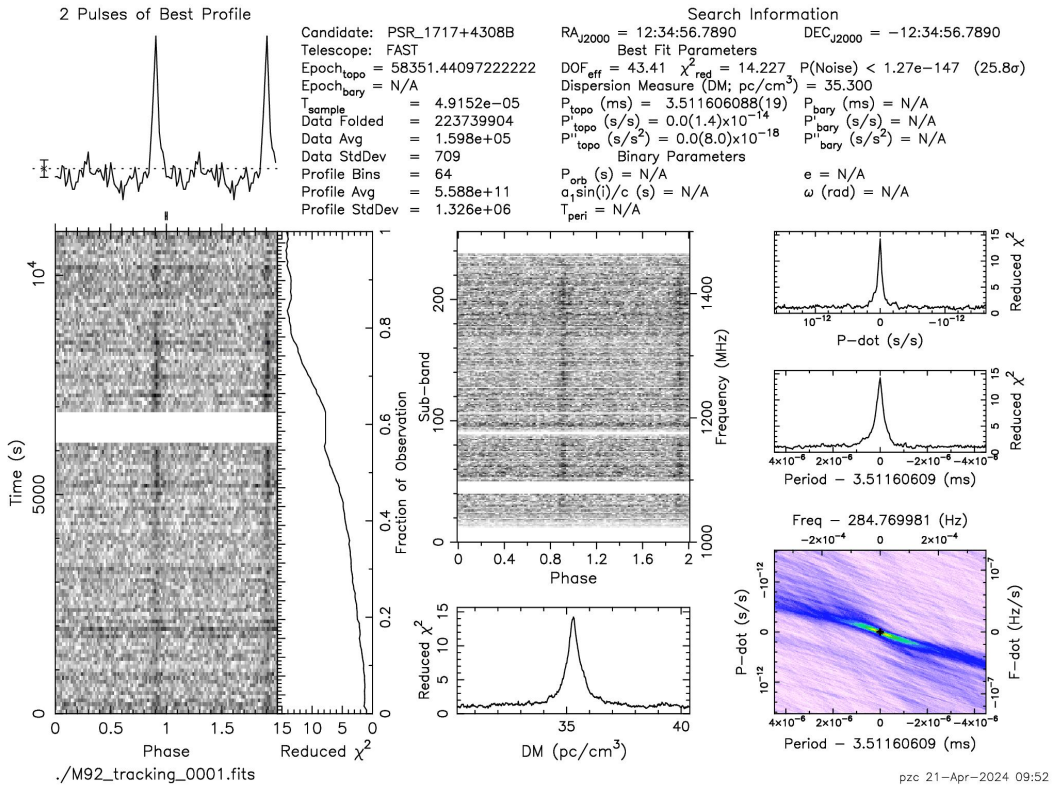
Other discoveries in M13 and M92

PID: PT2023_0185 PI: Yin Dejiang (Pan, Wang and Yan)

Project Title: Long-term monitoring for spider pulsars in Globular Clusters within FAST sky

M92B, P~3.511 ms, DM~35.35 pc cm^{-3}, PB ~ 2.3 days (Pan et al.)





Other discoveries in M13 and M92

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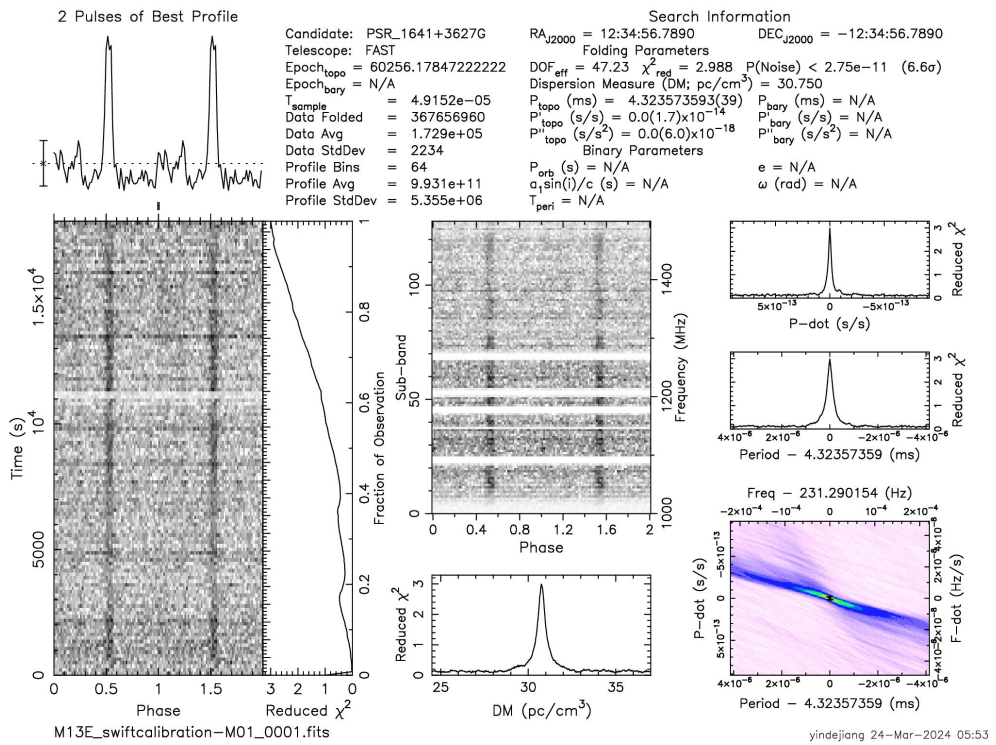
M13G, P~4.323 ms, DM~30.75 pc cm^{-3}, PB ~ 0.12 days

~1.7 orbits !

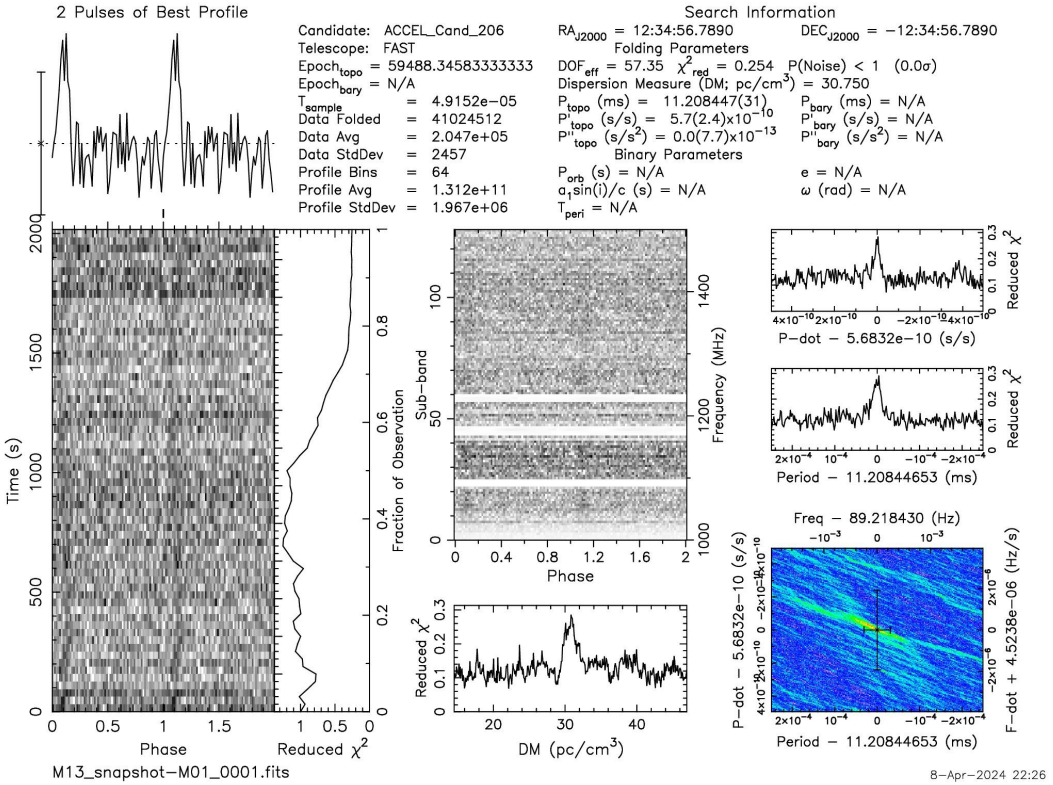


Binary model: BT

Mass function ($M_\odot$) = 0.000000318469 +0.000000000389

Companion mass ($M_\odot$): 0.008376 < 0.0097 < 0.0193

M13H, P~11.2 ms, DM~30.75 pc cm^{-3}, binary ?



Detection rate: 2 / 71

Conclusion

- Six new pulsars were discovered, a total of 17 (+3) pulsars in NGC 6517 now (13 from FAST!); With these discoveries, NGC 6517 is currently the GC with the most known pulsars in the FAST sky (3th in all GCs).
- The phase-connected timing solutions of NGC 6517K to O were obtained. The fraction of isolated pulsars in this GC (16 of 17, 94%) is consistent with previous studies indicating an overabundance of isolated pulsars in the densest GCs.

- Using empirical Bayesian method approach with the recent counts, we find that the expected number of potential pulsars in GCs seems to be correlated with the central escape velocity; hence, the GCs Liller 1, NGC 6441, M54 (NGC 6715), and ω-Cen (NGC 5139) are expected to host the largest numbers of pulsars.
- New discoveries in M13 and M92 (M13G,H and M92B).

Thanks For Listening!