Progress of CPTA Jitter analysis

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2023.07.05 FPS12 南阳

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Background

CPTA program

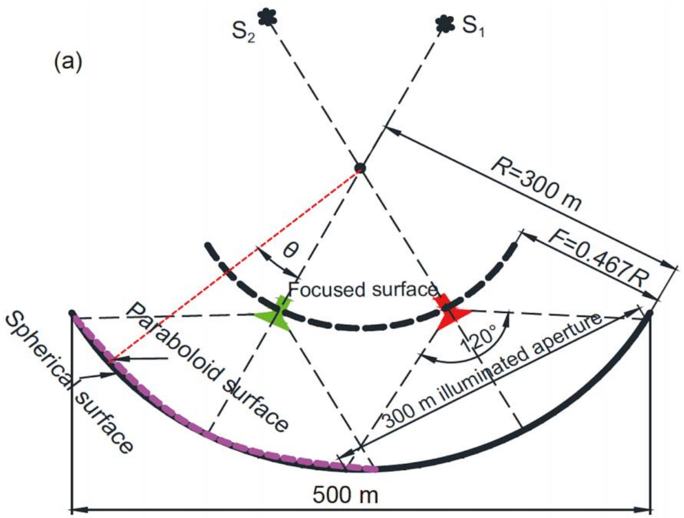
- Nearly 60 MSPs

Five-hundred-meter Aperture Spherical radio Telescope (FAST)

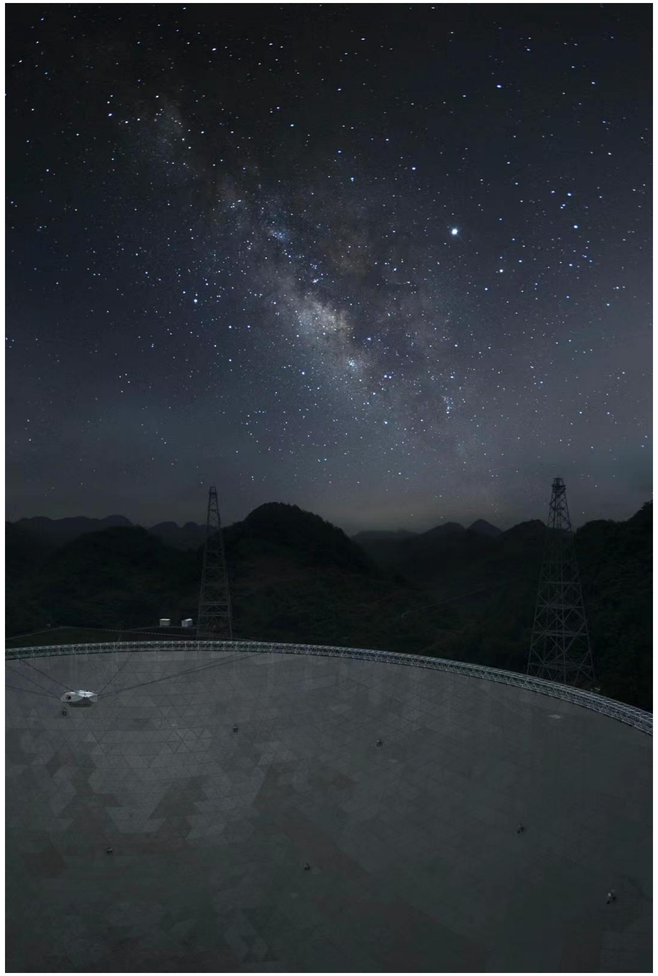
19-beam receiver：

1. 1.0-1.5 GHz
2. G ≈ 16 K/Jy
3. $T_{sys} \approx 20$ K

- Sensitive in L-band
- Able to see MSPs' single-pulse



Jiang et al., 2019



Method

The measurement error of TOAs on short time scales (e.g. few hours) can be written as:

$$\sigma_{\rm total}^2 = \sigma_{\rm rn}^2 + \sigma_{\rm J}^2 + \sigma_{\rm scint}^2 \quad (1)$$

where σ_{rn} is radiometer noise, depends on S/N.

σ_J is jitter noise we concerned in this work.

σ_{scint} represents for noise caused by scintillation which we ignored.

Assuming the timing residual to be Gaussian distributed,
then the PDF for ***r*** should be:

$$f(r;\mu,\Sigma) = \frac{1}{(2\pi)^{n/2}|\Sigma|^{1/2}} e^{-\frac{1}{2}(r-D\cdot\beta)^T\Sigma^{-1}(r-D\cdot\beta)} \quad (2)$$

Σ is covariance matrix.

Now, by using the method of MLE, we can calculate the jitter values.

$$L = \prod_{i=1}^{n} f(r;\mu,\Sigma)$$
$$(\hat{\mu},\widehat{\Sigma}) = \mathrm{argmax}\{\ln L\} \quad (3)$$

Pipeline:

1. Folding pulse profile:
   - with different integration length (e.g. 0.1s, 0.5s, 1s, 5s, 10s)
   - with single-pulse mode
2. RFI mitigation
3. Polarization calibration
4. Summing over frequency to 1 channel or several channels
5. Template fitting using tempo2 to obtain TOAs

Results: An example

PSR J1744-1134

- folding with series of int time for different observation date
- single-pulse timing residual
- red line represent for single-pulse jitter result and 1-σ error

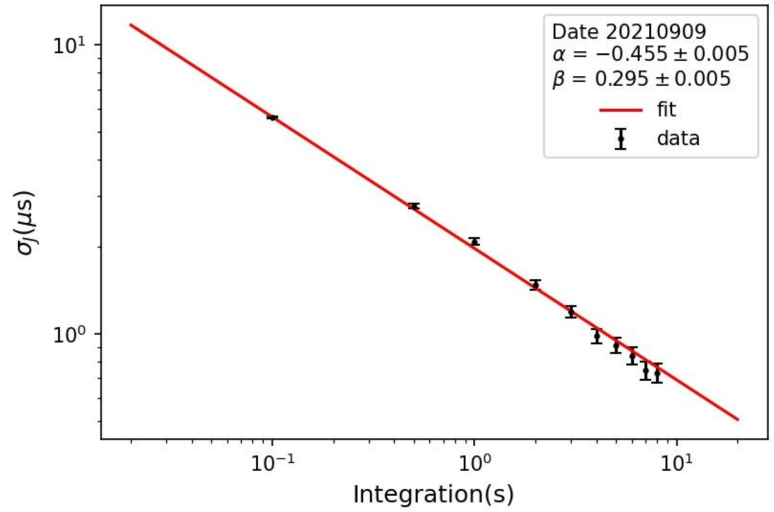


Fig (1)

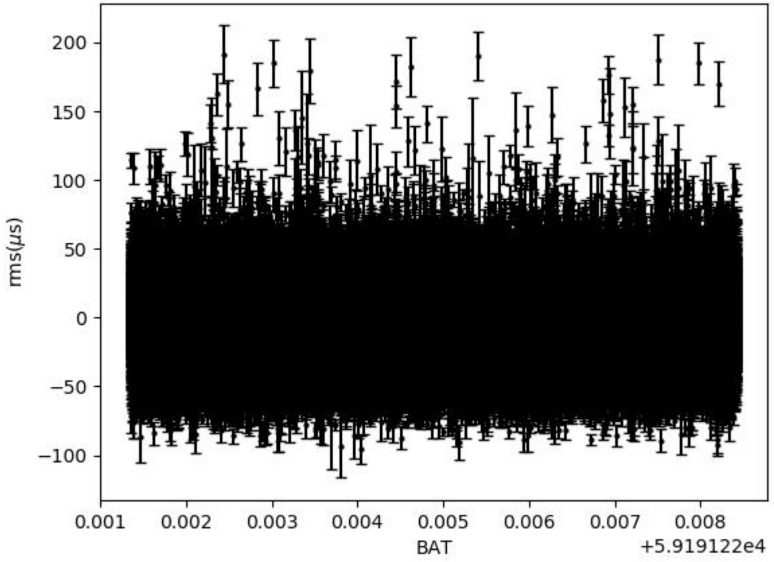


Fig (2)

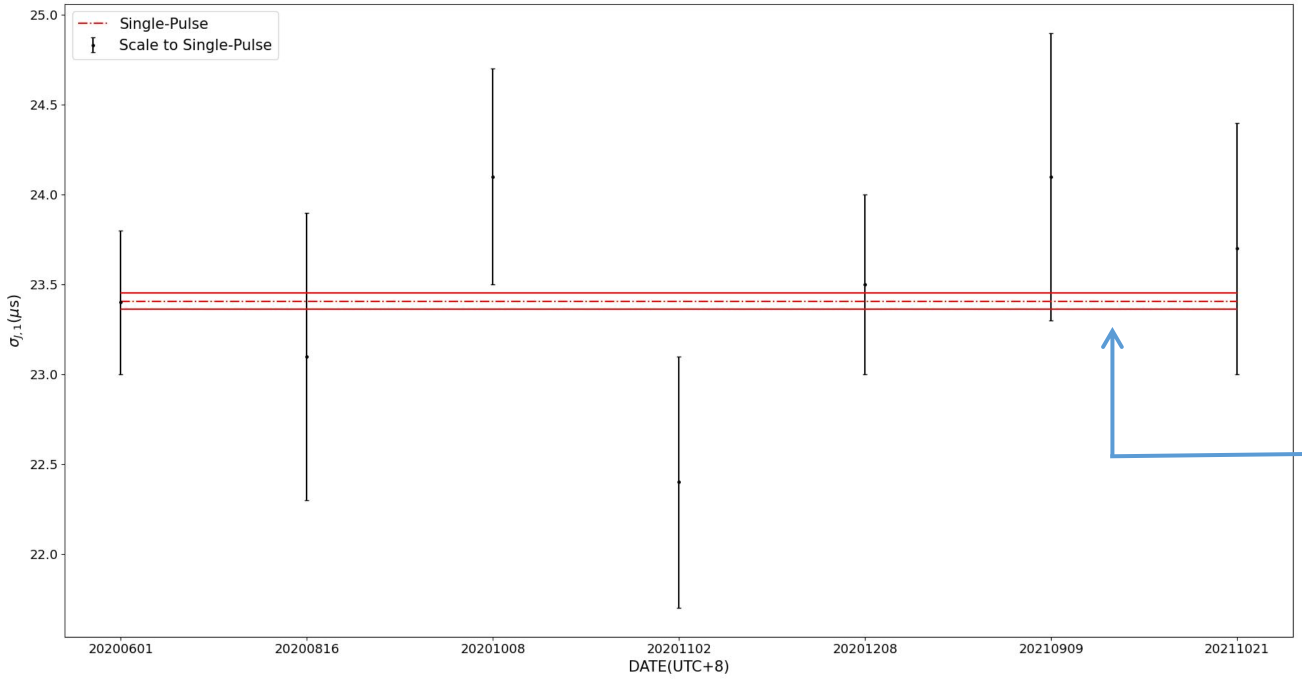


Fig (3)

Results for 32 MSPs

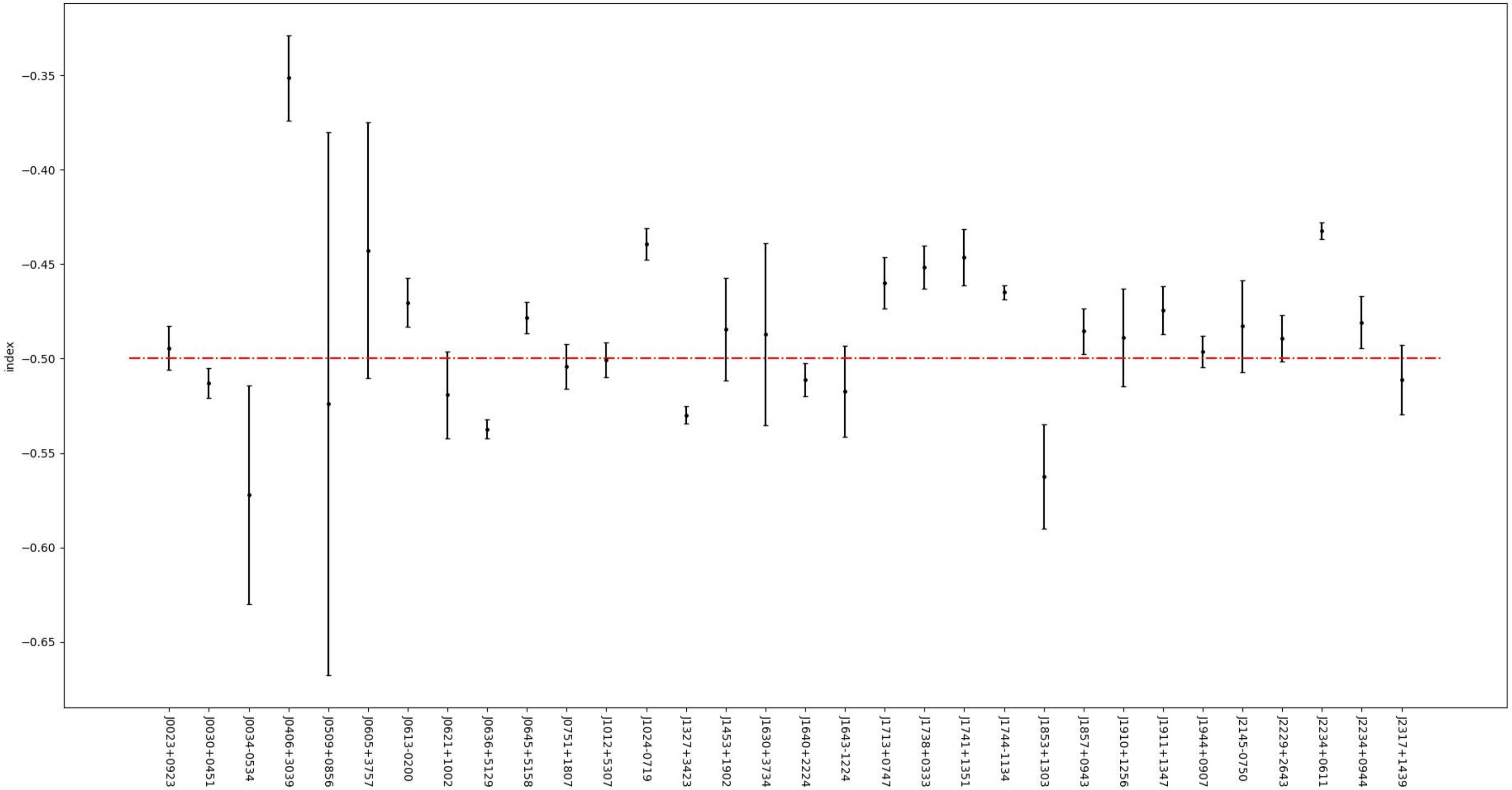
We measured the σ_J of 32 MSPs from CPTA program and scaled them to 1-hour and single-pulse level respectively:

Pulsar name J2000	Period (ms)	α	β	$\sigma_{J,1h}$ (ns)	$\sigma_{J,1}$ (μs)
J0023+0923	3.050	-0.494 ± 0.008	0.204 ± 0.003	27.9 ± 1.8	28.0 ± 1.3
J0030+0451	4.865	-0.513 ± 0.005	0.471 ± 0.004	44.4 ± 2.0	45.5 ± 1.4
J0034−0534	1.877	-0.572 ± 0.039	0.220 ± 0.012	15.3 ± 4.9	60.3 ± 14.8
J0406+3039	2.609	-0.351 ± 0.015	0.244 ± 0.012	98.7 ± 12.6	14.2 ± 1.3
J0509+0856	4.056	-0.524 ± 0.096	0.446 ± 0.034	38.3 ± 30.4	50.0 ± 26.8
J0605+3757	2.728	-0.443 ± 0.045	0.138 ± 0.017	36.6 ± 13.7	18.8 ± 5.1
J0613−0200	3.062	-0.470 ± 0.009	0.163 ± 0.006	30.9 ± 2.2	22.1 ± 1.1
J0621+1002	28.854	-0.519 ± 0.015	1.362 ± 0.007	327.0 ± 41.7	145.0 ± 8.3
J0636+5129	2.869	-0.537 ± 0.003	0.207 ± 0.004	19.8 ± 0.6	37.4 ± 0.8
J0645+5158	8.853	-0.478 ± 0.006	0.245 ± 0.004	35.0 ± 1.6	16.9 ± 0.5
J0751+1807	3.479	-0.504 ± 0.008	0.285 ± 0.004	31.0 ± 2.0	33.5 ± 1.5
J1012+5307	5.256	-0.501 ± 0.006	0.227 ± 0.004	28.0 ± 1.4	23.4 ± 0.8
J1024−0719	5.162	-0.439 ± 0.006	0.308 ± 0.004	55.7 ± 2.6	20.5 ± 0.6
J1327+3423	41.513	-0.530 ± 0.003	1.096 ± 0.004	162.6 ± 4.4	67.3 ± 0.9
J1453+1902	5.792	-0.484 ± 0.018	0.496 ± 0.006	59.4 ± 8.9	38.0 ± 3.6
J1630+3734	3.318	-0.487 ± 0.032	-0.281 ± 0.011	9.7 ± 2.6	8.4 ± 1.6
J1640+2224	3.163	-0.511 ± 0.006	-0.165 ± 0.007	10.4 ± 0.5	13.0 ± 0.5
J1643−1224	4.622	-0.517 ± 0.016	0.344 ± 0.005	31.9 ± 4.2	35.7 ± 3.1
J1713+0747	4.570	-0.460 ± 0.009	0.252 ± 0.003	41.4 ± 3.1	21.3 ± 1.1
J1738+0333	5.850	-0.452 ± 0.008	0.299 ± 0.004	49.3 ± 3.1	20.3 ± 0.8
J1741+1351	3.747	-0.446 ± 0.010	0.237 ± 0.003	44.6 ± 3.7	20.9 ± 1.2
J1744−1134	4.075	-0.465 ± 0.003	0.291 ± 0.003	43.4 ± 1.0	25.2 ± 0.4
J1853+1303	4.092	-0.563 ± 0.019	0.156 ± 0.006	14.3 ± 2.2	31.6 ± 3.3
J1857+0943	5.362	-0.485 ± 0.008	0.657 ± 0.003	85.2 ± 5.6	57.5 ± 2.4
J1910+1256	4.984	-0.489 ± 0.017	0.314 ± 0.006	37.6 ± 5.4	27.5 ± 2.6
J1911+1347	4.626	-0.474 ± 0.008	0.227 ± 0.003	34.7 ± 2.4	21.6 ± 1.0
J1944+0907	5.185	-0.496 ± 0.006	1.027 ± 0.004	182.7 ± 8.5	144.7 ± 4.4
J2145−0750	16.052	-0.483 ± 0.016	1.021 ± 0.008	201.5 ± 27.3	77.2 ± 5.4
J2229+2643	2.978	-0.489 ± 0.008	0.225 ± 0.003	30.5 ± 2.0	28.9 ± 1.4
J2234+0611	3.577	-0.432 ± 0.003	-0.070 ± 0.003	24.7 ± 0.6	9.7 ± 0.2
J2234+0944	3.627	-0.481 ± 0.009	0.029 ± 0.004	20.8 ± 1.6	15.9 ± 0.8
J2317+1439	3.445	-0.511 ± 0.012	0.026 ± 0.004	16.1 ± 1.6	19.3 ± 1.4

Results for 32 MSPs

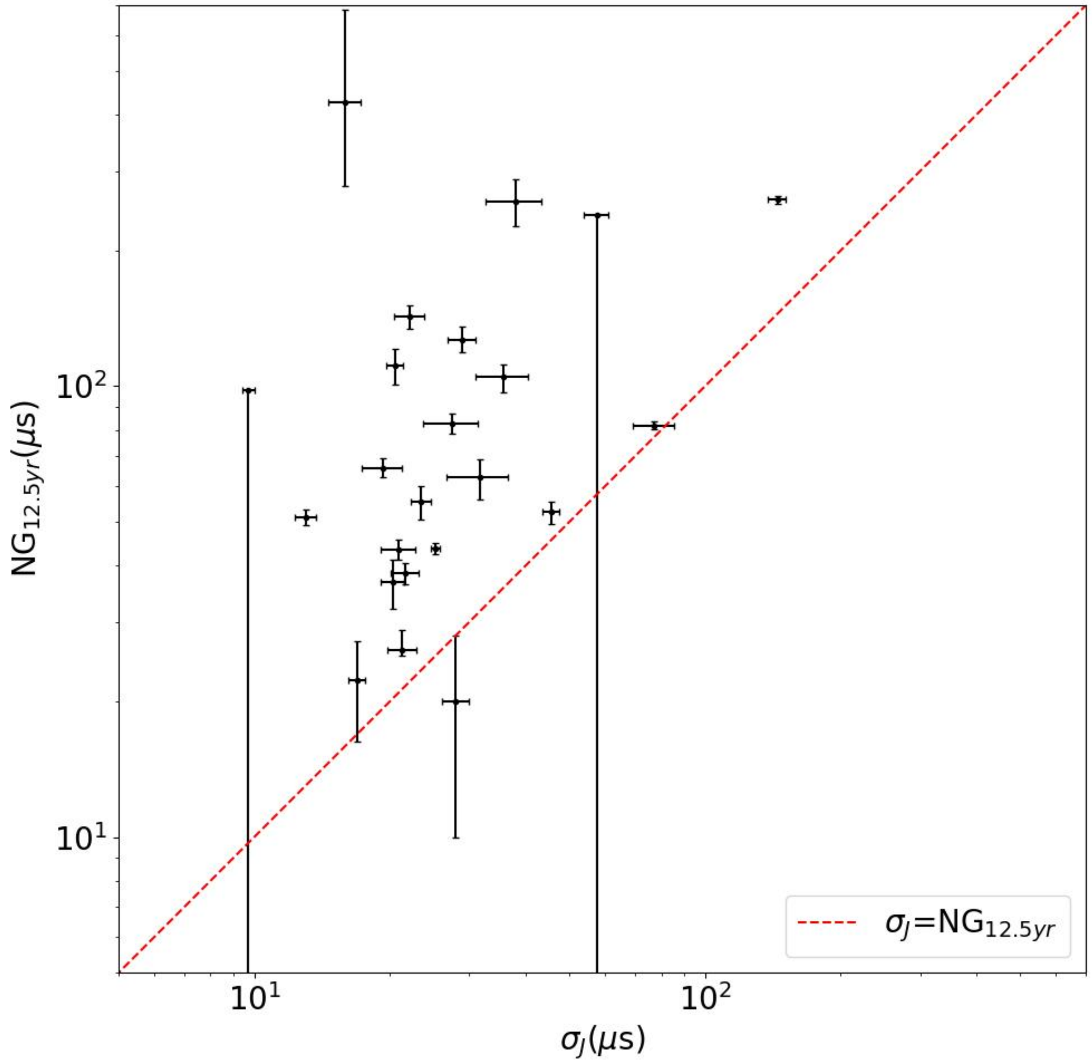
The fitting index α

- The scaling index α usually thought to be -0.5: $\sigma_J = \frac{\sigma_{J,1}}{\sqrt{N_p}}$
- And for our results:
- Red dashed line represents for α = -0.5



Results for 32 MSPs

Compared to NG-12.5 year jitter results (Lam et. al, 2019) and MeerKAT's results (A. Parthasarathy et al. 2021)



Pulsar name J2000	MeerKAT (ns)	FAST (ns)
J0030+0451	<60	50.4±1.0
J1024-0719	<30	31.0±1.3
J1744-1134	30±6	24.91±0.05
J2145-0750	200±20	201.5±27.3

Results for 32 MSPs

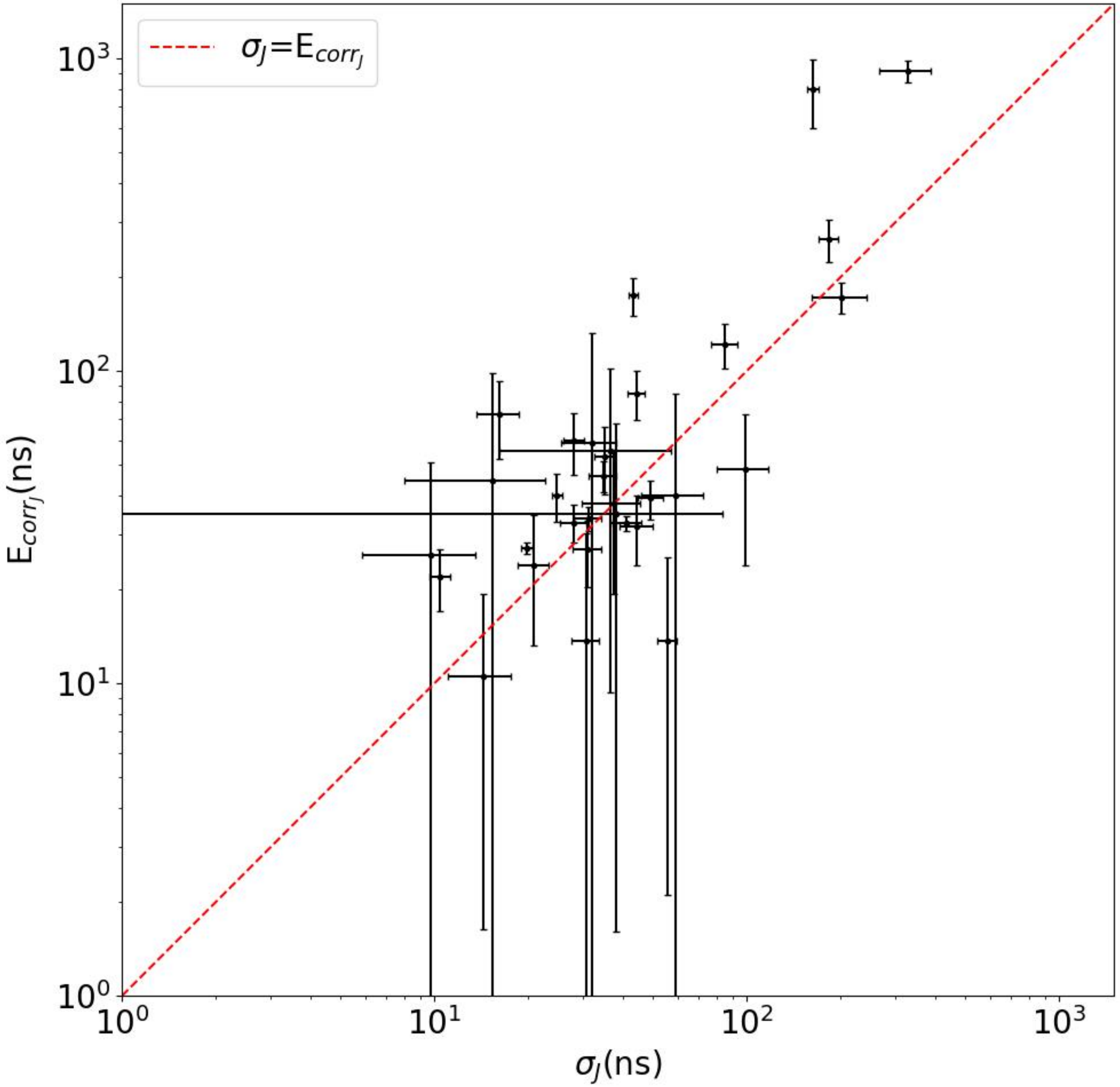
Compared to Ecorr parameter in CPTA noise analysis (scaled to 1h)

Usually, the white noise covariance matrix are written as :

$$\mathbf{C}_\mathrm{W} = (\sigma * \mathrm{Efac})^2 + \mathrm{Equad}^2 + \mathrm{Ecorr}^2 \mathbf{C}_\mathrm{Ecorr}\,, \qquad (1)$$

We assummed the uncorrelated jitter and correlated jitter are modeled as their RMS values be proportional to $\sqrt{t_{obs}}$, then:

$$\mathbf{C}_\mathrm{W} = (\sigma \mathrm{Efac})^2 + \mathrm{EQUADj}^2 \frac{1\mathrm{hr}}{t_\mathrm{obs}} + \mathrm{Ecorrj}^2 \frac{1\mathrm{hr}}{t_\mathrm{obs}} \mathbf{C}_\mathrm{Ecorr}\,, \qquad (2)$$



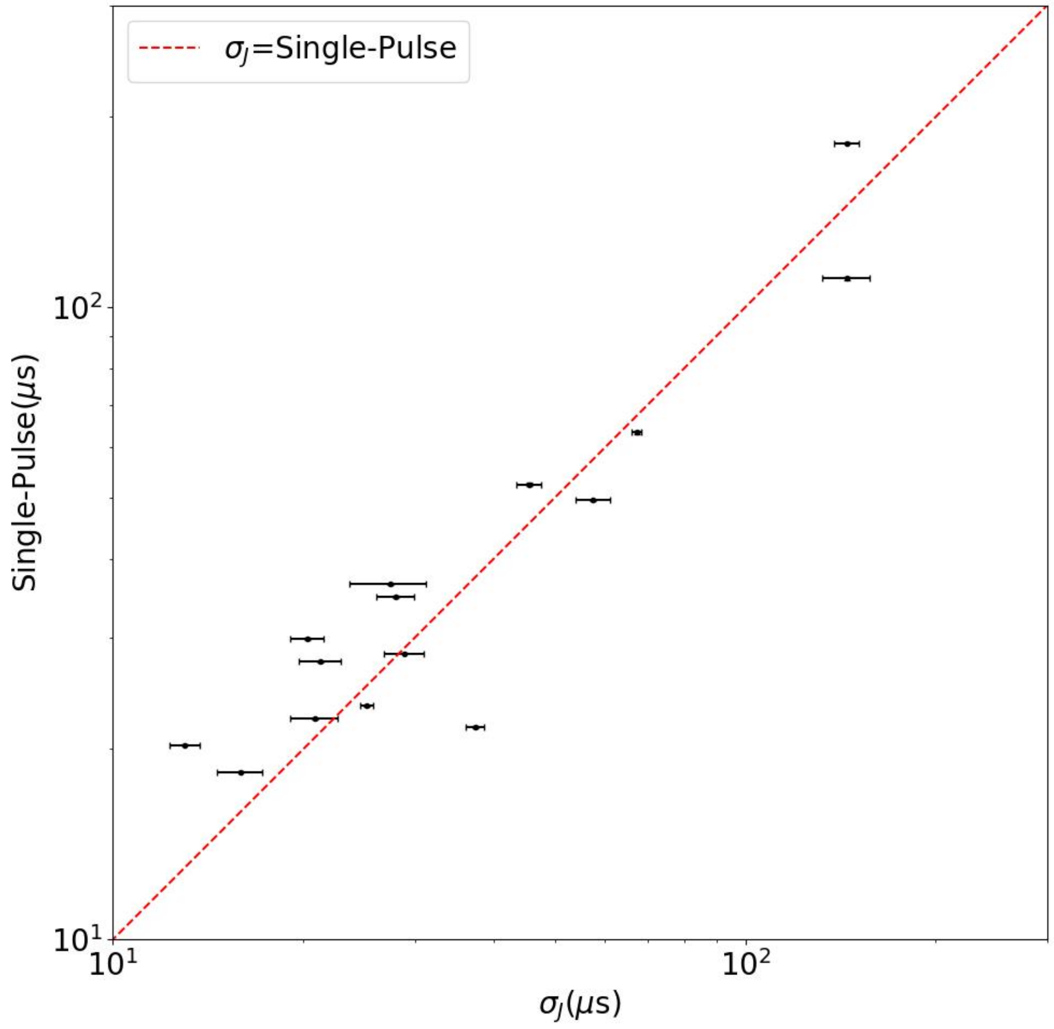
Results for single-pulse

17 of 32 MSPs are able to fold single-pulse profile using FAST

Single-pulse jitter results for 17 MSPs (frequency averaged)

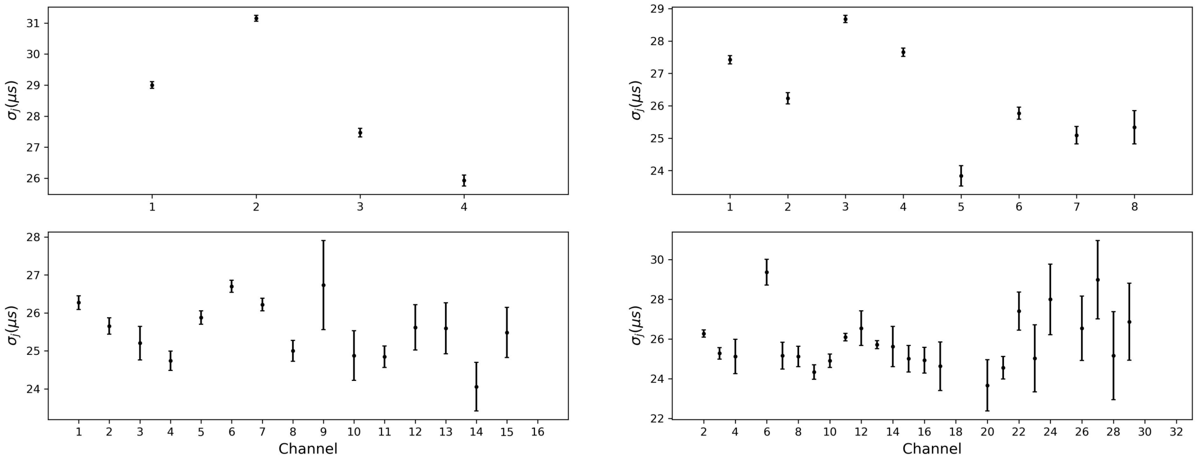
Pulsar name J2000	$\sigma_{J,1}$ (μs)
J0023+0923	34.84±0.08
J0030+0451	52.44±0.25
J0348+0432	105.19±1.02
J0621+1002	111.15±0.60
J0636+5129	21.65±0.10
J1327+3423	63.45±0.40
J1640+2224	20.30±0.03
J1713+0747	27.48±0.05
J1738+0333	29.94±0.12
J1741+1351	22.34±0.05
J1744-1134	23.41±0.05
J1857+0943	49.51±0.12
J1910+1256	36.46±0.11
J1944+0907	181.73±0.40
J2045+3633	107.70±0.42
J2229+2643	28.33±0.06
J2234+0944	18.40±0.05

Comparison between two method:



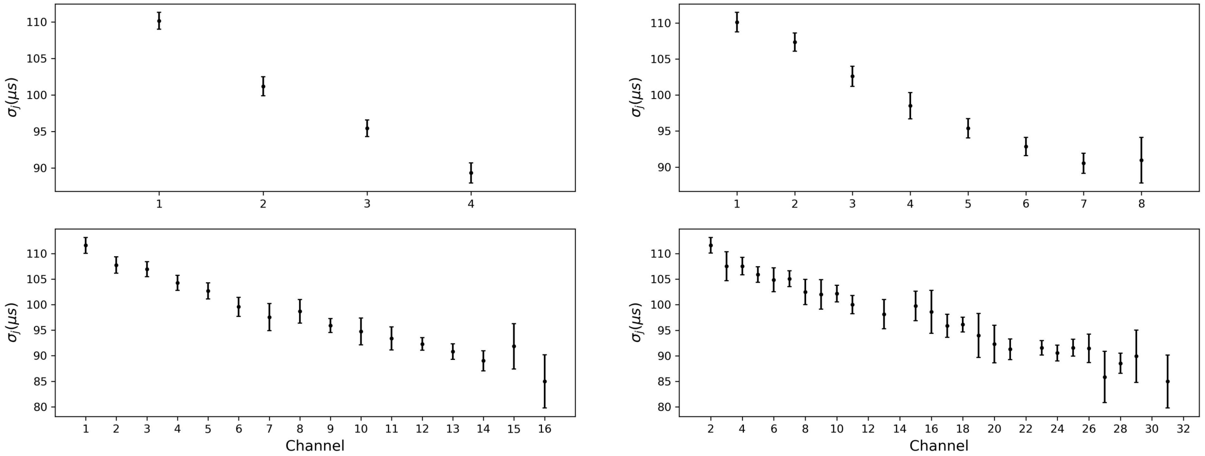
Results for single-pulse

For 10 MSPs, their single-pulse data were also divided into several channel in frequency band (4, 8, 16, 32) to investigate the jitter-frequency relation.



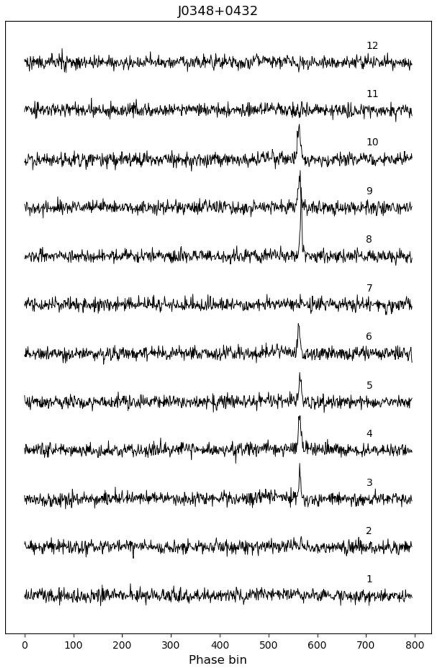
4 pulsars show no obvious jitter-frequency relation, like J0023+0923

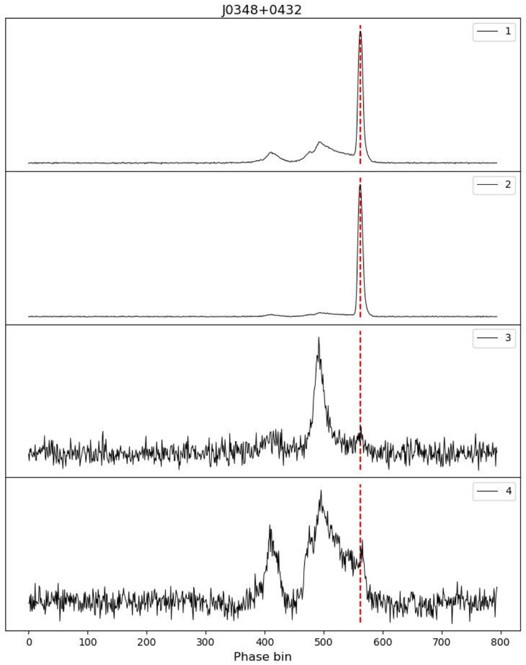
6 pulsars' jitter decrease as the frequency increase, like J0348+0432



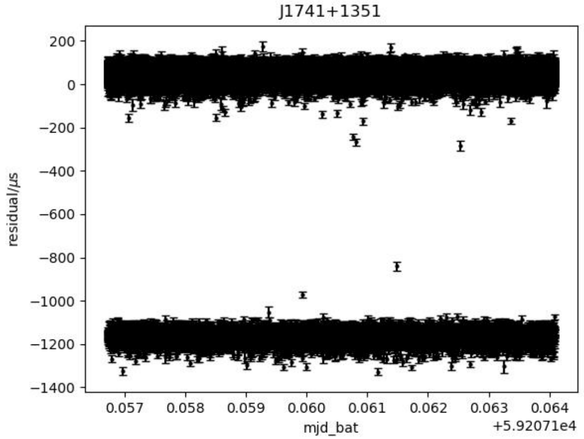
One more thing

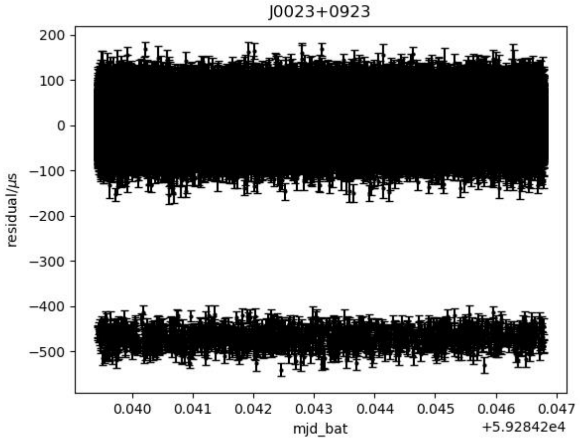
The mode change or nulling behavior are relatively rare in MSPs.
Three (B1957+20, J0621+1002, J1909-3744) cases were reported so far.





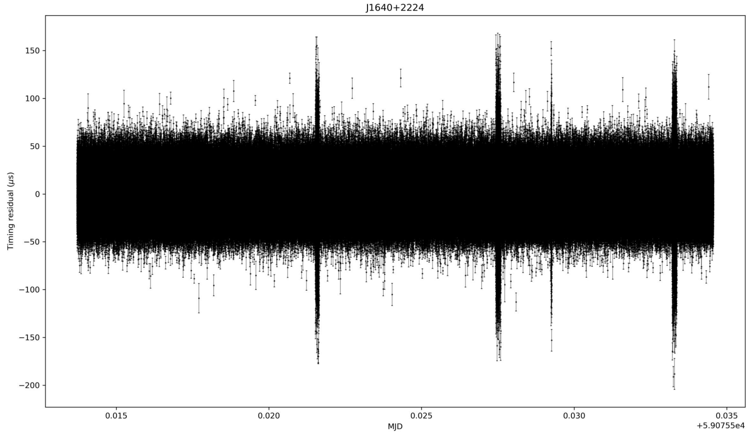
Mode change (1)
J0023+0923
J0348+0432
J1741+1351
……

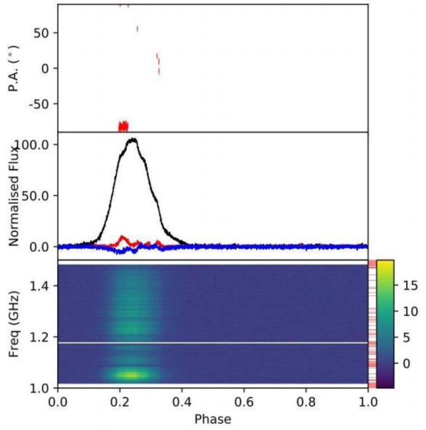




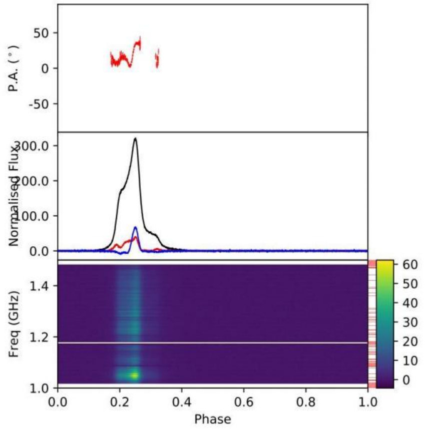
Mode change (2)

J1640+2224





ab-normal



normal

Conclusion

- We measured the jitter value of 32 millisecond pulsars from CPTA program. Our results of jitter values are consistent with the time scaled $Ecorr_J$ parameter in CPTA noise analysis and also the MeerKAT jitter results but generally lower than NG-12.5yr results.
- For 17 MSPs, we measured their jitter directly in the single-pulse level.
- 6 of 10 MSPs show jitter-frequency relation: jitter decrease as the frequency increase.
- The single-pulse of 8 MSPs show obvious mode change behavior.

THANKS