Glitches detected at Nanshan

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2020年8月29日

Outline

- Pulsars ,Pulsar Timing
- Our work :glitches
- Summary

Pulsar

●Neutron stars:highly magnetized,rapidly rotating, emission pulses.

● Formation: supernova explosion,white dwarfs collapse.

● Mass: ~ 1.4Msun

● B: 10^8 ~10^15G

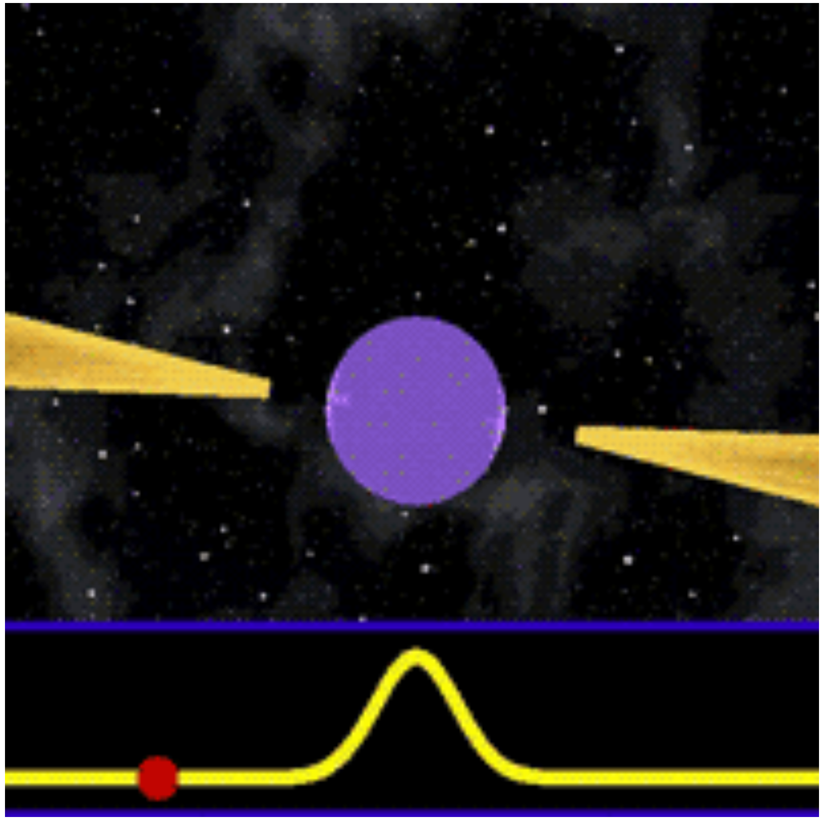
● Density:10^14 g / cm^3

● Period: ~ 1.4ms-10s

● Diameter: ~ 10-15km

● Population: at present, ~2811(~ 300MSP, most of MSP in binary)

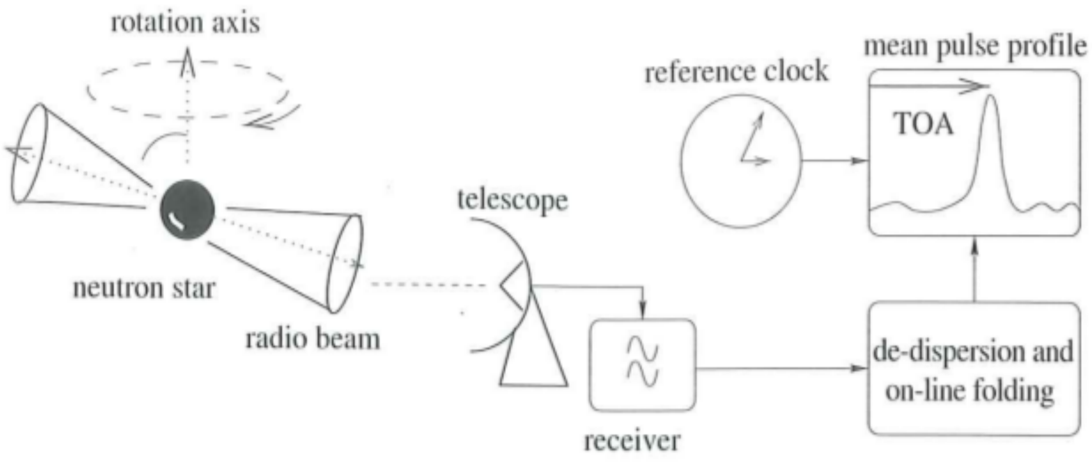
● High precision timing： good probes of interstellar medium,magnetic field, and GW background.

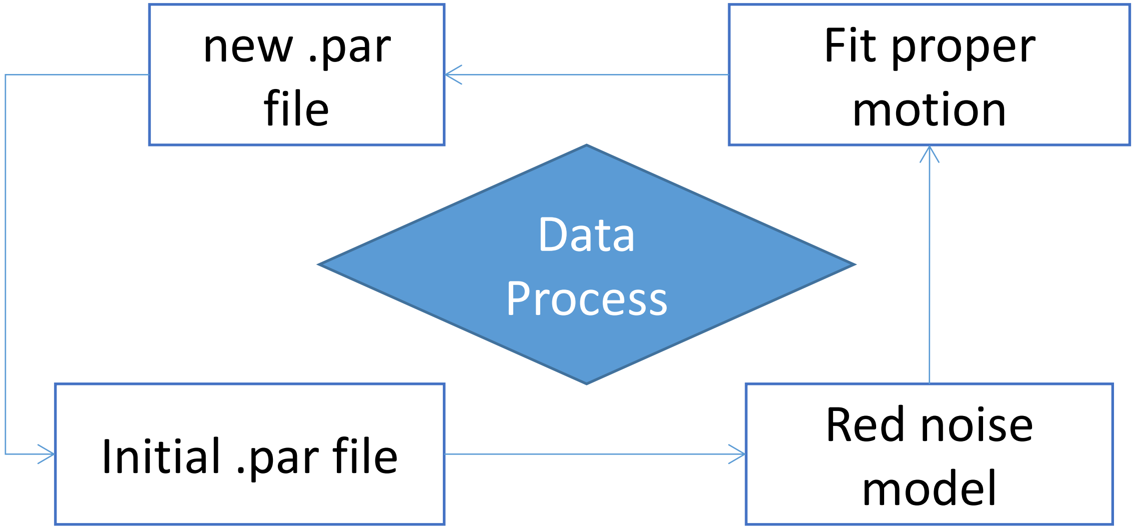


Pulsar Timing(Model & Steps)

$$
\begin{aligned}
T \;=\; & t_{\rm obs} - t_0 + \Delta_{\rm C} - D/f^2 + \Delta_{\rm R,\odot}(\alpha, \delta, \mu_\alpha, \mu_\delta, \pi) + \Delta_{\rm E,\odot} - \Delta_{\rm S,\odot} \\
& - \Delta_{\rm R}(x, e, P_{\rm b}, T_0, \omega, \dot{\omega}, \dot{P}_{\rm b}) - \Delta_{\rm E}(\gamma) - \Delta_{\rm S}(r, s) - \Delta_{\rm A}
\end{aligned}
$$

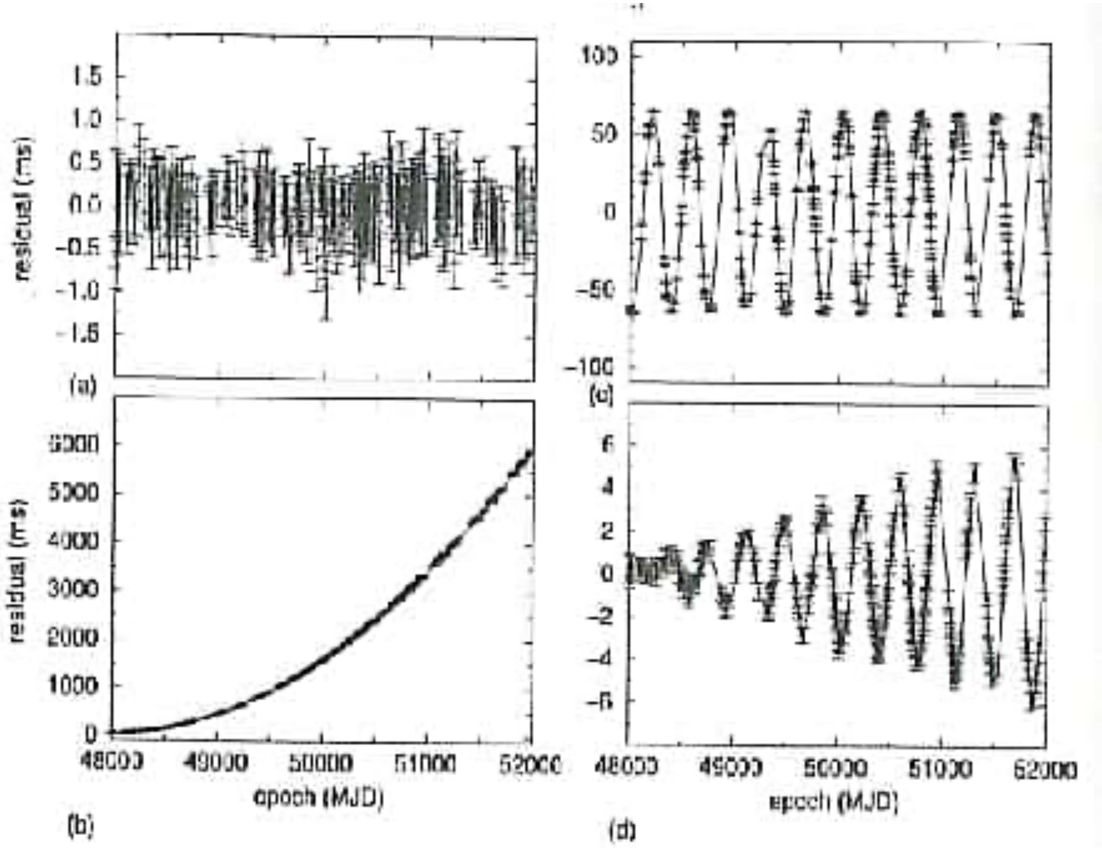
$$
\phi(T) = \phi_0 + \nu T + \frac{1}{2}\dot{\nu} T^2 + \frac{1}{6}\ddot{\nu} T^3 + \cdots
$$



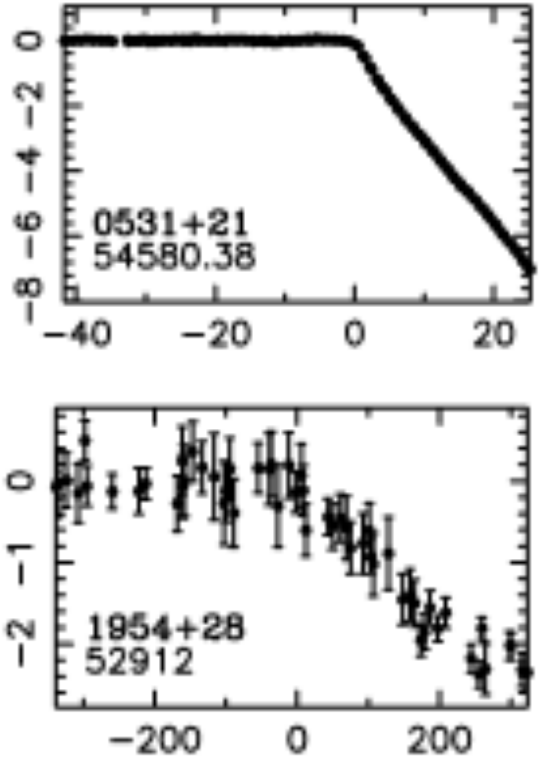


Pulsar Timing

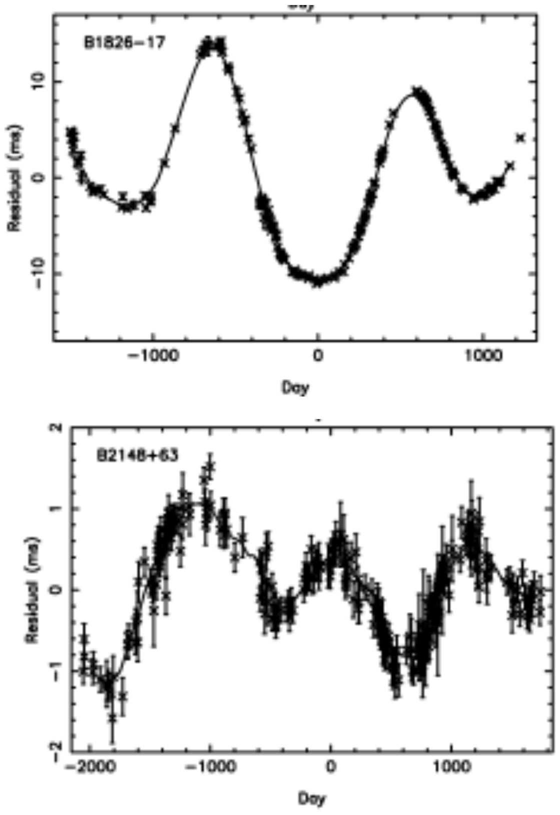
- A long time monitor for pulsars so as to obtain the TOAs.
- Compare pulse arrival times at an observatory with times predicted with a spin-down model , obtained the timing residual.
- The irregular period changes include two categories: glitch and timing noise.



Proper motion(Lorimer & Kramer, 2005)



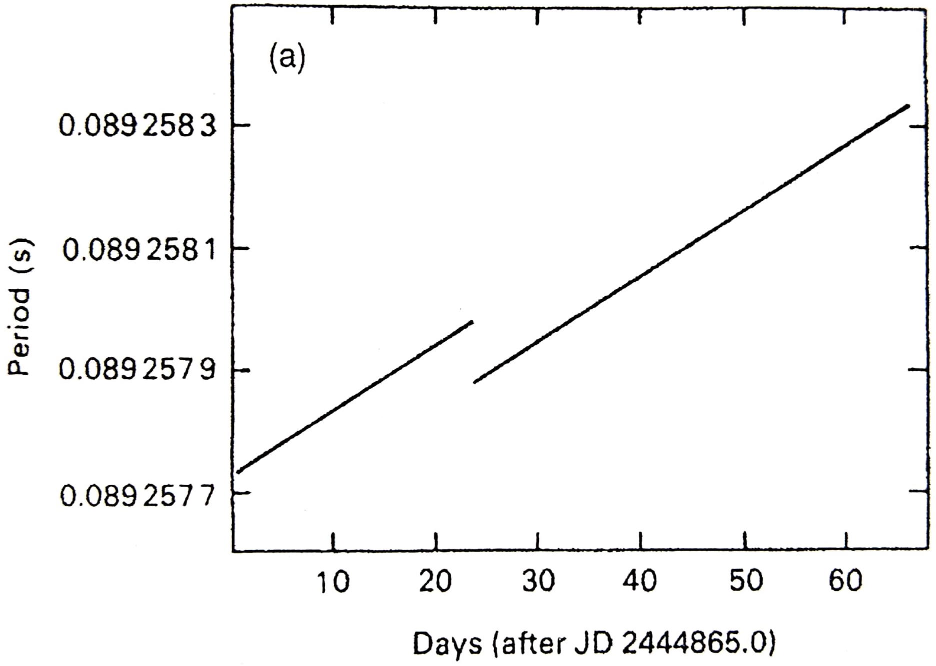
Glitch(C.M.Espinoza&A.G.Lyne2011)

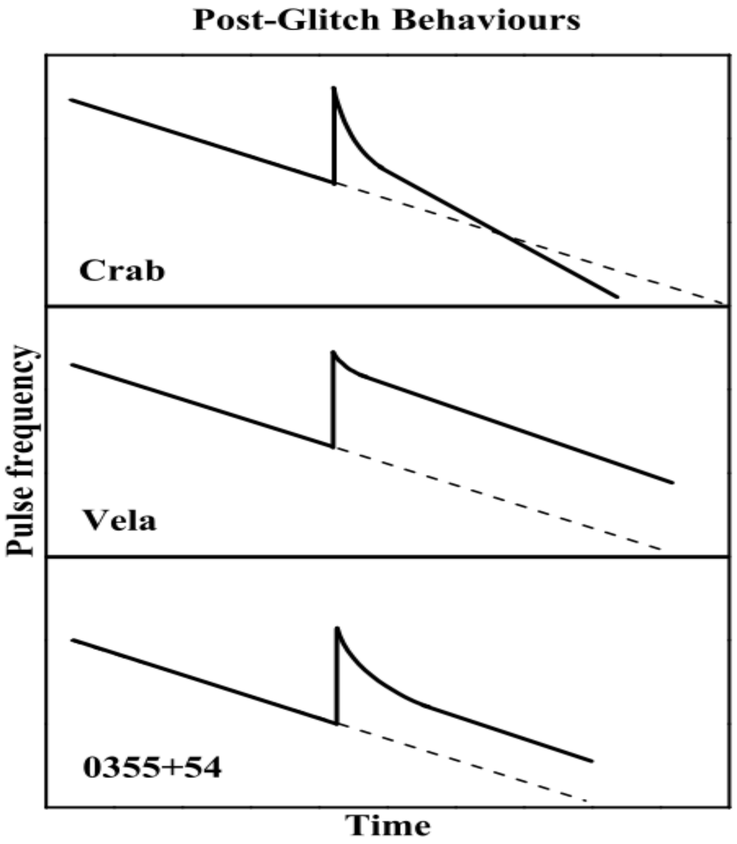


Timing noise (G.Hobbs&A.G.Lyne2010)

Glitch *and Timing noise*

Sudden jumps in rotational frequency(ν=Ω/2π)





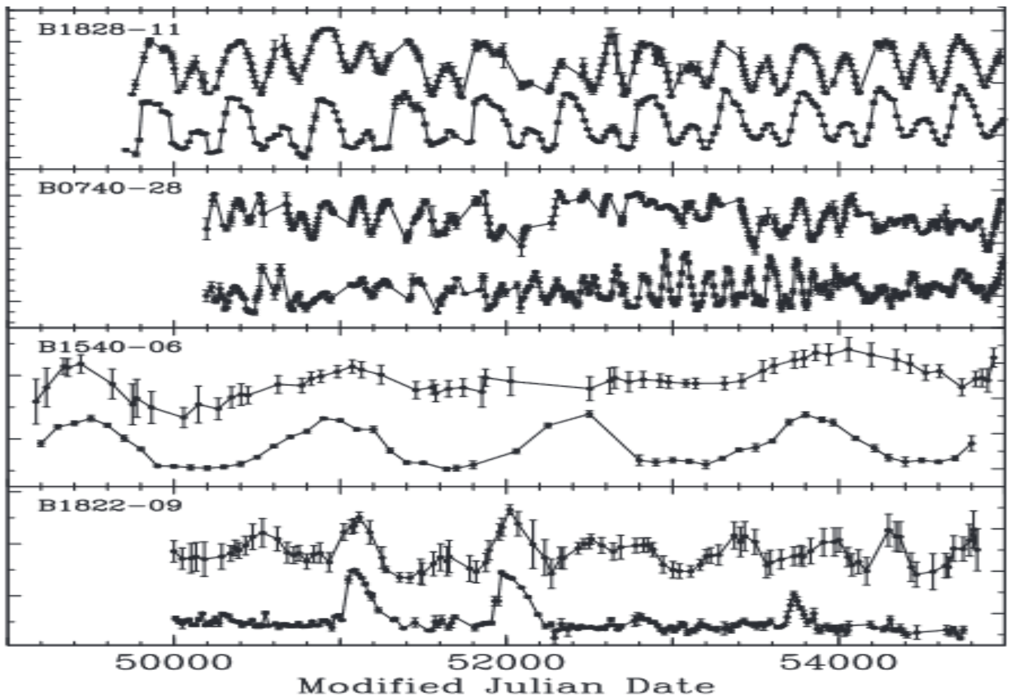
$\Delta \nu_g / \nu$: $10^{-12} - 10^{-5}$

PSR B0833-45,1981.10 (McCulloch et al.1983)

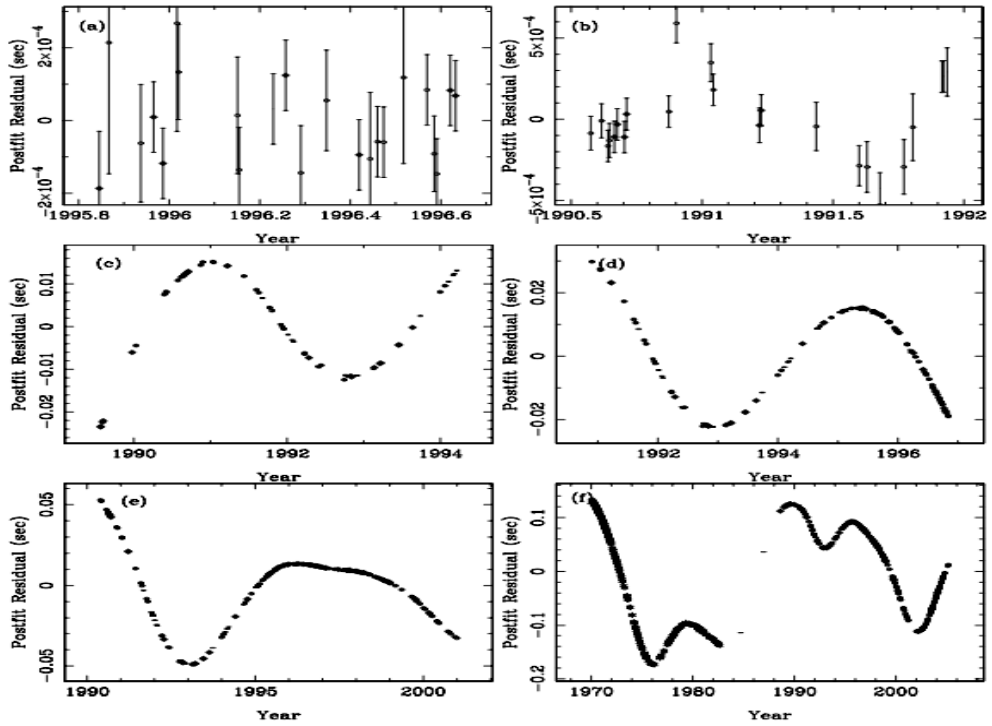
$Q = \Delta \nu_d / \Delta \nu_g$

Glitch and **Timing noise**

- The residuals show random fluctuation and the same trend in different observation frequencies
- Structure of timing residuals in different data segments are different
- The timing noise of young pulsars is stronger than that of old pulsars
- Boynton et al. (1972) , Crab: $P(f) \propto f^{\alpha}$, α ~ -2,-4,-6
- Coles et al. 2011, Cholesky, $P(f) = \frac{A}{[1+(f/f_c)^2]^{\alpha/2}}$

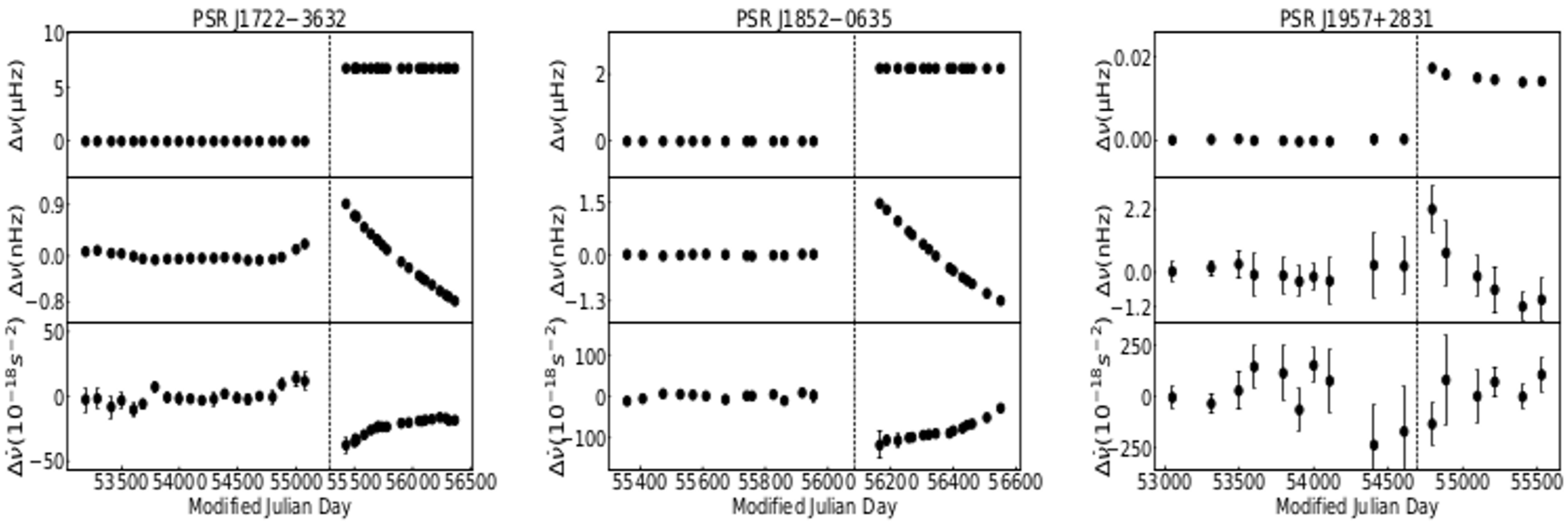


Lyne et al. 2010



PSR B1543-06 timing noise in different time(Hobbs et al.2010)

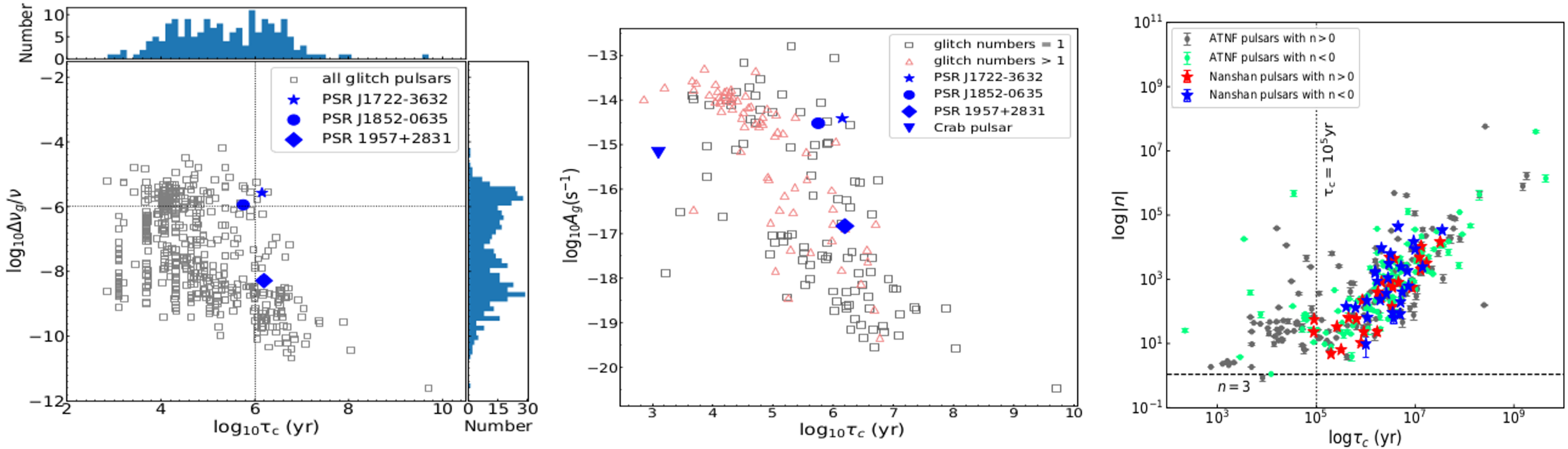
Our work （S.J.Dang et al.2020,ApJ）



- PSR J1722-3632, second oldest pulsar in great glitching pulsar.

PSR J2000 Name	J1722−3632	J1852−0635	J1957+2831
Glitch epoch(MJD)	55283(3)	56086(8)	54689(3)
$\Delta\nu_g$ (10^{-9}Hz)	6769.2(1)	2182.8(7)	20.9(3)
$\Delta\nu_g/\nu$ (10^{-9})	2702.18(4)	1144.1(3)	6.4(6)
$\Delta\dot{\nu}_g$ ($10^{-17}s^{-2}$)	−4.7(5)	−15(2)	−2.3(4)
$\Delta\dot{\nu}_g/\dot{\nu}$ (10^{-3})	0.89(9)	5.5(6)	0.7(6)
$\Delta\nu_d$ (10^{-9}Hz)	0.4(1)	4.7(5)	4(1)
τ_d (d)	240(20)	400(40)	110(10)
Q	0.00006(2)	0.0022(2)	0.2(3)
Data range (MJD)	53034-56879	54619-56718	52911-56719

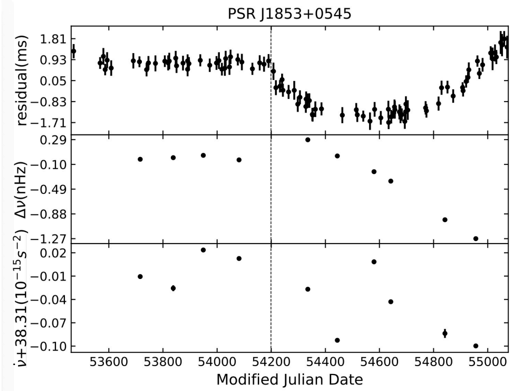
Our work（S.J.Dang et al.2020,ApJ）

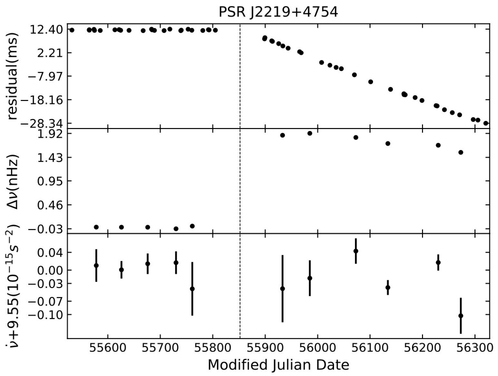


- http://www.jb.man.ac.uk/pulsar/glitches/gTable.html (190pulsars~557glitches)
- $\tau_c > 10^6$,fewer great glitches
- $A_g \equiv \frac{1}{T}\sum\frac{\Delta v_g}{v}$, A_g greatest, middle age pulsar
- $\tau_c < 10^5$, $n = \frac{\nu\ddot{\nu}}{\dot{\nu}^2}$ vs τ_c have no obvious relationship
- $\tau_c > 10^5$,n vs τ_c have strong correlation, $\rho = 0.79$

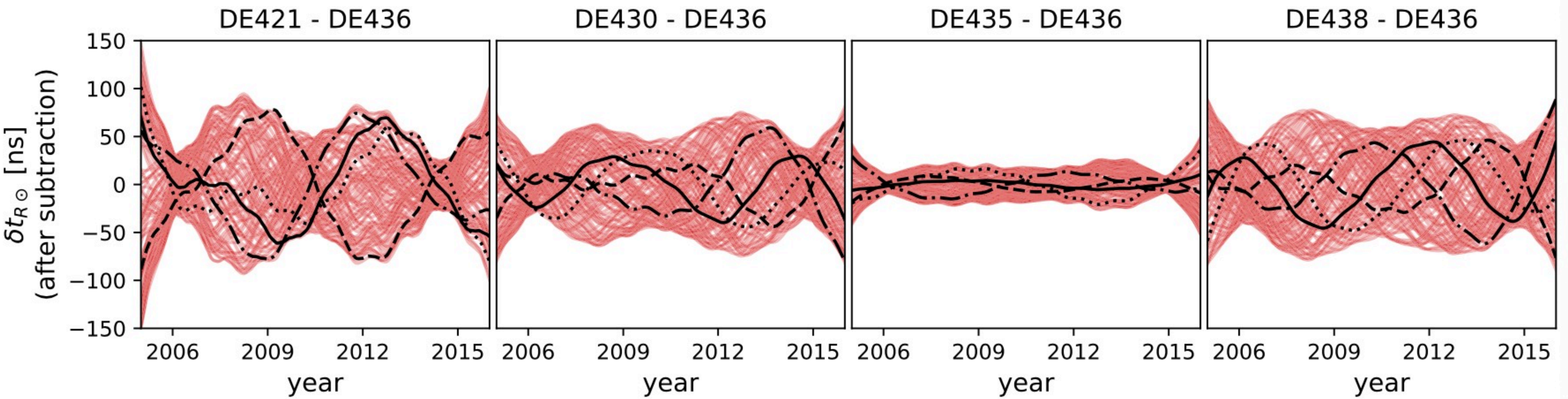
Follow-up work

1, Nanshan : 20 pulsars ~ 57 new glitches , small glitches
2, Question: Small glitches ?Timing noise ?





ptaSimulate : Simulating pulsar timing array data sets
1,Software for simulating TOAs, parameters (configuration files) of PTA pulsars
2,The standard outputs are .par and .tim files
3, One of the achievements （M. Vallisneri et al,2020,ApJ）



ptaSimulate: timing noise

- Models:

Timing noise $$P_1 = \frac{P_0}{\left(1 + \left[\frac{f}{f_c}\right]^2\right)^{\frac{\alpha}{2}}}$$

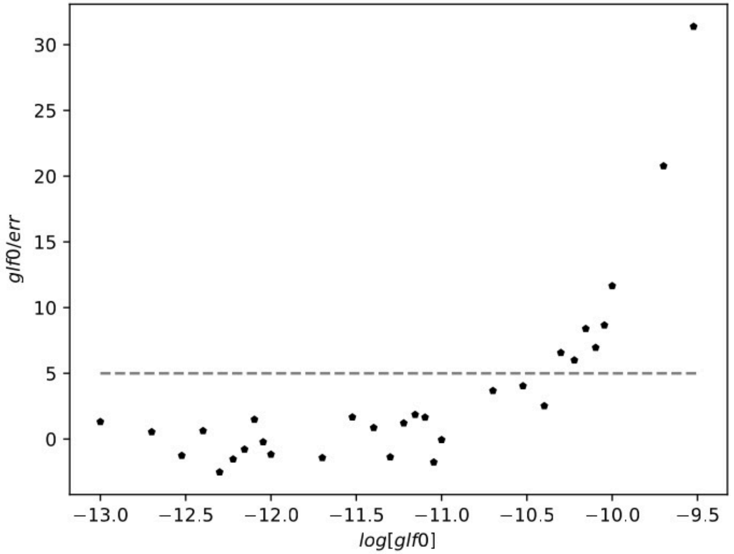
Jitter noise $$\sigma = \sigma_J \sqrt{\frac{t_{ref}}{t_{obs}}}$$

- Using timing noise models,3 different timescale pulsar
- 10 times of each group,120 times random simulation for each pulsar
- To power spectrum, alpha (-2～-6),p0 most important
- p0,greater or smaller than (1e),cause a glitch
- Timing noise to cause a glitch tend to greater than e-9,or bigger ,can`t cause frequent small glitches

Pulsar Name	Gl. No.	Epoch (MJD)	$\Delta\nu_g/\nu$ (10^{-9})	$\Delta\nu_g/\dot{\nu}$ (10^{-3})	Data span (MJD)	f_c (yr^{-1})	y-range (us)	alpha	p0	y-range span (us)
J0406+6138	2	54416(6)	0.23(7)	-1.0(5)	54112-54760	0.562	2545.35	-3	1e-21	2135.3-3781.27
								-4	1e-21	2236.08-3179.41
								-5	1e-21	1942.12-4643.29
								-6	1e-21	1841.06-3171.96
								-3	1e-22	2145.47-2905.72
								-4	1e-22	1771.48-3779.53
								-5	1e-22	1827.13-3350.50
								-6	1e-22	2081.24-4015.20
								-3	1e-23	2031.15-3119.49
								-4	1e-23	1884.82-3163.38
								-5	1e-23	1762.33-2902.72
								-6	1e-23	1880.66-3181.79
J0525+1115	1	56021(9)	0.31(2)	-2.0(3)	52460-56686	0.086	13650.01	-3	1e-17	36635.84-71961.92
								-4	1e-17	25156.24-52443.95
								-5	1e-17	15822.79-52004.19
								-6	1e-17	9268.32-30058.14
								-3	1e-18	11546.28-30139.68
								-4	1e-18	7348.33-21076.90
								-5	1e-18	6594.03-16750.98
								-6	1e-18	4522.84-10572.33
								-3	1e-19	5480.77-9717.89
								-4	1e-19	4177.43-8989.35
								-5	1e-19	3417.75-7664.66
								-6	1e-19	3007.00-6641.43
J1833-0827	11	56176(4)	0.71(5)	-0.07(2)	55860-56590	0.5	2827.5	-3	1e-20	2684.48-6695.99
								-4	1e-20	1703.23-4867.59
								-5	1e-20	1039.78-2979.84
								-6	1e-20	825.44-2421.40
								-3	5e-21	2103.68-3898.25
								-4	5e-21	1484.24-2636.97
								-5	5e-21	829.13-2636.97
								-6	5e-21	1068.01-2173.44
								-3	1e-21	1276.76-2743.22
								-4	1e-21	1052.73-2028.09
								-5	1e-21	888.99-1794.37
								-6	1e-21	738.28-1405.49

ptaSimulate: glitch

- Glitch model: setting glep,glph,glf0与glf1
- Setting glf0=1e-13～1e-8, got S/N parameter , the Fig. below
- Remove 10% of the head and tail, MJD moves every 30 days
- Select the minimum glitches detection limit based on glf0 / err > 5
- With the increase of set glitches parameters, the simulated glitches S/N increases exponentially



glf0/err of PSR J0525+1115 at MJD=54500

Pulsar Name	The min detection limit of glitches magnitude $(\Delta\nu/\nu)_{min}$ (10^{-9})
J0215+6218	0.02
J0525+1115	0.02
J0528+2200	0.008
J0631+1036	0.4
J0846-3533	0.05
J1705-3423	0.06
J1833-0827	0.005
J1836-1008	0.03
J1847-0402	0.02
J1853+0545	0.08
J1902+0615	0.04
J1909+1102	0.6
J1957+2831	0.3
J2219+4754	0.01
J2225+6535	0.06

Our work

- All the glitches values obtained by fitting are larger than the minimum glitch limit of Nanshan, but they are not completely distinguished from timing noise.

Pulsar Name	Gl. No.	Epoch (MJD)	$\Delta\nu_g/\nu$ (10^{-9})	$\Delta\dot{\nu}_g/\dot{\nu}$ (10^{-3})	Rms res. (μs)	Data span (MJD)	No. of ToAs	rate=k_{post}/k_{pre}	τ_d (Myr)
J1844+00	1	55676(11)	0.40(2)	4.6(5)	81.477	55294-55936	21	1.00515596562	4.4
	2	56026(10)	0.48(3)	0.3(6)	202.424	55677-56366	33	1.001262749717766	
	3	56366(9)	0.51(4)	−0.2(7)	217.062	56027-56720	34	0.9997323296569257	
J1847-0402	1	52028(7)	0.09(2)	−0.06(1)	62.157	51505-52300	24	1.00010799164	0.183
	2	52763(6)	0.3(2)	0.27(2)	56.006	52351-53000	23	1.00019476678	
	3	53019(4)	0.32(3)	−0.20(4)	167.570	52769-53530	34	0.9997940060290683	
	4	53465(6)	0.19(7)	−0.08(4)	395.514	53019-53808	44	0.9999634624615779	
	5	55104(44)	0.10(7)	−.10(5)	637.489	53809-55510	117	0.9999680758865384	
	6	55512(38)	0.397(6)	0.017(2)	76.916	54880-56457	37	1.00001932289	
	7	56457(23)	0.19(2)	0.12(2)	39.452	55511-56701	14	1.0002944107	
J1853+0545	1	54199(9)	0.109(5)	0.70(3)	78.022	53500-55110	53	1.0007637045	3.3
	2	55110(38)	0.096(5)	0.89(3)	61.303	54200-55826	36	1.00096682489	
	3	55826(24)	0.17(2)	0.1(1)	441.329	55120-56720	65	1.0001032503039418	
J1902+0615	1	55456(5)	0.088(4)	−0.131(7)	49.577	54300-56606	27	0.999990559302	1.38
J1909+1102	1	54659(2)	0.12(2)	1.23(2)	68.666	54400-54958	21	1.00136229737	1.70
	2	55320(5)	0.24(2)	−0.11(5)	232.255	54659-55956	52	0.9999757519301946	
	3	56164(23)	0.59(5)	−1.4(2)	744.505	55321-56718	53	0.9983197909959802	
J1957+2831	1	56268(25	0.37(9)	0.06(4)	789.092	54800-56718	54	1.0002151501036356	1.57
J2219+4754	1	51711(2)	0.31(1)	0.2(3)	29.458	51549-52102	19	1.00064634004	3.09
	2	52103(6)	0.21(1)	−0.5(1)	58.061	51710-52440	29	1.00033601214	
	3	52454(18)	0.18(1)	0.4(1)	64.625	52102-52874	37	1.00023644376	
	4	52926(23)	0.13(4)	0.2(4)	177.016	52460-53324	57	1.000828183817135	
	5	53224(26)	0.17(3)	−0.6(5)	142.285	52927-53650	35	0.9990504584239094	
	6	53650(50)	0.06(3)	−0.4(4)	182.778	53225-54018	41	0.9995736591486651	
	7	54018(10)	0.08(2)	−0.04(3)	181.037	53650-55011	102	1.0000547405564657	
	8	55012(7)	0.068(3)	−0.08(3)	38.938	54004-55496	44	0.999878144088	
	9	55497(35)	0.07(1)	0.3(1)	48.431	55011-55881	25	1.0003686613	
	10	55881(17)	1.23(1)	0.6(1)	45.730	55497-56346	22	1.00160282159	
	11	56347(26)	0.175(4)	−0.15(4)	12.203	55881-56718	14	1.00025163794	
J2225+6535	1	54668(5)	0.30(1)	1.57(7)	63.626	54300-55028	22	1.00093112866	1.1
	2	55028(15)	1.31(1)	0.51(5)	47.331	54668-55364	17	0.999755043671	
	3	55364(1)	1.19(1)	−0.25(5)	32.532	55028-55761	15	1.00004158578	
	4	55761.7(5)	1.02(1)	1.86(5)	49.527	55364-56100	14	1.0022829065	
	5	56142(2)	1.65(2)	1.54(7)	54.965	55761-56487	13	1.00169472223	
	6	56487(16)	2.42(3)	−1.0(2)	49.289	56141-56719	10	0.997915662805	

Pulsar Name	Gl. No.	Epoch (MJD)	$\Delta\nu_g/\nu$ (10^{-9})	$\Delta\dot{\nu}_g/\dot{\nu}$ (10^{-3})	Rms res. (μs)	Data span (MJD)	No. of ToAs	rate=k_{post}/k_{pre}	τ_d (Myr)
J0215+6218	1	55623(10)	0.082(6)	−0.2(1)	176.614	52500-56718	88	0.999830333494	13.1
J0406+6138	1	53885(6)	0.32(8)	3.3(9)	533.122	53200-54111	84	1.00412597208052	1.69
	2	54111(19)	0.44(9)	-1.0(9)	440.328	53886-54422	62	0.9983628694924105	
	3	54416(12)	0.22(6)	-1.1(5)	467.995	54112-54776	84	0.9989134976761003	
	4	54846(7)	0.27(4)	0.7(2)	471.324	54416-5529	96	1.0005779799826446	
	5	55565.3(5)	0.65(5)	2.31(7)	611.507	54846-55848	74	1.0021875245896357	
	6	55849(43)	0.097(3)	3.2(2)	56.568	55565-56132	17	1.00231440536	
J0525+1115	1	56021(18)	0.274(2)	−4(3)	374.914	52469-56718	372	0.997428866657	76.3
J0528+2200	1	54931.0(5)	0.2434(7)	1.209(4)	2.468	54000-55263	11	1.00113045971	1.48
	2	55263(6)	0.34(5)	-1.2(3)	416.661	54932-55723	34	0.9988609315466068	
	3	55724(17)	0.18(2)	0.5(2)	72.804	55263-55997	20	1.00043811976	
	4	55997(28)	0.422(6)	1.63(5)	232.027	55724-56327	37	1.0011302147	
J0631+1036	1	55103(32)	7.0(7)	0.3(2)	2140.899	54700-55278	104	0.999005030086	0.044
	2	55278(5)	6.5(4)	−0.2(2)	1616.228	55118-55540	61	0.999850864655	
J0846-3533	1	55661(19)	0.514(3)	1.57(5)	723.682	51547-56718	36	1.00161316284	11.05
J1705-3423	1	55490(27)	0.228(3)	−0.07(2)	60.791	54450-56718	44	1.00025040068	3.75
	2	55914(13)	0.22(2)	−2.8(2)	170.886	55491-56719	27	0.9969327868532146	
J1801-2304	1	53786(8)	2.5(5)	0.3(2)	2397.905	53320-54042	45	1.00036700233	0.058
	2	54064(13)	3(1)	0.2(4)	3774.135	53779-54287	34	1.0000857051950314	
	3	54888(6)	2.7(5)	−0.10(6)	3032.365	54043-55302	62	0.999869802898	
	4	55302(5)	3.2(3)	−0.49(10)	3420.395	54889-56155	40	0.9994044644256764	
J1818-1422	1	55834(14)	0.39(3)	0.1(1)	792.780	55000-56684	99	0.999967821386	2.27
J1830-1059	1	55677(10)	5.70(5)	0.06(2)	207.780	55300-56117	30	1.000183687	0.107
	2	56131(9)	4.9(1)	−0.65(4)	864.867	55678-56592	33	0.9994479461100115	
J1833-0827	1	51871(2)	0.22(2)	0.02(1)	134.933	51550-52262	65	1.00003834226	0.147
	2	52262(7)	0.21(3)	0.11(2)	175.224	51872-52555	60	1.00015464803	
	3	52555(14)	0.27(2)	−0.01(1)	104.270	52263-52940	43	0.999923980376	
	4	52979(6)	0.29(2)	0.17(1)	117.119	52555-53273	49	1.00017567076	
	5	53274(2)	0.24(3)	0.18(5)	56.398	52979-53394	20	1.00011096741	
	6	53394(12)	0.4(2)	0.1(3)	314.511	53274-53593	24	1.0000585521176115	
	7	53627(33)	0.49(8)	−0.13(7)	285.067	53395-54048	54	0.9999492387952236	
	8	54058(11)	0.26(1)	0.03(9)	98.164	53595-54433	37	1.00004135688	
	9	54433(40)	0.61(5)	0.29(3)	134.758	54058-54782	28	1.00025853376	
	10	54782(18)	0.85(4)	0.07(3)	149.885	54433-55100	30	1.00002721542	
	11	55105(46)	0.64(1)	−0.010(8)	42.826	54782-55461	18	1.00001536156	
	12	55487(26)	0.64(2)	0.06(1)	97.024	55105-55859	27	1.00002325835	
	13	55859(32)	0.72(2)	0.13(1)	94.641	55487-56167	35	1.00014300303	
	14	56176(9)	0.71(5)	−0.07(3)	340.849	55860-56590	53	0.999974711252	
J1835-1020	1	52778(21)	0.12(2)	0.53(8)	93.601	52497-53143	28	1.00003154822	0.81
	2	53144(3)	0.31(3)	0.24(9)	95.791	52778-53488	23	1.0004577351	
	3	53488(30)	0.42(7)	−0.08(2)	310.248	53144-53867	29	0.9996389422287125	
	4	53892(3)	0.43(6)	0.5(3)	424.632	53489-54222	17	1.0003014790663711	
	5	54223(8)	0.59(2)	−0.20(5)	79.226	53892-54570	23	1.00019821357	
	6	54570(5)	0.54(2)	0.01(5)	91.241	54222-54968	32	0.99982908189	
	7	54985(17)	0.57(2)	0.17(5)	93.191	54570-55301	32	1.00071803963	
	8	55301(6)	0.69(5)	0.1(1)	314.363	54986-55661	18	0.9997712831548133	
	9	55662(6)	0.75(2)	0.11(7)	96.953	55301-56028	29	1.00053447347	
	10	56028(7)	0.71(6)	−0.3(2)	401.405	55662-56626	19	0.9992729129866721	
J1836-1008	1	55755(39)	3.5(2)	−0.9(2)	3592.805	54000-56606	125	0.999212960632	0.756

Summary

● 1. Detected 57 new glitches of 20 pulsars,for PSR J0215+6218,PSR J0525+1115,PSR J0846-3533,PSR J1835-1020,PSR J1836-1008,PSR J1847-0402 and PSR J2219+4754 were first to glitch.

● 2. In the range of normal noise power index (- 2 ~ - 6), the noise intensity has the greatest influence on the power spectrum, and whether it can cause similar small jump is of one order of magnitude (1e). In addition, the obvious jump caused by timing noise is even larger in the order of e-9, and it does not necessarily lead to several successive small glitches.

● 3. With the increase of set glitches parameters, the simulated jump signal-to-noise ratio increases exponentially. All the glitching values obtained by fitting are larger than the minimum jump limit of Nanshan, but they are not completely distinguished from timing noise.

Thanks ！