Correlation between glitch and emission

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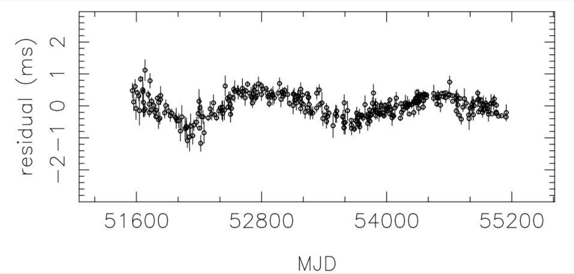
Outline

- Introduction
- The features of pulsar glitches
- Correlation between glitch and emission

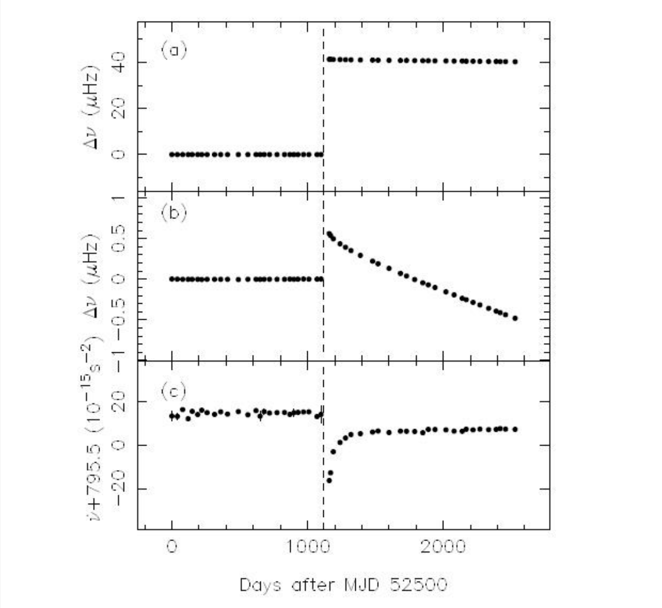
1. Introduction

- pulsar rotation: $$\phi(t) = \phi_0 + \nu(t-t_0) + \frac{1}{2}\dot{\nu}(t-t_0)^2 + \frac{1}{6}\ddot{\nu}(t-t_0)^3 + \ldots$$
- timing noise: fluctuation



- glitch: Sudden increase in pulsar rotation rate ν,
- Often
  - associated with jump in spin-down rate
  - followed by recovery

$$\phi_g = \Delta\phi + \Delta\nu_p(t-t_g) + \frac{1}{2}\Delta\dot{\nu}_p(t-t_g)^2 + \sum_{1}^{i}[1-e^{-(t-t_g)/\tau_{di}}]\Delta\nu_{di}\tau_{di}$$



yuan et al. 2010

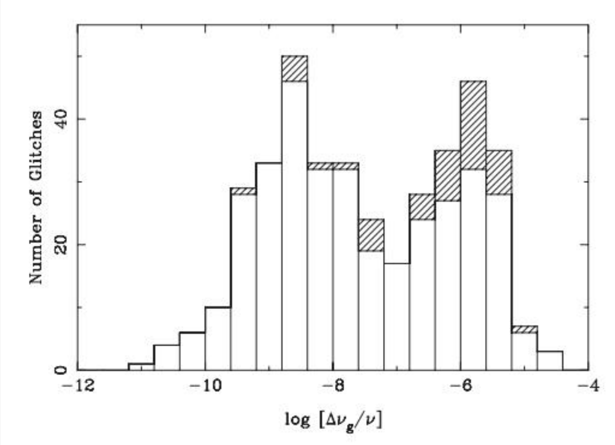
1. Introduction

- 520 knows glitches in 180 pulsars
- Most in young pulsars.
- Fractional size:

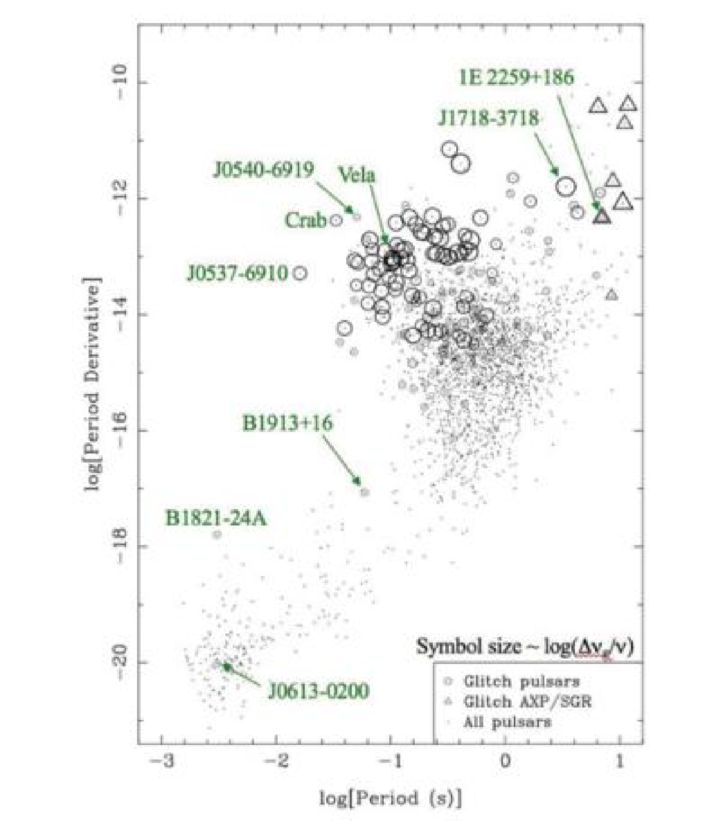
$$\Delta\nu_g/\nu = \frac{\nu_{post} - \nu_{pre}}{\nu} \approx 10^{-10} \cdots 10^{-5}$$

$$\Delta\dot{\nu}/\dot{\nu} = \frac{\dot{\nu}_{post} - \dot{\nu}_{pre}}{\dot{\nu}} \approx 10^{-4} \cdots 10^{-1}$$

- young pulsars generally glitch with large size $\Delta\nu/\nu \sim \times 10^{-6}$, e. g. Vela
- The youngest pulsars tend to smaller glitches $\Delta\nu/\nu \sim \times 10^{-8}$ or 10^{-7} , e.g. Crab
- Distribution: bi-modal



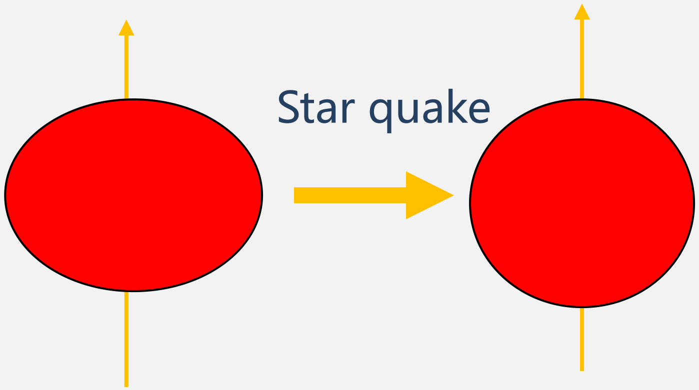
Yu et al. 2013

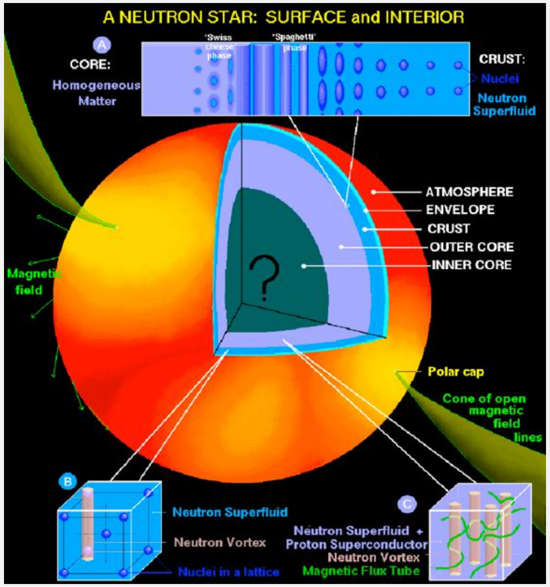


Manchester 2018

1. Introduction

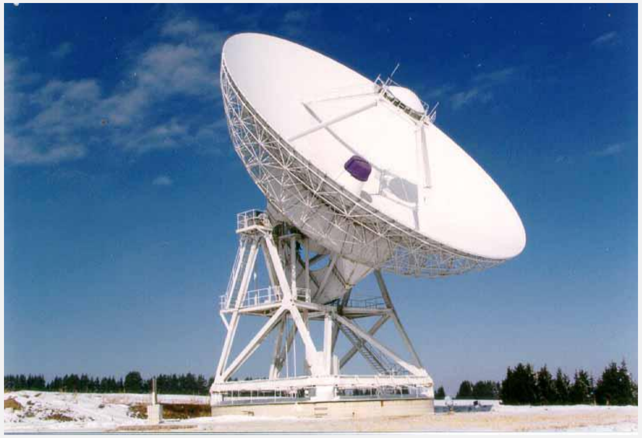
- Crust deformation: Step changes in crust deformation (Baym et al. 1969)
- Two component superfluid: Sudden unpinning of superfluid vortices (Anderson & Itoh 1975, Ruderman 1976, Alpar et al. 1981, Jones 1998)
- The vortex creep: the post-glitch relaxation (Alpar)
- A probe of the interior structure of pulsars
- offer an opportunity tostudy the strong interaction under extrem physical conditions.

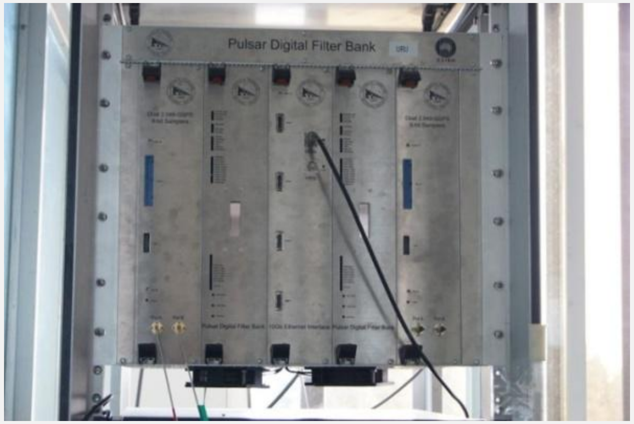




2. Features of glitches

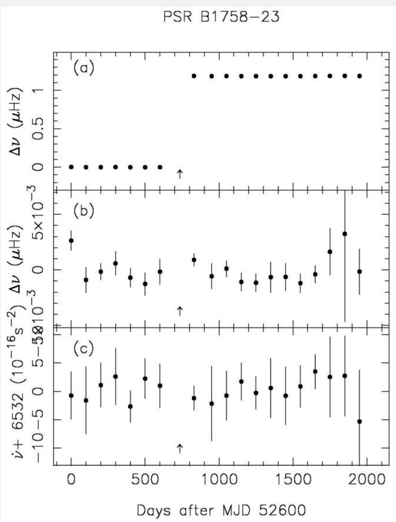
- Nanshan 25 m Radio Telescope, Urumqi, China
- L band receiver at 1540 MHz, BW of 320 MHz
- Analogue filter-bank. Digital filter-bank .
- 300 pulsars .
- Integration time of 4 – 16 min,
- three sessions each month.
- Sensitivity: 0.5 mJy
- > 50 Glitches are detected.

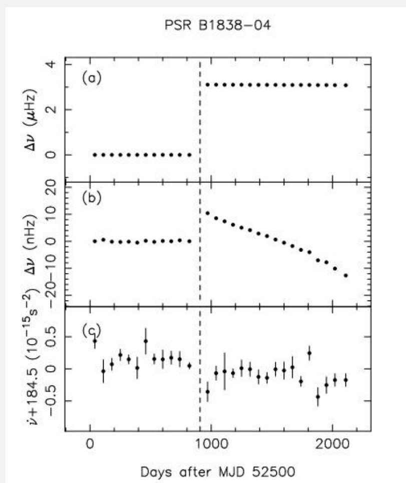




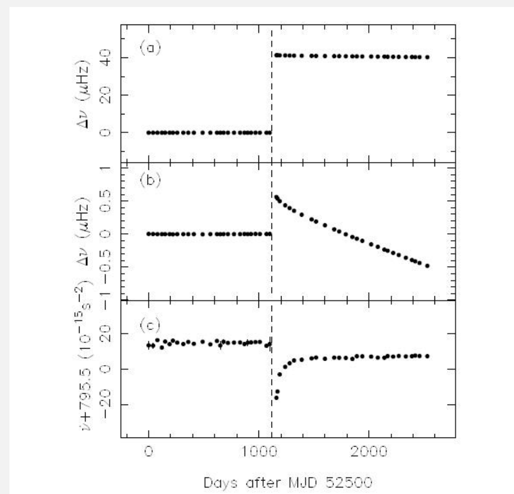
2. Features of glitches

- No obvious decay
- linear decay
- exponential decay
- exponential + linear decay
  - permanent change in spin-down rate





B2334+61



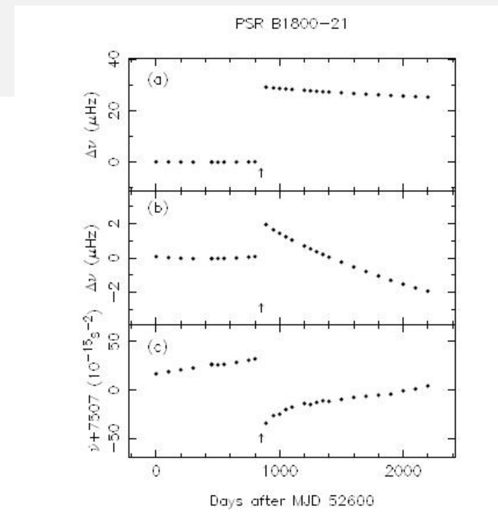


Figure 10. The glitch of PSR B1800−21: variations of (a) frequency residual $\Delta\nu$ relative to the pre-glitch solution, (b) an expanded plot of $\Delta\nu$ where the mean post-glitch value has been subtracted from the post-glitch data, and (c) the variations of $\dot{\nu}$.

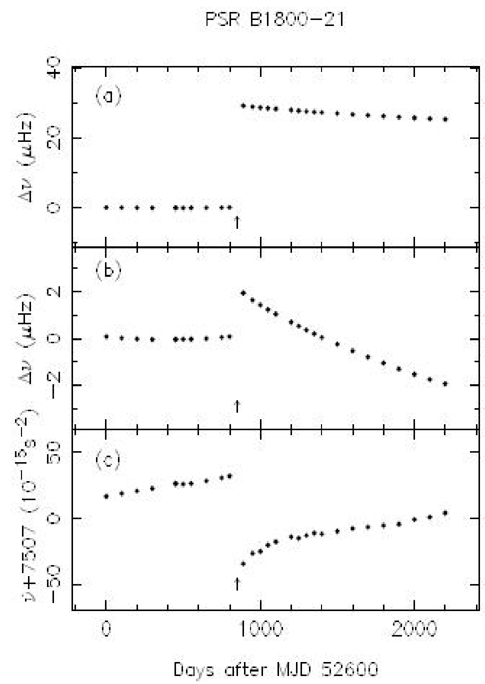
Yuan et al. 2010

2. Features of glitches

- Alpar et al. (1981, 1993, 1996) developed the two component model
- Exponential decay
- weakly pined vortices: vortex creep, a linear dynamical response --> exponential recovery
- linear decay
- strong pinned vortices: no creep, non-linear dynamical repose --> long-term linear increase in the spin-down rate

$$\Delta\nu_g = \Delta\nu_p + \Delta\nu_d$$

$$Q = \frac{\Delta\nu_d}{\Delta\nu_g}$$



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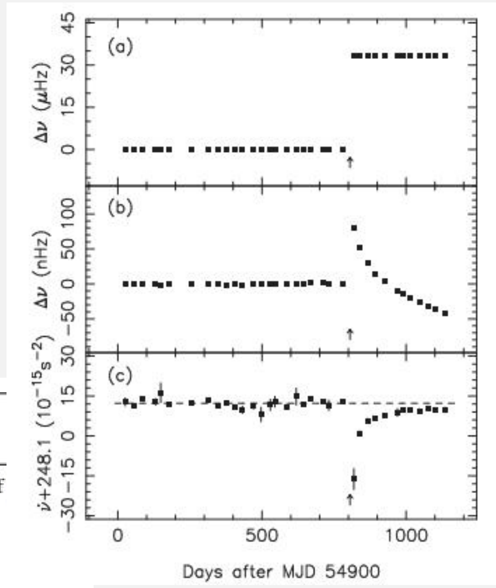
yuan et al. 2010

2. Features of glitches

- multi exponential terms
- five pulsars
- shorter term: 3 - 22 d
- longer term: 14 - 322,
- fast decays could be missed duo to observations gap

PSR	Epoch (MJD)	$\Delta\nu_{d1}$ (10^{-6} Hz)	Q_1	τ_{d1} (d)	$\Delta\nu_{d2}$ (10^{-6} Hz)	Q_2	τ_{d2} (d)	Ref
J0835−4510	40280(4)	0.0518(5)	0.001 98(2)	10(1)	0.4665(13)	0.017 82(5)	120(6)	Cordes, Downs & Krause-Polstorff
	41192(8)	0.0362(5)	0.001 58(2)	4(1)	0.300(2)	0.013 11(9)	94(5)	Cordes et al. (1988)
	42683(3)	0.009 68(11)	0.000 435(5)	4.0(4)	0.0786(4)	0.003 534(16)	35(2)	Cordes et al. (1988)
	43693(12)	0.0830(7)	0.002 42(2)	6.0(6)	0.3888(7)	0.011 34(2)	75(3)	Cordes et al. (1988)
	44888.4(4)	0.010 36(10)	0.000 813(8)	6.0(6)	0.0242(5)	0.001 90(4)	14(2)	Cordes et al. (1988)
	45192.1(5)	0.057 01(16)	0.002 483(7)	3.0(6)	0.1263(18)	0.005 50(8)	21.5(2.0)	Cordes et al. (1988)
	46259(2)	0.066(9)	0.0037(5)	6.5(5)	2.76(1)	0.1541(6)	332(10)	McCulloch et al. (1987)
	47519.80360(8)	0.1086(2)	0.005 385(10)	4.62(2)	3.396(8)	0.1684(4)	351(1)	McCulloch et al. (1990)
J1119−6127	54244(24)	18.6(218)	0.81(81)	15.7(3)	4.9(43)	0.214(136)	186(3)	Yu et al. (2013)
J1757−2421	55702 (6)	0.045(13)	0.0013(8)	15(6)	0.073(4)	0.0022(2)	97(15)	This work
J1803−2137	50765(15)	0.23(16)	0.0094(65)	12(2)	0.080(15)	0.003 30(64)	69(3)	Yu et al. (2013)
J2337+6151	53615(6)	0.19(3)	0.0046(7)	21.4(5)	0.119(4)	0.0029(1)	147(2)	Yuan et al. (2010b)

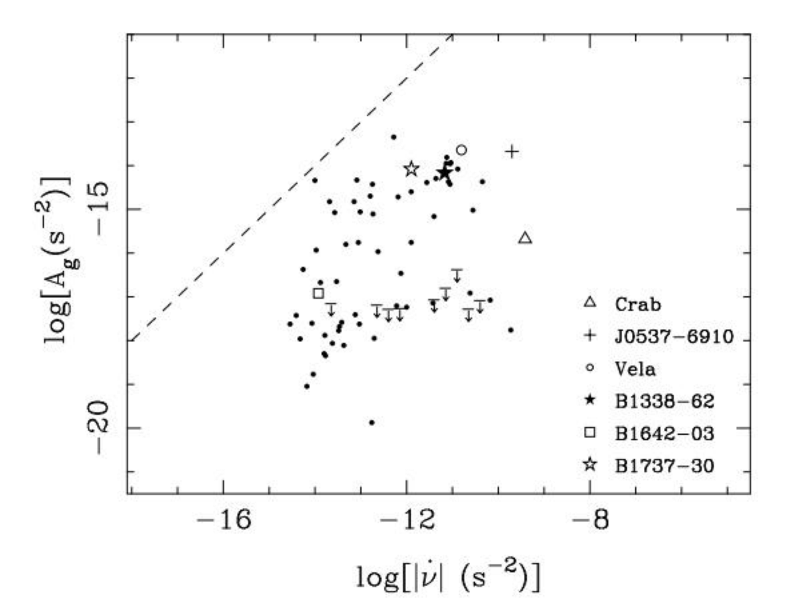


PSR J1757-2421
Yuan et al. 2017

2. Feature of glitches

- glitch activity parameter

$$A_g = \frac{1}{T} \sum \frac{\Delta \nu_g^i}{\nu}$$



- The dependence of activity parameter on the spin-down.
- A tendency for increasing activity with increasing spin-down rate.

Yuan et al. 2010

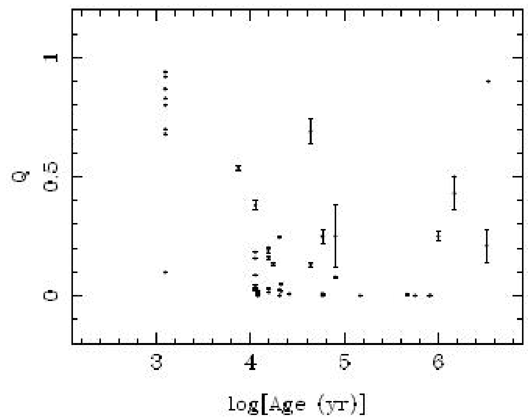


Figure 28. The fraction parameter Q in which a glitch $\Delta\nu_g$ decays, versus characteristic age.

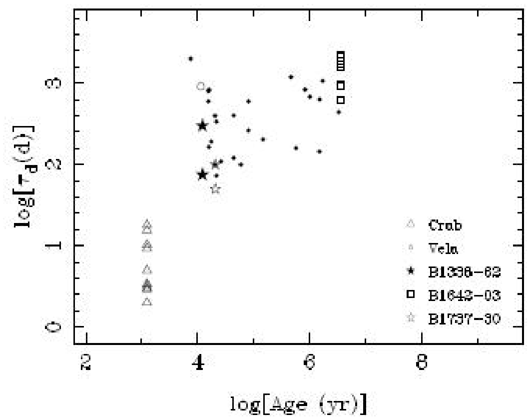


Figure 29. Glitch decay time-scale versus pulsar characteristic age.

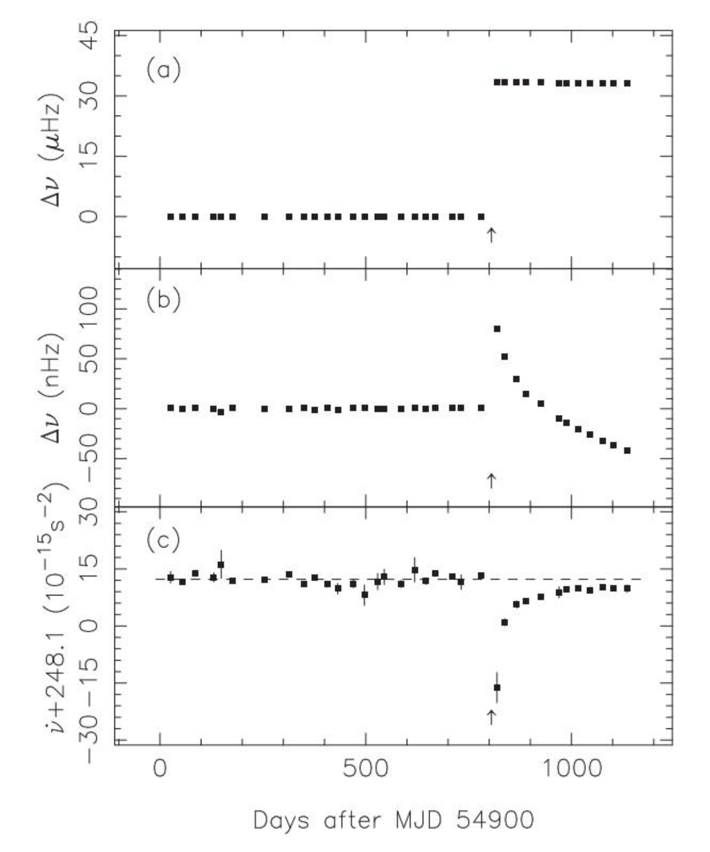
- Correlation between the degree of recovery and age of pulsars.
- Low degree of recovery for older pulsars
- long time-scale for aged pulsars.

2. Features of glitches

- The required ***momentum*** > reservoir.
- Entrainment of superfluid, unpinning of the crustal superfluid is insufficient to account for large glitch (Chamel 2012)
- Coupling parameter (Link et al. 1999)

  $G = 2\tau_c A_g$ $\quad$ $A_g = \frac{1}{T}\sum \frac{\Delta\nu_g^i}{\nu}$

- the minimum fraction of the moment of inertia that transfers angular momentum to the crust in glitches.
- Crustal G < 20% (Delsate et al. 2016)
- For PSR J1757−2421: G=45%
- Core superfluid may be required.



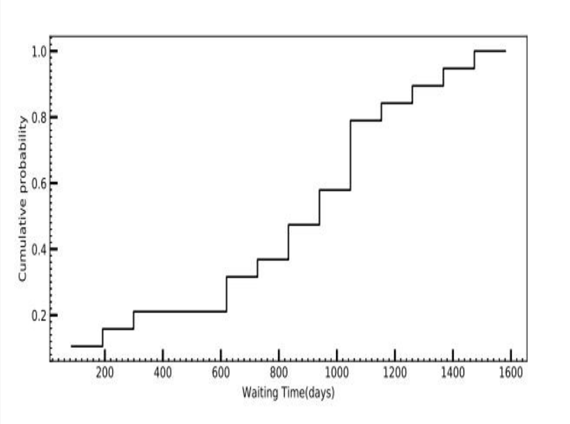
Yuan et al. 2017

2. Features of glitches

- Yunnan 40 m dish, Parkes 64 m
- Vela: not enough momentum in the crust (Li et al. 2016)
- For the Vela 2016 glitch $\Delta\nu/\nu \sim 1.43 \times 10^{-6}$ with long waiting time, G_m=0.08. core Superfluid is probably not involved.
- the cumulative probability of waiting time, deviate the exponential.
- the glitch occur quasi-periodically.
- mean of the waiting time ~ 919 d
- Akbal et al. (2017) predict that the 2013 glitch gave rise to a persistent shift.
- The the post-glitch spin-down rate have different slopes. no persistent shift.

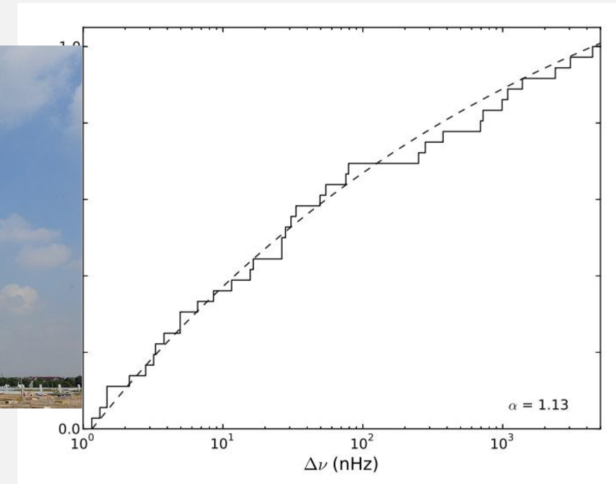
$$G = 2\tau_c A_g$$

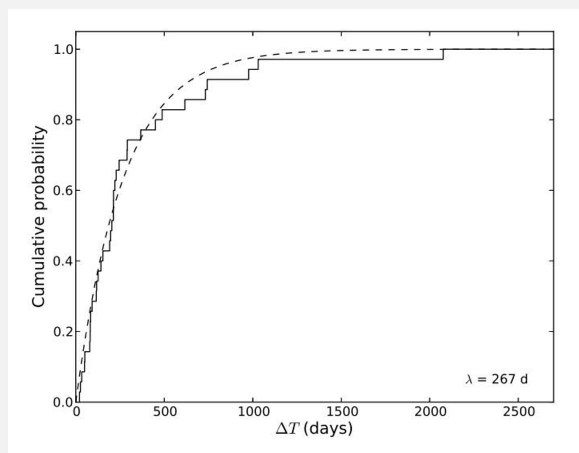
$$A_g = \frac{1}{T}\sum \frac{\Delta\nu_g^i}{\nu}$$

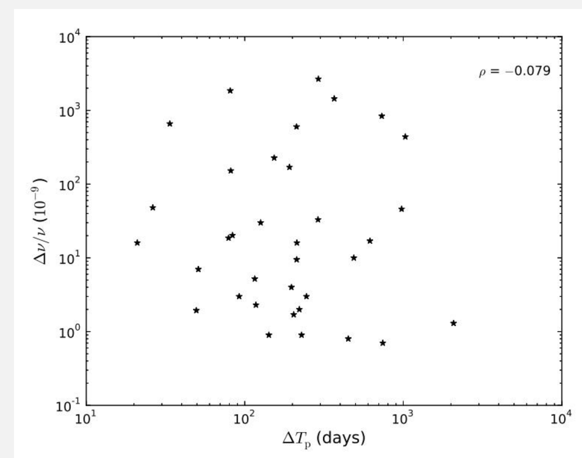


Xu et al. 2019

- Shanghai Tianma 65 m,
- B1737-30 a large glitch in last April.
- 36 events in 31 years.
- size distribution:
- power law with index of 1.13
- distribution of waiting time: Poisson probability density function
- no correlation for the glitch size and interval



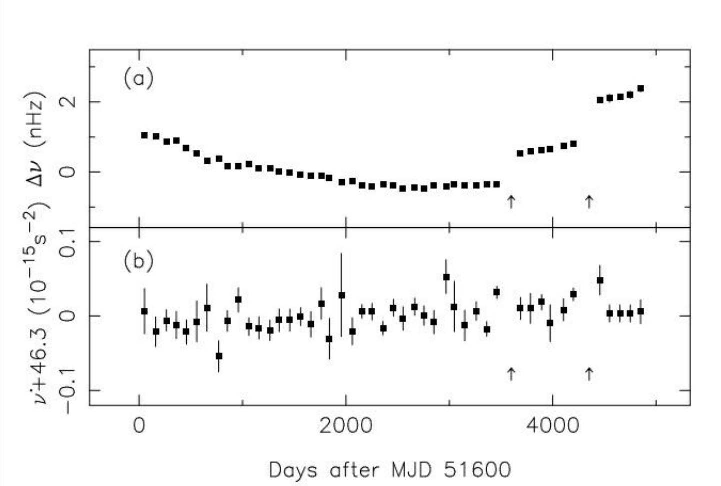




Liu et al. 2019

- J1705-1906, age of 1.16 Myr, $A_g = \frac{1}{T}\sum \frac{\Delta\nu_g}{\nu}$

  $A_g \sim 2.0 \times 10^{-11}\ yr^{-1}$
- relatively old pulsar have low glitch activity



- mean glitch rate: $\langle \dot{N}_g \rangle \propto |\dot{\nu}|^{0.47(4)}$
- Ng=0.083/yr > 0.019/yr,
- J1705 is more active that those with similar spin parameters.

- Fractional moment of inertial (FMI)
- FMI: 1.0E-6 -- 1.8 for 26 pulsars (Eya et al. 2017)
- consistent with the correlation between the fractional glitch size and the fractional moment of inertia.

$$\frac{I_{res}}{I_c} = -\sum_{1}^{n} \frac{1}{\dot{\nu}_c} \frac{\Delta\nu_i}{t_i},$$

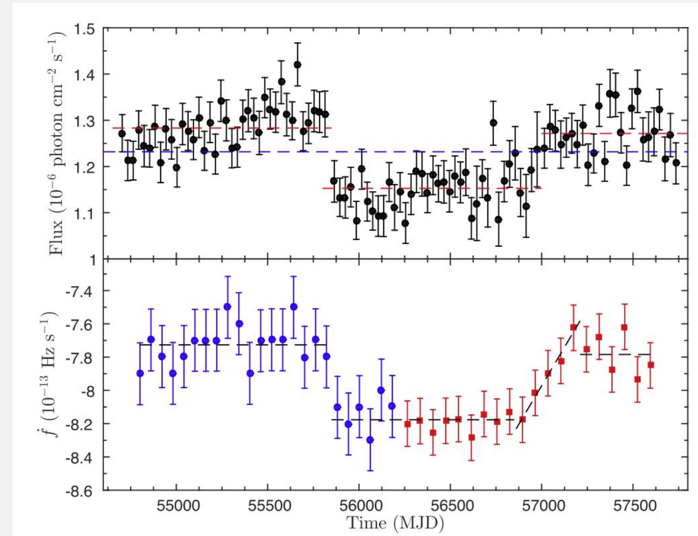
$$I_{res}/I \approx 3.37\times 10^{-4}$$

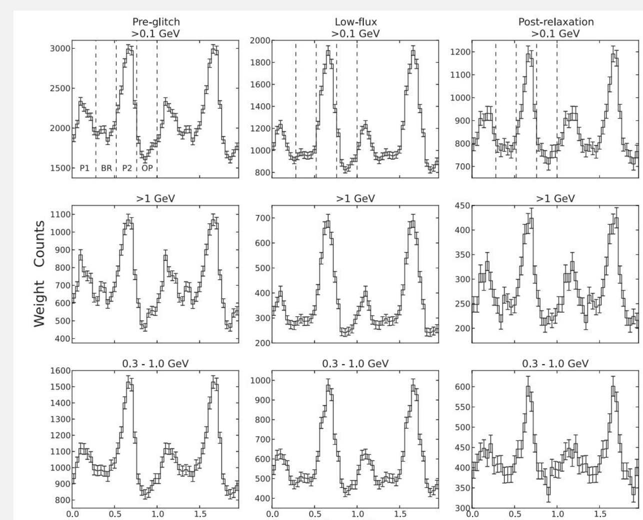
(Liu et al. 2018)

3. Correlation between glitch and emission

- gamma-ray pulsar - PSR J2021+4026
- A glitch on Oct. 2011. After the occurrence:
  - a high spin-down rate (~4% higher)
  - a low gamma-ray state (~18% lower)
  - profiles changed

  - the glitch trigger a mode change in the global magnetosphere.



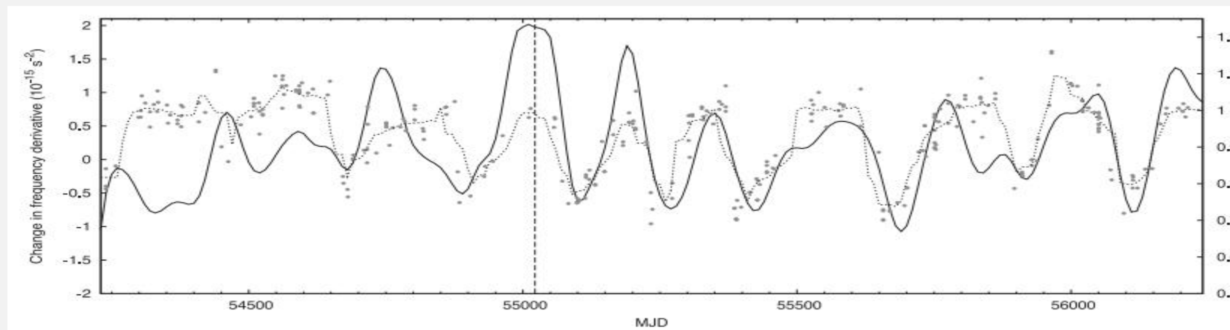


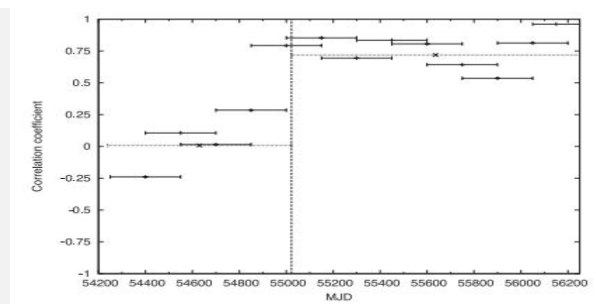
Zhao et al. 2017

3. Correlation between glitch and emission

- PSR B0740−28
- Two distinct emission state
- A glitch at MJD 55022
- Correlation between pulse shape and spin-down rate

- Interaction between the magnetosphere and the interior of the neutron star.

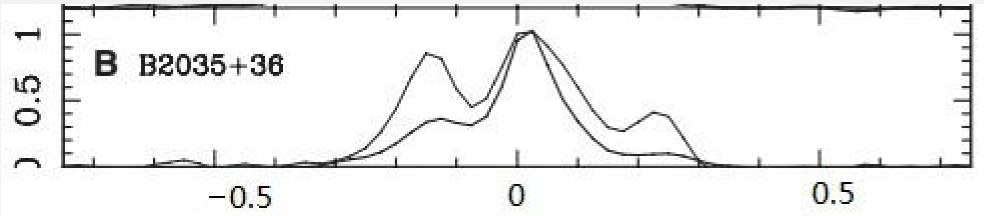


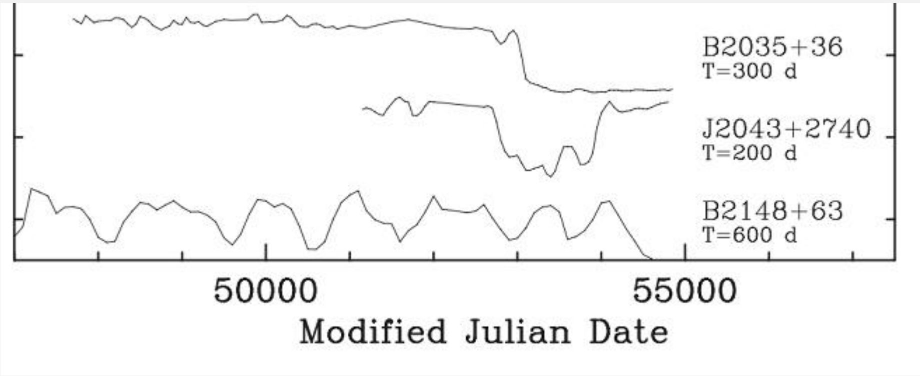


Keith et al. 2013

3. Correlation between glitch and emission

- p=0.6187 s
- dp/dt=4.5e−15 s/s
- Age= 2.18 Myr, Bs=1.69e12 G
- DM= 93.56 pc cm^(−3)
- s1400 = 0.8 mJy
- change in the pulse profile
- associated with an increase in the spin-down rate





Lyne et al. 2010

3. Correlation between glitch and emission

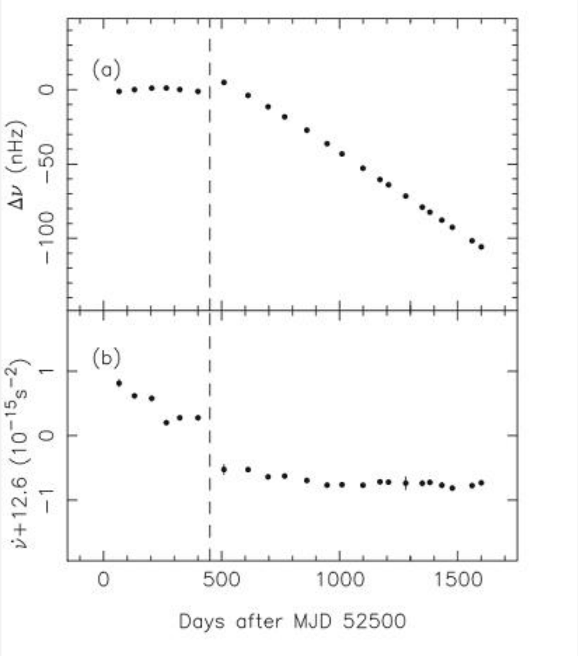
- a small glitch at ~ MJD 52950:

$$\Delta\nu/\nu \sim 7.7(8) \times 10^{-9}$$

$$\Delta\dot{\nu}/\dot{\nu} \sim 0.067(8)$$

- No exponential recovery,
- Unusual post-glitch behavior:
  - ν decreased over 1000d , overshoot the initial frequency.
  - $|\dot{\nu}|$ increase persistently over ~ 800d .
  -

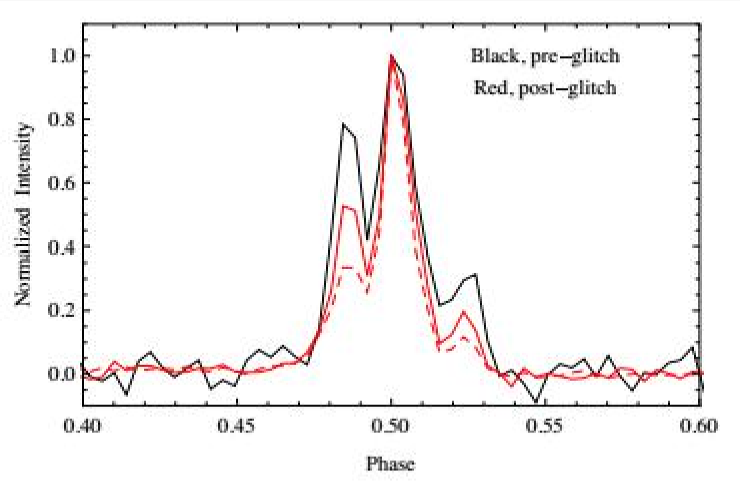
Nanshan, Aug. 2002 -- Aug. 2012

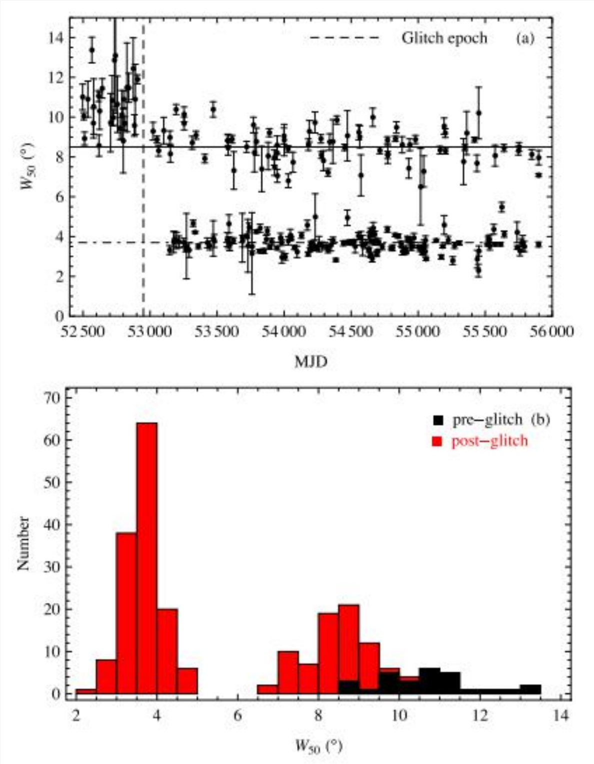


Kou et al. 2018

3. Correlation between glitch and emission

- Full Width at Half-Maximum (FWHM, W50)
- Mode changing after glitch:
  - Pulses became narrower:
  - The leading and trailing components are weaker.
  - Switch between two states.
  - Bi-modal distribution of post-glitch w50





Kou et al. 2018

- permanent increase in spin-down rate: 9.6%
- A change in the external braking torque,
- a gradually increasing braking torque,
- for example, variable out-flowing particle density in the magnetosphere (Kou & Tong 2015)
- 22% increase in the particle density is needed in the vacuum gap case.

$$\frac{\dot{\Omega}'}{\dot{\Omega}} = \frac{\eta(\kappa')}{\eta(\kappa)} \quad \Omega = 2\pi\nu$$

$$(\rho_{\rm e} = \kappa\rho_{\rm GJ})$$

$$\eta = \sin^2\alpha +$$
$$4.96\times 10^2\kappa B_{12}^{-8/7}\Omega^{-15/7}\cos^2\alpha$$

3. Correlation between glitch and emission

- In the MHD simulation: link to inclination angle (Spitkovsky 2006)

$$\Delta\dot{\nu}/\dot{\nu} = \sin 2\alpha\, \Delta\alpha/(1 + \sin^2 \alpha)$$

- The glitch may change the magnetic field and
- hence the inclination angle (Ng et al. 2016)
- the expected change in inclination angle is $\Delta\alpha$~8d if we assume α is 45d

3. Correlation between glitch and emission

- The detail of mode change need single pulse observation.
- Four radio pulsars show pulse profile change which are directly accompanied with glitch activity.
- PSR J1119−6127, J0742−2822, Vela, B2035+36
- glitch size: 7xe−9 to 5xe−6
- Age: 1.6 kyr to 2 Myr
- The “glitch-induced” magnetosphere behavior occurred in both relatively young pulsars and old pulsars, and has no obvious relation to the glitch size.

Livingstone 2010

Summary

- Glitch is a probe of the interior structure of neutron star.
- Glitches have diverse features.
- Glitch is not fully understood.
- expect to
  - more and more evidences which show the correlation between pulsar glitch and pulsar emission.
  - study the interaction between pulsar interior and magnetosphere.

Thank you!