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The Spin-down State Change and Mode Change Associated with Glitch Activity of PSR B2035+36

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Introduction

- Pulsar: the most stable 'clocks' in the universe

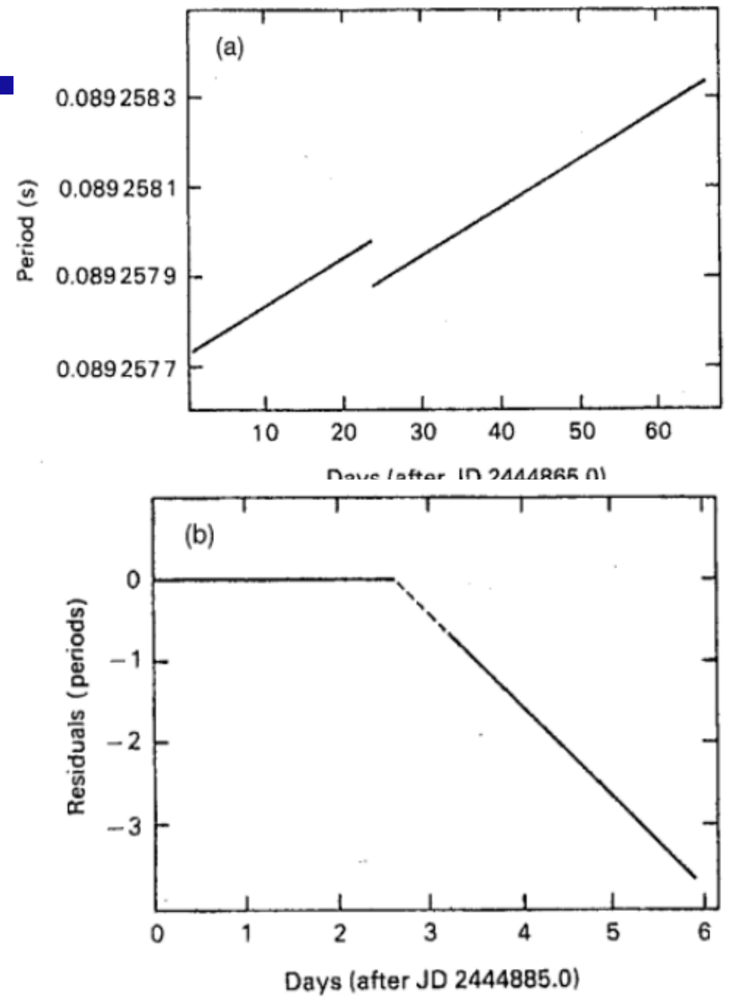
- Observational irregularities in pulsar timing :

➢Timing noise:

A fairly continuous erratic behavior

➢Glitch:

A sudden increase in spin frequency, often followed by a recovery process



The glitch in the Vela pulsar, October 1981 (Lyne & Smith 2012)

The pulsar glitch

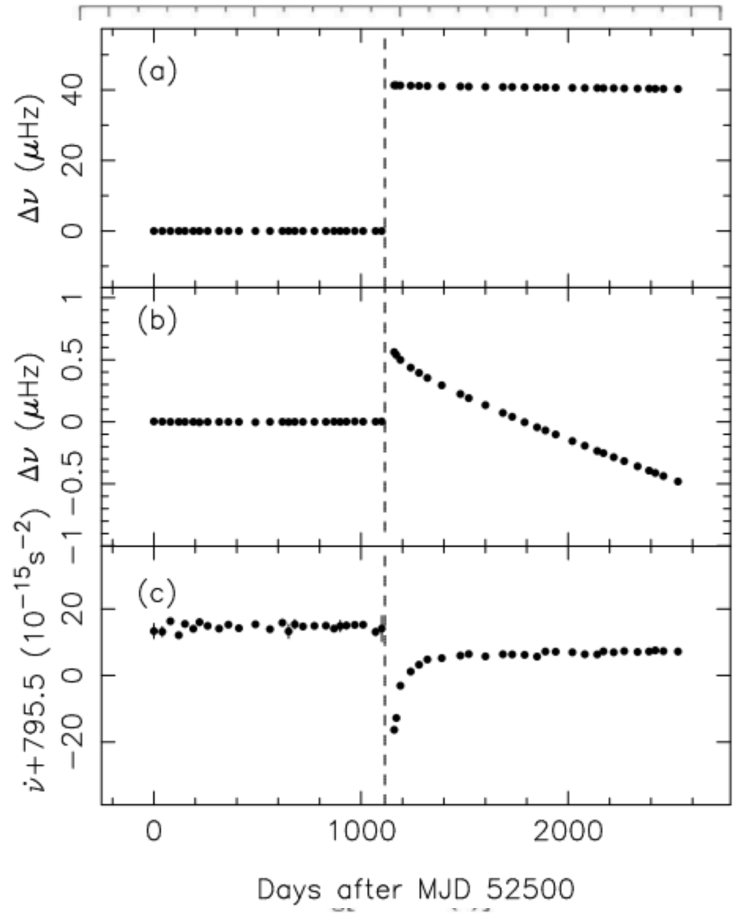
- Glitch size:

$$\Delta\nu/\nu \sim 10^{-12} - 10^{-5}(10^{-9} - 10^{-6})$$
$$\Delta\dot{\nu}/\dot{\nu} \sim 10^{-3} - 10^{-2}$$

- 520 known glitches in 180 different pulsars

- The recovery: $Q = \Delta v_d/\Delta v$
  - The Vela pulsar: $Q < 0.2$
  - The Crab pulsar: $Q > 0.8$

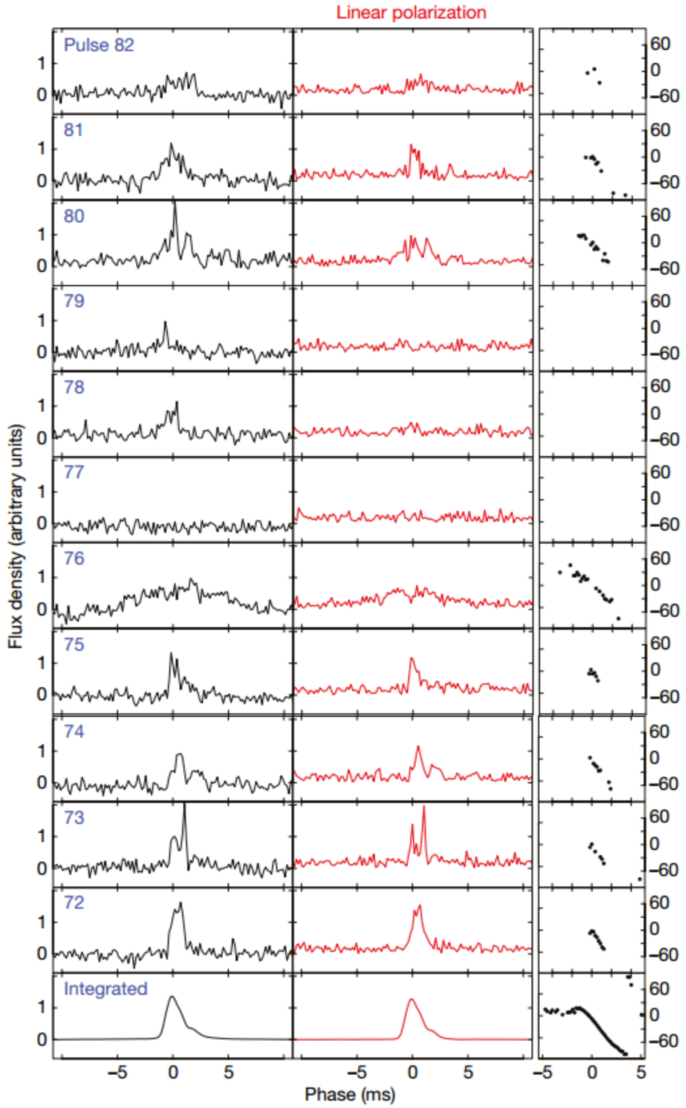
- Internal origion:
  - Star-quake (Baym et al. 1969; Zhou et al. 2014)
  - Unpinning of interior superfluid vortices (Anderson & Itoh 1975)



Variations of v and $\dot{v}$ of PSR B2334+61 (Yuena et al. 2010)

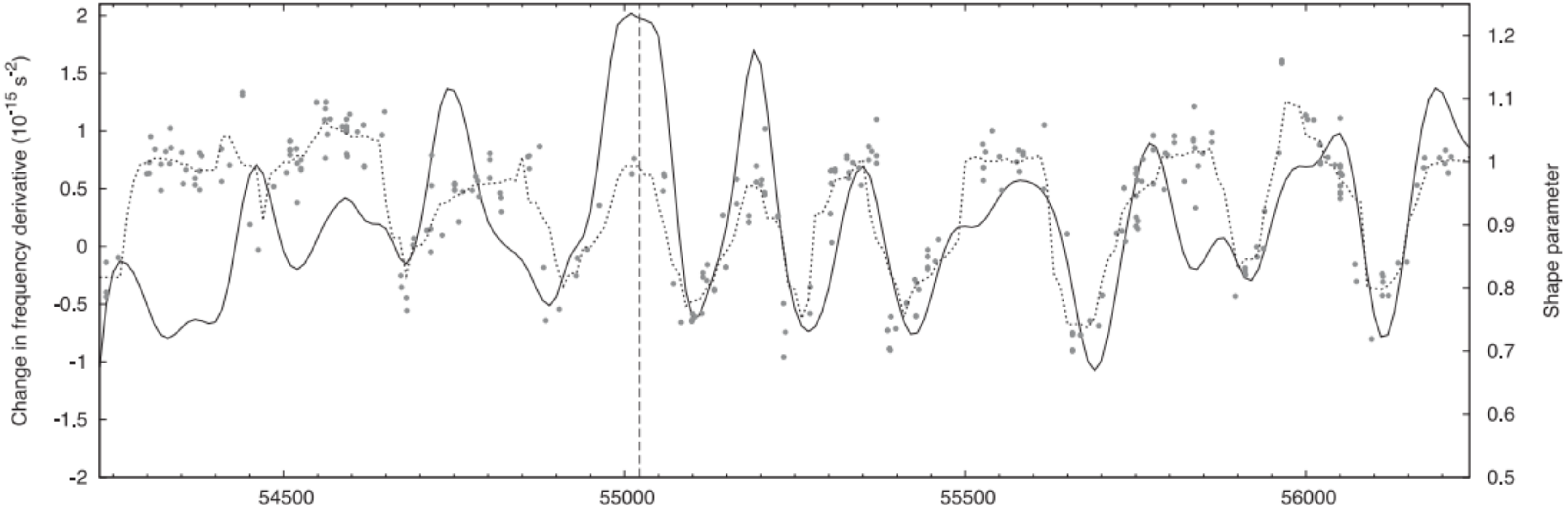
No radiative and pulse profile changes observed associated with most glitch events, except:

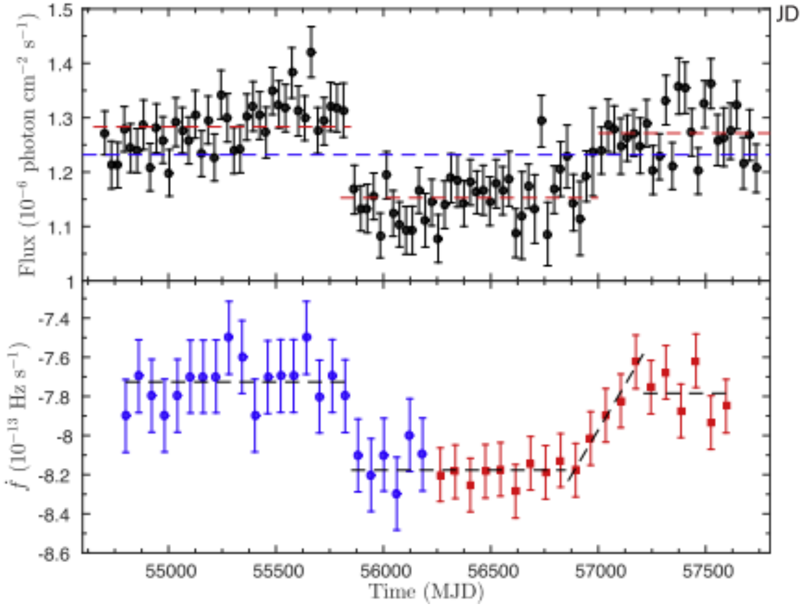
- ➢The Vela pulsar
  4.4s before glitch at 12/12/2016
- ➢PSR J1119-6127
  single peak → double peak (3 mins) (Weltevrede et al.2011)
- ➢PSR J0742-2822 ➡
  strong correlation between observed pulse shape and spin-down rate after glitch (Keith et al. 2013)
- ➢PSR J2021+4026
  4% increase in spin-down rate, 18% decrease in gamma-ray flux (Zhao et al. 2017)
- ➢PSR B2035+36,……



Single pulses before glitch of the vela pulsar (Palfreyman et al. 2018)

The $\dot{\nu}$ and pulse parameter variations of PSR B0742-2822
Keith et al. 2013





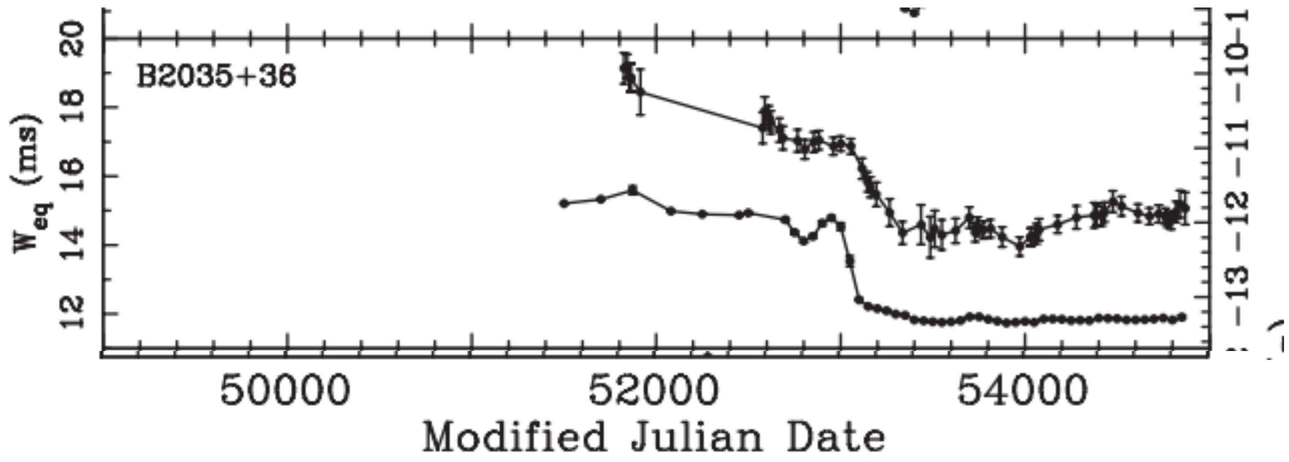
Evolution of the flux (top) and spin-down rate (bottom) of PSR J2021+4026.
Zhao, Ng, Lin et al. 2017

PSR B2035+36

- Radio pulsar (Dewey et al. 1985)
- $P = 0.6178\ s\ \dot{P} = 4.5024 * 10^{-15} \frac{s}{s}$ (Hobbs et al. 2004)

→ $B_s \sim 1.69 \times 10^{12}\,\mathrm{G} \quad \tau_c \sim 2.18\,\mathrm{Myr}$

- 13.28% increase in the spin-down rate & 28% change in pulse width (W_{eq}) (Lyne et al .2010)



Observation Method

- Nanshan 25-m radio telescope

➢ PSR B2035+36 was observed three times pre month.

➢ Data span: 08/2002~08.2010

➢ AFB: 128*2.5MHz sub-channels

off-line data → total intensity profiles → ToAs → ToAs at SSB

- The standard timing model at SSB:

$$\phi(t) = \phi_0 + \nu(t - t_0) + \frac{1}{2}\dot{\nu}(t - t_0)^2 + \frac{1}{6}\ddot{\nu}(t - t_0)^3 \ ,$$

- Pulsar glitch is described by a combination of step changes of ν and $\dot{\nu}$:

$$\nu(t) = \nu_0(t) + \Delta\nu_p + \Delta\dot{\nu}_p t + \Delta\nu_d e^{-t/\tau_d} \ ,$$

$$\dot{\nu}(t) = \dot{\nu}_0(t) + \Delta\dot{\nu}_p + \Delta\dot{\nu}_d e^{-t/\tau_d} \ ,$$

Results

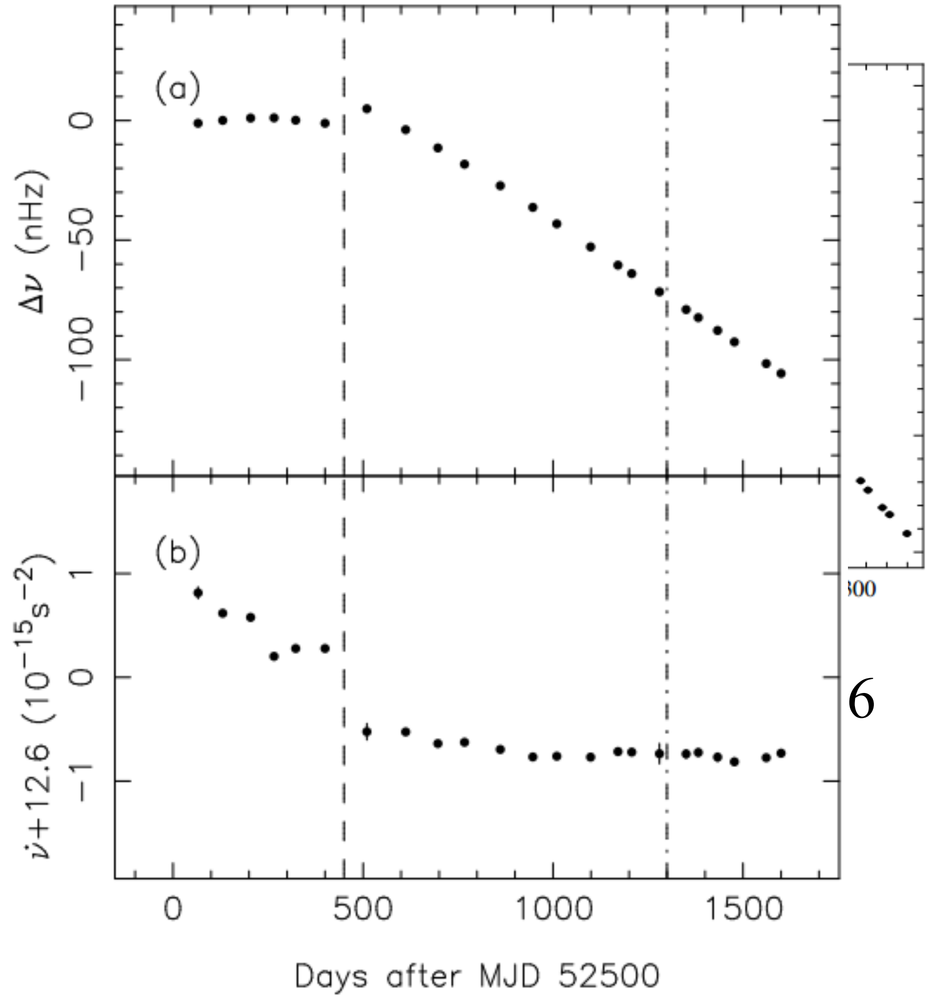
- Timing
- Mode changing

The glitch

- A small glitch at MJD 52950
- A relatively large increase in spin-down rate
- No recovery process observed (< 80days)

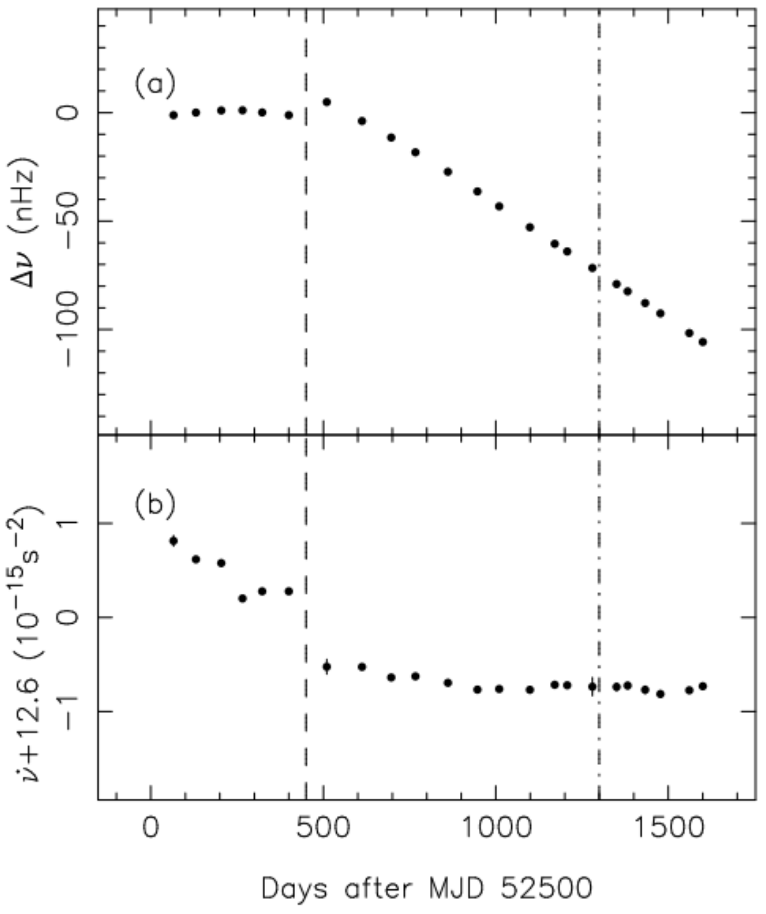
Table 2. Glitch parameters of PSR B2035+36, produced by TEMPO2.

Parameter	Value
Data span (MJD)	52705–53360
Glitch epoch (MJD)	52950(40)
$\Delta\nu_p$ (s^{-1})	$12.4(5) \times 10^{-9}$
$\Delta\nu/\nu$	$7.7(8) \times 10^{-9}$
$\Delta\dot{\nu}_p$ (s^{-2})	$-0.84(3) \times 10^{-15}$
$\Delta\dot{\nu}/\dot{\nu}$	$67(8) \times 10^{-3}$



Variations of ν and $\dot{\nu}$ of PSR B2035+36

The spin-down state change



Variations of ν and $\dot{\nu}$ of PSR B2035+36

- The spin-down rate increased 800 days after the glitch, opposite to the typical post glitch behavior!

→ ν decreases quickly

→9.6% increase in $|\dot{\nu}|$

- Compared with the variation trend pre-glitch, $\dot{\nu}$ post-glitch evolved to a more stable state

The pulsar turned to a higher and more stable spin-down state after the glitch !

Table 1. Timing parameters of PSR B2035+36.

Parameter	Pre-glitch	Post-glitch	
Pulsar name		B2035+36(J2037+3621)	
RA (h:m:s)		20: 37: 27.44(3)	
Decl. (° : ′ : ″)		+36: 21: 24.1(3)	
Pulse frequency, ν (s^{-1})	1.616250 000 20(6)	1.616249 249 98(3)	1.616247 561 227(9)
First derivative of pulse frequency, $\dot{\nu}$ (s^{-2})	$-1.2037(5) \times 10^{-14}$	$-1.3258(1) \times 10^{-14}$	$-1.32670(1) \times 10^{-14}$
Second derivative of pulse frequency, $\ddot{\nu}$ (s^{-3})	$-2.3(2) \times 10^{-23}$	$-5.2(2) \times 10^{-24}$	$8.32(7) \times 10^{-25}$
Data span (MJD)	52496–52907	52985–53794	53816–55899
Zero epoch for the timing solution (MJD)	52701	53389	54858
Number of ToAs	37	58	216
RMS timing residual (μs)	912	1280	1234
Time-scale		TDB	
Solar system ephemeris model		DE 421	

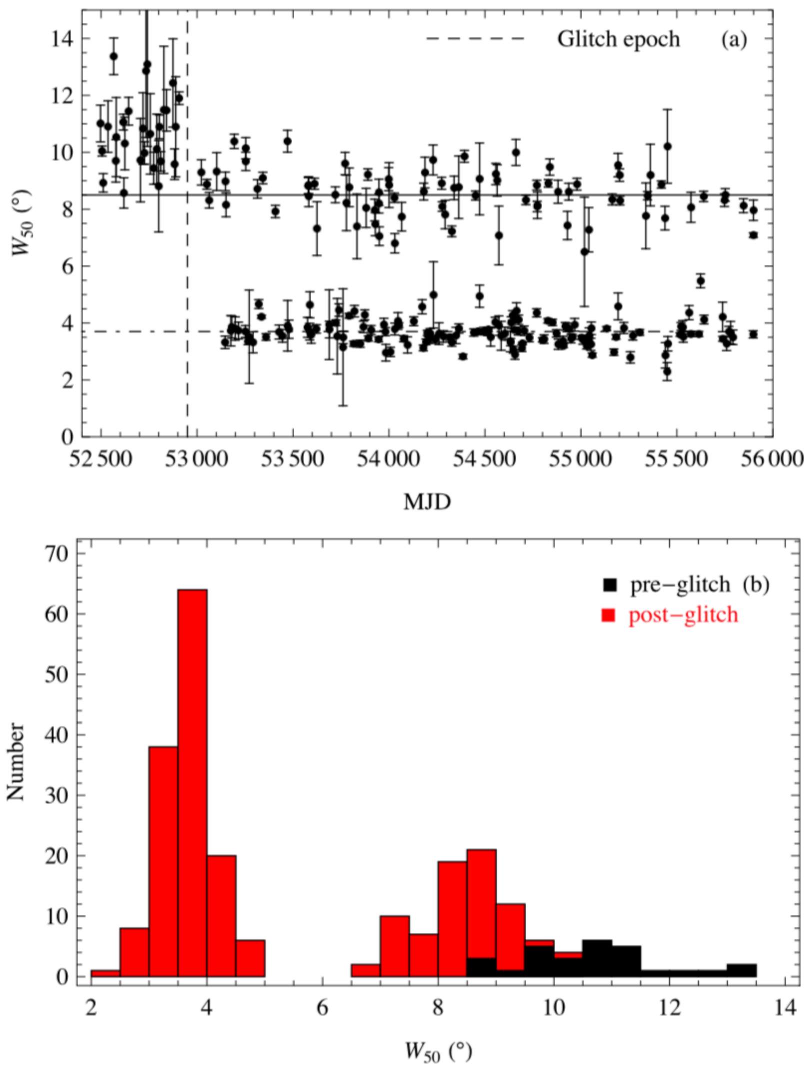
$\dot{\nu}$ became much stable after MJD 53800 (dot-dashed line)

Mode changing

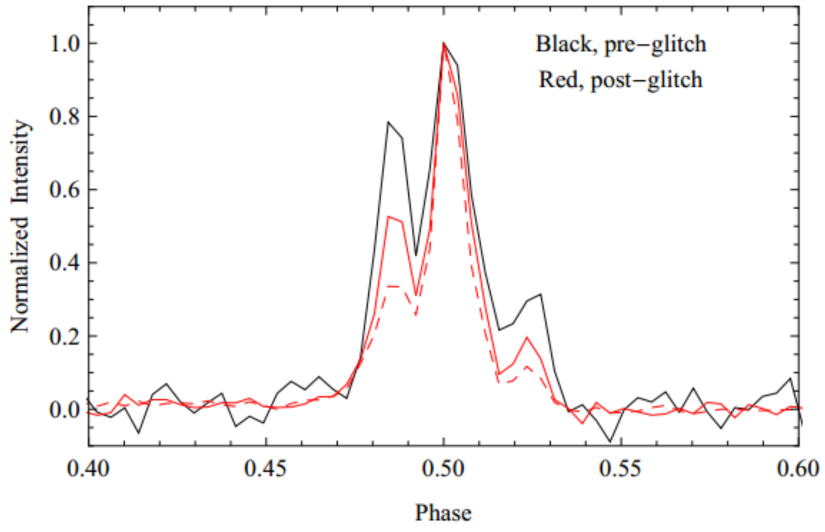
- Pulse width became narrower after the glitch
- Bimodal distribution of w_{50} after the glitch ,

The relatively narrow pulse is the dominant emission mode

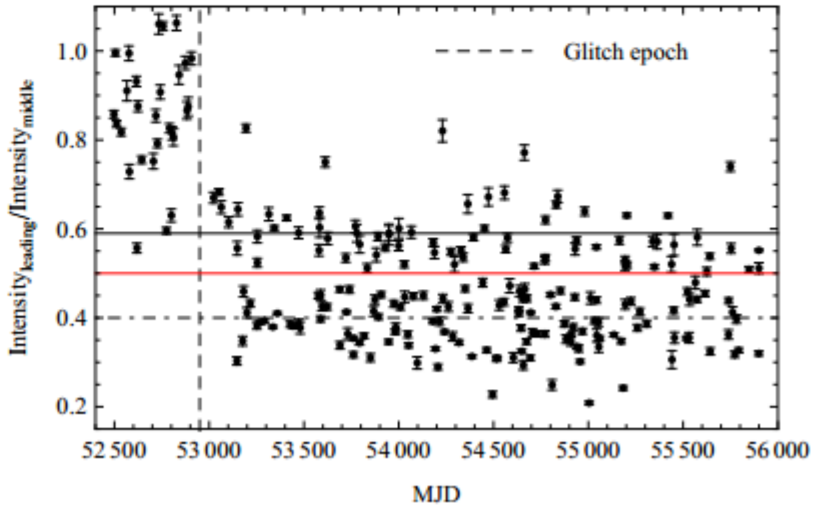
➢Emission mode changed accompanied with the glitch
➢The pulsar began to switch between two emission modes after the glitch



Distributions of W_{50} in units of degrees for PSR B2035+36.



The integrated normalized pulse profiles of different pulse profile modes of PSR B2035+36.



Distributions of intensity ratio between the leading components and middle components for PSR B2035+36.

- Three components, the middle component is dominant
- The leading and trailing components post-glitch became weaker than those pre-glitch
- The pulsar switched between two emission modes because of intensity variation in the leading and trailing components

Table 3. Pulse profile parameters. 'Wide' and 'narrow' mean pulse profiles with larger and smaller values of W_{50}.

Parameter	Pre−glitch	Post−glitch			
Datas pan (MJD)	52496–52907	52985–53794		53816–55899	
		narrow	wide	narrow	wide
Mean FWHM W_{50} (°)	10.7(1.4)	3.8(5)	8.9(4)	3.6(2)	8.4(8)
Number of pulse profiles	28	29	22	108	59
Intensity ratio of leading and middle components	0.86(6)	0.40(3)	0.62(5)	0.39(3)	0.57(4)

n_{nar}/n_{wid} : 1.32 (MJD 52985–53794) to ~1.83 (MJD 53816–55899)

→The dominant trend of the narrow pulse profile became more and more obvious as the pulsar evolved to a more stable rotation state.

Discussions

- Glitch →**internal** origin; spin-down & emission →**external** braking torque and magnetospherical radiation

➢ Wind braking modal (Xu & Qiao 2001; Kou & Tong 2015)

The glitch→ the density in the magnetosphere { the spin-down state change / the emission mode change }

$$\frac{\dot{\Omega}'}{\dot{\Omega}} = \frac{\eta(\kappa')}{\eta(\kappa)} \qquad \Delta\dot{\nu}/\dot{\nu} \sim 9.6\% \quad \frac{\Delta k}{k} \sim 22\%$$

- Force-free magnetosphere (Spitkovsky 2006; Zhao et al. 2017)

The glitch→ the inclination angle { the spin-down state change / the emission mode change }

$$\Delta\dot{\nu}/\dot{\nu} \sim 9.6\%, \Delta\alpha \sim 8°$$

Conclusions

- PSR B2035+36 underwent a small glitch with $\Delta\nu \sim 12.4(5) nHz$ around MJD 52950
- Spin-down state change
  - $|\dot{\nu}|$ increased persistently over 800 d after the glitch
  - opposite to the typical evolution post-glitch
  - 9.6 % larger than that pre-glitch
- Mode change
  - the pulse profile became narrower
  - the pulsar began to switch between two emission modes
  - the relatively narrow pulse profile gradually became dominant

→ **There should be a connection between magnetospherical behavior and glitch activity**

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Thanks!