State switching of gamma-ray pulsar J2021+4026

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Ng et al. 2016, ApJ
Zhao et al. 2017, ApJ
Wang et al. 2018, ApJ
Takata et al. 2019, submitted

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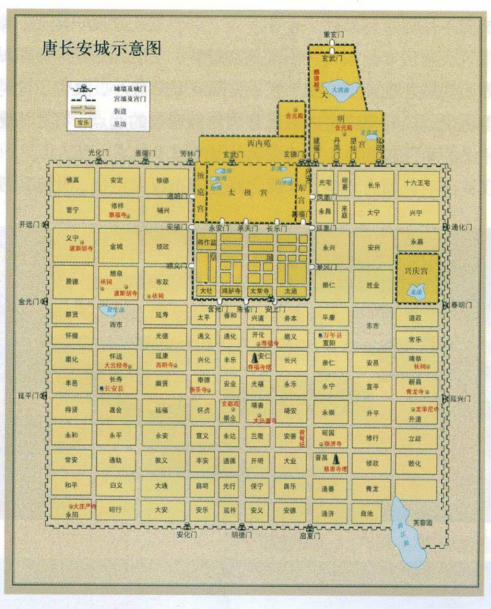

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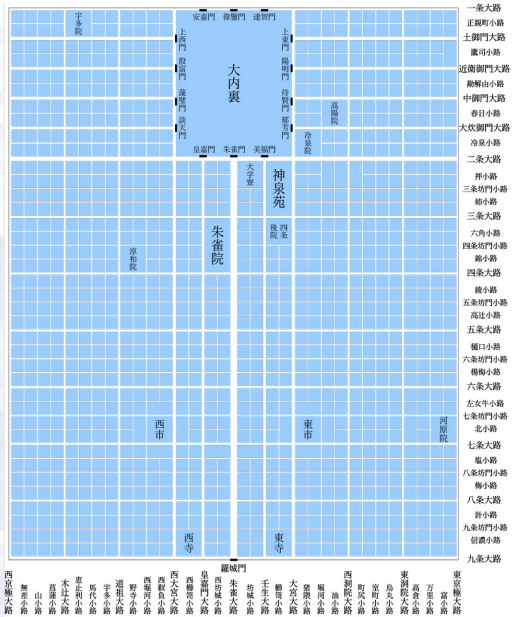

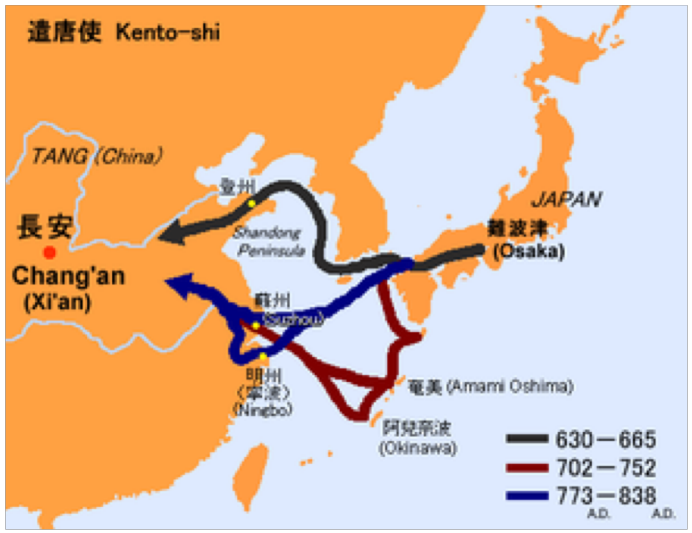

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  - Twisted magnetic field
  - Precession

1. Introduction

- State switching

-- **Transient (permanent-like) between different spin down rate states**.

-- It is sometimes associated with the pulsar's glitch.

-- Change of the radio pulse profile.

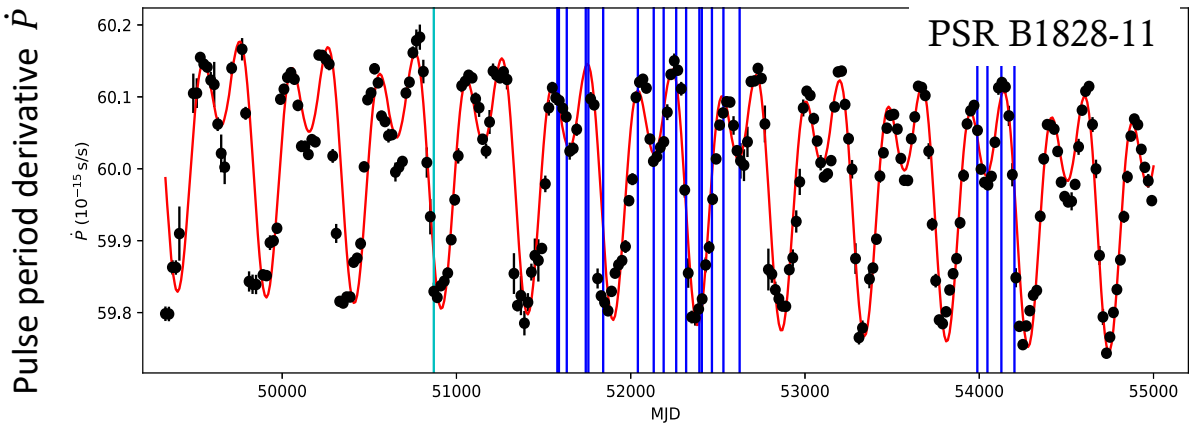
-- ~20 radio pulsars (maybe more….)

- Interpretation

-- Change of global magnetosphere structure.

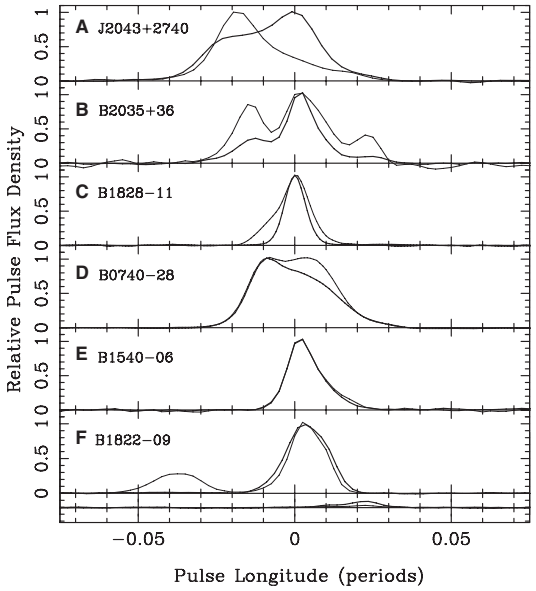
-- Free precession (Jones 2012) .

-- …..



(Stair et al. 2019)

Radio pulses
in different spin down states

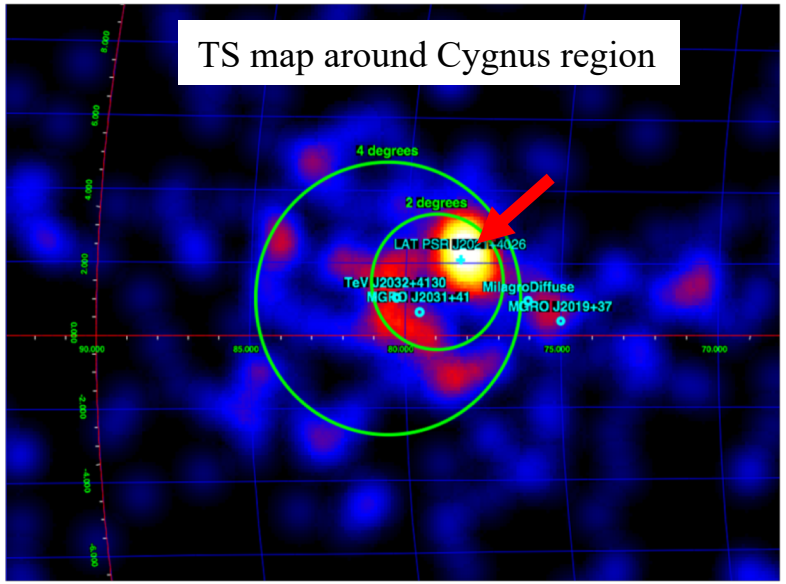


(Lyne et al. 2010)

Introduction

Is it possible to study the pulsar's state switching with high-energy emission?

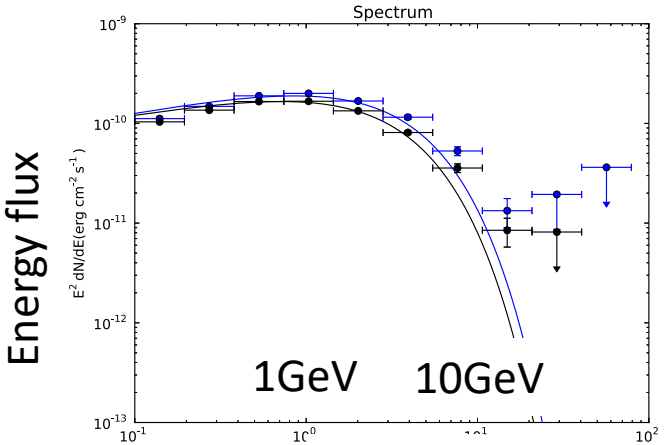
- PSR J2021+4026 (isolate)
- Cygnus region
- Radio quiet pulsar
- Bright gamma-ray source



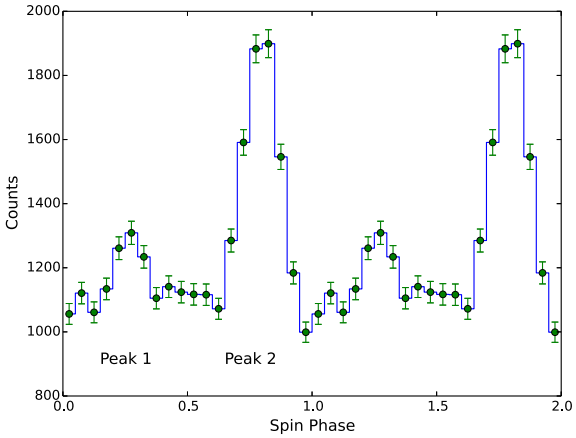
- Spin down parameters

- P ~ 265 ms
- $B \sim 4\times10^{12}$G
- $L_{sd}\sim3\times10^{36} erg/s$
- τ_{sd} ~ 77 kyr

Gamma-ray spectrum



>0.1GeV pulse profile



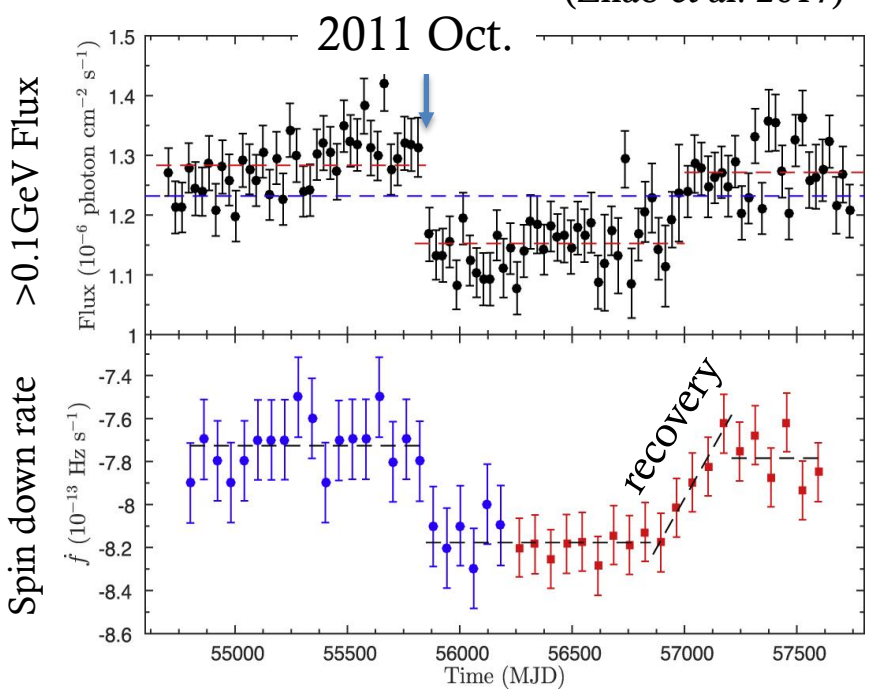
2. State switching of PSR J2021+4026

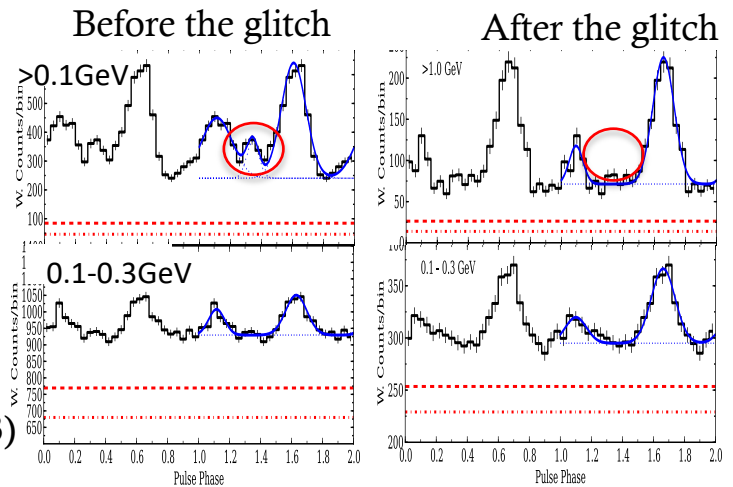
- 1st variable gamma-ray pulsar
- Glitch at 2011 October (Allafort et al. 2013)
- Spin down rate increased by ~6%.
- Gamma-ray flux decreased by ~15%.
- Gamma-ray pulse shape changed.

- State switching
- No usual glitch recovery was observed.
- Pulsar had stayed at **high-spin down/low gamma-ray flux state** at least ~3 years after the glitch

  (Ng et al 2016, Zhao et al. 2017)
- Recovery was observed around 2014 Dec. with a time scale of months.

(Zhao et al. 2017)





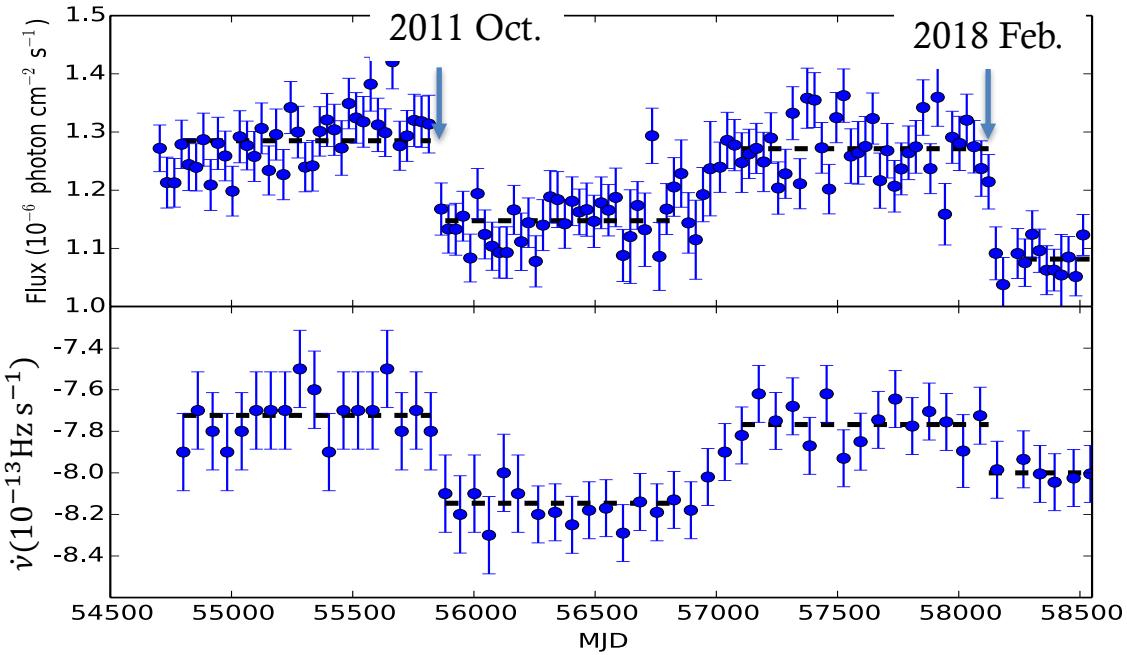
(Allafort et al. 2013)

2. State switching of PSR J2021+4026

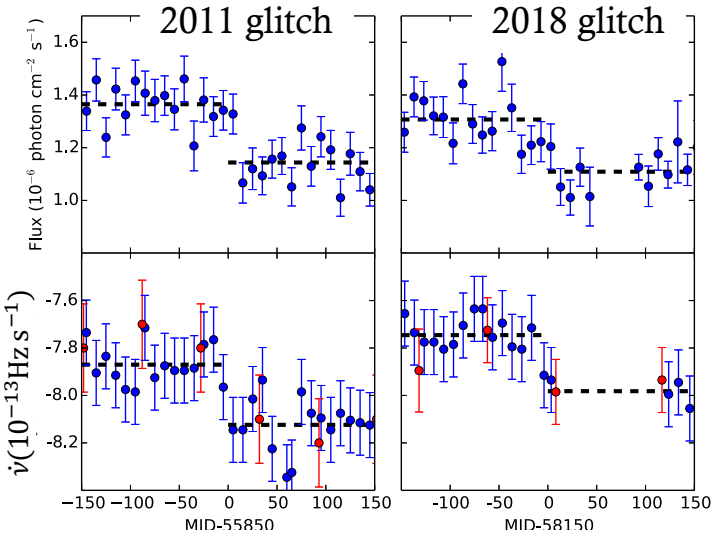
- New state change:

- New glitch was observed at 2018 Feb (Takata et al. 2019).
- The pulsar has entered new **high-spin down/low gamma-ray flux state**
- Current spin down rate and emission properties are consistent with the previous HSD/LGF state
- Switching was probably occurred with a time scale less than 10days.

~10 years evolution of >0.1GeV flux and spin down rate



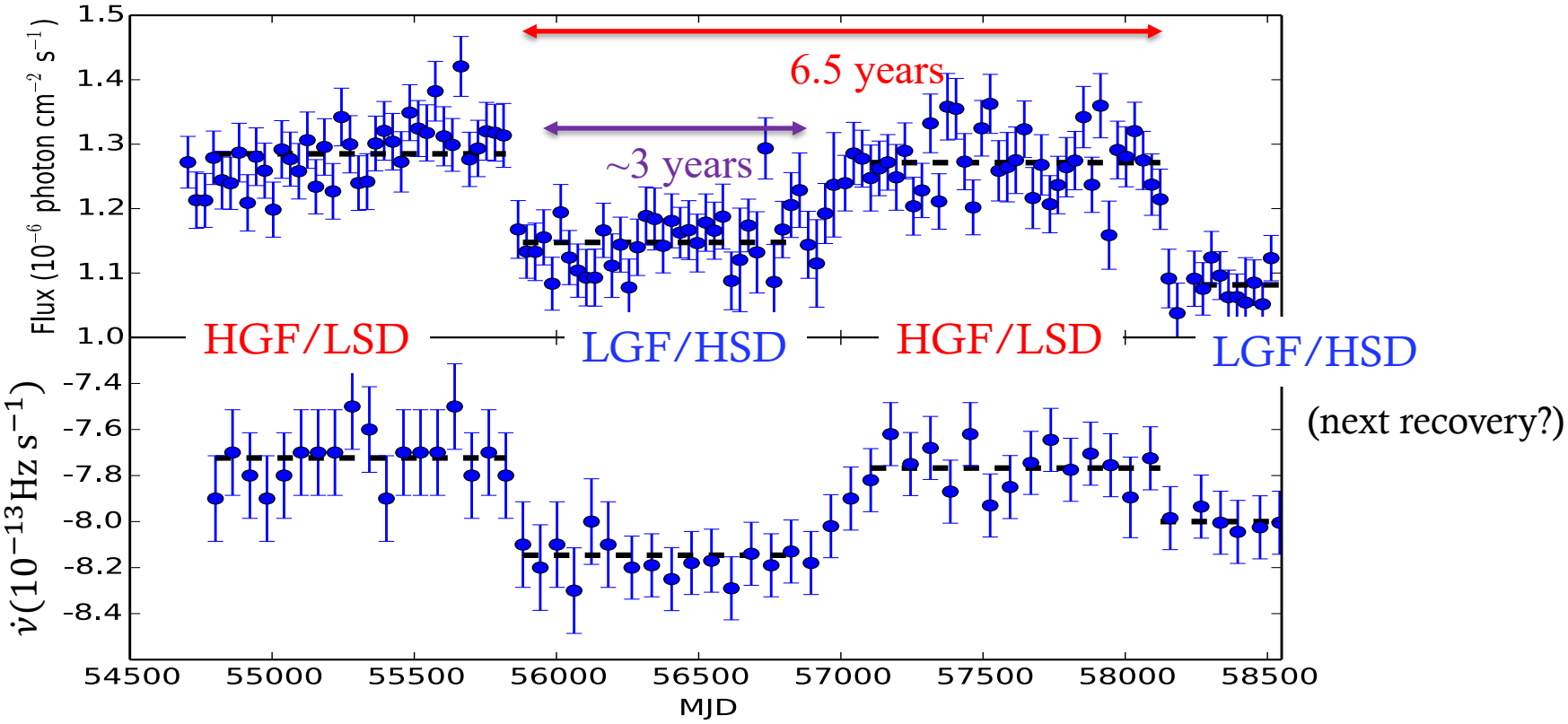
Around the glitch (10 days time bin)



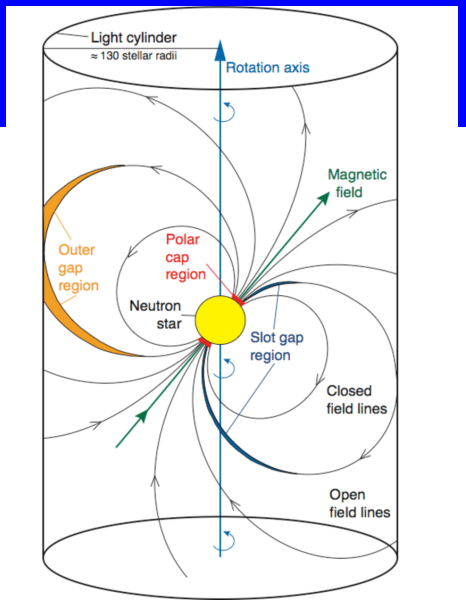
2. State switching of PSR J2021+4026

- Switching between different states:

- Glitch interval is probably τ_{glitch}~6-7 years
- The glitch triggers a state change from high gamma-ray flux/low spin down state (HGF/LSD) to low gamma-ray flux/high spin down state (LGF/HSD).
- Every LGF/HSD may continue about ~3 years.



3. Discussion



- Gamma-ray emission occurred near the light cylinder.

→Global change of the magnetosphere

- Rare event

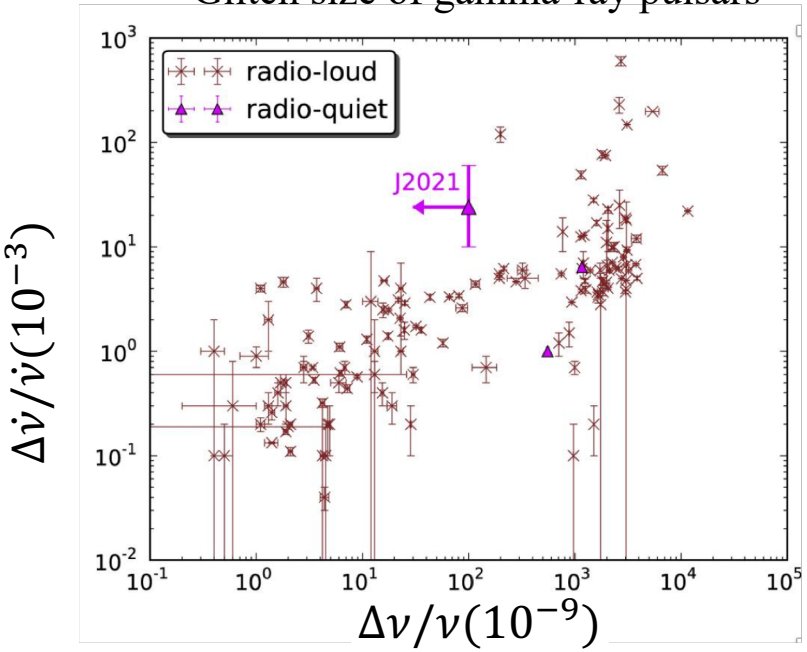
- >200 gamma-ray pulsars (~100MSPs).
- ~50 glitching gamma-ray pulsars.
- Only J2021+4206 is variable.

- Glitch affects polar cap structure?

- Fraction covering the surface by PC:

$$\delta = \left(R_{pc}/R_{NS}\right)^2 \sim 0.2\left(\frac{P}{0.1s}\right)\%$$

Glitch size of gamma-ray pulsars

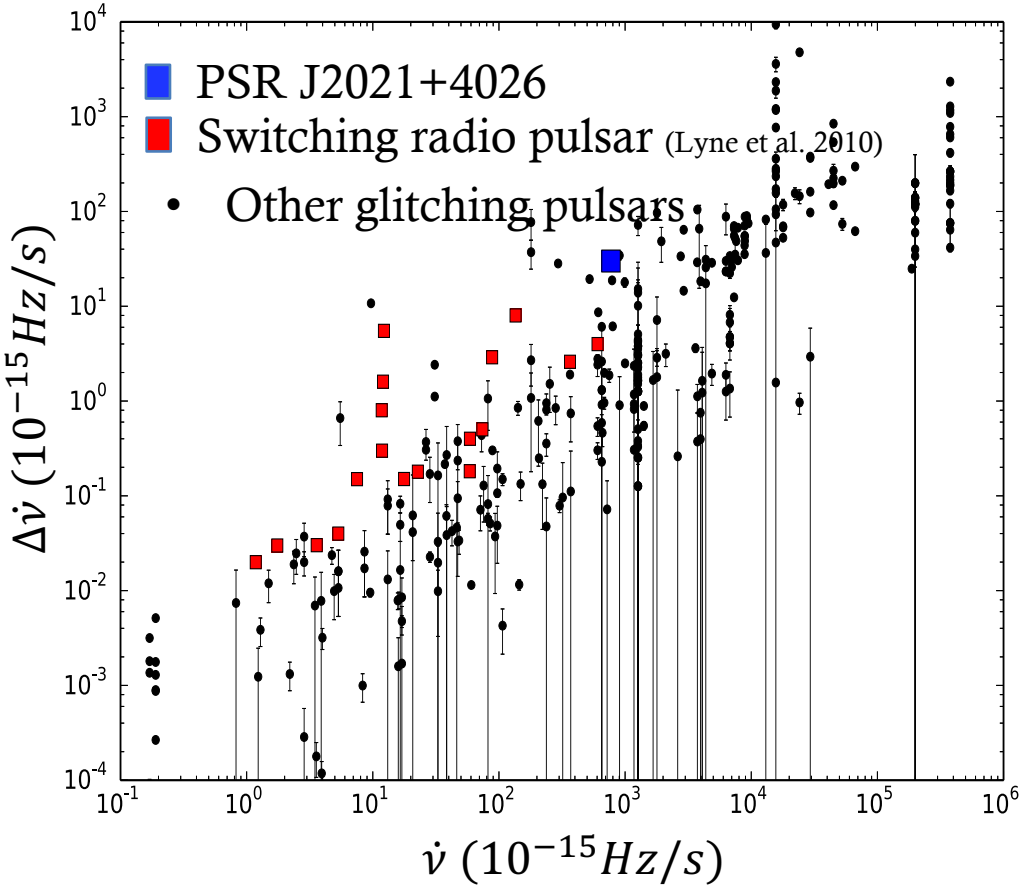


3. Discussion

- PSR J2021+4026 and switching radio pulsars pulsars have large jump in spin down rate.

- PSR J2021+4026 may be similar to switching radio pulsar?

Spin down rate vs. Jump of spin down rate



3. Discussion

- Several possibilities of the state change;

(a) Change of polar cap structure

(b) Twisted magnetic field

(c) Precession

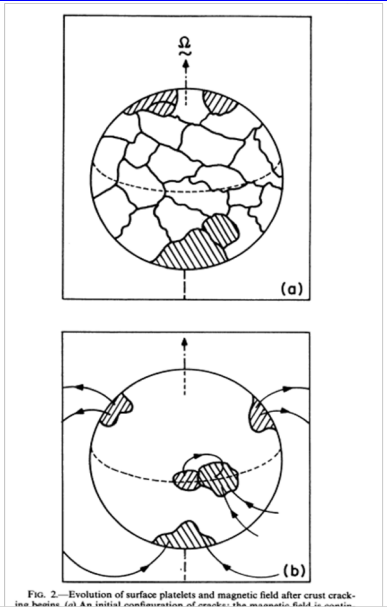
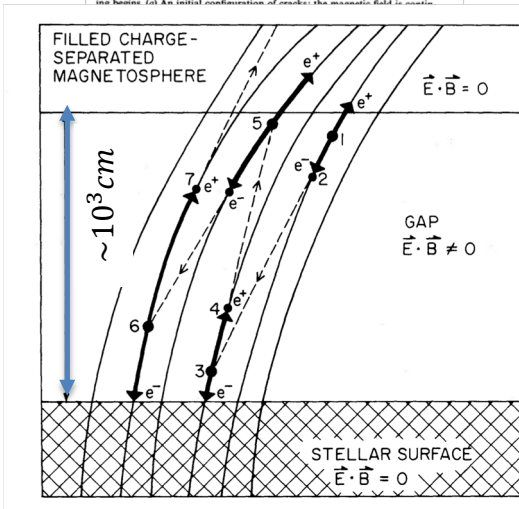


FIG. 2.—Evolution of surface platelets and magnetic field after crust cracking begins. (a) An initial configuration of cracks; the magnetic field is centric

(a) Change of polar cap structure

- Plate tectonic activity (Ruderman 1990; Cheng and Dail 1998)
- The crust cracking due to the magnetic shear stress causes a glitch → displacement of plate basing of the PC.



- Size of displacement

$$\frac{Displacement\ (\delta\ell)}{Interval\ (\tau_{glitch})} \sim \frac{R_{NS}}{\tau_{sd}} \longrightarrow \delta\ell \sim 10^2 cm \left(\frac{\tau_{glitch}}{7yrs}\right)\left(\frac{\tau_{sd}}{70kyrs}\right)^{-1}$$

- Size of the polar cap accelerator ~10^3cm
- Global current is related to the spin down rate

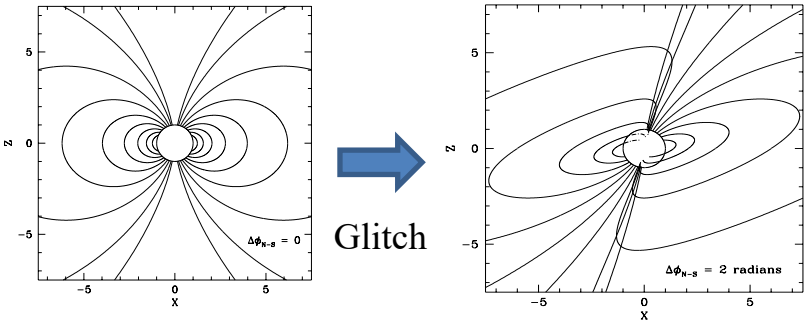
$\dot{\nu} \propto J_{cur}$

- Either increase or decrease
- $|\Delta\dot{\nu}| \ll \dot{\nu}$ (since always $J_{cur} \sim J_{GJ}$)

3. Discussion

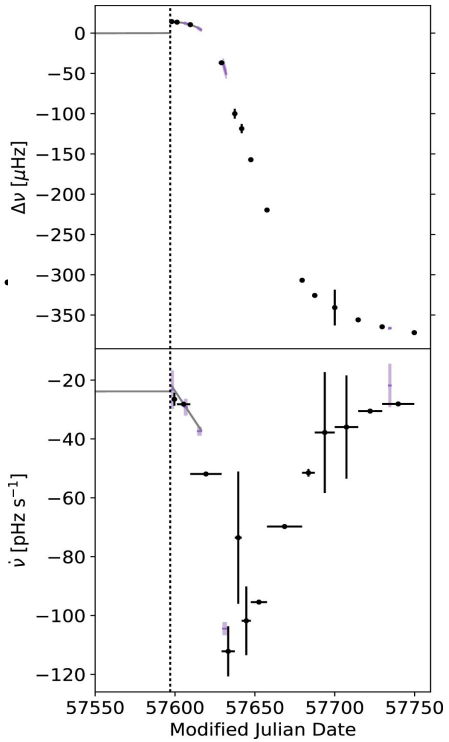
(b) Twisted magnetosphere

- Additional magnetic dipole momentum/open file lines affect to the spin down rate : $\dot{\nu} \propto \mu^2_{dipole}$
- Example : XTE J1810-197 (magnetar), PSR J1119-6127 (High-B radio PSR)
- $|\Delta\dot{\nu}| \sim \dot{\nu}$ is possible.



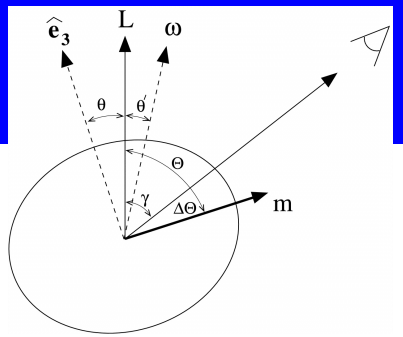
(Thompson et al. 2002)

- In this case, the increase of the X-ray emission owing to host spot of footprints of twisted magnetic field lines is expected.
- For PSR J2021+4026, however, no change of the X-ray emission were observed (Wang et al. 2017)



Spin down evolution after the 2016 glitch of PSR J1119-6127 (Archibald et al. 2019)

3. Discussion



(c) Precession

- Free precession can explain timing noise of some pulsars.

- Application to PSR J2021+4026
  - Ellipticity

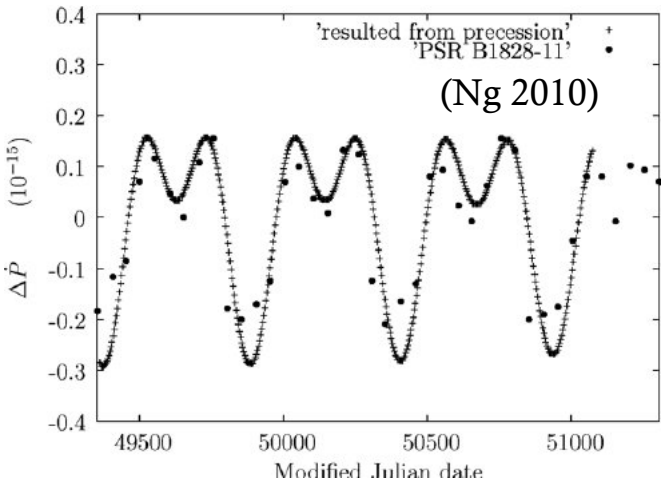
$$\epsilon \sim \frac{P_{spin}}{P_{pre}} \cdot \frac{I_{pre}}{I_{star}} \sim 10^{-9} \left(\frac{P_{spin}}{0.27s}\right)\left(\frac{P_{pre}}{7yrs}\right)\left(\frac{I_{pre}}{I_{star}}\right)$$

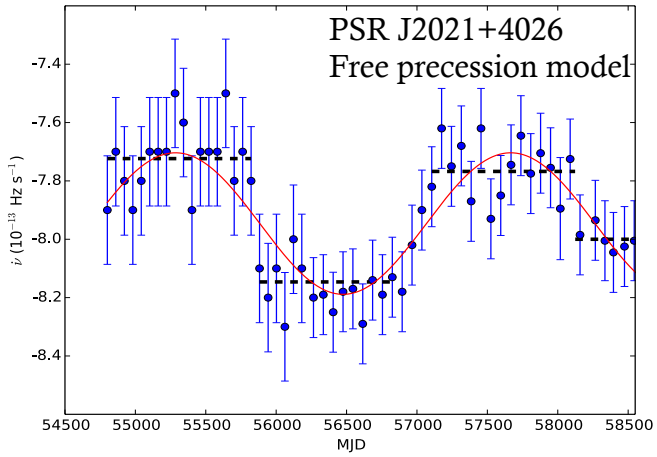
  - Wobble angle

$$\theta \sim \frac{|\Delta\dot{\nu}|}{\dot{\nu}} \sim 2^{\circ}$$

  - These are typical values inferred from other pulsars.

Note: The difficulty of this scenario is how explains the observed abrupt change in $\dot{\nu}$ with a time scale <10days of PSR J2021+4026.





Summary

- PSR J2021+4026 shows repeating glitch event with an interval ~7 years.

- The glitch triggers a state change from high gamma-ray flux/low spin down state to low gamma-ray flux/high spin down state.

- PSR J2021+4026 can be another example state switching pulsar.

- Glitch changes the structure of the global magnetosphere.

  - It would be caused by the change of structure of the polar cap accelerator owing to plate tectonic activity.

Summary

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Thank you !!