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PONTIFICIA UNIVERSIDAD CATÓLICA DE CHILE

# Glitches & Timing Noise


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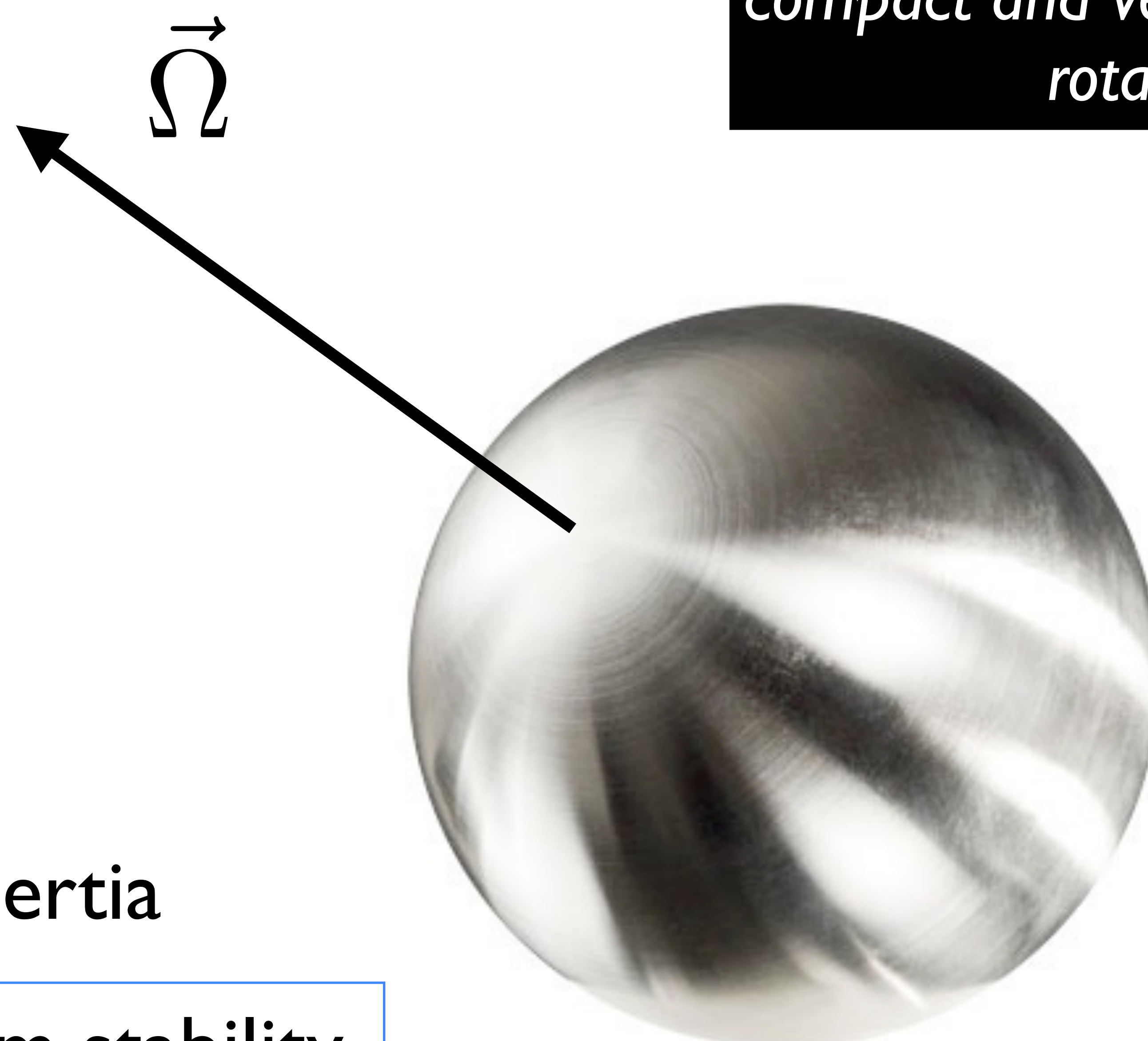
*NS as a solid, compact and very dense rotating body*

# *Ideal* **Pulsar rotation**

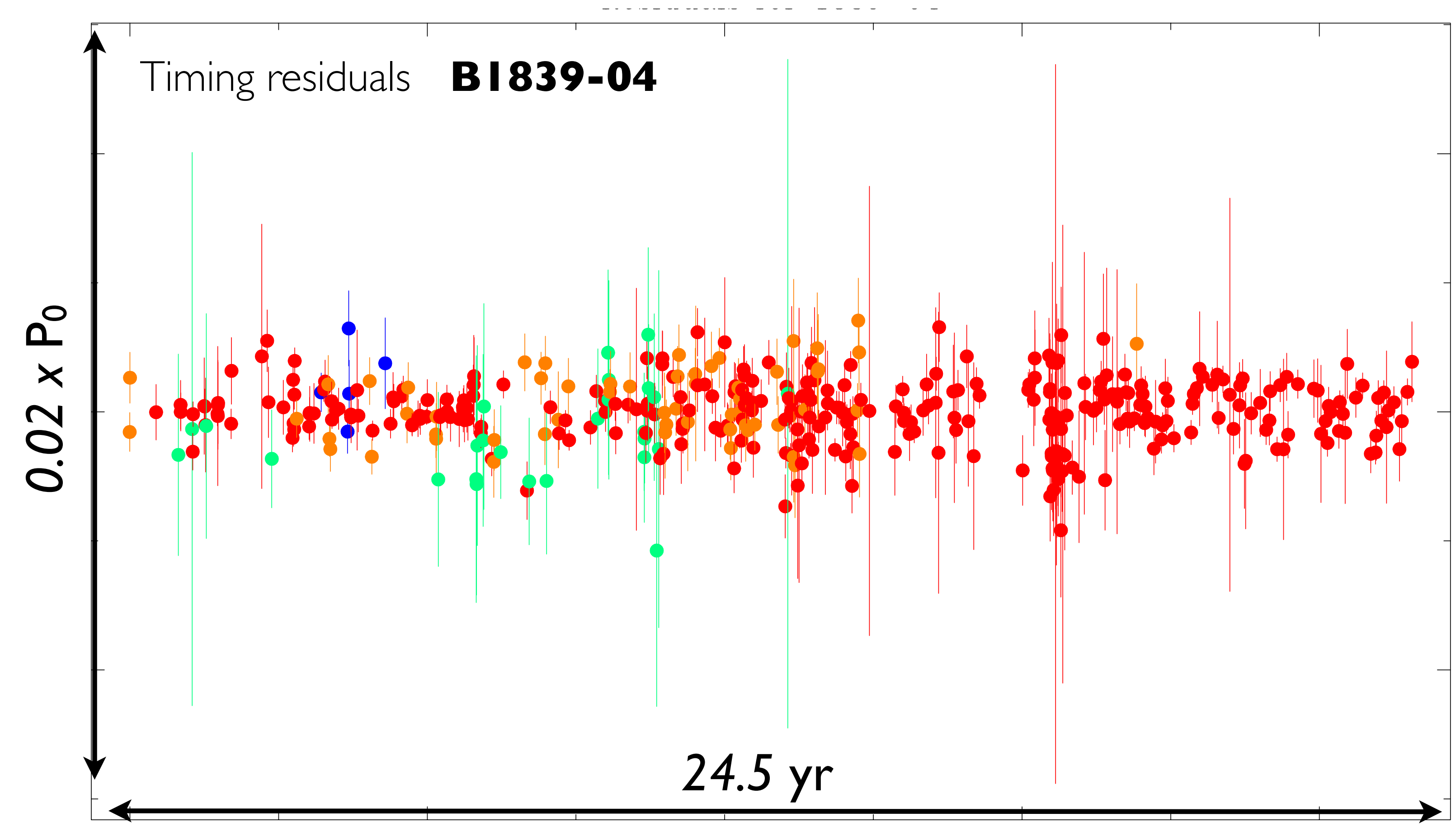



- Secular spindown
- Steady moment of inertia
- <u>Remarkable long-term stability</u>

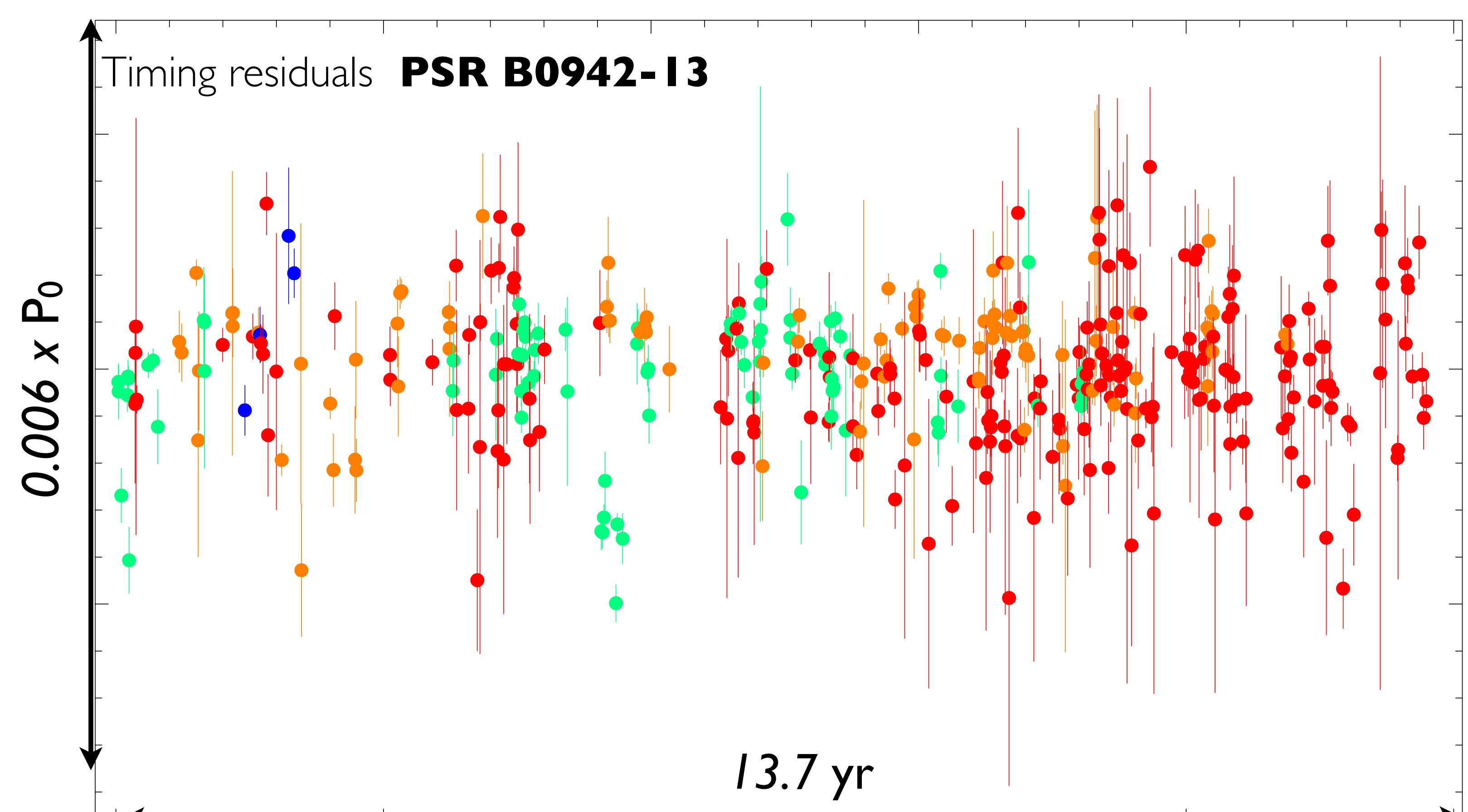
$$\phi(t) = \phi_0 + \nu_0(t - t_0) + \dot{\nu}_0 \frac{(t - t_0)^2}{2} + \cdots$$

# Ideal model works: Pulsar timing

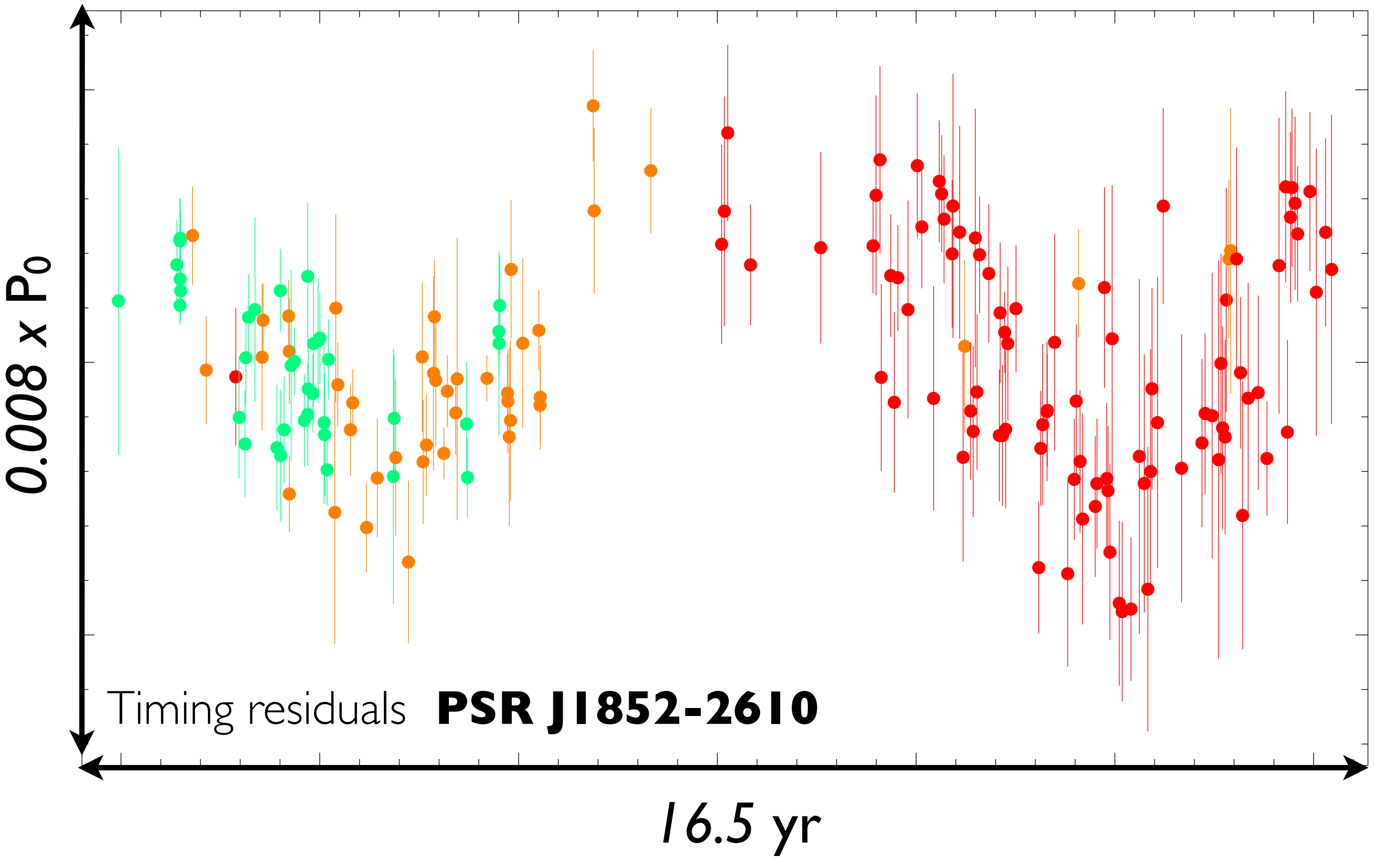
( motions and propagation effects corrected for )




However...

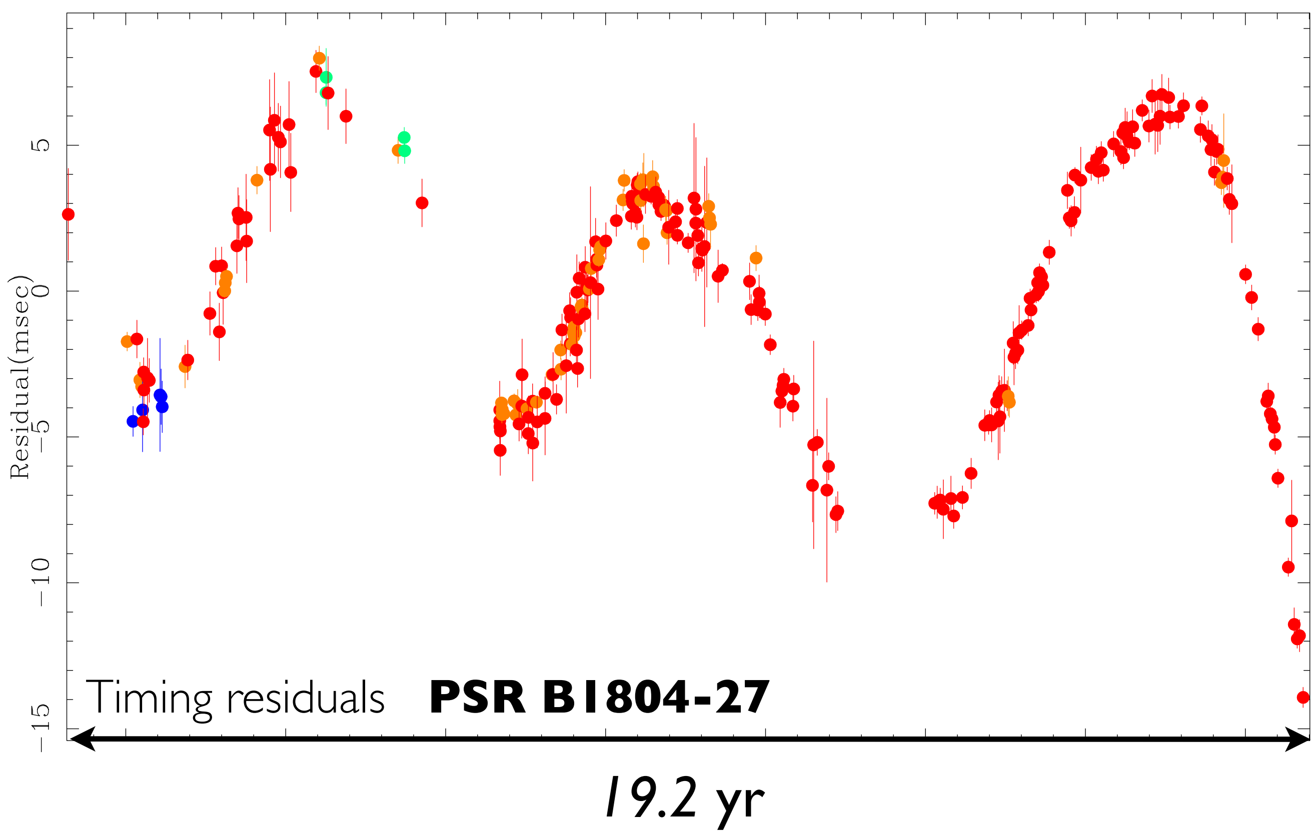


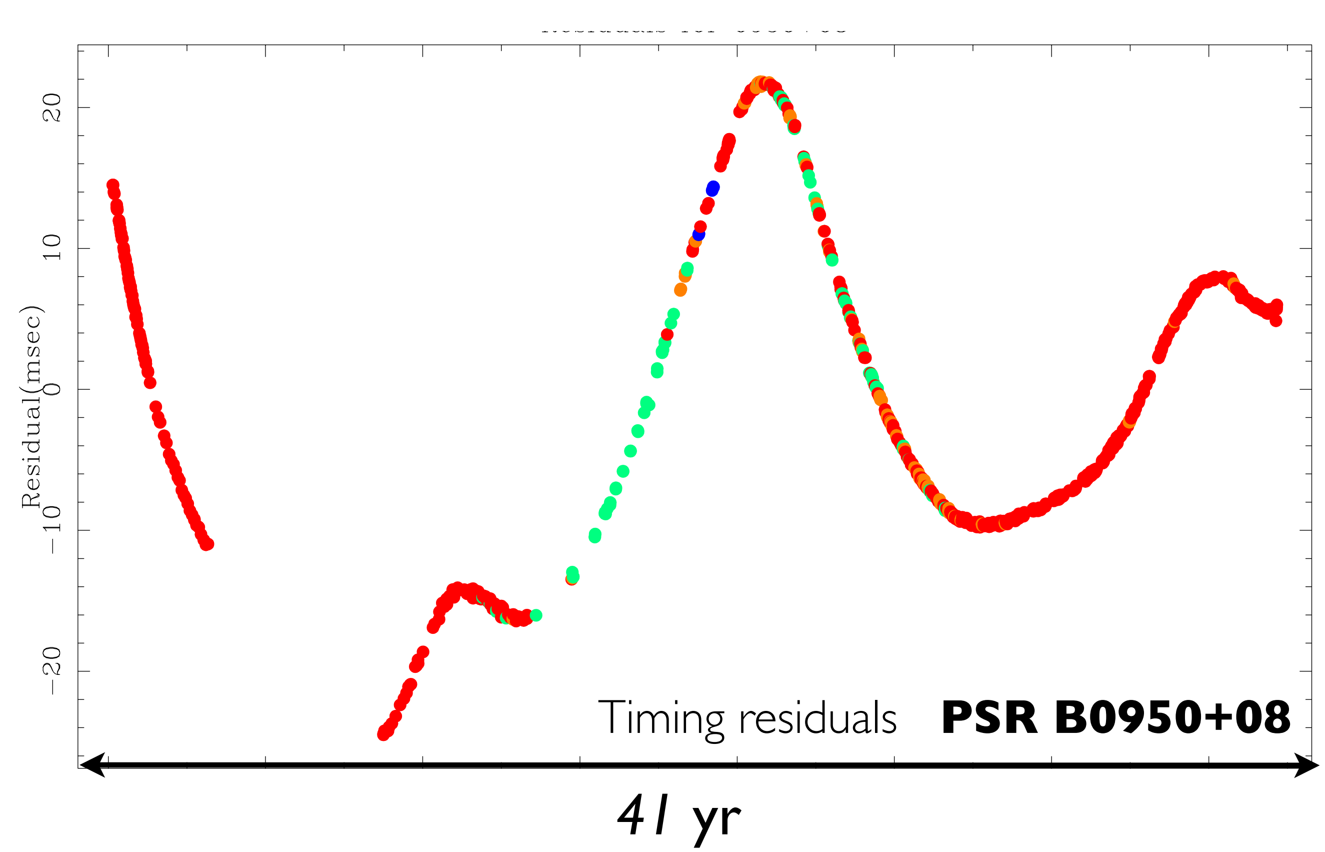

Jodrell Bank data




Many pulsars exhibit smooth trends deviating from the simple slow down

# Timing Noise



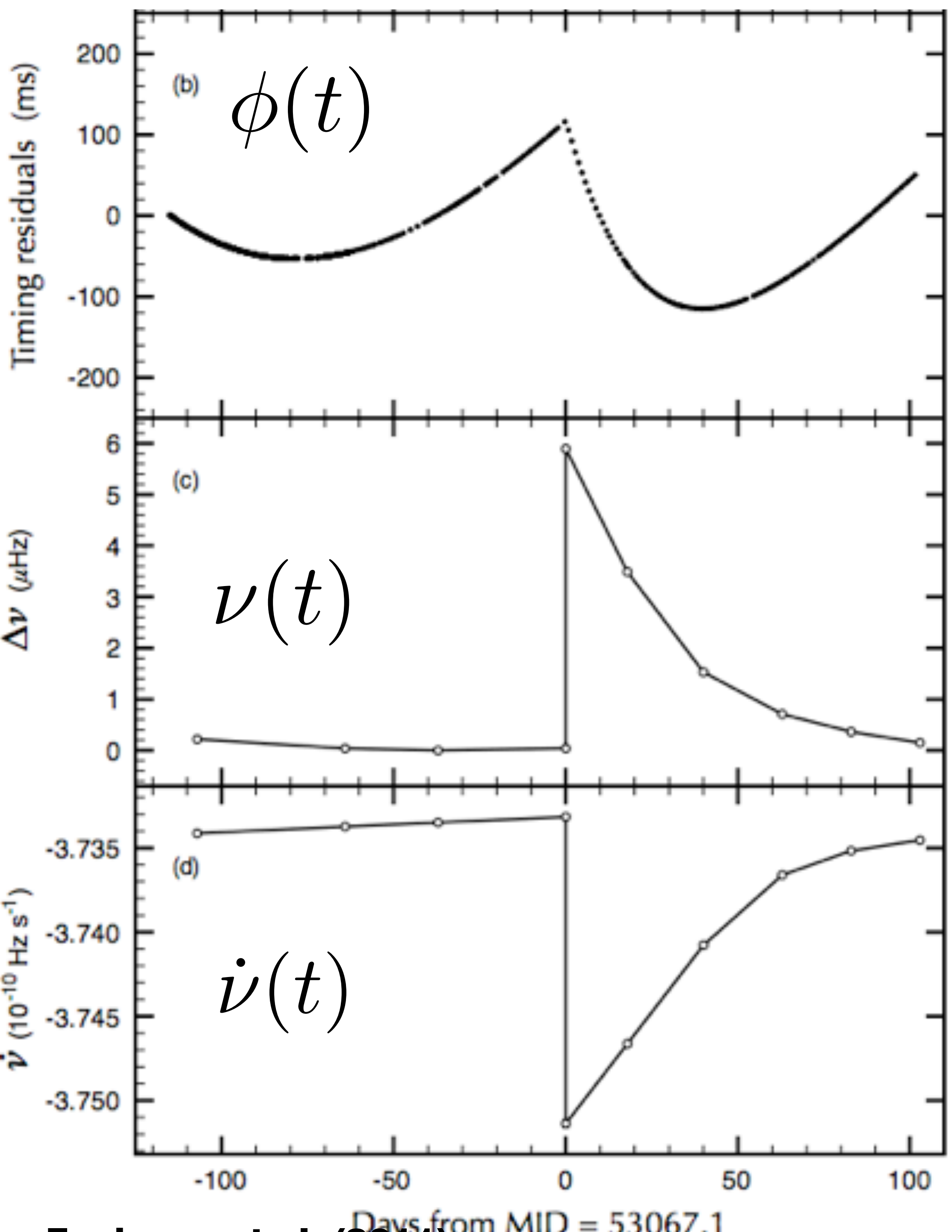




It might be present on all pulsars: improve precision and you will find it.

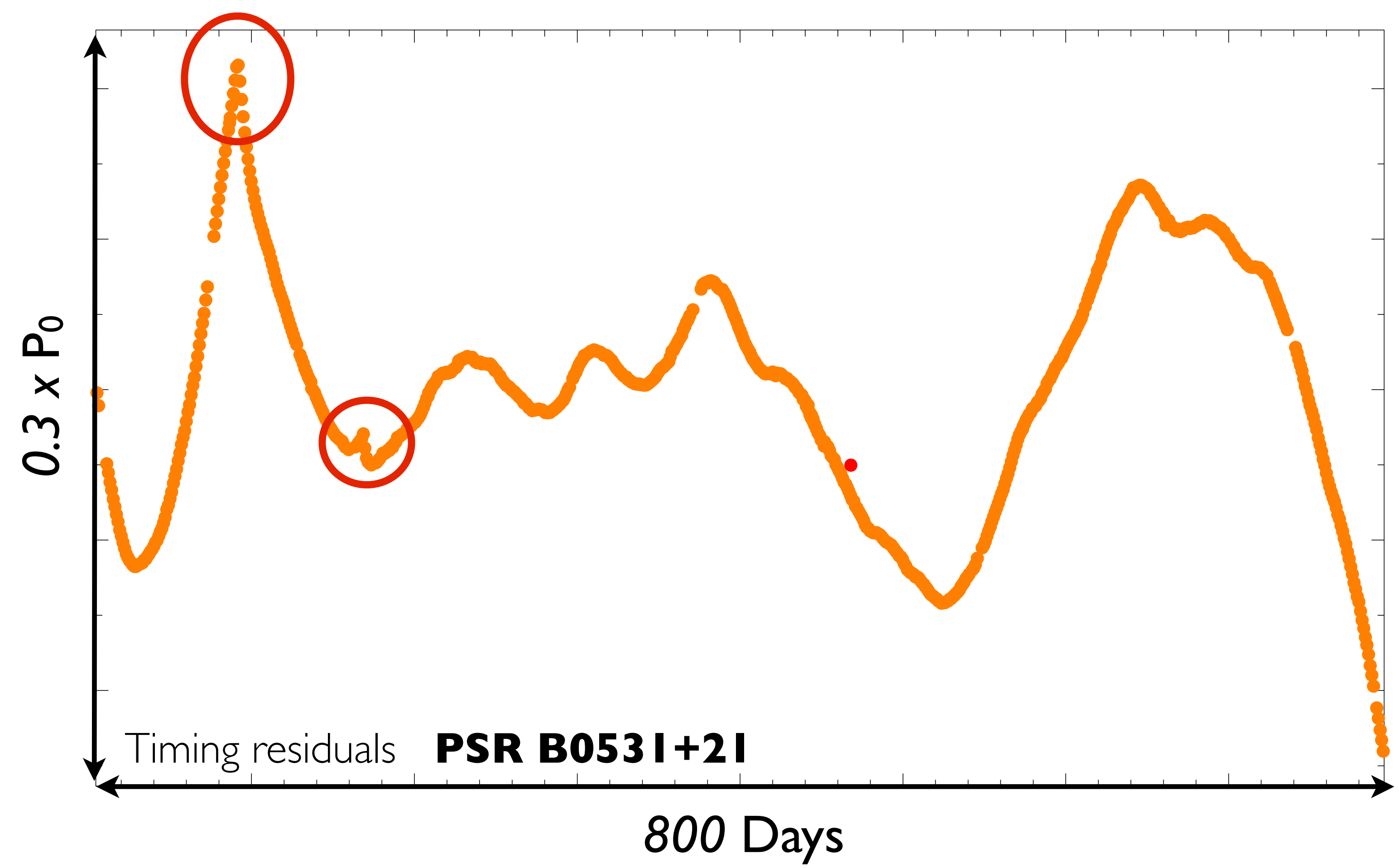
Jodrell Bank data

There is one specific signature that is sometimes there

# Glitches



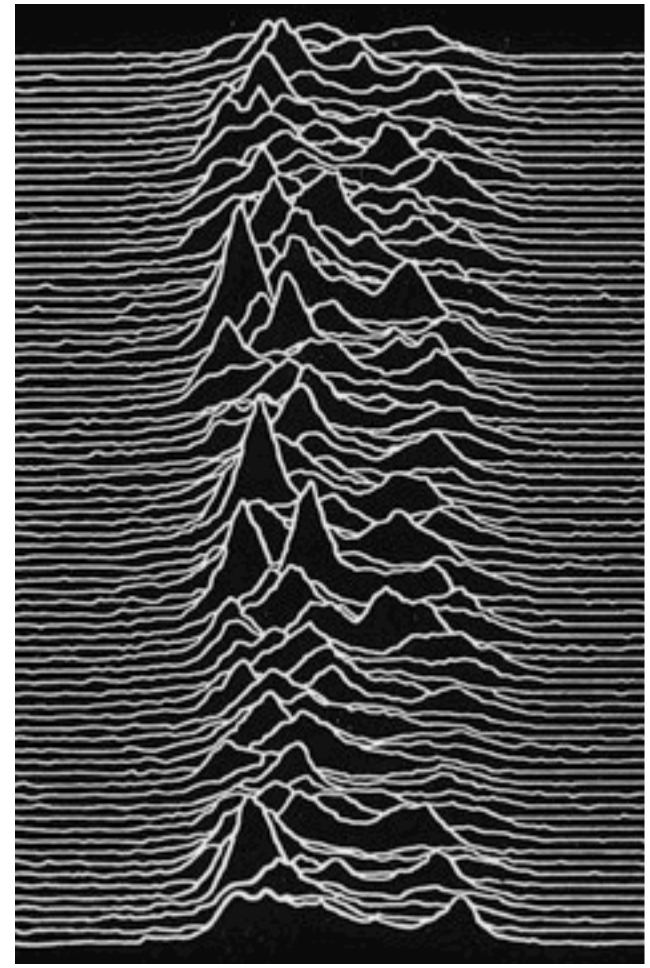

**Espinoza et al. (2011)**




High precision pulsar timing and the use of pulsars as celestial clocks will require good understanding of both these phenomena

Jodrell Bank data

+



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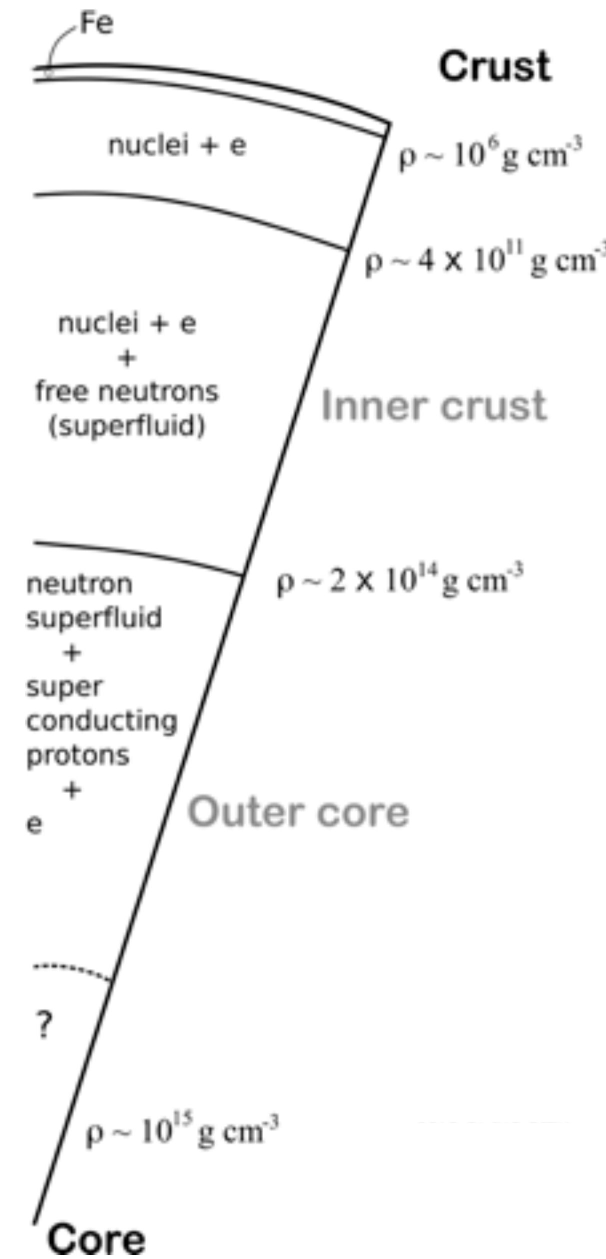



*Proposition to*

# improve the model:

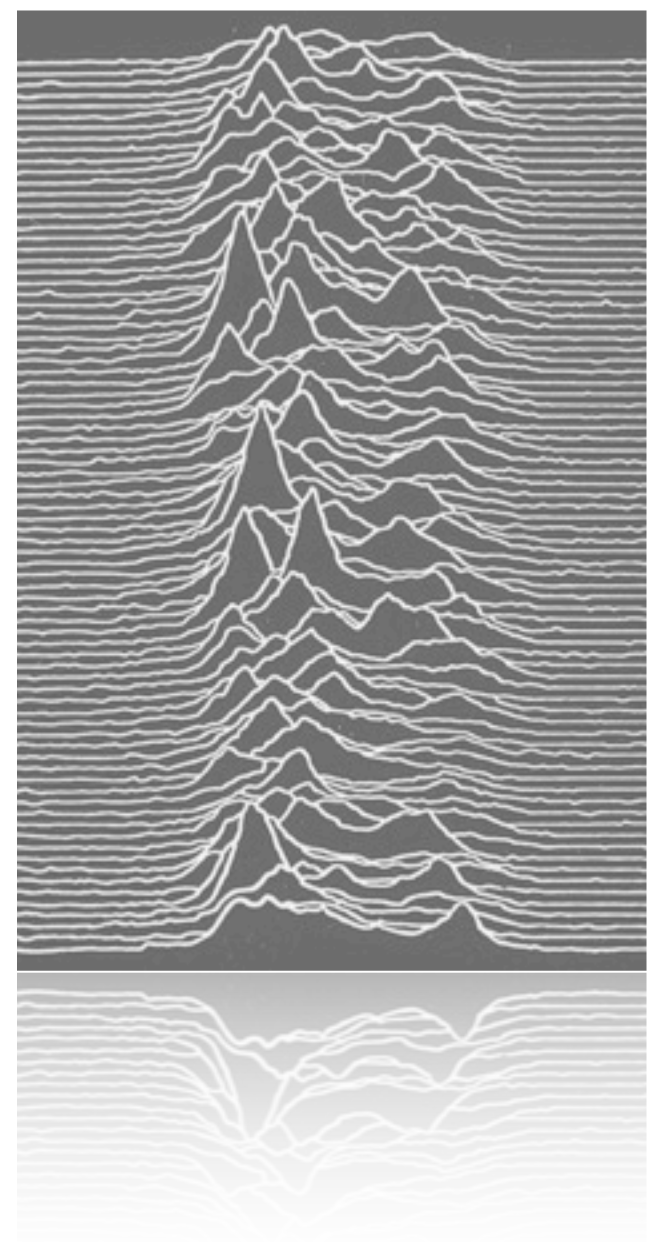
- Add variable plasma content in magnetosphere
- Add (partially decoupled) neutron superfluid inside

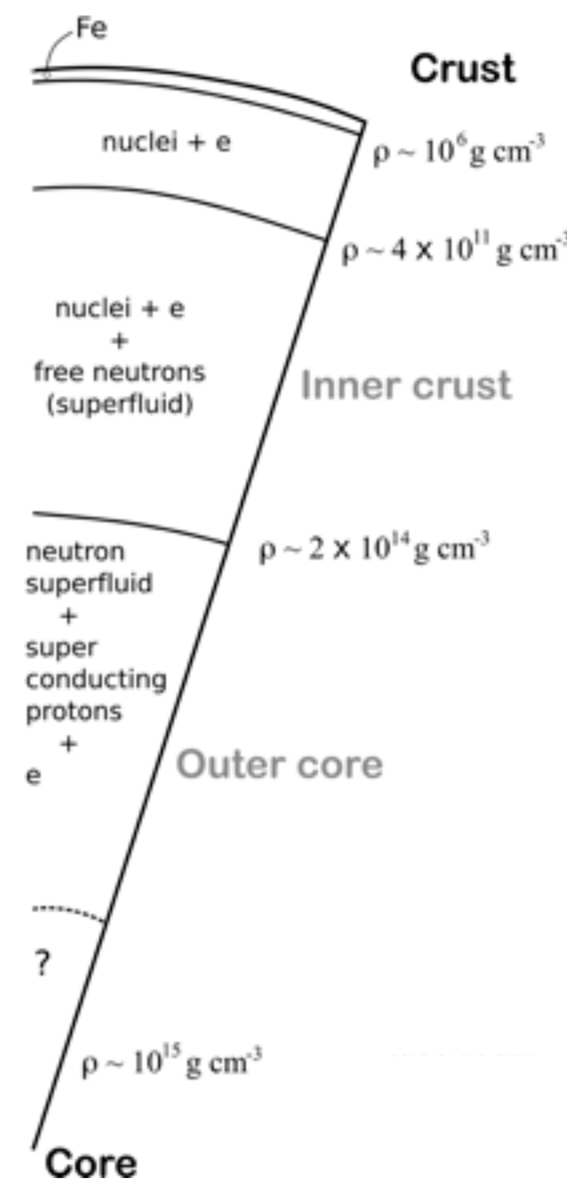
➡ Get timing noise and glitches

➡ Get observed irregular deviations from simple slowdown

# Outline

- Glitches | general
- Small glitches | confusion
- Timing noise
- Co-existence
- Summary / Questions





# Glitches

*Occasional spin-up events*

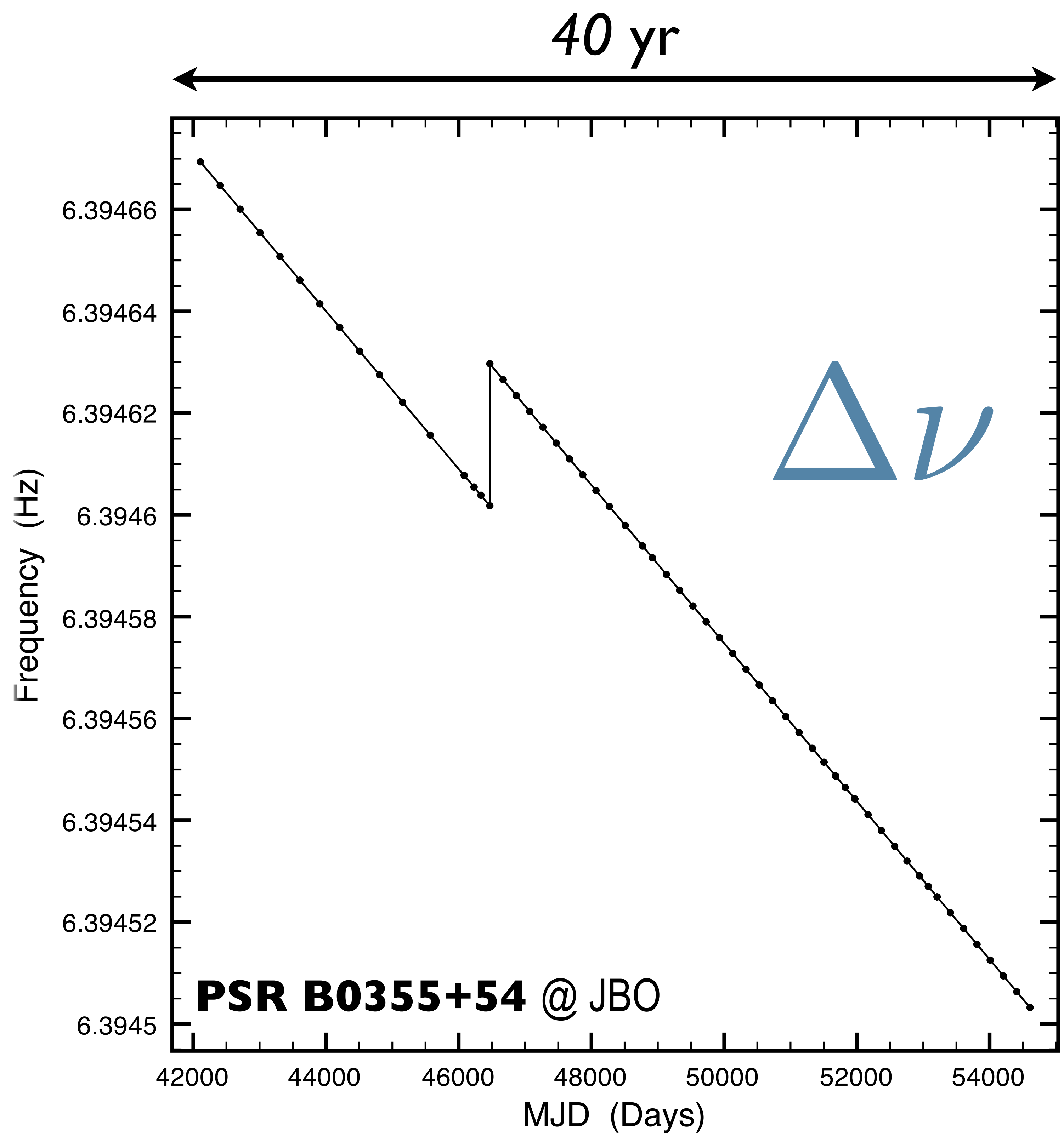
Observed sizes
cover ~5 decades

$$10^{-3} \leq \Delta\nu \leq 100\,\mu\text{Hz}$$

In general, radiatively quiet.

Associated to the interior of NSs.

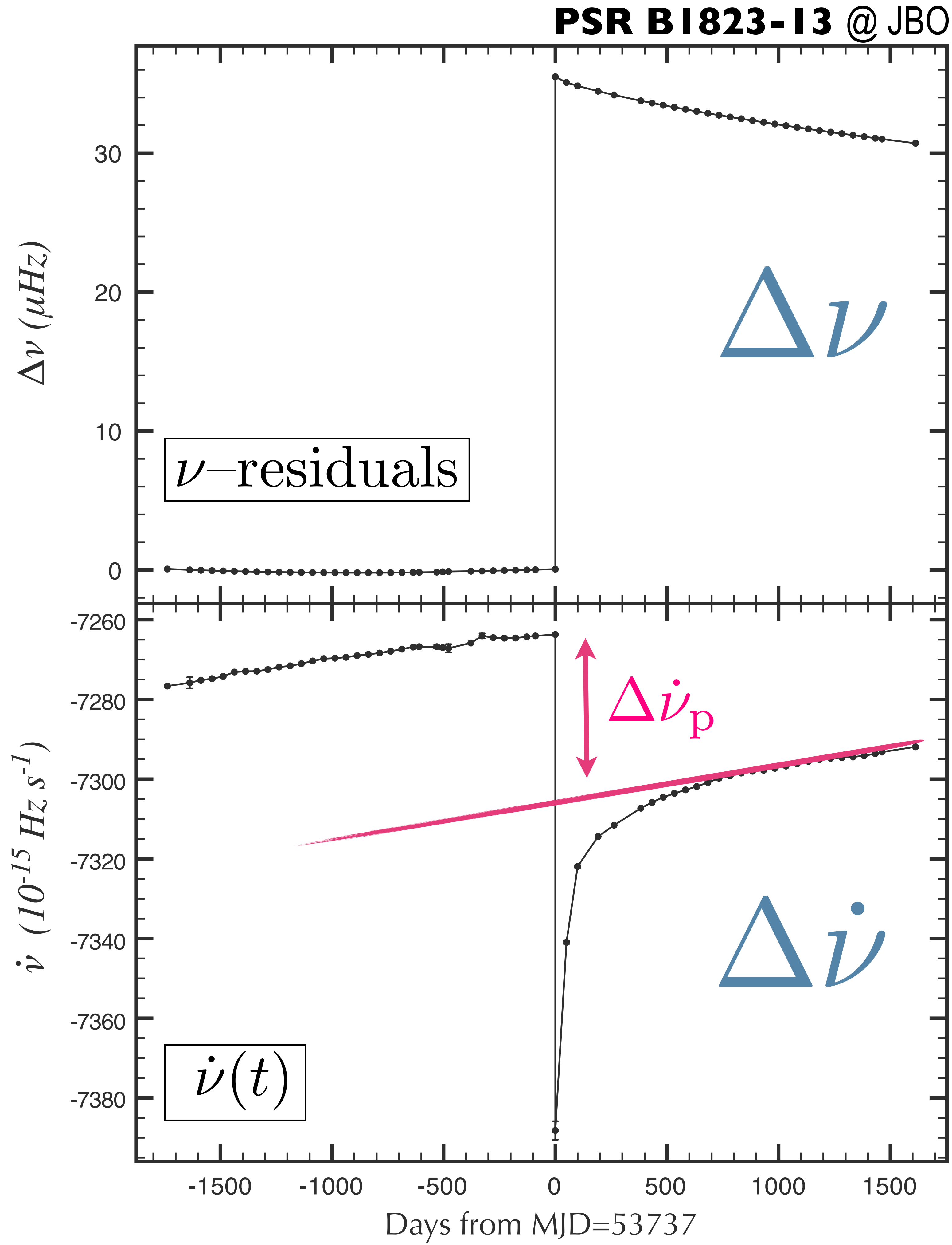
Present in most pulsar populations



# Glitches

Commonly followed by a <u>negative</u> change in spin-down rate.

Post glitch relaxations: rich phenomenology



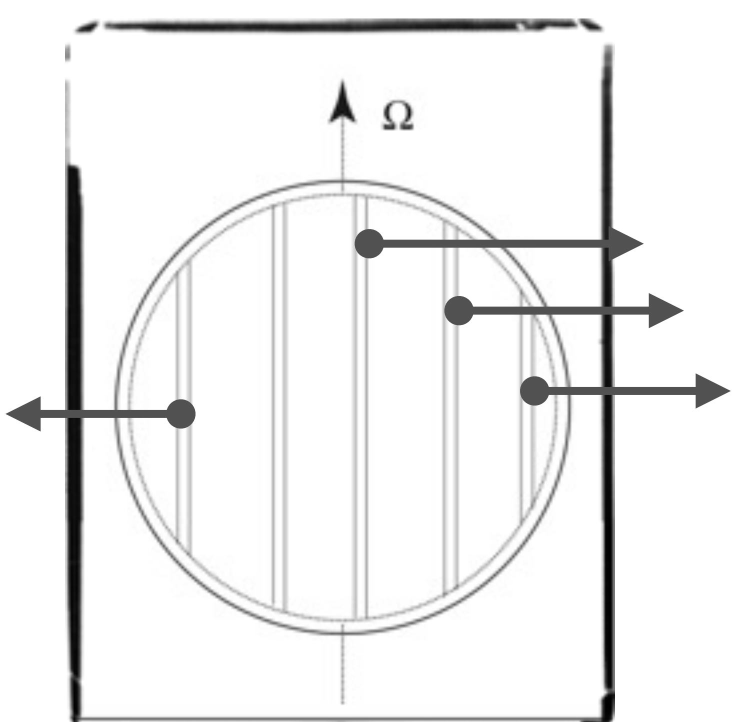
# What can produce a glitch?

- <u>Quakes:</u> discrete crust rearrangements driven by cooling or spindown (re-shaping) **(Baym et al. 1969)**

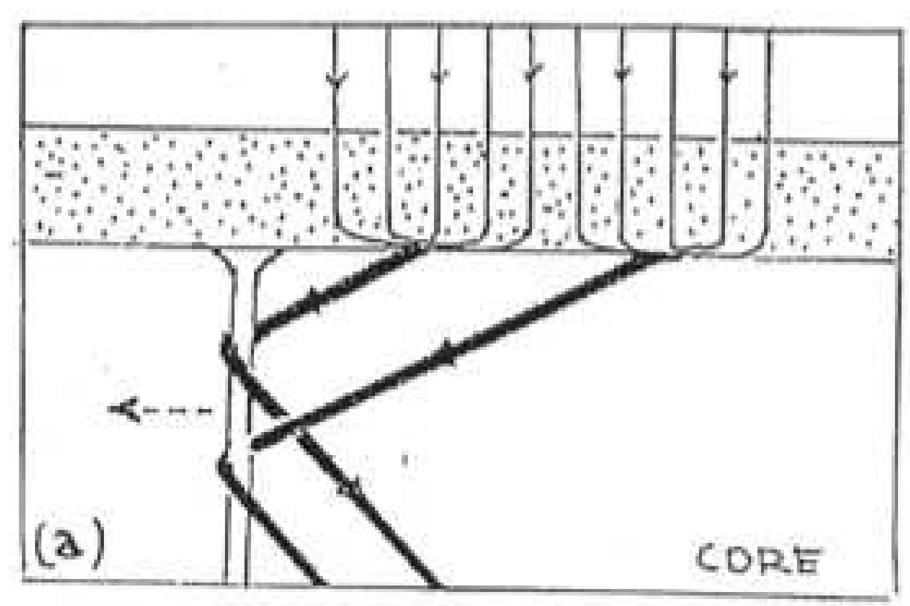
Cannot reproduce, alone, high activity of Vela (-like) pulsar(s).

- <u>Magnetic field stresses on the crust:</u> vortices dragging magnetic flux-tubes in their outward migration. **(Ruderman et al. 1998)**

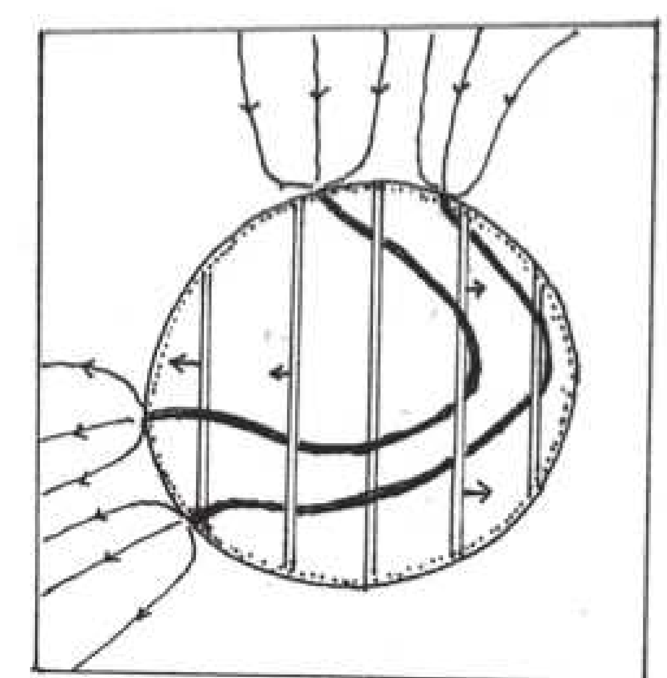
Assumptions:
- core magnetic field?
- vortex/flux-tube interaction?




adapted from M. Ruderman (2009)




**(Ruderman 2006)**

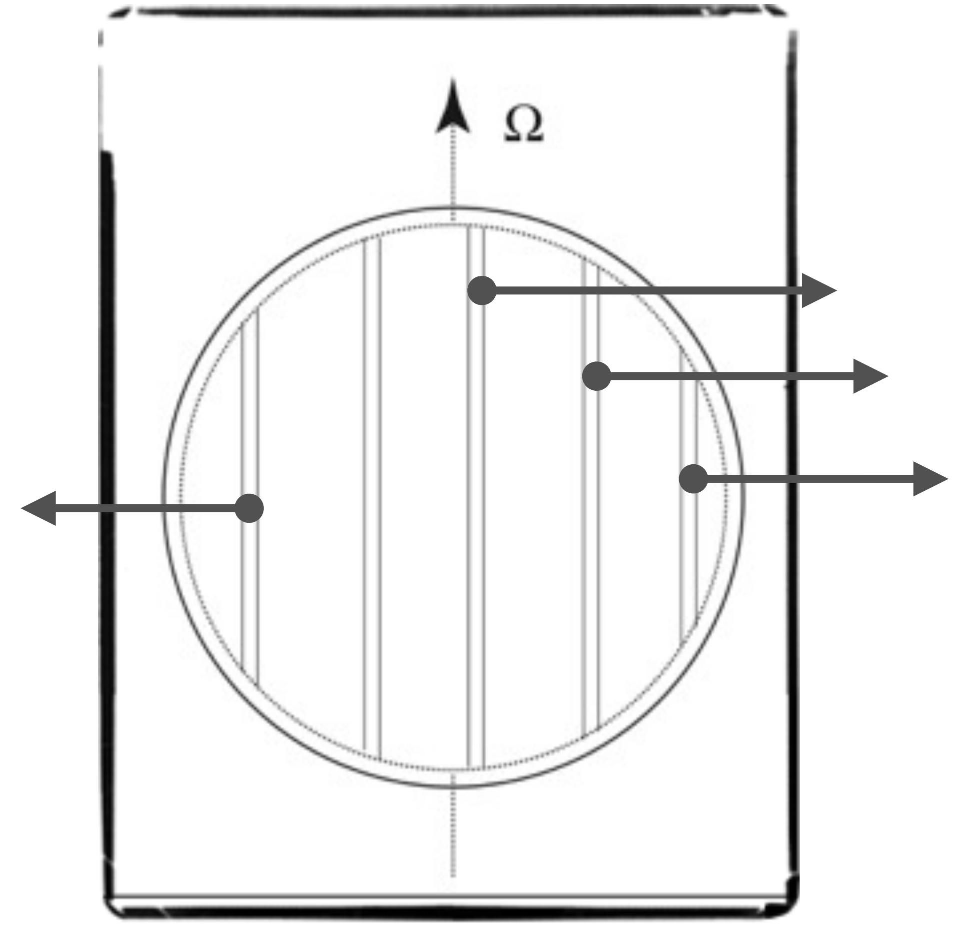


# What can produce a glitch?

▸ <u>Vortex pinning</u>:

rapid angular momentum transfer
from internal superfluid to outer crust.
Result of halted vortex migration.

(Anderson & Itoh 1975




<u>Triggers:</u>

- Critical lag: magnus force > pinning force
- Instabilities

➡ Predicts narrow size distribution, regularity.

- Avalanches
- Thermal unpinning by heating event.

➡ Predict power law size distributions, poissonian waiting times.

> Alpar et al. 1984; many many others)

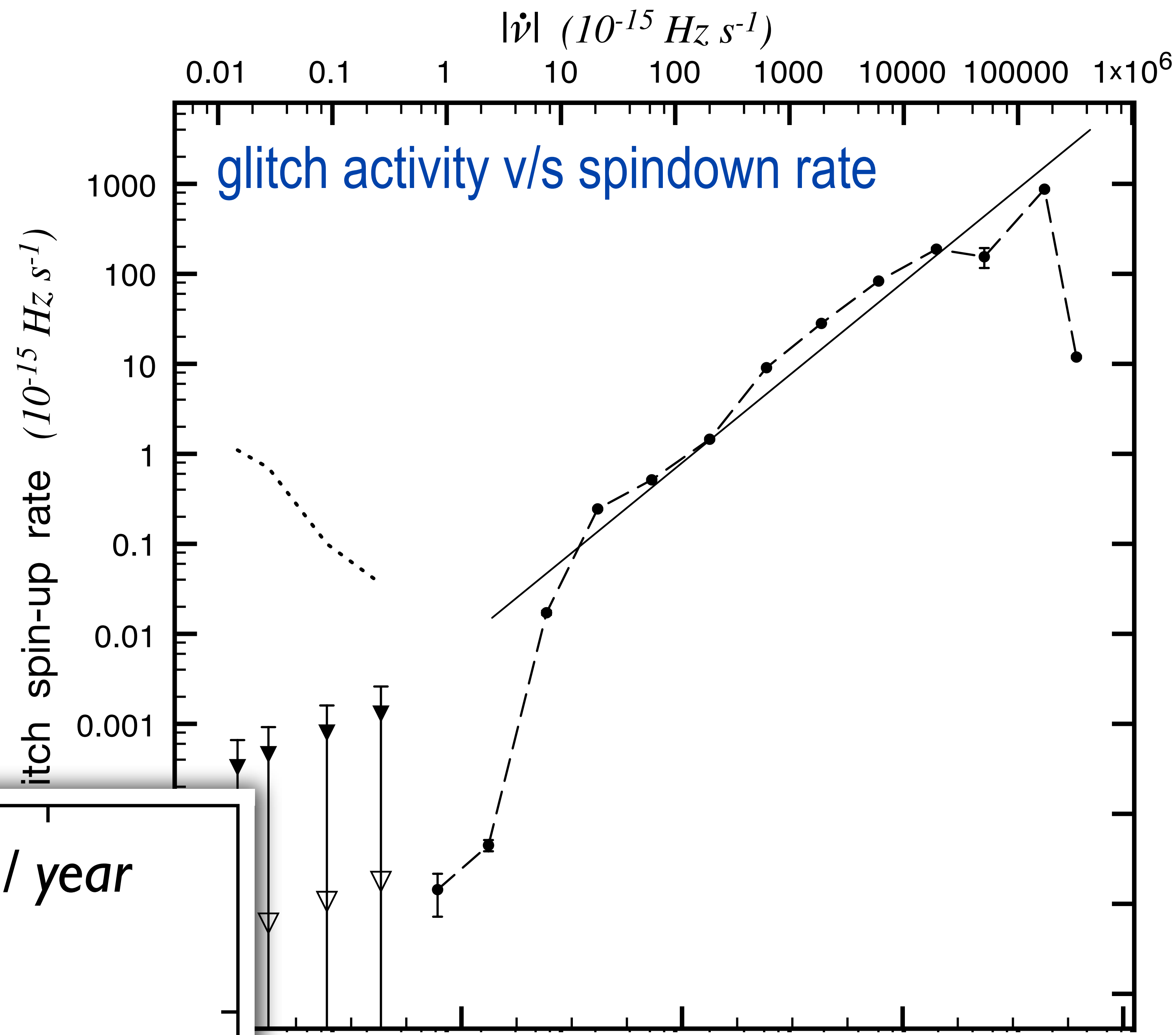
> Glampedakis & Andersson (2009)

> Melatos et al. (2008, 2009)

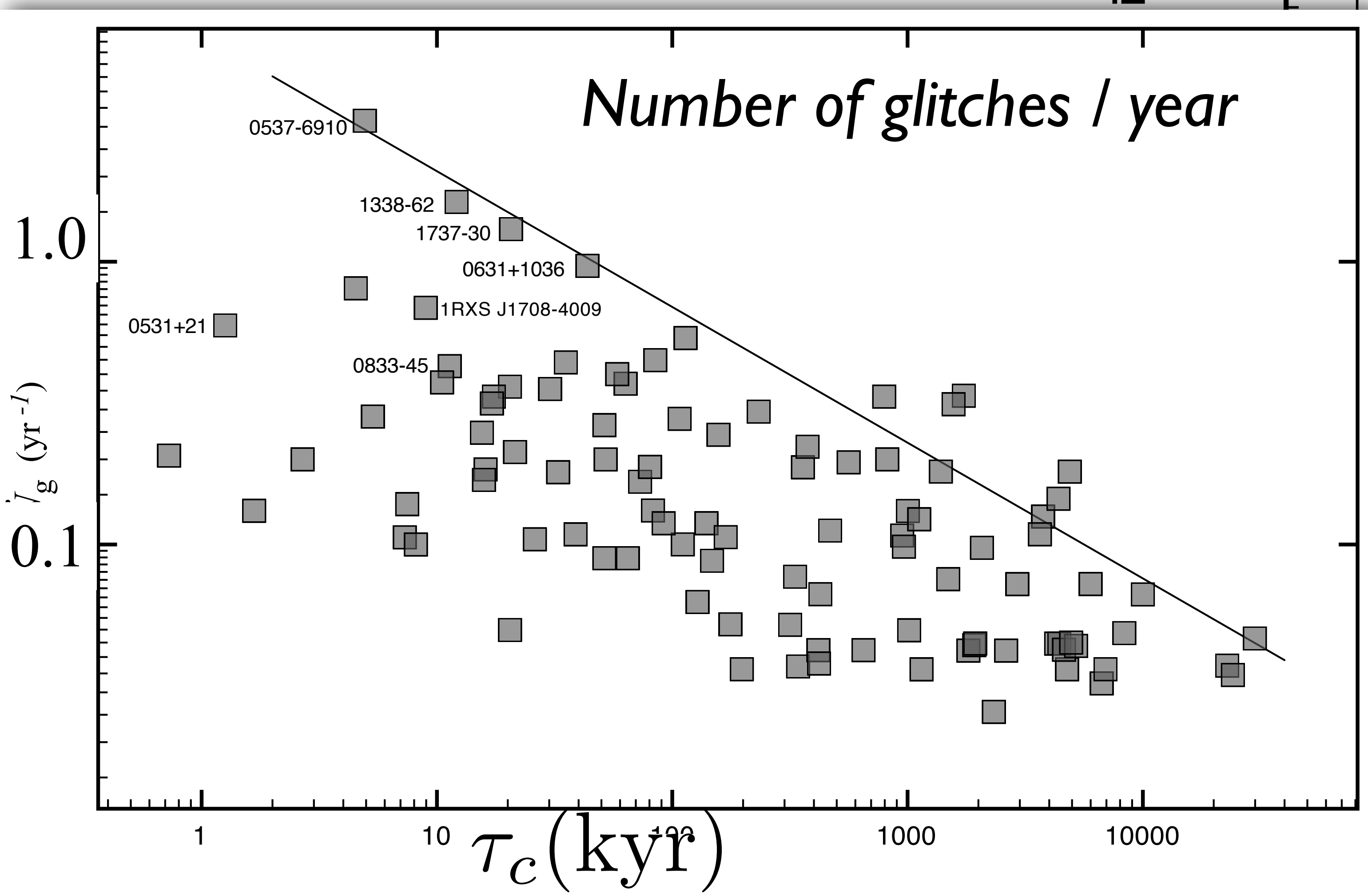
> Link & Epstein (1996)

Not complete !!

# The *glitch activity* increases with spindown rate: young pulsars tend to glitch more often




Espinoza et al. (2011)

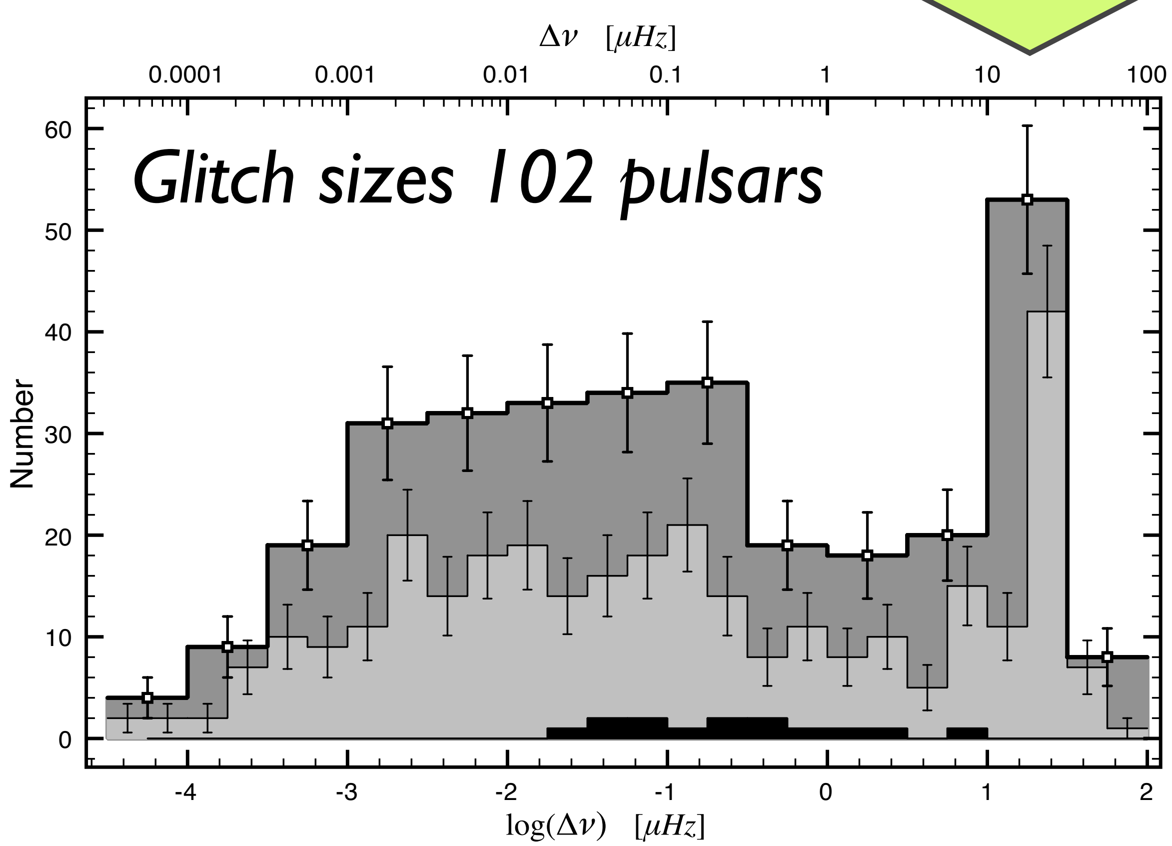



The linear relationship is consistent with most models

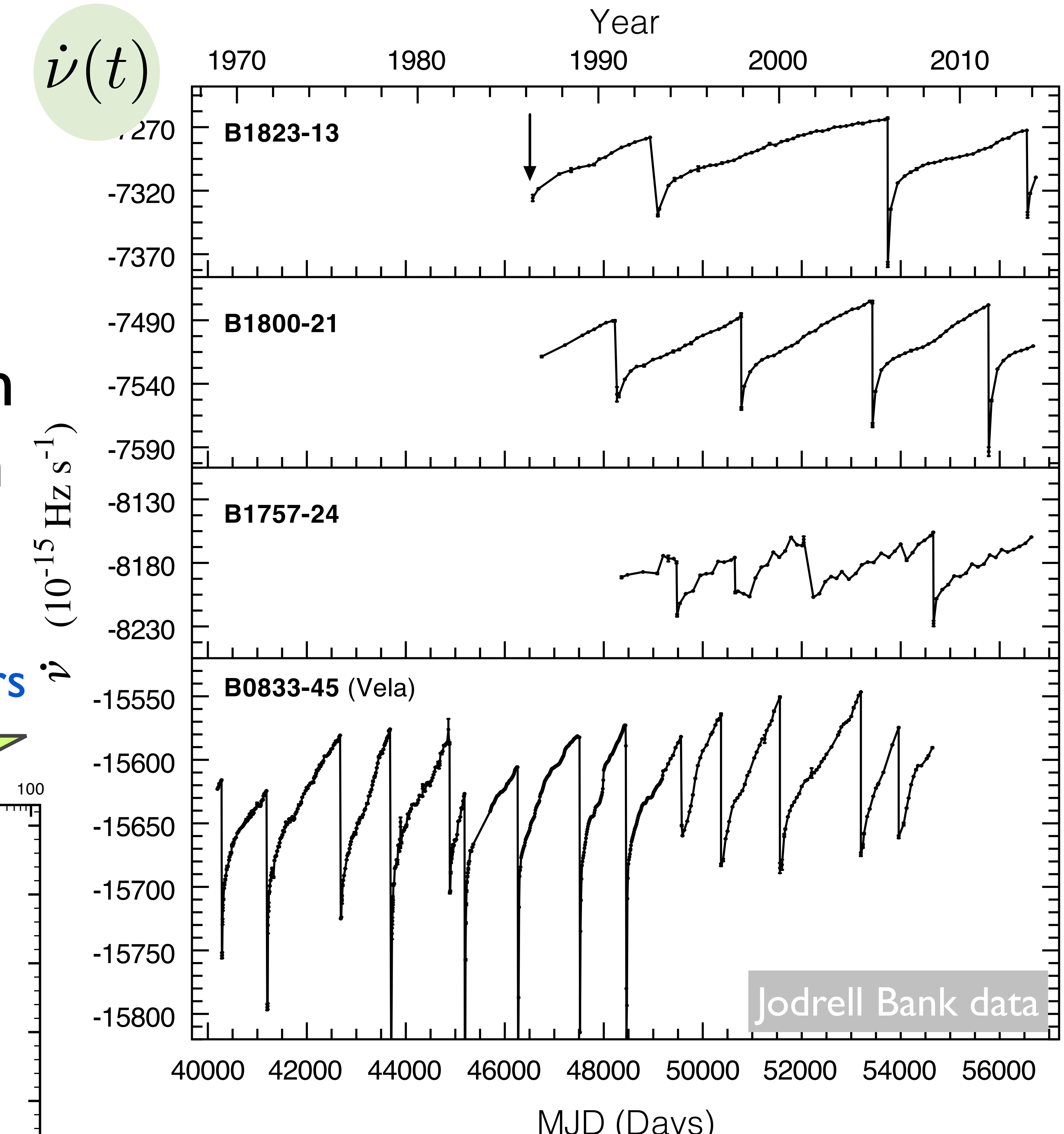
# Glitches

Can have large impact on long-term spin evolution

*Large glitches:*
*young, Vela-like pulsars*

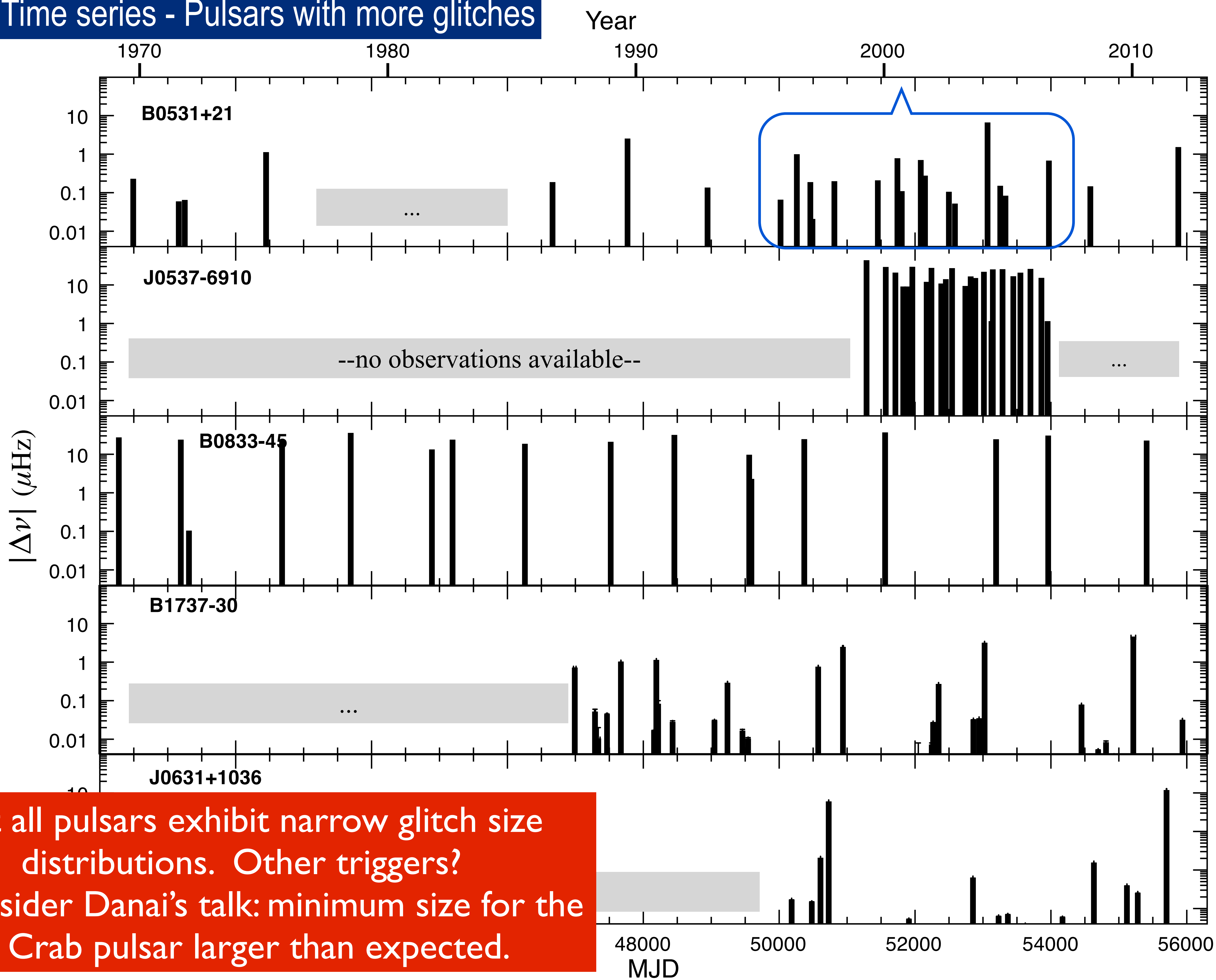



**Espinoza et al. (2011)**




In good agreement with vortex pinning model, with critical lag as trigger.

# Sizes & Time series - Pulsars with more glitches



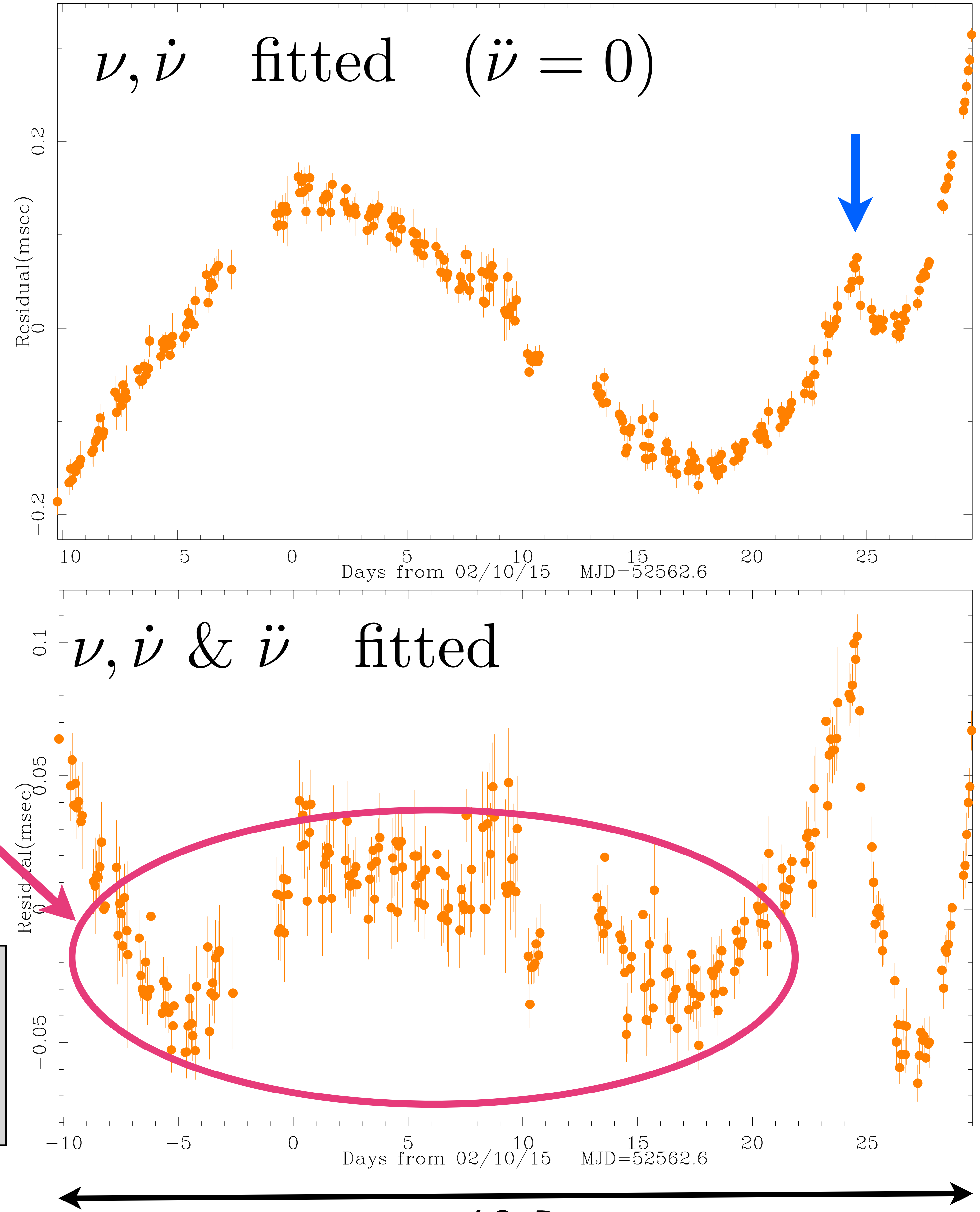

Not all pulsars exhibit narrow glitch size distributions. Other triggers?
Consider Danai's talk: minimum size for the Crab pulsar larger than expected.

# What about small glitches?

In general, (small)glitch detection is an uncertain process.

Small glitches can be confused with timing noise.

*- The Crab pulsar (JBO)-*



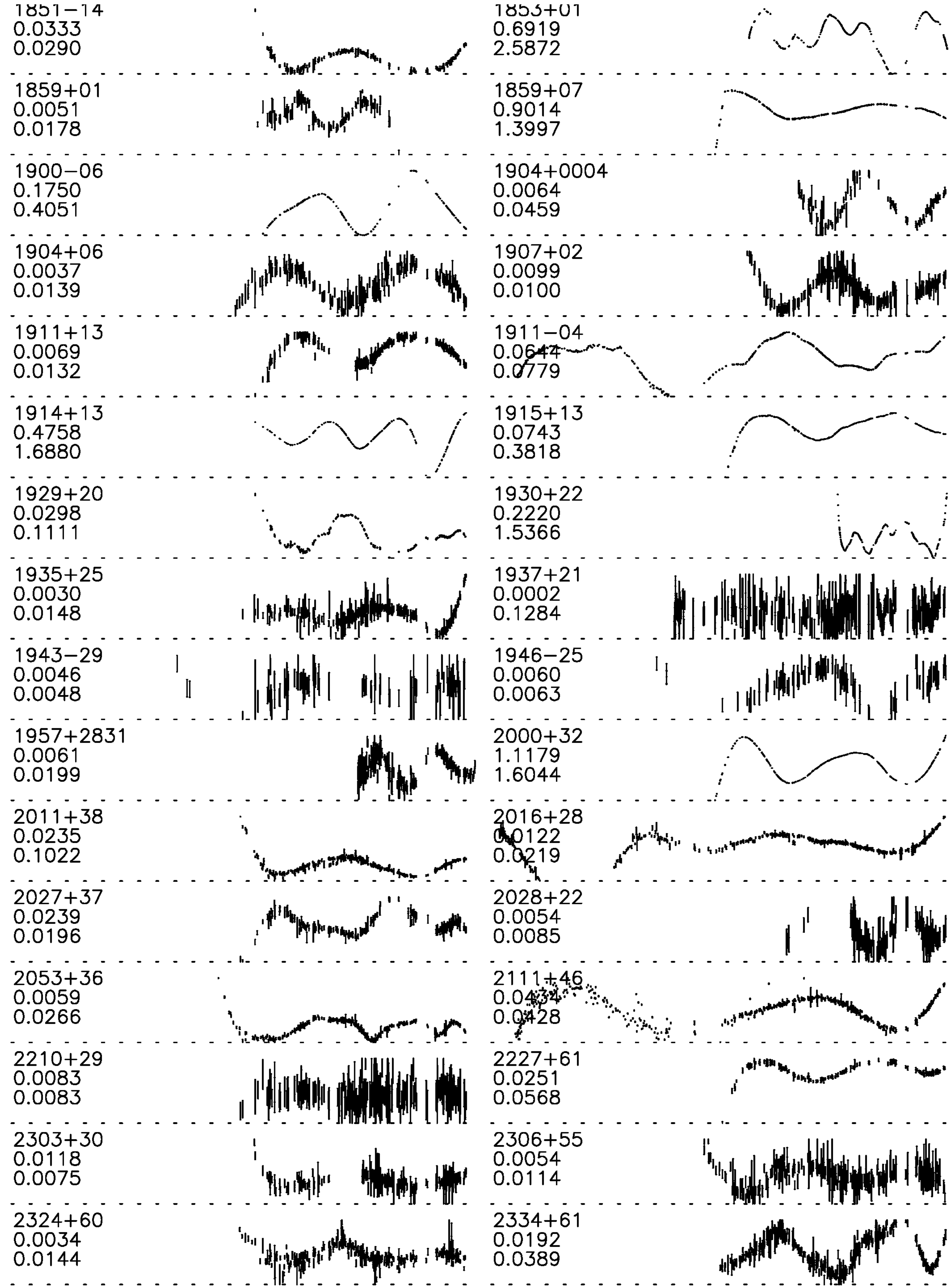

*40 Days*

How to differentiate them?
Can we detect very small glitches?
*...wait for Danai's talk.*

# Timing noise

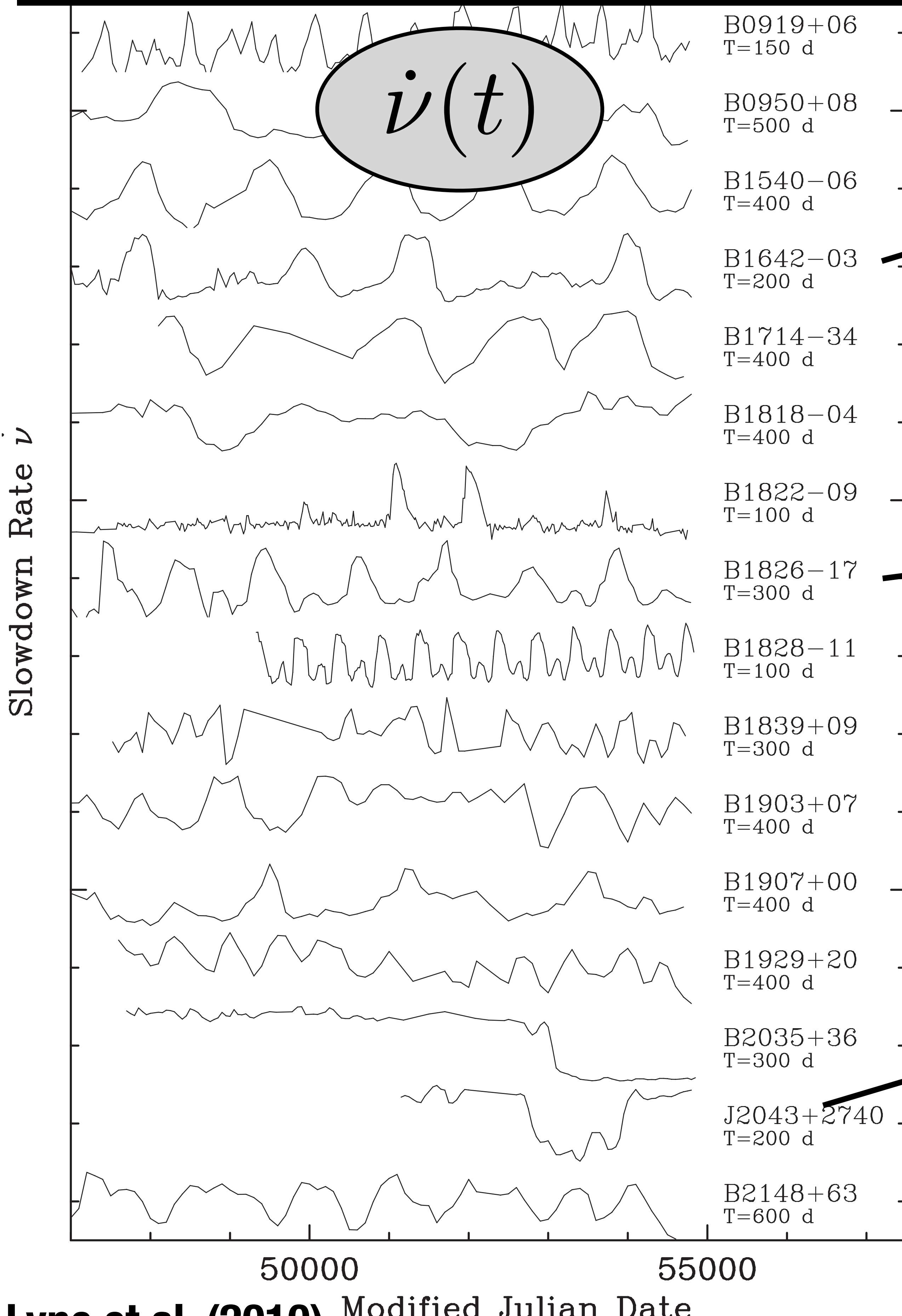
- Intrinsic to pulsar rotation.
- Common to all pulsars.
- Quasi-periodic (if enough data).
- Alternating between 2(+) spindown rates can emulate residuals

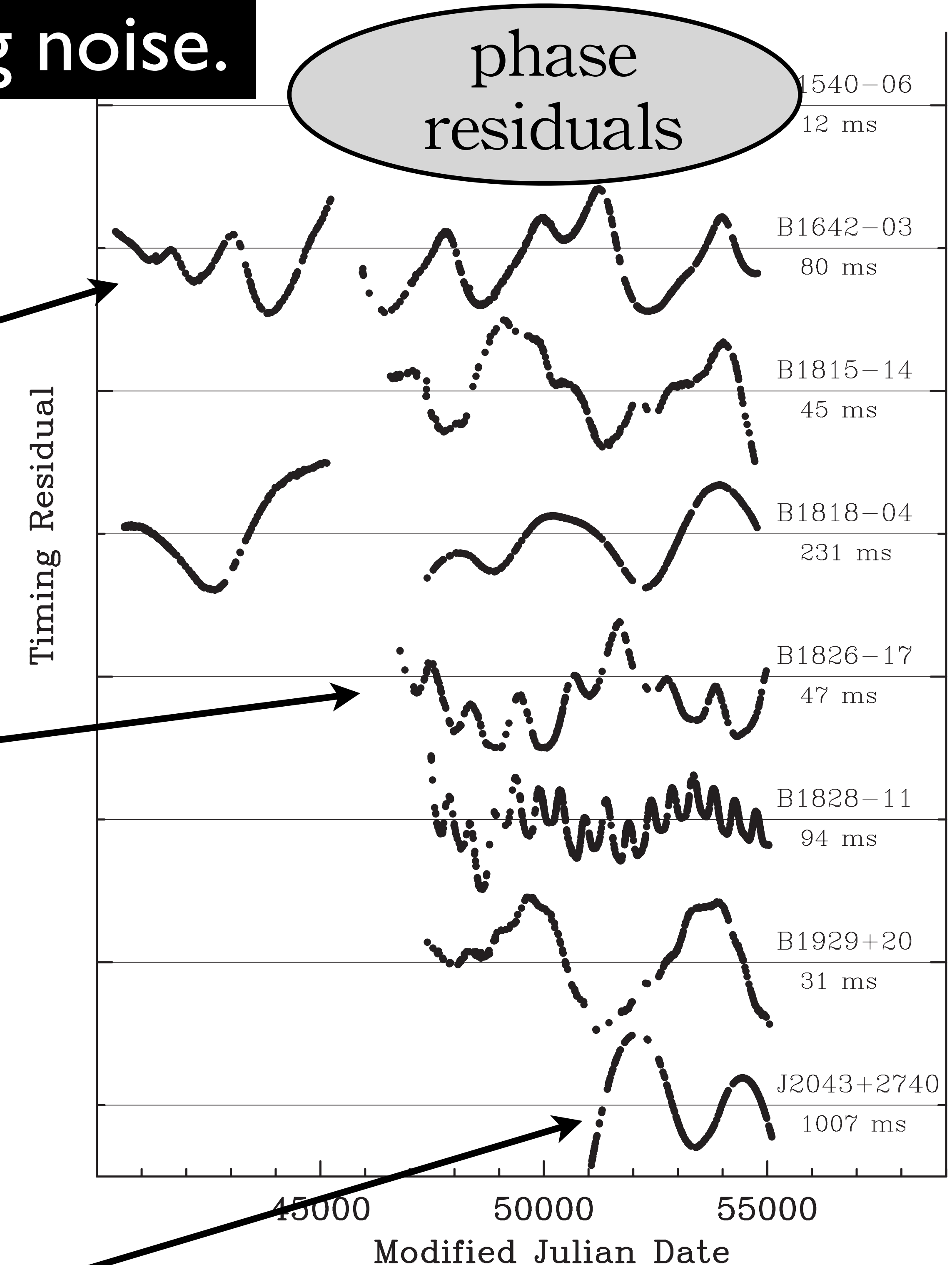
**Hobbs, Lyne** & **Kramer (2010)**




Timing residuals

# Pulsars with largest amounts of timing noise.



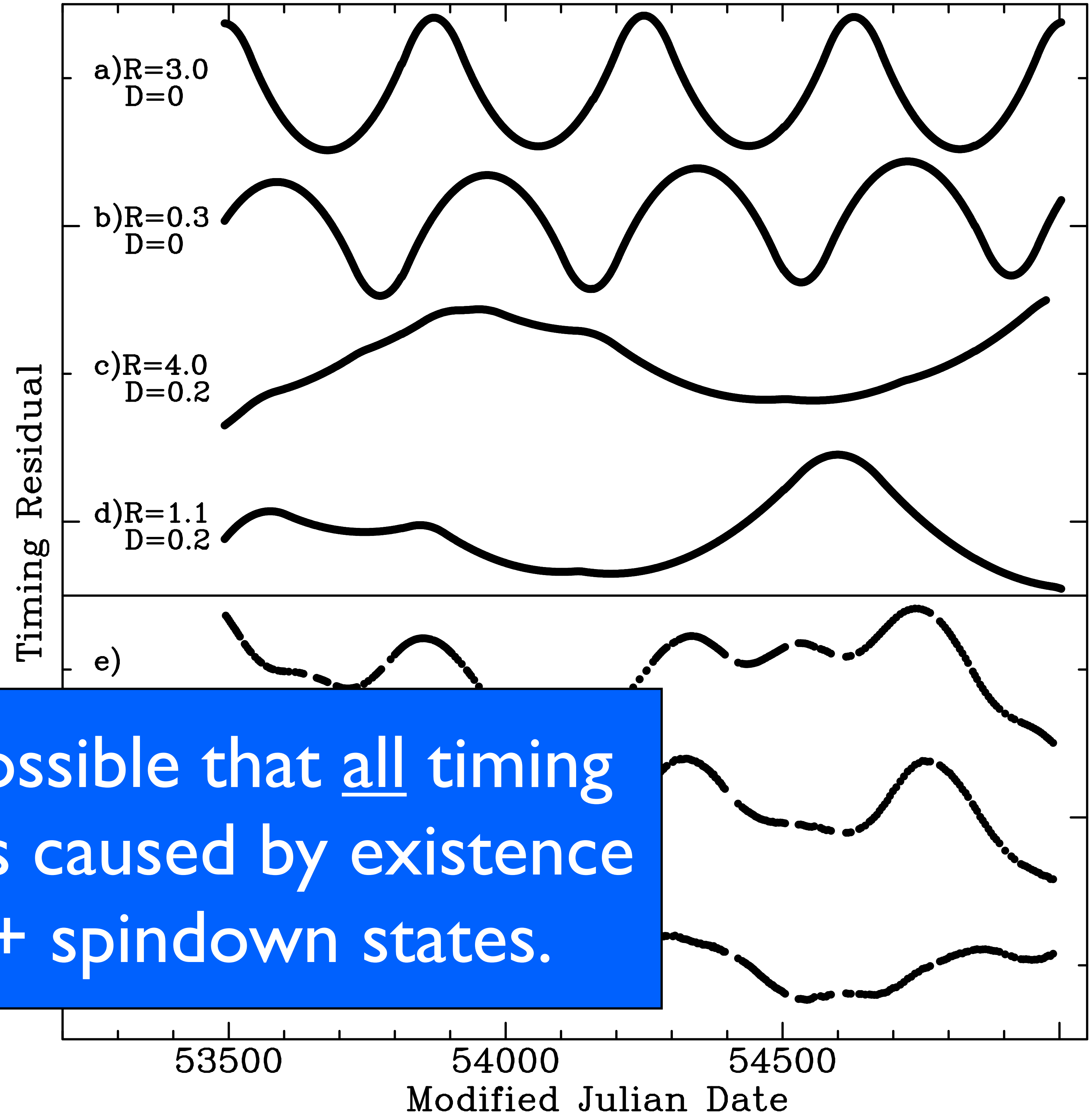

**Lyne et al. (2010)**

Timing noise is produced by existence of 2 or more spindown states.

# Simulation of data with spindown switching

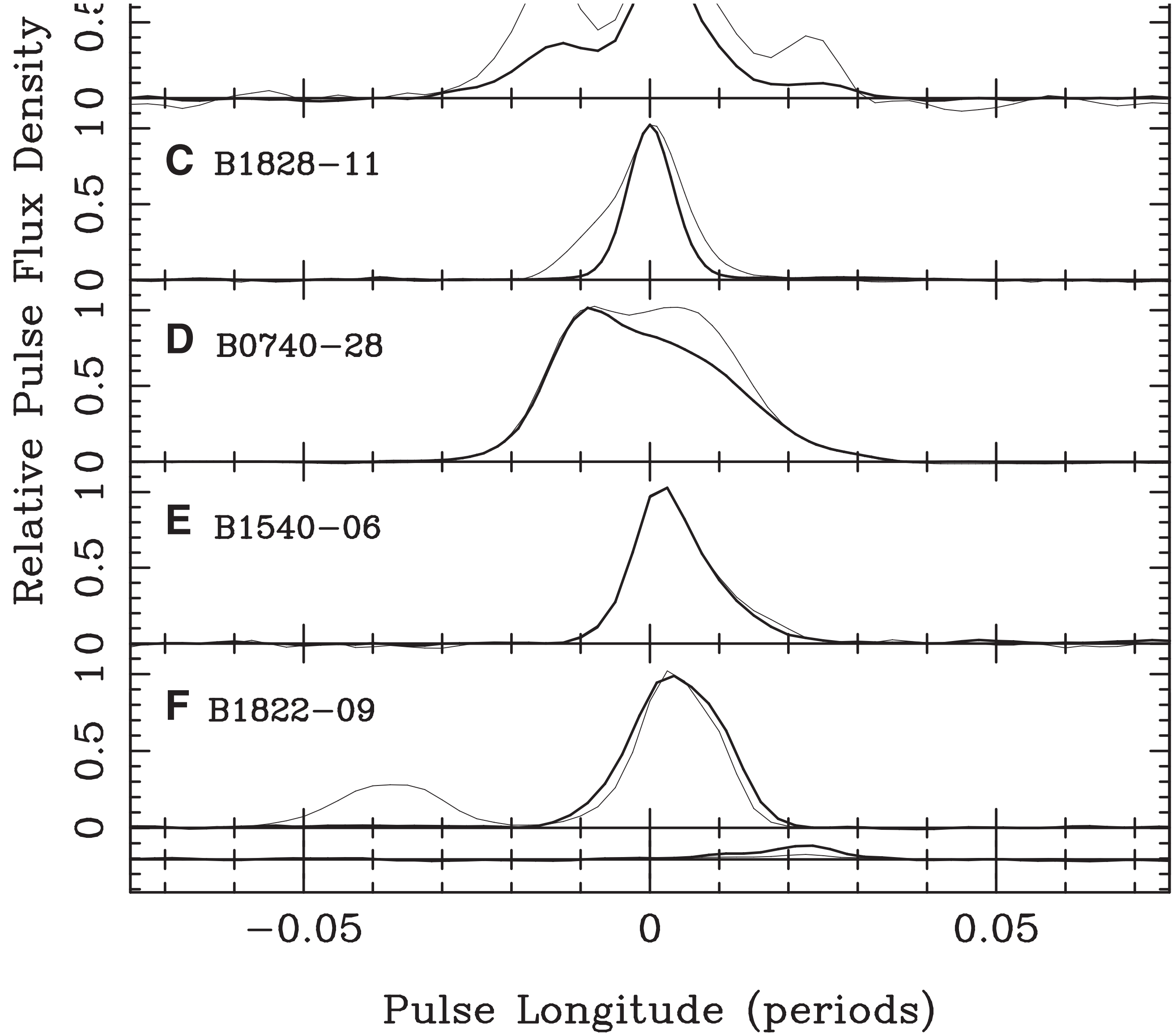
Periodic switching

quasi-periodic switching

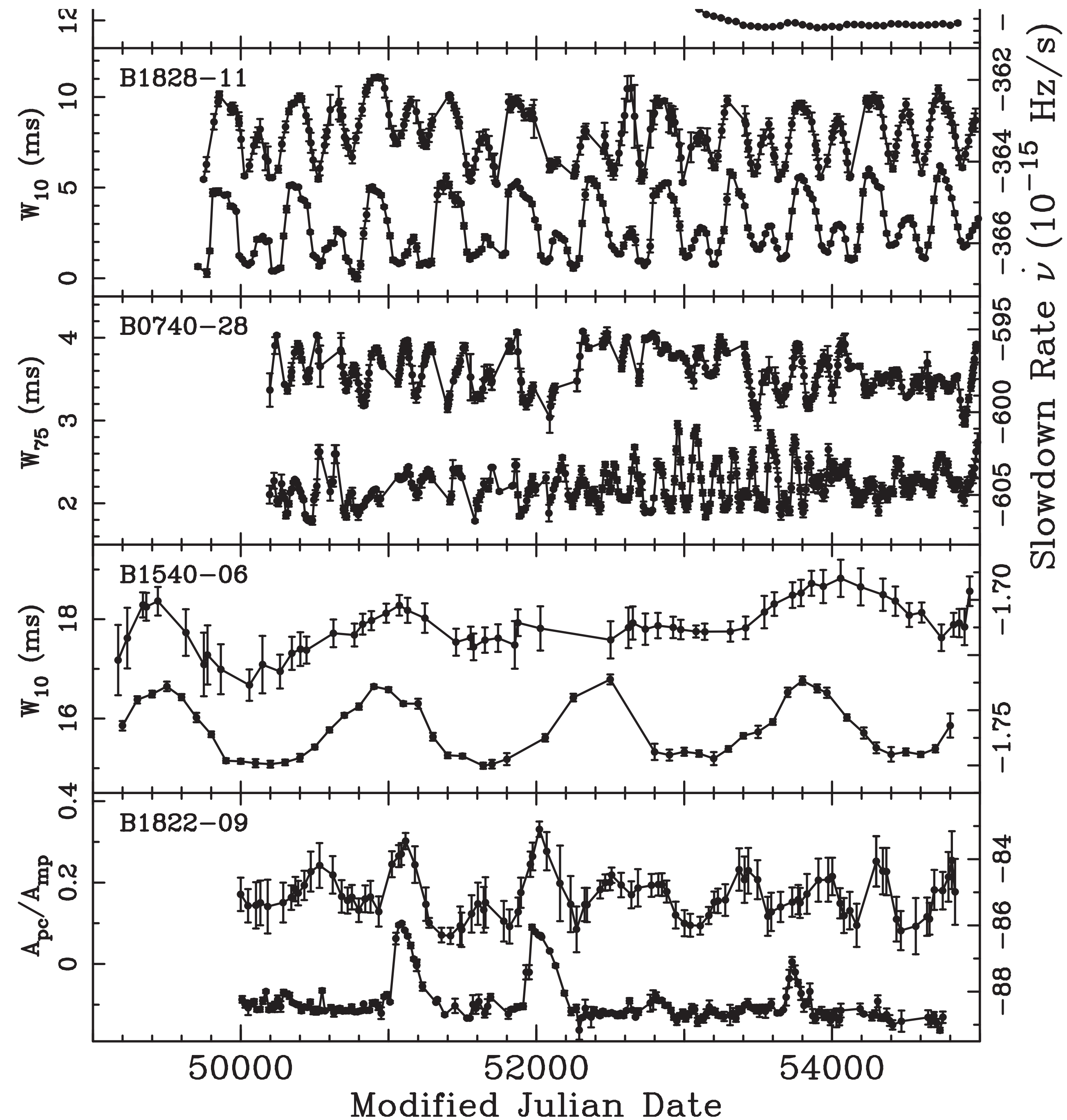



It is possible that <u>all</u> timing noise is caused by existence of 2+ spindown states.

**Lyne et al. (2010)**




Lyne et al. (2010)

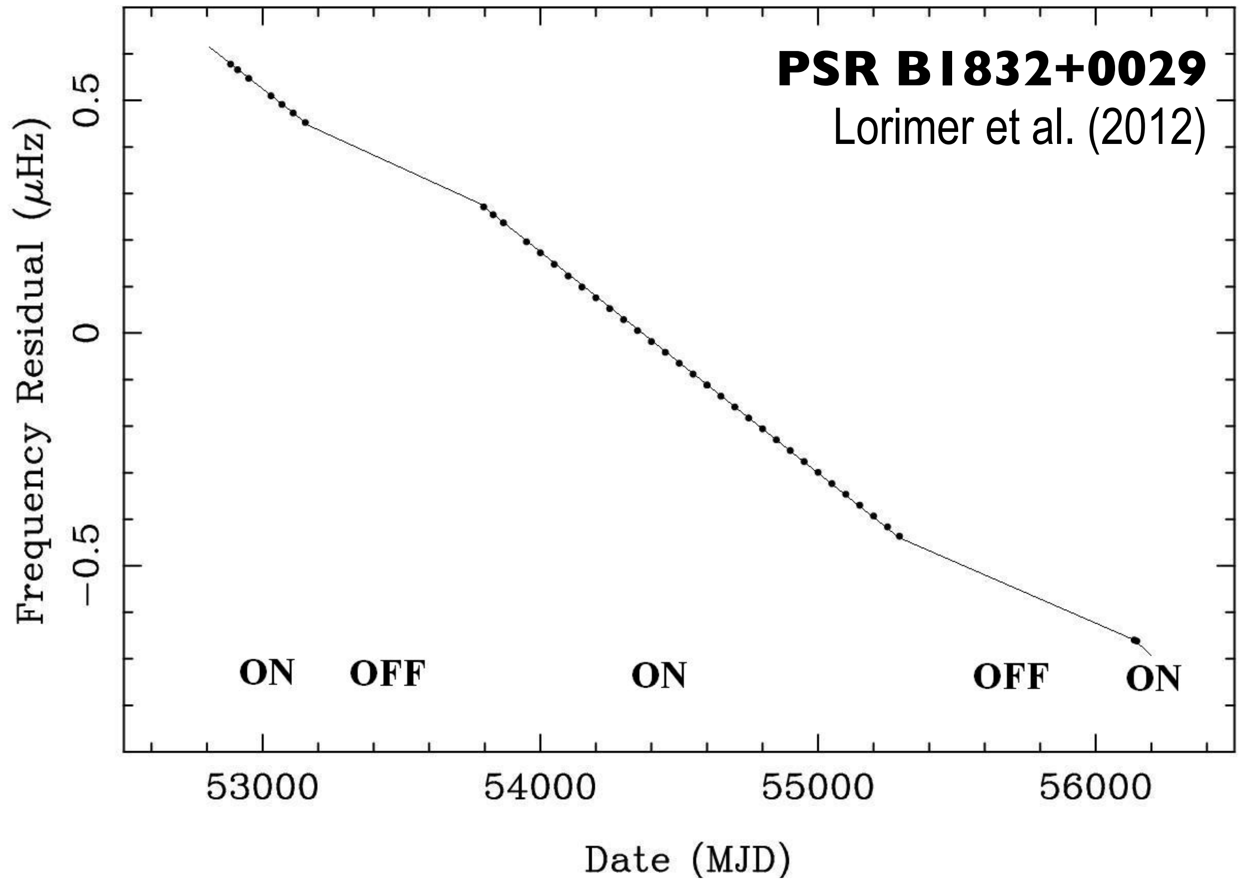



# Spindown states corresponding to magnetospheric switches

Effect may not be detectable in all pulsars --Sensitivity

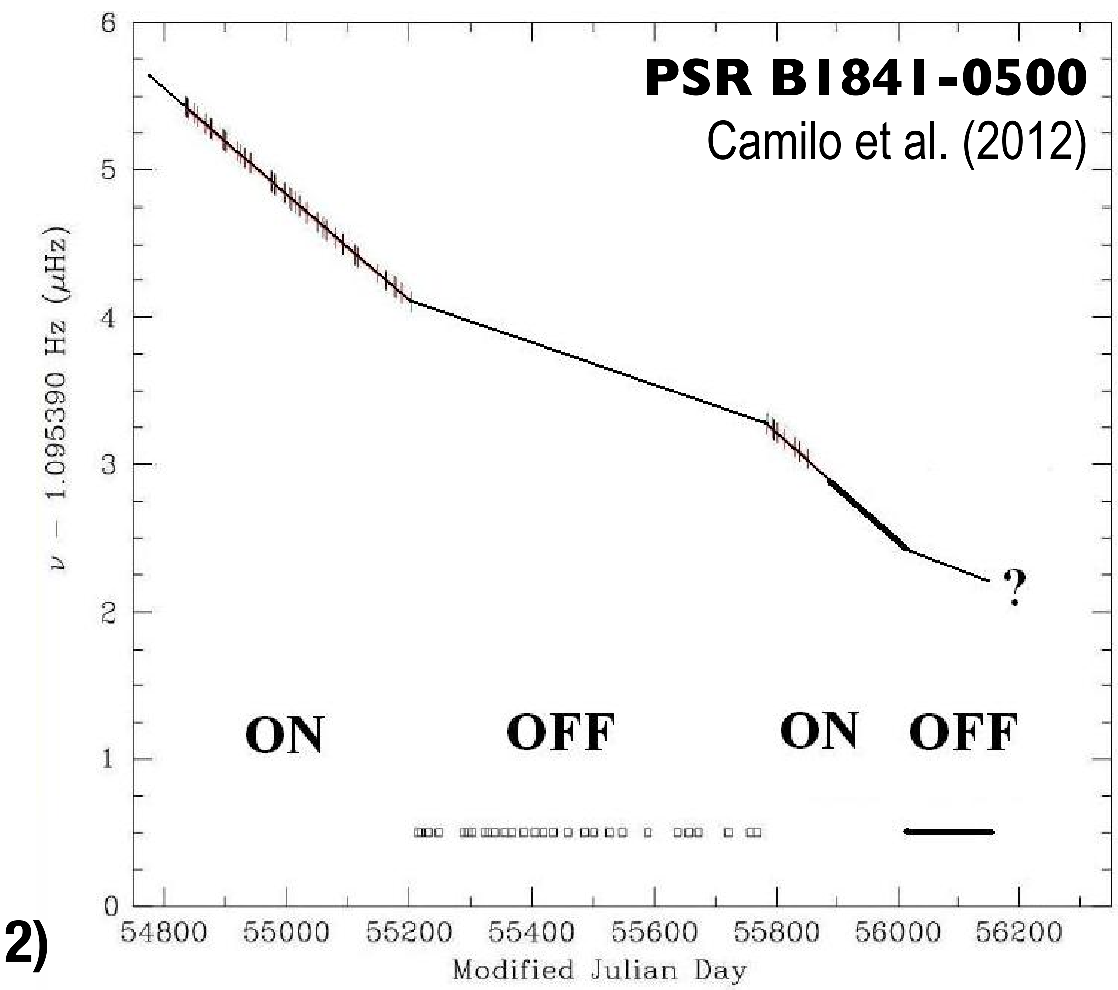
In general the largest spindown rate happens during pulse profile with enhanced emission *

Natural connection to nulling phenomenon, intermittent pulsars and maybe even RRATS.




# Extreme emission change

Intermittent pulsars: 2 emission states and two spindown rates.




From **Lyne et al. (2012)**

**Magnetospheric variability seems common feature. There are different time-scales and behaviours already observed at different wavelengths.**

<u>Models *(some)*:</u>

- Li et al. (2014) : conductivity variations magnetosphere
- Timokhin: close field lines region / current densities.
- Ian Jones (2011): modulated by precession.

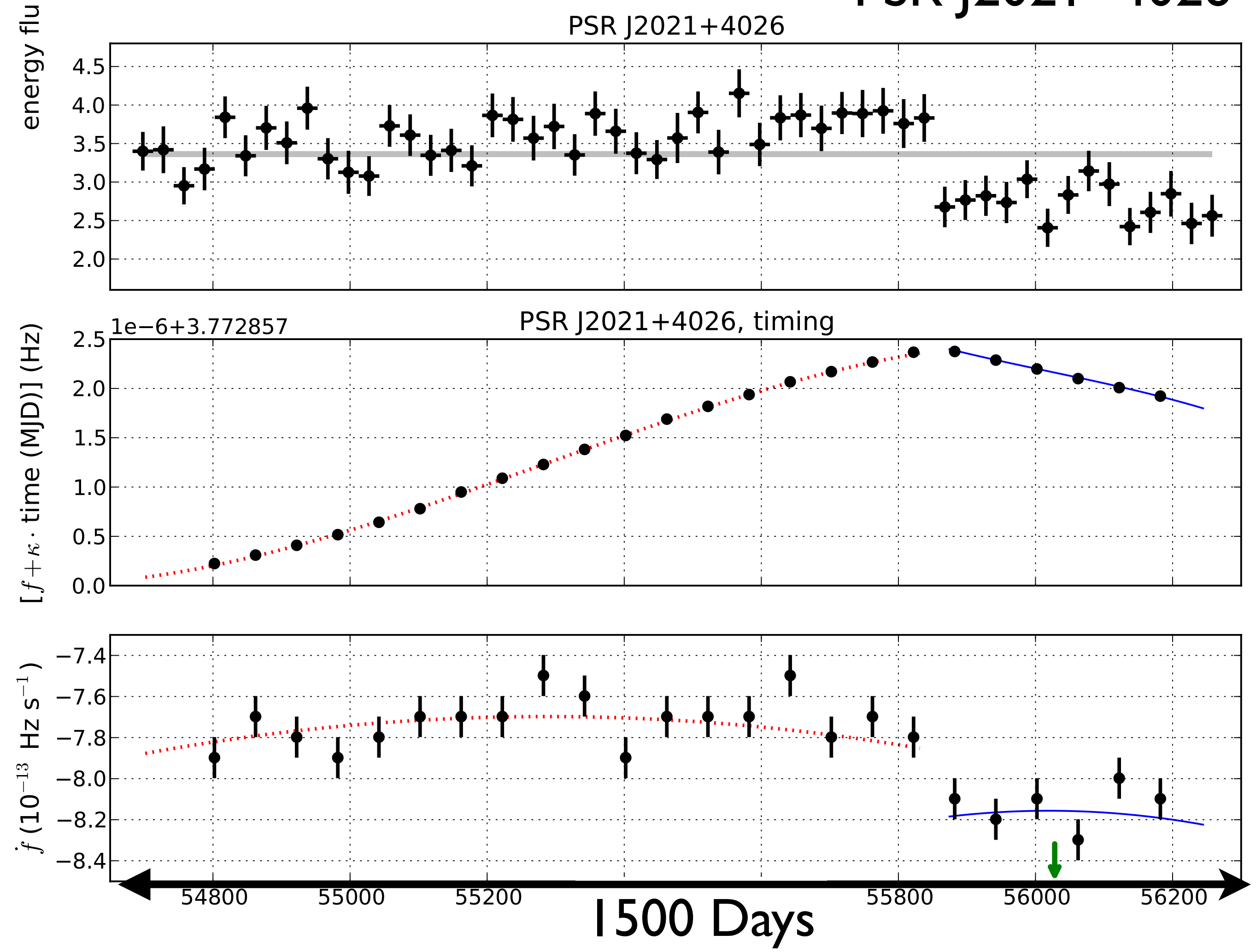
To understand we need more cases, more data.

W. Hermsen's talk: PSR 0943+10
rapid mode switching in radio / X-rays
(Hermsen et al. 2013)

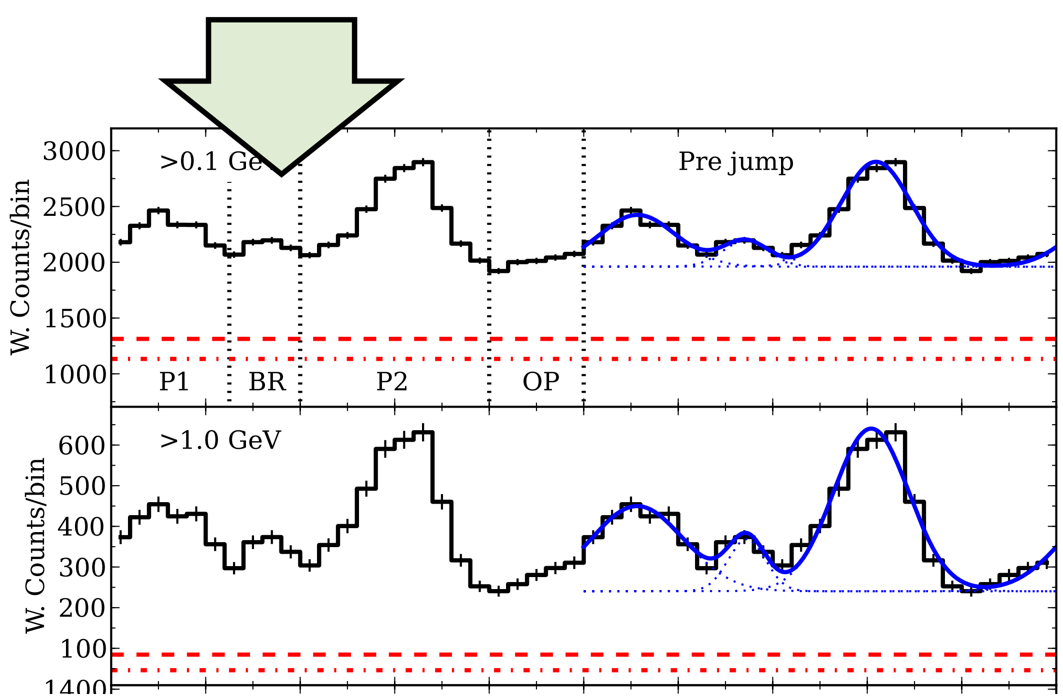
like the two following cases....

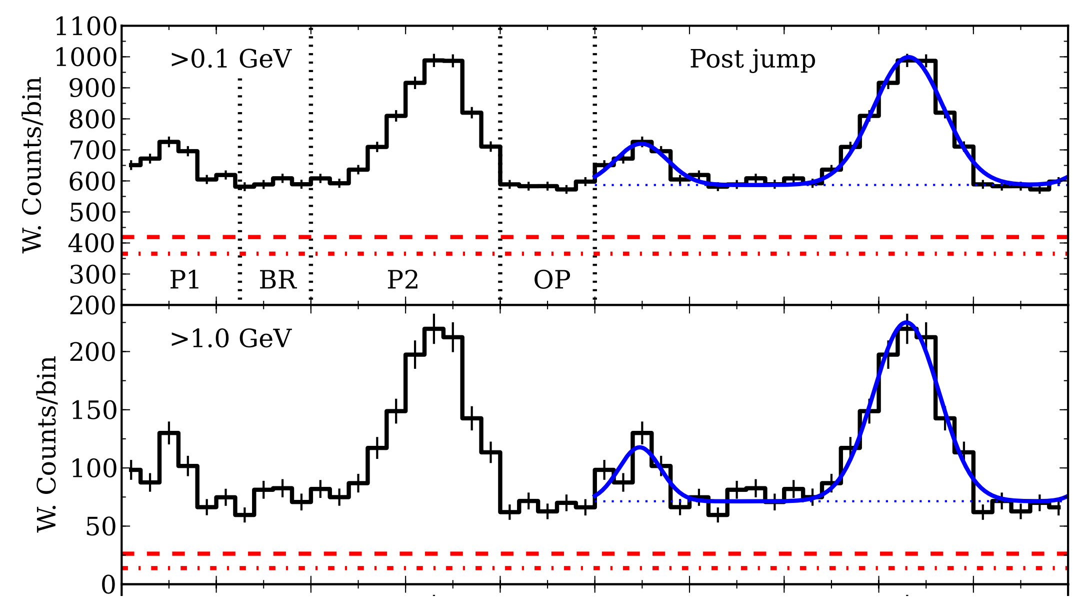
# Fermi Gamma-ray pulsar: 20% flux decrease (>100 MeV) associated with a 4% increase in spindown rate (in 1 week).

PSR J2021+4026



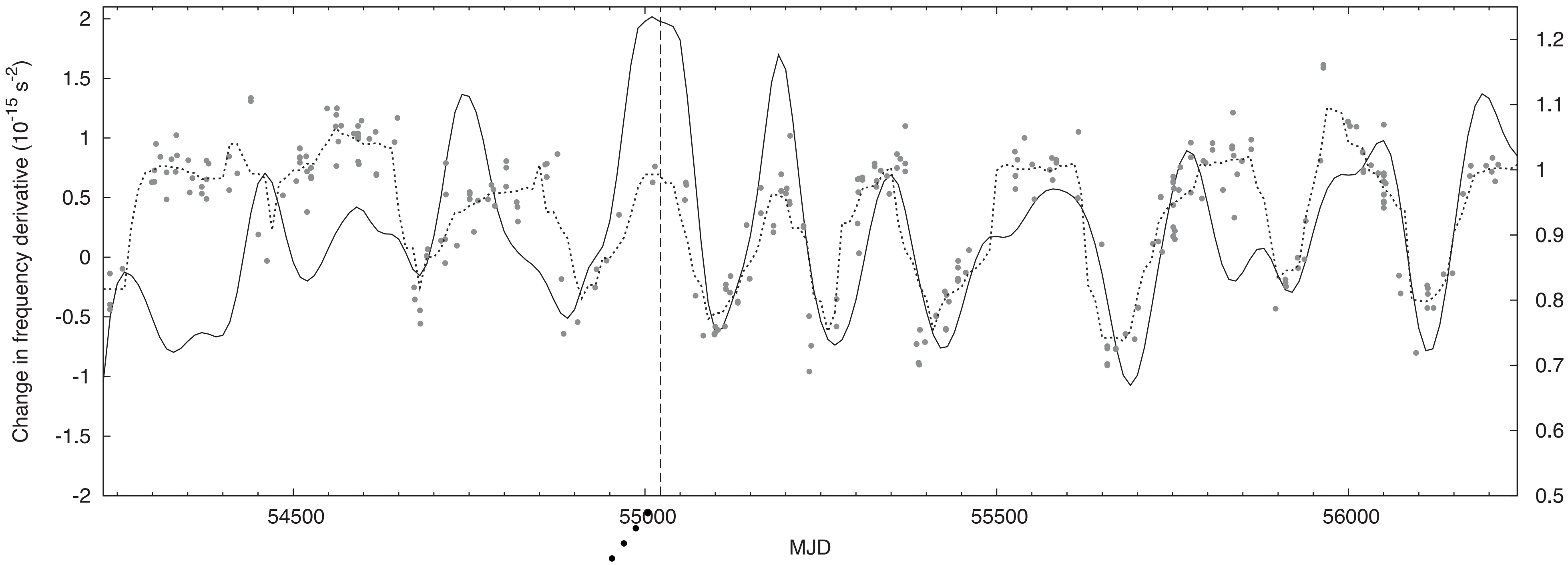

Allafort et al. (2013)

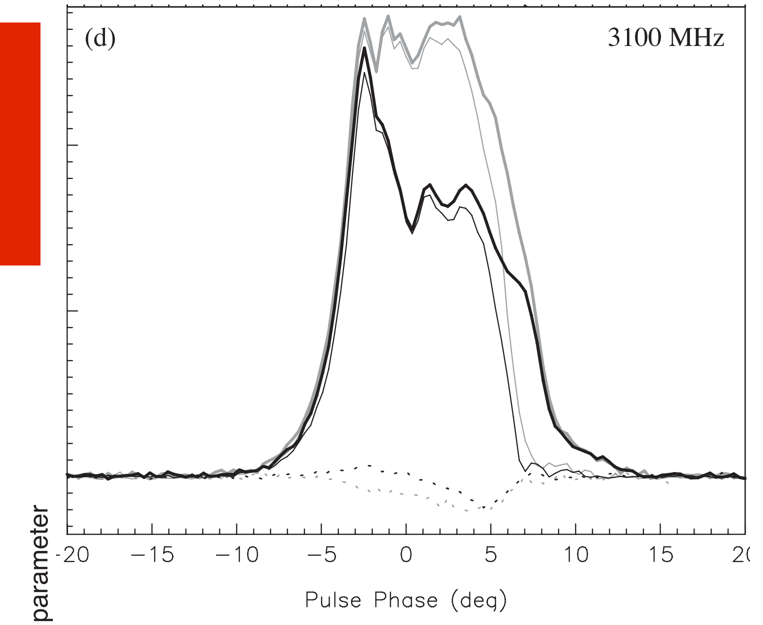



Timing noise (spindown changes) related to magnetospheric variability

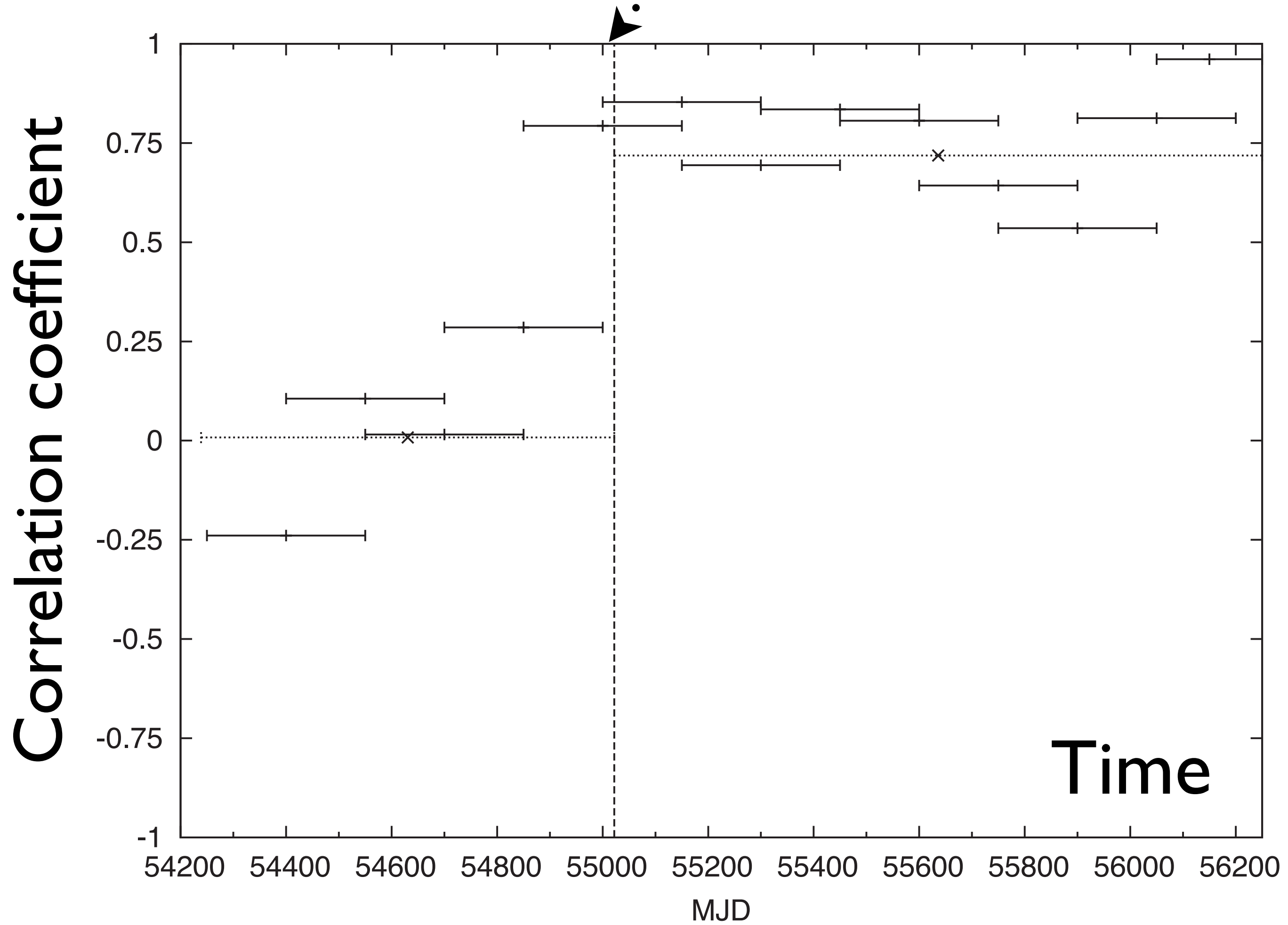
# Correlation between pulse shape variations and spindown switches **only after glitch**




PSR J0742-2822

**Keith et al. (2013)**




**Connection between glitches and exterior?**

Case of PSR J1119-6127
(Weltevrede et al. 2011)

Some magnetars
(Dib et al. 2014)

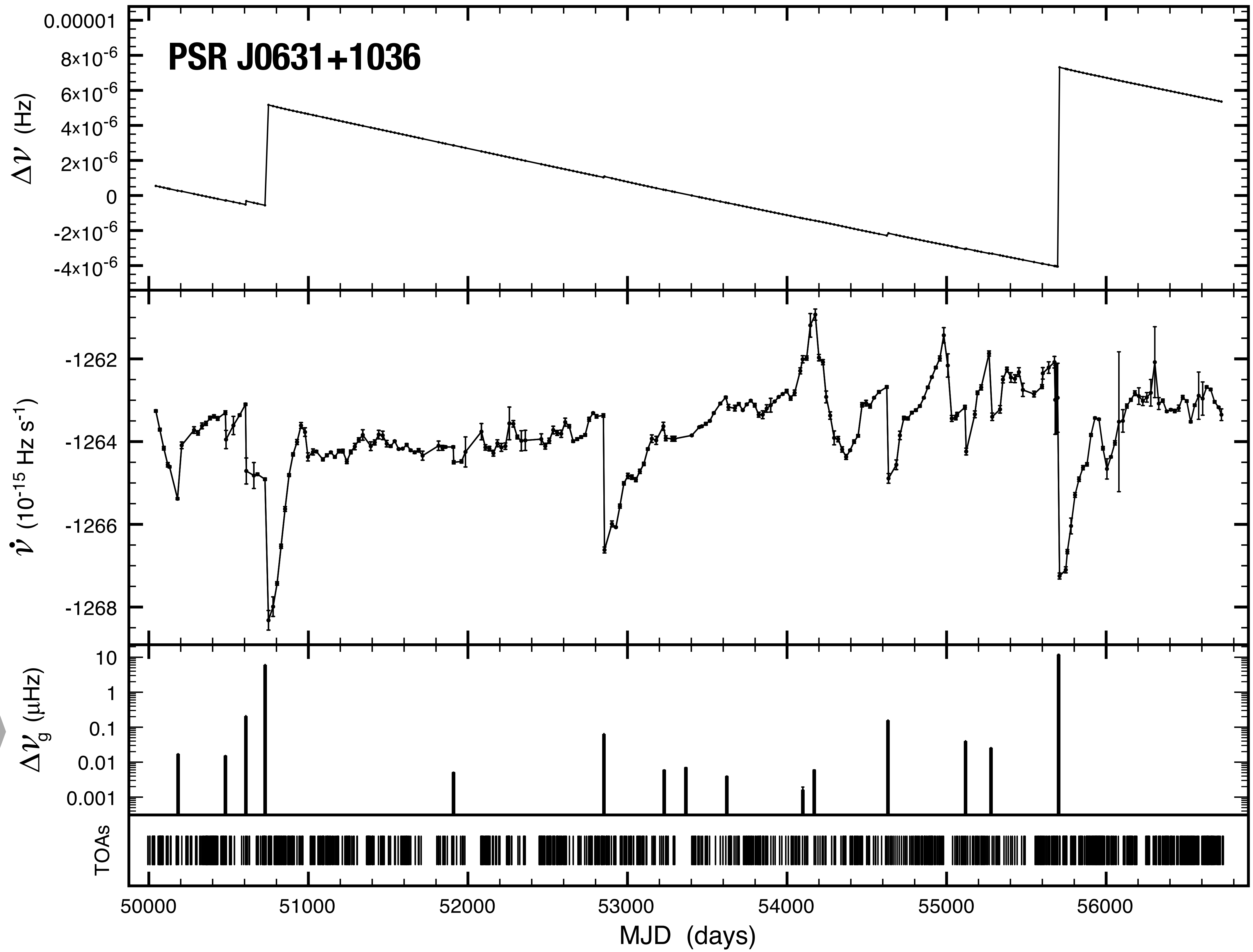
# Concluding...

Both phenomena coexist **Glitches & timing noise**

$\nu$–residuals

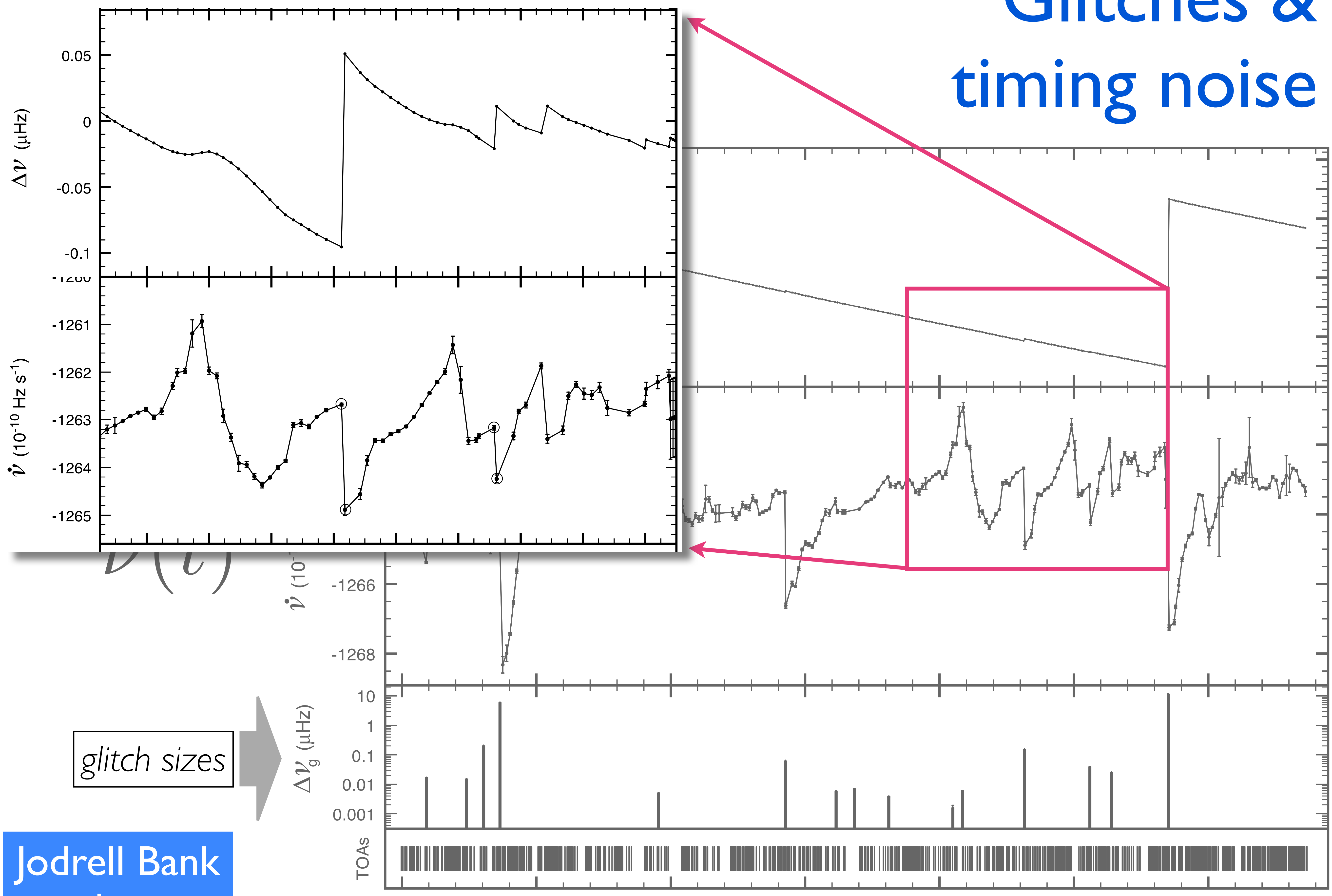
$\dot{\nu}(t)$

glitch sizes




Jodrell Bank data

# Glitches & timing noise



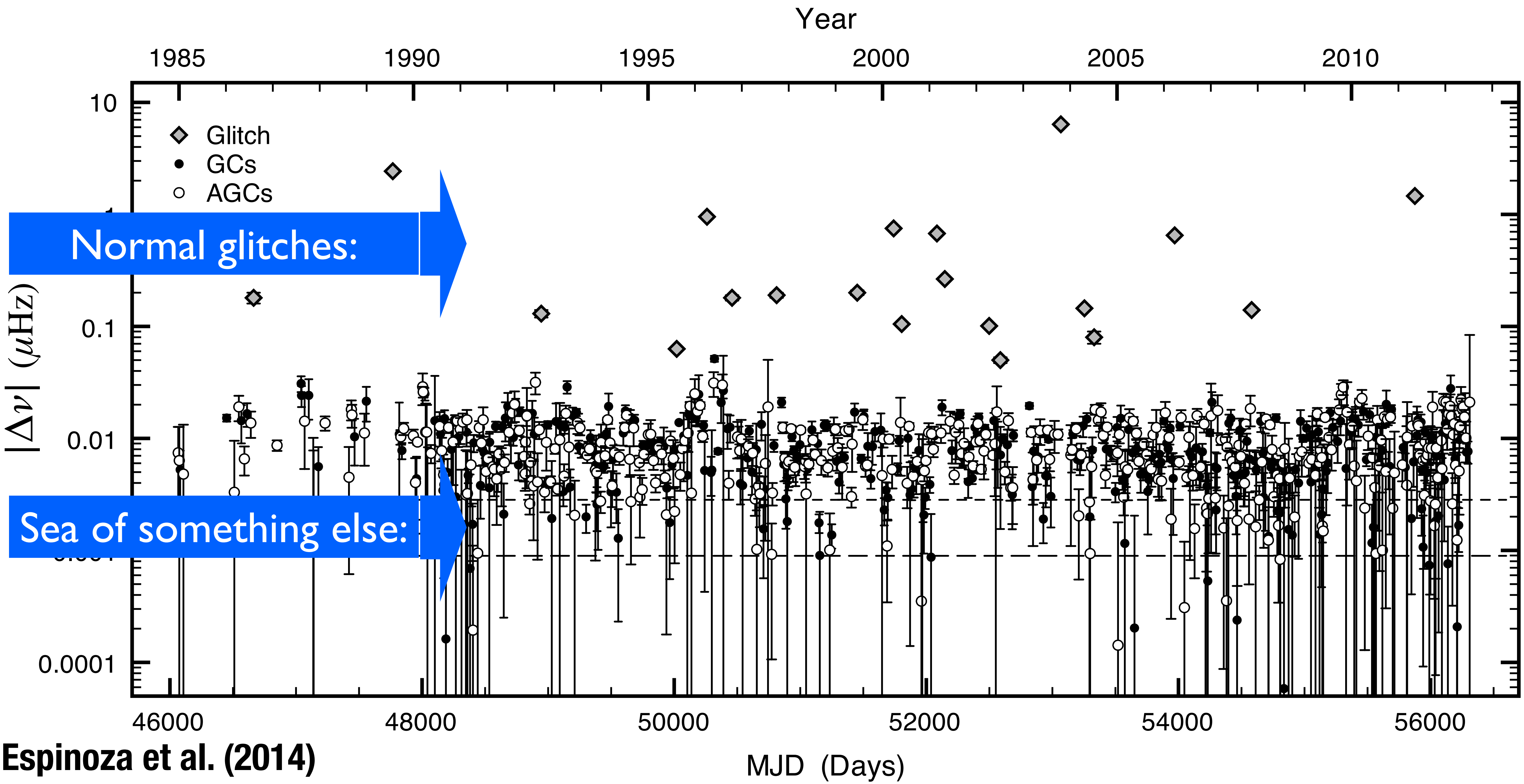

Jodrell Bank data

# Crab pulsar:

Measured all small irregularities like if they were glitches (or "anti-glitches")

- It could be that this is not the right description (DM variations; pure spindown rate changes)
- Maybe there is a second regime of superfluid effects (+, -). E.g.: Kantor & Guzakov; Melatos & Link (superfluid turbulence, 2014)
- Magnetospheric timing noise

*Work in progress...*




Espinoza et al. (2014)

# Summary/Questions

- glitches and timing noise are the major deviations from simple slowdown model.
- they correspond to external and internal dynamical processes capable of affect the rotation.
- What modulates magnetospheric states?
- Is the magnetospheric timing noise all the same?
- Is all timing noise produced in the magnetosphere? Is there a component produced by the superfluid? -- Second glitch regime
- Glitch triggers could be multiple. E.g.: quakes + critical lag

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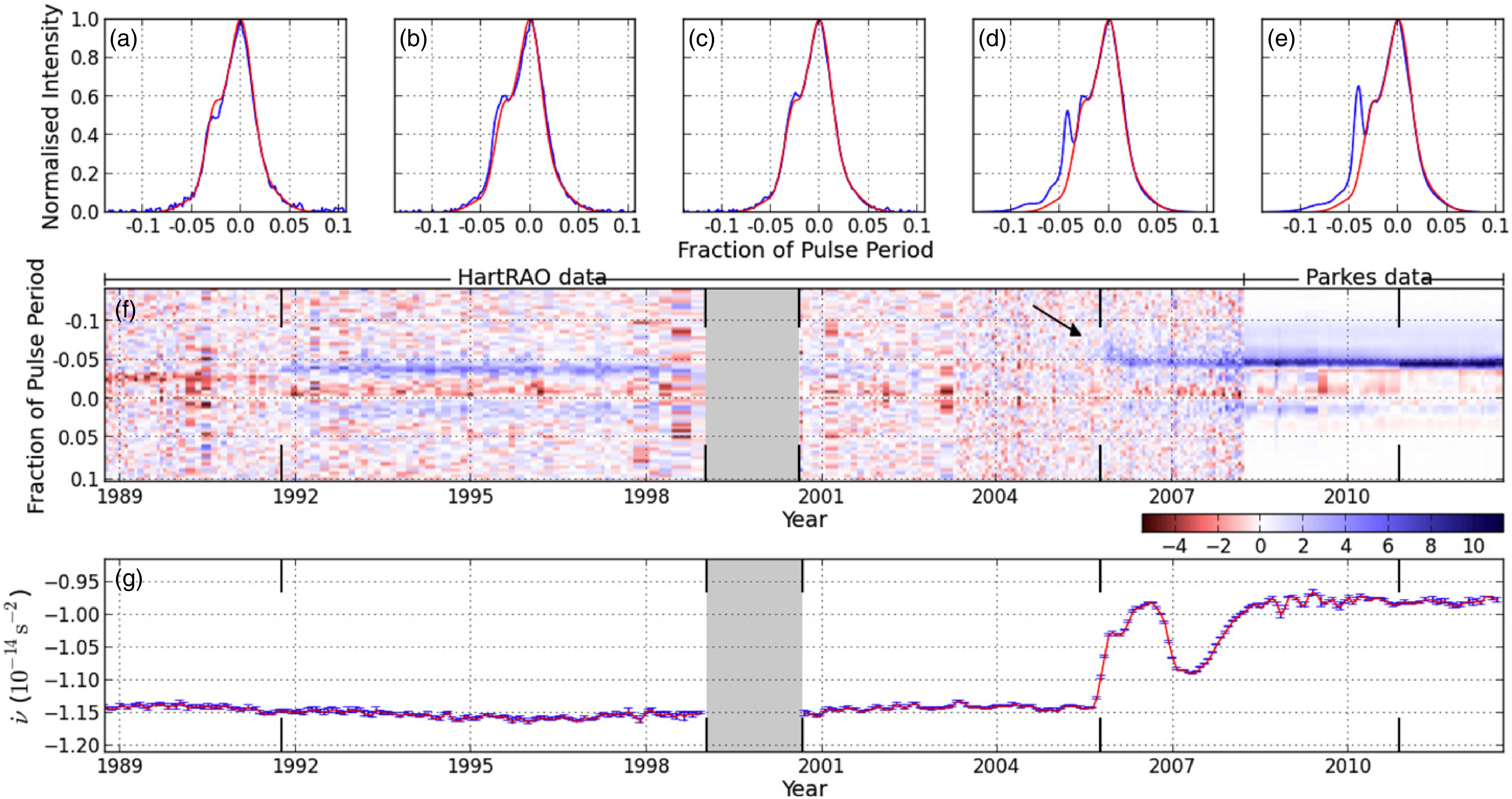
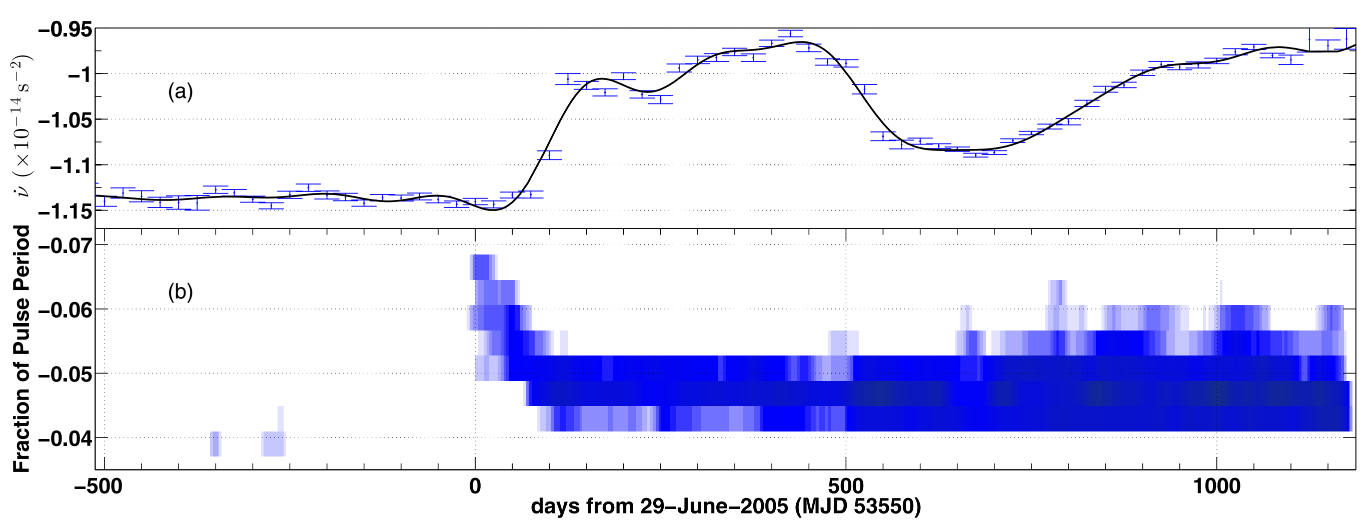
# However, spindown switches can be slow




**Brooks et al. (2014)**
**Karastergiou et al. (2011)**

Asteroid