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The glitch activity of the Crab pulsar

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The structure and signals of neutron stars - Florence

Glitches

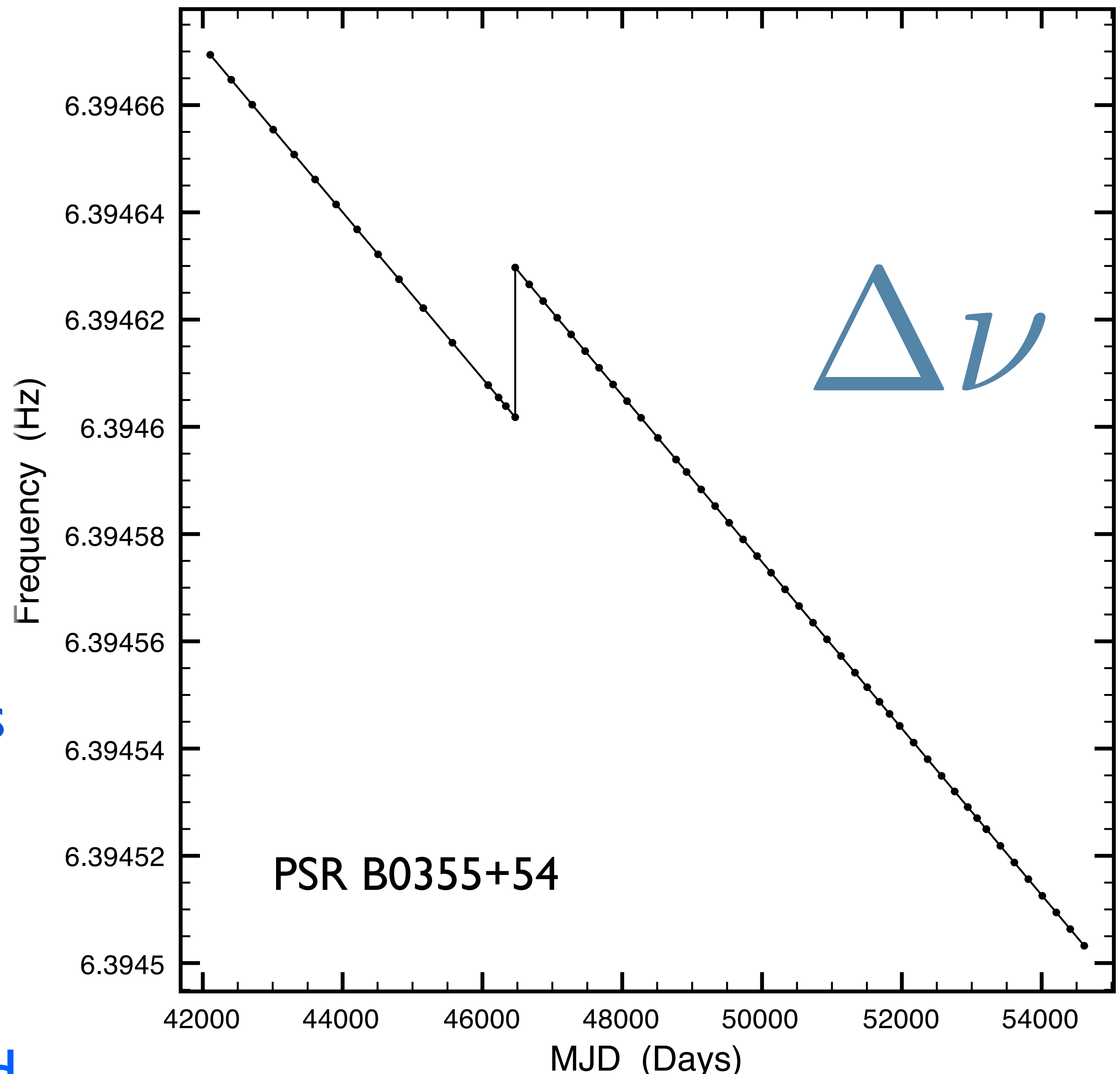
Occasional spin-up events interrupting the rotation.

Observed sizes cover ~5 decades

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

Common to all Neutron Stars

Glitch activity proportional to spin-down rate.

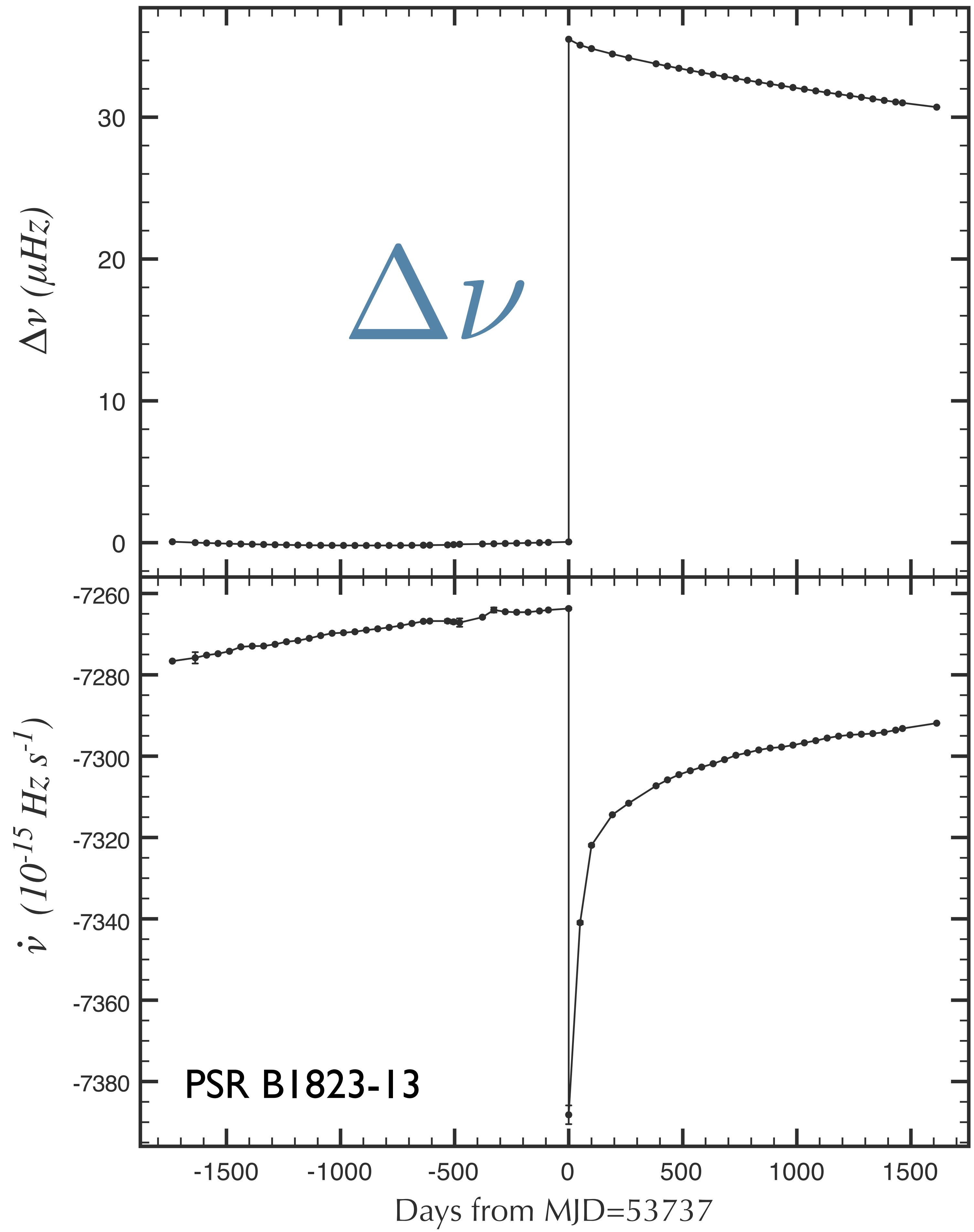


In general, radiatively quiet and therefore associated to the interior of NSs.

Glitches

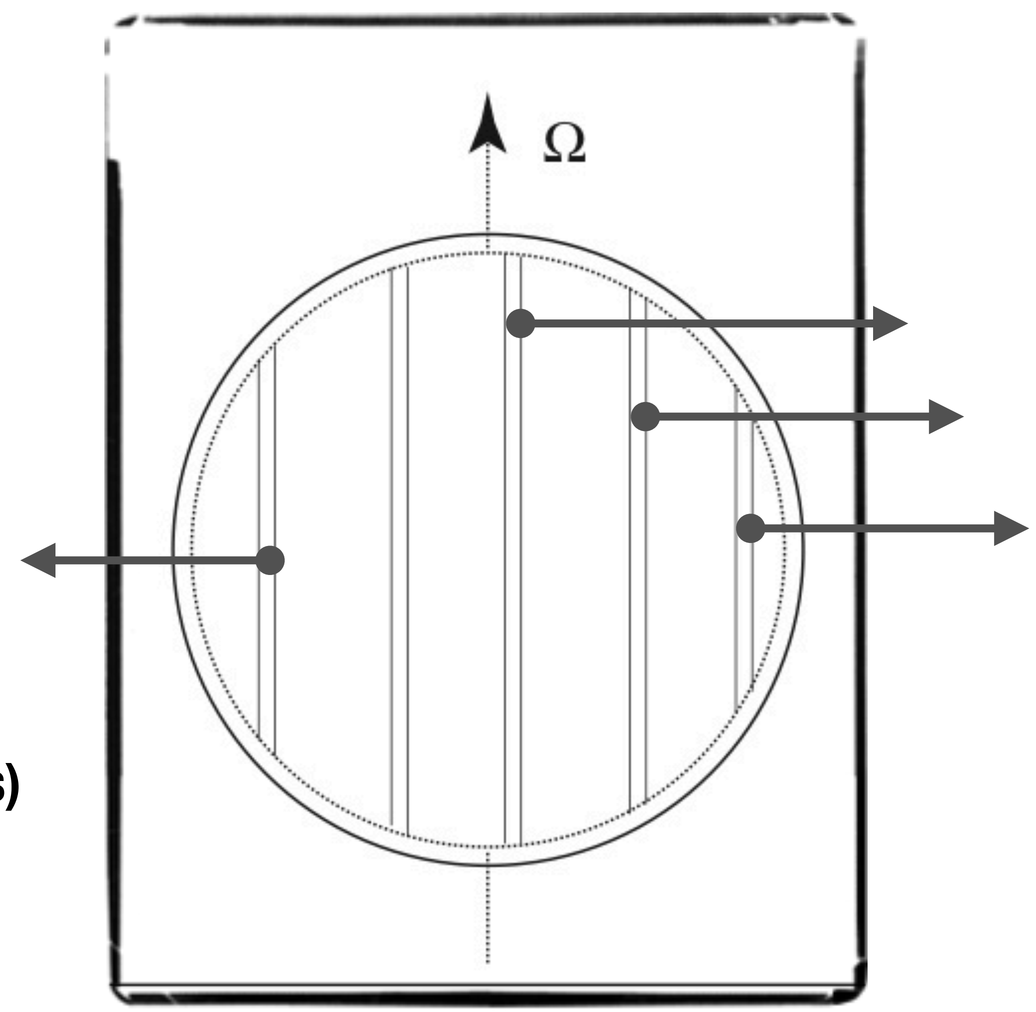
Commonly followed by a <u>negative</u> change in spin-down rate.

$$\Delta\dot{\nu}$$



What can produce a glitch?

- Crust rearrangements; cooling, re-shape via slowdown. **(Baym et al. 1969)**
- Rapid angular momentum transfer from internal superfluid to outer Crust; result of halted vortex migration. **(Anderson & Itoh 1975; Alpar et al. 1984; many many others)**
- Magnetic field stresses on the crust driven by vortex migration. **(Ruderman et al. 1998)**

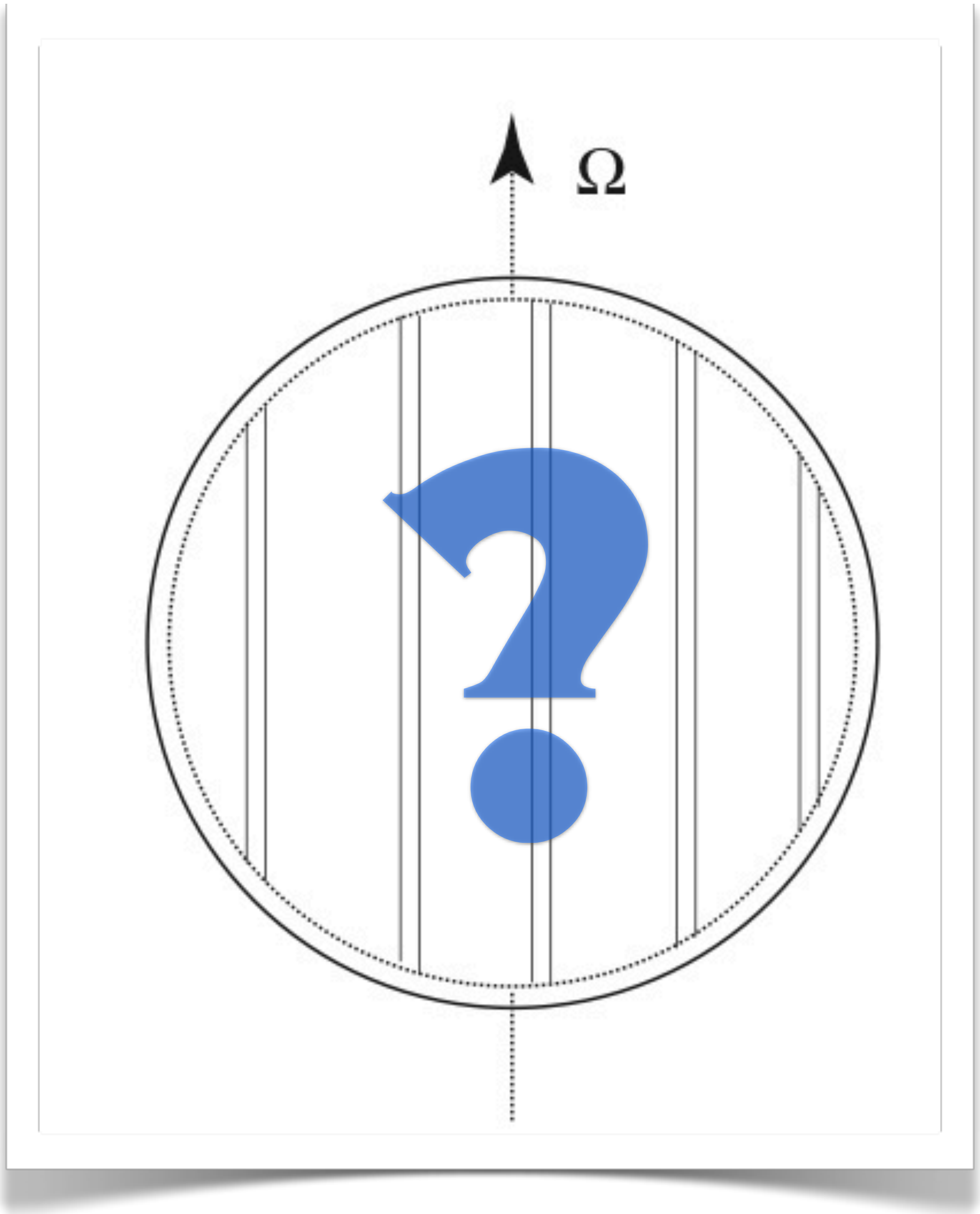


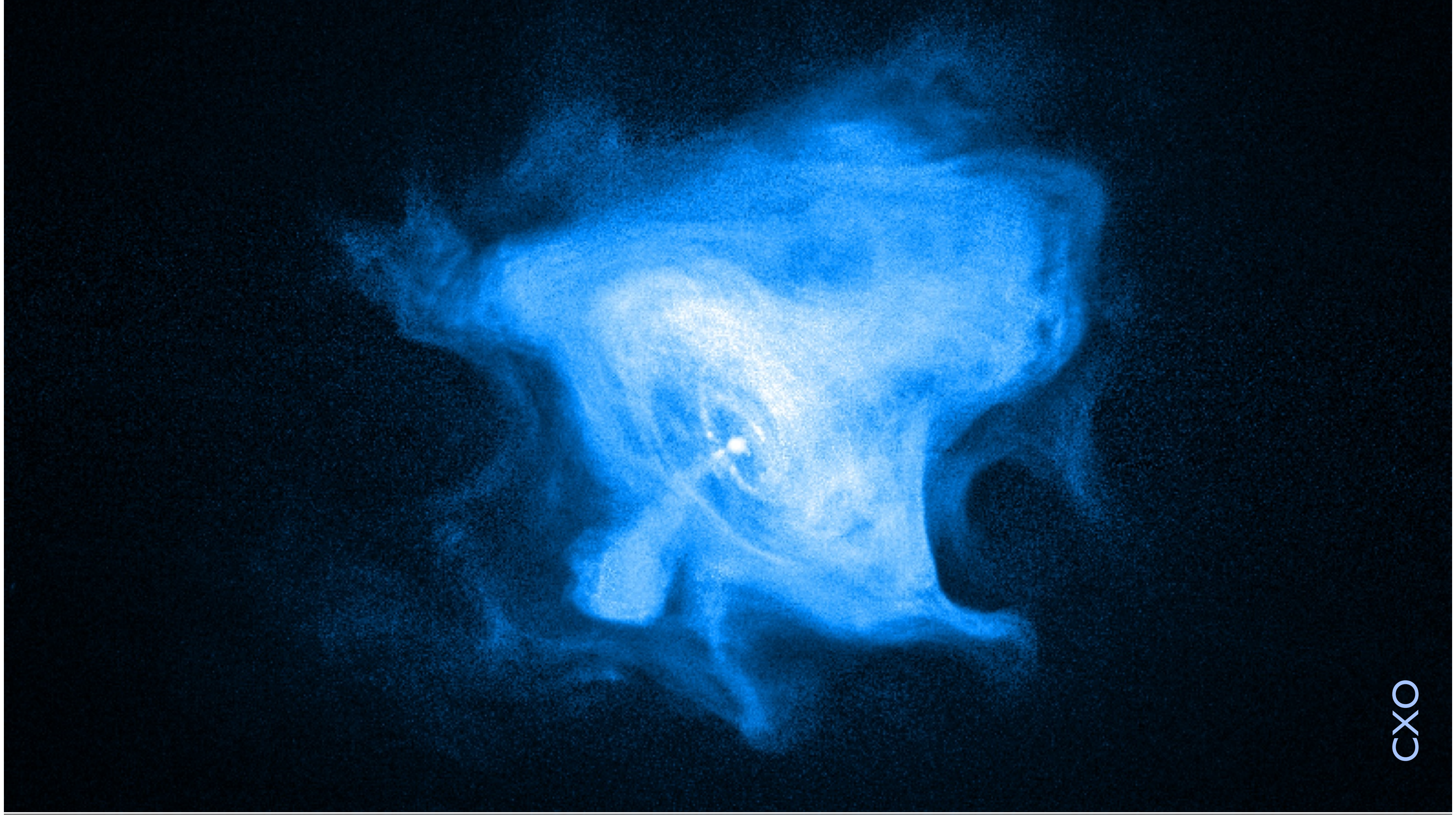
M. Ruderman (2009)

internal or crust process

Outline

- The Crab pulsar.
- Three main glitchy aspects:
  - Sizes (*detection limits*)
  - Recoveries (*new feature*!)
  - Waiting times (*episode*)
- Conclusions / Summary.





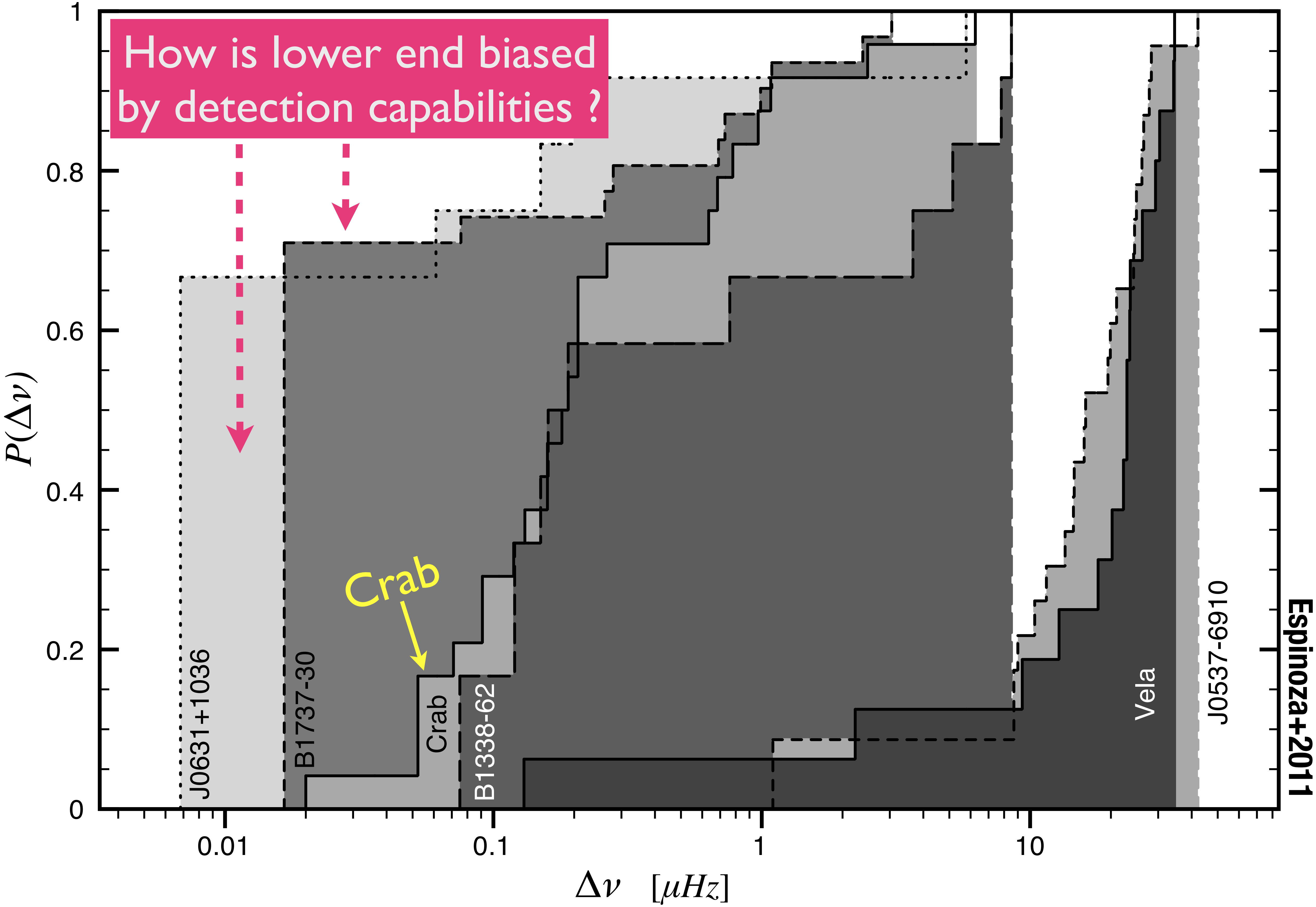
The Crab pulsar

Born during the AD 1054 supernova (i.e. 959 yr old)
Normal B-field but Energetic (high Edot)
Pulsations detected from low freq. radio up to VHE

24 glitches detected in 45 years

Cumulative size distributions for 6 PSRs:

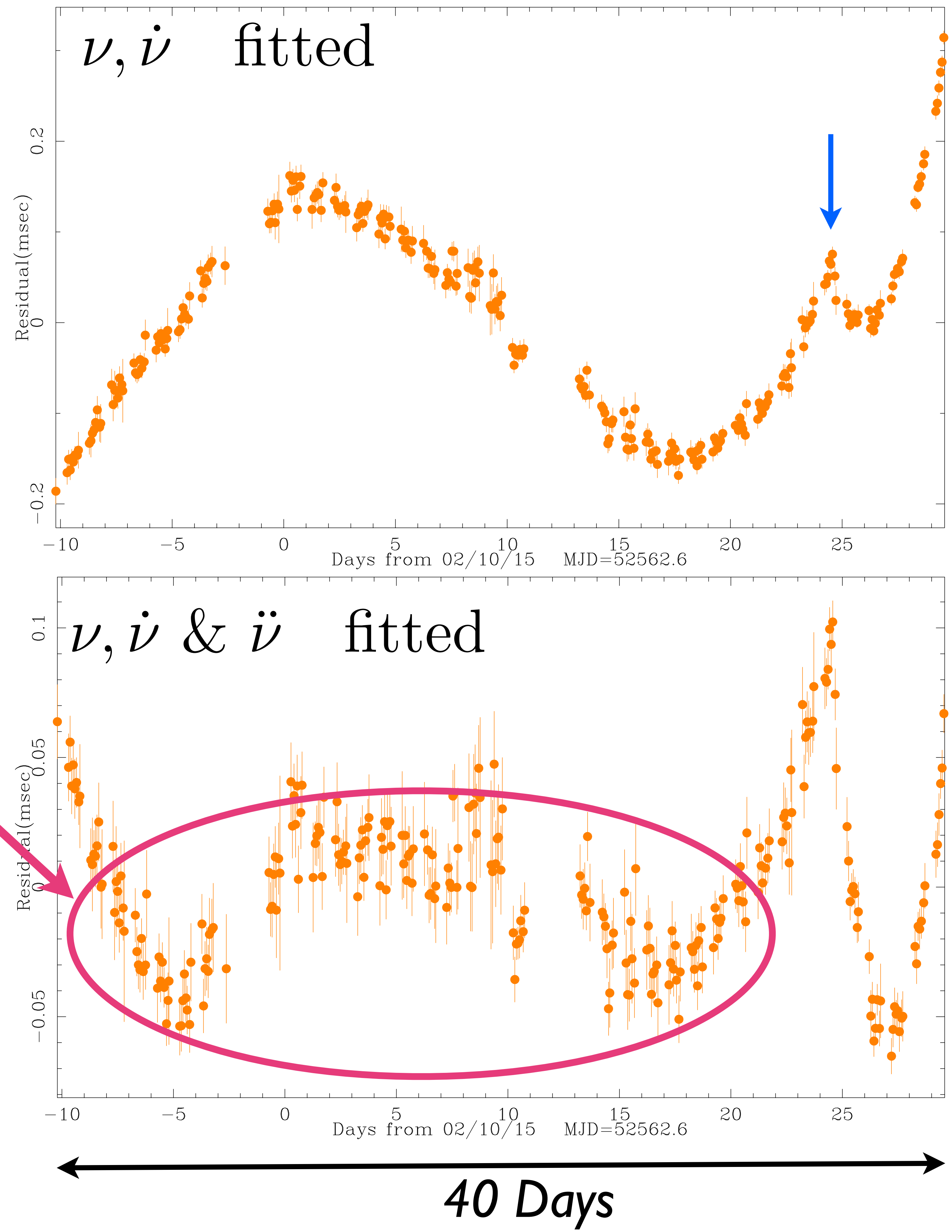
Crab: middle size glitches; power law.



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

Small glitches can be confused with timing noise.

- timing residuals -



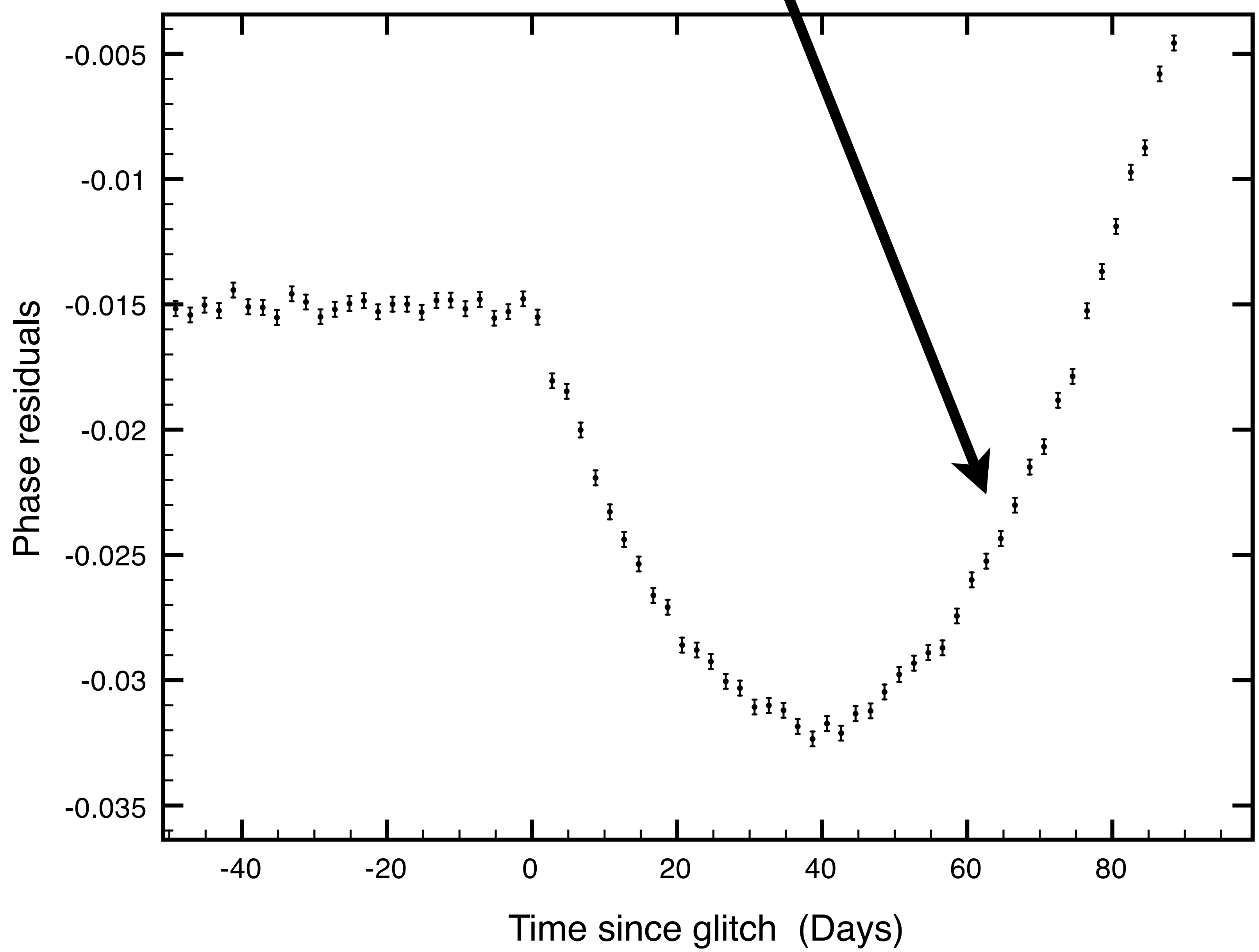
Limits on glitch detection

After glitch: $$\phi_g = -\Delta\nu(t-t_g) - \Delta\dot{\nu}\frac{(t-t_g)^2}{2} \quad ; \quad (t > t_g)\,.$$

Maximum detectable freq. step depends on cadence, RMS (\sigma) and spin-down rate change

$$\Delta\nu_{\rm lim} = \max\begin{cases} \Delta T|\Delta\dot{\nu}|/2 \\ \sqrt{2\,\sigma_\phi|\Delta\dot{\nu}|} \end{cases}$$

$$(\text{for} \quad \Delta\dot{\nu} < 0)$$



Espinoza+2014

The Crab pulsar

Jodrell Bank Observatory

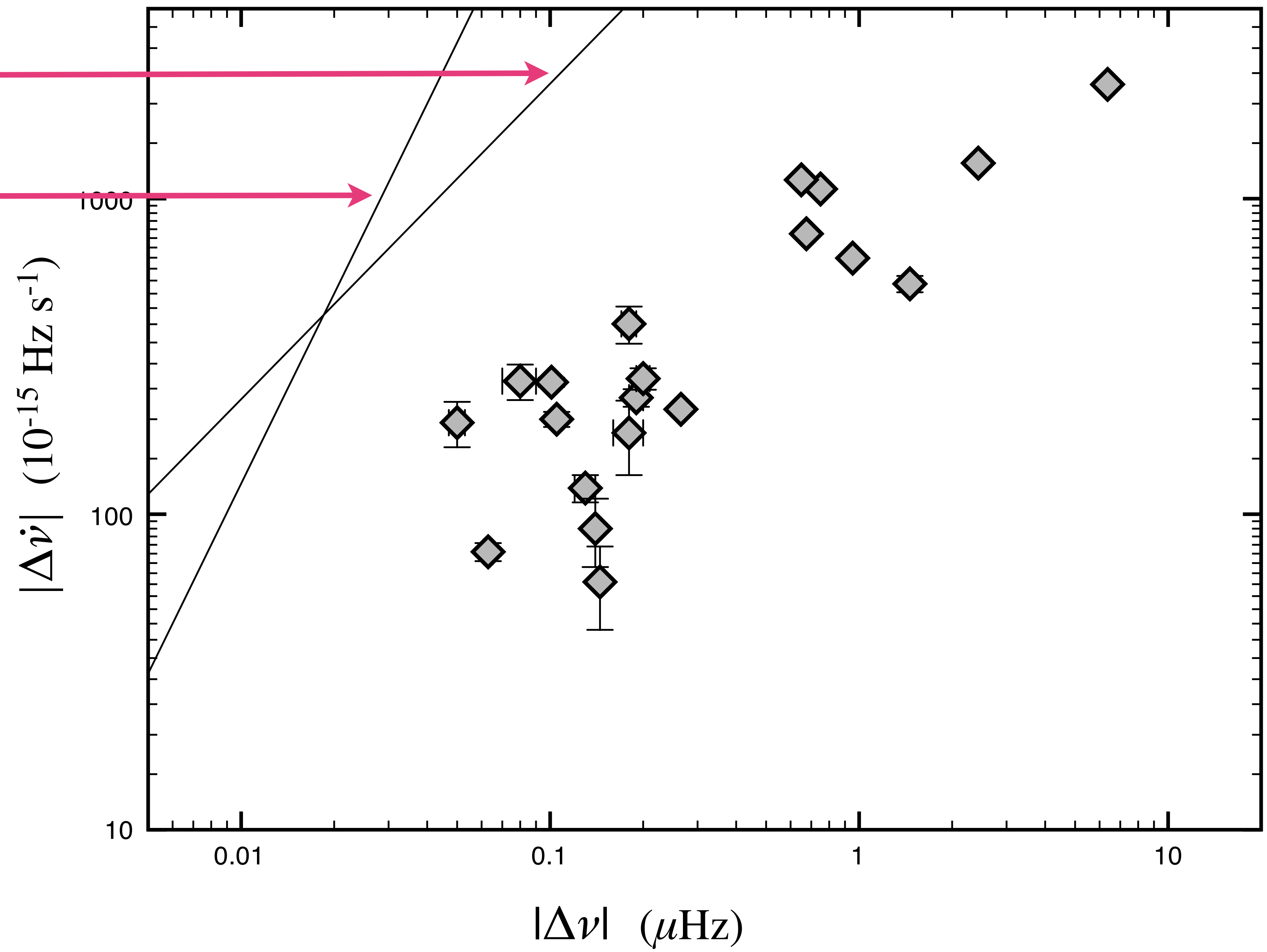
- Rotation monitored almost daily during 29 yr (42-ft telescope)

- 20 glitches in that period.

The 20 glitches
in the last 29 yr of data

$$\Delta\nu_{\rm lim} = \max \begin{cases} \Delta T|\Delta\dot{\nu}|/2 \\ \sqrt{2\,\sigma_\phi|\Delta\dot{\nu}|} \end{cases}$$

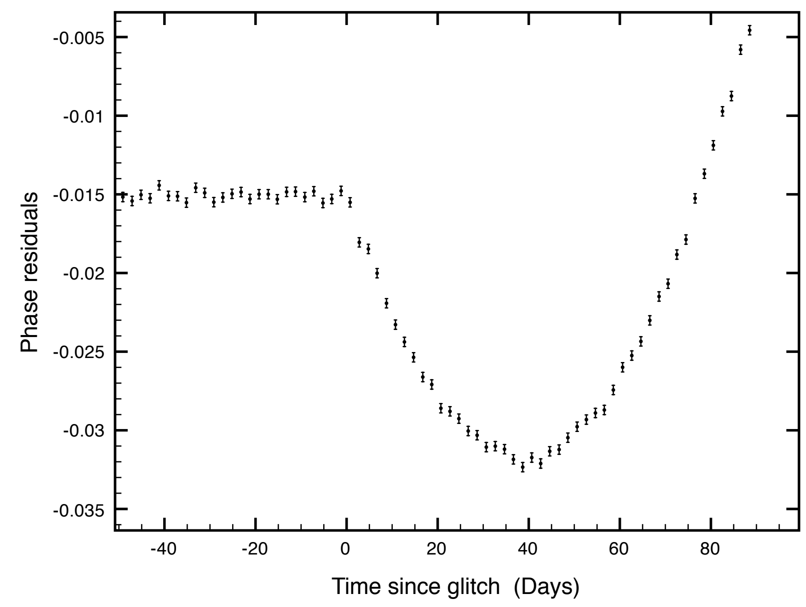
- ➡ Cadence ~ 1 day
- ➡ RMS ~0.0004 ph (20 TOAs)

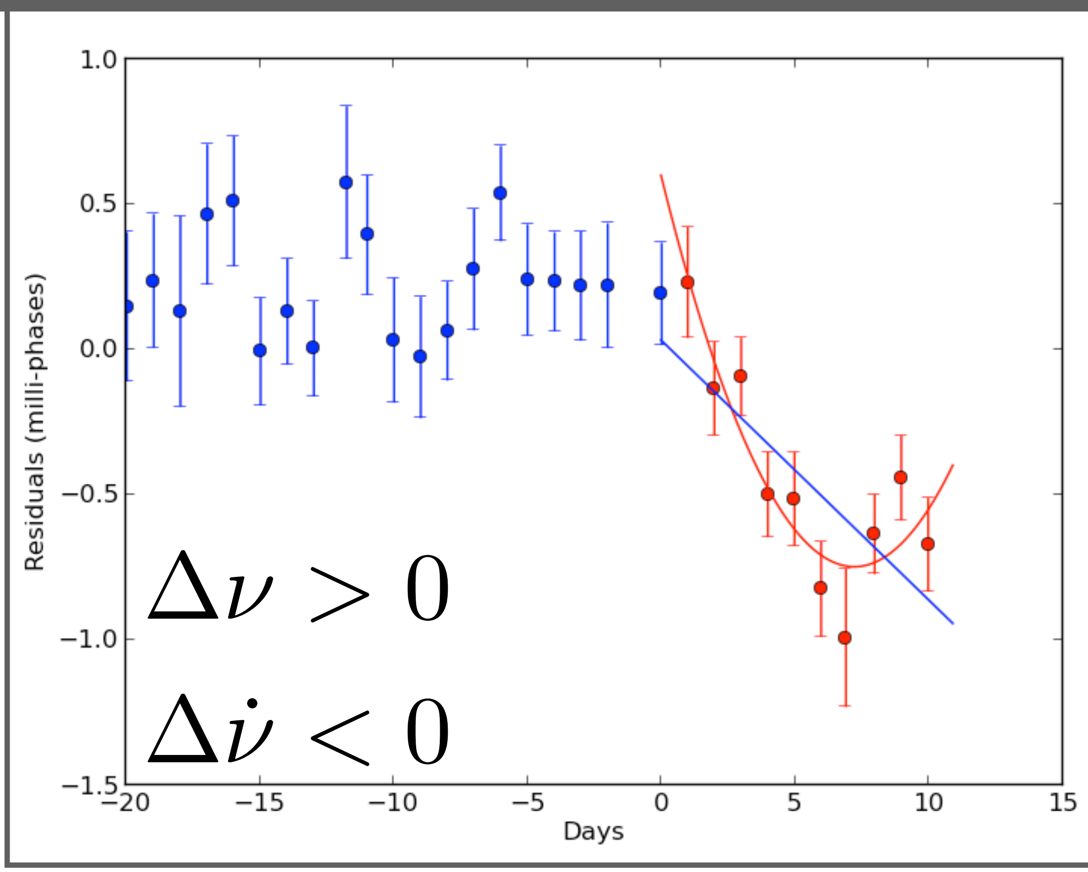


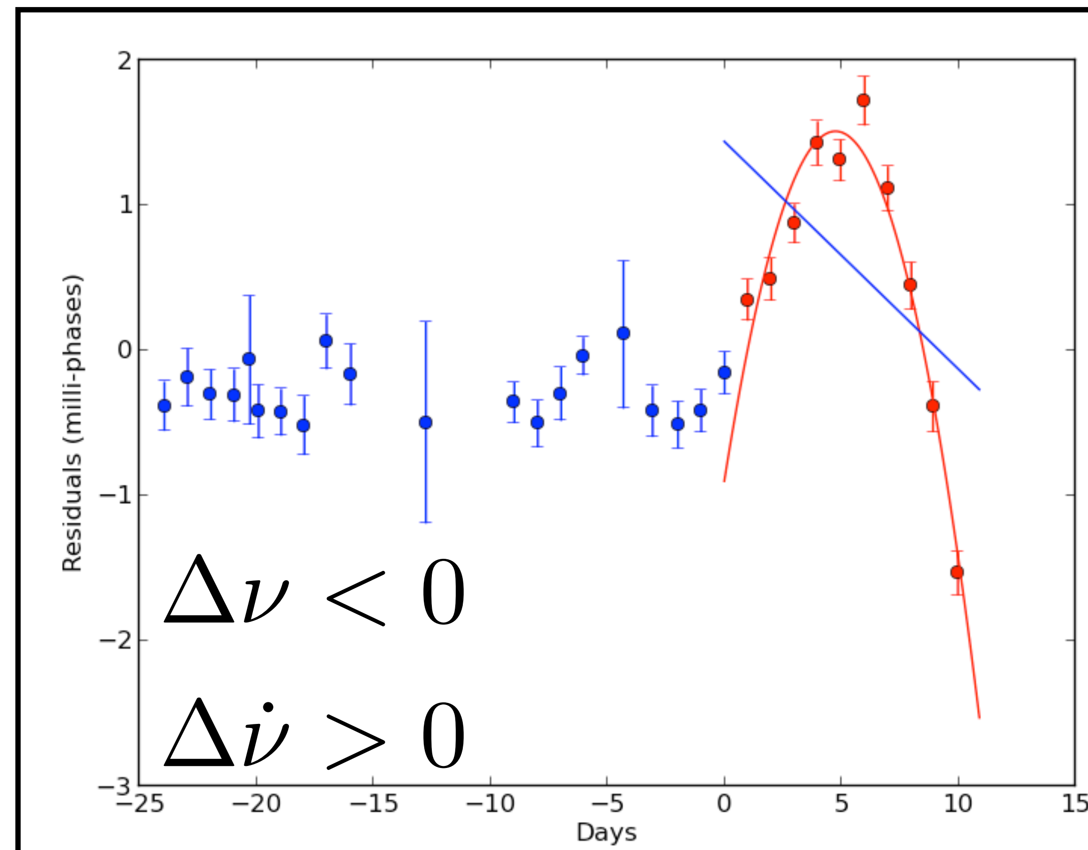
Have all glitches in this period already been detected?

There are no other glitches reported: Wong+2001; Wang+2012; Espinoza+2011

Developed automatic method to detect and measure every signature resembling a glitch





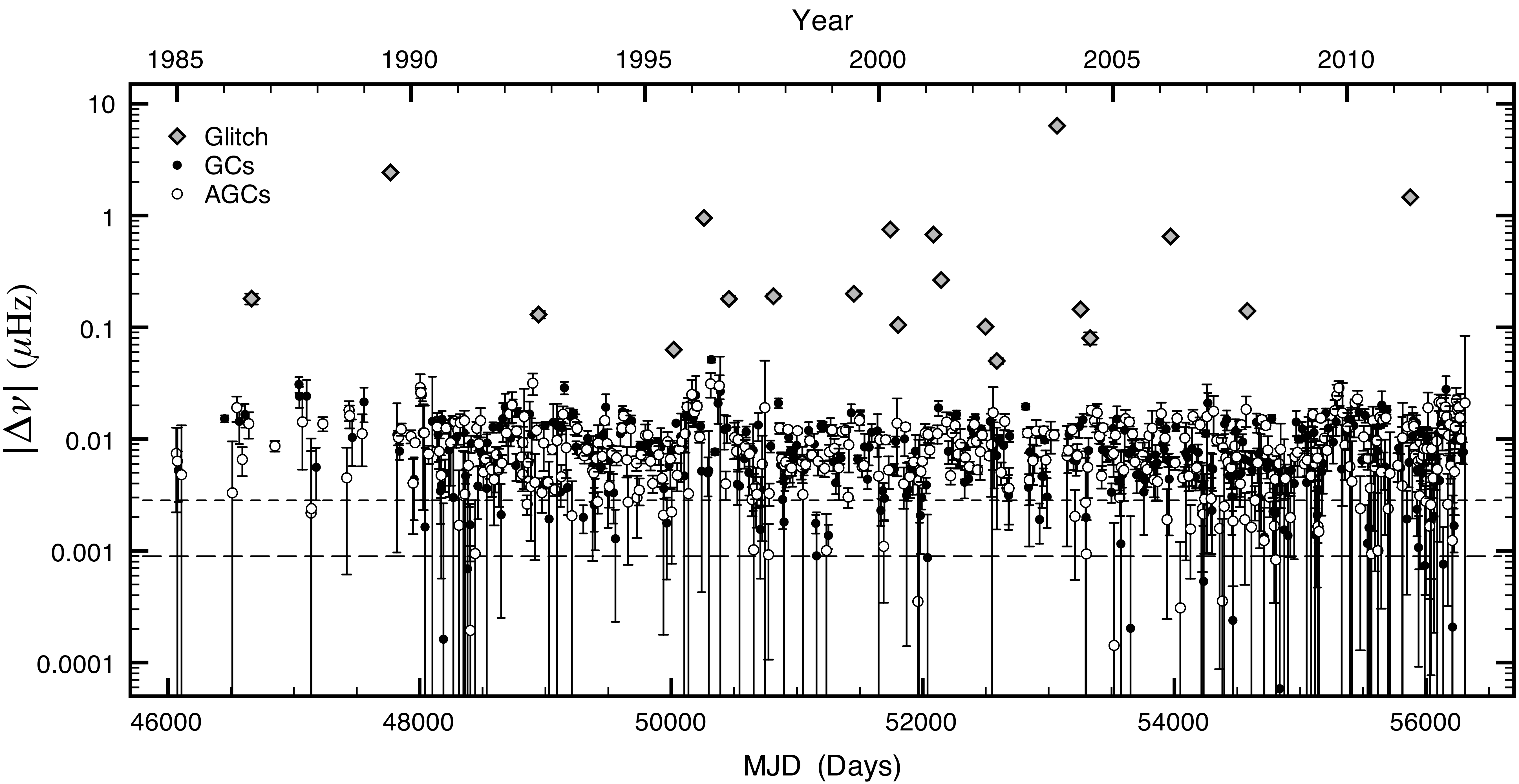


And the same was done for signatures with the exact opposite signs ("*anti-glitches*")

More details in Espinoza, Antonopoulou, Stappers, Watts & Lyne (2014).

...found 381 glitch candidates (GCs) and 383 *anti-glitch* (AGCs) candidates

Most candidates have $\Delta\nu < |0.03|$ μHz

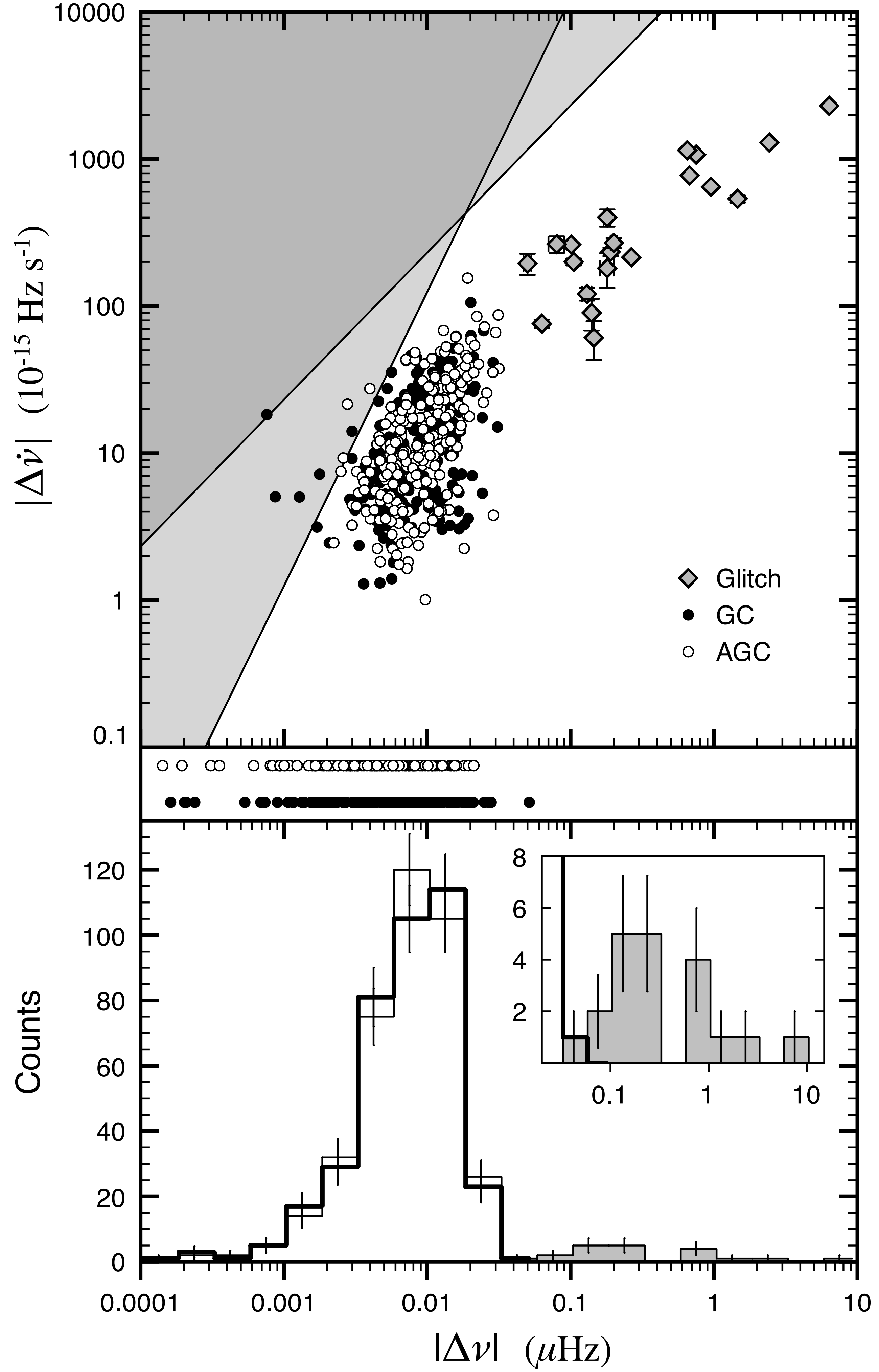


Espinoza+2014

F A C T S :

- Compared to previously known glitches, all candidates occupy a different place in the $|\Delta\nu|$–$|\Delta\dot{\nu}|$ plane.
- There are no "*anti-glitches*" above *0.03* μHz.

- Neither a power-law nor a lognormal dist. can describe the GCs + glitches together (KS *prob.* < *0.01%*).
- GCs and AGCs belong to same $\Delta\nu$ distribution (*96% prob.*).



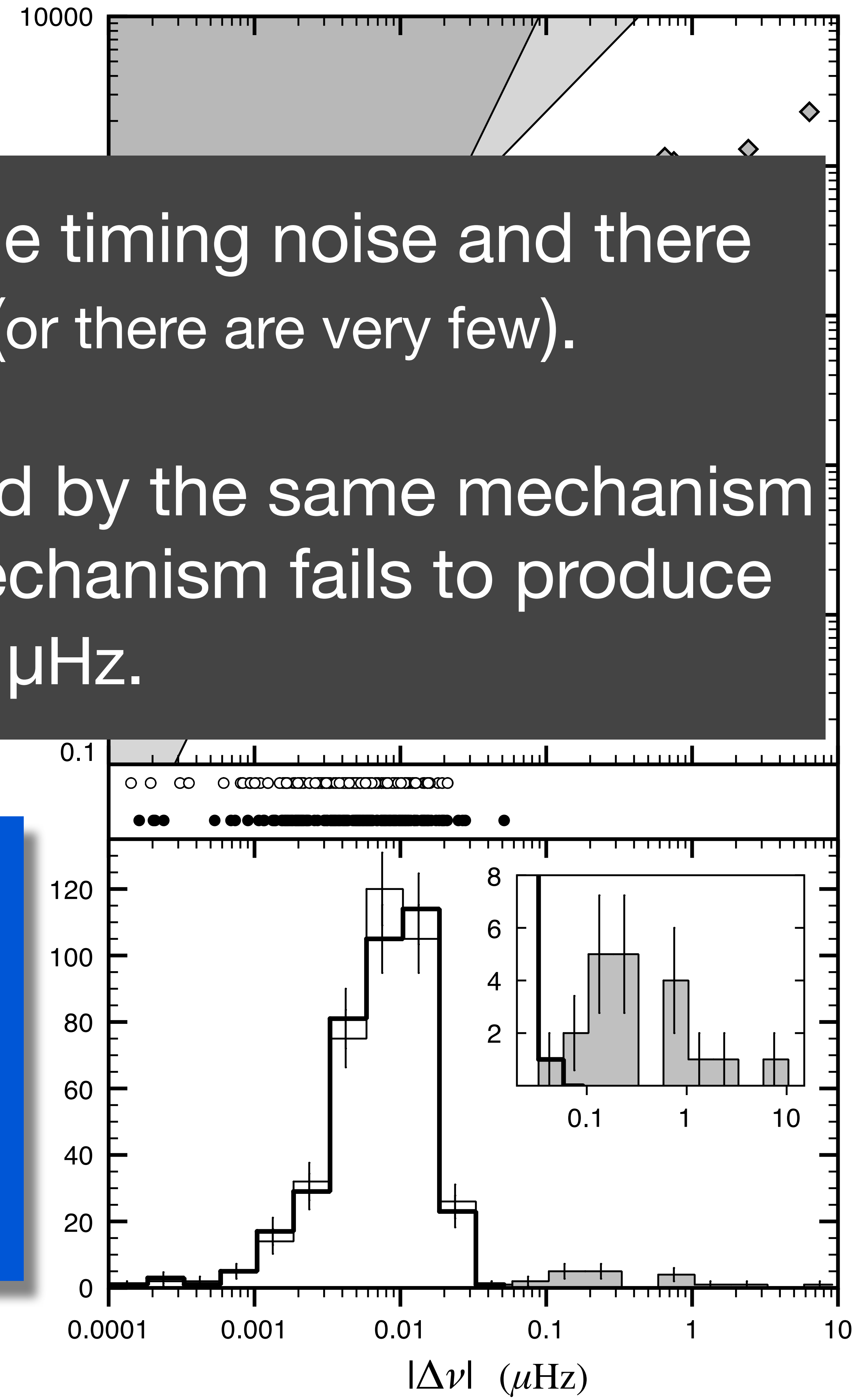
Espinoza+2014

Interpretations:

1) GCs and AGCs are part of the timing noise and there are no glitches below *0.05* μHz (or there are very few).

2) GCs and AGCs are generated by the same mechanism that produces glitches. This mechanism fails to produce "*anti-glitches*" larger than |*0.03*| μHz.

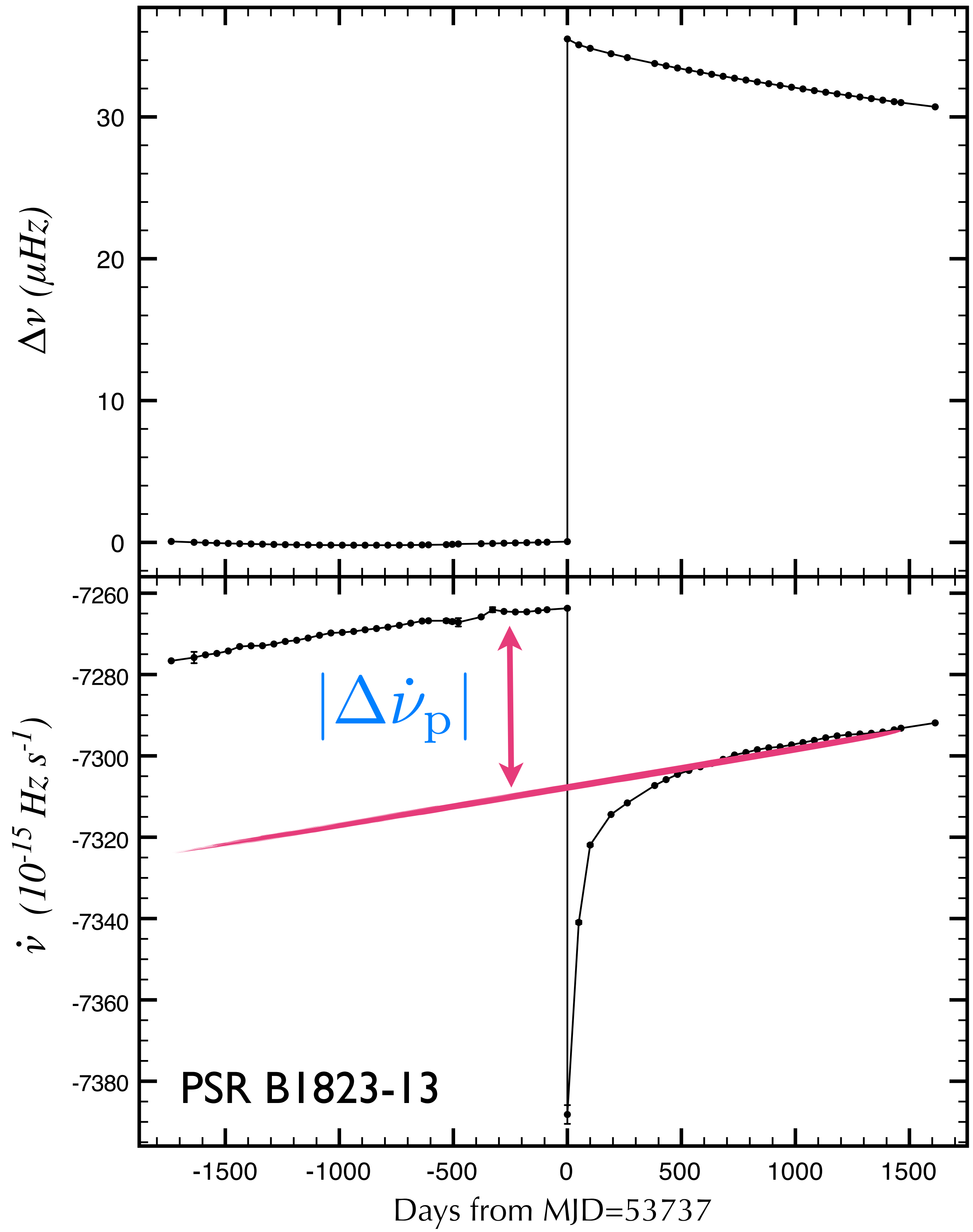
In any case, there is a break in the mechanism and it happens at freq. steps considerably larger than what could be expected by any model.

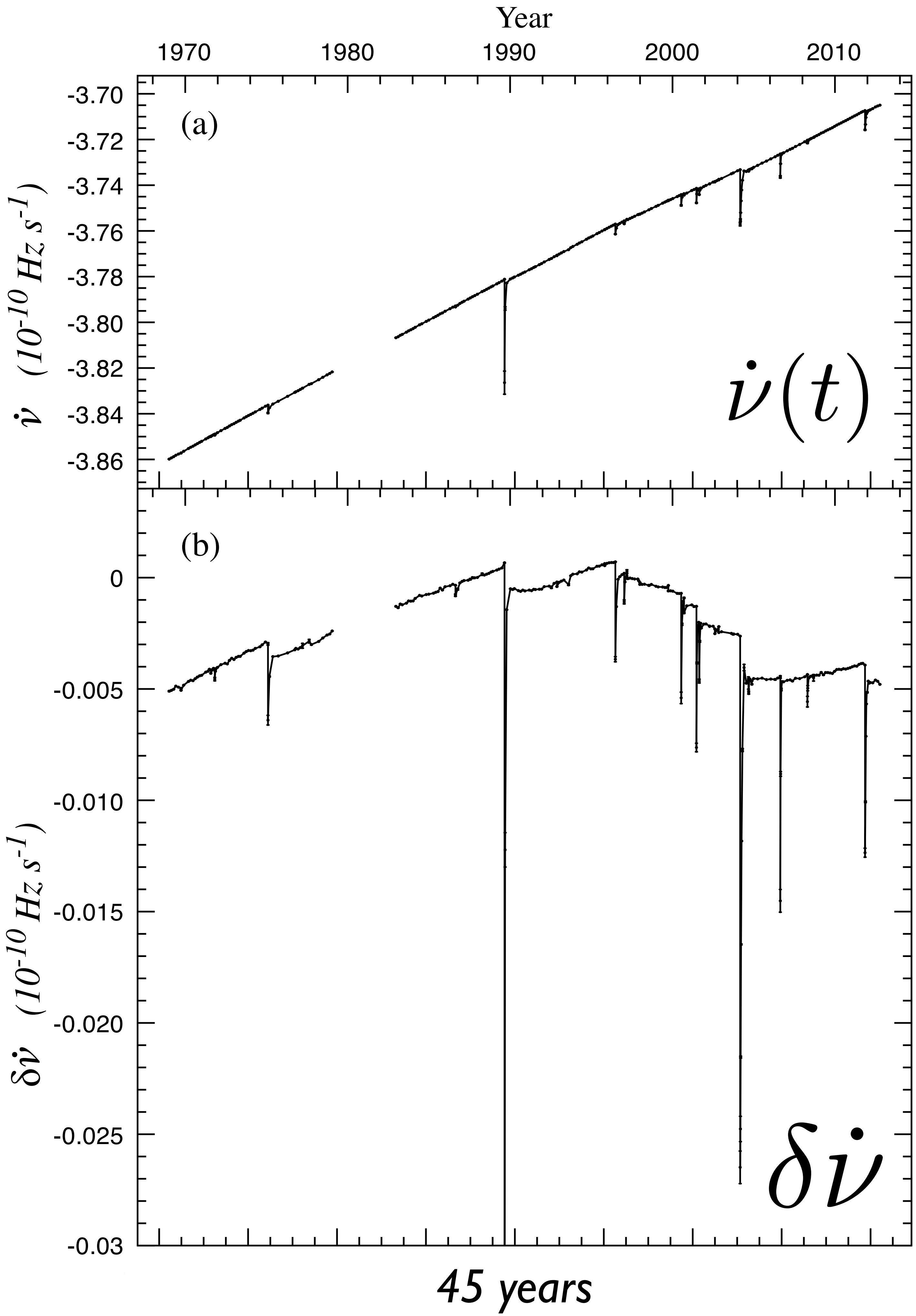


Glitch recoveries:

Persistent steps in spin-down rate

$$\dot{\nu}_{\rm g}(t) = \Delta\dot{\nu}_{\rm p} + \Delta\dot{\nu}_{\rm d} e^{-(t-t_{\rm g})/\tau_{\rm d}}$$





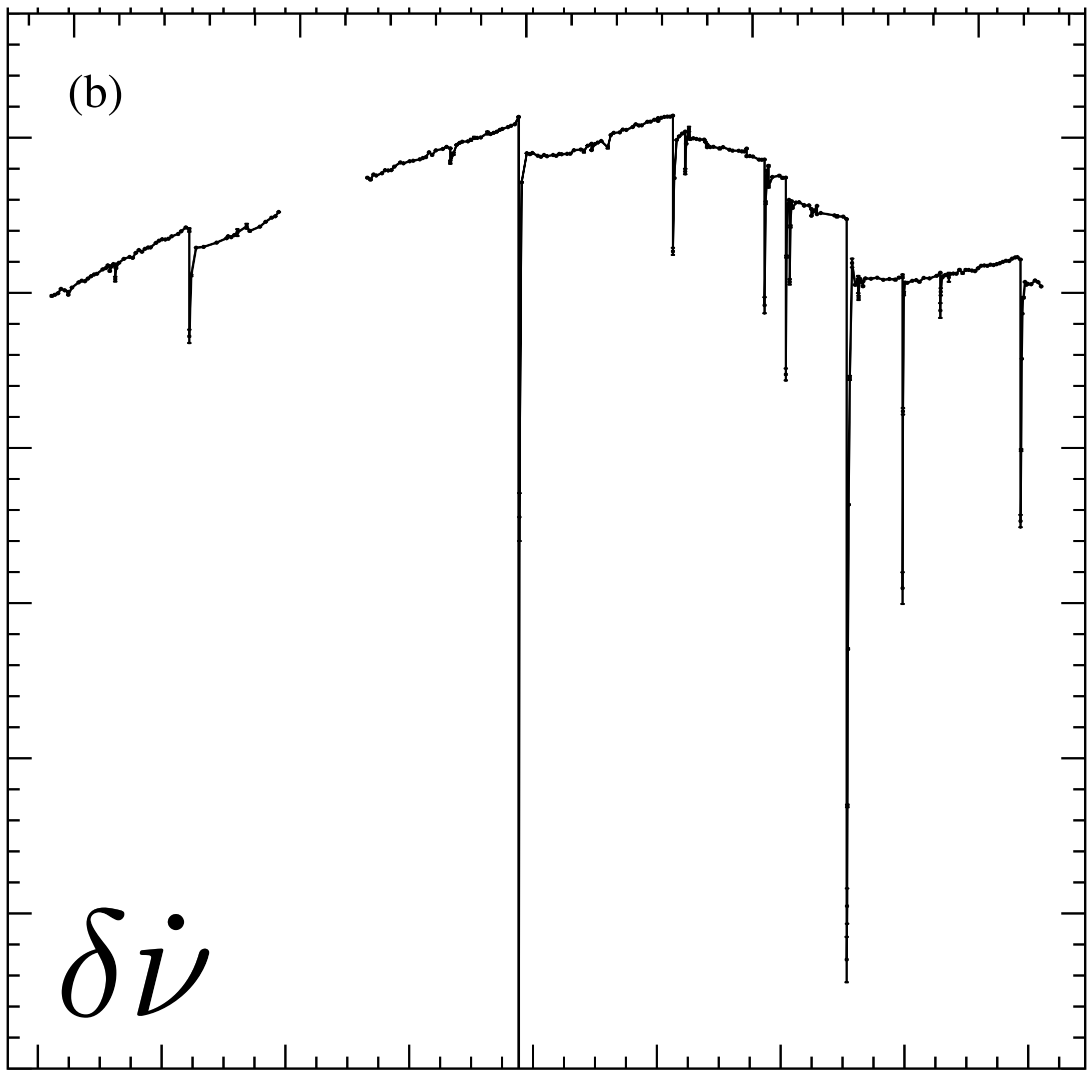
The persistent steps in the Crab pulsar:

- Reduce the effects of the slowdown rate by 6%.
- Decrease the global braking index from 2.5 to 2.34 (*i.e. increase of 0.2 on the slope of its movement on the P-Pdot diagram*).

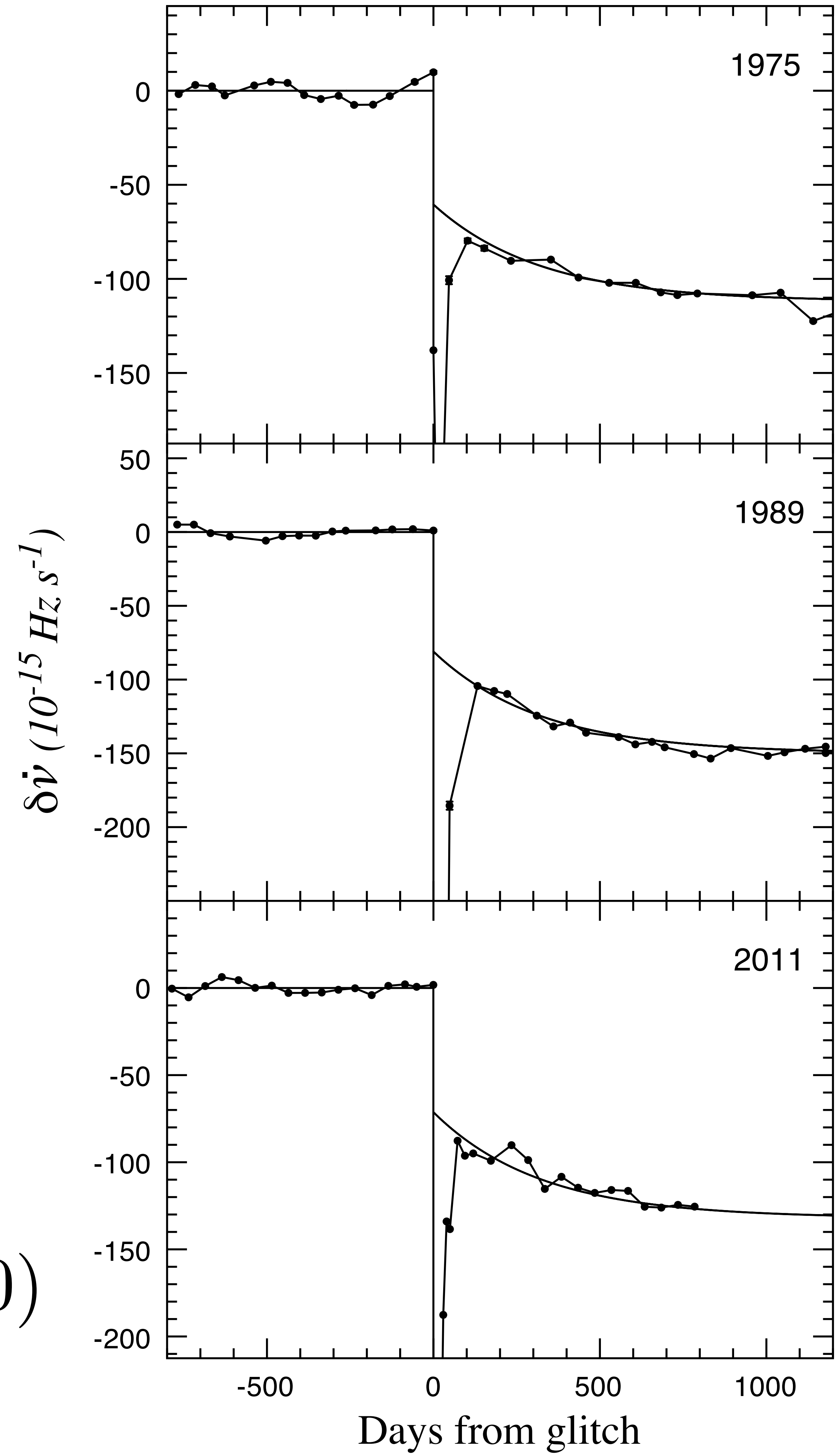
Lyne+2014 (submitted to MNRAS)

There is further exponential decrease after initial recovery.

Lyne+1993; 2014

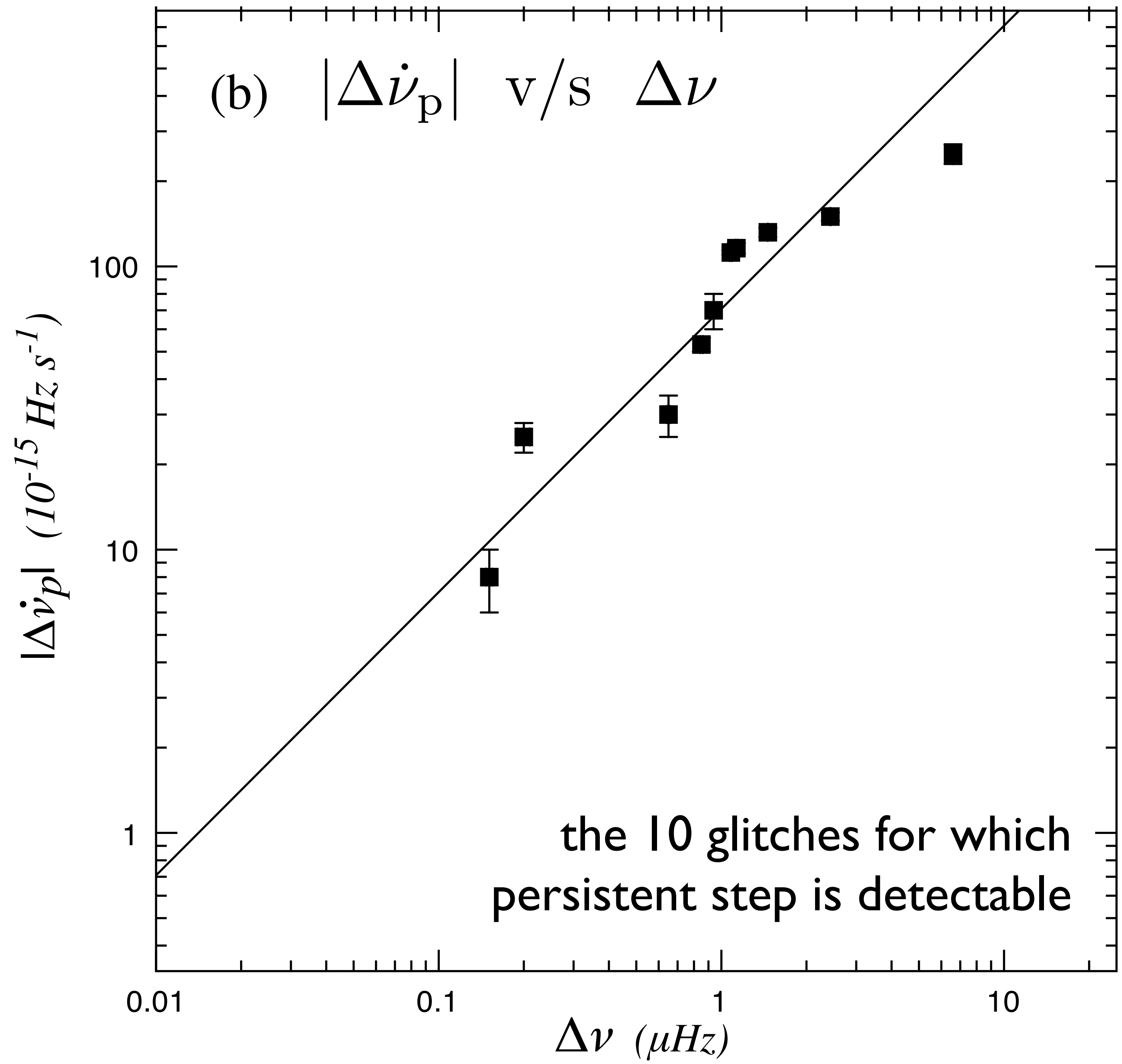


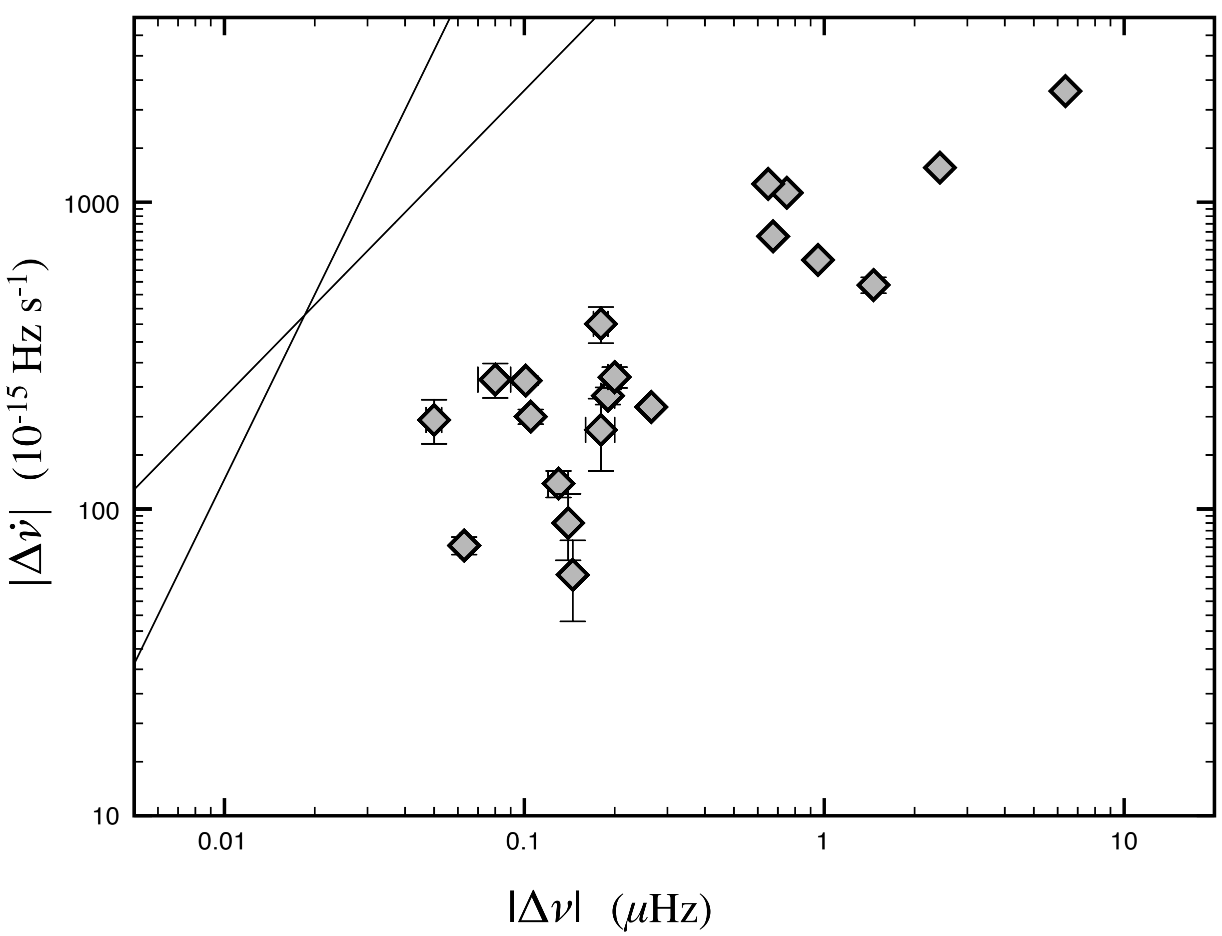
$$\delta\dot{\nu}_{\rm g} = \Delta\dot{\nu}_{\rm p} \times (0.46 \times e^{-t/320} - 1.0)$$



Lyne+2014

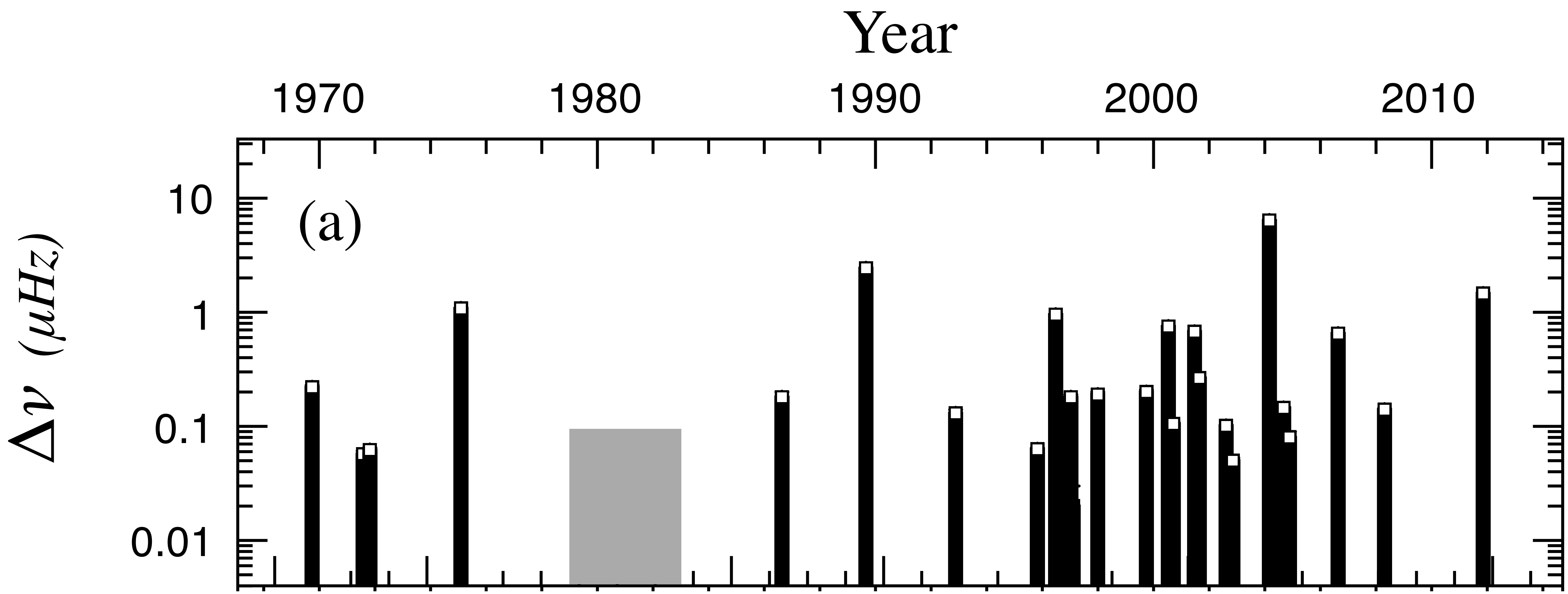
Persistent steps are proportional to freq. steps





Similar correlation is observed for the initial spin-down steps

Waiting times

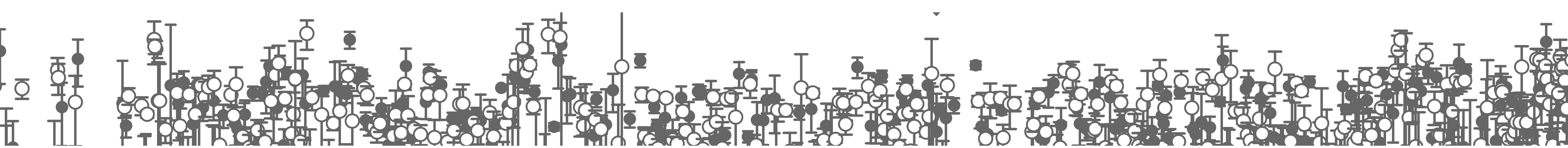


Not completely random: there is interval of 10 years containing 14 of the 24 glitches.

Summary

At least for the Crab pulsar:

- There aren't as many small glitches as it was expected (minimum size of ~*0.05* μHz), implying a break in the mechanism.
- There is second exponential increase in spin-down rate, after glitches, decaying towards persistent step.
- Persistent steps correlate ~linearly with frequency step. Spin-down steps are also correlated.
- There is a *10*-yr episode of increased glitch activity.

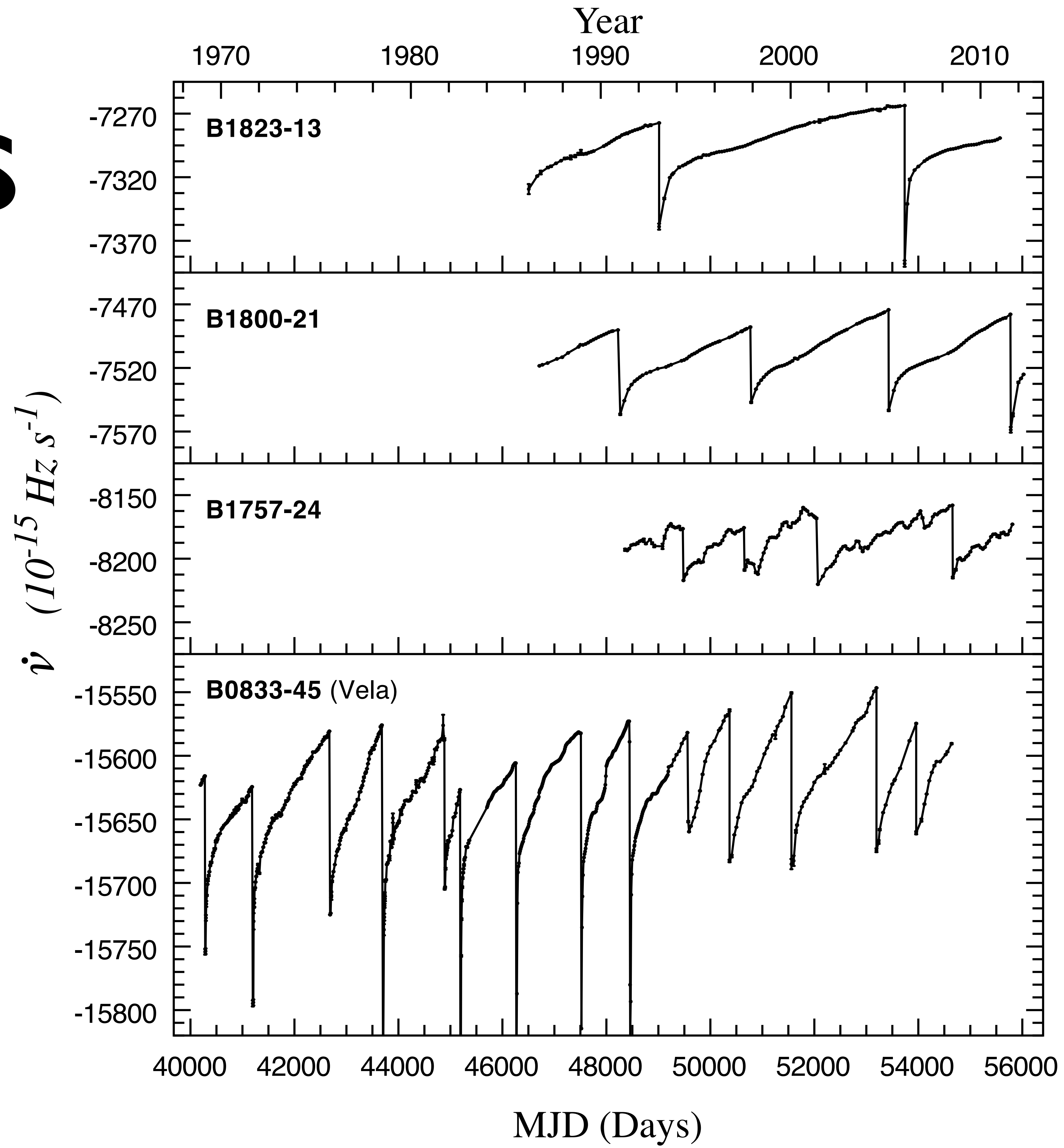


Fin

Glitches

Large glitches can have a significant effect on the long-term spin evolution.

- Braking indices
- Persistent effects

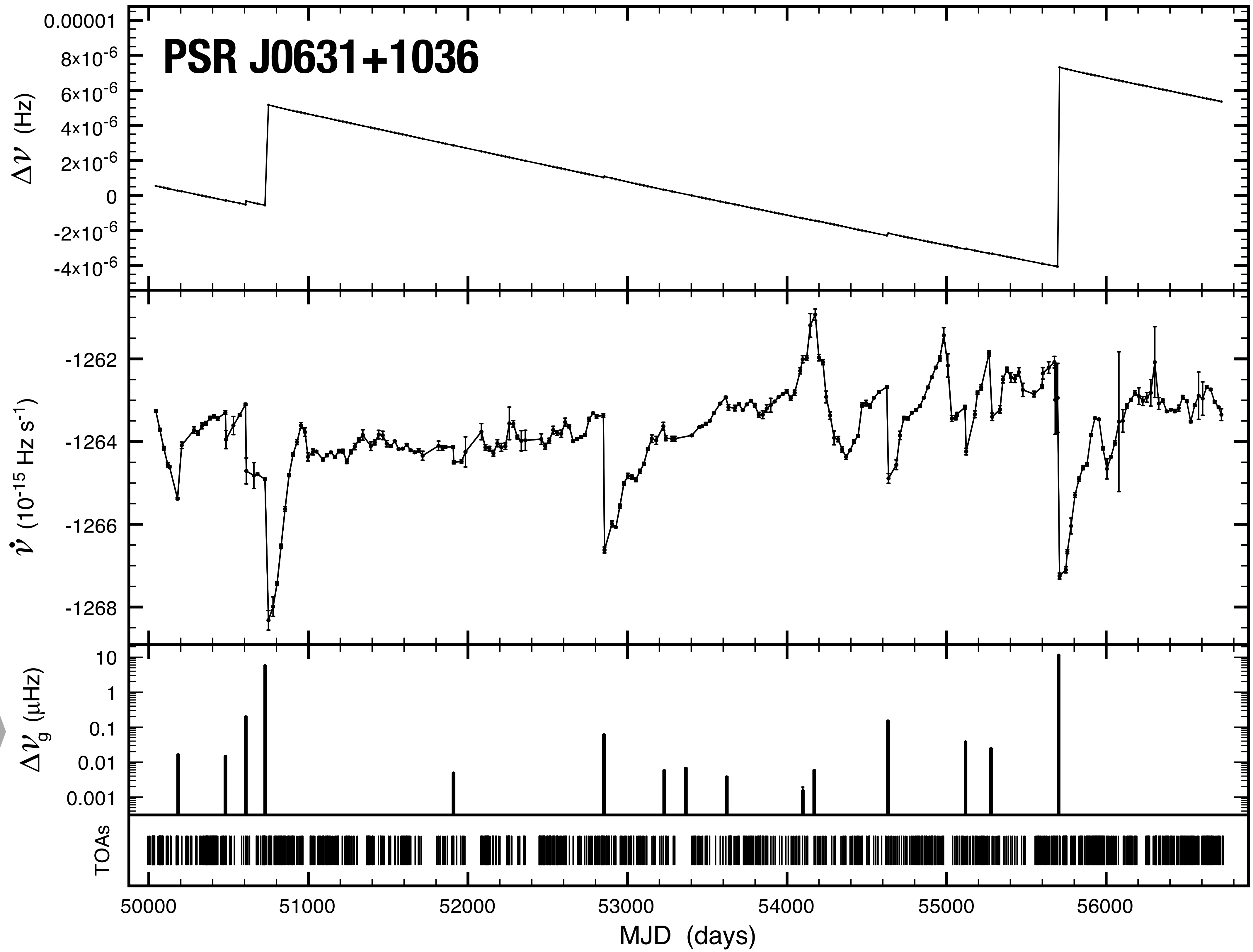


Glitches & timing noise

ν–residuals

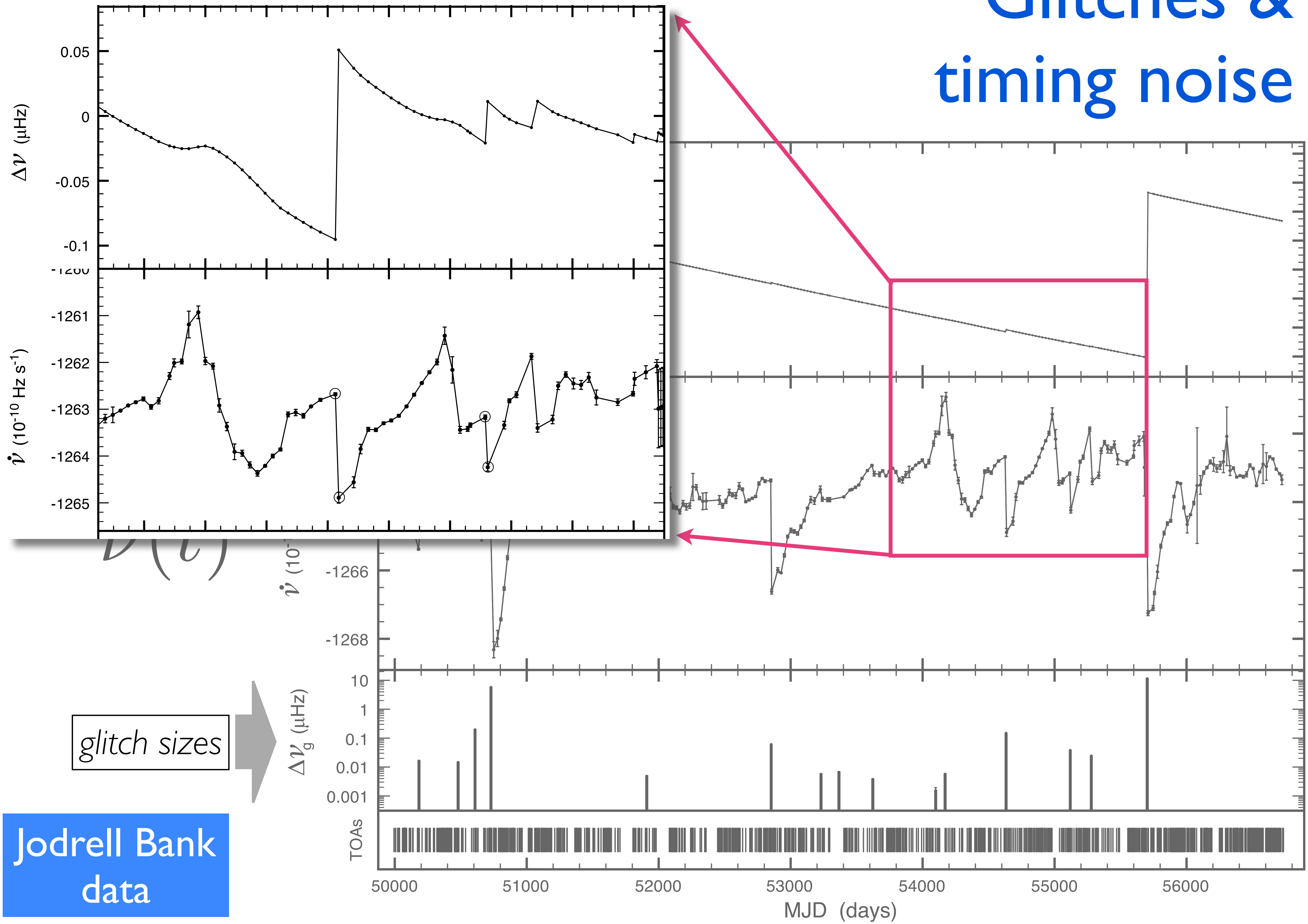
$\dot{\nu}(t)$

glitch sizes

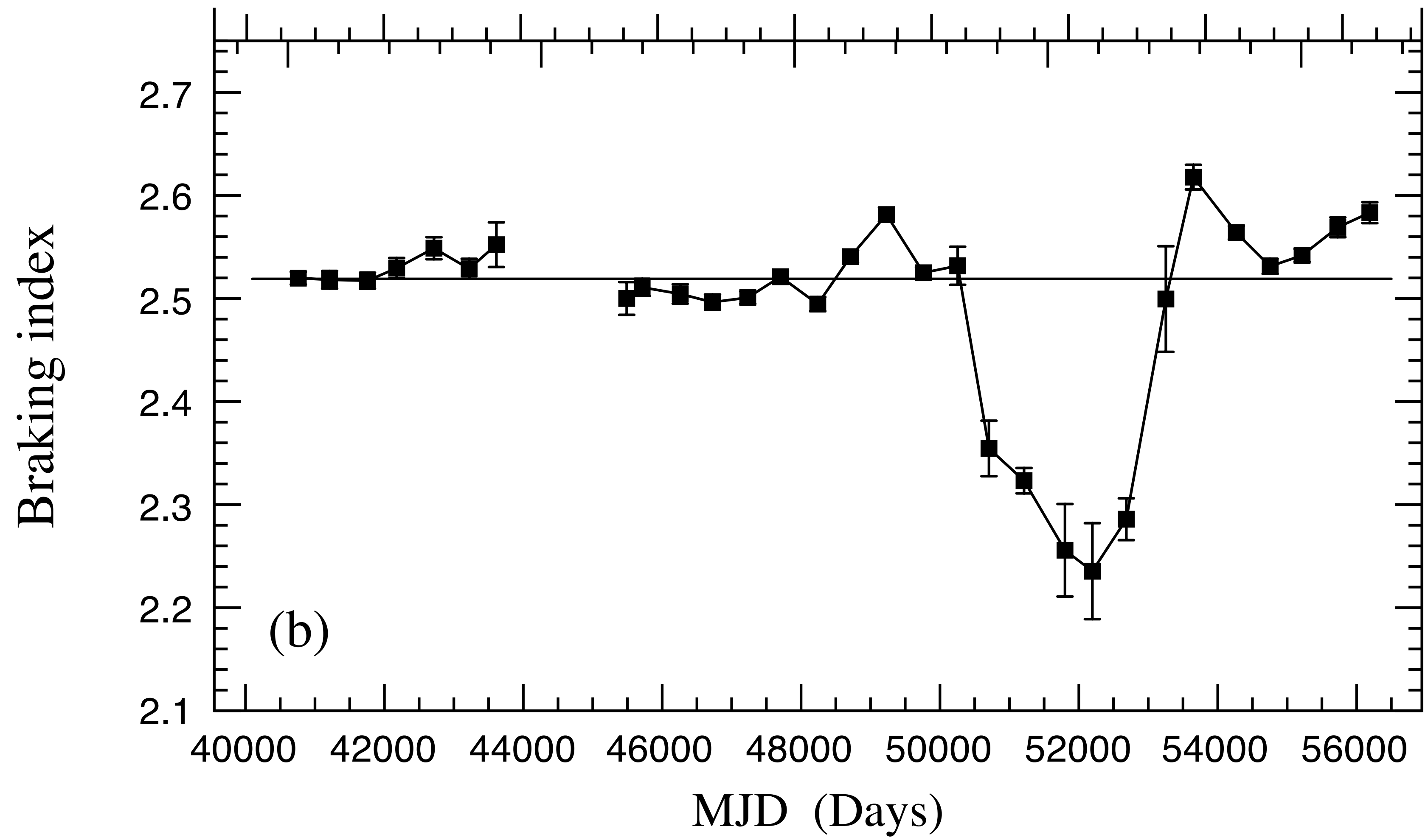


Jodrell Bank data

Glitches & timing noise



Jodrell Bank data



Episode coincides with period of low braking index.