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Characterising glitches and timing irregularities in pulsars and magnetars

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Glitches $\Delta\nu > 0 \quad \& \quad \Delta\dot{\nu} < 0$

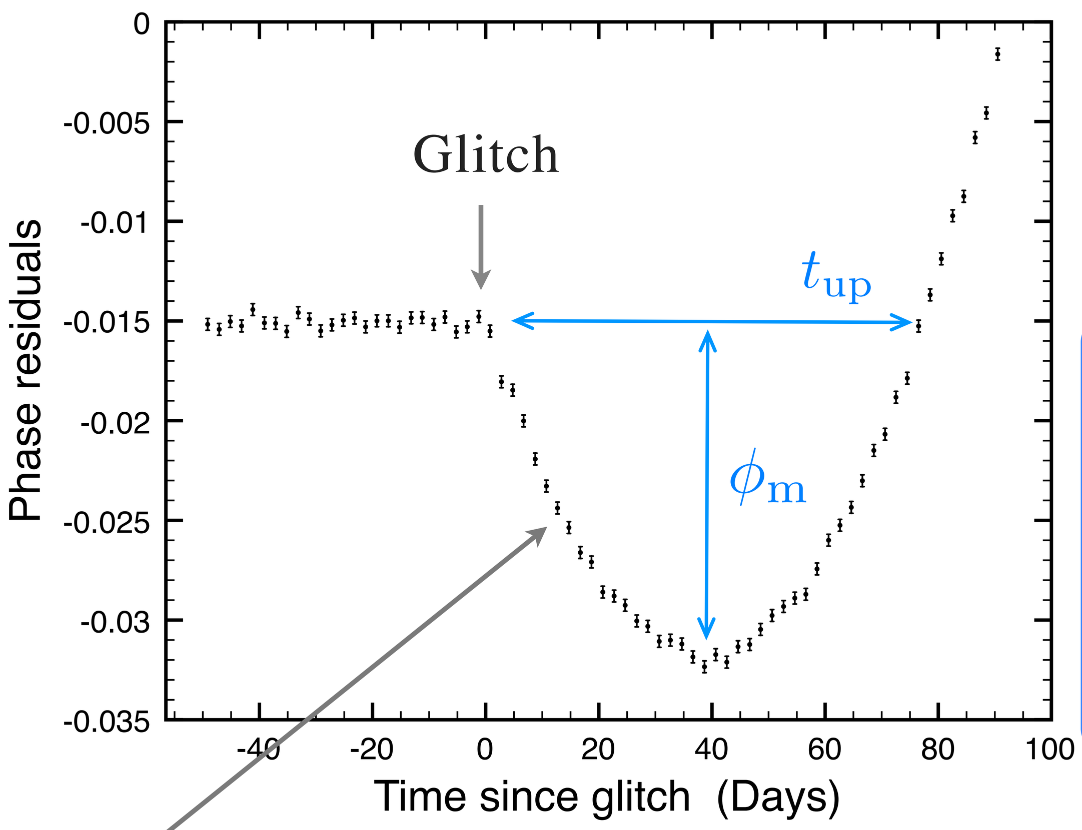
Glitches are unresolved positive steps in pulsar spin frequency, normally accompanied by a change in the spindown rate. After some glitches the frequency and the spin-down rate relax back to the pre-glitch state on timescales of up to ~100 days. These events are thought to be caused by the interaction of the neutron star crust with the internal neutron superfluid.

Many recent detections of small events show **unusual properties**, like positive spindown rate jumps [Yuan+2010, Chukwude+2010, Espinoza+2011]. We focus on these small events and study, for the first time, how they are detected and measured, with the suspicion that some of them are signatures of a different physical mechanism and should instead be classified as a different phenomena, namely timing noise.

The panels below show how the glitch signature is lost as the size of the spindown rate jump increases.

Here is what a glitch looks like

in a phase residuals plot, for a model that describes the rotation up until the glitch epoch.



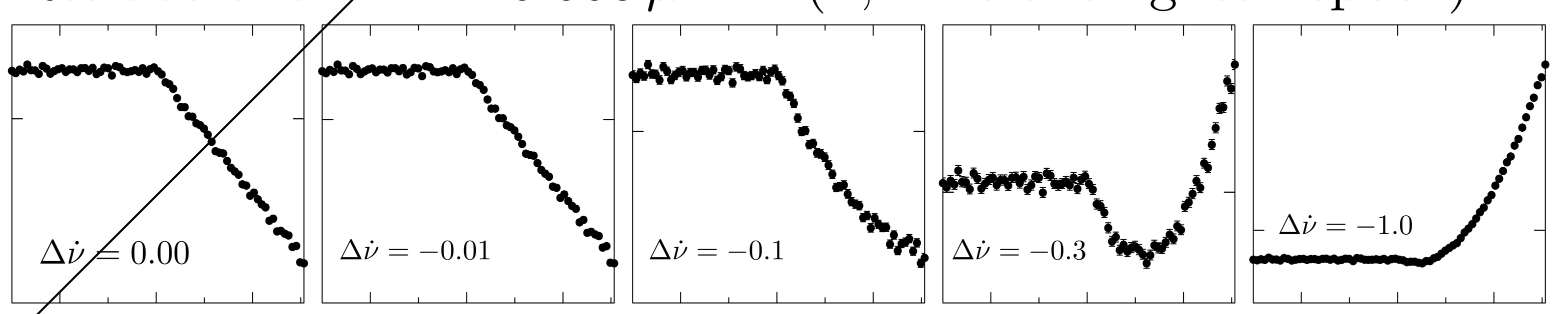
$t_{\rm up}$ Is the time at which the residuals become positive.

$\phi_{\rm m}$ Is the minimum value reached by the phase residuals.

After the glitch, the phase residuals can be described by a parabola plus a decaying term.

$$\phi_g = -\Delta\nu_p \Delta t - \Delta\dot{\nu}_p \frac{\Delta t^2}{2} + \tau_d^2\,|\Delta\dot{\nu}_d|\left(e^{\Delta t/\tau_d} - 1\right)$$

Residuals for $\Delta\nu = 0.003\,\mu$Hz (ν, $\dot{\nu}$ fit until glitch epoch)

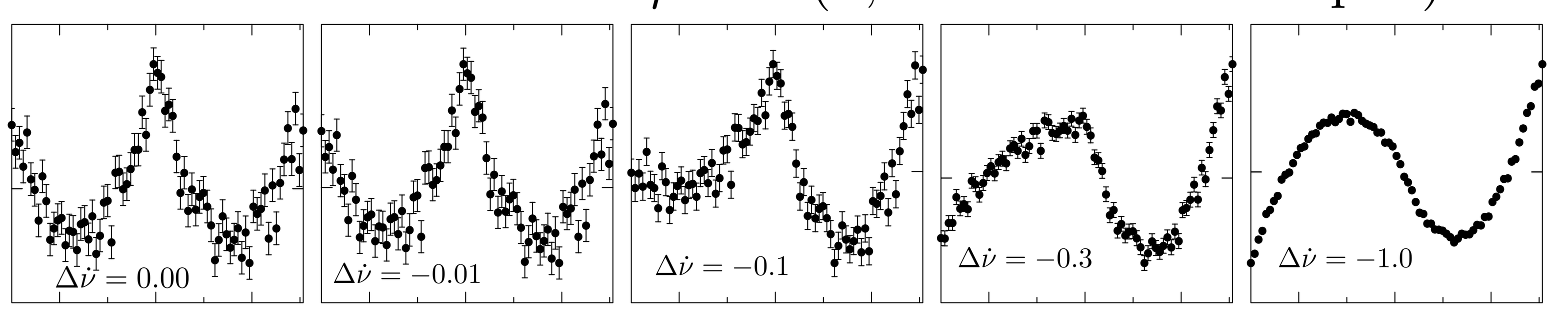


Increasing $|\Delta\dot{\nu}|_{\times 10^{-15}}$ Hz s^{-1} ⟶

fit until glitch

overall fit

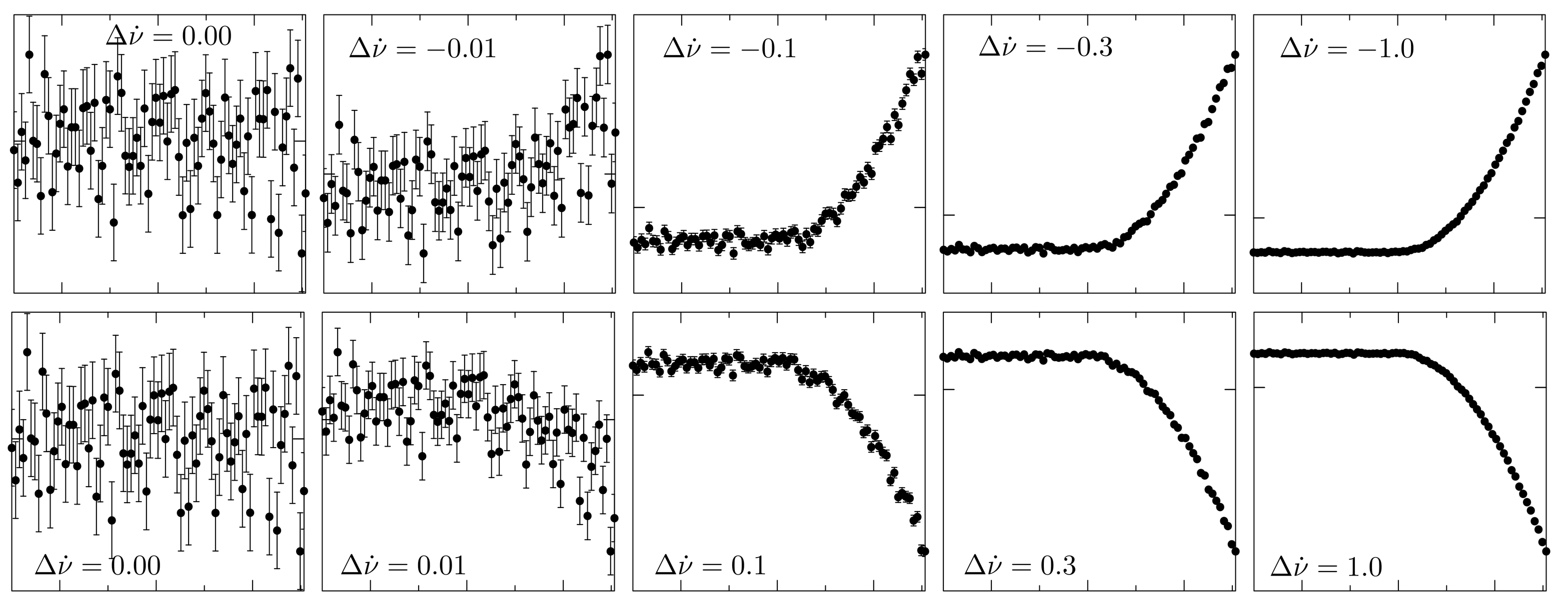
Residuals for $\Delta\nu = 0.003\,\mu$Hz (ν, $\dot{\nu}$ fit entire data span)



Increasing $|\Delta\dot{\nu}|_{\times 10^{-15}}$ Hz s^{-1} ⟶

Timing noise $\Delta\dot{\nu} > 0 \quad \& \quad \Delta\dot{\nu} < 0$

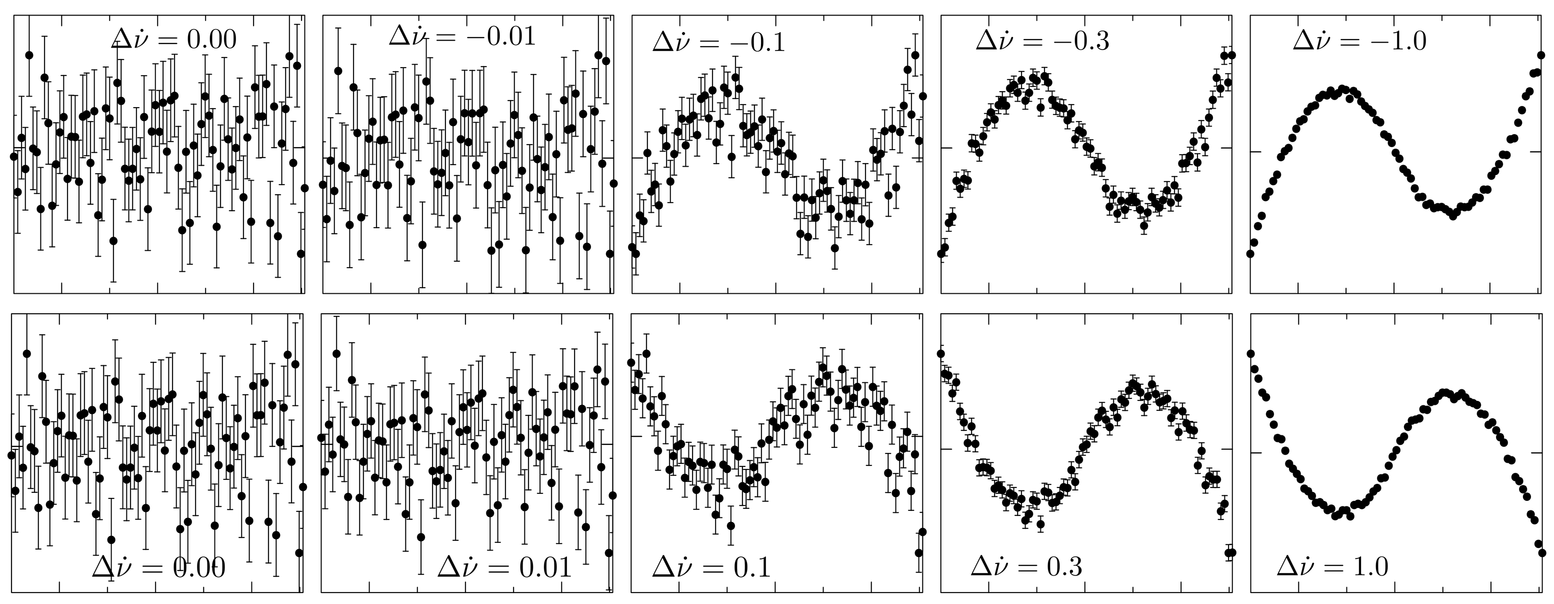
Residuals for $\Delta\nu = 0.0\,\mu$Hz (ν, $\dot{\nu}$ fit until glitch epoch)



$\Delta\dot{\nu} < 0$

$\Delta\dot{\nu} > 0$

Residuals for $\Delta\nu = 0.0\,\mu$Hz (ν, $\dot{\nu}$ fit entire data span)



Timing noise refers to unmodelled deviations from a simple spindown model, appearing as a random wandering of the phase residuals. As pictured by Lyne+2010, most timing noise could be caused by changes, with both signs, of the spindown rate.

Glitches and timing noise can be confused. Small glitches might remain undetected because they look like timing noise and timing noise might be confused with glitches (and reported as glitches with unusual properties).

What can we detect/have detected ? $\Delta\nu_{\rm min} \longleftrightarrow \Delta\dot{\nu}_{\rm min}$

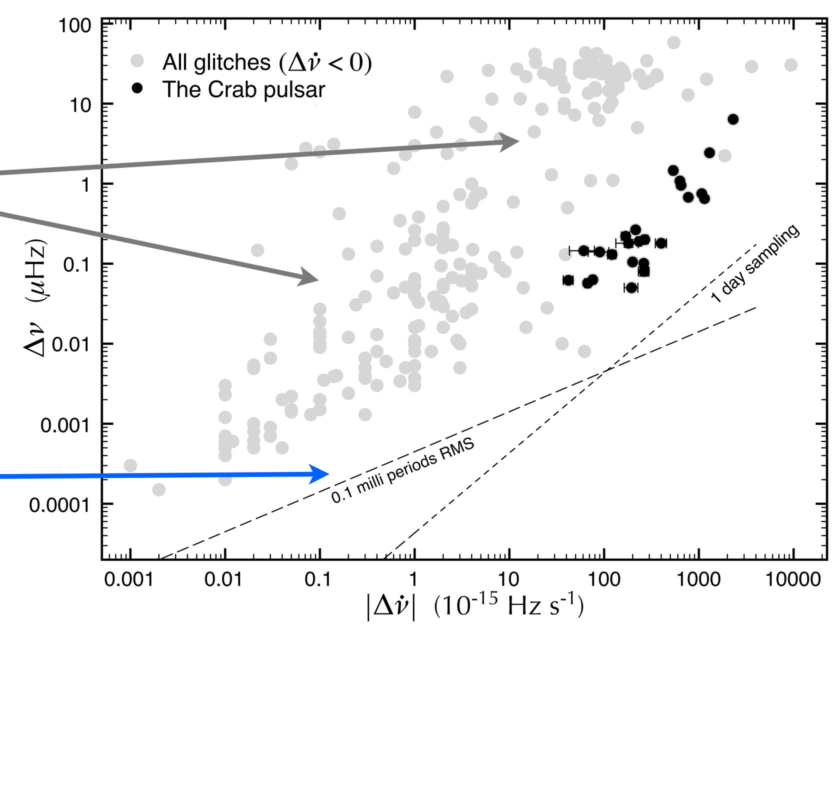
By demanding at least one datapoint before $t_{\rm up}$ and that $\phi_{\rm m}$ is larger than the typical RMS of the residuals (see the first figure) we can define glitch detection limits.

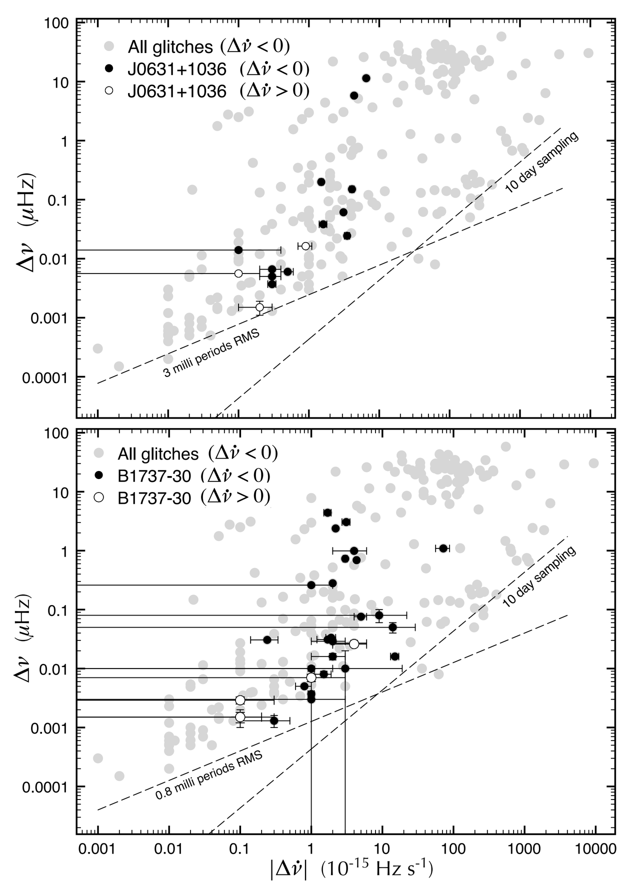
These plots show all detected glitches in three particular pulsars [JBCA glitch catalogue], and the detection limits corresponding to each pulsar, reflecting the regular observations carried out at Jodrell Bank observatory.

The distribution of glitches in the $\Delta\dot{\nu}$ — $\Delta\nu$ space is determined by our ability to detect them.
Glitches below the lines wouldn't be detected.

The plots also show all detected glitches, in more than 100 pulsars.

The two segmented lines represent lower limits determined by observing cadence and the RMS of the timing residuals





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Yuan+2010, MNRAS, 404, 289
Chukwude+2010, MNRAS, 406, 1907
Espinoza+2011, MNRAS, 414, 1679
Lyne+2010, Science, 329, 408
Glitch catalogue: http://www.jb.man.ac.uk/pulsar/glitches.html