How do young pulsars spin down?

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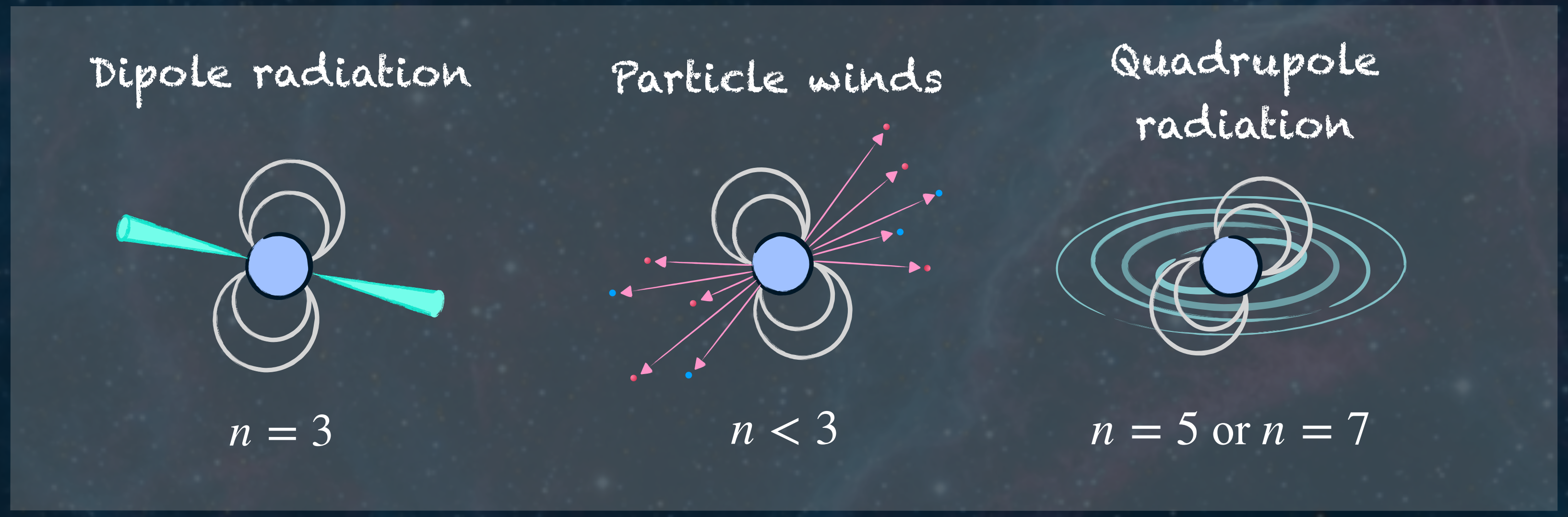
INTRODUCTION

We analysed a sample of 74 pulsars observed by the CSIRO Parkes 64-m radio telescope (*Murriyang*) over ~3-29 years to determine how their rotation evolves over long time scales. Pulsars are expected to spin down according to a power-law of the form

$$\dot{\nu} = -\kappa\nu^{n}. \qquad \textit{Eq. 1}$$

The braking index (n) can be used to infer the dominant torque acting on a pulsar.



However, the observed value of n can be much larger than 3 if κ in Eqn. 1 varies with time. This can happen for a variety of reasons, examples of which are shown below in Fig. 1.

Fig 1: Cartoon depicting processes that can result in anomalously high observed pulsar braking indices.

MEASURING BRAKING INDICES

The braking index of a pulsar can be inferred from measurements of its spin-frequency (ν), spin-down ($\dot{\nu}$) and second spin-frequency derivative ($\ddot{\nu}$) as

$$n = \frac{\nu\ddot{\nu}}{\dot{\nu}^2}. \qquad \textit{Eq. 2}$$

Many of the pulsars in our sample are affected by two kinds of rotational irregularities:

- Timing noise: long-term stochastic phase wandering.
- Glitches: sudden spin-up events caused by build-up & release of stress.

Both phenomenon need to be accounted for in order to obtain unbiased measurements of n.

52/74 of our pulsars had identifiable glitches found via both visual inspection and applying a hidden-Markov model glitch detector (Melatos et al. 2020).

After finding all the glitches, we then used an iterative Bayesian pulsar timing framework to fit the glitches and then marginalise over their effects. This allowed use to measure the braking indices for 33 pulsars (see Fig 2.).

Key points:

- Most pulsars found to have $n >> 3$.
- Distributions are indistinguishable from one-another.
- Two-component KS-test: $D_{\mathrm{KS}} = 0.16$ (p-value: 0.15).

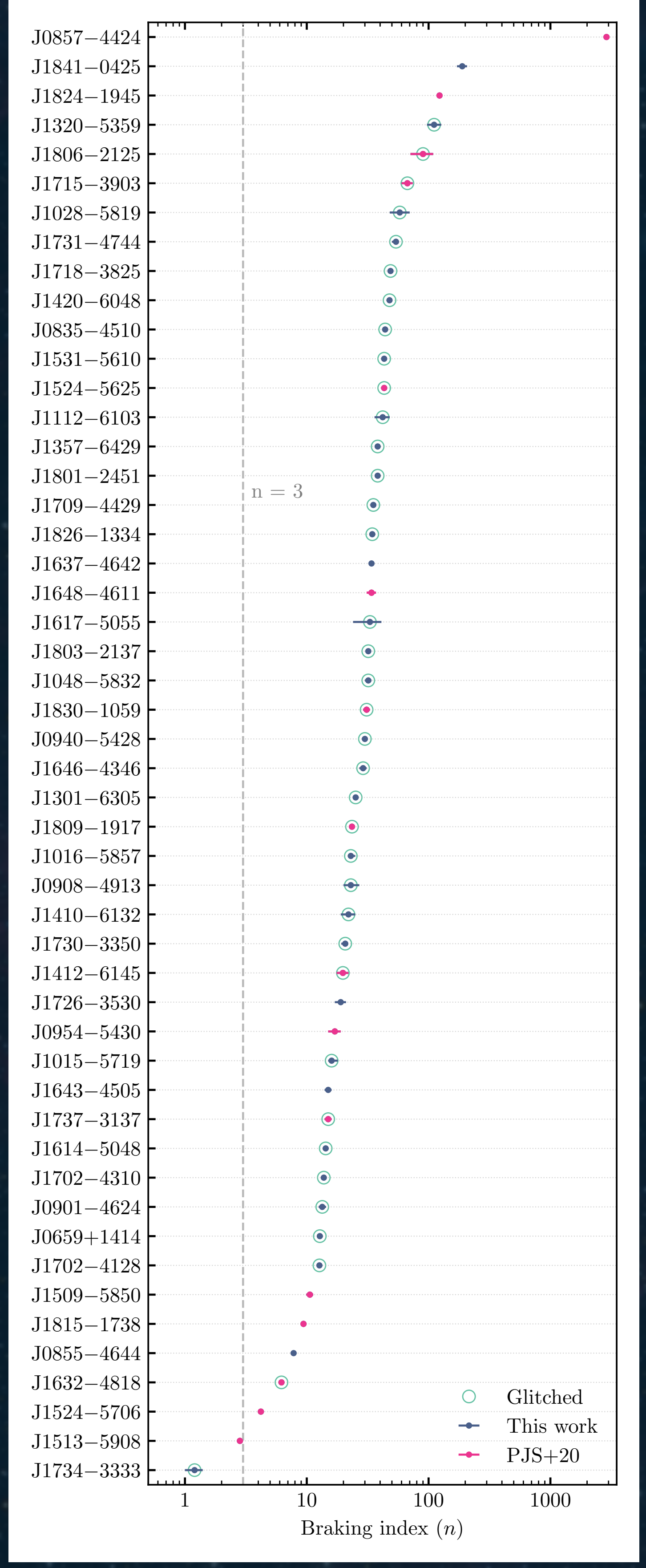


Fig. 2: Pulsar braking indices from this work (dark-blue) and Parthasarathy et al. 2020 (magenta). Circled pulsars have undergone glitches.

INTER-GLITCH BEHAVIOUR

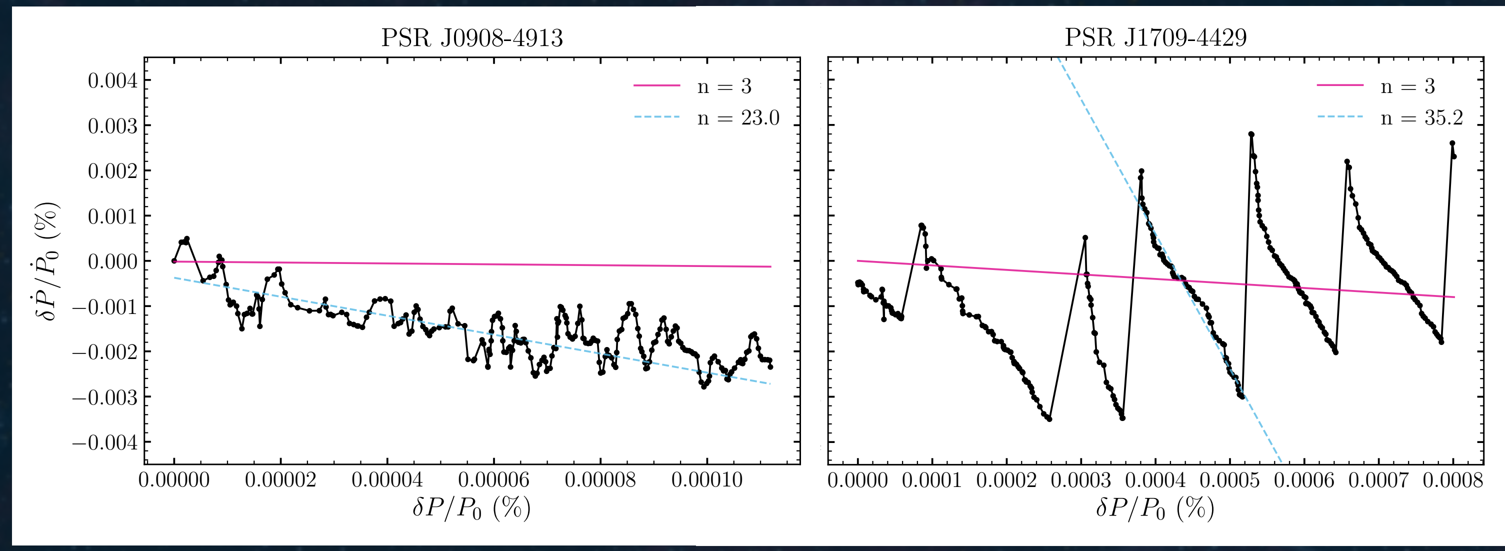


Fig 3: Observed fractional evolution of the spin-period (P) and period derivative ($\dot{P}$) of two pulsars with $n >> 3$.

Pulsars with $n >> 3$ but no large glitches (e.g. PSR J0908−4913 in Fig. 3):

- Consistent with inter-glitch evolution of pulsars with large glitches.
- But cannot rule out $n >> 3$ from a process that causes κ in Eqn. 1 to vary.

Pulsars with $n >> 3$ & large glitches (e.g. PSR J1709−4429 in Fig. 3):

- Inter-glitch $\ddot{\nu}$ depends on preceding $\Delta\dot{\nu}_g$ and wait-time to next glitch (see Fig. 4 below).
- Consistent with superfluid vortex creep (Alpar & Baykal 2006).

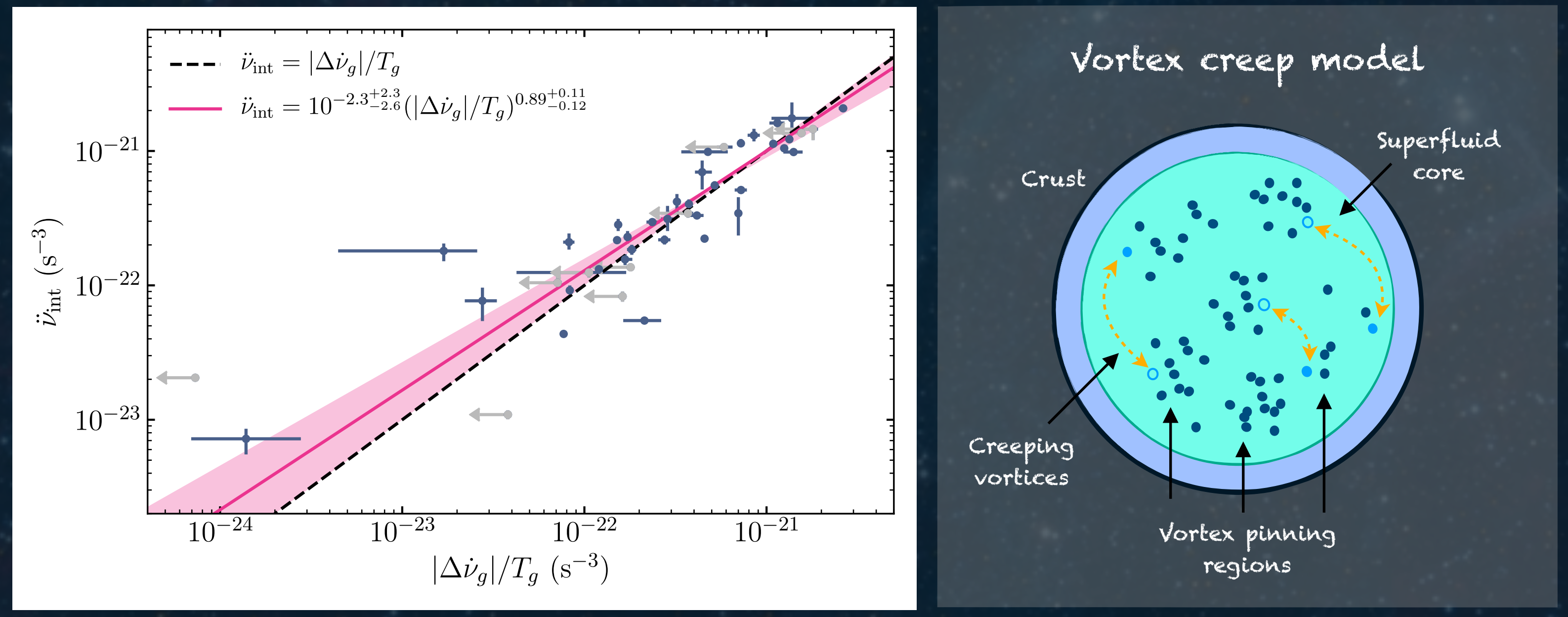


Fig 4: Inter-glitch measurements of $\ddot{\nu}$ versus the preceding change in spin-frequency and wait-time to the next glitch.

REFERENCES

Alpar & Baykal, *MNRAS*, 372 489 (2006); Lentati, L., et al., *MNRAS*, 437, 3004 (2014); Melatos, A., et al., *ApJ*, 896 78 (2020); Parthasarathy, A., et al., *MNRAS*, 494 2012 (2020)

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