Characterising **rotational irregularities** in the **radio pulsar population** with UTMOST

The UTMOST pulsar timing programme II: Timing noise across the pulsar population

Marcus E. Lower, Matthew Bailes, Ryan M. Shannon, Simon Johnston, Chris Flynn, Stefan Osłowski, et al., MNRAS 494, 228-245 (2020).

Background

There are three classes of timing irregularities that affect our ability to precisely measure the arrival times of a pulsar's pulses:

- ***White noise***, normally distributed fluctuations in pulse arrival times
- ***Red noise***, low-frequency stochastic variations in the pulse arrival times.
- ***Glitches***, transient spin-up events.

Red noise and glitches may be a result of processes internal to neutron stars, where the outer crust couples to the superfluid interior. Understanding their relationships with other pulsar properties may provide an insight to the physics of matter at ultra-high densities.

Bayesian framework

We used the power-law red noise model implemented in TempoNest[4] to generate posterior probability distributions for the red noise amplitude (A) and spectral index (β) of ***300 pulsars*** observed by UTMOST ***over 1-4 years***.

The impact of a pulsar's red noise can be quantified by an effective strength parameter given by

$$\sigma_{\rm RN}^2 = A^2 T^{\beta-1},$$

where T is how long the pulsar has been timed for.

To assess how red noise strength scales with pulsar spin-frequency (ν) and spin-down frequency ($\dot{\nu}$) across the population, we assume the recovered red noise strength posteriors were drawn from the Gaussian hyper-prior

$$\pi(\sigma_{\rm RN} \,|\, \mu_{\rm RN}, \varepsilon) = \frac{1}{\sqrt{2\pi\varepsilon^2}} \exp\left[-\frac{(\sigma_{\rm RN} - \mu_{\rm RN})^2}{2\varepsilon^2}\right],$$

where $\mu_{\rm RN}$ is a scaling relation given by

$$\mu_{\rm RN} = \xi\, \nu^a \,|\dot{\nu}|^b T^\gamma.$$

Posterior distributions for the scaling hyper-parameters are then generated using the PyMultiNest[2] nested sampler. Unlike previous works, ***our method is fully self-consistent*** as we recycle the posterior samples for each pulsar.

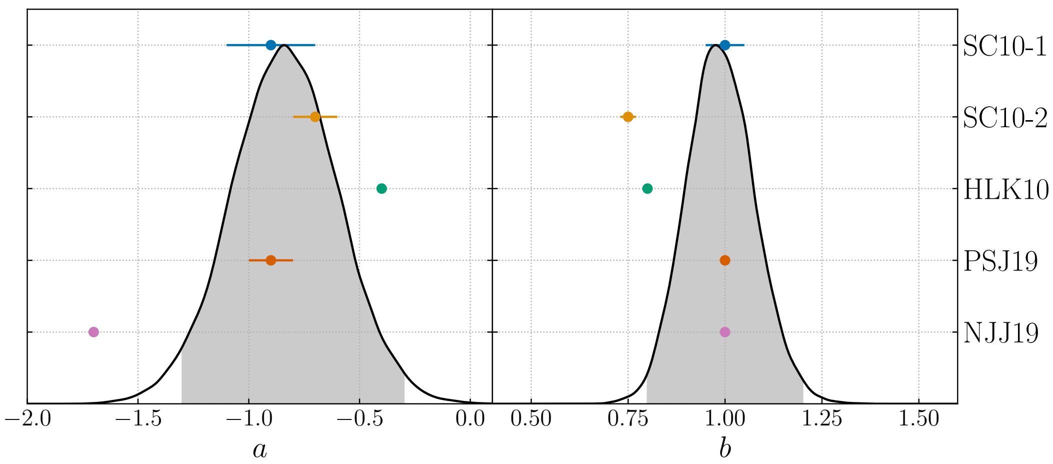

Fig. 2: Comparing posteriors for the spin frequency (a) and spin-down frequency (b) scaling indices to previous studies[7,3,6,5].

Pulsar timing with UTMOST

UTMOST[1] is an ongoing project using the Molonglo Observatory Synthesis Telescope to search for fast radio bursts and monitor more than 400 pulsars at radio frequencies between 820-850 MHz.

Pulsar timing accounts for each rotation of a pulsar by comparing the observed pulse arrival times to those predicted by a ***timing model***.

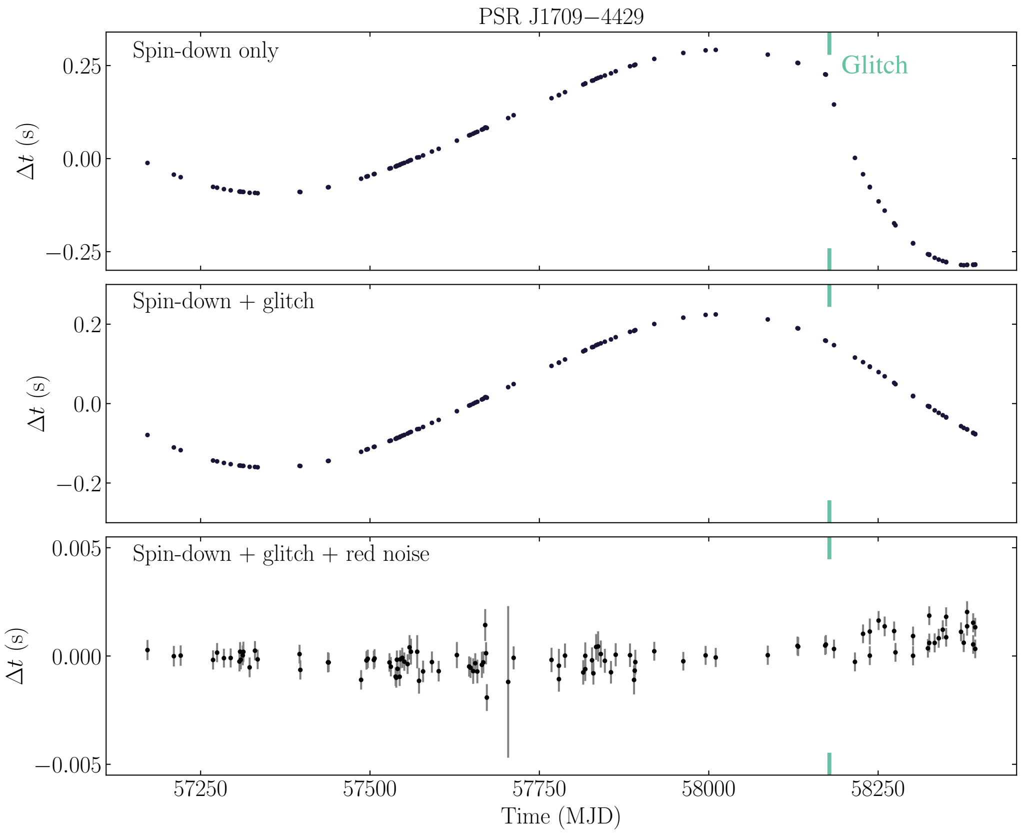

Fig. 1: Time of arrival residuals for PSR J1709-4429 after subtracting three different timing models.

Glitches

Using Bayesian model selection, we find two of the nine previously reported glitches seen by UTMOST are consistent with timing variations from red noise alone. We also report the discovery of ***three new glitches*** in PSRs J1257-1027, J1452-6036 and J1703-4851.

Red noise population analysis

We limited our population analysis to the ***280 slow pulsars*** in our sample to avoid potential biases from including millisecond pulsars and a single magnetar.

Performing hyper-parameter estimation on the full sample of slow pulsars, we recover the posterior distributions for the spin and spin-down frequency scaling parameters presented in Fig. 2. The results from previous studies that used longer data sets ($T \gtrsim 10$ years) are largely ***consistent with ours to 95% confidence***, displaying the capability of our framework when applied to only a small timing sample.

Our method can be easily adapted to use more complex models developed from theory and predict a more accurate, astrophysical hyper-prior on pulsar red noise.

References: **1)** Bailes M. et al., 2017, PASA, 34, 45, **2)** Buchner J. et al., 2014, A&A, 564, A125, **3)** Hobbs G., Lyne A., Kramer. M., 2010, MNRAS, 402, 1027, **4)** Lentati et al., 2014, MNRAS, 437, 3004, **5)** Namkham N., Jaroenjittichai P., Johnston S., 2019, MNRAS, 487, 5854, **6)** Parthasarathy A. et al., 2019, MNRAS, 489, 3810, **7)** Shannon R. M. & Cordes J. M., 2010, ApJ, 725, 1607.

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