Pulsar Astrophysics the Next Fifty Years
Proceedings IAU Symposium No. 337, 2017
P. Weltevrede, B.B.P. Perera, L.L. Preston
& S. Sanidas, eds.

doi:10.1017/S1743921317008766

Finding Pulsar Variability in 50 Years of Data

Paul Brook[1] **and Aris Karastergiou**[2]

[1]Department of Physics and Astronomy, West Virginia University,
Morgantown, WV 26506, USA
email: `paul.brook@gmail.com`

[2]Astrophysics, University of Oxford,
Denys Wilkinson Building, Keble Road, Oxford OX1 3RH, UK
email: `aris.karastergiou@physics.ox.ac.uk`

Abstract. Fifty years of pulsar data has led to the discovery of emission and rotation variability on timescales of months and years; we have developed techniques to identify this long timescale variability. Individual observations may be too noisy to identify subtle changes in a pulse profile; we use Gaussian process regression to model noisy observations and produce a continuous map of pulse profile variability. Generally, multiple observing epochs are required to obtain the pulsar spin frequency derivative. Gaussian process regression is, therefore, also used to monitor this rate of spindown. We have applied variability detection techniques to both millisecond and long period pulsar datasets. I will discuss the techniques used and present the most interesting results from the pulsars analysed.

Keywords. (stars:) pulsars: general, methods: statistical

---

1. Context

Pulsars are employed as precision timing tools due to the stability of their pulse profiles and of their rotation. Fifty years of data, however, has permitted the discovery of pulsar variability on timescales of months and years. A small, emerging population of radio pulsars have shown long-term pulse profile changes (Kramer *et al.* 2006; Lyne *et al.* 2010; Brook *et al.* 2014). These changes are often accompanied by timing noise: unexplained, systematic deviations from the modelled rotational behaviour of a pulsar (Hobbs *et al.* 2010). One interpretation is that timing noise is due to unmodelled variability in the spindown rate of the pulsar.

Long timescale variability studies are important, as any unmodelled changes in pulse profile or rotation is detrimental to experiments that rely on precision pulsar timing, such as the search for gravitational waves using pulsar timing arrays (McLaughlin 2013). Additionally, the emerging relationship between emission and rotation variability may hold information regarding the interiors and environments of pulsars.

2. Methods

We have developed a new technique for measuring spindown rate, by employing Gaussian process regression (GPR) to model the second derivative of the timing residuals. GPR is also used to model long-term pulse profile shape changes (Brook *et al.* 2016). GPR is a non-parametric technique which provides fully Bayesian error estimation. Also, our spindown calculation is entirely analytical in contrast to previous numerical techniques that use a sliding window of arbitrary size. Pulse profile variability detection is demonstrated in Fig. 1.

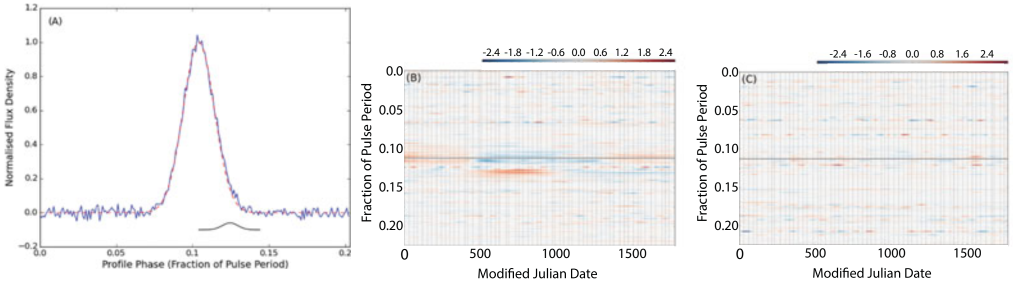

Figure 1. Panel A shows a simulated pulse profile (red dashed) combined with noise and a subtle additional profile component (blue solid). The location and maximum magnitude of the component, which grows and recedes over a 2.5 year span, is shown in black. Panel B is a GPR modelled variability map that highlights the differences between this simulated dataset and the average pulse profile shape. The vertical lines depict the simulated observations, between which the profile shape is inferred. Panel C shows the variability map that results after the simulated profiles are randomly shuffled in time and, therefore, the long timescale variability disappears.

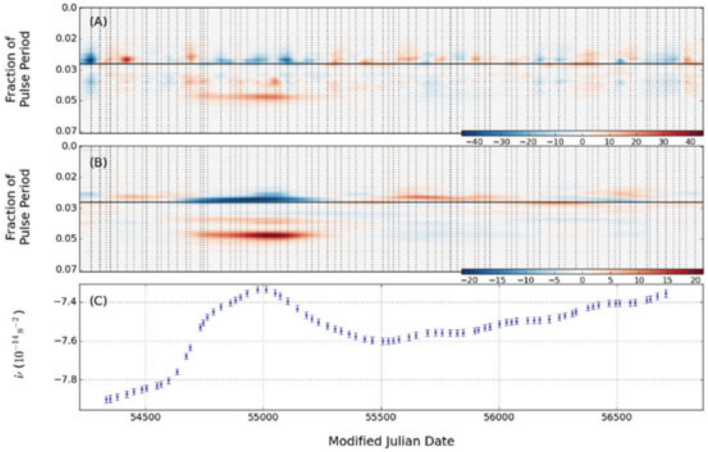

Figure 2. Panel B highlights the phases at which the profile deviates from the average. A strong change is seen to occur over the span of around two years. A drop of around 5% in spindown rate occurs simultaneously as seen in Panel C.

3. Results

Using the above techniques, we have (i) reproduced known pulsar variability and (ii) uncovered a striking new example of correlated spindown and profile shape variability in PSR J1602−5100 (Fig. 2). Such variability is presumed to be due to changing currents in the pulsar magnetosphere, although the source of the current change is unknown. These techniques are currently being applied to the NANOGrav (McLaughlin 2013) pulsar timing array MSP dataset in an attempt to mitigate any timing imprecision caused by pulsar variability.

References

Brook, P. R., Karastergiou, A., Buchner, S., Roberts, S. J., Keith, M. J., Johnston, S., & Shannon, R. M. 2014, *ApJ*, 780, L31

Brook, P. R., Karastergiou, A., Johnston, S., Kerr, M., Shannon, R. M., & Roberts, S. J. 2016, *MNRAS*, 456, 1374

Hobbs, G., Lyne, A., & Kramer, M. 2010, *MNRAS*, 402, 1027

Kramer, M., Lyne, A. G., O'Brien J. T., Jordan, C. A., & Lorimer, D. R. 2006, *Science*, 312, 549

Lyne, A., Hobbs, G., Kramer, M., Stairs, I. H., & Stappers, B. W. 2010, *Science*, 329, 408

McLaughlin, M. A. 2013, *Class. Quantum Grav.*, 30, 22