Poster contributions

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Advances in our understanding of the free precession candidate PSR B1828-11

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Abstract. We highlight the advances and difficulties in understanding PSR B1828-11, which undergoes long-term periodic modulations in its timing and pulse shape over several years. A model comparison of precession and magnetospheric switching models based on the long-term modulation data favours the former; we discuss the implications of this in the context of short timescale switching observed in this pulsar. Furthermore, we highlight the difficulties this pulsar poses for our understanding of pulsars due to the increasing rate of the modulation period and its behaviour during a recent glitch.

Keywords. pulsars: individual (PSR B1828-11)

The periodic modulations of PSR B1828-11 were first tentatively interpreted as evidence for planetary companions (Bailes *et al.* 1993), before observations of modulations in the pulse shape, correlated with the timing features, led to its identification as a free-precession candidate (Stairs *et al.* 2000). Motivated by mode-nulling and mode-changing events in other pulsars and using data time-averaged on short timescales, Lyne *et al.* (2010) reinterpreted the correlation in timing and pulse properties of PSR B1828-11 (along with those of several other pulsars) as evidence for magnetospheric switching, a process whereby the magnetosphere periodically switches between two stable configurations; the key evidence being that the pulse shape parameters did not smoothly vary between two extremes (as expected for precession with a Gaussian core emission (Akgün *et al.* 2006)), but instead "spend most of the time in just one extreme state or the other".

Understanding the cause of periodic modulations of PSR B1828-11 may have implications for the interior superfluid and may also provide a crucial insight into understanding the causes of the timing noise experienced by all pulsars at some level (Hobbs *et al.* 2010).

Short-term switching – When observed over a short duration ($\sim$ 1 hr), the pulsar switches between a wide and a narrow profile, and the proportion of time spent in each profile varies over the precession cycle, ultimately leading to the observed long-term variations in the pulse profile (Stairs *et al.* 2003). The short timescale nature of these switches does suggest they are magnetospheric in origin. But, this does not rule out a precession model. First, emission profiles with both core and conal blobs can explain the short-term switching under a precession interpretation, without any magnetospheric switching (Akgün *et al.* 2006). Second, precession may act as the clock of switching: the switching being biased by angles which are periodically varied (Jones 2012; Kerr *et al.* 2016); see also the idea of stochastic resonance (Cordes 2013).

Long-term switching – A simple question is "which of the two models, precession or magnetospheric switching, better explain the long-term timing and pulse shape modulations of PSR B1828-11?". To answer this, we performed a model comparison between precession and a phenomenological switching model (Perera *et al.* 2015); to make the comparison fair, we conditioned each model on the spin-down data and then calculated a Bayes factor between the two using the pulse shape data; the Bayes factor was found to favour the precession interpretation by a factor of $10^{2.7\pm0.5}$ (Ashton *et al.* 2016). On the basis of the long-term switching alone, precession is far from ruled out, but rather favoured over this switching model. This conclusion requires there is a mechanism similar to that proposed by Akgün *et al.* (2006) to explain the short-term changes in the pulse profile: further study understanding the plausibility of such a mechanism may therefore prove useful.

Problems with precession – We identified two further challenges to understanding PSR B1828-11. First, the $\sim$ 500 day modulation period has gradually been getting shorter over the full observation span at a rate of ≈ -0.01 s/s; in the context of precession, this unexpected results suggests that the deformation is growing on a timescale of ~ 213 yr (Ashton *et al.* 2017). A planetary explanation may provide a more natural explanation, although it faces challenges in explaining variations in the pule profile. Second, on MJD 55042, the pulsar underwent a glitch (Espinoza *et al.* 2011), but the modulation appears to be unaffected; this demonstrates inconsistencies in our understanding of precession or even glitches (Jones *et al.* 2017).

Conclusions – Though PSR B1828-11 is well behaved compared to most pulsars (in that its timing anomalies are stable and periodic), no complete model is able to explain all the features. But, by systematic study, we believe a lot more can be learnt. Further high-resolution observations will shed light on the interplay between the short-term switching and the long-term behaviour; extending the study of the modulation period to a longer set of data after the glitch, one could test for sudden changes in the modulations during the glitch, elucidating any dependence on the crust; studies of the polarisation (as done by Weisberg *et al.* (2010)) could also help us to better understand the system. By combining all of these observations and comparing predictive models, it seems very promising that progress can be made on understanding this object.

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