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Magnetospheric Switching in PSR B1828−11

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Abstract. PSR B1828−11 is a young pulsar once thought to be undergoing free precession and recently found instead to be switching magnetospheric states in tandem with spin-down changes. Here we show the two extreme states of the mode-changing found for this pulsar and comment briefly on its interpretation.

Keywords. pulsars: individual (PSR B1828−11)

1. Introduction

PSR B1828−11 is young pulsar with a spin period of 0.405 s and DM of about 160 pc cm^{-3} (Clifton *et al.* 1992). Years of routine observations with the Jodrell Bank Observatory showed that its period derivative varied with an approximately dual-sinusoidal pattern with periods of about 500 and 250 days. At the same time, the profile was seen to vary between "wide" and "narrow" states, with the average profile shape following the same pattern as $\dot{P}$. These phenomena were initially interpreted as evidence for free precession (Stairs, Lyne & Shemar 2000) and an abundant literature sprang up (e.g., Link 2006) attempting to understand such precession given the standard picture of the superfluid neutron-star interior with vortices pinned to the crust (e.g., Sedrakian, Wasserman & Cordes 1999).

The recognition of a difference of 50% in spin-down rate in PSR B1931+24 when that intermittent pulsar was in one of its weeks-long off states (Kramer *et al.* 2006) led to a new interpretation for these and other pulsars: namely that the changes in $\dot{P}$ were related to abrupt switches in the profile state, a phenomenon labeled "magnetospheric switching" (Lyne *et al.* 2010). PSR B1828−11 was also noted to show evidence of rapid

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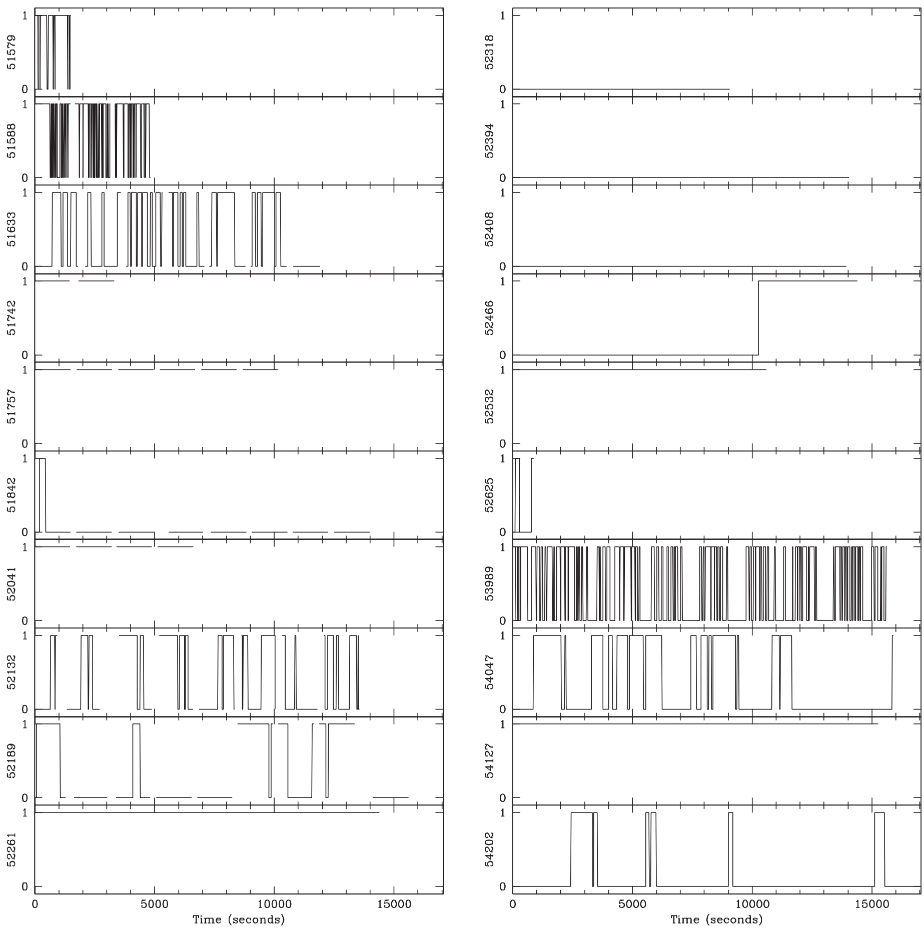

Figure 1. Narrow (1) and wide (0) states identified for the long data sets at different observing epochs. The last 4 epochs were observed with the GBT; the rest with Parkes.

profile changes, as in mode-changing pulsars. Meanwhile, other authors continued to develop alternative models for the effects seen in PSR B1828−11, including free precession combined with magnetospheric switching (Jones 2012) and non-radial oscillations (Rosen, McLaughlin & Thompson 2011). Seymour & Lorimer (2013) found evidence that the $\dot{P}$ variations are consistent with behaviour seen in low-dimensional chaotic systems. Their analysis suggests that the variations could be produced by a coupled system of three differential equations with $\dot{P}$ as one of the "governing variables" controlling the changes in the pulsar.

2. Data and Results

We obtained long (generally multi-hour) 1400-MHz observations of PSR B1828−11 on 20 occasions, sampling multiple cycles of the $\dot{P}$ variations as determined by Lyne *et al.* (2010). On 16 occasions we used the Parkes telescope, employing the $2 \times 512 \times 0.5$ MHz 1-bit filterbank with samples every 0.25 ms. On the last 4 occasions we used the Green Bank Telescope (GBT), employing the BCPM (Backer *et al.* 1997) with 96 1-MHz frequency channels with 72-μs sampling. Each observation was folded with 10-second sub-integrations using `dspsr` (van Straten & Bailes 2011) and wide and narrow

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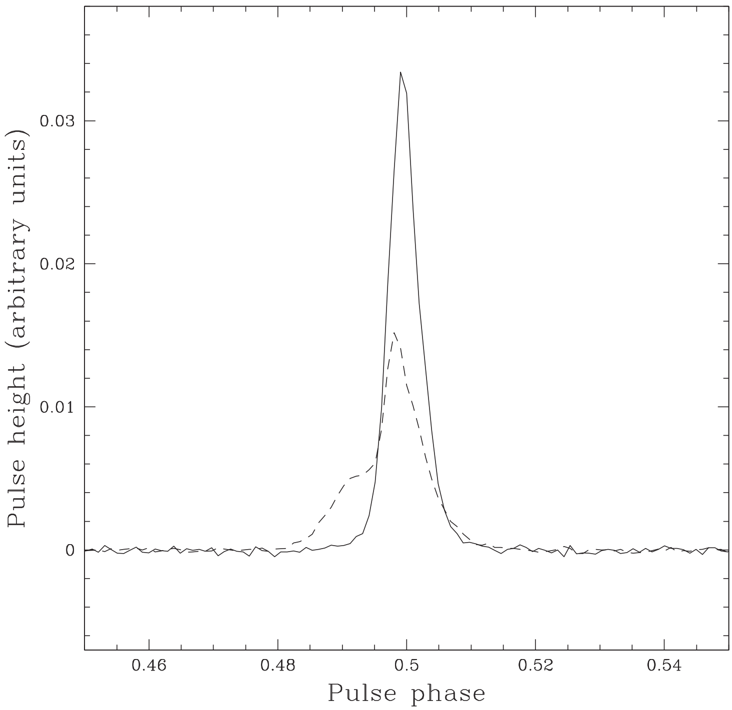

Figure 2. Cumulative narrow (solid) and wide (dashed) profiles for data taken with Parkes on MJD 52466.

profiles were identified by eye using viewing programs from the `PSRCHIVE` distribution (van Straten, Demorest & Osłowski 2012).

Full details of the data acquistion, reduction, analysis and interpretation will be shortly be presented elsewhere (Stairs *et al.*, in prep.). Here we present a subset of the results.

Mode-changing is seen in many of the long observations, while other days show only narrow or only wide profiles. Fig. 1 summarizes the states seen on each day. It is clear that the transition rate of the mode changes varies as well as the average profile shape.

Fig. 2 show the profiles observed with Parkes on MJD 52466. These were obtained by summing, respectively, all the 10-s sub-integrations labeled "narrow" or "wide" on that day. The flux density is uncalibrated. The cumulative profile for each Parkes epoch is well-described as a linear combination of these two extreme profiles; the GBT data are similarly well-described using one day's extrema. This agreement with two extreme profiles argues strongly against the precession model, in which one would expect smooth changes.

The mode-changing transition rate has a relationship to the $\dot{P}$ cycle which may indicate that this quantity forms the second governing variable in the chaos model; see Stairs *et al.* (in prep.) for a complete discussion. We advocate that other pulsars with known $\dot{P}$ quasi-periodicities be carefully examined for evidence of variable rates of mode-changing.

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