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Pulsar Timing at Urumqi Observatory

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Abstract We report on recent pulsar timing observations undertaken by the Urumqi Observatory. Observations for 74 radio pulsars have been made regularly at an observing frequency of 1540 MHz as part of the Urumqi Observatory timing program, which commenced in 1999 November at the 25-m Urumqi Nanshan telescope. Currently 284 pulsars are monitored with an average interval between observations of ∼9 days. The dedispersion is provided by a $2 \times 128 \times 2.5$ MHz filterbank/digitiser system. Accurate and updated periods, period derivatives and positions have been obtained for the majority of the 74 pulsars with timing observations spanning more than one year. For datasets spanning more than one year we have obtained improved positions, proper motions and velocities. Comparing our measurements of period and period derivative with earlier observations, we conclude that, long-term period and period-derivative fluctuations may be dominated by unseen glitches. We also present the observed results for ten glitches of four young pulsars detected in the last five years.

Key words: stars: neutron — pulsars

1 INTRODUCTION

Pulsar timing has long been used in order to determine crucial parameters such as pulsar periods, period derivatives and, provided the data span is at least one year, accurate pulsar positions and proper motions. Moreover, irregularities in rotation (glitches and/or timing noise), can be investigated by frequent and regular timing observations. Obviously, all of these measurements and investigations require high precision in the determination of the times-of-arrival (TOAs) of pulses. In order to minimise the extrinsic effects of possible perturbations in dispersion measure (DM) introduced by the interstellar medium (ISM) it is important that these timing observations be made at frequencies higher than 1 GHz.

The Urumqi Nanshan Pulsar Observing System has been continuously improved and updated since 1999 November, which has allowed us to make regular high precision timing observations of 280 selected radio pulsars. In this paper we briefly describe the observing system and report on nearly five years of timing observations for a subset of 74 radio pulsars using the 25-m Urumqi Nanshan telescope. Accurate periods, period derivatives, positions, proper motions and velocities were obtained for these pulsars along with parameters for ten glitches in four young pulsars.

2 OBSERVATIONS AND ANALYSIS

Our timing observations have been made using a 1540 MHz dual-channel, room-temperature receiver (∼ 100 K) between December 1999 to June 2002. The total bandwidth of the receiver is 320 MHz. A dual-channel cryogenic receiver has been used since July 2002, which allowed us to observe pulsars with a flux

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density greater than about 0.5 mJy at 1540 MHz. Now approximately 280 pulsars are observed three times per month.

The data are digitised to one-bit precision and recorded on disc. The sampling rate is 1 ms and integrations are typically 60-240 s. In our timing program, individual observations last for four integrations.

The data are subsequently folded at the pulsar's nominal topocentric period and then summed with appropriate phase shifts to allow for interstellar dispersion. The pulse profile obtained from each observation in this way is then convolved with a low-noise template profile of the pulsar at the appropriate frequency to obtain an accurate TOA. These TOAs are corrected to the barycentre of the Solar System using the TEMPO software package[1] and the improved JPL solar system ephemeris DE405 (Standish 1982, Standish 2004). A simple spin-down model involving the pulsar rotational frequency and its derivatives was used for fitting to the barycentric arrival times giving the pulse phase Φ at the time t as:

$$\Phi(t) = \Phi_0 + \nu_0(t - t_0) + \frac{1}{2}\dot{\nu}_0(t - t_0)^2 + \frac{1}{6}\ddot{\nu}_0(t - t_0)^3, \qquad (1)$$

where Φ_0 is the pulse phase at time t_0, and ν_0, $\dot{\nu}_0$ and $\ddot{\nu}_0$ are the pulsar rotational frequency, frequency derivative and frequency second derivative at time t_0 respectively. The differences between the actual pulse arrival times and the predicted arrival times derived from a best timing fit model (the timing residuals) give information on the pulsar's rotational behaviour.

3 TIMING RESULTS

3.1 Updated the Periods and Period Derivatives

Details of the timing results for the updated periods and period derivatives of 74 pulsars are given in the paper by Wang et al. (2001), so we only summarise the results here.

Improved periods and period derivatives were determined for all observed pulsars except the Crab Pulsar for which we have data spanning more than one year. The accuracy of the period determinations is generally better than 0.1 ns, and the typical root-mean-square residuals are a few hundred microseconds. We obtain the period and period derivative variations by comparing the new determined measurements with the previous best determinations from the references. Significant differences between our and previous periods are observed for most of the pulsars. The changes in period display a wide range of values. The largest period change was for PSR B1737−30, with $\Delta P \sim 1.2 \times 10^{-6}$ s, and the smallest value of ΔP has the magnitude of 10^{-11} s. With few exceptions, most period changes are small, with $\mid \Delta P \mid \leq 3\,\mu$s. We found an interesting correlation between period and period-derivative changes (ΔP and $\Delta\dot{P}$), illustrated in Figure 1, which shows a strong tendency for ΔP and $\Delta\dot{P}$ to have the same sign and to be correlated in amplitude. For random period noise, it would not produce such correlated changes in P and $\dot{P}$.

Assuming that a glitch causes an exponential decay, we obtained a model based on unseen glitches which agrees well with the observed changes in period and period derivatives. Our model also works for the Crab pulsar glitches. This agreement strongly suggests that long-term systematic fluctuations in pulsar periods and period derivatives are dominated by decay from unseen glitches.

3.2 Glitches in Four Young Pulsars

Ten glitches were observed in the spin rates of four young pulsars among the 74 samples, PSRs B0531+21 (the Crab Pulsar), B1737−30, B1822−09 and J1835−1106.

The jump parameters obtained from the timing observations for these glitches are listed in Table 1. We detected unusual glitches in two young pulsars, PSRs J1825−0935 (B1822−09) and J1835−1106 (Zou et al. 2004). The rotational behaviour of the two pulsars over an 1500-d period are shown in Figures 2 and 3. Values of ν and $\dot{\nu}$ were obtained from fits of the Equation (1) to independent short sections of data, typically of 30–60 days.

For PSR J1825−0935, a slow glitch characterised by a temporary decrease in the slowdown rate occurred between 2000 December 31 to 2001 December 6. This event resulted in a permanent increase in frequency with fractional size $\Delta\nu/\nu \sim 31.2(2) \times 10^{-9}$, however little effect remained in slowdown rate. The glitch in PSR J1835−1106 occurred abruptly in November 2001 (MJD 52220±3) with

[1] See http://www.atnf.csiro.au/research/pulsar/tempo/

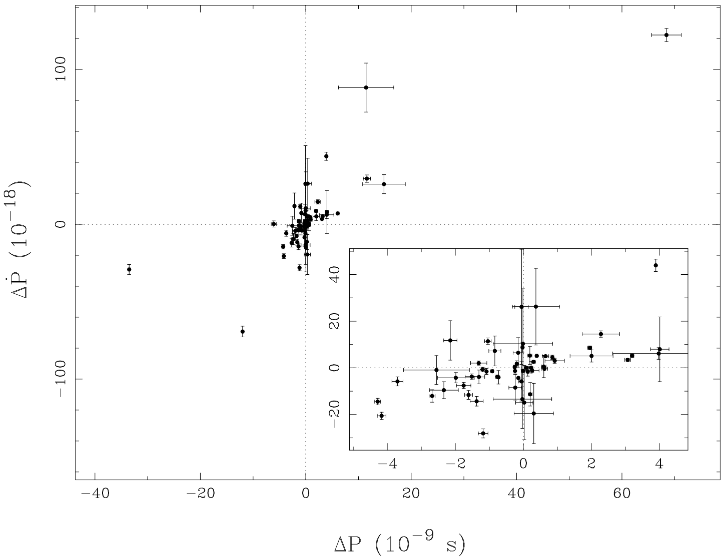

Fig. 1 Difference between the observed and predicted period derivatives $\Delta\dot{P}$, plotted against difference in period, ΔP. The inset is an expanded version of the central region (Wang et al. 2001).

Table 1 Jump and exponential recovery parameters for five pulsars. Uncertainties are 1σ and refer to the last digit quoted.

B name	J name	Glt No.	Glitch epoch (MJD)	Date	$\Delta\nu/\nu$ (10^{-9})	$\Delta\dot{\nu}/\dot{\nu}$ (10^{-3})	Q	τ_d d
0531+21	0534+2200	1	51740.8	000715	24(8)	5(2)	0.80	4(4)
		2	52084.3(2)	010624	11.5(4)	0.2	0.9(2)	25(6)
1822−09	1825−0935	1	51909–52249	001231–011206	31.2(2)	1.9(1)	–	–
		2	52798–52969	030608–031126	∼2.1(5)	∼–1.8(8)	–	–
—	1835−1106	1	52220(3)	011107	14.6(4)	−1.0(2)	–	–
1737−30	1740−3015	1	52235(3)	011122	5.1(2)	0.01(2)	–	–
		2	52271(10)	011228	10(1)	–1.1(5)	–	–
		3	52344(5)	020311	150(1)	2.0(5)	0.24	150
		4	52857(3)	030806	17.8(2)	1.2(1)	0.28	15
		5	52941(16)	031029	23.5(7)	1.8(4)	0.36	40

$\Delta\nu/\nu \sim 14.6(4) \times 10^{-9}$ and little or no change in the slow-down rate. A significant change in $\ddot{\nu}$ apparently occurred at the glitch with $\ddot{\nu}$ having opposite sign for the pre- and post-glitch data.

3.3 New Proper Motion Measurements

We have determined proper motions for 74 single radio pulsars by regular timing observations over a four year period. This work has yielded about 60 accurate determinations of proper motion, in which new or improved proper motions were obtained for 16 pulsars (Zou et al. 2005). Comparison with other measurements, especially the latest results from Hobbs et al. (2005), for the same pulsars suggests that, in general, our proper motion estimates derived from timing observations are in excellent agreement with previously published results. However, in several cases significant discrepancies were found. The improved proper motions imply a mean transverse velocity for the sample of 443 km s^{-1}, about a factor of 1.5 greater than the earlier estimates of $300 \pm 30\,\mathrm{km\,s^{-1}}$ (Lyne & Lorimer 1994), which indicates a strong selection effect in pulsar surveys. The mean space velocity of pulsars at birth given by Lorimer et al. (1997) is about $500\,\mathrm{km\,s^{-1}}$ and the mean transverse velocity derived from convincing associations between pulsars and supernova remnants is $530 \pm 180\,\mathrm{km\,s^{-1}}$ (Lyne & Lorimer, 1994), so our result is in agreement with these. In Zou et al. (2005) we discussed the potential difficulties in estimating pulsar velocities from proper motions

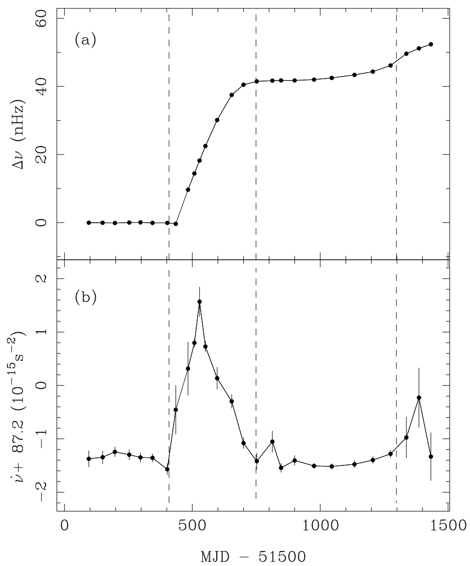

Fig. 2 Variation of ν and $\dot{\nu}$ for PSR J1825−0935. (a) Frequency residuals $\Delta\nu$ relative to the pre-glitch solution. (b) Observed variations of $\dot{\nu}$ (Zou et al., 2004).

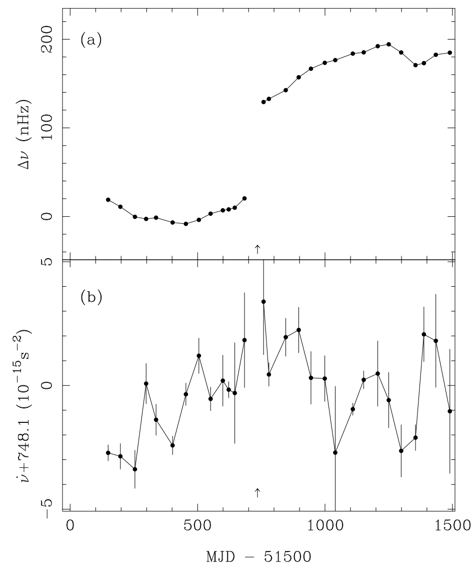

Fig. 3 Variation of ν and $\dot{\nu}$ across the glitch of PSR J1835−1106. (a) The frequency residual $\Delta\nu$ after subtracting a fit of ν and $\dot{\nu}$ to the pre-glitch data, and (b) Observed variations of $\dot{\nu}$ (Zou et al., 2004).

due to the poor pulsar distance model. We also analysed the velocity distribution of single radio pulsars in the Galaxy.

4 SUMMARY AND CONCLUSIONS

We have presented the results of a series of pulsar timing programs spanning 5 years. From the timing data we have obtained accurate estimates of the pulsar periods, period derivatives, positions, proper motions and velocities. Ten glitches were observed in the timing residuals of four young pulsars. In the near future we will use the Nanshan telescope to investigate multi-frequency polarisation observations, the time variation of the pulsar intensity, higher precision pulsar timing (including millisecond pulsar timing), timing noise and interstellar scintillation.

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