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New timing parameters and positions for 16 southern radio pulsars

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ABSTRACT

We report timing observations on 16 pulsars obtained using the Ooty Radio Telescope operating at 327 MHz. Using these observations, spanning over a year, we have obtained values of period derivatives for the first time and refined the estimates of the periods for all pulsars in this sample. We also report improved positions for all cases where the earlier position estimates had an uncertainty of a few arcmin.

Key words: stars: neutron – pulsars: general.

1 INTRODUCTION

One of the hallmark characteristics of pulsars is the regularity of their rotation periods (P), which can be determined to a reasonable accuracy by measuring the arrival time of the pulsars at suitably spaced epochs. The secular slowdown of the pulsars, which results in quadratic variation in the phase, becomes measurable in a time span of a few months. Most of the long period pulsars have period derivatives ($\dot{P}$) of the order of 10^{-15} s s^{-1}. The millisecond pulsars have $\dot{P}$s that are smaller by ~ 5 orders of magnitude than those of the normal pulsars.

Although more than 700 pulsars have been discovered so far, a considerable fraction of them does not have $\dot{P}$ measurements yet. This limits the sample size for many population studies of pulsars. More importantly, exclusion of the subset of a sample for which, say $\dot{P}$s are not measured, may introduce a systematic bias if, for example, some property of the excluded pulsars deviates systematically from that of the sample used. Given that most of the pulsars that do not yet have $\dot{P}$ measurements would be from the more recent surveys and that those more recent surveys are on average more sensitive, there will be a bias against fainter pulsars in the studies using parameters requiring the $\dot{P}$ values. Hence, population studies related to surface magnetic fields, characteristic age, luminosity etc. can suffer from such a bias unless it is carefully corrected for. New measurements of parameters such as $\dot{P}$ are also important to enlarge the sample of pulsars that may have glitching and timing activity. This would increase the probability of finding any younger interesting object that may give new clues to improve our understanding of the interior structure of a neutron star. The young pulsars would normally have small values of the characteristic age, which is estimated as $\tau_{\rm ch} = P/2\dot{P}$ once $\dot{P}$ is known.

We have made timing observations of 16 recently discovered southern pulsars using the Ooty Radio Telescope at 327 MHz, with a preliminary aim of obtaining their period derivatives. We have also obtained improved positions for all the pulsars in our list. Details of observations are described in the second section, analysis procedure in the third section and finally the results are discussed in the fourth section.

2 OBSERVATIONAL DETAILS

The Ooty Radio Telescope (ORT), used for our timing observations, has a reflector that consists of a parabolic cylinder of dimension 530×30 m^2 and a linear feed array at the focus (Swarup et al. 1971). It operates at 326.5 MHz with a bandwidth of 15 MHz. The pulsar receiver that we used was built for the purpose of a pulsar search (Ramkumar et al. 1994). It consists of a 4-bit sampler at the input, which samples the incoming baseband signals of 8-MHz bandwidth at the Nyquist rate and feeds them into a 512-point Fast Fourier Transform (FFT) engine. This FFT engine produces 256-point complex spectra which are converted to power spectra using look-up tables. The resultant power spectra are pre-integrated over a span of ~ 0.5 ms defining our sampling interval. A block integration of 8192 pre-integrated samples (amounting to ~ 4 s average) is performed for each of the 256 frequency channels to calculate the running means, and these are subtracted from the pre-integrated samples. The differences are then 1 bit quantized and stored on magnetic tapes. With a sampling interval of 0.5 ms, roughly one million 1-bit samples per frequency channel are collected in 10 min of observation.

We selected ~ 30 recently discovered pulsars (Lorimer 1994; Manchester et al. 1996) the period derivatives of which were not known. However, given the available observing time and the signal-to-noise ratios achievable in 10-min runs, we have attempted long-term monitoring of only 16 pulsars. The data for the rest of the sample will be discussed elsewhere. The sample was chosen to lie within $\pm 55°$ in declination, considering the reduction in the ORT sensitivity at higher declination and to ensure signal-to-noise ratios ≥ 50 in each of the 10-min integrations. Every pulsar was observed for 10 min twice a day for 2–3 d every month. So far, the observations have been carried out for 1 yr (from 1995 July to 1996 July). During every observing session a strong continuum source was observed in a beam-switching mode to calibrate the back-end receiver. The beam switching was arranged to be synchronous with the 1-s pulse (1-PPS) from a Global Positioning System (GPS) receiver (with ~ 20 ms on-source per s). This procedure provided us with a pulsar-like signal at the input of our receiver with a peak pulse flux density equal to the calibrator flux. We also used these observations to determine the variations in the clock frequency of the sampler, which were then corrected for in the analysis.

A time-stamping scheme built specially for these observations recorded the start time of the observation (as read from the observatory clock) to an accuracy of 0.1 μs and also measured the drift (and/or the frequency offset) of the observatory Rb standard with respect to the GPS reference to the same accuracy, by comparing the 1-PPS signals from both standards. The clock offset and the start times were recorded by a PC controlling the receiver for each observation of 10-min duration.

3 TIMING ANALYSIS PROCEDURE

Pulsar timing analysis involves a comparison of the arrival times of the pulses at the observatory with the expected arrival times based on timing models of pulsar rotation. This analysis was performed off-line in a series of stages as follows.

3.1 Average profiles

The dispersion effect resulting from the free electrons in the intervening medium results in smearing of a pulsed signal when observed over a finite bandwidth; this reduces the peak pulsed flux and consequently the signal-to-noise ratio. In the present case, the spectral channel width of 31.25 kHz results in a smearing of 0.5 ms (equal to our sampling interval) for a dispersion measure of ≈ 70 pc cm^{-3}. We de-dispersed the data by correcting for the delay gradient across the channels before combining them. The resultant time series were then folded with an apparent period predicted on the basis of previous estimates of the pulsar parameters and the ephemeris of the Earth's motion. The average pulse profiles for the 16 pulsars are shown in Fig. 1.

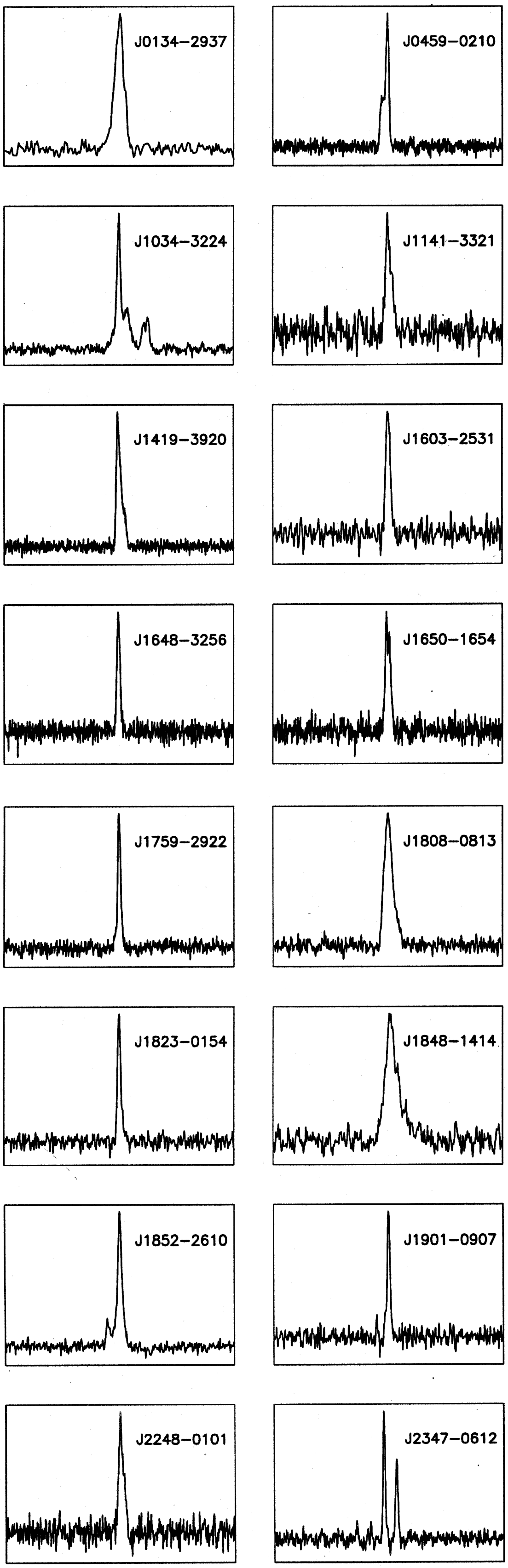

Figure 1. The integrated profiles for the 16 pulsars observed at 327 MHz. The profile in each case covers the whole of the pulsar period.

3.2 Local arrival time

The next step in the analysis of timing data is the estimation of pulse-arrival times at the observatory. Following the usual procedure, the phase of the pulse centroid in the averaged profile was obtained by measuring the delay corresponding to the maximum in the cross-correlation of the averaged profile with a template profile. Estimation of the maximum of the cross-correlation function was performed using a 5-point polynomial fit around the peak of the function, giving an improved estimate of the delay of the pulse profile with respect to the template profile. The value of the delay ($\Delta t_{\text{profile}}$) was added to the starting time (T_{start}) of the observation to obtain the arrival time (T_{pulse}) of the averaged profile at the observatory as

$$T_{\text{pulse}} = T_{\text{start}} + \left[\text{int}\left(\frac{T}{2P}\right)\right] P + \Delta t_{\text{profile}} + \Delta t_{\text{ref}}, \tag{1}$$

where T is the integration time, P is the period used for folding and Δt_{ref} is the pulse offset in the template profile. The individual pulses show wide variety in the intensity as seen from pulse to pulse, however, the pulsar intensity is seen to be much more stable after the 10-min integrations.

3.3 Estimation of barycentric arrival time and timing parameters

The arrival times of pulses at the observatory are affected by the Earth's rotation and motion in space. By referring the arrival times to an inertial frame, the Solar System Barycentre (SSB), the arrival times are made independent of the observer's motion. We use the TEMPO software package (Taylor & Weisberg 1989) and the JPL DE200 ephemeris (Standish 1982) to convert the local arrival time to the arrival time at the SSB.

Once a series of barycentric arrival times is obtained, improved values of the pulsar parameters such as the period (P) and period derivative ($\dot{P}$) can be obtained using the least-squares method, with phase residuals that are defined as the time difference between the observed pulse arrivals and the expected arrival times derived from a model of pulsar spin-down behaviour (see Manchester & Taylor 1977). Residual fitting was carried out for the data initially over short spans (a few tens of min) to obtain a better estimate of the period. The fitting was then extended to hours and then to days to ensure that the pulse numbering remained valid. Most of the pulsars in our list had more than a few arcmin of error in their positions, which could result in incorrect pulse numbering in spite of above-mentioned bootstrapping. Initial estimates of position and period derivatives were therefore obtained by performing a first-order fit to the pulsar period as a function of epoch. Using these initial estimates, the phase residuals were re-estimated and the bootstrapping method was applied to the phase residuals, from which improved estimates of the positions, P and $\dot{P}$ were obtained. The improved estimates were found to be within the uncertainties of the initial estimates obtained from the period residuals. The rms spread of the post-fit phase residuals is typically a few milliperiods for all the pulsars.

4 RESULTS AND DISCUSSION

The best-fitting rotational parameters and improved positions obtained from the arrival-time analysis, and the parameters such as surface magnetic field (B) and characteristic age (τ_{ch}) derived using our new estimates of P and $\dot{P}$ for the present sample, are listed in Table 1. The period (P) and the period derivative ($\dot{P}$) are quoted for a reference epoch chosen near the starting time of the data span. For all these pulsars, the period uncertainties (after the second-order fit) are improved to 1 part in 10^{11} compared with 1 part in 10^{5} as given in the catalogue. The period derivatives for all the pulsars in our list have been obtained for the first time.

It is important to mention that the telescope we used for our observations responds to only the north–south polarization component of the signal. Pulsar signals being highly linearly polarized, this limitation results in variations in the observed pulse shapes depending on the ionospheric con-

Table 1. Improved positions, rotational and derived parameters for 16 pulsars. Column 1 gives the pulsar names according to the J2000 convention. (Note that the pulsar names denoted by an asterisk are the modified names of J1141 − 3321, J1419 − 3920, J1808 − 0813, J1901 − 0907 and J2347 − 0612 in accordance with their improved positions.) Columns 2 and 3 list the improved positions of the pulsars. Columns 4 and 5 give the rotational parameters P and $\dot{P}$ obtained from the timing analysis respectively. Column 6 gives the reference epoch for P and $\dot{P}$ measurements. Columns 7 and 8 list the values of the characteristic age (τ_{ch} in yr) and the magnetic field (B in Gauss) derived respectively using the rotational parameters. The numbers in the brackets indicate 1σ uncertainties in the last digit quoted.

	Improved Positions						
Pulsar Name (J2000)	**RA** h m s	**Dec** ° ’ ”	**Period** (s)	**Period Derivative** (10^{-15} ss^{-1})	**Reference Epoch** (MJD)	**log(τ_{ch})**	log(B)
J0134-2937	01 34 18.649(3)	-29 37 17.15(5)	0.136961577727(2)	0.0801(1)	49900.04252	7.4	11.0
J0459-0210	04 59 51.979(9)	-02 10 06.4(4)	1.13307600931(7)	1.410(5)	49900.19350	7.1	12.1
J1034-3224	10 34 19.452(8)	-32 24 26.0(1)	1.15059041263(4)	0.215(3)	49900.36458	7.9	11.7
J1141-3322*	11 41 42.759(6)	-33 22 36.8(1)	0.145733745933(4)	0.2309(3)	49900.45592	7.0	11.3
J1418-3921*	14 18 50.421(7)	-39 21 18.3(2)	1.09680607062(3)	0.939(2)	49900.54673	7.3	12.0
J1603-2531	16 03 04.959(9)	-25 31 44.55(6)	0.283070264097(5)	1.5964(4)	49900.71204	6.5	11.8
J1648-3256	16 48 06.073(8)	-32 56 41.9(5)	0.71945492855(2)	3.533(2)	49900.74562	6.5	12.2
J1650-1654	16 50 27.15(2)	-16 54 47(2)	1.7495514797(1)	3.21(1)	49899.88815	6.8	12.3
J1759-2922	17 59 48.231(4)	-29 22 12.0(5)	0.57439988675(1)	4.6204(8)	49902.80180	6.3	12.2
J1808-0812*	18 08 09.39(1)	-08 12 53.7(7)	0.87604418427(6)	1.196(5)	49899.95145	7.1	12.0
J1823-0154	18 23 52.146(5)	-01 54 03.4(2)	0.75977737196(2)	1.118(2)	49902.88460	7.0	12.0
J1848-1414	18 48 39.09(1)	-14 14 12(1)	0.29776954631(2)	0.005(2)	49902.92316	9.0	10.6
J1852-2610	18 52 59.531(3)	-26 10 22.2(4)	0.336337124382(3)	0.0838(2)	49902.94124	7.8	11.2
J1901-0906*	19 01 52.974(6)	-09 06 07.5(4)	0.89096381268(3)	0.805(2)	49900.99981	7.2	11.9
J2248-0101	22 48 26.89(2)	-01 01 46.7(7)	0.47723306412(2)	0.658(1)	49901.12477	7.1	11.8
J2346-0610*	23 46 50.88(3)	-06 10 04(1)	1.18146325802(5)	1.119(4)	49934.05808	7.2	12.1

tributions to the line-of-sight rotation measure during individual observations. However, if the rotation measure of the pulsar is high, we expect such changes to be small, considering that there would be sufficient Faraday rotation of the incident polarization vector across the observed 8-MHz bandwidth. As our observations were made at various hour angles (which should vary the Faraday rotation contributed by the ionosphere) we do not expect that any systematic pattern in the pulse arrival times results over the 1-yr span of observations.

It should be pointed out that in some cases our estimates of pulsar positions can have an error larger than that indicated, if there is any contribution from 'timing noise'. This is because a substantial fraction of the contribution resulting from the timing noise will have variations (left after the second-order fit) that have one cycle across the span of our observations, which happens to be 1 yr in the present case. However, timing noise is seen predominantly in young pulsars (Lyne, Pritchard & Shemar 1995). Hence, considering the derived characteristic ages for the pulsars, it seems unlikely that any significant contribution from timing noise may exist in the residuals subjected to position fits.

Fig. 2 shows the location of pulsars in our sample in a $\log(\dot{P})$–$\log(P)$ diagram. 11 of the 16 pulsars in our sample fall within the main island of the normal pulsars, while four pulsars definitely stand out, considering the implied values of the magnetic field. A possible population of recycled pulsars in the field range of $10^{10.5}$–$10^{11.5}$ G was identified by Deshpande, Ramachandran & Srinivasan (1995). The above-mentioned four pulsars would belong to this population. Given that only ~ 11 per cent of the observed pulsar population is found to have fields of $10^{10.5} < B < 10^{11.5}$, it is interesting that 25 per cent of our sample chosen with no explicit bias falls in this range. Although statistically this may not be very significant, it definitely illustrates the kind of bias that may exist in the distribution of pulsars for which $\dot{P}$ values are not yet known. It is also interesting that the pulsars in our sample are located mostly at large z-heights from the Galactic plane. It is important to note, however, that this sample of high-z pulsars is an arbitrary subsample of a much larger sample that was provided by an extensive all-sky survey (Manchester et al. 1996). We expect our sample to help in improving the statistics at such high z-heights at the least and possibly in correcting the bias, if any, that may exist against the population at large distances from the Galactic plane.

Continued timing observations would be worthwhile in the case of the four low-field pulsars (particularly J1848 − 1414), considering that the region they occupy in the $P-\dot{P}$ diagram is seen to have significant probability that the pulsar is a member of a binary system. However, if any of these pulsars is in a binary system, then the orbital period is unlikely to be shorter than 1 yr and our estimates of the period derivative and the new positions would be in error.

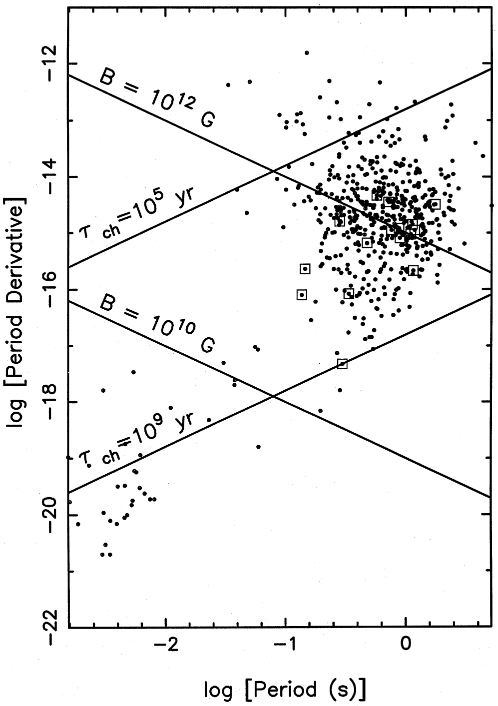

Figure 2. Distribution of pulsars in a $\log(\dot{P})$–$\log(P)$ diagram. The dots highlighted by the squares represent our sample.

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