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A Statistical Analysis of Radio Pulsar Timing Noise

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Abstract We present an analysis of the timing observations on 27 radio pulsars, collected at Hartebeesthoek Radio Astronomy Observatory (HartRAO), with time spans ranging between ~ 9 and 14 yr. Our results show that the measured pulsar frequency second derivatives are non-stationary. Both the magnitude and the sign of the $\ddot{\nu}$ values depend upon the choice of epoch and data span. A simple statistical analysis of the observed second time derivative of the pulse frequency ($\ddot{\nu}_{\rm obs}$) of a large sample of 391 (25 HartRAO and 366 Jodrell Bank Observatory) pulsars reveals that $\ddot{\nu}$ is only marginally correlated with both the pulsar spin-down rate ($\dot{P}$) and the characteristic age (τ_c). We find correlation coefficients of ~ 0.20 and -0.30 between the measured braking indices and, respectively, $\dot{P}$ and τ_c. This result reaffirms earlier conclusions that the braking indices of most radio pulsars, obtained through the standard timing technique, are strongly dominated by sustained random fluctuations in the observed pulse phase.

Key words: methods: statistical — neutron — pulsars: general

1 INTRODUCTION

As rotation-driven neutron stars, radio pulsars are expected to slow down steadily as angular momentum is carried away from the system via pure magnetic dipole radiation and particle acceleration (Goldreich & Julian 1969). For most isolated pulsars, the slowing down should follow a simple power law relation of the form

$$\dot{\nu} = -K\nu^n, \tag{1}$$

where ν and $\dot{\nu}$ are, respectively, the pulse rotation frequency and its first time derivative, K is an arbitrary positive constant and n is the torque braking index. In terms of pulsar rotational observables, the braking index is given (e.g. Manchester & Taylor 1977) by

$$n = \frac{\nu\ddot{\nu}}{\dot{\nu}^2}, \tag{2}$$

where $\ddot{\nu}$ is the second time derivative of the pulsar spin frequency. In principle, radio pulsar braking index can be estimated by fitting Equation (2) to precision pulsar timing data with long enough time coverage (Lorimer & Kramer 2005). Measurements of ν, $\dot{\nu}$ and $\ddot{\nu}$ have, however, remained a major thrust of observational pulsar astronomy. Such measurements, in addition to giving some detailed insights into the long-term rotational behaviour of radio pulsars (Stairs, Lyne & Shemar 2000; Shabanova, Lyne & Urama 2001; Chukwude, Ubachukwu & Okeke 2003; Chukwude 2007), are extremely important for constraining the mechanism for pulsar braking processes (Shapiro & Teukolsky 1983). In the standard vacuum dipole

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radiation model, the pulsar braking torque processes arise from magnetic dipole radiation at the pulsar rotation frequency. In the context of this model, n takes a canonical value of 3 (Manchester & Taylor 1977; Lyne & Graham-Smith 1998).

However, long-term radio pulsar timing observations have shown that meaningful measurements of pulsar rotation parameters, especially $\ddot{\nu}$, are highly complicated by a wide range of rotational irregularities: the more spectacular glitch events (Cordes, Downs & Krauss-Polstorff 1988; Lyne & Pritchard 1988; Lyne, Pritchard & Graham-Smith 1996; Wang et al. 2001) and the yet poorly understood timing noise activity (Boynton et al. 1972; Cordes & Helfand 1980; D'Alessandro et al. 1993, 1995). While the prevalence of fluctuations of timing noise origin in the rotation of radio pulsars is now fairly well established (Cordes & Helfand 1980; Cordes & Downs 1985; Arzoumanian et al. 1994; D'Alessandro et al. 1995; Chukwude 2002), its implications for the measurements of pulsar braking index ($\ddot{\nu}$) are just beginning to be appreciated (Johnston & Galloway 1999; Chukwude 2003).

Recently, Chukwude (2003) presented measurements of the braking indices of 27 radio pulsars based on phase-connected timing analysis of fairly continuous timing observations that span ~ 13 years. The author found that the measured braking indices ($\ddot{\nu}_{\rm obs}$) have different signs and amplitudes that are, in most cases, many orders of magnitude larger than those expected from pulsar intrinsic torque braking processes. In addition, $|\ddot{\nu}_{\rm obs}|$ were found to be strongly ($> 85\%$) correlated with some parameters used to parameterize timing noise fluctuations in the HartRAO sample. Accordingly, Chukwude (2003) interpreted the observed braking indices, at least in objects with relatively large characteristic ages, as mere measures of timing noise fluctuations in the pulsar rotation.

Following Chukwude (2003), the observed radio pulsar braking index ($\ddot{\nu}_{\rm obs}$) can be modeled as

$$\ddot{\nu}_{\rm obs} = \ddot{\nu}_{\rm tno} + \ddot{\nu}_{\rm pre}, \tag{3}$$

where $\ddot{\nu}_{\rm tno}$ is the component quantifying all forms of fluctuations (both systematic and random) about the assumed standard spin-down law and $\ddot{\nu}_{\rm pre}$ measures the contributions from the intrinsic torque braking processes. In the context of the simple dipole torque braking process (Manchester & Taylor 1977), the second time derivative of the pulse rotation frequency is given by

$$\ddot{\nu}_{\rm pre} = -\frac{\ddot{P}}{P^2} + 2\frac{\dot{P}^2}{P^3}, \tag{4}$$

where P is the pulsar rotation period and $\dot{P}$ and $\ddot{P}$ are, respectively, its first and second time derivatives. Following Equation (2), the systematic frequency second derivative is related to the pulsar characteristic age by

$$\ddot{\nu}_{\rm pre} = \frac{n\dot{\nu}^2}{\nu}, \tag{5}$$

where n is the braking index, ν and $\dot{\nu}$ are, respectively, the spin frequency and its first time derivative. Given that pulsar characteristic age $\tau_c \equiv \nu/2\dot{\nu}$, Equations (4) and (5) suggest a positive and negative correlation between intrinsic pulsar braking index ($\ddot{\nu}_{\rm pre}$) and, respectively, $\dot{P}$ and τ_c. A study of these correlations could be used to constrain the nature of the observed pulsar braking index.

In this paper, we analyse the archival HartRAO timing data on 27 pulsars in order to investigate the stationarity of the observed braking indices with respect to both data span length and epoch of measurement. Furthermore, we assemble, what is to date, the largest sample of radio pulsars with significantly measured frequency second derivative ($\ddot{\nu}_{\rm obs}$). This sample of 391 pulsars, which consists of objects that span 3, 6 and 8 orders of magnitude in, respectively, P, $\dot{P}$ and τ_c spaces, is analysed in order to constrain the nature of the measured pulsar braking indices.

2 OBSERVATIONS AND DATA ANALYSIS

Timing observations of radio pulsars at Hartebeesthoek Radio Astronomy Observatory in South Africa commenced since 1984 and are still on-going at the time of this writing. The HartRAO pulsar timing observations were, however, interrupted between June 1999 and December 2000 during upgrade of the observatory hardware. As a consequence, only the timing data accumulated between January 1984 and May 1999 are reported in this paper. Observations were made regularly at intervals of ~ 14 days at either 1668 or

2272 MHz using the 26-m HartRAO radio telescope. Pulses were recorded through a single 10 MHz bandwidth receiver at both frequencies and no pre-detection de-dispersion hardware was implemented. Detected pulses were smoothed with an appropriate filter-time constant, and integrated over $N_{\rm p}$ consecutive rotation periods, where $N_{\rm p}$ is different for different pulsars. An integration was usually started at a particular second by synchronization to the station clock, which was derived from a hydrogen maser and was referenced to the Universal Coordinated Time (UTC) via a Global Positioning Satellite (GPS) network.

All topocentric arrival times obtained at HartRAO, between 1984 and 1999, were transformed to infinite observing frequency at the Solar System Barycentre (SSB) using the Jet Propulsion Laboratory DE200 solar system ephemeris and the TEMPO software package (*http:// www.atnf.csiro.au /research/pulsar/tempo*). Subsequent modeling of the barycentric times of arrival (TOAs) was accomplished with the HartRAO in-house timing analysis software (CPHAS), which is based on the standard pulsar timing technique of Manchester & Taylor (1977) and is well described in Flanagan (1995). At the solar system barycentre, the time evolution of the rotational phase of a non-binary pulsar is well-approximated by a polynomial of the form (Manchester & Taylor 1977):

$$\phi(t) = \phi_0 + \nu(t - t_0) + \frac{1}{2}\dot{\nu}(t - t_0)^2 + \frac{1}{6}\ddot{\nu}(t - t_0)^3, \tag{6}$$

where ϕ_0 is the phase at an arbitrary time t_0. In principle, Equation (6) was fitted to the TOAs using CPHAS. The pulsar position and dispersion measure were taken from Chukwude (2002) and were held constant throughout the fitting procedures. Weighted least-squared fits were used and the weightings were based on TOAs formal errors, estimated from the local scatter of the TOAs (Flanagan 1995). The pulsar TOA residuals, at each frequency, were divided into successive blocks of length ΔT (where $50 \leq \Delta T \leq 150$ d). The error assigned to each TOA is the two-sample variance of the block within which it falls. Blocks with <25 pairs of data were corrected for small-number statistics using Student's-t distribution. The independence of the data formal errors is reasonably preserved since our analysis involved fitting models to data time spans T (where $T \gg \Delta T$). Where necessary, the formal errors were scaled further during the fitting procedure in order to achieve reduced χ^2 values close to 1.0. This method resulted in phase residuals, defined as the difference between pulse phases predicted by the best fit model and the measured TOAs, and the best fit rotational parameters.

Stationarity or constancy of $\ddot{\nu}_{\rm obs}$ with respect to data span length (Δt) was investigated by fitting Equation (6), first, to $\sim$ 2000-d block of arrival time data centred about the midpoint of the entire data set available for a particular pulsar. The epoch was chosen to be an integral Modified Julian Date and set near the centre of the $\sim$ 2000-d data span (hereafter referred to as the central epoch). With the central epoch held constant, subsequent measurements of $\ddot{\nu}_{\rm obs}$ were obtained by steadily increasing the data block length, in steps of 500 d (i.e. 250 d, on both sides of the central epoch), until the entire data span length for a particular pulsar was covered. Similarly, the dependence of $\ddot{\nu}_{\rm obs}$ on epoch was probed by sliding a model of ν, $\dot{\nu}$ and $\ddot{\nu}$ of length $\sim$ 2000 d along the pulsar's TOAs in steps of 500 d. Overlapping fits were used, primarily, in order to obtain a reasonable number of the relevant spindown parameter ($\ddot{\nu}_{\rm obs}$). However, the method is believed to give a better description of the time evolution of pulsar spin-down parameters (Flanagan 1995; Chukwude 2002).

3 RESULTS

The phase residuals, defined as the difference between the best model-predicted and observed pulse arrival times, of the 27 HartRAO pulsars are shown in Figures 1 and 2, while the relevant measured and calculated parameters are summarized in Table 1. Col. 1 contains the pulsar name using the B1950.0 naming convention; Cols. 2 and 3 list the frequency derivative and the associated formal standard error; Cols. 4 and 5 give the frequency second derivative and its formal error; Col. 6 lists the model-predicted frequency second derivative ($\ddot{\nu}_{\rm pre} \equiv n\dot{\nu}^2/\nu$) for pure dipole electromagnetic braking with $n = 3$; the number of observations, root mean square residuals, data span length, characteristic age and period derivative are listed in Cols. 7, 8, 9, 10 and 11, respectively, while Col. 12 gives the stability parameter (Δ_8).

The values of $\dot{\nu}$ and $\ddot{\nu}_{\rm obs}$ reported in this paper are, generally, in good agreement with previous independent measurements. For eight out of ten radio pulsars, for which there is significant overlap between HartRAO and Jodrell Bank timing observations (Hobbs et al. 2004), the agreement in the parameter values

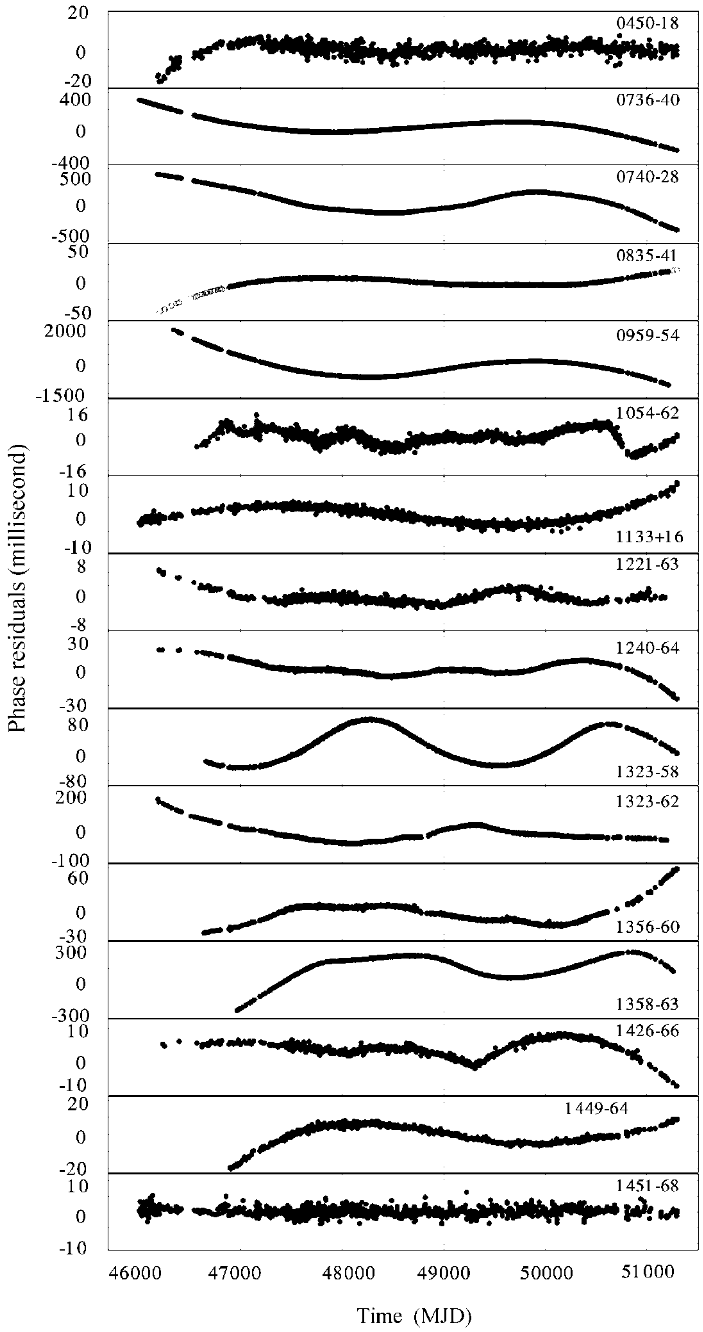

Fig. 1 Time curves of phase residuals, obtained from second-order, least-squares polynomial fit, for PSRB 0450–18, 0736–40, 0835–41, 0959–54, 1054–62, 1133+16, 1221–63, 1240–64, 1323–58, 1323–62, 1356–60, 1358–63, 1426–66, 1449–64 and 1451–68.

is better than 2%. This is generally within the limits of quoted formal errors in the parameters. The TOAs of the other two pulsars (B0450−18 and B1133+16) are strongly dominated by measurement uncertainty, precluding any significant measurements of the spin-down parameters. The relatively large spectral indices of these two pulsars (Lorimer et al. 1995) probably account for their low flux level at HartRAO observ-

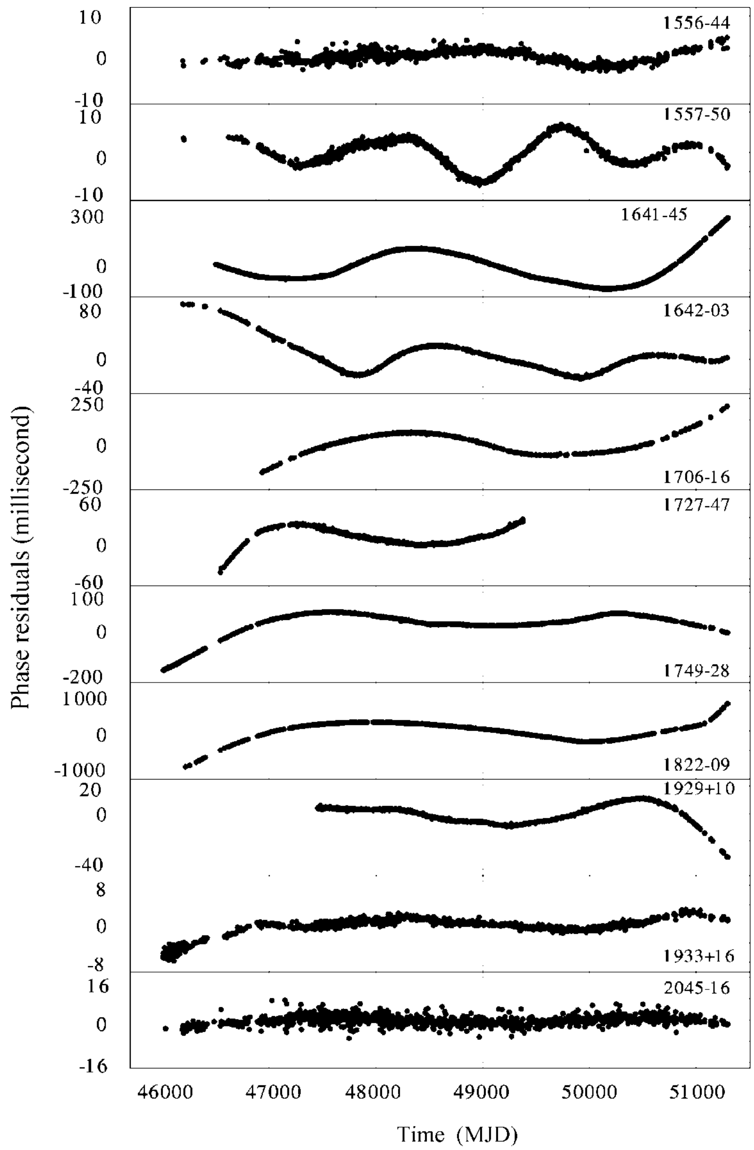

Fig. 2 Time curves of phase residuals, obtained from second-order, least-squares polynomial fit, for PSRB 1556–44, 1557–50, 1641–45, 1642–03, 1706–16, 1727–47, 1749–28, 1822–09, 1929+10, 1933+16 and 2045–16.

ing frequencies. The remaining 17 pulsars have as yet no published measurements of frequency second derivative and $\dot{\nu}$ is known to evolve significantly with epoch (e.g. Chukwude 2002).

The amount of timing noise activity in the HartRAO data was estimated by calculating the pulsar clock stability parameter, Δ_8 defined (following Arzoumanian et al. 1994) as

$$\Delta_8 = \frac{1}{6\nu}|\bar{\ddot{\nu}}_{\rm obs}|t^3, \tag{7}$$

where ν is the pulsar spin frequency and $|\bar{\ddot{\nu}}_{\rm obs}|$ is the average value of the braking indices obtained from fits of Equation (6) to $t \simeq 1200$-d independent blocks of TOAs. Pulsars for which $|\ddot{\nu}_{\rm obs}| < 2\sigma_{\ddot{\nu}_{\rm obs}}$, where

Table 1 Observed and Calculated Parameters of 27 HartRAO Pulsars

Object PSR B (1)	$\dot{\nu}$ $10^{-15}\mathrm{s}^{-2}$ (2)	$\Delta\dot{\nu}$ a (3)	$\ddot{\nu}_{\rm obs}$ $10^{-25}\mathrm{s}^{-3}$ (4)	$\Delta\ddot{\nu}_{\rm obs}$ a (5)	$\ddot{\nu}_{\rm pre}$ $10^{-25}\mathrm{s}^{-3}$ (6)	Ndata (7)	Rms μs (8)	Tspan Days (9)	τ_c Myr (10)	$\dot{P}$ 10^{-15}s s^{-1} (11)	Δ_8 (12)
0450−18	−19.091821	18	0.051	12	0.0060	1360	3032	5095	1.513	5.752	−1.54
0736−40	−11.467300	16	−7.674	6	0.0015	1910	12436	5290	3.673	1.628	−1.44
0740−28	−604.73385	6	−35.54	8	1.829	1732	83380	5095	1.549	16.813	−0.94
0835−41	−6.271580	5	0.3795	10	0.0009	1608	1174	5095	3.311	3.542	−1.88
0959−54	−24.994522	12	−13.827	4	0.0271	1548	80339	4875	0.447	51.910	0.09
1054−62	−20.01190	4	−0.326	6	0.0051	1593	3277	4727	1.862	3.571	−1.23
1133+16	−2.645946	6	0.0652	8	0.0002	1525	640	5000	5.012	3.734	−2.85
1221−63	−105.71397	4	−0.141	10	0.0726	955	1272	4988	0.692	4.954	−1.72
1240−64	−29.819964	12	−0.744	4	0.0104	1497	3776	5290	1.349	4.500	−1.32
1323−58	−14.12989	6	4.402	6	0.0029	1395	33051	4640	2.344	3.228	−1.01
1323−62	−67.258115	14	−1.706	4	0.0719	1359	15688	5008	0.447	18.885	−1.05
1356−60	−389.86801	7	5.064	7	0.5814	1081	2891	4659	0.316	6.338	−0.98
1358−63	−23.58777	5	8.692	8	0.0140	875	73036	4300	0.794	16.663	−0.22
1426−66	−4.489741	12	−0.190	9	0.0005	946	3834	4900	4.490	2.776	−1.85
1449−64	−85.23778	6	1.592	10	0.0391	1033	2462	5105	1.023	2.746	−2.20
1451−68	−1.424633	10	−0.037	4	<0.0001	1282	1060	4990	42.52	0.099	<−2.94
1556−44	−15.42827	5	0.212	8	0.0018	1260	1249	5100	3.981	1.019	−1.83
1557−50	−136.46835	6	−0.046	7	0.1076	1272	3272	4677	0.603	5.062	−1.40
1641−45	−97.11850	8	4.1687	6	0.129	2450	135500	4900	0.359	20.090	0.50
1642−03	−11.85138	5	−0.123	6	0.0016	1098	15929	5057	3.467	1.778	−0.85
1706−16	−14.73178	4	6.341	7	0.0043	697	11910	4365	1.622	6.291	−1.26
1727−47	−237.60720	5	3.560	8	1.4056	906	6341	3190	0.079	163.59	−0.82
1749−28	−25.670282	9	−0.099	4	0.0111	1439	23254	4960	1.096	8.119	−0.99
1822−09	−88.36158	10	14.262	6	0.1809	868	38796	4980	0.234	52.432	−0.11
1929+10	−22.542298	17	−2.185	7	0.0035	1239	5870	3845	3.090	1.156	−1.61
1933+16	−46.638826	14	0.145	10	0.0234	1529	1092	5290	0.933	6.002	−2.10
2045−16	−2.848134	7	0.0086	12	0.0005	1458	1597	4965	10.959	2.818	<−2.73

[a] Errors are 2σ formal standard errors and refer to the last significant digit.

$\sigma_{\ddot{\nu}_{\rm obs}}$ is the formal error in the braking index, for all the independent estimates, $\Delta_8 < 2\bar{\sigma}_{\ddot{\nu}_{\rm obs}} t^3/6\nu$. Our estimates of the stability parameter, which lie between ~ -2.9 and +0.09, are generally in good agreement with previous results (e.g. Arzoumanian et al. 1994). The relatively high values of Δ_8 suggest that timing noise activity is significantly enhanced in the present sample. Furthermore, the magnitudes and signs of the observed braking indices were found to vary randomly with data span lengths and epochs of measurement. In particular, we find up to 500% difference in the magnitude of the braking indices measured from ~ 2000 and 5000-d blocks of data while the value of the parameter measured at different epochs could differ by more than a factor of 400 for a given pulsar. Figure 3 is the plot of $|\ddot{\nu}|$ against the data span length for a selection of six HartRAO pulsars, with braking indices of comparable amplitude. For two of the pulsars (B0740–28 and B1822–09), $|\ddot{\nu}_{\rm obs}|$ increases with Δt while it decreases for the other four objects. The changes in $|\ddot{\nu}_{\rm obs}|$ are generally steeper at $\Delta t < 3000$ d. However, most pulsars show no discernable dependence of $|\ddot{\nu}_{\rm obs}|$ on data span length. The variations of $|\ddot{\nu}_{\rm obs}|$ with epoch were found to be random for the entire HartRAO pulsar sample.

Figure 4 shows, on a $\log-\log$ scale, the plots of $|\ddot{\nu}_{\rm obs}|$ and $\ddot{\nu}_{\rm pre}$ against $\dot{P}$ for the complete sample of 391 pulsars. The sample is made up of 25 HartRAO pulsars, excluding PSRs B0450−18 and B1133+16 whose timing residuals are dominated by measurement uncertainty, and 366 JBO pulsars. The values of $\dot{\nu}$ and $\ddot{\nu}$ for these two objects were taken from Hobbs et al. (2004). The final sample consists of objects that are conventionally classified as normal and millisecond pulsars, and constitute $\sim 30\%$ of the known radio pulsar population. Figure 4b shows an apparent trend (at least for objects with $\dot{P} \geq 10^{-17}$ s s^{-1}) in which objects with large $\dot{P}$ are, on average, characterised by large $\ddot{\nu}_{\rm pre}$. A similar trend exists for $\ddot{\nu}_{\rm obs}$ (Fig. 4a) but at a much reduced level. Figures 5a and 5b are, respectively, $\log-\log$ plots of $|\ddot{\nu}_{\rm obs}|$ against the pulsar characteristic age (τ_c) and $\ddot{\nu}_{\rm pre}$ against τ_c. As expected, there is quite a strong (negative) correlation between $\ddot{\nu}_{\rm pre}$ and τ_c, indicating that pulsars with relatively small τ_c have large $\ddot{\nu}_{\rm pre}$. A similar pattern exists, though only marginally, in $|\ddot{\nu}_{\rm obs}|$ plot, with a possible cutoff at $\tau_c \geq 10$ Myr. Simple linear regression analyses of

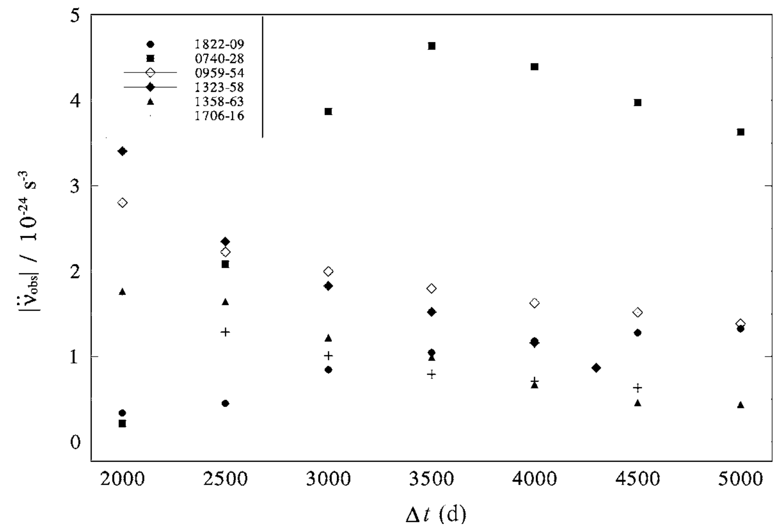

Fig. 3 Shows how $|\ddot{\nu}_{\rm obs}|$, obtained as described in the text, varies with data span length (Δt) for a representative set of six HartRAO pulsars. The 2-σ Error bars are below the size of the symbols.

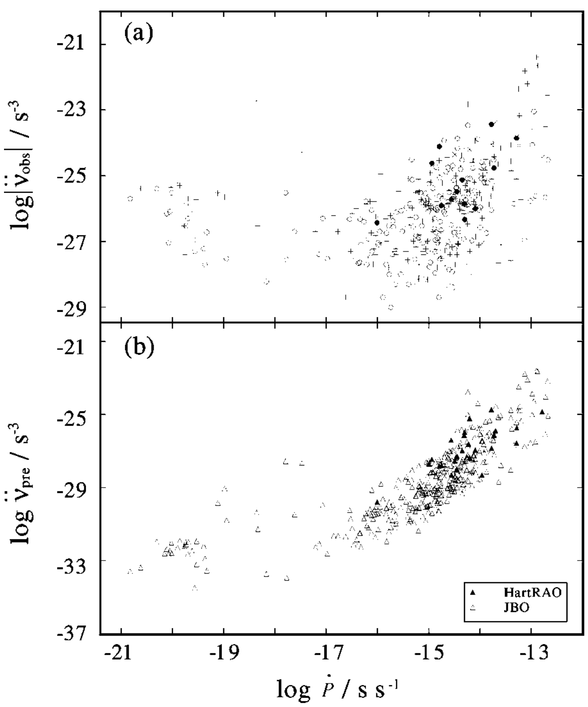

Fig. 4 Scatter plots, for a sample of 391 pulsars, showing the relationships between the logarithms of (a) the absolute magnitude of the observed frequency second deriavtive ($|\ddot{\nu}_{\rm obs}|$) and the spin-down rate ($\dot{P}$), of (b) the model-predicted frequency second derivative ($\ddot{\nu}_{\rm pre}$) and the spin-down rate. Key: 1a) $+$ = +ve $\ddot{\nu}_{\rm obs}$ (JBO); $\bullet$ = –ve $\ddot{\nu}_{\rm obs}$ (JBO); $\times$ = +ve $\ddot{\nu}_{\rm obs}$ (HartRAO); $\circ$ = –ve $\ddot{\nu}_{\rm obs}$ (HartRAO).

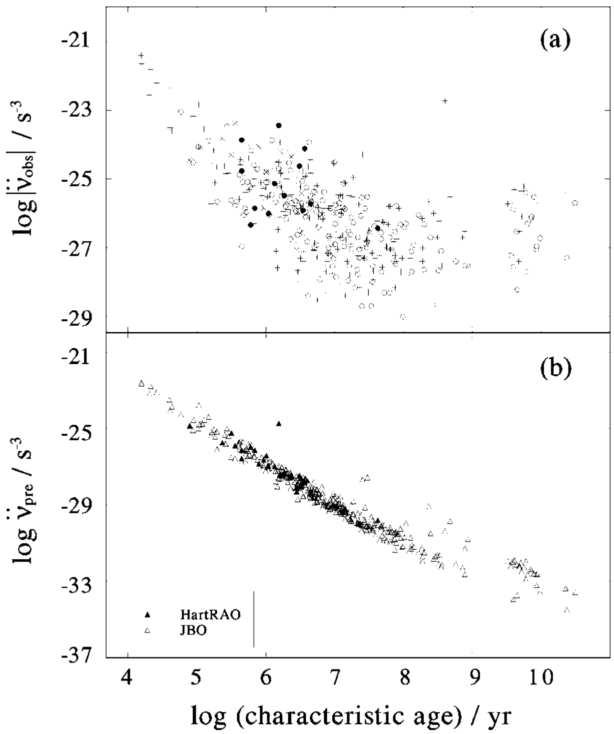

Fig. 5 Scatter plots, for a sample of 391 pulsars, showing the relationships between the logarithms of (a) the absolute value of the braking index ($|\ddot{\nu}_{\rm obs}|$) and the spin-down age (τ_c), and (b) the model predicted braking index ($\ddot{\nu}_{\rm pre}$) and the spin-down age. Key: 2a) $+$ = +ve $\ddot{\nu}_{\rm obs}$ (JBO); $\bullet$ = –ve $\ddot{\nu}_{\rm obs}$ (JBO); $\times$ = +ve $\ddot{\nu}_{\rm obs}$ (HartRAO); $\circ$ = –ve $\ddot{\nu}_{\rm obs}$ (HartRAO).

the present data yield a correlation coefficient $r \sim 0.80$ between $\log \ddot{\nu}_{\rm pre}$ and $\log \dot{P}$ and $-\ 0.98$ between $\log \ddot{\nu}_{\rm pre}$ and $\log \tau_c$. The $\ddot{\nu}_{\rm pre} - \dot{P}$ correlation improves to ~ 0.85 when objects with $\dot{P} < 10^{-17}$ s s^{-1} are excluded from the analysis. These values contrast sharply with r ~ 0.20 and -0.50 found as the correlation coefficients between $\log |\ddot{\nu}_{\rm obs}|$ and, respectively, $\log \dot{P}$ and $\log \tau_c$. The $\ddot{\nu}_{\rm obs} - \tau_c$ correlation coefficient reduces to ~ -0.30 if about 12 pulsars with $\tau_c < 0.1$ Myr and $\ddot{\nu}_{\rm obs}/\ddot{\nu}_{\rm pre} \simeq 1$ are excluded from the sample.

4 DISCUSSION

The predominance of timing noise activity in the present HartRAO pulsar sample is evident in the result of the foregoing analysis: more than half of the 27 pulsars have $\Delta_8 > -1.0$, and one pulsar, PSR B0959–54, has $\Delta_8 > 0$. An accumulation of timing noise, in the form of steps of random walk and/or microglitches of one preferred sign, could over time produce a spurious, non-stationary cubic term (Boynton et al. 1972; Cordes & Downs 1985; D'Alessandro et al. 1995). Furthermore, spurious braking indices could result from unobserved glitches and some kinds of long-term systematic changes in the pulsar rotation rates (Johnston & Galloway 1999; Chukwude et al. 2003, 2007; Shabanova 2005). Given the stochastic nature of the radio pulsar timing noise activity, the amplitude of noise dominated cubic terms would be both anomalous and highly non-stationary (Cordes & Downs 1985).

Observed braking indices with amplitudes that vary with data span lengths, could be better associated with pulsars whose timing activity is dominated by steps of random walk and/or microglitches (i.e. $\ddot{\nu}_{\rm obs} \simeq \ddot{\nu}_{\rm tno}$). In this scenario, a large accumulation of steps of random walk and/or microglitches of one preferred sign in $\dot{\nu}$ would probably result in a non-zero mean amplitude. The resulting amplitude change in $\dot{\nu}$, either positive or negative, would depend on the observation span length. Given that the events are random, there is a higher probability of having a net accumulation of steps and/or jumps of the same sign, yielding large

$|\ddot{\nu}_{\rm obs}|$ for relatively short data span lengths. However, as the data span length increases, the mean amplitude of the steps and/or jumps will probably approach zero, as the probability of having equal number of events with opposite sign and comparable amplitudes increases. This result underscores the importance of using longer span of data in measuring the parameter. On the other hand, an increase in $|\ddot{\nu}_{\rm obs}|$ with data span length could be linked to a steady net accumulation of jumps in $\dot{\nu}$ of the same sign. The timing activity of such objects would, probably, be dominated by glitches and/or microglitches. Interestingly, while the pulsar B0740–28 shows an overwhelming predominance of microglitch events during the period covered by our analysis (Chukwude 2002), the current timing data on B1822–09 are known to contain at least two glitch events (Shabanova 2005, and references therein).

A major effect of radio pulsar timing noise activity is to degrade the quality of the measured rotational parameters (ν, $\dot{\nu}$ and $\ddot{\nu}$) and the parameters derived from these (e.g. the characteristic age τ_c). The size of the expected systematic braking index ($\ddot{\nu}_{\rm pre}$, assuming the standard model) is extremely small ($\sim 10^{-33} \leq \ddot{\nu}_{\rm pre} \leq 10^{-23}$) for the present sample. This could be as much as 30 and 18 orders of magnitude, respectively, less than the expected ν and $\dot{\nu}$. Consequently, the effects of timing noise fluctuation are expected to be most severe in $\ddot{\nu}$, and to increase as the parameter becomes smaller. The large dispersion in the $|\ddot{\nu}_{\rm obs}| - \dot{P}$ plot for $\log \dot{P} > -17$, is a consequence of the pervasiveness of timing noise in the measured braking indices, especially in pulsars with a very small spindown rate. For pulsars with $\log \dot{P} < -17$, the expected systematic component of $\ddot{\nu}$ is extremely small and is completely swamped by the timing noise fluctuations (i.e. $\ddot{\nu}_{\rm tno} \gg \ddot{\nu}_{\rm pre}$). Consequently, the marginal correlation fizzles out at $\log \dot{P} < -17$. A similar argument holds for the τ_c-dependent dispersion in $|\ddot{\nu}_{\rm obs}|$, in Figure 5a, and for the non-existence of an apparent pattern beyond $\tau_c = 10\,$Myr. It is noteworthy that the $\ddot{\nu}_{\rm pre} - \dot{P}$ correlation is highly degraded for objects at the lower left corner of Figure 4b. These pulsars are characterised by exceptionally small $\ddot{\nu}_{\rm pre}$ ($< 10^{-29}$ s^{-3}) and $\dot{P}$ ($< 10^{-18}$ s^{-2}) which could easily be swamped by timing noise fluctuation. Equally pertinent, in Figure 5b, is the fact that few data points are located above the line describing $\ddot{\nu}_{\rm pre}$ data. These objects form a small group of pulsars whose spindown rates are unusually large for the inferred characteristic ages. For instance, a 1.5 Myr pulsar B0740–28 is associated with $\dot{\nu} \simeq -604 \times 10^{-15}$ s^{-2}, which is at least a factor of 10 larger than those of other pulsars of similar characteristic age.

Very recently, Urama, Link & Weisberg (2006) have reported a 91% correlation and an 87% anti-correlation between $|\ddot{\nu}_{\rm obs}|$ and, respectively, $\dot{\nu}$ and τ_c, for a subsample of the JBO pulsars (Hobbs et al. 2004). We believe that these relatively stronger correlations could be attributable to the stringent selection criteria imposed by the authors on their subsample, with bias in favour of objects with relatively large systematic frequency second derivative ($\ddot{\nu}_{\rm pre}$). Consequently, the subsample consisted of only objects with relatively large spindown rates ($\dot{\nu} \geq 10^{-15}$ Hz s^{-1}), short characteristic age ($\tau_c < 100\,$Myr) and small spin rates ($\nu < 10\,$Hz). From the foregoing discussion, the effects of timing noise fluctuations are expected to be least severe in this subset of pulsars. Nonetheless, the pervasive effects of timing noise are still evident in the subsample, as a large (~ 3 orders of magnitude) dispersion in $|\ddot{\nu}_{\rm obs}|$ at $\dot{\nu} \leq 10^{-14}$s^{-2} and at $\tau_c \geq 1.0\,$Myr. It is also noteworthy that the amplitude of the period derivative ($\dot{P} \equiv -\dot{\nu}/\nu^2$) used in our analysis is ~ 4 orders of magnitude smaller than the corresponding $\dot{\nu}$, and could easily be buried in fluctuations of timing noise.

5 CONCLUSIONS

We have undertaken an analysis of the observed braking indices of a sample of 27 radio pulsars in order to further constrain their exact nature. Our result reveals that the parameter is highly non-stationary with respect to both time and data span length. An analysis of a sample of 391 objects with significantly measured braking index, reveals evidence for severe contamination of the observed frequency second derivative by timing noise fluctuation. It is found that the effects of timing noise on $\ddot{\nu}_{\rm obs}$ is, on average, less severe for objects with relatively small characteristic age and large spin-down rate. Our results do not preclude the existence of pulsars with significant intrinsic component of $\ddot{\nu}$ that could be measurable.

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