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Timing parameters for 59 pulsars

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ABSTRACT

Timing parameters are presented for 59, mostly southern, pulsars derived from observations using the Molonglo Observatory Synthesis Telescope over about 2.4 yr from 1986 to 1988. For 45 of the pulsars, either the positions or the period parameters are more accurate than those previously available. Comparisons of the new and previously published parameters show good agreement in most cases. However, several apparently significant position changes are obtained and, in six cases at least, these can be interpreted as proper motions. Significant changes in period parameters are also observed in several pulsars, and evidence is found for one or more large glitches in the period of PSR 1641 − 45.

Key words: astrometry– pulsars: general – pulsars: individual: PSR 1641 − 45.

1 INTRODUCTION

The position, the pulsational period and the rate at which this period is changing are basic pulsar parameters. These parameters are required for essentially all pulsar studies, as they allow the pulse phase to be predicted and, therefore, synchronous integration of pulsar data. They also provide direct information on the distribution and evolution of pulsars. The braking of pulsar rotation is believed to result from the reaction to charged particle acceleration or low-frequency electromagnetic radiation by the rapidly rotating and highly magnetized neutron star. If the pulsar magnetic field is dipolar, the pulsar characteristic age, which is equal to the true age if the initial period was much less than the present period, is given by $\tau = P/(2\dot{P})$, where P is the pulsar period and $\dot{P}$ is its first time-derivative. Similarly, the strength of the dipole field at the surface of the neutron star is proportional to $(P\dot{P})^{1/2}$.

All of these parameters may be derived from observations of the arrival times of pulses made over an extended period. The radio mean pulse profiles of pulsars are generally very stable in shape and may be used to determine the time at which the pulse has a certain phase, usually chosen to be the pulse peak, at the observatory. These arrival times are affected by the motion of the Earth, and must be corrected to the Solar system barycentre which is assumed to be in an inertial frame. This correction involves the position of the pulsar. The barycentric arrival times can then be fitted to determine the pulsar parameters. In practice, initial estimates of the parameters are used to predict when a pulse should arrive and to determine the difference between the observed and predicted arrival times. A set of these differences, or timing residuals as they are commonly called, can be fitted with functions which are proportional to the corrections to the assumed parameters or to new parameters. Provided that the data span is a year or more, the position correction terms are decoupled from other parameters and very accurate pulsar positions can be derived.

In this paper we present parameters for 59 pulsars derived from pulse arrival-time observations. For most of these pulsars, relatively accurate parameters were available from observations made a decade or more earlier. The present observations update and, in most cases, improve on these earlier measurements. Comparison of the current and earlier results has revealed significant changes in both pulsar positions and period parameters in several cases.

2 OBSERVATIONS AND RESULTS

The observations were carried out using the Molonglo Observatory Synthesis Telescope (MOST), which operates at 843 MHz (Mills 1981), between 1986 February 6 and 1988 July 23. The telescope receives a single circular polarization and has a system equivalent flux density of about 60 Jy. The observed bandwidth of 3.2 MHz was divided into 16 contiguous frequency channels. After detection and low-pass filtering, the channel data were sampled synchronously with

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the pulsar period, normally with 256 samples per period. For some short-period pulsars, a submultiple of this number was used. An on-line computer was used to integrate the data, sum them over frequency with the appropriate delays to compensate for dispersion and write them to magnetic tape for further analysis. Observations were typically 5–20 min in duration, depending on the mean flux density of the pulsar. Integrations were started on a UTC second; the observatory rubidium standard was checked almost daily against UTC using a system based on timing of TV frame pulses.

In off-line analysis, the observed mean profiles were correlated with a standard profile for each pulsar, to determine arrival times at the observatory of a reference point on the profile. These were translated to the Solar system barycentre using the Jet Propulsion Laboratory DE200 ephemeris, and the program TEMPO was used for least-squares fitting and parameter determination.

Results from the analysis are given in Tables 1 and 2. The first two columns of both tables give the B1950 pulsar name and the corresponding J2000 equivalent. Columns 3–6 of Table 1 give the J2000 coordinates of the pulsar from the timing analysis. For these, and other parameters, the quoted errors are twice the rms deviation given by the least-squares fitting process. The final two columns of Table 1 give the B1950 mean positions. These positions were derived from the J2000 coordinates using the Starlink coordinate conversion program COCO, and do not include the *e*-terms of annual aberration. They are therefore directly comparable to timing positions derived using an ephemeris based on the B1950 coordinate system. Table 2 gives the derived pulsar period

Table 1. Pulsar timing positions.

PSR B	PSR J	R.A. (J2000) h m s	Err s	Dec. (J2000) ° ′ ″	Err ″	R.A. (1950) h m s	Dec. (1950) ° ′ ″
0031–07	0034–0721	00 34 09.0	0.3	−07 21 59	8	00 31 36.49	−07 38 31
0148–06	0151–0635	01 51 22.74	0.03	−06 35 03.1	1.1	01 48 52.60	−06 49 51.7
0149–16	0152–1637	01 52 10.848	0.007	−16 37 52.67	0.16	01 49 46.444	−16 52 39.56
0203–40	0206–4028	02 06 01.268	0.009	−40 28 04.33	0.14	02 03 57.190	−40 42 21.07
0254–53	0255–5304	02 55 56.221	0.008	−53 04 21.36	0.08	02 54 24.196	−53 16 244.7
0403–76	0401–7608	04 01 51.68	0.07	−76 08 13.8	0.3	04 03 15.06	−76 16 25.2
0447–12	0450–1248	04 50 08.763	0.015	−12 48 07.0	0.4	04 47 49.504	−12 53 12.6
0450–18	0452–1759	04 52 34.090	0.008	−17 59 23.40	0.14	04 50 21.10	−18 04 18.6
0523+11	0525+1115	05 25 56.437	0.016	+11 15 20.1	0.8	05 23 09.560	+11 12 45.7
0538–75	0536–7543	05 36 30.79	0.08	−75 43 56.7	0.2	05 38 18.73	−75 45 35.3
0727–18	0729–1836	07 29 32.371	0.009	−18 36 42.28	0.17	07 27 19.386	−18 30 25.14
0736–40	0738–4042	07 38 32.356	0.014	−40 42 40.56	0.16	07 36 50.825	−40 35 46.22
0740–28	0742–2822	07 42 49.08	0.02	−28 22 44.1	0.4	07 40 47.82	−28 15 33.5
0808–47	0809–4753	08 09 43.890	0.009	−47 53 55.14	0.09	08 08 12.493	−47 45 00.52
0818–13	0820–1350	08 20 26.355	0.006	−13 50 55.25	0.15	08 18 06.029	−13 41 23.09
0818–41	0820–4114	08 20 15.37	0.09	−41 14 35.3	1.0	08 18 29.54	−41 05 02.8
0835–41	0837–4135	08 37 21.173	0.006	−41 35 14.29	0.07	08 35 33.266	−41 24 42.11
0905–51	0907–5157	09 07 15.900	0.010	−51 57 59.25	0.10	09 05 40.583	−51 45 50.94
0940–55	0942–5552	09 42 15.83	0.09	−55 52 52.3	0.9	09 40 37.87	−55 39 07.8
0941–56	0942–5657	09 42 54.462	0.016	−56 57 43.44	0.14	09 41 18.585	−56 43 57.31
0942–13	0944–1354	09 44 28.957	0.020	−13 54 41.4	0.4	09 42 04.407	−13 40 52.4
0959–54	1001–5507	10 01 37.98	0.11	−55 07 06.7	1.1	09 59 51.65	−54 52 37.2
1054–62	1056–6258	10 56 25.55	0.06	−62 58 47.6	0.4	10 54 27.99	−62 42 45.1
1133–55	1136–5525	11 36 02.17	0.08	−55 25 08.3	0.8	11 33 38.97	−55 08 32.2
1154–62	1157–6224	11 57 15.240	0.016	−62 24 50.87	0.13	11 54 43.697	−62 08 08.92
1221–63	1224–6407	12 24 22.185	0.009	−64 07 53.91	0.07	12 21 34.715	−63 51 16.84
1240–64	1243–6423	12 43 17.158	0.020	−64 23 23.85	0.13	12 40 18.270	−64 06 58.37
1317–53	1320–5359	13 20 53.922	0.014	−53 59 06.38	0.18	13 17 49.115	−53 43 23.76
1358–63	1401–6357	14 01 52.48	0.02	−63 57 45.54	0.19	13 58 10.69	−63 43 17.75
1424–55	1428–5530	14 28 26.297	0.016	−55 30 50.2	0.2	14 24 54.693	−55 17 26.4
1426–66	1430–6623	14 30 40.872	0.018	−66 23 05.04	0.14	14 26 35.293	−66 09 46.39
1449–64	1453–6413	14 53 32.737	0.010	−64 13 15.59	0.08	14 49 25.287	−64 01 01.16
1451–68	1456–6843	14 56 00.158	0.014	−68 43 39.25	0.09	14 51 29.026	−68 31 31.57
1530–53	1534–5334	15 34 08.37	0.02	−53 34 19.3	0.3	15 30 22.47	−53 24 17.1
1540–06	1543–0620	15 43 30.16	0.03	−06 20 45.8	1.4	15 40 50.34	−06 11 18.8
1556–44	1559–4438	15 59 41.535	0.004	−44 38 46.11	0.12	15 56 11.062	−44 30 17.27
1556–57	1600–5751	16 00 19.93	0.04	−57 51 14.7	0.6	15 56 14.75	−57 42 47.2
1557–50	1600–5044	16 00 53.066	0.018	−50 44 21.2	0.3	15 57 08.866	−50 35 56.4
1600–49	1604–4909	16 04 22.999	0.012	−49 09 58.34	0.14	16 00 42.02	−49 01 46.9
1641–45	1644–4559	16 44 49.281	0.019	−45 59 09.5	0.4	16 41 10.339	−45 53 39.1

Table 1 – *continued*

PSR B	PSR J	R.A. (J2000) h m s	Err s	Dec. (J2000) ° ′ ″	Err ″	R.A. (1950) h m s	Dec. (1950) ° ′ ″
1648–42	1651–4246	16 51 48.79	0.08	–42 46 11	2	16 48 16.17	–42 41 10
1706–16	1709–1640	17 09 26.430	0.014	–16 40 58.4	1.1	17 06 33.194	–16 37 13.0
1717–29	1720–2933	17 20 34.15	0.02	–29 33 15	2	17 17 23.15	–29 30 16.6
1718–32	1722–3207	17 22 02.967	0.009	–32 07 44.3	0.6	17 18 47.908	–32 04 52.1
1742–30	1745–3040	17 45 56.305	0.004	–30 40 22.9	0.4	17 42 43.022	–30 39 14.4
1747–46	1751–4657	17 51 42.233	0.011	–46 57 24.8	0.2	17 47 57.019	–46 56 40.3
1749–28	1752–2806	17 52 58.681	0.017	–28 06 37	2	17 49 49.261	–28 05 59
1818–04	1820–0427	18 20 52.62	0.02	–04 27 38.4	1.1	18 18 13.65	–04 29 04
1821–19	1824–1945	18 24 00.49	0.06	–19 45 50	13	18 21 02.82	–19 47 28
1822–09	1825–0935	18 25 30.652	0.012	–09 35 25.2	0.7	18 22 45.643	–09 37 10.5
1826–17	1829–1751	18 29 43.121	0.012	–17 51 02.9	1.8	18 26 47.981	–17 53 06.1
1844–04	1847–0402	18 47 22.834	0.014	–04 02 14.2	0.5	18 44 44.415	–04 05 34.2
1845–01	1848–0123	18 48 23.60	0.02	–01 23 58.2	0.7	18 45 48.20	–01 27 22.7
1915+13	1917+1353	19 17 39.82	0.03	+13 53 56.3	0.6	19 15 21.62	+13 48 27.9
1929+10	1932+1059	19 32 13.874	0.006	+10 59 31.78	0.16	19 29 52.013	+10 53 04.06
1933+16	1935+1616	19 35 47.834	0.010	+16 16 40.05	0.18	19 33 31.870	+16 09 57.80
1937–26	1941–2602	19 41 00.34	0.02	–26 02 01	2	19 37 56.89	–26 09 02
2045–16	2048–1616	20 48 35.56	0.08	–16 16 48	4	20 45 47.16	–16 27 56
2327–20	2330–2005	23 30 26.809	0.019	–20 05 28.6	0.5	23 27 49.737	–20 22 01.6

Table 2. Pulsar period parameters.

PSR B	PSR J	Period (s)	Err	$\dot{P}$ ($\times10^{15}$)	Err	Res.(ms)	Nr obs	MJD range
0031–07	0034–0721	0.94295100027	12	0.409	13	5.3	28	46468–47233
0148–06	0151–0635	1.46466445165	4	0.444	3	0.91	20	46468–47335
0149–16	0152–1637	0.832741452547	6	1.2984	7	0.27	26	46468–47233
0203–40	0206–4028	0.630550140847	6	1.1994	5	0.36	29	46469–47335
0254–53	0255–5304	0.447708444058	3	0.0306	3	0.27	29	46469–47364
0403–76	0401–7608	0.545252742352	16	1.5382	12	1.0	28	46470–47335
0447–12	0450–1248	0.438014126894	11	0.1033	8	0.71	23	46469–47335
0450–18	0452–1759	0.548937986023	5	5.7564	4	0.39	30	46468–47364
0523+11	0525+1115	0.354437585224	7	0.0732	6	0.69	26	46469–47335
0538–75	0536–7543	1.24585559629	5	0.565	3	0.72	17	46610–47335
0727–18	0729–1836	0.510155557814	11	19.0066	7	0.43	27	46609–47364
0736–40	0738–4042	0.374919300996	5	1.6016	4	0.70	37	46468–47366
0740–28	0742–2822	0.166758621359	8	16.8219	5	1.3	34	46608–47364
0808–47	0809–4753	0.547199235502	4	3.0825	4	0.36	31	46468–47365
0818–13	0820–1350	1.238129161193	12	2.1041	9	0.36	31	46470–47365
0818–41	0820–4114	0.54544553350	4	0.013	5	3.0	21	46468–47149
0835–41	0837–4135	0.751622117781	9	3.5469	5	0.26	32	46608–47365
0905–51	0907–5157	0.253556015011	3	1.8303	2	0.38	32	46469–47365
0940–55	0942–5552	0.66436748807	6	22.854	5	3.4	33	46469–47233
0941–56	0942–5657	0.808127417142	11	39.6284	11	0.42	24	46470–47149
0942–13	0944–1354	0.570264114648	10	0.0455	9	0.39	12	46470–47232
0959–54	1001–5507	1.43658262920	12	51.396	12	4.2	36	46468–47233
1054–62	1056–6258	0.422447188684	16	3.5757	11	1.7	35	46468–47366
1133–55	1136–5525	0.36470557624	2	8.2151	15	2.1	21	46468–47366
1154–62	1157–6224	0.400522048340	4	3.9313	3	0.42	27	46468–47335
1221–63	1224–6407	0.2164762031209	14	4.95332	9	0.26	34	46468–47365
1240–64	1243–6423	0.388480921041	5	4.5006	2	0.55	42	46468–47468
1317–53	1320–5359	0.279729147244	4	9.2543	2	0.49	28	46468–47365
1358–63	1401–6357	0.842789632370	14	16.7258	8	0.62	33	46468–47365
1424–55	1428–5530	0.570290462862	7	2.0805	4	0.43	23	46468–47364

Table 2 – *continued*

PSR B	PSR J	Period (s)	Err	$\dot{P}$ ($\times 10^{15}$)	Err	Res.(ms)	Nr obs	MJD range
1426–66	1430–6623	0.785440757324	8	2.7695	5	0.29	16	46468–47365
1449–64	1453–6413	0.1794847539641	11	2.74610	7	0.31	42	46468–47366
1451–68	1456–6843	0.2633768148933	19	0.09826	13	0.38	41	46468–47365
1530–53	1534–5334	1.36888090921	2	1.4260	18	0.51	19	46470–47335
1540–06	1543–0620	0.70906387025	2	0.8826	14	0.62	11	46470–47365
1556–44	1559–4438	0.2570560976508	11	1.01916	8	0.19	27	46468–47366
1556–57	1600–5751	0.194454482247	8	2.1252	4	1.11	21	46470–47366
1557–50	1600–5044	0.192600176304	3	5.0622	2	0.77	38	46468–47366
1600–49	1604–4909	0.327417572788	13	1.0194	11	0.77	9	46469–46889
1641–45	1644–4559	0.455059775403	10	20.0902	6	0.66	23	46523–47365
1648–42	1651–4246	0.84408066596	9	4.812	5	3.3	27	46523–47364
1706–16	1709–1640	0.653053865368	8	6.3075	9	0.27	12	46470–47232
1717–29	1720–2933	0.62044816817	2	0.7432	13	0.97	27	46523–47366
1718–32	1722–3207	0.477157345417	8	0.6470	4	0.40	29	46546–47366
1742–30	1745–3040	0.367425906691	3	10.6592	2	0.22	30	46546–47366
1747–46	1751–4657	0.742352395470	10	1.2911	6	0.41	27	46523–47364
1749–28	1752–2806	0.562557857834	12	8.1394	8	0.59	18	46470–47365
1818–04	1820–0427	0.59807602125	2	6.3197	17	1.1	17	46470–47365
1821–19	1824–1945	0.18933359977	2	5.2248	13	1.6	12	46546–47366
1822–09	1825–0935	0.76897223949	2	52.432	3	0.53	21	46547–47366
1826–17	1829–1751	0.307131499128	6	5.5619	3	0.49	19	46523–47366
1844–04	1847–0402	0.597760501935	15	51.7099	10	0.57	18	46547–47366
1845–01	1848–0123	0.65943059121	3	5.2184	16	0.79	18	46608–47366
1915+13	1917+1353	0.194629140089	8	7.1984	5	1.3	21	46469–47366
1929+10	1932+1059	0.226517662811	2	1.15645	13	0.31	22	46469–47366
1933+16	1935+1616	0.358738600597	4	6.0022	3	0.38	20	46469–47366
1937–26	1941–2602	0.402857638289	7	0.9556	4	0.71	30	46470–47366
2045–16	2048–1616	1.96157266044	2	10.9554	14	0.54	38	46469–47366
2327–20	2330–2005	1.64362095394	2	4.6258	17	0.59	29	46468–47364

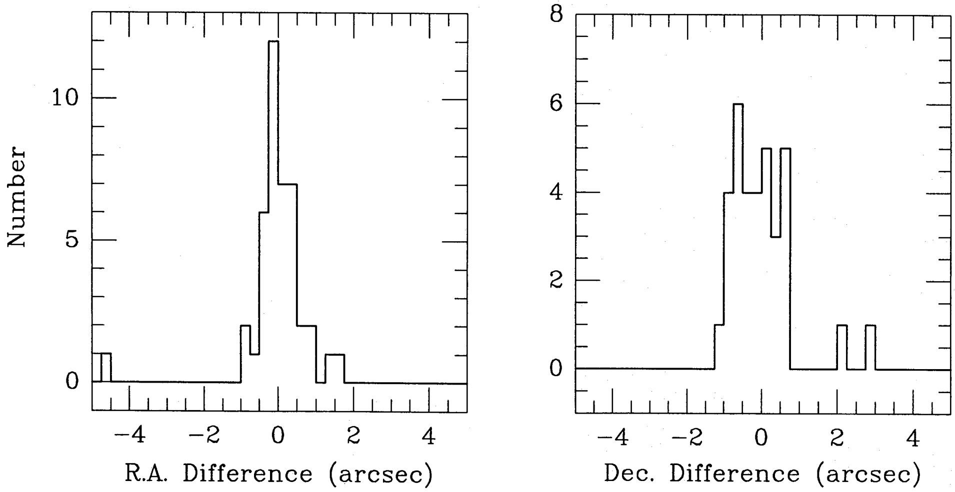

Figure 1. Histogram of differences between timing positions from this work and previously published positions.

and first period-derivative, along with their estimated errors; for these parameters the errors are in the last-quoted digit. Also given in Table 2 are the rms phase residual from the final least-squares fit, the number of arrival times fitted and the interval (in Modified Julian Days) covered by the observations.

3 DISCUSSION

All of these pulsars had previously published positions, periods and period derivatives, mostly from the timing observations of Newton, Manchester & Cooke (1981), Manchester et al. (1983) or Downs & Reichley (1983). In a few cases, previous positions were from interferometric observations. For one pulsar, PSR B1648 − 42, there was a limit only on the period derivative. The present results improve on the previously published data, in the sense of being more recent and, in 45 cases out of the 59 total, having smaller quoted errors.

The interval between the previous and present observations is typically about a decade and, in some cases, as long as 18 yr, so comparisons of the two data sets are of interest. Fig. 1 shows the distribution of position differences for those pulsars which have errors in the difference of less than 1 arcsec and differences of less than 5 arcsec. Most of the differences are less than 1 arcsec, but some are larger. Of the 59 total, 17 pulsars have a difference in one or both coordinates whose absolute value exceeds twice the estimated uncertainty. These differences and their uncertainties are listed in Table 3, along with the interval between the previous and present observations and references for the previously published data.

For PSR 1822 − 09, the comparison is with the recent interferometric position of Fomalont et al. (1992), and the epoch difference is small. The apparently significant declination difference must result from underestimated errors in the timing solution due to irregularities in the pulsar period. For the others, the position change may be attributed to proper motion of the pulsar. Table 4 lists the derived proper motions, along with the distance to the pulsar derived from the dispersion measure using the Galactic electron density model of Taylor & Cordes (1993), the corresponding transverse velocity, and previously published proper motions where available. In several cases, specifically PSR 0538 − 75, 0940 − 55, 0941 − 56, 1240 − 64, 1358 − 63 and 1557 − 50, the implied velocities are very high and of modest significance. It is likely that, in these cases at least, the position difference is not as significant as it appears, probably because of the effects of irregularities in the pulsar period. For PSR 0736 − 40, the implied velocity is also extremely high. In this case, however, the derived proper motion is in excellent agreement with the value obtained by Downs & Reichley (1983) and hence is believable. The most likely explanation for the high velocity is that the estimated distance to the pulsar is too large. This pulsar is within the Gum nebula, and it is probable that an intervening H II region contributes to its dispersion measure. For PSR 1929 + 10 and 1933 + 16 also, the agreement between the present and previous proper motion estimates is excellent. For PSR 1449 − 64, 1451 − 68, 1600 − 49 and 2045 − 16 the estimates differ by up to four times the uncertainty in the difference. In summary, the results given in Table 4 show that reliable proper motion estimates can be obtained from pulsar timing, but that the errors are often two or three times the formal estimates.

Table 3. Pulsar position differences.

PSR B	$\Delta\alpha$	$\Delta\delta$	Interval	Ref.
	″	″	yr	
0203−40	−0.10 ± 0.21	0.7 ± 0.3	9.2	1
0254−53	−0.01 ± 0.16	0.55 ± 0.13	7.9	2
0538−75	−0.5 ± 1.5	2.7 ± 1.2	9.4	1
0736−40	−0.87 ± 0.16	0.58 ± 0.17	15.3	3
0940−55	0.9 ± 0.8	2.9 ± 0.9	9.0	1
0941−56	−0.50 ± 0.21	0.12 ± 0.17	8.9	1
1240−64	−0.4 ± 0.3	−0.7 ± 0.3	11.7	2
1358−63	1.5 ± 0.5	−0.5 ± 0.7	9.2	1
1449−64	0.04 ± 0.09	−0.84 ± 0.22	10.2	2
1451−68	−0.21 ± 0.09	−0.61 ± 0.10	11.9	2
1556−44	0.33 ± 0.06	−0.34 ± 0.16	11.9	2
1557−50	1.0 ± 0.3	−0.5 ± 0.8	11.9	2
1600−49	−0.16 ± 0.15	−1.2 ± 0.3	8.6	1
1822−09	0.14 ± 0.19	−2.3 ± 0.7	1.1	4
1929+10	1.71 ± 0.27	0.5 ± 0.3	17.8	3
1933+16	−0.05 ± 0.14	−0.54 ± 0.18	18.4	3
2045−16	3.7 ± 1.2	−6 ± 4	18.3	3

References: (1) Newton, Manchester & Cooke (1981); (2) Manchester et al. (1983); (3) Downs & Reichley (1983); (4) Fomalont et al. (1992).

Table 4. Pulsar proper motions.

	From position differences					Prev. published values		
PSR B	μ_α mas yr^{-1}	μ_δ mas yr^{-1}	μ mas yr^{-1}	Dist. kpc	Vel. km s^{-1}	μ_α mas yr^{-1}	μ_δ mas yr^{-1}	Ref.
0203-40	−10 ± 25	75 ± 35	80 ± 35	0.8	310			
0254-53	0 ± 20	70 ± 15	70 ± 15	1.1	360			
0538-75	−60 ± 160	290 ± 130	295 ± 130	1.1	1500			
0736-40	−60 ± 10	40 ± 10	70 ± 12	15.7	5100	−56 ± 9	46 ± 8	1
0940-55	105 ± 90	325 ± 105	340 ± 140	6.3	10200			
0941-56	−55 ± 25	15 ± 20	60 ± 25	5.1	1400			
1240-64	−35 ± 25	−60 ± 30	70 ± 30	12.2	4100			
1358-63	160 ± 50	−55 ± 80	170 ± 55	2.6	2100			
1449-64	5 ± 10	−80 ± 20	80 ± 22	1.9	720	−16 ± 1	−21 ± 1	2
1451-68	−20 ± 10	−51 ± 8	54 ± 8	0.5	120	−16 ± 1	−12 ± 1	2
1556-44	25 ± 5	−30 ± 15	40 ± 10	1.7	310	−11 ± 17	20 ± 50	3
1557-50	80 ± 30	−40 ± 65	90 ± 40	6.3	2800			
1600-49	−20 ± 20	−145 ± 40	145 ± 40	3.6	2500	−30 ± 7	−1 ± 3	2
1929+10	95 ± 15	30 ± 20	100 ± 15	0.1	36	99 ± 6	39 ± 4	2
1933+16	−2 ± 8	−30 ± 10	30 ± 10	7.9	1100	2 ± 3	−25 ± 5	1
2045-16	210 ± 65	−330 ± 220	390 ± 190	0.6	1200	85 ± 16	−43 ± 17	3

References: (1) Downs & Reichley (1983); (2) Bailes et al. (1990); (3) Fomalont et al. (1992).

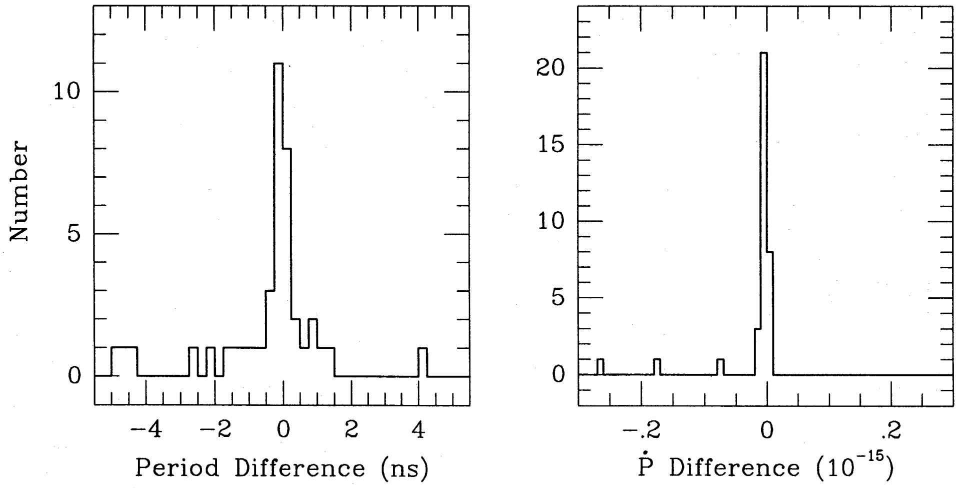

Figure 2. Histogram of differences in period and period derivative between the present and previously published values.

Pulsar periods can be compared in a similar way. However, because the periods are increasing with time, the results must be referred to a common epoch before comparison. The epoch chosen was that of the measurement to which the extrapolation of the other measurement, either forward or backward, gave the smallest error. Fig. 2 illustrates the differences in period and period derivative between the present and previously published values for differences whose errors are less than 0.5 ns and 0.02×10^{-15} respectively. The remarkable period stability of most pulsars is evident; in general their periods can be predicted to better than 0.5 ns over more than a decade.

There are, nevertheless, larger differences for some pulsars. Table 5 lists those differences whose absolute value is more than four times the estimated error in the difference, along with the interval in years between the two measurements. Most of these differences are small and can be attributed to 'timing noise' – irregular and unresolved fluctuations in the pulsar period. Larger differences exist for PSR 0959 − 54, 1358 − 63, 1641 − 45 and 1822 − 09. It has been mentioned above that the previous timing solution for PSR 1822 − 09 is apparently in error. For PSR 0959 − 54 and 1358 − 63, there has been a substantial change in both period and period derivative. The period changes are of positive sign and so are not 'glitches' of the type seen in many young pulsars. It seems most likely that these pulsars have larger than average timing noise. Both have relatively large period derivatives (Table 2) and there is a correlation between period derivative and period noise (Cordes & Downs 1985).

By far the largest and most significant change is the decrease of more than 350 ns in the period of PSR 1641 − 45. A glitch in the period of this pulsar was observed in 1977 (Manchester et al. 1978). This glitch was of magnitude 87 ns and was accompanied by a small increase in the period derivative. The observations by Manchester et al. (1983), used in the present comparison, were after this glitch and ended on MJD 43744 (1978 August 24). There seems little doubt that there have been one or more glitches in the period of this pulsar between 1978 August and the start of the present observations, MJD 46523 (1986 April 3), with a total decrease in period of 364 ns. This corresponds to a fractional decrease of 8×10^{-7}, almost as large as the Vela glitches (Cordes, Downs & Krause-Polstorff 1988).

Table 5. Pulsar period and period derivative differences.

PSR B	ΔP ns	$\Delta \dot{P}$ 10^{-15}	Interval yr	Ref.
0450−18	−0.67 ± 0.21	0.0070 ± 0.0010	14.4	1
0727−18	−5.0 ± 0.2	0.0586 ± 0.0012	8.0	2
0736−40	−2.0 ± 0.1	−0.0124 ± 0.0005	11.6	3
0740−28	4.0 ± 0.2	−0.0098 ± 0.0009	11.6	3
0835−41	−4.35 ± 0.15	0.001 ± 0.003	8.9	4
0905−51	0.77 ± 0.07	−0.003 ± 0.002	8.9	4
0940−55	−10.7 ± 0.9	0.115 ± 0.006	8.9	4
0941−56	−4.6 ± 0.3	0.011 ± 0.002	8.9	4
0959−54	38.1 ± 0.5	−0.269 ± 0.009	8.9	4
1133−55	−0.3 ± 0.4	−0.013 ± 0.002	8.9	4
1317−53	0.58 ± 0.06	−0.0046 ± 0.0007	8.9	4
1358−63	43.4 ± 0.3	−0.179 ± 0.008	8.9	4
1424−55	0.86 ± 0.14	−0.007 ± 0.004	8.9	4
1449−64	−0.09 ± 0.02	−0.0014 ± 0.0007	9.9	3
1540−06	−1.65 ± 0.13	−0.0004 ± 0.0015	8.0	2
1556−44	0.07 ± 0.01	−0.0004 ± 0.0008	11.6	3
1600−49	1.33 ± 0.17	0.0077 ± 0.0012	8.9	4
1641−45	−363.7 ± 0.2	−0.014 ± 0.004	9.2	3
1706−16	25.1 ± 0.5	−0.0725 ± 0.0014	16.9	1
1749−28	−2.7 ± 0.5	−0.014 ± 0.002	18.3	5
1818−04	−1.1 ± 0.3	−0.018 ± 0.002	16.9	1
1821−19	1.0 ± 0.4	−0.013 ± 0.002	8.9	4
1822−09	−25.9 ± 1.8	0.11 ± 0.12	8.3	4
1915+13	−0.94 ± 0.02	−0.0045 ± 0.0005	12.3	6
1929+10	0.44 ± 0.04	−0.0003 ± 0.0013	13.9	6
1933+16	−0.26 ± 0.02	−0.0013 ± 0.0003	12.4	6
2045−16	−1.49 ± 0.11	−0.0056 ± 0.0014	16.7	1

References: (1) Helfand et al. (1980); (2) Backus, Taylor & Damashek (1982); (3) Manchester et al. (1983); (4) Newton, Manchester & Cooke (1981); (5) Hunt (1971); (6) Gullahorn & Rankin (1978).

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