

Pulsars in FIRST Observations

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Abstract We identify 16 pulsars from the Survey of Faint Images of the Radio Sky at Twenty-cm (FIRST) at 1.4 GHz. Their positions and total flux densities are extracted from the FIRST catalog. By comparing the source positions with those in the PSR catalog, we obtain better determined positions of PSR J1022+1001, J1518+4904, J1652+2651, and proper motion upper limits of PSR J0751+1807, J1012+5307, and J1640+2224. The proper motions of the other ten pulsars are consistent with the catalog values.

Key words: pulsar: general — stars: neutron

1 INTRODUCTION

Pulsars receive a large kick velocity during the period of birth, so they move away from their birth place, where the center of supernova remnant is believed to be. Measuring the proper motions of pulsars can derive an independent estimate of their ages, which has a number of astrophysical uses, for example, in the studies of the evolution of neutron star magnetic field and of pulsar emission beam.

There are three methods of measuring proper motion: (1) traditional optical method, (2) timing measurement, and (3) interferometric measurement. The first technique has been applied to a few pulsars that can be seen in optical wavelengths (Mignani et al. 2000). Pulsar proper motion can also be obtained from regular timing observations when carried out over a sufficiently long interval. However, timing noise restricts its usefulness except for millisecond pulsars (Kaspi, Taylor & Ryba 1994; Bell et al. 1995; Nice & Taylor 1995; Wolszczan et al. 2000). Interferometric observations measure the angular transverse motion of a pulsar in the sky, relative to a set of reference sources (e.g. McGary et al. 2001). This technique is so far the most productive method of determining pulsar proper motion.

FIRST (Becker et al. 1995) is a project designed to produce the radio equivalent of the Palomar Observatory Sky Survey over 10 000 square degrees of the North Galactic Cap — using the B-configuration of NRAO Very Large Array (VLA) at 1.4 GHz. The observations have a resolution of 5'', and the positional accuracies have 90% confidence error circles of radius <0.5'' at the 3 mJy level and 1'' at the detected threshold 1 mJy.

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We have tried to identify the pulsars in the FIRST catalog, and then to investigate their proper motions.

2 IDENTIFICATIONS

There are 42 known pulsars listed in the PSR catalog which are located in the sky region covered by FIRST. We searched FIRST radio sources within $30''$ around each pulsar, and found 17 above the survey sensitivity. At the 1 mJy threshold, FIRST detected ~ 90 sources per square degree. The probability for chance coincidence within a circle of $30''$ radius is about 0.6%. We noted that pulsar positions in the PSR catalog and in FIRST are at different epochs. If a pulsar has a large proper motion, e.g. 400 mas per year (the largest known), then after 30 years, the position offset would be $12''$. So, we should not miss any known pulsars if we search radio sources within $30''$ around each pulsar.

Pulsar positions in the PSR catalog generally have a typical uncertainty better than $0.1''$, but occasionally up to a few arcsec for new discoveries. For the 17 identified sources, Table 1 lists in Columns 1 through 5, the PSR J-name, the positions with uncertainties in bracket, the epoch for the positions and the flux densities at 1.4 GHz from the PSR catalog, and in columns 6 through 10, the FIRST catalog parameters, the positions, their uncertainties, and the flux densities.

Table 1 Pulsar Positions and Flux Densities from the PSR Catalog and the Values of Nearby FIRST Sources within $30''$

PSR J-	RA (2000) h m s	DEC (2000) ° ' "	Epoch MJD	Flux mJy	RA (first) h m s	DEC (first) ° ' "	σ	Epoch MJD	Flux mJy
0751+1807	07 51 09.1582(7)	+18 07 38.71(5)	49301	1	07 51 09.148	+18 07 38.72	0.89	50996	1.42 (15)
0826+2637	08 26 51.310(2)	+26 37 25.57(7)	40264	10(2)	08 26 51.438	+26 37 22.83	0.35	49901	11.14 (14)
0922+0638	09 22 13.977(3)	+06 38 21.69(4)	46573	4.2(9)	09 22 14.005	+06 38 22.82	0.36	51361	10.33 (14)
0943+1631	09 43 30.042(4)	+16 31 35.49(6)	47555	1.4(4)	09 43 30.092	+16 31 34.67	1.17	51361	1.51 (14)
0953+0755	09 53 09.316(3)	+07 55 35.60(4)	46058	84(8)	09 53 09.286	+07 55 35.94	0.28	51361	83.13 (15)
1012+5307	10 12 33.4326(4)	+53 07 02.66(1)	49220	3	10 12 33.387	+53 07 02.09	0.63	50631	2.20 (14)
1022+1001	10 22 58.06(6)	+10 01 54(3)	49780	2	10 22 58.015	+10 01 52.84	0.54	51361	3.69 (15)
1115+5030	11 15 38.35(2)	+50 30 13.6(3)	44240	3(2)	11 15 38.483	+50 30 25.70	0.30	50631	32.50 (14)
1136+1551	11 36 03.296(4)	+15 51 00.7(1)	42364	30(5)	11 36 03.180	+15 51 09.62	0.31	51361	20.62 (14)
1239+2453	12 39 40.475(3)	+24 53 49.25(3)	46058	10(2)	12 39 40.386	+24 53 49.87	0.34	49901	11.53 (15)
1509+5531	15 09 25.724(9)	+55 31 33.01(8)	48383	8.0(10)	15 09 25.674	+55 31 32.90	0.37	50631	10.02 (15)
1518+4904	15 18 16.6(1)	+49 04 35(1)	49896	15	18 16.832	+49 04 34.19	0.45	50631	5.03 (13)
1543+0929	15 43 38.826(6)	+09 29 16.8(2)	42304	5.9(9)	15 43 38.835	+09 29 16.50	0.41	51361	6.18 (15)
1607-0032	16 07 12.117(2)	-00 32 40.18(6)	42307	5(2)	16 07 12.078	-00 32 40.98	0.63	50996	3.93 (15)
1640+2224	16 40 16.7417(1)	+22 24 09.015(3)	49360	16	40 16.698	+22 24 08.98	0.87	50996	1.92 (15)
1652+2651	16 52 03.0(3)	+26 51 40(1)	49800	16	52 03.080	+26 51 39.85	0.39	49901	6.27 (14)
2145-0750	21 45 50.4693(2)	-07 50 18.34(1)	48979	7.0(9)	21 45 50.477	-07 50 18.35	0.62	50631	4.10 (18)

The FIRST survey was conducted over a long period, from 1994 to 1999, and had no accurate epoch listed in the FIRST catalog, thus we estimated the approximate epoch year by the color displayed in the images given in the FIRST observations, and take the MJD for the middle of each year as the approximate observation epoch (Table 1, Col. 9). This should be adequate for the proper motion discussion considering the position uncertainties of the sources given in Table 1.

There are 13 pulsars that have been identified (in Table 1 except J1115+5030) by comparing the peak flux densities of sources between the FIRST and the PSR catalogs. Consistency in the pulsar flux densities between the two catalogs is shown in Figure 1.

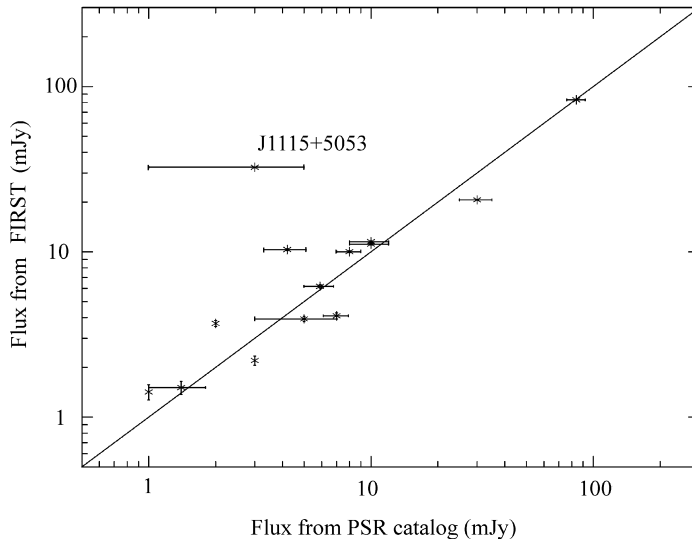


Fig. 1 Comparison of pulsar flux densities from the PSR catalog and the FIRST measurement.

3 DISCUSSION

3.1 Undetected Pulsars

The flux densities measured by VLA at 1.4 GHz of most of the identified pulsars are comparable to the flux densities listed in the PSR catalog. PSR J1115+5030 has a flux density of 32.50 mJy in FIRST but 3 mJy in the PSR catalog (Fig. 1), and its position offset is $12.17''$. If so, we acquire its proper motion $\mu_\alpha \cos \delta = -73 \pm 24 \text{ mas yr}^{-1}$, $\mu_\delta = 691 \pm 24 \text{ mas yr}^{-1}$, which are much larger than those listed in the PSR catalog, $\mu_\alpha \cos \delta = -22 \pm 3 \text{ mas yr}^{-1}$, $\mu_\delta = -51 \pm 3 \text{ mas yr}^{-1}$. Therefore, we think the FIRST source is probably a chance coincidence, and the pulsar was not detected in the survey.

Most of the undetected pulsars may be either fainter than the survey threshold 1 mJy or influenced by interstellar scintillation (e.g., Gupta et al. 1994) which both helps and hinders the detection (Cordes & Lazio 1991). In Table 2, we list two pulsars with flux densities larger than the 1 mJy threshold but were not clearly detected in the FIRST survey. Both of them are only marginally shown in the FIRST images.

Table 2 Pulsars which should be Detected by FIRST but were not

PSR J-	RA	DEC	1.4 GHz
	h m s	° ' "	mJy
0823+0159	08 23 09.76(1)	+01 59 12.8(5)	1.5(7)
0837+0610	08 37 05.649(3)	+06 10 14.08(5)	4.0(10)

3.2 Flux Densities, Positions and Proper Motions

We can see from Table 1 that PSR J1518+4904, J1640+2224 and J1652+2651 have no flux densities listed in the PSR catalog. We believe that the flux densities and the positions in FIRST are more reliable than those in the PSR catalog. The very accurate positions for the three pulsars J1022+1001, J1518+4904 and J1652+2651 (see Table 1) should be noted.

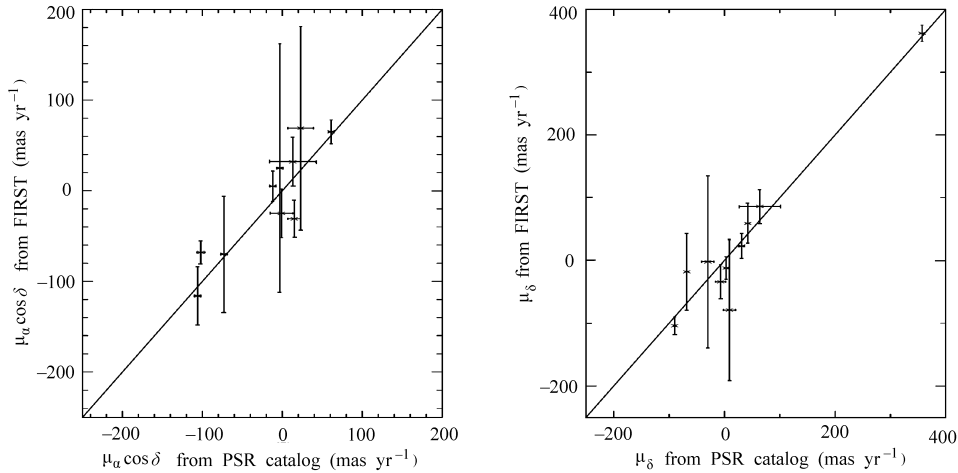


Fig. 2 Comparison of pulsar proper motions in ascension (left) and declination (right) listed in the PSR catalog and derived from FIRST.

Table 3 Pulsar Proper Motions or Upper Limits

PSR -J	$\mu_{\alpha} \cos \delta$ mas yr ⁻¹	μ_{δ} mas yr ⁻¹	Δ RA "	Δ DEC "	$\mu_{\alpha} \cos \delta$ mas yr ⁻¹	μ_{δ} mas yr ⁻¹	Notes
0751+1807	...	...	-0.15±0.89	0.01±0.89	-31 ± 191	2 ± 192	pm upper limit
0826+2637	61±3	-90±2	1.73±0.35	-2.74±0.36	65 ± 13	-104 ± 14	pm consistent
0922+0638	13±9	64±37	0.42±0.36	1.13±0.36	32 ± 27	86 ± 27	pm consistent
0943+1631	23±16	9±11	0.72±1.17	-0.82±1.17	69 ± 112	-79 ± 112	pm consistent
0953+0755	15±8	31±5	-0.45±0.29	0.34±0.29	-31 ± 20	23 ± 20	pm consistent
1012+5307	...	...	-0.41±0.63	-0.57±0.63	-106 ± 163	-147 ± 163	pm upper limits
1022+1001	...	...	-0.66±1.05	-1.16±3.05	...	...	new position
1115+5030	22±3	-51±3	-1.28±0.42	12.10±0.42	...	...	no detection
1136+1551	-102±5	357±3	-1.68±0.32	8.92±0.33	-68 ± 13	362 ± 13	pm consistent
1239+2453	-106±4	42±3	-1.22±0.34	0.62±0.34	-116 ± 32	59 ± 32	pm consistent
1509+5531	-73±4	-68±3	-0.43±0.39	-0.11±0.38	-70 ± 64	-18 ± 61	pm consistent
1518+4904	...	...	2.28±1.57	-0.81±1.10	...	...	new position
1543+0929	-12±4	3±3	0.13±0.42	-0.30±0.45	5 ± 17	-12 ± 18	pm consistent
1607-0032	-1.0±14	-7±9	-0.58±0.63	-0.80±0.63	-25 ± 27	-34 ± 27	pm consistent
1640+2224	...	...	-0.61±0.87	-0.04±0.87	-136 ± 193	-8 ± 193	pm upper limits
1652+2651	...	...	1.08±4.52	-0.15±1.07	...	...	new position
2145-0750	-3±4	-30±11	0.11±0.62	-0.01±0.62	25 ± 137	-2 ± 137	pm consistent

The positions derived from the FIRST observations are compared with the pulsar positions in the PSR catalog and the proper motions are calculated if possible. The results are listed in Table 3. Proper motions given in the PSR catalog are listed in columns 2 and 3 for comparison. Columns 4 and 5 give the position offsets. Proper motions or upper limits we obtained are listed in columns 6 and 7. For the three pulsars, PSR J0751+1807, J1012+5307 and J1640+2224, we only got upper limits. The proper motion on right ascension of PSR J1136+1551 seems to be marginally changed. The proper motions of the other ten pulsars are quite consistent with those listed in the PSR catalog (Fig. 2).

4 SUMMARY

In the sky region covered by FIRST, a total of 17 sources near known pulsars have been found. By comparing the pulsar positions and flux densities from FIRST and from the PSR catalog (the updated version of Taylor et al. 1993), we obtained new flux densities for six pulsars and accurate positions for three pulsars PSR J1022+1001, JJ1518+4904 and J1652+2651. For ten pulsars, we derived values of proper motion consistent with those in the PSR catalog, and for other three, we acquired upper limits of their proper motions.

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