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Young Pulsars from the Parkes Multibeam Pulsar Survey and their Associations

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Abstract. The Parkes multibeam pulsar survey is covering a 10°-wide strip of the southern Galactic plane from $l = 260°$ to $l = 50°$. It utilizes a 13-beam receiver operating in the 20-cm band on the Parkes 64-m radio telescope and is much more sensitive than any previous large-scale survey. Most of the 608 pulsars discovered so far are relatively distant and many are young, with 37 having a characteristic age of less than 10^5 years. At least one of these is associated with a supernova remnant and four other probable associations are suggested. Several multibeam pulsars have high values of the parameter $\dot{E}/d^2$ and are within the position error contours of unidentified EGRET gamma-ray sources. These possible associations will be tested with the advent of new gamma-ray telescopes.

1. Introduction

The Parkes multibeam pulsar survey is a large-scale survey of the southern Galactic plane from $l = 260°$ to $l = 50°$ and with $|b| < 5°$ using the Parkes 64-m radio telescope and the multibeam receiver. This receiver has 13 beams arranged in a hexagonal pattern, each with dual linear polarization and a bandwidth of 288 MHz centered on 1374 MHz. The average system temperature is about 21 K, corresponding to a system-equivalent flux density of about 30 Jy. Signals from each polarization of each beam are filtered to give 96 3-MHz channels, the outputs of which are summed in polarization pairs, high-pass filtered, integrated and one-bit digitized at intervals of 250 μs. The observation time per pointing is 35 min. Using clusters of workstations at the various collaborating institutions, data are dedispersed with up to 325 trial dispersion measures (DMs) and searched for periodic signals. For low-DM pulsars with periods in the range 10 ms to 5 s, the limiting sensitivity of the survey is about 0.2 mJy.

The survey commenced in mid-1997 and approximately 95% of the 2670 pointings required to complete it have been observed. Most of the data have been processed, resulting in the discovery of 608 pulsars, including eight binary pulsars and four millisecond pulsars. The survey and discovery of the first 100 pulsars are described in some detail by Manchester et al. (2001). Other papers announcing discoveries of special interest are referenced in that paper.

2. Young pulsars from the Multibeam Survey

As shown in Figure 1, the Parkes multibeam survey has been especially successful in discovering young and highly magnetized pulsars. In fact, the five radio pulsars with the highest known surface dipole magnetic fields were all discovered in this survey. Of the 608 new pulsars, 37 have characteristic ages $\tau_c < 100$ kyr, a much higher proportion of young pulsars compared to previous surveys. Surprisingly, about one third of these apparently young pulsars, including the youngest, PSR J1119−6127 (Camilo et al. 2000), have periods of more than 400 ms, with five exceeding 1 s. A preliminary 'pulsar current' analysis (cf. Lorimer et al. 1993) assuming a simple disk Galaxy and a beaming factor of five gives a birthrate of about one pulsar every 180 years, consistent with earlier estimates.

3. Supernova Remnant Associations

With so many newly discovered young pulsars, it is obvious that a search for associated supernova remnants (SNRs) is likely to be worthwhile. Following the recognition that PSR J1119−6127 is a very young pulsar, a search of the Molonglo Galactic Plane Survey (MGPS; Green et al. 1999)[1] showed a faint ring of emission centered on the pulsar. Radio observations with the Australia Telescope Compact Array (ATCA) (Crawford et al. 2001) and X-ray observations with ASCA (Pivovaroff et al. 2001) confirmed this association.

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[1] See `http://www.astrop.physics.usyd.edu.au/MGPS`

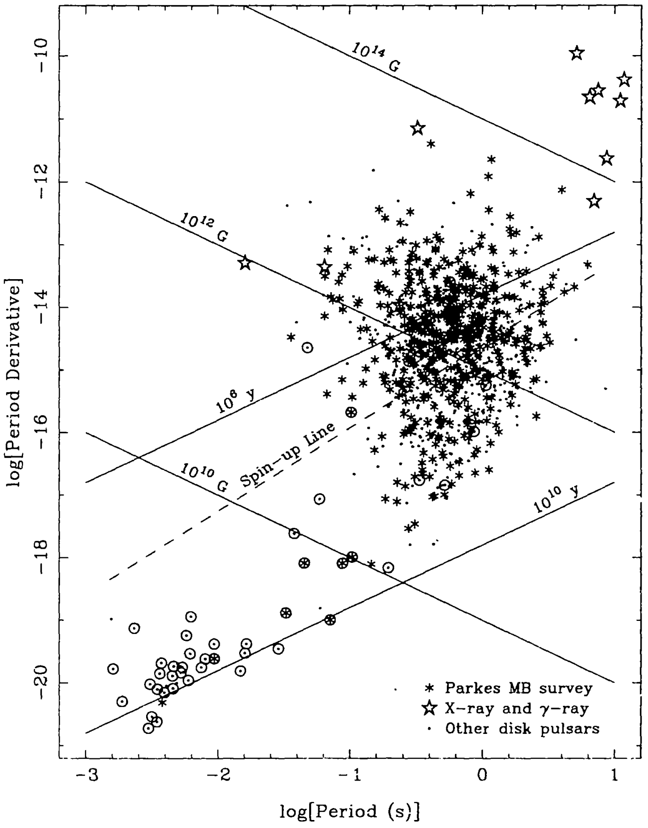

Figure 1. $P-\dot{P}$ diagram for known disk pulsars, including anomalous X-ray pulsars (AXPs) and soft γ-ray repeaters (SGRs) with known periodicities and slow-down rates. Pulsars discovered in the Parkes multibeam survey are marked with an asterisk, those detected at X-ray or γ-ray wavelengths only are marked with an open star and binary pulsars are indicated by a circle around the symbol. Lines of constant characteristic age $\tau_c = P/(2\dot{P})$ and surface dipole magnetic field $B_s = 3.2 \times 10^{19} (P\dot{P})^{1/2}$ G, and the spin-up line giving the minimum period attainable by spin-up due to accretion are marked on the figure.

We have used the ATCA and the MGPS to search for possible SNRs around the remaining 15 multibeam pulsars with ages less than 50 kyr.[2] No data are available for PSRs J0729−1448 and J1837−0604, both with ages of about 35 kyr, and there was no obvious association for PSRs J1702−4310 (17 kyr), J1112−6103 (33 kyr), J1015−5719 (39 kyr), J1637−4642 (41 kyr) and J0940−5428 (42 kyr). The remaining eight young pulsars, along with PSR J1119−6127, are listed in Table 1. This table lists pulsar periods and characteristic ages, the best estimate of the pulsar distance, in most cases derived from the DM using the Taylor & Cordes (1993) Galactic electron density model, the possibly associated SNR, its apparent radius, the ratio of the pulsar radial distance from the apparent center of the SNR to the SNR radius (β) and the status of the association.

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[2] See `http://www.atnf.csiro.au/research/pulsar/pmsurv/pmpsrs.db`

Table 1. Possible Supernova Remnant Associations

PSR J	P (ms)	τ_c (kyr)	d (kpc)	SNR	$R_{\rm SNR}$ (pc)	β	Status
1119−6127	407	1·6	5*	G292.2−0.5	12	0·00	Certain
1357−6429	166	7·3	4	G309.8−2.6	25	?	Possible
1734−3333	1169	8·1	7	G354.8−0.8	21	2·2?	Possible
1420−6048	68	13	8	G313.4+0.2	33	0·2	Probable
1413−6141	285	14	2*	G312.4−0.4	8	0·35	Probable
1726−3530	1110	14	10	G352.2−0.1	8	0·0	Probable
1632−4818	813	20	8	G336.1−0.2	35	0·15	Probable
1016−5857	107	21	3*	G284.3−1.8	13	1·0	Possible
1524−5706	1116	50	22	G322.5−0.1	48	0·9	Unlikely

*Distance estimate based on SNR

G309.8−2.6 was suggested by Duncan et al. (1997) as a possible SNR. An ATCA image shows the bright feature southwest of the pulsar position and weaker emission to the north, but no obvious connection to the pulsar.

G354.8−0.8 is a shell remnant previously identified by Whiteoak & Green (1996). The pulsar lies well outside the remnant and normally would not be considered a likely association. However, the remnant is teardrop shaped and pointed directly toward the pulsar with a bright spot at the point of the teardrop. Furthermore, there is weak evidence for a larger ring-shaped emission feature on the opposing side. It is possible that the SNR has a bi-annular morphology (cf. Manchester 1987) and is larger than previously thought.

PSR J1420−6048 lies within and has been associated with a complex region of radio and X-ray emission sometimes known as the Kookaburra (D'Amico et al. 2001; Roberts, Romani & Johnston 2001). The pulsar lies between the two most prominent emission features, both of which have a distorted ring shape. It is possible that this is another example of a bi-annular SNR morphology.

G312.4−0.4 is a ring-shaped SNR with two bright regions connected by a bridge of emission (Whiteoak & Green 1996). PSR J1413−6141 lies on this bridge of emission, approximately midway between the two bright regions. This gives the system a morphology very similar to that of PSR B1509−58 / G320.4−1.2 (Manchester 1987; Gaensler et al. 1999) and PSR B1338−62 / G308.8−0.1 (Kaspi et al. 1992) and suggests that collimated winds from the pulsar may be responsible for the bright regions.

Figure 2(a) shows the MGPS image of the region surrounding PSR J1726−3530. The pulsar is located right at the center of a beautiful shell having bilateral symmetry. This shell, previously uncataloged, has been named G352.2−0.1. Its morphology and relation to the pulsar strongly suggest that it is an SNR associated with the pulsar. Assuming it has the age and distance of the pulsar, its expansion velocity is a very reasonable 1100 km s^{-1}.

PSR J1632−4818 is a 20-kyr-old pulsar which Figure 2(b) shows is located close to the center of another previously uncataloged shell source which we have named G336.1−0.2. Although the region is complex, we believe that this shell

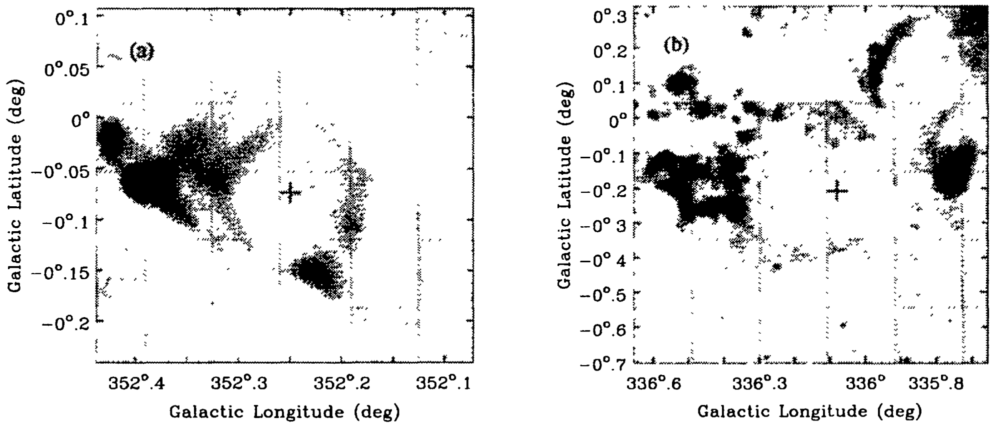

Figure 2. Images from the Molonglo Galactic Plane Survey of probable supernova remnants surrounding young Parkes multibeam pulsars. The cross marks the position of the pulsar. (a) G352.2−0.1 and PSR J1726−3530. (b) G336.1−0.2 and PSR J1632−4818.

source is likely to be a SNR associated with the pulsar. The implied velocity of the pulsar (250 km s^{-1}) and of the shell (1700 km s^{-1}) are both reasonable.

PSR J1016−5857 and its possible association with the SNR G284.3−1.8 have been discussed by Camilo et al. (2001).

PSR J1524−5706 lies near the edge of the SNR G322.5−0.1 (Whiteoak & Green 1996). While the implied pulsar velocity is reasonable, this SNR has what appears to be a central plerion component, which probably contains the associated pulsar. Therefore PSR J1524−5706 is unlikely to be associated with this SNR.

In summary, the Parkes multibeam survey has increased the number of certain or probable pulsar–SNR associations by five, three of these being with previously unrecognized remnants. It is interesting to note that SNRs associated with young but long-period pulsars such as PSRs J1119−6127 and J1726−3530 are typically difficult to independently identify. Such objects are likely to remain undetected unless the associated pulsar is beamed toward us.

4. Possible Gamma-ray Associations

Most pulsars known to pulse at γ-ray energies are young. The parameter $\dot{E}/d^2$, where $\dot{E}$ is the spin-down luminosity and d is the pulsar distance, is a good indicator of γ-ray detectability. Table 4. lists six multibeam pulsars which are high on a list of all pulsars ranked by $\dot{E}/d^2$ and which are located within the error circles (radius R_γ) of unidentified EGRET γ-ray sources. The β_γ parameter is defined analogously to the β in Table 1. The discovery of the top two on this list, PSRs J1420−6048 and J1837−0604, and their possible association with EGRET sources was discussed by D'Amico et al. (2001). Because most young pulsars suffer significant period irregularities, it is not feasible to search the EGRET database for these pulsars. Confirmation of these associations will have to await the launch of future γ-ray telescopes such as *AGILE* and *GLAST*.

Table 2. Possible Gamma-ray Associations

PSR J	P (ms)	τ_c (kyr)	$\dot{E}/d^2$ Rank	EGRET 3EG	R_γ (deg)	β_γ (deg)
1420−6048	68	13	11	J1420−6038	0.32	0.56
1837−0604	96	34	22	J1837−0606	0.19	0.90
1015−5719	140	39	34	J1014−5705	0.67	0.30
1016−5857	107	21	38	J1013−5915	0.72	0.67
1413−6141	285	13	74	J1410−6147	0.36	0.78
1412−6145	315	50	127	J1410−6147	0.36	0.40

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