THE PARKES MULTIBEAM PULSAR SURVEY

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The Parkes multibeam pulsar survey is a high-frequency, fast-sampled survey of the Galactic Plane, expected to discover at least 500 new pulsars. To date, over 200 pulsars have been found, including several young pulsars and at least one with a very high magnetic field. Seven of the new stars are in binary systems; this number includes one probable double-neutron-star system, and one pulsar with an extremely massive companion.

1 Introduction and Survey Parameters

Large-area searches for new pulsars require multiple filtered channels across a wide bandwidth, in order to search a wide range of dispersion measures (DMs), and rapid sampling, in order to be sensitive to fast-spinning pulsars. Pulsars are steep-spectrum objects; therefore historically most pulsar searches have been conducted at frequencies of a few hundred MHz. However, this choice of frequency introduces certain undesirable selection effects. In particular, pulse broadening due to dispersion smearing and multipath interstellar scattering limits the sensitivity of the search to distant (high-DM), short period pulsars. Also, the high galactic background temperature significantly increases the telescope system noise near the galactic plane; thus a higher observing frequency, such as 1.4 GHz, is a better choice for surveys concentrating on this region of the sky.

Two such high-frequency surveys have been conducted in the recent past: one used the 76-m Lovell telescope at Jodrell Bank in the U.K. to search the Northern part of the Galactic plane, finding 40 pulsars,[1] while a complementary search at the 64-m Parkes telescope in Australia found 46 pulsars.[2]

Recently, a new multibeam receiver[3] has been installed at Parkes, allowing simultaneous observations of 13 patches of the sky. The system was originally designed for a survey of HI in the local universe, but is also being used for a pulsar search in a 10°-wide strip along the galactic plane. With the multibeam receiver, the time required to survey a given part of the sky is reduced by a factor of 13. Moreover, in the time since since the completion of the earlier surveys,

Table 1: Parameters of Four 21-cm Pulsar Surveys

	Jodrell[1]	Parkes[2]	Parkes	Jodrell
Nbeams	1	1	13	4
$\|b\|$	$< 1°$	$< 4°$	$< 5°$	$< 5°$
l	$-5°$–$100°$	$-90°$–$20°$	$-100°$–$50°$	$50°$–$120°$
t_{int} (min)	10	2.5	35	35
t_{samp} (ms)	2.0	1.2	0.25	0.25
Bandwidth (MHz)	$2 \times 8 \times 5$	$2 \times 64 \times 5$	$2 \times 96 \times 3$	$2 \times 32 \times 3$
S_{sys} (Jy)	60	70	36	30
S_{min} (mJy)	1.2	1.0	0.15	0.2
Pulsars found	40	46	in progress	forthcoming
Acceleration search	No	No	Yes	Yes

receiver sensitivities have increased, and computer and recording-medium speeds have improved greatly, allowing faster sampling of wider bandwidths, and longer integration times. The new survey, and its planned counterpart at Jodrell Bank, make full use of these advancements, and will therefore be considerably more sensitive to fast and distant pulsars than the earlier searches. A comparison of the parameters of the four surveys is given in Table 1.

Each beam of the new receiver is approximately 0.25° wide; the beams centres are spaced 2 beamwidths apart. The 35-min pointings are arranged in groups of four, as shown in Figure 1, giving complete sky coverage on a hexagonal grid. A total of 2670 pointings of the 13 beams are required to cover the survey region.

Analysis procedures are similar to those used in previous surveys,[4] with dedispersion followed by transformation into the modulation frequency domain using a Fast Fourier Transform (FFT) and harmonic summing to optimize sensitivity to the typically short duty-cycle pulses. The pulse frequencies of pulsars in close binary orbits may be subject to significant changing Doppler shifts during the 35-minute pointings; hence segmented "acceleration searches" will be conducted to look for drifting periodicities.

Suspects from the initial processing are scheduled for reobservation to confirm their identity as pulsars. The centre beam of the multibeam system is used to make five observations, typically of 6-min duration, at the nominal position and four surrounding points spaced $9'$ from the nominal position. In most cases this gives detections at two or three positions, allowing an improved position to be determined, as well as confirming the pulsar. Where no detection results from these observations, a 35-min observation is made at the nominal position.

After confirming each pulsar, a series of timing observations is begun at either or both of the Parkes 64-m telescope and the Lovell 76-m telescope at Jodrell Bank. Almost all of the detected pulsars north of declination $-35°$ (some 40% of the total to date) are being timed only at Jodrell Bank.

For both Jodrell Bank and Parkes data, each pulse profile obtained by summing over an observation is convolved with a high signal-to-noise "standard profile" for the corresponding pulsar, producing a topocentric time of arrival (TOA). These are then processed using the TEMPO program (see WWW address http://pulsar.princeton.edu/tempo) which converts them to barycentric TOAs at infinite frequency and performs a multi-parameter fit for the pulsar parameters. Barycentric corrections are obtained using the Jet Propulsion Laboratory DE200 solar-system ephemeris.[5] Except for especially interesting cases, it is proposed to make timing observations of each pulsar over about 12 months, giving an accurate position, period, period derivative and dispersion measure. This provides the basic parameters necessary for follow-up

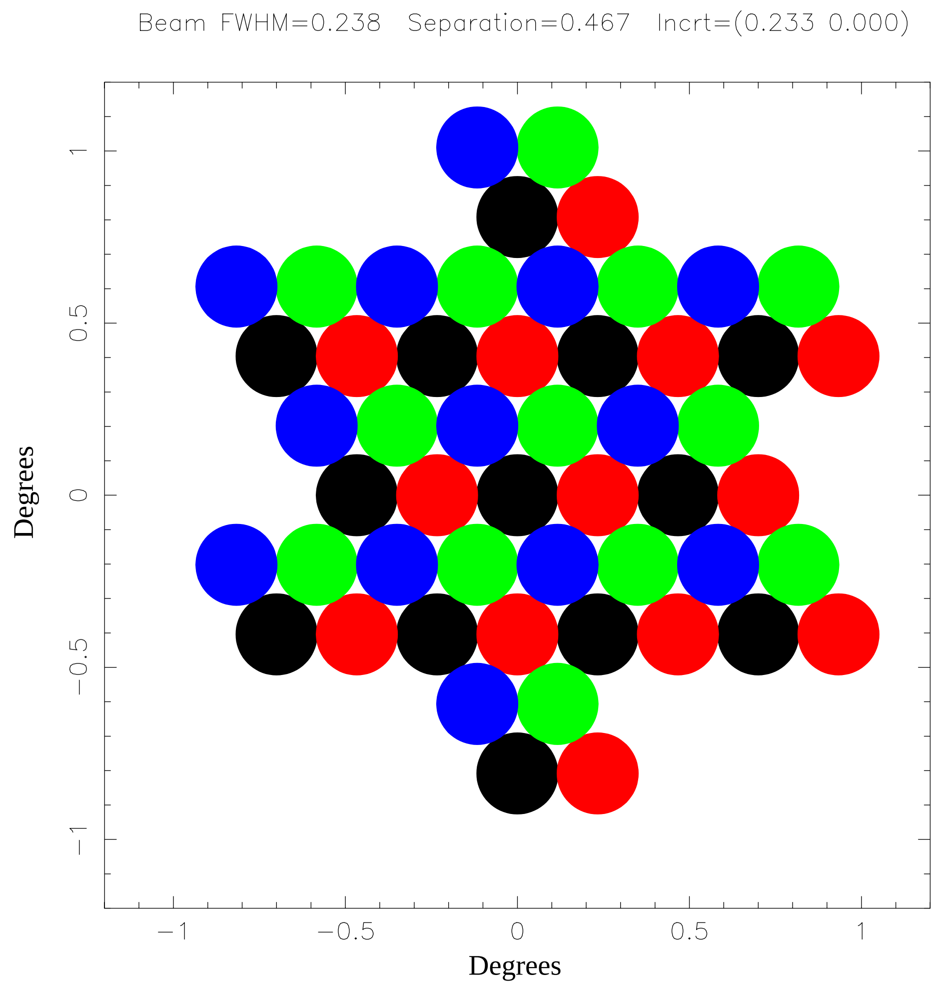

Figure 1: Four-pointing tessellation pattern of the 13 beams on the sky.

studies such as investigations of the Galactic distribution of pulsars and studies of the interstellar medium. Many of the pulsars are relatively young and subject to timing irregularities and initial data on these will also be obtained.

2 Survey Status and New Discoveries

As of Oct. 1998, approximately 40 per cent of the required pointings had been observed, and about 40 per cent of these had been processed. Confirmation observations had been made on most of the better suspects, resulting in the detection of 220 previously unknown pulsars, including the 1000th pulsar ever discovered. More than 100 previously known pulsars had also been detected. These results show that the survey is going to be outstandingly successful. The discovery rate is an unprecedented one pulsar per hour of survey observing time, more than an order of magnitude better than any previous pulsar survey.

A plot of the distribution in galactic coordinates of the new pulsars is presented in Figure 2, with the boxed region shown in greater detail. The great success of the multibeam survey relative to previous searches is easily seen.

Due to the choice of high observing frequency, narrow filterbank channels and fast sampling, the present survey is extremely sensitive to distant pulsars. Figure 3 plots the dispersion-measure distribution of the newly-found pulsars and of all previously-known pulsars which are not in globular clusters. Of the 220 new pulsars discussed above, 175 have DM $> 250\,\mathrm{pc\,cm^{-3}}$;

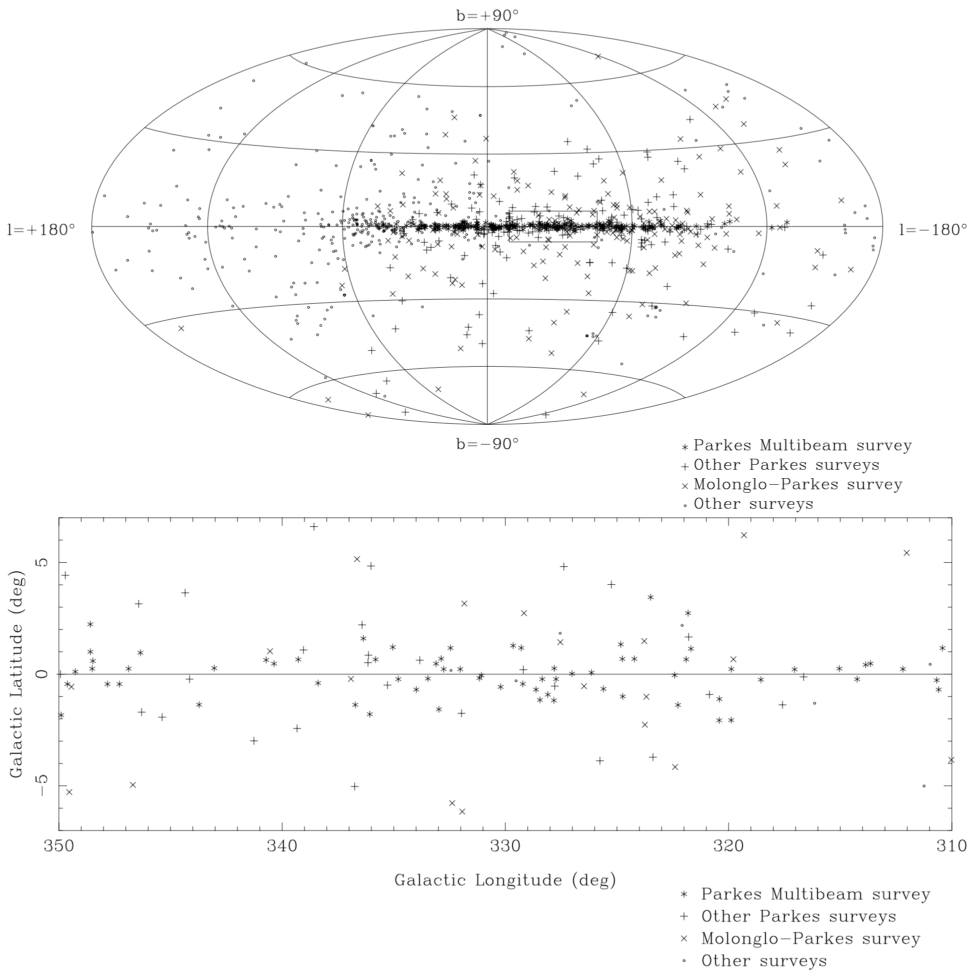

Figure 2: The 220 new Parkes multibeam survey pulsars in galactic coordinates; the lower panel is an enlargement of the boxed region.

this has nearly tripled the previous number of 99 such pulsars. In contrast, there are very few new pulsars with $\mathrm{DM} < 100\,\mathrm{pc\,cm^{-3}}$, as most of this population has been found in earlier surveys.

The survey has uncovered 8 apparently isolated pulsars with spin periods between 45 ms and 90 ms. It is probable that these are young pulsars, though this will only be confirmed by further timing observations, from which their period derivatives and hence their characteristic ages ($\tau_c = P/(2\dot{P})$) may be determined. There is also a pulsar with a relatively long spin period (0.4 s), but an extremely short characteristic age of 1600 years. The implication is that this pulsar has an extremely high magnetic field.

Another area of great success for the search has been in the discovery of binary pulsar systems: 7 have been found to date. Five of these pulsars have spin periods between 9 ms and 88 ms, and nearly circular orbits. These are likely to be neutron-star–white-dwarf systems, and the Keplerian mass functions indicate that some of the companions may in fact be heavy CO white dwarfs. Prior to the start of this survey, only four such neutron-star–CO-white-dwarf systems were known;[6] the fact that they represent a greater fraction of the new discoveries indicates that this pairing may not be as rare as previously believed.

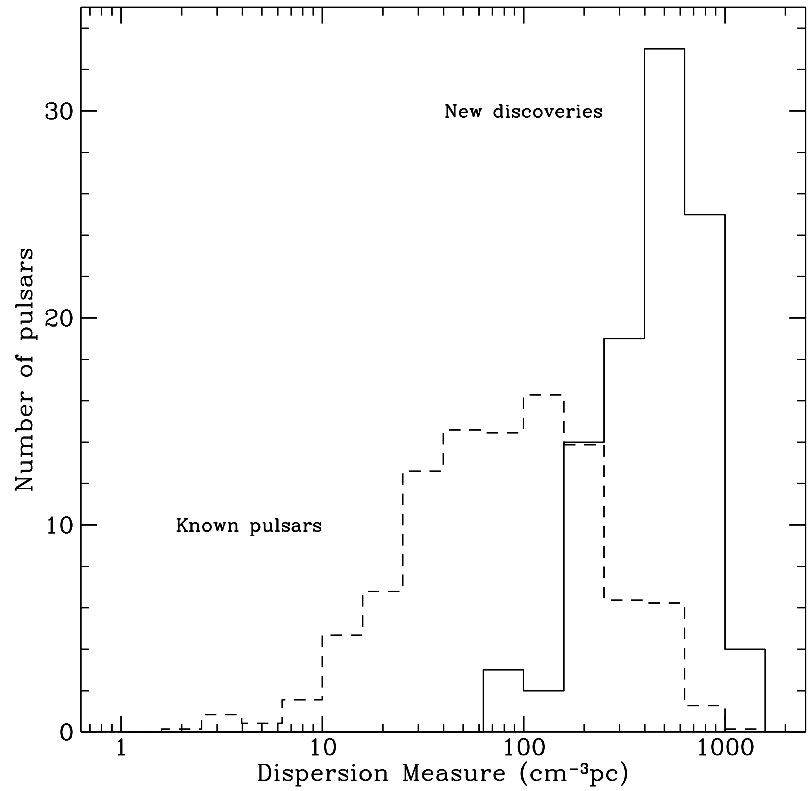

Figure 3: Dispersion measure distribution of all previously-known non-globular-cluster pulsars (dashed line) and the new Parkes multibeam survey pulsars (solid line), with normalized areas. The distributions reflect the greater sensitivity of the current survey to distant pulsars.

The two remaining systems are more unusual. One has an 18-day orbit with large eccentricity ($e \simeq 0.8$), and a minimum companion mass of $0.8\,M_\odot$. This is almost certainly a double-neutron-star system, the first to be discovered in the Southern hemisphere. The velocity curve for this pulsar across three orbits is displayed in Figure 4. While this system, like the similar PSR J1518+4904,[7] is not in a close enough orbit to permit tests of general relativity, it will nevertheless provide a valuable contribution to our understanding of the formation and population statistics of such binaries. The last system is perhaps the most intriguing: the pulsar is in an 8-month, highly-eccentric orbit, and has a companion of minimum mass $11\,M_\odot$. The nature of the companion is as yet undetermined; this pulsar system will therefore be the target of optical and/or infrared-wavelength observations in the near future.

3 Future Prospects

The Parkes multibeam pulsar survey is proving to be extremely successful. Though the discovery rate will decline from the current one pulsar per hour of observation as regions further from the Galactic plane are surveyed, predictions suggest that the survey may detect as many as 500 previously unknown pulsars, providing a large increment to the total of about 750 pulsars known before the survey commenced, and a significant database for many different follow-up studies. If the fraction of binary pulsars found remains constant, it is reasonable to expect 15 or 20 new systems, some of which may well prove even more fascinating than those already discovered.

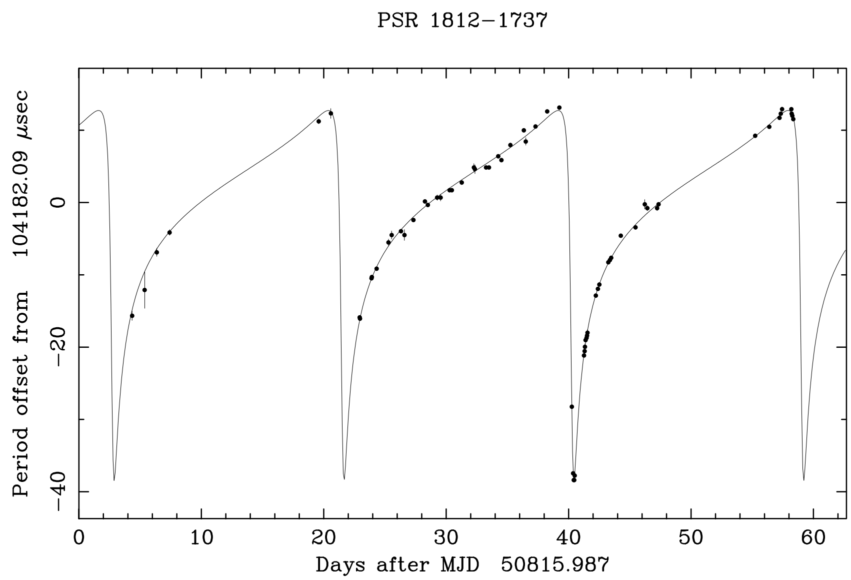

Figure 4: Velocity curve of the probable double-neutron-star binary pulsar, across three cycles of the 18-day orbit.

Acknowledgments

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