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The second Molonglo pulsar survey – discovery of 155 pulsars

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Summary. An extensive survey for pulsars has been undertaken using observations at the Molonglo Radio Observatory and the Australian National Radio Astronomy Observatory, Parkes. Essentially all of the sky south of declination +20° was uniformly searched, resulting in the detection of 224 pulsars. Of these, 155 were new detections, bringing the total number of known pulsars to 304. Parameters including positions, periods, dispersion measures, pulse widths and mean flux densities are given for all of the newly detected pulsars and, where there is an improvement over previously published values, for the previously known pulsars also. Three of the new objects have dispersion measures > 500 cm^{-3} pc and one has a period > 4 s.

Introduction

In the nine years from the detection in 1967 of the first pulsar (Hewish *et al.* 1968) to 1976, a total of 149 pulsars were discovered. Although many different groups were successful in detecting pulsars, 110 of these pulsars were first detected in one of three major surveys: the first Molonglo survey (Large & Vaughan 1971 – 31 new pulsars); the Jodrell Bank survey (Davies, Lyne & Seiradakis 1972, 1973 – 39 new pulsars) and the University of Massachusetts Arecibo survey (Hulse & Taylor 1974, 1975 – 40 new pulsars). The Molonglo survey covered most of the sky south of declination +20° (~ 7 sr) with detection by visual examination of chart records, the Jodrell Bank survey covered ~ 1 sr along the galactic plane and used a computer search for periodic signals and the Arecibo survey covered ~ 0.05 sr, also along the galactic plane, and used a two-dimensional computer search for periodic and dispersed signals. The minimum detectable mean flux densities were respectively about 80, 15 and 1.5 mJy for the three surveys. These surveys are important because they provide a sample of the galactic population of pulsars obtained in a relatively uniform way with

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known instrumental selection effects. Analyses of these data to determine the galactic distribution and luminosity function of pulsars have been carried out by Large (1971), Roberts (1976), Davies, Lyne & Seiradakis (1977) and Taylor & Manchester (1977). The sample sizes available for these analyses were respectively 29, 44, 51 and 90 pulsars.

In this paper we report on a new pulsar survey. The whole sky south of declination +20° was observed using the east–west arm of the Molonglo Cross. The main data analysis, consisting of a search for periodic and dispersed signals, was performed on an off-line computer. Confirmation observations of candidate pulsars resulting from analysis of the Molonglo data were made using the Parkes 64-m telescope; the Parkes observations also gave improved parameters for the confirmed pulsars. The observing frequency for both the Molonglo and Parkes observations was 408 MHz. A total of 224 pulsars were detected in the survey and, of these, 155 were new detections. The new survey therefore more than doubles the number of known pulsars and provides a large uniform sample of pulsars suitable for statistical analyses. A preliminary report on the survey has been given by Lyne (1977).

Molonglo observations

The survey observations were made at the Molonglo Radio Observatory, operated by the University of Sydney, using the east–west arm of the Mills Cross antenna. This arm has a collecting area of about 18 000 m^2 and, with uniform aperture illumination, forms a beam of half-power width 4°.3 in declination and 1.4 arcmin in the right ascension direction. (In normal Cross operation, tapered illumination is used to reduce sidelobe responses.) In order to increase the observation time per transit of a source, the multi-beaming system normally used on the north–south arm of the Cross (Mills *et al.* 1963) was transferred to the east–west arm. This formed 11 beams overlapping at the half-power points. Data from the central eight beams were recorded giving an observation time per source of 44.7/cos δ s, where δ is the declination. To improve the sensitivity of the system, 88 preamplifiers were constructed and installed on the antenna close to the feeds. Each preamplifier consisted of a single transistor stage with input and output matching and typically had a noise figure of 1.3 dB and gain of 16 dB at 408 MHz. With the preamplifiers installed, the overall system temperature was 240 ± 15 K, including a 30 K background sky contribution; the corresponding system equivalent flux density is 47 ± 3 Jy. Compared to the system before installation of the preamplifiers, these values represent a reduction in system noise by a factor of approximately 2.5.

The overall bandwidth of the system, defined in the next stage of amplification, was 4 MHz. After combination in the multi-beaming networks, signals for each of the eight beams passed through an automatic gain control system (time constant 10–100 s depending on the input level) and then through a double-tuned filter system giving four contiguous frequency channels, each of bandwidth about 0.8 MHz. The detected outputs of these channels were filtered using networks for which the frequency response was 6 dB down at 2.5 and 105 Hz. For observations where dispersion removal was not required, the four channel filters could be bypassed giving a single 4-MHz bandwidth for each beam. This arrangement provided a larger total bandwidth and better rejection of interfering signals compared with simply summing the detected outputs of the four 0.8-MHz filters.

Each of the 32 (or eight) outputs was sampled at 10-ms intervals by an on-line computer using a multiplexer and analogue/digital converter system. The data were then passed through a digital low-pass filter having a relatively sharp cut-off at 25 Hz and the result sampled at 20-ms intervals. These data were then scaled, truncated to four bits per sample and output on magnetic tape. Header information also recorded on the magnetic tape in cluded the declination, solar time and comments. The computer internal clock was synchronized to Australian Eastern Standard Time to within ±10 ms. As a check on data quality, histograms of the noise distribution in each channel were printed out at the start of each observation or on command.

The survey covered essentially all of the sky between declinations −85 and +20°, a total area of 8.4 sr or 67 per cent of the celestial sphere. Scans were made at constant declination and were spaced in declination by 2°.5. The sensitivity was therefore reduced by 1 dB at points midway between adjacent scans. The survey was conducted in two parts. Firstly the region with galactic latitude $|b| < 18°$ and declination $\delta < +20°$ was surveyed using the system having four frequency channels per beam. The Large and Small Magellanic Cloud regions ($04^h\,30^m < \alpha < 06^h\,15^m$, $-74° < \delta < -64°$ and $00^h\,00^m < \alpha < 01^h\,30^m$, $-78° < \delta < -69°$ respectively where α is right ascension) were also surveyed with this system. Secondly, the whole region with $-85° < \delta < +20°$ was surveyed with a single 4-MHz channel for each beam. For convenience these two parts are henceforth referred to as the low-latitude and the high-latitude surveys respectively. As described in the following section, data from the low-latitude survey were analysed using dispersion removal techniques and so were sensitive for pulsars with high dispersion measure whereas there was no dispersion removal for data from the high-latitude survey. The low-latitude survey commenced on 1977 April 8 and was essentially complete by the end of June. The high-latitude survey commenced at this time and was completed on 1977 August 31. The entire survey required a total of 105 days of observations.

Analysis of the Molonglo data

Data from the Molonglo observations were searched for periodic and dispersed signals using both a fast Fourier transform (FFT) routine and direct folding of the data at specified periods. Analysis of the low-latitude observations was carried out on the CSIRO Cyber 76, located in Canberra, and the high-latitude observations were analysed on the University of Sydney Cyber 72. The basic period range searched was 0.04–2.4 s; pulsars with periods outside this range could be detected but with reduced sensitivity. For the low-latitude survey the maximum dispersion measure (DM) searched was related to galactic latitude. For $|b| < 1°.3$ a total of six dispersion bands were searched with the maximum DM (i.e. sensitivity down by 3 dB for pulsars of period $\gtrsim 0.5$ s) about 800 cm^{-3} pc. For $|b| > 6°.6$ only one dispersion band was searched with the maximum DM ~130 cm^{-3} pc. Between two and five dispersion bands were searched at intermediate latitudes. For the high-latitude survey the maximum DM searched was 130 cm^{-3} pc at all latitudes and for the Magellanic Cloud observations it was 520 cm^{-3} pc. The full data analysis was performed for every 0.7 beamwidth in right ascension, that is, for every $3.9/\cos\delta$ s of observation time.

We give here a brief description of the analysis procedure; a more detailed description can be found in Taylor (1978, in preparation). The data corresponding to the transit of a given right ascension through the eight beams were dedispersed if necessary and then transformed using an FFT routine. For $|\delta| < 30°$ the data block consisted of 2048 dedispersed samples; at higher declinations there were 4096 samples. Periods corresponding to the five spectral points of highest intensity were then determined, firstly for the basic spectrum and then for folded spectra obtained by summing 2, 4, 8 and 16 harmonics respectively, giving a total of 25 candidate periods. The data were then folded at each of these 25 candidate periods in turn and the folded data smoothed with running means of 2, 3, 4 and 6 points. Parameters for the best profile with an apparent pulse amplitude greater than a specified threshold were then recorded as representing a possible pulsar. The threshold found empirically to be consistent with a reasonable number of random detections corresponded to a signal/noise ratio of 5.4. The program also searched for individual pulses in the data with a signal/noise ratio in excess of five. Provided these did not occur simultaneously in all beams, a detection was recorded.

In a second phase of the search program, all of the available data for each of the possible pulsars were folded and the signal/noise ratio of the resulting profile was optimized by varying the assumed period, dispersion measure, right ascension and declination. Profiles with a signal/noise ratio higher than a threshold of 6.3 were then taken as suspect pulsars and details were output.

A total of over 2500 suspects were obtained from the analysis of both parts of the survey. Many of these were multiple detections of the stronger pulsars or were readily recognizable as interference. For the next stage of the survey, the confirmation observations at Parkes, it was necessary to select from these suspects a list of candidate pulsars. The main criteria used were the signal/noise ratio of the detection and the appearance of the profile, the latter being rather subjective. A total of over 500 candidate pulsars were selected and graded according to our estimate of the probability that they were in fact real pulsars. About 40 per cent of the candidates had been observed on adjacent scans on different days; these objects received the highest grading. Of the 500 candidates, about 400 were from the low-latitude part of the survey.

Parkes observations

Candidate pulsars from the Molonglo survey were observed using the 64-m antenna of the Australian National Radio Astronomy Observatory, Parkes, operated by the CSIRO. There were four separate sessions: 1977 April 22–26, June 27–July 10, September 26–October 3 and October 19–23. For pulsars confirmed by these observations, improved estimates of the declination, pulse period, dispersion measure, pulse profile parameters and mean flux density were obtained. Previously known pulsars were also observed to determine mean flux densities and, in some cases, to improve other parameters.

The observations were made at the same frequency as those at Molonglo, namely 408 MHz. Orthogonal linear polarizations were received using a circular slot feed (*cf.* Howell 1975) and amplified using transistor preamplifiers similar to those installed on the Molonglo east–west arm. After conversion to an intermediate frequency of 30 MHz and band-limiting, the signals for each polarization were split into 24 adjacent frequency bands, each of bandwidth 250 kHz. Corresponding outputs for the two polarizations were summed to give 24 total intensity signals which, after smoothing, were sampled every 5 ms by an on-line computer. The system temperature for each channel was approximately 150 K including a 30 K background contribution, corresponding to an equivalent system flux density of 180 Jy. Observations of Hydra A, for which a flux density of 132 Jy was assumed, were used to calibrate the flux density scale. The beamwidth of the Parkes antenna at 408 MHz is approximately 53 arcmin.

Candidate pulsars from the Molonglo observations had well-determined right ascensions but a large uncertainty in declination ($\pm 2^\circ.5$). A mode of observation in which the Parkes antenna was slowly scanned either northwards or southwards across the range of possible declinations was therefore adopted. Data were recorded continuously during the scan and analysed at quarter-beamwidth intervals after the antenna had traversed one beamwidth. The scan rate normally adopted was one beamwidth every 5 min.

The data from the high-frequency half and from the low-frequency half of the filter bank were separately dedispersed using the nominal DM from the Molonglo observations. Blocks of data, the length of which depended on the uncertainty of the nominal period, were folded at this nominal period to form a series of subintegration profiles. When scanning of a full beamwidth was complete, the subintegration profiles were summed with varying phase shifts to form a set of profiles corresponding to periods within the range of uncertainty of the nominal period. These profiles were then smoothed with a running mean of 2, 3, 4, 6 or 8 points and parameters for the profile with the largest signal/noise ratio recorded. An improved estimate of the period was obtained by splitting the data into two time blocks, forming profiles using the best period and cross-correlating these profiles. In a similar way an improved dispersion measure was obtained by cross-correlating profiles formed separately from the upper- and lower-frequency bands. The declination scan was continued until either a significant signal was detected or the limit of the declination range was reached. For some of the weaker candidates several declination scans were required before a positive detection was obtained. This was especially true for low DM pulsars, since in these cases the observed signal amplitude is significantly affected by interstellar scintillation.

After detection of a significant signal, the antenna was directed at the determined declination and a 20-min observation was made to provide improved estimates of the period, dispersion measure and mean flux density and to obtain a pulse profile with improved resolution. All confirmed pulsars were observed with the folding interval set to six times the nominal value to check that the pulsar period had been correctly identified. Typical uncertainties in the derived parameters are 15 arcmin for declinations, a few microseconds for periods and $10\,cm^{-3}\,pc$ for dispersion measures. At least two 20-min observations were made for all pulsars with DM $< 40\,cm^{-3}\,pc$ to improve estimates of both the dispersion measure and the mean flux density.

In order to obtain a uniform data set, similar 20-min observations were made for all previously known pulsars detected in the Molonglo survey. Declination scans were also made for several known pulsars having large uncertainties in this coordinate.

Results

About 320 candidate pulsars from the Molonglo survey were observed at Parkes, resulting in the confirmation of 155 new pulsars. Approximately 75 per cent of both the candidates observed and the confirmed pulsars were from the low-latitude part of the survey. No pulsars were detected in the high-dispersion search of the Magellanic Cloud region. It is likely that the majority of the unconfirmed candidates were spurious or random detections, since the nominal sensitivity of the Parkes system exceeded that of the Molonglo system except on the hotter sections of the galactic plane. They would, however, include a number of weaker pulsars which are either sporadic emitters or strongly affected by interstellar scintillation.

Parameters for the new pulsars are given in Table 1. The pulsars are named according to the PSR convention first suggested by Turtle & Vaughan (1968) and since widely adopted. Following the name, the right ascension (equinox 1950.0) and its error are given. These values are from analysis of the Molonglo data and include compensation for the tilt of the Molonglo reflector. The remaining parameters are from the Parkes observations: declination (equinox 1950.0) and its error, pulse period and its error, epoch of the period measurement (Julian Day − 2400000), dispersion measure and its error, pulse equivalent width (pulse area divided by peak intensity), W_e, pulse width at 50 per cent of the peak intensity, W_{50}, and mean flux density, S, of the pulsed emission.

Table 1. Parameters of new pulsars.

PSR	R.A. (1950) h m s	s	Dec. (1950) ° '	'	Period (s)	(μs)	Epoch (MJD)	DM (cm^{-3} pc)		W_e (ms)	W_{50} (ms)	S (mJy)
0148-06	01 48 54	± 2	-06 55	± 15	1.464651	± 10	43415	27	± 5	72	150	25
0149-16	01 49 46	2	-16 50	20	0.832741	3	43400	13	3	20	20	40
0203-40	02 03 58	2	-40 50	15	0.630549	3	43430	13	3	15	12	15
0403-76	04 03 20	6	-76 15	20	0.545252	3	43430	22	3	22	22	20
0447-12	04 47 49	2	-12 55	15	0.438014	2	43325	40	6	23	21	15
0523+11	05 23 09	2	+11 15	15	0.354437	3	43260	80	10	19	15	17
0538-75	05 38 21	6	-75 50	15	1.245852	5	43430	18	4	72	72	55
0559-05	05 59 33	2	-05 30	15	0.395968	3	43325	75	8	22	21	17
0559-58	05 59 59	3	-58 05	20	2.261300	200	43430	40	30	70	50	5
0621-04	06 21 52	2	-04 15	15	1.039086	25	43325	60	20	56	56	10
0656+14	06 56 57	2	+14 25	15	0.384860	2	43260	9	4	25	15	10
0727-18	07 27 19	2	-18 20	15	0.510150	4	43325	61	6	22	25	13
0743-53	07 43 54	3	-53 50	15	0.214837	3	43325	121	10	37*	31*	22
0756-15	07 56 11	2	-15 20	20	0.682265	2	43335	62	6	15	12	6
0808-47	08 08 13	2	-47 45	10	0.547196	9	43325	227	8	49*	41*	42
0818-41	08 18 29	2	-41 15	15	0.545446	6	43325	110	10	95	155	50
0820+02	08 20 35	2	+02 10	15	0.864878	5	43430	24	4	25	23	30
0826-34	08 26 20	2	-34 07.5	1†	1.848960	20	43440	52	5	480	775	300
0839-53	08 39 09	3	-53 20	20	0.720608	8	43420	145	10	48	38	18
0840-48	08 40 30	2	-48 35	15	0.644355	10	43325	200	10	15	15	6
0844-35	08 44 10	2	-35 20	15	1.116090	50	43335	115	25	100	150	10
0853-33	08 53 38	2	-33 25	15	1.267539	6	43335	86	6	23	24	8
0855-61	08 55 56	3	-61 30	15	0.962509	6	43335	95	6	24	21	8
0901-63	09 01 30	3	-63 15	15	0.660315	6	43330	76	10	21	18	8
0903-42	09 03 09	2	-42 45	20	0.965181	10	43335	150	15	32	28	6
0904-74	09 04 29	6	-74 55	15	0.549552	3	43430	49	4	25	22	18
0905-52	09 05 41	2	-52 05	15	0.253555	2	43325	104	5	26	20	45
0906-17	09 06 19	2	-17 25	15	0.401625	2	43335	16	3	15	15	18
0909-72	09 09 24	5	-72 05	15	1.362896	10	43330	53	8	22	12	6
0919+06	09 19 34	2	+06 50	10	0.430613	2	43260	27	2	14	14	55
0922-52	09 22 30	± 2	-52 45	± 15	0.746294	± 5	43320	153	± 5	13	10	13
0923-58	09 23 05	3	-58 10	15	0.739492	5	43330	85	10	50	42	20
0932-52	09 32 47	2	-52 35	15	1.444773	10	43330	98	5	30	30	12
0940+16	09 40 46	2	+16 55	20	1.087410	15	43335	28	5	85	80	18
0941-56	09 41 19	3	-56 50	10	0.808116	4	43330	152	6	16	11	11
0942-13	09 42 03	2	-13 35	15	0.570265	2	43430	13	2	12	12	16
0950-38	09 50 12	2	-38 15	20	1.373820	30	43415	165	20	50	60	10
0953-52	09 53 42	2	-52 50	10	0.862120	3	43260	158	5	17	10	23
0957-48	09 57 30	2	-48 05	15	0.670088	10	43260	92	10	45	100	17
1001-47	10 01 24	2	-47 30	15	0.307072	3	43260	98	8	14	14	10
1010-23	10 10 10	2	-23 30	15	2.517930	20	43440	20	10	50	50	8
1014-53	10 14 39	3	-53 45	20	0.769580	6	43330	62	8	21	21	4
1015-56	10 15 22	3	-56 00	20	0.503459	5	43260	438	10	25	20	16
1030-58	10 30 15	3	-58 55	20	0.464200	30	43330	415	50	95*	75*	14
1039-19	10 39 12	2	-19 20	15	1.386414	20	43415	60	20	70	80	10
1040-55	10 40 01	3	-55 10	10	1.170861	10	43320	310	10	32	33	10
1044-57	10 44 19	3	-57 55	20	0.369426	3	43330	238	10	23	20	17
1054-62	10 54 28	3	-62 40	10	0.422446	3	43325	323	8	40*	36*	38
1056-78	10 56 28	8	-78 50	15	1.347402	10	43330	54	10	30	25	8
1056-57	10 56 55	3	-57 25	10	1.184994	5	43330	108	8	24	20	15
1105-59	11 05 53	3	-59 30	20	1.516510	20	43335	120	20	40	40	5
1110-65	11 10 37	4	-65 55	15	0.334212	3	43325	250	10	25	20	17
1110-69	11 10 54	4	-69 15	15	0.820486	5	43330	150	8	22	18	10
1114-41	11 14 20	2	-41 00	10	0.943158	5	43325	41	3	19	15	30
1118-79	11 18 10	8	-79 20	15	2.280600	20	43415	30	10	45	50	10
1119-54	11 19 02	3	-54 25	10	0.535784	2	43260	205	5	18	14	26
1133-55	11 33 39	3	-55 00	10	0.364702	2	43260	82	6	17	15	25
1143-60	11 43 42	3	-60 20	15	0.273373	2	43330	113	8	18	16	15
1159-58	11 59 53	3	-58 05	15	0.452801	2	43330	144	5	15	15	21
1222-63	12 22 52	3	-63 40	15	0.419614	6	43330	420	15	22	22	7
1232-55	12 32 31	± 3	-55 00	± 10	0.638235	± 10	43260	100	± 30	45	55	6
1236-68	12 36 58	4	-68 30	15	1.301908	10	43330	100	10	26	22	7
1237-41	12 37 35	2	-41 30	25	0.512242	3	43430	45	8	12	10	3
1256-67	12 56 09	4	-67 25	20	0.663330	5	43330	92	10	25	25	5
1302-64	13 02 09	4	-64 40	15	0.571645	5	43260	504	10	45	40	35
1309-53	13 09 04	3	-53 50	15	0.728152	8	43260	135	10	30	25	13
1309-55	13 09 51	3	-55 00	10	0.849240	6	43260	134	5	29	25	20
1317-53	13 17 48	3	-53 40	15	0.279727	2	43320	96	8	13	10	14
1322-66	13 22 32	6	-66 40	15	0.543007	6	43325	205	10	50	62	25
1323-63	13 23 10	3	-63 40	15	0.792668	10	43260	510	15	48*	40*	20
1323-58	13 23 43	3	-58 55	20	0.477988	8	43330	290	10	76*	86*	32
1325-43	13 25 08	2	-43 45	15	0.532699	2	43325	40	3	18	15	22
1325-49	13 25 31	2	-49 05	15	1.478722	10	43260	118	8	25	15	10
1336-64	13 36 30	4	-64 45	20	0.378622	4	43325	75	10	15	15	8
1352-51	13 52 46	2	-51 35	10	0.644299	3	43260	110	5	13	10	23
1356-60	13 56 25	3	-60 25	15	0.127501	1	43330	295	8	30*	30*	95
1358-63	13 58 10	3	-63 40	10	0.842783	2	43260	97	3	14	15	60
1417-53	14 17 04	3	-53 55	15	0.935765	10	43260	124	6	25	25	10
1424-55	14 24 55	3	-55 10	10	0.570291	3	43260	82	4	20	20	35
1436-63	14 36 27	3	-63 30	15	0.459604	3	43325	124	6	14	15	17

Table 1 – *continued*

PSR	R.A. (1950) h m s	s	Dec. (1950) ° '	'	Period (s)	(μs)	Epoch (MJD)	DM (cm^{-3} pc)		W_e (ms)	W_{50} (ms)	S (mJy)
1454-51	14 54 11	2	-51 25	20	1.748295	15	43325	36	8	24	12	4
1503-51	15 03 06	4	-51 45	25	0.840735	15	43260	60	8	22	17	20
1503-66	15 03 19	4	-66 40	15	0.355656	3	43330	130	8	9	5	8
1504-43	15 04 13	2	-43 40	10	0.286757	5	43330	48	5	12	10	20
1507-44	15 07 27	2	-44 10	15	0.943870	20	43330	75	10	50	40	14
1510-48	15 10 45	2	-48 25	20	0.454840	4	43330	55	8	12	12	8
1523-55	15 23 51	3	-55 50	15	1.048703	10	43260	365	15	50*	40*	28
1524-39	15 24 42	4	-39 20	10	2.417590	20	43325	50	10	35	35	9
1540-06	15 40 50	2	-06 15	10	0.709064	2	43430	18	2	15	12	30
1541-52	15 41 15	2	-52 55	15	0.178554	1	43260	36	2	10	8	26
1550-54	15 50 06 ±	3	-54 25 ±	20	1.081310 ±	40	43260	200 ±	40	50	50	18
1552-31	15 52 10	2	-31 25	15	0.518111	6	43330	72	12	35	35	15
1552-23	15 52 32	2	-23 35	20	0.532576	8	43415	55	15	25	22	8
1555-55	15 55 23	3	-55 40	15	0.957243	8	43260	210	10	27	26	16
1556-57	15 56 16	3	-57 40	20	0.194454	2	43335	180	10	18	15	14
1600-27	16 00 05	2	-27 00	10	0.778311	3	43325	48	4	23	21	20
1600-48	16 00 42	2	-48 55	15	0.327417	2	43260	141	5	13	10	50
1609-47	16 09 51	2	-47 05	15	0.382375	3	43260	162	10	13	10	20
1612+07	16 12 15	2	+07 45	10	1.206807	5	43415	21	5	22	20	16
1612-29	16 12 45	2	-29 45	20	2.477600	30	43430	40	10	45	40	5
1620-42	16 20 19	2	-42 45	20	0.364592	8	43330	310	20	40*	35*	20
1620-08	16 20 34	2	-08 45	20	1.276438	10	43415	70	10	22	18	5
1630-60	16 30 47	3	-60 05	20	0.529118	10	43330	135	20	45	45	5
1641-68	16 41 38	4	-68 30	15	1.785627	5	43330	40	8	85	90	15
1647-53	16 47 44	4	-53 00	20	0.890540	10	43325	160	20	30	25	11
1647-52	16 47 48	2	-52 20	10	0.635052	6	43260	180	5	21	21	34
1648-42	16 48 17	2	-42 40	20	0.844070	30	43325	540	50	305*	335*	105
1648-17	16 48 39	2	-17 05	15	0.973388	5	43330	31	3	30	30	14
1649-23	16 49 57	2	-23 50	15	1.703740	15	43330	70	15	36	36	8
1659-60	16 59 49	3	-60 05	15	0.306320	5	43325	60	15	75	95	20
1701-76	17 01 12	6	-76 05	25	1.191040	50	43440	35	15	25	25	2
1702-18	17 02 41	2	-18 55	10	0.298986	2	43325	23	2	13	10	28
1707-53	17 07 49	3	-53 45	20	0.899219	10	43325	110	10	18	18	6
1718-02	17 18 22	2	-02 05	15	0.477717	6	43325	70	10	60	60	24
1719-37	17 19 35	2	-37 05	20	0.236168	2	43420	100	8	13	10	30
1729-41	17 29 16	2	-41 20	20	0.627982	10	43335	190	20	35	35	9
1737-39	17 37 47	2	-39 25	10	0.512210	3	43330	158	5	22	20	30
1737+13	17 37 48	2	+13 15	15	0.803049	8	43415	50	6	33	35	25
1738-08	17 38 39	2	-08 35	15	2.043090	30	43330	75	15	75	90	17
1740-03	17 40 30	2	-03 45	15	0.444643	2	43330	35	5	12	10	8
1745-13	17 45 29 ±	2	-13 05 ±	15	0.394135 ±	5	43335	100 ±	6	14	15	25
1745-56	17 45 31	3	-56 05	15	1.332310	10	43260	60	10	20	12	6
1756-22	17 56 23	2	-22 05	20	0.460969	5	43330	175	10	18	15	20
1804-27	18 04 02	2	-27 15	15	0.827766	10	43325	305	15	40	40	12
1804-08	18 04 54	2	-08 45	10	0.163727	1	43335	111	3	12	10	55
1806-53	18 06 40	3	-53 40	15	0.261050	2	43415	45	6	15	15	16
1813-36	18 13 42	4	-36 20	15	0.387016	3	43330	95	8	15	15	13
1820-31	18 20 31	2	-31 00	15	0.284053	2	43325	52	6	12	10	16
1821-19	18 21 03	2	-19 40	15	0.189332	2	43325	225	10	30*	26*	55
1821+05	18 21 05	2	+05 55	10	0.752906	3	43335	66	3	19	16	40
1828-60	18 28 46	3	-60 25	20	1.889440	60	43430	40	30	60	65	6
1834-10	18 34 08	2	-10 00	20	0.562720	30	43330	290	50	120*	130*	30
1839+09	18 39 34	2	+09 10	15	0.381319	2	43415	48	5	12	10	22
1842+14	18 42 38	2	+14 55	15	0.375461	3	43335	44	5	14	14	18
1845-19	18 45 22	2	-19 55	15	4.308195	20	43325	20	8	70	75	12
1851-80	18 51 30	10	-80 00	15	1.279190	10	43420	45	8	35	35	10
1851-14	18 51 53	2	-14 35	20	1.146590	30	43420	130	30	55	65	8
1907+03	19 07 39	2	+03 45	15	2.330280	50	43335	95	25	170	240	30
1907-03	19 07 52	2	-03 10	15	0.504603	6	43325	205	10	40	40	20
1923+04	19 23 56	2	+04 20	20	1.074080	10	43420	100	10	25	23	10
1937-26	19 37 58	2	-26 10	20	0.402857	5	43420	50	8	16	20	8
1940-12	19 40 37	2	-12 45	10	0.972427	3	43325	29	3	16	12	14
1941-17	19 41 13	2	-17 45	15	0.841160	3	43330	56	6	25	20	6
1942-00	19 42 54	2	-00 55	15	1.045621	20	43330	55	15	60	60	8
1943-29	19 43 44	2	-29 05	20	0.959420	20	43420	30	20	25	20	6
1946-25	19 46 24	2	-25 45	25	0.957615	10	43420	20	10	20	15	7
2003-08	20 03 34	2	-08 00	15	0.580866	10	43325	25	10	55	55	18
2043-04	20 43 22	2	-04 30	10	1.546937	5	43330	38	5	24	22	18
2044+15	20 44 20	2	+15 45	20	1.138286	3	43330	35	5	25	10	12
2048-72	20 48 40	5	-72 15	10	0.341335	2	43430	16	4	32	35	30
2113+14	21 13 50 ±	2	+14 05 ±	20	0.440152 ±	5	43415	54 ±	10	22	22	15
2123-67	21 23 20	4	-67 00	15	0.325771	2	43430	35	5	20	20	15
2151-56	21 51 32	3	-56 55	15	1.373660	80	43440	5	10	60	60	8
2152-31	21 52 17	2	-31 25	10	1.030001	2	43430	12	5	24	23	18
2321-61	23 21 32	3	-61 20	15	2.347520	50	43440	15	10	50	50	5

* Profile widths for these pulsars appear to be significantly affected by interstellar scattering.
† Declination from Molonglo Cross observations (see Durdin *et al.* 1978, in preparation).

Table 2. Improved parameters for previously known pulsars.

PSR	R.A. (1950) h m s	s	DM (cm^{-3} pc)		W_e (ms)	W_{50} (ms)	S (mJy)
0254-53			15.9	±0.5	13	13	14
0301+19					42	60	28
0450-18					28	30	55
0628-28					79	71	275
0736-40					57	46	190
0740-28							210
0818-13					24	20	90
0833-45							4400
0834+06					26	23	65
0835-41					12	13	150
0940-55					19	12	90
0950+08							500
0959-54					26	20	95
1055-52			30.5	2.0	32	100	125
1133+16					30	32	350
1154-62					49	40	115
1221-63	12 21 34	± 3	96	3			50
1240-64							110
1323-62	13 23 57	3			170	150	160
1359-51*	13 59 41	2	39	5	25	15	10
1426-66					18	20	85
1449-64							185
1451-68							350
1530-53					27	20	60
1541+09					75	50	65
1556-44							110
1558-50	15 58 35	2			38	30	65
1601-52	16 01 26	2	32	3	45	72	60
1604-00					15	12	45
1641-45			475	8	215	225	375
1642-03							440
1700-32	17 00 07	2			45	50	45
1700-18	17 00 56	2	45	10	20	20	10
1706-16					15	15	60
1717-29	17 17 23	2	40	5	30	30	30
1718-32	17 18 48	± 2			20	20	60
1727-47					20	22	190
1730-22	17 30 25	2			35	25	20
1732-07*	17 32 22	2	72	± 3	12	10	23
1742-30	17 42 42	2	86	4	16	10	55
1747-46					15	15	95
1749-28					20	22	1200
1813-26	18 13 28	2	130	10	65	75	30
1818-04					16	14	170
1819-22	18 19 57	2	125	15	65	65	25
1822-09	18 22 46	2			20	20	50
1826-17	18 26 48	2	215	8	55	45	70
1831-03	18 31 04	2			35	25	80
1831-04	18 31 47	2	79	5	45	45	95
1844-04	18 44 45	2			32	24	75
1845-01	18 45 49	2			60	55	60
1846-06	18 46 26	2			30	30	25
1857-26					34	42	120
1859+03					90	85	125
1900+01	19 00 57	2			25	20	60
1900-06	19 00 59	2	190	6	22	20	22
1907+00	19 07 02	2			15	15	10
1907+02			168	4	15	10	20
1907+10	19 07 28	2					55
1911-04					16	14	120
1914+09	19 14 12	2	58	6	15	10	15
1915+13							50
1917+00			91	6	25	18	30
1918+19	19 18 53	2	165	15	85	85	25
1929+10							130
1933+16							260
1944+17					23	21	60
2045-16					58	86	130
2327-20	23 27 50	2	8.3	1.5	26	26	45

* Name changed because of improved position (see text).

Table 3. Improved declinations and periods for previously known pulsars.

PSR	Dec. (1950.0) ° ′ ″	Period (s)	(μs)	Epoch (MJD)
1323-62		0.529907 ±	6	43440
1359-51*	-51 10±15	1.380177	5	43420
1601-52		0.658012	2	43260
1700-18	-18 40 20	0.804340	8	43440
1732-07*	-07 15 10	0.419335	2	43325
1907+02		0.989829	6	43420
2327-20	-20 18 7†	1.643617	3	43335

* Name changed because of improved position (see text).
† Lyne & Large (1976).

One object, PSR 0826 – 34, deserves special mention. This pulsar has an extremely broad profile with two main components and is extremely sporadic in its emission. The mean flux density quoted for this pulsar in Table 1 is from an observation when the pulsar was emitting strongly and hence may be an overestimate of the long-term mean flux density by as much as an order of magnitude. A more detailed report on PSR 0826 – 34 may be found in Durdin *et al.* (1978, in preparation).

A total of 69 previously known pulsars were also detected during the Molonglo survey observations. These pulsars were all observed at Parkes in order to obtain a uniform set of data, particularly mean flux densities, suitable for statistical analyses. For many of these pulsars the right ascensions obtained from the Molonglo data and the dispersion measures and pulse widths obtained from the Parkes data are improvements over the previously published values. Table 2 lists the known pulsars detected in the survey and these improved parameters. PSR 1732 – 07 is the same pulsar as that previously known as PSR 1730 – 07 (e.g. Manchester & Taylor 1977). This pulsar, which was discovered by Lyne & Large (1976), had a misidentified right ascension.

Table 3 gives improved declinations and periods for several previously known pulsars. PSR 1359 – 51 (previously known as PSR 1359 – 50) and PSR 1700 – 18 had poorly known declinations so scans were made at Parkes to improve this parameter. An independent determination of the declination of PSR 1732 – 07 is given in Table 3 and the declination of PSR 2327 – 20 (Lyne & Large 1976) is also quoted for completeness. For PSR 1359 – 51 and PSR 1907 + 02, the previously published periods (Vaughan & Large 1970; Richards, Rankin & Zeissig 1974) are too small by a factor of 2. For PSR 1601 – 52 the period quoted in Table 3 is substantially different from that quoted by Komesaroff *et al.* (1973), 0.675953 s ± 5 μs. However, the other parameters quoted in Table 2 are in good agreement with the data of Komesaroff *et al.* An independent determination of the declination at Parkes gave the result $-52° 50' \pm 15'$, also in good agreement with the Komesaroff *et al.* value. It therefore appears, despite the discrepancy in period, that we have redetected the previously known pulsar and not a different one. There was no evidence from the present observations for substantial variations in the period of this pulsar.

A total of 36 previously known pulsars at declinations south of +20° were not detected by the Molonglo survey. Of these, 30 were pulsars discovered at Arecibo (Hulse & Taylor 1974, 1975) which had mean flux densities at or below the point where the Molonglo survey becomes incomplete. The remaining six pulsars are PSR 0031 – 07, 0943 + 10, 1353 – 62, 1557 – 50, 1754 – 24 and 1911 + 03. Of these PSR 1353 – 62, 1557 – 50 and

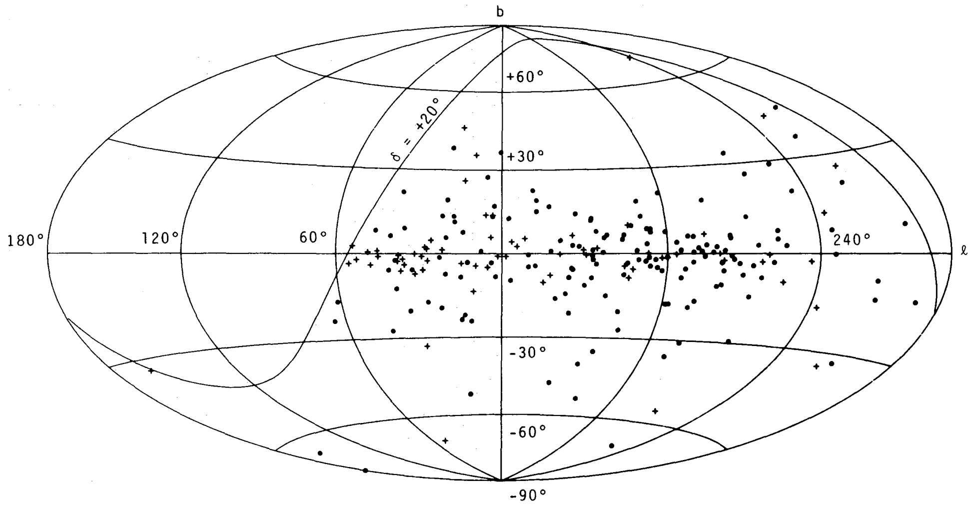

Figure 1. Equal area plot in galactic coordinates of the 224 pulsars detected in the second Molonglo pulsar survey. New detections are marked with a filled circle and previously known pulsars with a cross. The survey covered essentially all of the sky south of declination + 20°.

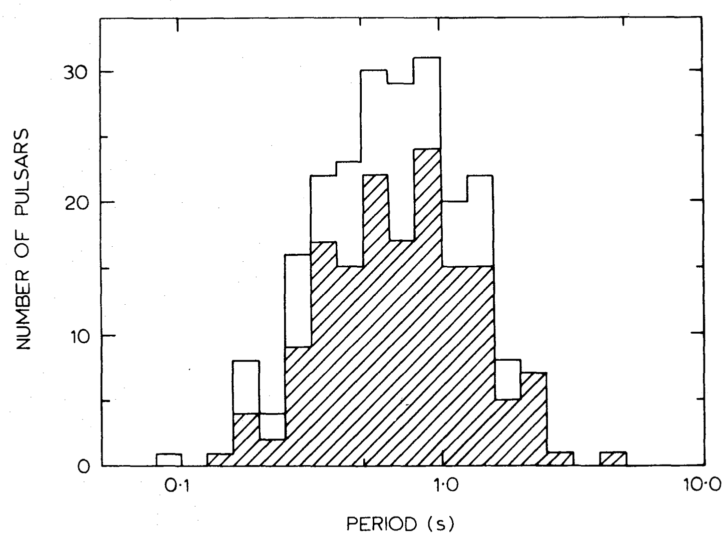

Figure 2. Period distribution of the pulsars detected in the second Molonglo pulsar survey. New detections are represented by the hatched area.

1754 – 24 have short periods and large dispersion measures and so are likely to have their pulsed flux density reduced below the Molonglo threshold by the effects of interstellar scattering. PSR 0031 – 07 and 0943 + 10 are well known to be sporadic emitters (Huguenin, Taylor & Troland 1970; Vitkevich *et al.* 1969) and were presumably not pulsing at the time they were within the Molonglo beam. PSR 1911 + 03 has a long period (2.33 s) and is also likely to be a sporadic emitter (see note added in proof).

The galactic distribution of the 224 pulsars detected in the survey is shown in Fig. 1. This figure shows the well-known concentration of pulsars in latitude toward the galactic plane and in longitude toward the galactic centre.

Distributions of observed periods, dispersion measures and mean flux densities are shown in Figs 2, 3 and 4 respectively. The period distribution for the new pulsars is similar to that for previously known pulsars, except that none of the new pulsars had very short periods

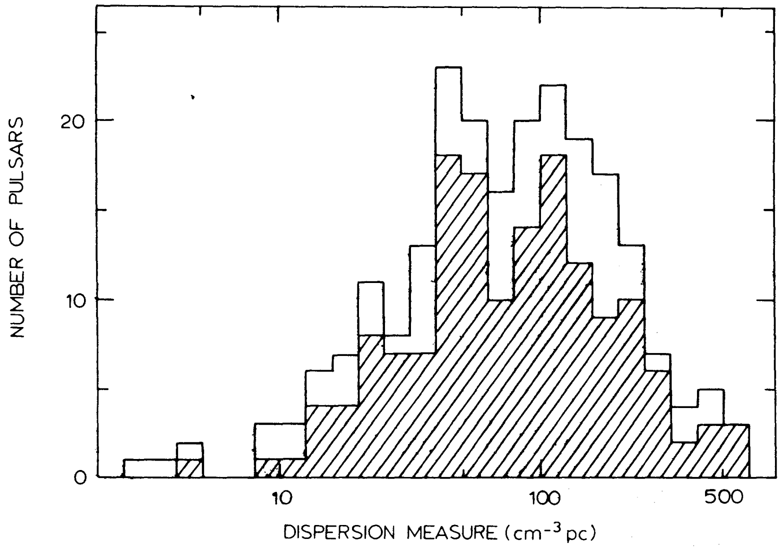

Figure 3. Distribution of dispersion measures for pulsars detected in the second Molonglo pulsar survey. New detections are represented by the hatched area.

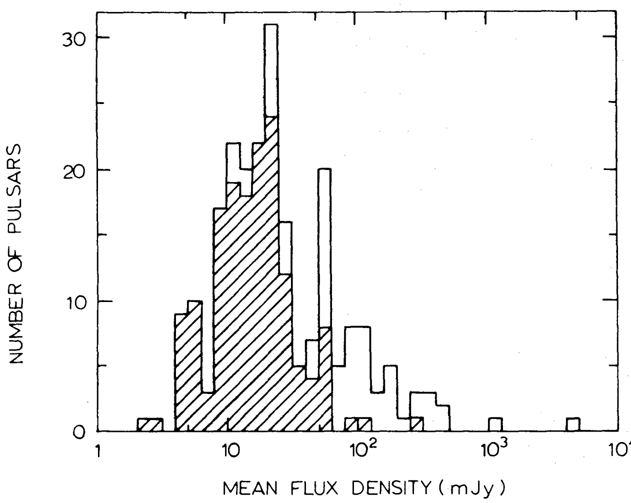

Figure 4. Distribution of mean pulsed flux density for pulsars detected in the second Molonglo pulsar survey. New detections are represented by the hatched area.

(< 100 ms) whereas several had long periods. One of these, PSR 1845 – 19, has the longest period of any known (radio) pulsar, 4.308 s. There was no evidence that any of the pulsars discovered are members of binary systems, although the initial period range searched was more than sufficient to accommodate Doppler shifts from binary systems similar to PSR 1913 + 16 (Taylor *et al.* 1976). The period distribution of the 149 previously known pulsars (e.g. Manchester & Taylor 1977) has an apparently significant dip at periods about 1.0 s. This dip is much less pronounced in the distribution for the pulsars observed in this survey, suggesting that it may not be physically significant.

The DM distribution (Fig. 3) is also similar to that of the previously known pulsars. Three of the new pulsars, PSR 1302 – 64, 1323 – 63 and 1648 – 42, have DM > 500 cm^{-3} pc, which is larger than for any previously known pulsar.

The new pulsars have, on the average, a smaller mean flux density than the previously known pulsars. This is to be expected, since the first Molonglo survey (Large & Vaughan

1971) covered approximately the same area but with lower sensitivity. Fig. 4 suggests that, for pulsars having typical duty cycles, the survey is complete to a mean flux density level of about 15 mJy. This is in accord with the sensitivity threshold calculated on the basis of the system equivalent flux density.

Conclusions

A large-scale pulsar survey covering two-thirds of the celestial sphere has resulted in the detection of 224 pulsars. Of these, 155 are new detections, bringing the total number of known pulsars to 304. Right ascensions, declinations, periods, dispersion measures, pulse widths and mean flux densities have been determined for all of the new pulsars. To obtain a uniform data set, these parameters (except declination) were also determined for all of the previously known pulsars detected in the survey. The survey therefore provides a uniform sample suitable for statistical analyses of 224 pulsars, more than four times as large as that from any previous single survey.

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Note added in proof

It is possible that the new pulsar PSR 1907 + 03 is in fact a redetection of the previously known pulsar PSR 1911 + 03.