A CATALOGUE OF GALACTIC RADIO SOURCES

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[*Manuscript received December* 11, 1967]

Summary

The results of a survey of radio sources in the galactic plane in the longitude range 180° to 40° with the 1 mile Molonglo Cross telescope at 408 MHz are presented. The methods of observation and reduction are described briefly. The catalogue lists the position, flux density, size, and spectral index for 80 sources.

I. Introduction

In 1966 a survey of the southern galactic plane was made with the east–west arm of the Molonglo cross-type radio telescope (Mills *et al.* 1963). This was the first stage of an experiment designed to investigate the nature of galactic supernova remnants. The survey covered the longitude range 180° to 40°. From the results of the survey a catalogue of 80 radio sources has been compiled. The catalogue is believed to be complete to defined limits of flux density and angular size. Sources with an angular diameter of less than 1′ have been excluded from the catalogue since a variety of statistical tests indicate that this class of sources is not of galactic origin.

The catalogue sources have since been observed with the pencil beam imaging system of the radio telescope. This has permitted a more accurate determination of declination and has removed several uncertainties due to confusion. Contour maps have also been prepared of the brightness distribution across the larger sources, but a presentation of these and an examination of the results in the light of various theories of supernova remnants will be deferred to a later article.

II. Observations

The initial finding survey was made during the early part of 1966 with the then recently completed east–west arm of the Molonglo radio telescope. For this survey the arm (a cylindrical paraboloid 1 mile by 38 ft) had an approximately uniform east–west illumination. The operating frequency was 408 MHz and the bandwidth 2·5 MHz. The aerial radiation pattern was a fan beam 1′·43 (right ascension) by 4°·2 (declination). The system noise was about 600°K.

Drift scans were taken at 2° intervals in declination. A source should appear on at least three scans. Each scan was analysed independently by hand and the results were then collated to determine the declination of each source. The background in the neighbourhood of the source was estimated and a baseline interpolated beneath the source trace. For sources with a north–south extent of less than 1° the area between the baseline and the trace is a direct measure of the integrated flux density of the source. The flux density scale was related to the C.K.L. scale by

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adopting 3C 273 and 3C 444 as calibrating sources. The flux densities assumed were $56 \cdot 8$ and $27 \cdot 1$ f.u.* respectively (Kellerman 1964).

The extended sources of the survey have all been observed with the recently completed cross telescope. This instrument has an approximately circular response pattern, $2' \cdot 8$ diameter at half-power at the zenith; the resolution in declination varies with zenith distance. Contour maps have been produced for the larger sources in the survey. The sensitivity of the telescope varies with declination in a way that has not yet been determined; the source flux densities have therefore been obtained from the fan beam observations. For several sources, inspection of the contour maps revealed that a few sources were present simultaneously in the fan beam. In these cases the flux densities have been estimated from the pencil beam records; the flux densities obtained by integrating the pencil beam contours were related to the fan beam flux densities.

Estimates have been made of the angular dimensions of each source. The measurements have been made at the half-power level; however, localized peaks in a complex source were averaged over the surface of the source so as to make the angular dimensions representative of the whole source. This procedure is clearly an approximation but it has the advantage of describing a complex source by two parameters.

For the small diameter sources ($\theta < 3'$) the diameters were estimated from the fan beam observations. The pencil beam records were used for the remainder.

Since the radio telescope operates, at present, on one frequency only (408 MHz), the spectral indices have been estimated from comparisons with surveys made at different frequencies with different instruments. Spectral indices have been determined principally from Hill's (1968) survey at 1410 MHz with a $13'$ resolution, since this is the highest resolution survey available for comparison. Outside the region covered by Hill's survey, comparison was made with various published surveys: Mills, Slee, and Hill (1958, 1960, 1961); Westerhout (1958); Mathewson, Healey, and Rome (1962). All these surveys have a resolution of about $1°$; the spectral information is therefore uncertain, but probably adequate to distinguish between a thermal and a nonthermal spectral index. Approximately 50% of the sources are listed in other catalogues. For the sources not listed, the sign of the spectral index has been estimated from an inspection of the contour maps.

Errors

No attempt has been made to achieve the high positional accuracy that is attainable with this instrument. Since the majority of the sources are resolved by the telescope, the accuracy is determined by the precision with which one can define the centroid of a source. The standard error is estimated as 9% of the source diameter.

The standard error in flux density is estimated as 15%. The error is due partly to the uncertainty in the aerial calibration but mainly to the difficulty in defining the zero level of an extended source. The error in the spectral index is estimated as $0 \cdot 3$ in the region common to Hill's survey. Outside this region only the sign is significant.

* 1 f.u. $= 10^{-26}$ W m^{-2} Hz^{-1}.

III. Survey Limits

The survey covered the galactic plane between the limits $|b^{\mathrm{II}}| < 6°\cdot 5$, $180° < l^{\mathrm{II}} < 40°$. As Hill's survey is restricted to the longitude range $280° < l^{\mathrm{II}} < 355°$, only in this region is the spectral information complete.

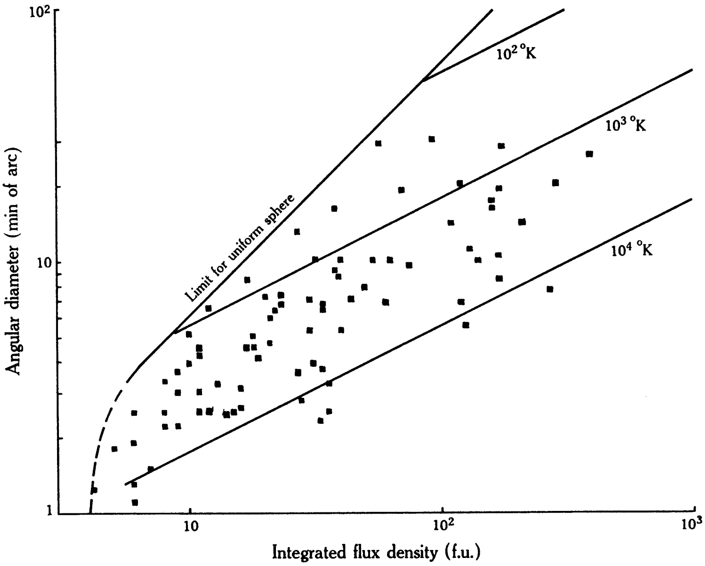

Fig. 1.—Angular diameter versus integrated flux density plotted for each source in the catalogue. The theoretical sensitivity limit (corresponding to a simple supernova model) is also shown. Curves corresponding to disks of uniform brightness 10^2, 10^3, and 10^4 °K are included for comparison.

For the purpose of the experiment it was important that the list of nonthermal sources constitute a statistically uniform sample. This requires that the selection criteria (which govern the inclusion of sources in the catalogue) be known and maintained during the data analysis.

Because source confusion is a major problem in surveys with a fan beam, sources were included in the fan beam catalogue only if they satisfied two conditions:

(1) the peak intensity S_{p} of the source should exceed 4 f.u., and

(2) the east–west half-power angular diameter should be less than 30′.

It was felt that with these restrictions the survey would be complete and the possibility of fluctuations in the galactic background being included in the catalogue might be minimized. The pencil beam records have been examined to ensure that no sources have been included which depended on the particular orientation of the fan beam.

It will be noted that the cutoff does not occur at a limiting brightness, but is some function of size and flux density. The precise relation depends on the particular distribution of energy over the surface of the source.

For a sphere of uniform emissivity (corresponding to a simple supernova remnant model), the limiting criterion takes the form

$$S_{\mathrm{p}} = 4\ \mathrm{f.u.} = \tfrac{3}{4}\sqrt{\pi}\, S_{\mathrm{int}}\, \theta_0/\theta_{\mathrm{r}}\,, \tag{1}$$

where S_{int} is the integrated flux density of the source, θ_{r} the angular radius of the source ($\theta_{\mathrm{r}} > 2'$), and θ_0 is related to the half-power beamwidth of the east–west radiation pattern (θ_{A}) by the relation

$$\theta_0 = \theta_{\mathrm{A}}/0\cdot 94\sqrt{\pi}\,, \qquad \theta_{\mathrm{A}} = 1'\cdot 43\,.$$

The limiting relation between $2\theta_{\mathrm{r}}$ and S_{int} given by equation (1) has been plotted in Figure 1. Also shown are the points corresponding to the sources in the survey. The sources show no marked concentration to the theoretical curve, suggesting that small variations in the selection criteria are unlikely to alter markedly the number of sources in the catalogue. Curves corresponding to disks of uniform brightness have also been included for comparison.

IV. Exclusion of Class II Sources from the Survey

Two classes of radio sources can be distinguished on the basis of their spatial distribution; the following classification (Mills 1952) has been adopted for convenience:

Class I. Sources concentrated to the galactic plane.

Class II. Sources distributed isotropically over the celestial sphere.

Since the main objective of the present survey is to obtain a list of galactic sources, it is clearly desirable to identify the class II sources observed in the survey, as the great majority of these sources are presumably extragalactic. A galactic component may exist but cannot yet be differentiated. Analyses of the 4C survey (Holden 1966; Hughes and Longair 1967) have shown no concentration of sources to the galactic plane, suggesting that the two classes might be distinguishable on the basis of their angular diameter, since the 4C interferometer has a reduced response for extended sources.

In Figure 2, the angular diameter of each source is plotted against its galactic latitude. It appears that the sources with angular diameters of less than $1'$ are isotropic in b^{II} while those with larger diameters are concentrated to the plane. A χ^2 test on the distribution of the small diameter sources ($\theta < 1'$) in galactic coordinates showed a 60% probability that the sources were drawn from a population randomly distributed over the survey region. To test further the possibility that the small diameter sources are not class I, a survey was made at high latitudes to estimate the gross features of the class II population: areal density and number–flux distribution.

The number of small diameter sources observed in the galactic survey is 47 and the number predicted from an extrapolation of the high latitude survey is 53; the agreement is reasonable. Number–flux distributions were also constructed for both surveys. The distributions are similar, although the number of sources in each case is too small for much significance to be attached to the result.

From these tests it would appear that the sources with angular diameters of less than 1′ are predominantly class II. These sources have therefore been excluded from the catalogue.

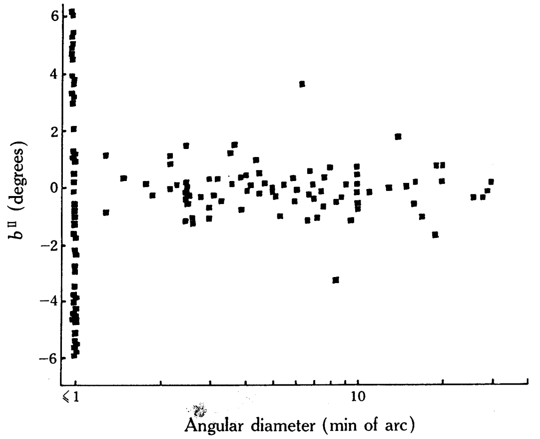

Fig. 2.—Angular diameter versus galactic latitude distribution for all sources in the survey.

The high latitude survey indicated that a small number of sources (five) with angular diameters in the range $1' < \theta < 2'$ should be found by chance in the galactic survey. The six such sources observed have been included in the catalogue as they are all close to the plane, $| b^{\mathrm{II}} | < 2°$. In addition, three of the sources occur in regions of high source concentration. It is probable, however, that some of these sources are class II. An extrapolation of the high latitude survey results also suggests that the catalogue will contain approximately three class II sources with diameters exceeding 2′. These estimates are based on a high latitude survey to which were applied the same selection criteria as in the main survey. For this reason the proportion of sources with diameters exceeding 1′ is rather less than might be expected from the work of other observatories on the angular structure of extragalactic sources.

V. Survey Reliability

The good agreement between the number of small diameter sources of the survey and the extrapolated numbers from the high latitude survey suggests that the limiting peak flux density criterion is realistic. The probability of a source satisfying the selection criteria and not being included in the catalogue is felt to be low.

There are two further aspects of reliability that one would wish to estimate:

(1) the possibility of a large complex source being analysed as a set of small sources, and

(2) the converse problem, confusion.

The preliminary results from the Mills Cross revealed several cases of confusion and one possible case of component separation. After correcting these cases, it is believed that the survey is complete to the specified limits.

TABLE 1

SOURCE CATALOGUE

(1) Source No.	(2) Galactic Coordinates l^{II} °	(3) b^{II} °	(4) Position R.A. h	m	s	(5) (1950·0) Dec. °	′	(6) S_{int} (f.u.)	(7) Spectral Index α	(8) Angular Diam. ′	(9) Other Catalogue Nos.
1	197·0	−0·9	06	16	09	+13	37·5	6	−0·2	1·3	4C 13·32
2	207·3	+1·1	06	42	38	+5	33·0	4	−1·0	1·3	4C 05·29
3	264·1	−3·3	08	33	18	−45	36·0	17	(−)	8·4	
4	265·16	+1·46	08	57	44	−43	33·6	34	+0·2	3·7	MHR4 RCW36 MSH08−48
5	267·95	−1·06	08	57	25	−47	19·2	159	+0·4	17	MSH08−47 RCW38 MHR5
6	268·9	−1·1	09	00	38	−48	6·0	20	(+)	7·2	
7	269·13	−1·12	09	01	47	−48	14·7	9	(+)	3·0	
8	274·01	−1·15	09	22	45	−51	46·7	16	(+)	2·6	
9	282·01	−1·15	10	04	55	−56	55·6	14	+0·6	2·3	
10	284·29	−0·29	10	22	28	−57	29·3	120	+0·3	6·8×12	
11	285·27	−0·04	10	29	42	−57	46·3	9	+0·5	2·2	
12	286·16	−0·06	10	35	27	−58	14·0	27	+0·5	13	
13	290·12	−0·76	11	00	52	−60	37·9	170	−0·7	10·4	MSH11−61
14	291·29	−0·71	11	09	55	−61	04·4	16	+0·8	2·1×4·5	RCW57(a) MSH11−62
15	291·62	−0·53	11	12	56	−60	59·5	170	+0·8	8·4	MHR14 RCW57(b)
16	295·18	−0·60	11	41	12	−62	09·9	40	−0·2	10	
17	304·58	+0·11	13	02	40	−62	26·6	21	−0·7	4·7	
18	305·19	+0·14	13	07	54	−62	22·8	120	+0·6	20	RCW74 MHR25
19	309·73	+1·74	13	43	28	−60	10·0	210	−0·5	18×8	MHR29 MSH13−62
20	310·90	−0·49	13	57	03	−62	02·4	22	−0·5	3·5×9	
21	319·14	−0·38	14	59	06	−58	51·0	23	−0·1	7·1	
22	320·16	+0·80	15	01	33	−57	19·6	8	+0·3	2·2	
23	320·33	−1·03	15	09	33	−58	49·7	30	−0·2	5·3	
24	322·32	−1·21	15	23	03	−57	55·6	8	−0·8	2·5	
25	326·20	−1·75	15	48	28	−56	04·0	170	−0·2	19	MSH15−56 MHR44
26	326·66	+0·56	15	41	03	−53	58·0	60	−0·3	6·8	
27	327·35	+0·40	15	45	24	−53	39·9	54	−0·9	10	
28	327·7	−0·3	15	50	49	−53	39·6	6	−0·1	1·9	
29	328·45	+0·25	15	51	45	−53	05·7	13	−0·3	3·2	
30	331·1	+0·1	16	06	27	−51	58·4	5	+0·2	1·8	1606−51·9(B)
31	332·1	−0·4	16	12	49	−51	09·3	6	+0·4	2·5	1612−51(B)
32	332·41	+0·14	16	11	30	−50	33·3	28	−0·3	16	MSH16−51 1611−50(B)
33	332·43	−0·41	16	13	54	−50	55·8	30	−0·5	7	RCW103 1613−50(B)
34	333·0	−0·6	16	16	10	−50	54·0	36	Thermal*	9·3	1616−50(B)
35	333·1	−0·5	16	17	00	−50	33·0				1617−50·5(B)
36	333·3	−0·4	16	17	43	−50	20·0	200	Thermal*		1617−50·3(B)
37	333·6	−0·2	16	18	23	−50	0				1618−49(B)

* The fan beam observations were badly confused in this region. The quoted values are therefore approximations only, but the sources have been included in the catalogue for completeness. Beard (1966) indicated that these sources are all thermal.

TABLE 1 (*Continued*)

(1)	(2)	(3)	(4)			(5)		(6)	(7)	(8)	(9)
Source No.	Galactic Coordinates l^{II} °	b^{II} °	Position R.A. h	m	s	(1950·0) Dec. °	′	S_{int} (f.u.)	Spectral Index α	Angular Diam. ′	Other Catalogue Nos.
38	335·6	−0·3	16	27	20	−48	24·0	10	−0·6	5·1	
39	337·0	0·0	16	31	30	−47	30·0	110	−0·5	21×6	MHR55
40	337·35	+0·95	16	29	06	−46	29·5	18	−0·2	11	
41	337·80	−0·21	16	35	22	−46	51·9	17	(−)	5×4	
42	337·92	−0·50	16	37	32	−47	02·0	8	+0	3·3	
43	338·39	+0·24	16	36	32	−46	16·5	11	+0·8	3·2×2·9	
44	338·43	+0·03	16	37	15	−46	18·5	12		5×8	
45	342·05	+0·13	16	50	11	−43	30·3	93	−0·3	30	MHR58 MSH16−4*8*
46	345·34	+1·43	16	55	52	−40	07·7	12	0·0	2·5	
47	348·62	+0·03	17	11	19	−38	27·2	124	−0·4	8×3	MSH17−3*3*
48	348·70	+0·36	17	10	47	−38	06·4	36	−0·4	1·5×5	MHR63
49	351·12	+0·65	17	16	29	−36	02·8	44	+0·2	7	NGC6334 MHR64
50	351·21	+0·47	17	17	38	−36	01·0	18		4·5	
51	351·29	+0·67	17	17	03	−35	49·6	140		15×5	
52	351·7	−1·2	17	25	47	−37	0	23	0·0	6·7	
53	353·10	+0·73	17	21	54	−34	15·0	280	+0·2	20	W22 MHR65
54	359·8	+1·2	17	37	07	−28	42·0	9		3·6	
55	0·84	+0·08	17	44	09	−28	10·3	33	(−)	2·3	
56	1·05	−0·15	17	45	33	−28	04·5	50	(−)	6·3×10	
57	4·5	+6·9	17	27	40	−21	25·0	36	−0·6	2·5	Kepler's supernova MSH17−2*11*
58	5·98	−1·18	18	00	38	−24	22·9	75	0·0	9·5	W29
59	6·6	−0·2	17	58	35	−23	19·0	57	(−)	29	W28
60	6·7	−5·9	18	20	17	−26	0	6		1·1	
61	9·3	−1·3	18	08	22	−21	24·0	31	(+)	3·9	
62	10·15	−0·33	18	06	18	−20	19·8	28	+0·2	2·8	W31
63	10·5	+0·7	18	02	45	−21	26·0	70	(+)	19	
64	12·78	−0·19	18	11	14	−17	57·7	63	(−0·2)	10	W33A MSH18−1*4*
65	14·65	+0·02	18	14	12	−16	13·1	38	+0·1	9·1	W33B
66	15·04	−0·70	18	17	37	−16	13·2	270	(+)	7·6	Omega
67	18·86	+0·32	18	21	24	−12	22·6	34	−0·9	6·6	MSH18−1*9*
68	21·2	+0·3	18	26	32	−10	54·5	21	(+)	5·9	
69	21·81	−0·59	18	30	18	−10	12·0	160	(+)	16	MSH18−1*3*
70	23·5	−0·2	18	31	35	−8	44·0	130	−0·2	11	W41 MSH18−0*8*
71	25·1	−0·1	18	33	36	−6	51·0	19	(+)	4·1	
72	25·37	−0·20	18	35	35	−6	51·7	18	(+)	5	
73	27·38	+0·01	18	38	41	−4	59·4	11	−0·4	4·2	4C−04·71 MSH18−0*9*
74	28·79	+3·46	18	28	57	−2	08·0	34	(+)	6·4	
75	29·70	−0·26	18	43	51	−3	02·7	11	−1·1	2·5	4C−03·70
76	30·77	−0·05	18	45	04	−1	59·9	40	+0·3	5·3	W43
77	31·90	+0·05	18	46	47	−0	56·9	27	+0·0	3·6	4C−00·72 MSH18−0*12*
78	33·07	+0·05	18	48	57	+0	05·0	32	(+)	10	
79	33·2	−0·4	18	50	14	−0·2		39	(+)	8·7	
80	34·64	−0·40	18	53	27	+01	18·0	390	−0·4	22×30	W44 MSH18+0*11*

VI. Catalogue

Table 1 gives details of the 80 sources. The sources are listed in order of increasing galactic longitude (l^{II}).

Column 1. Source number.

Columns 2 and 3. Mean position in galactic coordinates.

Columns 4 and 5. Mean position in equatorial coordinates (epoch 1950·0).

Column 6. Integrated flux density in flux units.

Column 7. Spectral index α; this is defined by the expression $S = f^{\alpha}$, so that a thermal source has a positive spectral index.

Column 8. Angular diameter in min of arc, measured at the half-power level.

Column 9. Other catalogue numbers. Abbreviations used are:

MSH, Mills, Slee, and Hill (1958, 1960, 1961); W, Westerhout (1958); RCW, Rodgers, Campbell, and Whiteoak (1960); MHR, Mathewson, Healey, and Rome (1962); (B), Beard (1966); 4C, Gower, Scott, and Wills (1967). No catalogue number has been quoted when there is a gross inconsistency between the low resolution flux densities and the present values. This situation would arise, for example, if a small source were embedded in a broad region of emission.

VII. Acknowledgments

This work was supported by grants from the U.S. National Science Foundation and the Australian Research Grants Committee. I should like to thank Professor B. Y. Mills for his helpful suggestions. I am indebted to Mr. E. R. Hill for the use of his 1410 MHz survey results. I gratefully acknowledge a CSIRO Studentship and a General Motors–Holden Scholarship.

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