AN ALL–SKY CATALOGUE OF STRONG RADIO SOURCES AT 408 MHz

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Abstract

A catalogue of 160 extragalactic radio sources stronger than 10 f.u. at 408 MHz has been compiled by selecting sources from the Parkes and 3CR surveys but adopting the most accurate values of flux density that are available. The sky coverage of 10·1 sr omits only the galactic plane and Magellanic Cloud regions. The flux density scale due to Wyllie has been used throughout.

I. Introduction

In the determination of the number–flux density relation for extragalactic radio sources, the accuracy of the high flux density end of the curve is limited by statistical uncertainties due to the small number of available sources. The aim of the present paper is to reduce these uncertainties to a minimum by providing a catalogue (see Table 1) which includes sources from the largest possible solid angle of sky, while maintaining a uniform flux density scale and the highest possible accuracy for individual flux densities. The statistics of this catalogue have been used by Mills *et al.* (1973, present issue pp. 417–25) to define the high flux density end of the $\log N$–$\log S$ relation obtained from the data of the first Molonglo catalogue (MC1) (Davies *et al.* 1973).

It was necessary to use finding surveys from both hemispheres in order to cover all declinations. Existing surveys covering a large solid angle of sky include: MSH (Mills *et al.* 1958, 1960, 1961) which covers the declination range $+10°$ to $-80°$ at 86 MHz; 3CR (Bennett 1962) which covers $-5°$ to $+90°$ at 178 MHz; and the Parkes catalogue (Bolton *et al.* 1964; Price and Milne 1965; Day *et al.* 1966; Shimmins *et al.* 1966; combined catalogue, Ekers 1969) which covers $+20°$ to $-90°$ at 408 MHz. Almost all 3CR sources have been reobserved with greater resolution and sensitivity at other frequencies (Kellermann *et al.* 1969), thus providing a more accurate version of the 3CR catalogue. In addition, the structures of 3CR sources have been investigated using aperture synthesis (Macdonald *et al.* 1968; Mackay 1969). Flux densities for a considerable number of the stronger sources in the Parkes catalogue were also available from observations at 408 MHz made with the Molonglo cross. The present catalogue makes use of all these programs of reobservation.

II. Selection of Sources

(*a*) Southern Region

For the sky south of declination $+20°$, sources were initially selected from the combined Parkes catalogue (Ekers 1969) but the initial flux densities were obtained on the scale used in the original zone surveys, by removing the scaling factors given by

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Ekers. Wyllie (1969*b*) has shown that this results in agreement with his scale (Wyllie 1969*a*), which is the flux scale adopted in the present paper.

The completeness of the Parkes catalogue decreases steadily below about 4 f.u., but there is no definite lower limit. However, the all-sky catalogue presented here is confined to sources stronger than 10 f.u., for which the Parkes catalogue is essentially complete. Nevertheless, in a number of cases the Parkes catalogue gives flux densities at 1410 and/or 2650 but not at 408 MHz. A list of about 30 such sources was compiled, which should not have excluded any sources stronger than 10 f.u. at 408 MHz. Information about these sources at 408 MHz was obtained from Hunstead (1972*a*), Schilizzi (1972), and a short program of observations at the Molonglo Radio Observatory carried out by the author.

These observations were made with the fan beam of the east–west arm of the cross in the manner described by Clarke *et al.* (1969) and Hoskins and Murdoch (1970) but chart recording was used instead of digital techniques since accurate positions were not required. The fan beam of the east–west arm had a half-power width of $4^\circ\cdot 3$ in declination by about $1'\cdot 5$ in right ascension (or $1'\cdot 9$ if taper was applied to the arm). Integrated flux densities of extended sources were thus easily obtained from the area under a total-power record (Wyllie 1969*b*). Although the confusion error for the fan beam scans is higher than for the pencil beams of the complete cross, this presented no problem for the strong sources considered here if they were not significantly broadened. Comparison with standard sources observed by Hunstead (1972*a*) showed that for compact sources the error due to confusion and noise was $\pm 0\cdot 3$ f.u., while the calibration error was $\pm 5\%$. In the case of extended sources, variations in the background were more troublesome and uncertainties ranging up to about 20% in some cases were assigned by inspection of the scans. The majority of the sources observed in this way were weaker than 10 f.u., as expected. Only four were above this limit.

(*b*) *Northern Region*

In the declination zone north of $+20^\circ$, the initial selection was taken from the source list of Kellermann *et al.* (1969), which includes all 3CR sources in the northern region covered by this catalogue. Flux densities at $\nu = 178$, 750, and 1400 MHz were taken from the list, and second-degree (parabolic) interpolation in the $\log S$–$\log \nu$ plane was used to give a flux density at 408 MHz, which was then increased by the scaling factor of 10% as described in Section V. The relatively narrow range of frequencies involved meant that parabolic fitting was quite accurate for most spectra. Inspection of a number of spectra over a wider frequency range suggested that a random interpolation error of $\pm 5\%$ be adopted. The uncertainties in the three observed flux densities of each source, as given by Kellermann *et al.*, were combined in the appropriate error propagation formula (see e.g. Bevington 1969) to give the equivalent uncertainty at 408 MHz, which was added in quadrature to the interpolation error.

The above procedure resulted in a source list selected from the 3CR 178 MHz survey, but with flux densities at 408 MHz. It was thus essential to consider whether this list was complete to the desired limit at 408 MHz. As the 3CR survey is complete to 9 f.u. at 178 MHz while the lower limit of the present catalogue at 408 MHz is 10 f.u., incompleteness could arise from sources of less than 9 f.u. at 178 MHz but more than 10 f.u. at 408 MHz, i.e. only for inverted spectrum objects, which are rare. The sources missed occupy a triangular region in the α–$\log S_{178}$ plane, where α is the spectral index.

To obtain an estimate of the density of sources in this region, a power-law distribution was assumed for the number–flux density relation at 178 MHz, and spectral data were obtained from the sample of all 306 extragalactic 3CR sources. A simple numerical integration showed that the fraction of sources missed is $\frac{1}{2}\% \pm \frac{1}{2}\%$, and hence the incompleteness incurred in the transfer from 178 to 408 MHz is negligible.

III. Sky Coverage of Catalogue

The all-sky catalogue is intended to include only extragalactic objects and hence it is necessary to exclude a certain region along the galactic plane, where optical obscuration makes it impossible to systematically identify and eliminate all galactic sources. The few galactic sources well away from the plane were easily distinguished.

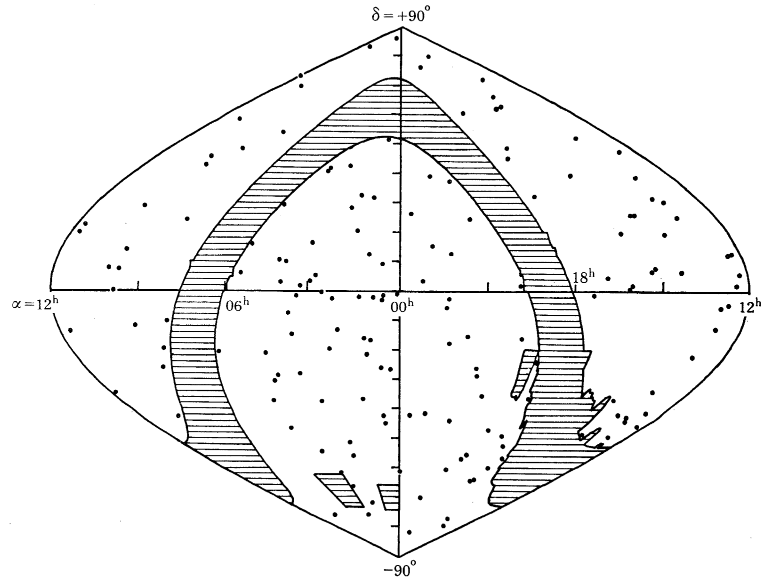

Fig. 1.—Sky coverage of the catalogue on an equal areas plot, with the position of each source marked and the excluded area indicated by shading.

The statistics (Kellermann *et al.* 1969) of identifications as a function of new galactic latitude b suggested $\pm 10°$ as suitable exclusion limits. The 3CR catalogue has no excluded region itself, hence these limits were easily adopted in the northern zone by omitting all sources with $|b| \leqslant 10°$. The Parkes catalogue, however, does exclude parts of the galactic plane, including small areas having $|b| > 10°$, as shown in Figure 1 of Ekers (1969). It was thus not possible to obtain a uniform exclusion of only the region $|b| \leqslant 10°$. The actual excluded region for the present work is shown on an equal areas plot in Figure 1. It is bounded either by $|b| = 10°$ or by the Parkes survey boundary, whichever is further from the galactic plane. The excluded regions for the Magellanic Clouds are the same as those given in the Parkes catalogue. Figure 1 also shows the position of each source in the present catalogue. The solid angle of sky covered by the catalogue, which must be known for use in number–flux density counts, was found to adequate accuracy using graphical methods to be 10·1 sr.

IV. Flux Densities

The flux density of each source was taken from the single best measurement available, for reasons given later in this section. The various catalogues and observational programs used for obtaining flux densities were:

(1) *Hunstead* (*1972*a). Accurate peak flux densities of 43 sources were obtained from this catalogue. Only those sources with little or no detected extension were selected in order to avoid an underestimation of their flux densities. Confusion and noise errors are negligible, while the overall calibration error is taken as $\pm 6\%$, a conservative estimate.

(2) *Wyllie* (*1969*b). Integrated flux densities of four moderately extended sources were obtained from these fan beam observations at Molonglo, other sources in Wyllie's list being covered by (1) above. The confusion error is $\pm 0 \cdot 4$ f.u. and the calibration error is $\pm 5\%$.

(3) *Schilizzi* (*1972*). Integrated flux densities of 21 extended sources were made available to the author from results obtained with the Molonglo cross by Schilizzi. The error in the measurements is $\pm 7\%$.

(4) *Condon* et al. (*1971*). This paper includes accurate relative flux density measurements at 318 and 606 MHz, made at Arecibo. Integrated flux densities were used where specified, and linear interpolation of the (logarithmic) spectra was employed to give flux densities at 408 MHz, of which eight are included here. Measurements at 111·5 MHz were also given by Condon *et al.* but these have greater uncertainties, while the narrow frequency range between 318 and 606 MHz allowed little error in linear interpolation. Comparison with 18 sources observed at Molonglo showed that the flux density scale used had to be raised by 13% to agree with that of Wyllie. Flux density errors were carefully investigated by Condon *et al.* and both fixed (confusion and noise) and proportional (calibration) errors were given. These, in conjunction with the random interpolation error and uncertainty of the scaling factor, lead to a confusion and noise error of $\pm 0 \cdot 1$ f.u. and total calibration error of $\pm 7\%$ at 408 MHz. Finally, these observations were used only north of declination $+10°$ to minimize errors due to large zenith angles.

(5) *Munro* (*1971*a, *1971*b, *1972*). Flux densities of five sources were obtained from these observations of 4C sources at Molonglo. Only sources with no detected broadening were used. The error in the measurements is $\pm 10\%$.

(6) *Cameron* (*1971*a, *1971*b). Integrated flux densities of six sources were obtained from these observations of bright galaxies made at Molonglo. The estimated uncertainties are $\pm 10\%$.

(7) *Kellermann* et al. (*1969*). Flux densities of 51 sources were obtained by interpolation and scaling from these observations. The full range of declinations north of $-05°$ was used (rather than north of $+20°$, where this catalogue provided the initial source selection).

(8) *Molonglo fan beam*. Integrated flux densities of four of the sources listed in the Parkes catalogue as confused, uncertain, or without a flux density measurement at 408 MHz were obtained from the author's observations at Molonglo (see Section II(*a*)).

(9) *Parkes catalogue*. Flux densities of 18 sources were obtained from this catalogue. A comparison of Parkes flux densities and those of Hunstead (1972*a*) for 58 sources showed that the original Parkes scale was consistent with the Wyllie scale, as noted in Section II(*a*) above, and that the uncertainties in the Parkes measurements could be taken as $\pm 1 \cdot 5$ f.u. $\pm 7\%$.

Each source selected by the process described in Section II was allotted its flux density from the first catalogue of the above listing in which it appeared, i.e. the above numbers (1) to (9) indicate the order in the hierarchy of catalogues. This order was generally based on the standard errors of the flux densities although, where appropriate, preference was given to high resolution observations. In addition, some of the catalogues were mutually exclusive owing to their restrictions on declination or source extension.

This procedure naturally introduced some inhomogeneity to the flux densities as a class, yet it was impossible to eliminate all such effects for a catalogue covering all declinations. The alternative procedure of using weighted mean flux densities would have scarcely improved the homogeneity and was unworkable for a number of reasons, which include the bias introduced by the presence of standard errors proportional to the flux density and the broadness of the error classes in Kellermann *et al.* (1969). It was not possible to obtain a rational scheme using all flux densities, and hence the single best measurement of each was used.

In some cases a source, initially chosen from the Parkes or Kellermann *et al.* (1969) catalogues as being above the 10 f.u. limit, would be below this limit when assigned its best flux density value. Such sources were of course omitted from the final catalogue but, to prevent any systematic error arising from this procedure, all the "correcting" catalogues were searched for sources stronger than 10 f.u., which were listed as weaker than 10 f.u. in the appropriate selection catalogue. Although the correcting catalogues are obviously not complete, selection of sources in them was not strongly dependent on flux density, and hence the above procedure is allowable. While lacking some homogeneity, the final catalogue is still suitable for number–flux density counts, as can be seen by considering its two component parts: the correcting catalogues yield a set of flux densities which is nearly a subset of the true values so that the distribution in flux density is unimportant; while the uncorrected flux density values of the remaining sources are subject to larger systematic effects due to random errors (as described below in Section VII). The distribution of the latter values is of course governed by the initial selection catalogues and the correcting catalogues, which thus determine the flux density ranges most affected by these errors. This is expected and simply means that, where fewer corrections are available, residual errors are greater. The corrected number–flux density relation should always lie between the initial and true relations.

V. Flux Density Scale

Although the choice of absolute flux density scale does not affect the slope of the source counts, it is still desirable to use the best possible scale to obtain the correct density of sources per steradian. The absolute scale was for a number of years taken from the work of Conway *et al.* (1963; hereinafter referred to as the CKL scale). Recently, evidence has been mounting that this scale is too low by an amount which increases with decreasing frequency. Wyllie (1969*a*) made absolute flux density measurements with the east–west arm of the Molonglo telescope and established a scale that is approximately 10% higher than CKL. The situation was reviewed by Scott and Shakeshaft (1971), who presented evidence that the CKL scale is 22% ±5% low at 81·5 MHz. These authors quoted the work of Niell and Jauncey (1971) at Arecibo showing that the KPW scale (the flux density scale adopted by Kellermann *et al.* (1969), which is very similar to the CKL scale) is 12% ±3% lower than the Wyllie scale at 430 MHz. Recent measurements by Baars and Hartsuijker (1972) are in agreement with the Wyllie scale to within 1·6%. In the light of this evidence, the use of the Wyllie scale for the present catalogue is amply justified, especially as it is the scale used for the Molonglo catalogue of radio sources with which the present results are to be combined. The KPW flux densities were increased by 10%, in accordance with Wyllie (1969*a*). For comparison with other scales, the Wyllie scale was implemented largely through the use of Hunstead's (1972) subcalibrators, which have been accurately compared with Wyllie scale sources.

VI. All-sky Catalogue of Strong Sources

The final catalogue of strong radio sources is given in Table 1.

Column 1 gives the Parkes-type designation of the source. For sources with declinations south of +27°, this was obtained from the Parkes catalogues (the zone +20° to +27° being covered by Shimmins and Day 1968). North of this limit a Parkes-type number was simply constructed from the positions quoted here. For some highly extended northern sources the Parkes-type number allotted here is somewhat arbitrary.

Column 2 lists the number given to the source in the 3CR catalogue (Bennett 1962).

Columns 3 and 4 give the right ascension and declination respectively. These positions were obtained from the references given in the explanation below of Column 5, in approximately the hierarchy H, AG, FM, S, M, PK, C1, C2, MC. It must be emphasized, however, that the positions are included only for convenience and are not a homogeneous set.

Column 5 gives the reference for position. The abbreviations used are: H, Hunstead (1972*a*); AG, Adgie and Gent (1966); FM, Fomalont and Moffet (1971); S, Schilizzi (1972); M, Munro (1971*a*, 1971*b*, 1972); PK, Parkes catalogues; C1, Macdonald *et al.* (1968); C2, Mackay (1969); MC, Cameron (1971*a*, 1971*b*). The catalogues of H, AG, and FM give accurate positions for point sources, which are here rounded to 0·1 s in right ascension and 1″ arc in declination. The catalogues of S and MC provide 408 MHz centroids, and positions from M are also at 408 MHz. However, many of the positions given in the Parkes catalogues refer to 1410 MHz, and hence could differ from the 408 MHz centroid for extended sources. For northern sources of considerable angular extent, the *approximate* centroid of the emission was found from the maps given in references C1 and C2, and these should be consulted if more detailed information is required. Where positions are approximate, they are given to lower precision in the table.

TABLE 1

ALL-SKY CATALOGUE OF SOURCES WITH $S_{408} \geqslant 10$ f.u.

(1) PKS-type number	(2) 3CR number	(3) Position (1950·0) R.A.	(4) Dec.	(5) Posn. ref.	(6) S_{408} (f.u.)	(7) S_{408} ref.	(8) ΔS_{408} (%)	(9) Notes*
0003−00	2	$00^h03^m49·0^s$	−00°21′10″	AG	10·0	M	11	
0023−26		00 23 18·9	−26 18 52	H	16·5	H	6	
0034−01	15	00 34 30·6	−01 25 45	H	10·7	H	6	
0035−02	17	00 35 47·1	−02 24 08	H	15·7	H	6	
0038+09	18	00 38 14·6	+09 46 56	FM	13·2	M	11	
0039−44		00 39 46·9	−44 30 29	H	10·1	H	6	
0040+51	20	00 40 19·7	+51 47 07	AG	27·8	K	8	
0043−42		00 43 55·8	−42 24 06	PK	21·0	PK	10	
0045−25		00 45 06·1	−25 33 34	MC	16·2	MC	10	1
0055−01	29	00 55 01·0	−01 39 35	PK	11·6	K	8	
0104+32	31	01 04 42	+32 07 36	C1	12·3	K	8	2
0105−16		01 05 48·8	−16 20 21	H	12·0	W	6	
0106+13	33	01 06 15	+13 04 27	C1	32·2	A	7	2
0114−21		01 14 25·8	−21 07 52	H	10·6	H	6	
0117−15		01 17 59·8	−15 35 57	H	13·8	H	6	
0123−01	40	01 23 26·0	−01 35 47	S	18·9	S	10	
0131−36		01 31 43·2	−36 44 29	S	17·2	S	7	
0133+20	47	01 33 40·5	+20 42 10	C1	13·7	A	7	2
0134+32	48	01 34 49·9	+32 54 21	AG	39·6	K	8	
0154+28	55	01 54 19·4	+28 37 04	AG	10·4	K	8	
0210+86	61·1	02 10 45	+86 05 07	C1	19·6	K	8	3
0213−13·2		02 13 11·6	−13 13 24	H	11·9	PK	14	
0218−02	63	02 18 21·9	−02 10 34	H	11·8	H	6	
0219+42	66	02 19·8	+42 47	C1	23·7	K	8	4
0235−19		02 35 24·9	−19 45 29	H	13·0	H	6	
0240−00	71	02 40 07·1	−00 13 31	H	11·8	H	6	
0241−51		02 41 53·6	−51 22 34	S	11·2	S	7	
0245−55		02 45 29·3	−55 54 07	PK	12·2	PK	14	
0252−71		02 52 19	−71 17·2	PK	14·1	PK	12	
0255+05	75	02 55 04·9	+05 50 41	PK	15·5	K	8	
0305+03	78	03 05 48·9	+03 55 18	AG	13·9	K	8	
0307+16	79	03 07 11·5	+16 54 38	M	16·8	M	11	
0315+41	83·1	03 15 13	+41 40 07	C1	19·4	K	8	2
0316+41	84	03 16 29·7	+41 19 52	AG	36·7	K	8	5
0320−37		03 20 48	−37 23 09	MC	259	MC	10	6
0325+02	88	03 25 18·9	+02 23 23	S	11·2	S	7	
0331−01	89	03 31 42·6	−01 21 29	AG	10·9	M	11	
0349−14		03 49 09·7	−14 38 18	PK	11·5	PK	15	
0349−27		03 49 31·9	−27 53 24	S	13·7	S	7	
0350−07		03 50 05·3	−07 19 48	H	10·0	H	6	
0356+10	98	03 56 11	+10 17 17	C2	27·9	A	7	2
0404+03	105	04 04 44·3	+03 33 19	S	12·7	S	7	
0408−65		04 07 58·1	−65 52 49	H	50·8	H	6	
0410−75		04 09 58·9	−75 14 57	H	38·1	H	6	
0410+11	109	04 10 55·1	+11 04 47	AG	11·9	K	8	

* See notes at end of table.

TABLE 1 (*Continued*)

(1) PKS-type number	(2) 3CR number	(3) Position (1950·0) R.A.	(4) Dec.	(5) Posn. ref.	(6) S_{408} (f.u.)	(7) S_{408} ref.	(8) ΔS_{408} (%)	(9) Notes*
0420−62		04ʰ20ᵐ19·0ˢ	−62°30′41″	H	10·7	H	6	
0427−53		04 27 49·9	−53 56 11	S	13·0	S	7	
0433+29	123	04 33 55·4	+29 34 13	AG	121·2	K	8	
0442−28		04 42 36·7	−28 15 12	PK	22·0	PK	10	
0453−20		04 53 14·1	−20 38 56	H	10·9	H	6	
0518+16	138	05 18 16·7	+16 35 27	H	17·3	H	6	
0518−45		05 18 20·8	−45 49 31	S	135	S	7	7
0521−36		05 21 12·9	−36 30 17	H	37·6	H	6	
0528+06	142·1	05 28 48·0	+06 28 16	FM	12·6	M	10	
0634−20		06 34 24	−20 34 12	S	22·7	S	15	
0651+54	171	06 51 10·9	+54 12 50	AG	10·3	K	8	
0802+24	192	08 02 34	+24 18 50	C2	13·1	K	8	3
0806−10		08 06 29·9	−10 19 10	H	11·6	W	6	
0809+48	196	08 09 59·4	+48 22 08	AG	40·2	K	8	
0834−19		08 34 55·9	−19 41 22	H	10·4	H	6	
0842−75		08 42 10·7	−75 29 36	H	12·7	H	6	
0859−25		08 59 36·3	−25 43 29	H	17·6	H	6	
0906+43	216	09 06 17·6	+43 06 00	AG	11·5	K	8	
0915−11		09 15 41·3	−11 53 05	PK	132·0	PK	7	8
0917+45	219	09 17 50	+45 51 48	C1	24·3	K	8	2
0931+83	220·3	09 31 11·6	+83 28 54	FM	10·5	K	13	
0939+14·2 } 0939+14·0 }	225	09 39 30·6	+14 01 24	S	11·1	S	7	
0945+07	227	09 45 08·4	+07 39 22	M	20·1	K	8	
0949+00	230	09 49 25·3	+00 12 35	AG	11·8	FB	12	
0951+69	231	09 51 43·0	+69 54 59	FM	13·3	K	8	
0958+29	234	09 58 57·1	+29 01 37	AG	17·9	K	8	
1005+07	237	10 05 22·0	+07 44 58	H	16·6	H	6	
1018−42		10 17 56·2	−42 36 22	H	12·4	H	6	
1030+58	244·1	10 30 19·4	+58 30 16	AG	11·8	K	8	
1136−13		11 36 38·5	−13 34 07	H	11·2	H	6	
1140+22	263·1	11 40 49·2	+22 23 37	FM	10·3	K	8	
1142+19	264	11 42 31·0	+19 53 28	AG	15·7	A	7	
1151−34		11 51 49·3	−34 48 49	H	10·7	H	6	
1157+73	268·1	11 57 45·5	+73 17 28	FM	15·0	K	8	
1215−45		12 15 27·3	−45 43 48	H	10·0	H	6	
1216+06	270	12 16 50·1	+06 06 09	PK	35·3	MC	10	1
1222+13	272·1	12 22 31·5	+13 09 46	C1	13·2	A	7	
1226+02	273	12 26 32·6	+02 19 35	H	63·0	H	6	
1228+12	274	12 28 18·3	+12 39 49	C1	519	MC	10	9
1239−04	275	12 39 44·8	−04 29 55	H	10·3	H	6	
1245−41		12 46 03·1	−41 02 22	MC	12·0	MC	10	1
1252−12		12 52 00·1	−12 17 07	PK	17·6	PK	11	
1253−05		12 53 35·7	−05 31 06	H	14·3	H	6	
1254+47	280	12 54 41·4	+47 36 33	AG	13·4	K	8	

* See notes at end of table.

TABLE 1 (*Continued*)

(1) PKS-type number	(2) 3CR number	(3) Position (1950·0) R.A.	(4) Dec.	(5) Posn. ref.	(6) S_{408} (f.u.)	(7) S_{408} ref.	(8) ΔS_{408} (%)	(9) Notes*
1302−49		13ʰ02ᵐ33·1ˢ	−49°11′53″	MC	12·6	MC	10	1
1309−22		13 08 57·5	−22 00 42	H	21·2	H	6	
1318−43		13 18 16·3	−43 26 18	S	10·0	S	7	
1322−42		13 22 24	−42 45·0	PK	2740	PK	20	10
1328+25	287	13 28 16·2	+25 24 37	AG	13·2	K	8	
1328+30	286	13 28 49·7	+30 45 59	AG	23·8	K	8	
1332−33		13 32 52·7	−33 37 23	S				
1333−33		13 33 43·3	−33 42 41	S	30·8	S	7	
1334−33		13 34 45·1	−33 53 55	S				
1336+39	288	13 36 38·2	+39 06 27	AG	10·6	K	8	
1350+31	293	13 50 02·9	+31 41 43	AG	10·5	K	8	
1355−41		13 55 56·8	−41 38 17	H	12·9	W	6	
1409+52	295	14 09 33·3	+52 26 13	AG	57·4	K	8	
1416+06	298	14 16 38·8	+06 42 19	H	25·7	H	6	
1420+19	300	14 20 40·8	+19 49 09	AG	10·3	A	7	
1421−49		14 21 14	−49 01·4	PK	12·7	FB	6	
1451−36		14 51 22·4	−36 27 56	PK	11·5	PK	15	
1458+71	309·1	14 58 57·0	+71 52 10	FM	16·6	K	8	
1502+26	310	15 02 49	+26 11 15	C2	30·4	K	8	4
1508+08	313	15 08 33	+08 03 15	C1	11·8	K	8	2
1511+26	315	15 11 30·9	+26 18 35	AG	11·9	A	7	
1514+07	317	15 14 17·1	+07 12 16	H	24·9	H	6	
1547−79		15 47 39·2	−79 31 42	H	10·4	H	6	
1553+20	326·1	15 53 57·4	+20 13 00	FM	10·8	K	9	
1559+02	327	15 59 58·6	+02 06 24	S	25·0	S	7	
1602+01	327·1	16 02 12·9	+01 26 02	FM	13·8	K	8	
1609+66	330	16 09 14	+66 04 22	C1	17·2	K	8	2
1626+39	338	16 26 55·8	+39 39 34	AG	21·2	K	8	
1634+62	343	16 34 01·4	+62 51 43	FM	11·2	K	8	
1637−77		16 37 02·9	−77 09 57	PK	13·5	PK	13	
1637+62	343·1	16 37 55·1	+62 40 34	FM	11·8	K	8	
1648+05	348	16 48 40·8	+05 04 36	PK	169·5	K	8	11
1717−00	353	17 17 56·6	−00 55 49	M	142·8	K	8	
1733−56		17 33 23	−56 32 04	S	20·2	S	7	
1754−59		17 54 38·1	−59 46 45	H	12·4	H	6	
1814−51		18 14 07·8	−51 59 22	H	13·6	H	6	12
1814−63		18 14 46·1	−63 47 01	H	34·7	H	6	
1817−64		18 17 27	−64 00·9	PK	10·5	FB	6	
1827−36		18 27 37·0	−36 04 45	H	25·8	H	6	
1828+48	380	18 28 13·6	+48 42 44	AG	36·7	K	8	13
1833+32	382	18 33 12	+32 39 16	C1	11·8	A	7	4
1839−48		18 39 26·7	−48 39 43	PK	12·0	PK	14	
1842+45	388	18 42 34·6	+45 30 28	AG	16·2	K	8	
1845+79	390·3	18 45 33	+79 43 21	C1	27·8	K	8	2
1859−23		18 59 47·4	−23 34 18	PK	11·7	PK	15	

* See notes at end of table.

TABLE 1 (*Continued*)

(1) PKS-type number	(2) 3CR number	(3) Position (1950·0) R.A.	(4) Dec.	(5) Posn. ref.	(6) S_{408} (f.u.)	(7) S_{408} ref.	(8) ΔS_{408} (%)	(9) Notes*
1932−46		$19^h32^m18\cdot9^s$	−46°27′24″	H	36·8	H	6	12
1938−15		19 38 24·6	−15 31 35	FM	15·2	FB	6	
1939+60	401	19 39 38·8	+60 34 33	AG	13·4	K	8	
1949+02	403	19 49 44·1	+02 22 42	H	15·6	W	6	
1954−55		19 54 19·7	−55 17 40	PK	14·8	PK	12	
2006−56		20 06 22·9	−56 35 56	S	10·7	S	10	
2032−35		20 32 37·2	−35 04 30	H	16·1	H	6	12
2041−60		20 41 18·0	−60 29 56	H	11·0	H	6	
2058−28		20 58 39·5	−28 13 15	S	15·3	S	7	
2104−25		21 04 26·5	−25 39 02	S	28·1	S	7	
2104+76	427·1	21 04 45·9	+76 21 05	FM	13·6	K	8	
2121+24	433	21 21 30·7	+24 51 23	AG	35·3	K	8	
2135−14		21 35 00·6	−14 46 27	PK	10·0	PK	17	
2140−43		21 40 23·9	−43 26 32	PK	10·0	PK	17	
2141−81		21 40 41·9	−81 46·6	PK	10·0	PK	17	
2152−69		21 53 02·3	−69 55 17	S	67·6	S	7	
2153+37	438	21 53 45·5	+37 46 14	AG	25·4	K	8	
2211−17		22 11 42·5	−17 16 34	H	31·3	PK	8	
2212+13	442	22 12 19·4	+13 35 50	S	10·1	S	7	
2221−02	445	22 21 15·5	−02 21 16	S	18·9	S	7	
2223−05		22 23 11·0	−05 12 19	H	12·8	H	6	12
2243+39	452	22 43 32	+39 25 30	C1	33·6	K	8	3
2250−41		22 50 12·3	−41 13 44	H	13·9	H	6	
2251+15	454·3	22 51 29·6	+15 52 56	H	12·5	H	6	12
2313+03	459	23 14 02·4	+03 48 57	H	16·3	H	6	
2331−41		23 31 45·4	−41 42 03	H	15·3	H	6	
2335+26	465	23 36	+26 45	C1	23·8	K	8	4
2356−61		23 56 24·6	−61 11 26	S	61·2	S	7	

* Notes:

1. Cameron (1971*a*).
2. Mean position of double source.
3. Mean position of complex source.
4. Approximate mean position of complex source.
5. Source variable at 750 and 1400 MHz; epoch 1967·0.
6. Cameron (1971*b*).
7. Pictor A.
8. Hydra A.
9. Virgo A; Cameron (1971*b*).
10. Centaurus A; flux density from Cooper *et al.* (1965); arbitrary standard error.
11. Hercules A.
12. Source may be variable at 408 MHz (Hunstead 1972*b*); epoch 1969·5.
13. Source variable at 1400 MHz; epoch 1967·0.

Column 6 gives the flux density of the radio source, and column 7 gives the reference from which it was obtained. The abbreviations used (apart from H, S, M, MC, and PK, which were defined above for column 5) are: W, Wyllie (1969*b*); A, Condon *et al.* (1971); K, Kellermann *et al.* (1969); FB, Molonglo fan beam observations made by the author.

Column 8 gives the percentage standard error in the flux density.

Column 9 gives reference numbers to notes given at the end of the table.

VII. Discussion of Instrumental Effects

(*a*) *Reliability of Flux Densities*

In any catalogue which is to be used for number–flux density counts it is essential to consider whether the errors in flux densities due to calibration errors, noise, confusion, and source extensions will cause significant systematic errors in the counts. It is known that this can occur through the preponderance of weak sources (see e.g. discussions by Murdoch and Large 1968; Murdoch *et al.* 1973). Such problems are minimal in this catalogue, due mainly to the high flux densities involved and the relatively large statistical uncertainties which render precise corrections futile. Both the Parkes and 3CR surveys were employed for selection of sources at flux densities well above their lower limits, thus considerably increasing their reliability. In particular, this results in a very large number of beam areas per source, which minimizes confusion effects. For the present composite catalogue, which contains observations with widely differing resolutions, the concept of beam areas per source is somewhat less useful but the effective value obviously lies between the extremes of about 400 for the Parkes beamwidth and about 10^5 for Hunstead (1972*a*) and indicates that blending and obscuration are negligible for the strong sources. The more numerous weaker sources will still cause small errors in some flux densities due to confusion but these can be dealt with as a small r.m.s. confusion error. The restriction to strong sources well above the lower limit of the surveys also means that noise errors are small, and the overall signal to noise ratio for almost all sources is better than 10:1. It is important to distinguish here between the two categories of errors in flux density: those that are fixed (for a given instrument), such as noise or confusion, and the various calibration errors that are proportional to flux density.

Fixed errors are dealt with by Murdoch *et al.* (1973). For the cases when the true source count distribution is assumed to be a power law with (integral) slope γ over some flux density range, they give tables of the systematic count overestimation, thus enabling corrections to be made when the signal to noise ratio is high, as in the present catalogue. The overestimation is 2% (or 2·6%) when γ is 1·5 (or 1·8) and the signal to noise ratio at the lower limit is 10:1.

The effect of errors proportional to flux density is to cause a constant fractional overestimation of the counts for any flux density range (in contrast to the above case where overestimation is worse at low flux densities, causing a steepening of the observed counts). A brief treatment of the overestimation arising from proportional errors is given in the Appendix. When both types of error are present, the net overestimation factor is obtained simply from the product of the separate factors, since the two errors for any one flux density are independent and the overestimation due to proportional errors is independent of flux density.

For the composite catalogue presented here the effective (r.m.s.) value of standard error is near 9%, the bulk of the errors being of the proportional type. A detailed analysis of the source by source distribution of errors has not been undertaken. Instead an upper limit to the effects of the errors has been found by taking a somewhat pessimistic estimate of $\pm 10\% \pm 1$ f.u. for each source. This leads to a total count overestimation of 3% (or 4%) if γ is $1 \cdot 5$ (or $1 \cdot 8$), compared with the statistical uncertainty of 8%. The error in the fitted slope is $0 \cdot 017$ (or $0 \cdot 025$) from the results of Murdoch *et al.* (1973) while the statistical uncertainty is $0 \cdot 12$ (or $0 \cdot 14$) from the results of Crawford *et al.* (1970). It is clear that random errors in the flux densities do not necessitate any corrections to the counts.

(*b*) *Effects of Source Extensions*

Errors in the catalogue due to resolution of sources should be negligible because the two surveys used for selection were both carried out with quite low resolution, and only objects of very low surface brightness could have been missed. For the weaker sources in the catalogues, the approximate upper limits for angular size are 20′ arc for Parkes, while the 3CR survey employed a rising flux density limit from about 10′ arc to 1°, with complete cutoff beyond 1° (see Fig. 1 of Bennett 1962).* As a check on completeness for extended sources, the MSH catalogue was searched for sources stronger than 70 f.u. at 86 MHz, and which did not appear in the Parkes catalogue. Only 7 were found from a total of 103, and each of these was classified in MSH either as doubtful or with an integrated flux density *considerably* greater than its peak flux density and so was probably a background variation. Additional information was obtained from the high frequency observations in one of the Parkes surveys (Bolton *et al.* 1964) where only 20 out of 297 sources were noted as broadened and hence had angular sizes greater than about 3′ arc at 2650 MHz. Allowing for the expected steep decrease in numbers with increasing size, this again supports the view that only one or two sources are likely to have been missed.

No problems due to source extensions arise in the use of the correcting catalogues since these fall into one of the following categories. Low resolution: K, PK; integrated flux densities: S, W, A, MC, FB; and selected point sources: H, M (using the abbreviations defined in Section VI).

Lastly, the possibility of errors in counting double or multiple sources remains. Again, the wide beams of 3CR and Parkes mean that almost all associated doubles have in fact been catalogued as one source. Bridle *et al.* (1972) find that even with a narrower beam than Parkes, only about 4 true doubles in 330 sources have been catalogued as two objects, and hence this error is again negligible compared with statistical errors. The case of two unrelated sources being catalogued as one is an aspect of confusion, and has been dealt with in subsection (*a*) above.

* M31 is excluded from the 3CR catalogue because the emission covers some $10° \times 6°$ and it is excluded here because the flux density is not well known.

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Appendix

Systematic Errors in Counts due to Random Proportional Errors in Flux Densities

If S represents the true flux density, F the observed flux density, and $P(S)$ and $P(F)$ the respective probability distributions (or differential counts) then these quantities are fundamentally related by

$$P(F)\,\mathrm{d}F = \int_0^\infty P(F\,|\,S)\,P(S)\,\mathrm{d}S\,\mathrm{d}F, \tag{A1}$$

where $P(F\,|\,S)\,\mathrm{d}F$ is the probability of a source of flux density S being observed as F to $F+\mathrm{d}F$, i.e. it gives the description of errors. The model assumed for the true source count $P(S)$ is a power law with integral slope γ and a cutoff at some small flux density to ensure convergence when $\gamma \geqslant 1$.

Proportional errors can be described by a log normal distribution, which gives equal probabilities of over- or under-estimating a flux density by a given *factor*, irrespective of the absolute value:

$$P(F\,|\,S) = \frac{1}{\chi F(2\pi)^{\frac{1}{2}}}\exp\left\{-\tfrac{1}{2}\left(\frac{\ln(F/S)}{\chi}\right)^2\right\}. \tag{A2}$$

The magnitude of the proportional error is specified by χ, the standard deviation of $\ln(F/S)$. Substituting in equation (A1) and integrating via several changes of variable, there follows

$$P(F) = KF^{-(\gamma+1)}\exp(\tfrac{1}{2}\chi^2\gamma^2). \tag{A3}$$

This is well approximated by

$$P(F) = KF^{-(\gamma+1)}(1+\tfrac{1}{2}\chi^2\gamma^2) \tag{A4}$$

for moderate errors. Proportional errors are generally given not as a factor, but as a (slightly ambiguous) additive term, e.g. $\pm 10\%$. In this case,

$$\chi = \ln(1+\varepsilon), \tag{A5}$$

where ε would be $0\cdot 1$ in the above example. The observed count is given as a product of the true count and the overestimation factor which involves just χ and γ.