GALACTIC RADIATION AT RADIO FREQUENCIES

VIII. DISCRETE SOURCES AT 100 Mc/s BETWEEN DECLINATIONS +50° AND —50°

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Summary

One hundred and four discrete sources have been found from a survey covering declinations +50 to —50°. The individual sources are compared in position and flux density with those of previous surveys. The observed distribution shows the concentration of sources of all brightnesses to the galactic equator found by Brown and Hazard (1953) and the concentration of the bright sources to the equator found by Mills (1952*a*, 1952*b*, 1952*c*). A new concentration of faint sources is evident in the southern galactic hemisphere. There is strong evidence for departures from a homogeneous isotropic distribution for the sources outside a 20° zone about the galactic equator. Ten identifications between sources and visible objects are suggested; seven of these are between faint sources and extragalactic nebulae of photographic magnitude about 12·5, and three with galactic nebulosities. One of the latter is the expanding shell of Nova Aquila 1918.

I. Introduction

This paper describes the results of a new survey at 100 Mc/s of the celestial sphere for discrete sources. It is the sixth major survey; previous surveys have been made by Stanley and Slee (1950), Ryle, Smith, and Elsmore (1950), Mills (1952*a*), Brown and Hazard (1953), and Shain and Higgins (1954). Pertinent details of all the surveys are given in Table 1. The present survey has revealed the existence of the largest number of sources so far, although the number of sources per unit area is somewhat smaller than those of surveys 2 and 4, as is the limit of sensitivity of the survey. The area covered (about 70 per cent. of the celestial sphere) is slightly smaller than that of survey 3 and the limit of sensitivity about the same; the reason for the higher source density is the higher resolving power of the present aerial system.

Sea interference technique was used in the observations, employing the aerial system shown in Plate 1. The aerial diagram in azimuth consists of a main beam approximately 12° between half-power points and a number of very weak side lobes. In the vertical plane the main beam is only about 16° wide due to the large separation between the two banks, but there are major side lobes 20° each side of the main beam. However, interference effects from a source passing through the side lobes do not occur owing to the use of a wide receiver bandwidth and other factors which have been described in a previous paper (Bolton and Slee 1953). Sea reflection reduces the width of the main beam in the vertical plane to about 8°.

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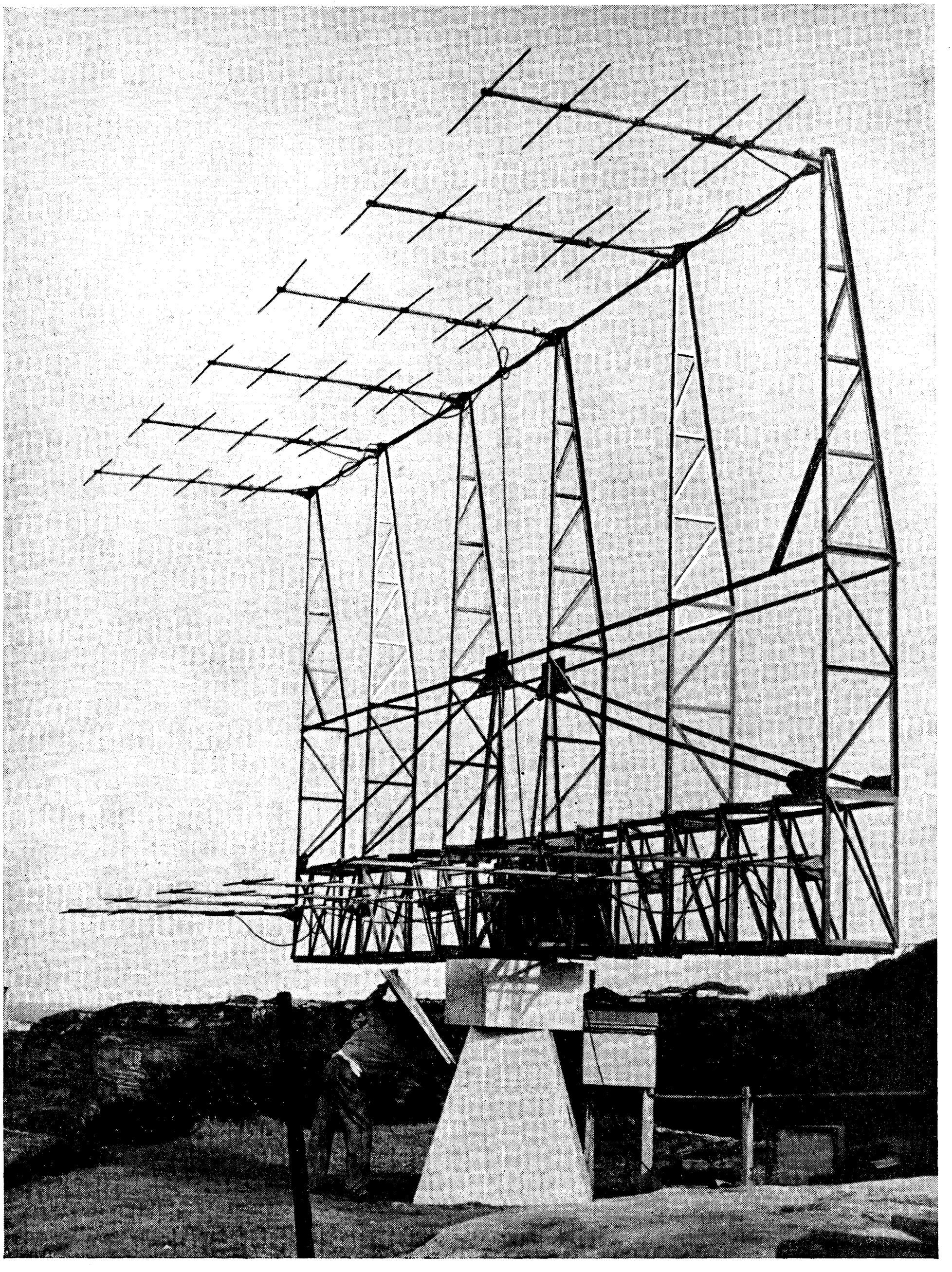

12-Yagi array used in the observations. The two vertical banks are about 1·6 wavelengths apart.

The aerial resolving power and the receiver sensitivity are not much greater than those used in the previous survey by two of the authors. The principal reason for the much larger number of sources found in the present survey is the improved receiving technique which permits entirely automatic operation of the equipment and better " seeing " of the interference patterns due to the sources. These improvements have been described by Bolton and Slee (1953).

A comparison has been made between the results of this survey and the others. As has been found by Mills (1952*a*) and Brown and Hazard (1953) in similar comparisons of previous surveys, there is good agreement between the positions and flux densities of the brighter sources. There is also good agreement for some of the fainter sources which are relatively isolated, but the agreement deteriorates for sources in areas of high source density. The reasons for this

TABLE 1
SURVEYS OF DISCRETE SOURCES

No.	Observers	Frequency (Mc/s)	Limit of Sensitivity (W m^{-2} (c/s)$^{-1}$)	Approximate Aerial Beam (to Half-power Points)	Region Covered (Dec.)	Number of Sources
1	Stanley and Slee (1950)	100	10^{-24}	9 by 17°	50 to —50°	22
2	Ryle, Smith, and Elsmore (1950)	81	3×10^{-25}	$1\frac{1}{2}$ by 90°	90 to 10°	50
3	Mills (1952*a*, 1952*b*, 1952*c*)	100	5×10^{-25}	14 by 24°	50 to —90°	77
4	Brown and Hazard (1953)	158	5×10^{-26}	2 by 2°	70 to 40°	23
5	Shain and Higgins (1954)	18	3×10^{-23}	17 by 17°	10 to —90°	37
6	Present authors	100	5×10^{-25}	8 by 12°	50 to —50°	104

lack of agreement are not difficult to understand. With the interference method of observation, the recorded output of the receiver represents the sum of the effects of all the sources within the primary beam of the aerial. The effects of one outstanding source can be interpreted with a considerable degree of certainty. Where confusion exists on the records, the observer naturally adopts the simplest possible explanation of the complex patterns and trusts that his interpretation is correct. If incorrect, it can result in extreme cases in the assignations of positions and flux densities to sources that do not in fact exist at all. For such sources Minkowski has coined the word " blends ". In a particular region of the sky, observations with aerials of different beams will show confusion in a different manner and degree and the interpretation of the confused patterns may often be different. This situation emphasizes the value of having several surveys with different types of aerials, for the sources common to the surveys may then be accepted as genuine and not products of individual enqipments.

In survey work, the sea interferometer has one advantage over other types of interferometer in that the source suddenly appears over the sharp edge formed by the Earth's shadow. This feature is of great value in studying regions of high source density. The records obtained in the present survey have been carefully examined for patterns due to sources reported by other observers. The negative results obtained in some cases must, however, be regarded with some caution as there are several possible explanations. The simplest is that the source is a blend and does not exist near the reported position. Another is that the source has a complex brightness distribution and perhaps extends over an angle greater than the fringe separation of the sea interferometer in the direction perpendicular to the axis of the interferometer. Further, in comparing the results of surveys at widely spaced frequencies, it is always possible that, due to an abnormal variation of flux density with frequency, a source which appears relatively bright at one frequency may be too faint to be detected at another.

The 104 sources of this survey have been examined to determine possible trends in the spatial distribution, and 10 identifications between sources and visible objects are suggested.

II. The Observations

The results of the survey are summarized in Table 2 which consists of five lists of sources. The list to which each source has been assigned depends on the circumstances of its observation, particularly the degree of confusion between the interference pattern of the source and others in its neighbourhood.

List 1 includes a few well-known bright sources, for which accurate positions have been determined and in some cases identifications established with visible objects.

List 2 contains sources for which no confusion exists in our observations and which agree in position with sources reported by other observers.

List 3 contains sources for which no confusion exists in our observations but which have not been listed by other observers. Several of the sources in this list agree approximately in position with those in catalogues by other observers but the agreement is not sufficiently good to warrant their inclusion in list 2.

List 4 contains sources for which some degree of confusion exists in our observations ; however, the results given are believed to be fairly accurate.

List 5 contains sources for which a considerable degree of confusion exists in our observations and the particulars given are only reliable provided the observations have been correctly interpreted.

In quite a number of cases the positions of sources in lists 4 and 5 agree well with those of sources reported by other observers.

The first column in these lists contains the authors' personal catalogue number, which places the sources in order of discovery (this system of numbering is continued from the survey by Stanley and Slee (1950)). The second column contains the standard three-letter abbreviation for the constellation in which the

TABLE 2

LIST 1

Authors' Catalogue Number	Constellation	Position		l (deg)	b (deg)	Error in Time of Rising $\Delta(RT)$ (min)	Error in Azimuth at Rising ΔA (deg)	Flux Density S at 100 Mc/s (10^{-25} W m^{-2} (c/s)$^{-1}$)	Source Level $\log_{10} S$	Other Catalogue Numbers
		R.A. (hr min)	Dec. (deg)							
10*‡¶	For	03 17	—37¼	207	—57	1	2	24	1·4	M03—3
2*†‡	Tau	05 31	22	152	— 4	—	—	185	2·3	M05+2, R05·01
21‡§	Pup	08 20	—42½	228	— 3	1	2	18 (350)	1·3 (2·5)	M08—4, S08—4
26*	Hya	09 16	—12	212	+26	1	2	28	1·4	M09—1A, S09—1
4*†‡	Vir	12 28	12½	259	+74	—	—	125	2·1	M12+1, R12·01, S12+1
6*†‡‖	Cen	13 22	—42¾	277	+19	—	—	180	2·3	M13—4, S13—4
7	Her	16 49	6	352	+27	1	2	40	1·6	M16+0, R16·01
1*†‡	Cyg	19 58	40½	44	+ 5	—	—	1200	3·1	M19+4, R19·01, H.B.19, S20+x

* Accurate positions for these sources have been determined by Mills (1952*b*).

† Mills has shown that these sources have angular diameters of a few minutes of arc (1952*c*).

‡ Identified with visible objects (Baade and Minkowski 1954).

§ This source has an angular width of the order of 1°. The figures in brackets refer to the total flux density and level, the others to the apparent quantities when the source is observed with the sea interferometer (fringe spacing 1°).

‖ This source is possibly associated with an object of about 2° angular width close to it (Bolton *et al.* 1954).

¶ The source is possibly associated with objects of larger angular size (Bolton *et al.* 1954).

TABLE 2 (*Continued*)

LIST 2

Authors' Catalogue Number	Constellation	Position		l (deg)	b (deg)	Error in Time of Rising $\Delta(RT)$ (min)	Error in Azimuth at Rising ΔA (deg)	Flux Density S at 100 Mc/s (10^{-25} W m^{-2} (c/s)$^{-1}$)	Source Level $\log_{10} S$	Other Catalogue Numbers
		R.A. (hr min)	Dec. (deg)							
71	Phe	01 56	—40	222	—70	2	3	5	0·7	M02—4
97	Cet	02 36	— 3	142	—53	3	5	5	0·7	M02—0
62	Cet	02 04	—10	141	—63	2	2	7	0·85	M02—1
40	Per	03 09	41	118	—13	3	4	8	0·9	M03+4, H.B.6 (R03·02)
8	Per	04 30	31	137	—10	2	2	30	1·5	M04+3 (R04·01)
76	Aur	05 08	46	130	+ 5	3	2	7	0·85	H.B.9 (M05+4)
22*	Pic	05 09	—43½	215	—35	1	2	25	1·4	M05—4, S05—4
99	Mon	08 08	— 6	197	+16	2	4	6	0·8	M08—0
86	Lyn	09 16	46	141	+46	2	4	7	0·85	H.B.12, R09·01 (M09+4)
50	Vel	10 20	—43½	245	+12	2	3	8	0·9	M10—4
56	Crt	11 38	—15	249	+44	3	3	5	0·7	M11—1
28†	Cen	13 35	—60	277	+ 1	—	—	70	1·8	M13—6, S13—5
80	S Cp	15 10	11	342	+51	3	2	6	0·8	M15+1
81	Her	16 36	41	31	+41	2	5	8	0·9	M16+4 (R16·03)
27†	Tr A	16 10	—61	293	— 8	—	—	80	1·9	M16—8
120	S Cd	18 16	— 8	350	+ 2	3	2	15	1·2	M18—0

* The source is possibly associated with objects of larger angular size (Bolton *et al.* 1954).

† The high order fringes of these bright circumpolar sources led to their detection by Stanley and Slee (1950) with the sea interferometer. The positions are those given by Mills (1952*a*).

TABLE 2 (*Continued*)

LIST 3

Authors' Catalogue Number	Constel-lation	Position R.A. (hr min)	Position Dec. (deg)	l (deg)	b (deg)	Error in Time of Rising $\Delta(RT)$ (min)	Error in Azimuth at Rising ΔA (deg)	Flux Density S at 100 Mc/s (10^{-25} W m^{-2} (c/s)$^{-1}$)	Source Level $\log_{10} S$	Other Catalogue Numbers
35	Psc	00 58	15	96	—47	2	3	7	0·85	(M00+1)
38	Cet	00 40	— 2	90	—64	2	3	7	0·85	
73	Cet	00 11	— 8	70	—70	3	3	6	0·8	
83	Scl	00 23	—29	345	—87	2	4	5	0·7	
92	Tri	01 38	32	104	—29	2	5	6	0·8	(R01·01)
41	Tri	01 30	28	103	—33	2	5	4	0·6	(R01·01)
95	Ari	02 02	15	118	—43	3	3	5	0·7	
53	Cet	03 00	3	143	—44	2	3	9	0·95	
39	Tau	04 06	10	160	—28	2	2	6	0·8	
69	Lep	05 12	—25	194	—30	2	2	7	0·85	
52	Mon	06 26	— 6	183	— 6	3	2	7	0·85	
70	Pyx	08 57	—25	219	+15	2	3	7	0·85	
96	Leo	09 51	8	199	+45	3	5	7	0·85	(M09+0)
98	Sex	10 42	0	220	+50	3	2	12	1·1	
102	Ant	10 07	—29	234	+22	2	3	7	0·85	
15	Leo	11 42	18	213	+73	2	2	9	0·95	
30	Vir	12 19	5	257	+66	2	2	14	1·1	
65	Com	13 08	30	20	+83	2	3	10	1·0	(M13+2)
111	Hya	13 58	—25	291	+33	2	2	8	0·9	
49	SCt	15 30	20	358	+50	3	5	8	0·9	
79	Boo	14 05	10	322	+63	3	3	7	0·85	
64	SCt	15 58	3	342	+37	2	2	8	0·9	
74	SCt	15 20	— 2	329	+41	3	2	5	0·7	
114	Sco	16 44	—43	310	0	2	9	15	1·2	
58	Oph	17 44	—20	336	+ 2	2	2	20	1·3	(M17—2A)
68	Sco	17 43	—31	327	— 3	2	2	12	1·1	(M17—2B)
17	Sco	17 08	—34	320	+ 2	2	5	15	1·2	
23	Aql	18 45	8	7	+ 2	4	6	12	1·1	(M19+0)
11	Aql	18 39	2	2	+ 1	3	2	27	1·4	
48	Aql	19 18	16	18	0	2	2	20	1·3	
75	Sag	19 33	—17	350	—19	3	3	8	0·9	(S19—2)

TABLE 2 (*Continued*)

LIST 3 (*Continued*)

Authors' Catalogue Number	Constellation	Position R.A. (hr min)	Position Dec. (deg)	l (deg)	b (deg)	Error in Time of Rising $\Delta(RT)$ (min)	Error in Azimuth at Rising ΔA (deg)	Flux Density S at 100 Mc/s (10^{-25} W m^{-2} (c/s)$^{-1}$)	Source Level $\log_{10} S$	Other Catalogue Numbers
66	Tel	19 34	—46	320	—28	3	2	8	0·9	(M19—5)
33	Vol	20 00	26	32	— 4	2	4	7	0·85	
113	Cap	20 57	—25	350	—40	3	3	9	0·95	(S21—3)
63	Cap	21 22	—20	359	—45	2	2	7	0·85	
89	Aqr	22 26	— 5	30	—50	3	3	5	0·7	
61	Aqr	23 30	—14	38	—68	3	5	5	0·7	

LIST 4

Authors' Catalogue Number	Constellation	Position R.A. (hr min)	Position Dec. (deg)	l (deg)	b (deg)	Error in Time of Rising $\Delta(RT)$ (min)	Error in Azimuth at Rising ΔA (deg)	Flux Density S at 100 Mc/s (10^{-25} W m^{-2} (c/s)$^{-1}$)	Source Level $\log_{10} S$	Other Catalogue Numbers
54	Cet	00 56	3	98	—58	2	2	6	0·8	
105	Cet	00 27	—20	65	—81	3	5	5	0·6	S00—1
57	Phe	00 37	—40	272	—78	2	8	7	0·85	
107	For	02 00	—25	175	—72	4	2	5	0·6	(M01—2)
72	Phe	02 22	—47	230	—63	3	4	7	0·85	
100	Eri	04 20	—16	179	—38	3	5	5	0·7	(S04—2)
91	Aur	06 20	36	146	+12	2	3	6	0·8	(R06·01)
67	C Ma	06 41	—20	198	— 9	4	5	7	0·85	(M07—2)
90	Gem	07 16	36	150	+23	2	2	6	0·8	
94	Gem	07 00	20	164	+14	2	5	6	0·8	
103	Pup	07 14	—33	214	— 9	2	7	7	0·85	
84	Lyn	08 00	48	142	+33	2	12	7	0·85	H.B.11, R08·01
82	U Ma	10 30	43½	140	+60	2	3	6	0·8	(M10+4)
87	LMi	11 42	31	162	+77	2	10	10	1·0	(M11+3A)
59	Boo	15 04	43	37	+57	2	3	6	0·8	(M14+4)
44	Boo	14 43	30	12	+63	2	10	6	0·8	(M14+2)
88	Her	17 45	24	16	+22	3	2	8	0·9	
55	Her	17 23	20	10	+25	3	4	7	0·85	
116	Cr A	18 00	—44	317	—12	2	10	9	0·95	
106	Cap	21 53	—16	8	—49	4	5	8	0·9	
118	Ps A	21 52	—33	341	—53	3	2	5	0·7	
60	Cap	22 30	—14	18	—57	2	5	6	0·8	
77	Psc	23 07	5	52	—50	2	5	4	0·6	
108	Aqr	23 18	—17	25	—68	2	5	5	0·7	

TABLE 2 (*Continued*)

LIST 5

Authors' Catalogue Number	Constellation	Position R.A. (hr min)	Position Dec. (deg)	l (deg)	b (deg)	Error in Time of Rising $\Delta(RT)$ (min)	Error in Azimuth at Rising ΔA (deg)	Flux Density S at 100 Mc/s (10^{-25} W m^{-2} (c/s)$^{-1}$)	Source Level $\log_{10} S$	Other Catalogue Numbers
109	Cet	01 35	—12	131	—70	4	10	4	0·6	
47	Er	03 08	—16	169	—54	3	5	6	0·8	
122	Cae	04 46	—30	198	—37	5	5	6	0·8	(M04—3)
121	Lep	05 48	—17	190	—19	4	2	7	0·85	(M06—1) (S06—1)
32	Gem	07 00	15	169	+11	4	10	6	0·8	
93	Leo	09 56	28	170	+54	3	3	7	0·85	
19	Sex	09 40	0	206	+39	3	5	4	0·6	
119	Vel	09 08	—42	234	+ 5	1	2	10	1·0	
101	Hya	10 46	—20	237	+35	4	10	5	0·7	
123	Hya	11 00	—32	247	+26	3	7	5	0·7	(M10—3)
78	Vir	13 26	10	303	+69	4	5	4	0·6	
110	Hya	14 54	—29	303	+25	4	14	10	1·0	
112	Lup	15 48	—34	309	+14	3	3	14	1·2	
51	Oph	17 12	10	359	+25	5	10	15	1·2	
36	Aql	18 47	12	12	+ 4	3	5	10	1·0	
31	Vul	21 13	20	38	—20	5	6	10	1·0	
117	Gru	21 30	—42	327	—49	3	20	5	0·7	(M21—4)
45	Peg	22 24	4	38	—44	3	4	5	0·7	
115	Scl	23 32	—29	352	—75	4	10	5	0·7	(S23—2)

source is situated, the third to sixth the position, and the seventh and eighth the limits of error in the position of the source. The ninth column contains the flux density of the source at 100 Mc/s ; the errors in the flux densities relative to that of the source Virgo–A which was taken as the standard are probably not more than ± 20 per cent. Column 10 is the " level " or radio magnitude defined, following Mills, as $L = \log_{10} S$ where S is the flux density in units of 10^{-25} W m^{-2} (c/s)$^{-1}$. In column 11 are the catalogue numbers assigned to various sources by other observers ; where there is some doubt about the identifications the catalogue numbers are in brackets. The following abbreviations are used : M for Mills, R for Ryle, Smith, and Elsmore, H.B. for Brown and Hazard, and S for Shain and Higgins. Additional information on some sources is contained in the footnotes following Table 2.

The limits of error in position are not, as is customary, given in Right Ascension and declination since the factors determining the position are the sidereal time at which the source crosses the optical horizon and the azimuth bearing of the source at that time. For sources of declination greater than about 25°, the rate at which the source passes through the fringe system of the interferometer is used to supplement the latter. The accuracy in the determination of the rising time, $\Delta(RT)$, depends partly on the number of observations of the source, which helps to reduce the uncertainty introduced by the variable atmospheric refraction at low angles and by the degree of confusion. The accuracy in azimuth at rising, ΔA, depends on the number of observations of the source, the degree of confusion, and, in the case of sources near the galactic plane, on the change in the background noise during the observation of the source. (The change in sensitivity of the equipment due to the change in background level effectively alters the polar diagram of the aerial as far as the observation of the source is concerned and thus complicates the direction finding.) The area contained by the limits of error is a parallelepiped which changes shape with the declination (for examples see Stanley and Slee (1950)) ; its smallest side is generally that determined by the error in time of rising. These errors increase on the average for the sources in the higher list number and in the case of a source in list 4 or list 5 are subject to the interpretation of the observations being correct.

In general nothing certain is known about the angular widths of the sources of this survey. The sea interferometer used in the observations has a fringe separation of 1° and thus it can be assumed that in most cases the angular sizes of the sources are less than 1°. An exception is that of Puppis–A (source 21, list 1) which is known to have an angular width of about 1° overall ; however, a sea interference pattern is produced by a bright local patch near one edge of the source (see Bolton *et al.* 1954). It is thought unlikely that any of the sources away from the galactic plane have angular sizes of more than a few minutes of arc, but it is possible that the sea interference patterns of some of the sources near the galactic equator may be due to bright patches or central concentrations of much more extended objects.

III. A Comparison of the Various Surveys

(a) *Overall Comparison*

An examination of the sources of the present survey and those given in surveys by Ryle, Smith, and Elsmore (1950), Mills (1952*a*, 1952*b*, 1952*c*), and Brown and Hazard (1953) shows that 3 sources are common to all the surveys, 7 common to three (5 with Mills and Ryle, 1 with Mills and Brown, and 1 with Brown and Ryle), and 35 to two (33 with Mills and 2 with Ryle).

(b) *Comparison with Mills's Survey*

Mills's list contains 69 sources (including the two circumpolar sources 28 and 27) in the area common to his survey and our own. Of these, 42 or 60 per cent. agree in position to within 3°. For these sources the two determinations of the flux densities are compared in Figure 1 (*a*). The abscissa represents the source level of the present survey and the ordinate the difference in levels (i.e. the logarithm of the ratio of flux densities). The dots refer to the sources of our lists 1 and 2 and the open circles to the remaining sources. For the majority of the sources the level differences are less than 0·2 and a scatter of this order may be considered reasonable in view of the experimental accuracy claimed in each case. There is a slight tendency for the level difference to increase for the fainter sources which means that Mills's estimates of the flux densities of the fainter sources are higher than ours.

Nine sources lie well outside the 0·2 scatter in level differences. These sources are: 21, M08−4; 58, M17−2A; 68, M17−2B; 23, M19+0; 123, M10−3; 86, M09+4; 82, M10+4; 76, M05+4; and 40, M03+4. The first, source 21 (Puppis–A), is known to have an angular size of the order of 1°; our measurements refer to the total flux density and Mills's only to the effective flux density of that part of the central concentration which gives rise to the pattern on his interferometer. The discrepancy is thus resolved in this case. The next three sources are close to the galactic plane; the discrepancies in these cases may be due to the angular sizes being comparable with the fringe separations of the interferometers and the different axes of the interferometers, or may be due to errors in calibration (the sources are in regions of high background radiation). No reason can be offered for the discrepancy in the case of the fifth source except that the error in one or both cases may be due to confusion with neighbouring sources. The four remaining sources have one feature in common—they are all north of Dec. +40°. Examination of the level differences for all the sources north of +40° shows that Mills's estimate of flux density is higher than ours in all cases. This suggests a systematic error and Mills (personal communication) has informed the authors that he may have underestimated the effect of ground reinforcement on his results for the sources of high northerly declination.

(c) *Comparison with Ryle's Survey*

In the area common to the two surveys there are 32 sources in our list and 35 in Ryle's list. Only 11 of these appear to be identical, which at first sight seems very poor agreement. However, of the 32 in our list, many are of low declination where the sensitivity of Ryle's interferometer is fairly low. Further, of the 35 in his list, many are below the limit of detection of our instrument.

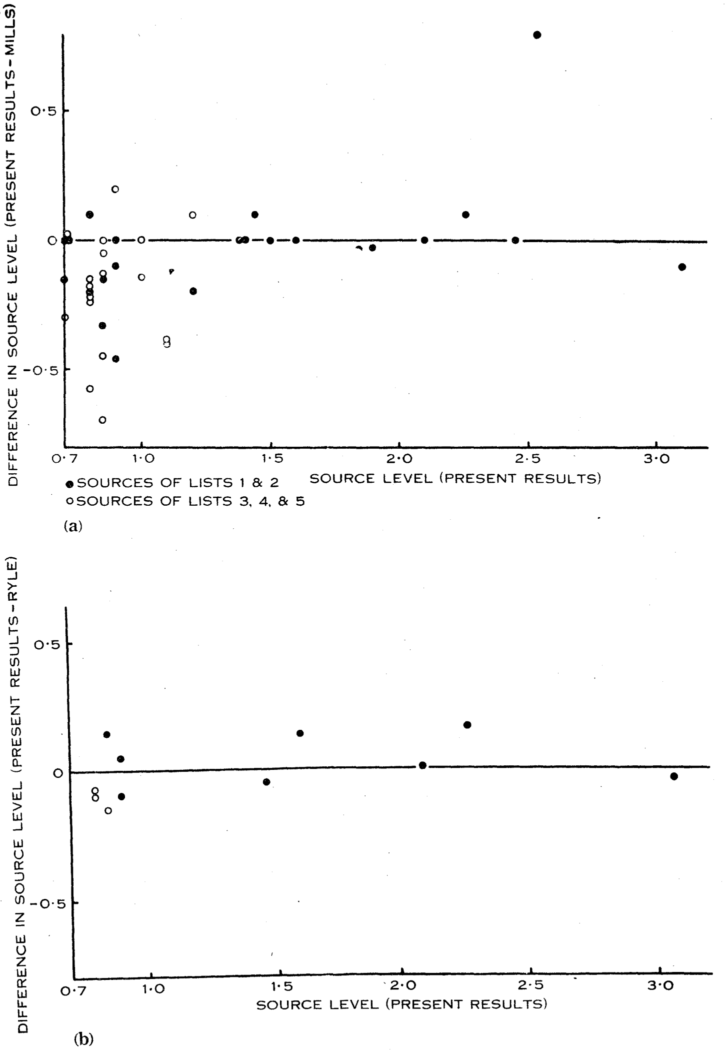

Fig. 1 (*a*).—Comparison between the " levels " of sources common to the present survey and that of Mills. The abscissa is the level given by the present survey and the ordinate the difference between the present value and that due to Mills. The dots refer to sources in lists 1 and 2 and the open circles to the remainder.

Fig. 1 (*b*).—A similar comparison between the sources common to the present survey and that by Ryle, Smith, and Elsmore.

Of the 17 sources within the limit of detection, 11 are identical with sources in our list and thus the agreement is of about the same standard as in the previous comparison with Mills's results.

The level differences are compared, as before, in Figure 1 (*b*). There is less scatter in the level differences than in the previous comparison and no change with absolute levels. This comparison would indicate that there is no change in flux density with frequency. Observations by Stanley and Slee (1950) of the radio-frequency spectra of four bright sources and other comparisons of individual measurements by Shain (1954) and Brown and Hazard (1953) suggest spectra of the form $S \propto f^{-n}$ where n is of the order of unity. The difference in levels should therefore be $n \log(f_1/f_2)$ which is $-0 \cdot 1$ for n unity and f_1 and f_2, 100 and 80 Mc/s. The fact that this difference does not show up in Figure 1 (*b*) suggests a systematic error in the measurement of flux densities in one or both surveys.

(*d*) *Comparison with Brown's Survey*

In the area common to the two surveys there are eight sources in our list and nine of flux density greater than 3×10^{-25} W m^{-2} (c/s)$^{-1}$ at 158 Mc/s in Brown's list. Of these nine, two are extended objects and one is on the northern limit of our survey. Of the remaining six, five agree well in position. There are so few identical sources that the levels are not worth comparing in detail. However, it appears that the flux density at 100 Mc/s is greater in all cases than that at 158 Mc/s but there is a considerable range of actual ratios.

(*e*) *Comparison with Shain and Higgins's Survey*

There are 74 sources in our list and 31 in Shain and Higgins's list (including the circumpolar sources 27 and 28). Of these, 13 are common to the two—a somewhat poorer result than the previous comparisons. However, it should be remembered that the observing frequencies are much further apart in this case and that Shain and Higgins's method of observation is very different from ours. They did not employ an interferometer but deduced the existence of the sources from local " peaks " on the contours of the background distribution at 18 Mc/s, and they point out that some of these sources may therefore have large angular sizes, well in excess of the fringe separation of our interferometer. We have not considered the difference in levels for the sources common to the two surveys as Shain (1954) has already made a detailed comparison between his and Mills's results.

(*f*) *Reliability of the Present Survey*

These comparisons enable us to make some estimate of the general reliability of the results of the present survey. The agreement between the individual sources of the various surveys has been found to be quite high after due allowance has been made for factors such as the different sensitivities of the instruments and conditions of the surveys. Sources which may be considered as definitely existing are those which can be identified with sources reported by other observers—the 8 sources of list 1, the 16 sources of list 2, 8 of the sources of list 4, 5 of the sources of list 5—a total of 37. To these we may confidently add the 36 sources of list 3 (8 of these are possible identifications with sources of other observers) giving a total of 73 or 70 per cent. of the total. It is also reasonable to assume that quite a number of the remainder in lists 4 and 5 are correctly reported so that the percentage is probably much higher.

IV. Suggested Identifications

The ultimate purpose of any survey such as this is the " identification " of the sources. This can be done in two ways ; the direct method of correlating the positions of radio sources with visible objects and the indirect method of studying the distribution of the sources. The latter may lead to identification through the finding of radio and visible emitters in a common spatial distribution.

As far as the first approach is concerned, we may rely on the already established identifications between sources and visible objects to guide the search. The choice seems to lie between extragalactic nebulae with certain anomalies and galactic nebulae whose common characteristic is a large dispersion of gas velocities. The latter type is mostly objects of extremely low luminosity and present some difficulties to the astronomer with quite large telescopes. The radio astronomer, armed only with a collection of star atlases or catalogues, can hardly expect to suggest identifications of this type. With extragalactic nebulae the situation is rather different ; the difficulty of the low luminosities does not always exist but a difficulty of position accuracy is immediately apparent. The positions of the sources are only approximate, the average limit-of-error rectangle for the sources of the present survey covers about 5 deg^2 and there are about 100 sources, or one to every 300 deg^2 of the sky covered. In the same region, reference to the Shapley-Ames catalogue of extragalactic nebulae shows that the average density of galaxies down to the 13th magnitude is about 1/30 deg^2. Thus there appears to be a one-in-six chance of finding a galaxy brighter than 13th magnitude within the limit-of-error rectangle of a source. For 14th magnitude galaxies the chances are nearly even. It is apparent that suggesting identifications on such an arbitrary basis without some supporting evidence would be quite unjustified.

However, a suggested identification, if it can be made, is valuable for two reasons. Firstly, it draws to the attention of the astronomer the possibility of peculiarities in a galaxy about which practically nothing may be known except its position in the sky and a very rough description of its appearance. Secondly, it gives hope to the radio astronomer, intent on making accurate determinations of position, that a certain identification may result from his efforts—for there are cases where an extremely accurate position has not led to the identification of a source with any visible object. These cases represent a certain waste of effort.

A more positive approach to the question can be made if, in addition to position measurements, we take account of the ratio of optical and radio emission of the already established extragalactic radio emitters. At one end of the scale Brown has shown that there is a fairly uniform relation between the optical and radio emission of certain (assumed) normal galaxies including our own Galaxy and several others of the local group of galaxies. Of these only the flux density of Andromeda (and the Magellan Clouds possibly) is sufficient to enable their detection with the present equipment. The angular sizes are, however, too great for detection with the interferometer of fringe separation of 1°. At the other end of the scale there is the second brightest radio source, that in Cygnus, which is identified with a pair of very faint galaxies in collision. With such a high ratio of radio to optical emission, it would be hopeless to search for objects with a similar ratio whose radio flux density is 100 times smaller. In between, there are two and possibly three galaxies whose ratio of radio to optical emission is about 100 times that for the normal galaxies. These are the galaxies NGC 4486, 5128, and possibly 1316. To find the level difference, which is the logarithm of the ratio of optical to radio intensities in common units, we have to multiply the optical magnitude by 0·4 and add it to the radio level. This gives level differences in the three cases of 6·3, 5·1, and 5·4 ; these are fairly close and have a mean of 5·7. If there are other galaxies with the same ratio, for sources down to a level of 0·8, they should be brighter than 13th magnitude. On this basis we suggest the seven galaxies in Table 3 as possible abnormal radio

TABLE 3

SUGGESTED IDENTIFICATIONS OF SOURCES WITH EXTRAGALACTIC NEBULAE

Source	List	Galaxy			Remarks on Position Agreement	Ratio of Radio to Optical Level, $L+0\cdot 4m$
		NGC Number	Type	Mag.		
38	3	227	—	13·1	Observations and position agreement very good	6·1
102	3	3125	—	13·0	Some scatter in observations. Positions within 1°	6·0
30	3	4303	SBc	10·4	Observations and position agreement very good	5·3
88	4	6482	E	12·2	Some scatter in observations but line of rising passes through nebula	5·6
77	4	7541	Sb	12·8	Within limits of error	5·7
47	5	1209	—	12·5	Observations fair. Positions within 1°	5·8
19	5	2967	S	12·4	A faint source. Agreement good	5·6

emitters. The radio and optical positions are in good agreement and the difference in levels of the order indicated. Moreover, the galaxies are all in regions of fairly low density (i.e. down to the magnitude limit taken) so that there are no alternative identifications possible from nearby galaxies. The density of galaxies in the regions is far less than the average of 1/30 deg^2, considered earlier, as most of the galaxies down to 13th magnitude are concentrated in the Virgo and Fornax clusters. If a fair proportion of the latter were abnormal, we would not expect to distinguish many of them owing to the resultant confusion in the radio observations.

The average difference in levels for the three identifications and the seven suggested is about 5·7. This may be compared with Brown's value of 3·6 (in equivalent units) for normal galaxies at 158 Mc/s. The correction for the radio spectrum between 100 and 158 Mc/s is probably not more than $0 \cdot 4$ (assuming a variation of flux density inversely proportional to frequency). Thus the radio emission from the abnormal galaxy exceeds that of a normal galaxy of the same optical magnitude by a factor of about 100. It is suggested that the one exception to Brown's almost uniform ratio for normal galaxies, NGC 891, may also be of this abnormal type. Brown has explained this case by assuming that the dark band of the spiral, which is seen almost edge-on, obscures most of the visible light. However, it seems that the discrepancy is much too great to admit this explanation.

In addition to the extragalactic nebulae, the following galactic objects are suggested as possible radio sources on the basis of the position measurements : source 11 with the expanding shell of Nova Aquila 1918 and sources 58 and 119 with the planetary nebulae NGC 6445 and 2792. In the case of source 11, the radio position is 2° away from the nova shell on the line of rising passing through the nova position. Although 2° is fairly close to the limit of error, it is not large in view of the particular difficulties in this case.* The expanding shell does seem to be the type of object that could produce high radio emission, considering the other objects in which high gas velocities are associated with abnormal radio emission.

V. The Distribution of the Sources

(a) *Instrumental Effects Affecting the Observed Distribution*

Before examining the distribution of the sources in detail, it is necessary to consider the consequences of instrumental selection on the results. Instrumental selection can be of two types, one due to a change of sensitivity in the equipment with position on the celestial sphere and the other due to a combination of the actual source distribution and the resolving power of the aerial. The first type may be again subdivided.

Firstly, some variation in sensitivity might be expected with the declination of the source. A source of declination 0° passes through the fringe system at the rate of one fringe in 5 min, a source of 40° declination at one fringe in 10 min, and the rate decreases rapidly towards the limit of the survey. Variations in receiver gain, the presence of external interference, and other factors are more likely to affect the " seeing " of the slow interference patterns due to sources of high declination than the rapid ones of low declination. A test was therefore made of the observed distribution to see whether this effect was present in the results. No marked effect was found as can be seen from Figure 2 (*a*) which shows the distribution of sources amongst seven equal area zones bounded by parallels of declination. The result is compared with the data of Mills's survey in Figure 2 (*b*). It appears that Mills's survey tended to favour sources of high declination as his results show a relative excess in zone 7, but this may be in part

* The line of rising can be determined with relative certainty but in this case it is difficult to secure an intersecting line and so establish the position of the source on the line of rising. As the declination is very low the method of finding it from the fringe period is inaccurate and, as the source is close to the galactic plane, the change in sensitivity during the period of observation renders direction finding on the source unreliable.

due to the higher sensitivity in high northern declinations already mentioned. Both results show a relative deficiency in zone 6 (declinations $33\frac{1}{2}$–$41\frac{1}{2}$°).

Secondly, the sensitivity of the equipment varies with the background noise from the Galaxy received by the aerial. The effect of the background noise is inherent in any observations of this type but the extent of the effect is determined by the aerial system and the receiver noise factor. The present aerial with its relatively low resolving power does not reflect the true background distribution, the variation in which is of the order of 20 or 30 : 1. It receives power from all directions within the beam and the variation in this over the celestial sphere is only of the order of 4 or 5 : 1. Moreover, the total output of the receiver is due to the sum of the power received by the aerial and the noise

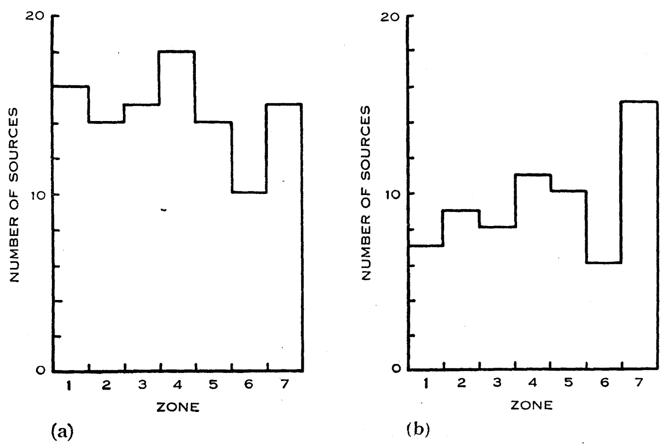

Fig. 2.—Diagrams illustrating the uniformity of the material of the present survey and that by Mills. The number of sources observed in seven equal area zones bounded by parallels of declination north and south of the celestial equator are shown. Zones are ± 0–$6\frac{1}{2}$°, $6\frac{1}{2}$–$12\frac{1}{2}$°, $12\frac{1}{2}$–$19\frac{1}{2}$°, $19\frac{1}{2}$–$26\frac{1}{2}$°, $26\frac{1}{2}$–$33\frac{1}{2}$°, $33\frac{1}{2}$–$41\frac{1}{2}$°, and $41\frac{1}{2}$–50°.

generated in the receiver and associated cables. The sensitivity of the equipment is inversely proportional to the total receiver output, and in the present case varies by about 2 : 1 between the aerials directed towards the galactic poles and in the direction of the galactic centre. Undoubtedly the variation in sensitivity* due to this cause is present in the results of our observations but we consider that it is probably overshadowed by another effect in regions near the galactic plane—the shielding due to a concentration of bright sources.

Shielding due to a bright source or a number of bright sources is probably the prominent instrumental effect in the observed distribution of the sources.

* Taking these considerations to their limit of absurdity, the most uniform results from a survey would be obtained for no background variation. This would require either an aerial with no directivity, a receiver with an infinite noise factor, or a frequency of observation where the background noise is zero. All these factors are opposite to those desirable for obtaining large numbers of sources from a survey.

In the neighbourhood of a bright source, fainter sources cannot be detected owing to the overriding effect of the bright one. The shielding by a bright source of the area round it depends on the shape and size of the aerial beam so that different surveys suffer to different extents. In most cases the shielded area extends all round the bright source but with the sea interferometer the pattern due to a faint source can be distinguished until the bright one appears over the horizon. Thus, with a given aerial, observations over the sea contain only half the shielded area of any other type of observation with the same aerial.

(*b*) *Examination of the Observed Distribution on a Number Basis*

The observed distribution of the sources of this survey is shown in galactic coordinates on an equal-area chart in Figure 3. The brighter sources (with flux densities of greater than 10^{-24} W m^{-2} (c/s)$^{-1}$) are shown as black dots and the

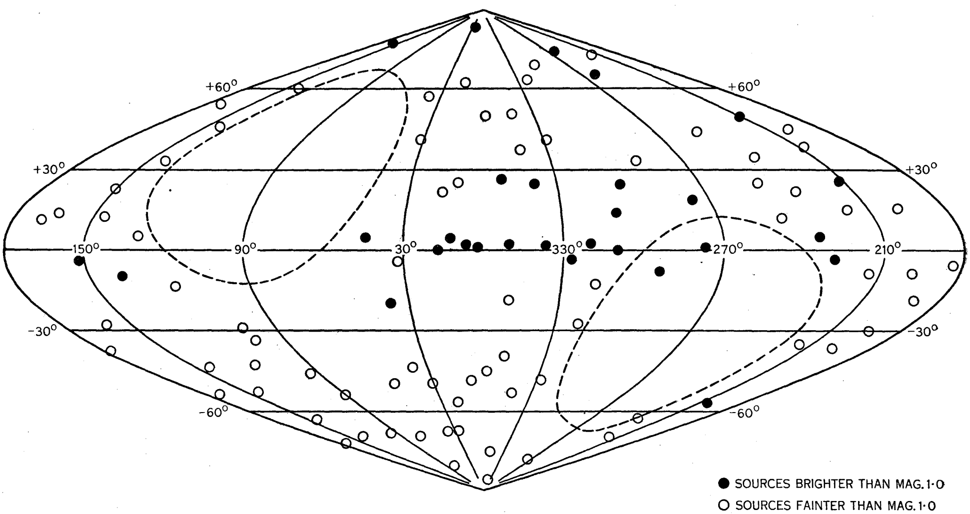

Fig. 3.—The distribution of the sources shown on an equal-area chart in galactic coordinates. The areas enclosed by the dotted lines are north of Dec. 50° and south of Dec. —50°. The black dots are sources whose flux densities are greater than or equal to 10^{-24} W m^{-2} (c/s)$^{-1}$ at 100 Mc/s (i.e. levels greater than or equal to 1·0).

fainter ones as open circles. The dotted lines enclose the circumpolar regions ; the two sources within the south circumpolar area are numbers 27 and 28 which were detected from their high-order fringes (see footnotes to Table 2). Two features stand out in the distribution, the concentration of bright sources to the galactic plane and the concentration of faint sources in the southern polar cap. These concentrations are shown up in Figure 4 (*a*) which gives the number of sources in each of seven equal-area zones bounded by parallels of galactic latitude on each side of the galactic equator. The black rectangles represent the brighter sources. Some correction is necessary to this figure as some of the zones contain different amounts of the circumpolar areas. Correction on an area basis results in Figure 4 (*b*) in which the features of Figure 4 (*a*) are still present in the same marked manner. (This correction can only be done on a number basis and not magnitude and number.) Figure 4 (*c*) is the result for the sources of Mills's survey treated in a similar manner. Our results confirm Mills's finding of a concentration of bright sources to the galactic plane but give it as a concentration both in *number* and *magnitude.* The south polar concentration of faint sources is a new result but should be considered in the light of shielding effects. Figure 4 (*a*) could be considered as showing a relative deficiency of faint sources in low southern latitudes and all northern latitudes. The former might be due to shielding by the effects of the line of bright sources along the galactic equator and the latter by the few bright sources scattered in the northern hemisphere. Shielding in the northern hemisphere could produce the effect observed, but we consider that the relative concentration near the south pole or the relative deficiency of sources in low southern latitudes is too great to be a purely instrumental effect.

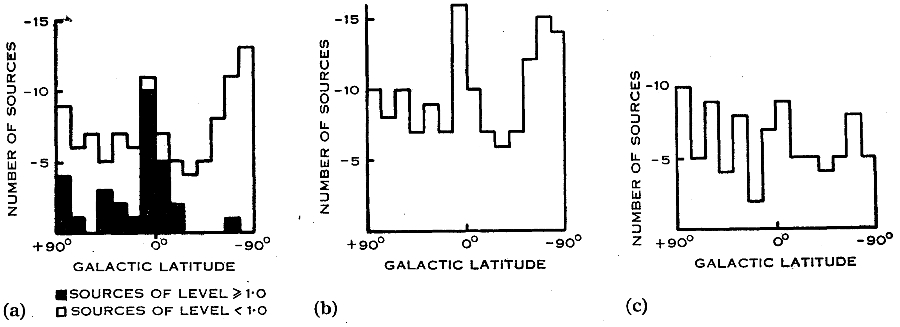

Fig. 4.—The observed distribution of the sources in 14 equal-area zones bounded by parallels of galactic latitude. (*a*) Showing the distribution of the bright and faint sources ; (*b*) as in (*a*) but corrected for the differences in those parts of the zones in circumpolar regions ; (*c*) as in (*b*) for the sources in Mills's list.

(*c*) *Examination of the Observed Distribution in both Number and Level*

Both Ryle, Smith, and Elsmore (1950), and Mills (1952*a*) have investigated the uniformity in the distribution of the sources by considering the relation between the number of sources greater than a certain level and that level. The method is similar to that used in testing the spatial uniformity of extragalactic nebulae. It can easily be shown that for a homogeneous isotropic distribution of sources of the same absolute magnitude (and for a small dispersion in absolute magnitudes) the logarithm of the number of sources greater than a level L is proportional to $-1 \cdot 5L$ (i.e. $N \propto S^{-3/2}$). Ryle, examining the distribution of some 50 sources, mainly well away from the galactic plane, found just this factor. Mills for a more even sample of the celestial sphere found a factor closer to unity. However, when he divided the sources into those within a zone 24° wide about the galactic equator and those outside, he found a factor of $-0 \cdot 75$ for the former and $-1 \cdot 5$ for the latter. He suggested that for those near the galactic plane, the result pointed to a distribution in a flattened disk and for those outside an isotropic distribution.

We have followed Mills in analysing our results. Various ogives of the log (number of sources greater than level L) against L are shown in Figures 5 (*a*)–(*e*). Figure 5 (*a*) is for all the sources, (*b*) for those within 10° of the galactic plane, (*c*) for the sources outside this zone, and (*d*) and (*e*) for the individual hemispheres outside these zones. The last four are in terms of the number of sources per steradian. For all the sources together the slope of the line is somewhat irregular but has a mean of about unity, in agreement with Mills. For the sources within 10° of the galactic plane the slope is about 0·6, again in agreement with Mills. In the other cases the slopes are much steeper than that required by the isotropic distribution. All the curves show some falling off above a level of 0·75 (near the limit of the survey) which is to be expected. The result for the individual hemispheres outside the equatorial zone means that there are more *faint* sources

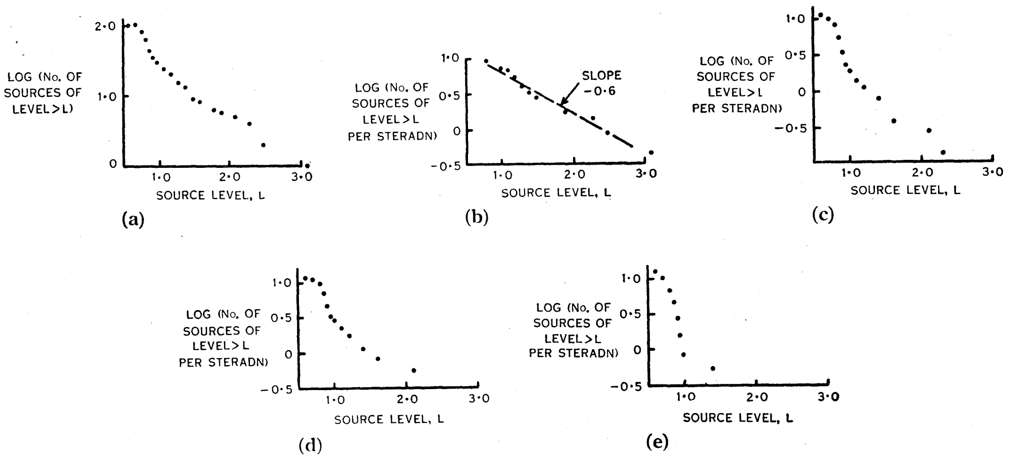

Fig. 5.—Ogives showing the relation between the number of sources greater than a certain level and that level. (*a*) 104 sources of the survey ; (*b*) 21 sources within a zone 20° wide about the galactic equator ; (*c*) 83 sources outside the zone of (*b*) ; (*d*) 40 sources north of the equatorial zone ; (*e*) 43 sources south of the equatorial zone. In (*b*)–(*e*) the ordinates are in terms of the number of sources per steradian.

than would fit in with the idea of the uniform distribution. Correction of the results for the effects of shielding would enhance this trend in the distribution rather than destroy it. Our survey and that of Mills have both approximately the same sensitivity limit ; it is clear that with the higher aerial resolving power the additional sources that have been discerned are mainly faint sources and this has made the difference in the results for the area outside the zone about the galactic equator.

VI. Discussion

The results of this survey have (1) offered the possibility of some further identifications of sources with visible objects, principally extragalactic nebulae, and (2) raised interesting points on the distribution of the sources. The latter would appear to warrant some further discussion.

Firstly, the distribution indicates, as Mills has suggested, a concentration of the bright sources to the galactic plane and, as Brown and Hazard have found, an overall concentration of the sources towards low galactic latitudes. The concentration of bright sources shown by either Figure 3 or Figure 4 (*a*) is relatively independent of the flux density limit arbitrarily chosen (10^{-24} W m^{-2} $(c/s)^{-1}$) ; of the 30 brightest sources, 14 are within 5° of the galactic equator. If the limit is made 1·5 units, 11 out of the 18 are within 5° of the galactic equator ; if it is 2·0 units 8 out of the 15 sources are within this zone. The overall concentration shows up in Figure 4 (*b*) where the number of sources only is considered and, in addition, it must be remembered that correction for shielding due to the presence of a large proportion of relatively bright sources would have the effect of increasing the total number in the zone about the equator. Of the sources in this zone it is also noticeable that most of them are round the direction of the galactic centre ; there are nine sources within $\pm 50°$ of longitude 330° compared with only three within $\pm 50°$ of longitude 150°. The concentration of the sources may thus be twofold, towards the equator and more particularly towards the direction of the galactic centre.

There is also an apparent concentration of sources near the south galactic pole, which does not appear to be due to instrumental effects. For both galactic hemispheres there seem to be too many faint sources compared with an isotropic distribution of objects of all about the same absolute brightness ; this again is not believed due to instrumental selection for correction for this would increase the trend of the results. A plausible explanation is that the Sun (if these sources are galactic) or the Galaxy (if the sources are extragalactic) is in a local region of low source density and that somewhere towards the limit of the survey we reach a region of much higher density. Such deviations from uniformity are frequently observed in the statistics of the distribution of extragalactic nebulae—where objects in a large cluster influence the results at a certain stage. However, there is not much point in speculating too far on this result as it could also be produced by a large dispersion in absolute magnitudes amongst the sources of the survey.

VII. References

Baade, W., and Minkowski, R. (1954).—(in press.)
Bolton, J. G., and Slee, O. B. (1953).—*Aust. J. Phys.* **6** : 420.
Bolton, J. G., Westfold, K. C., Stanley, G. J., and Slee, O. B. (1954).—*Aust. J. Phys.* **7** : 96.
Brown, R. H., and Hazard, C. (1953).—*Mon. Not. R. Astr. Soc.* **113** : 123.
Mills, B. Y. (1952*a*).—*Aust. J. Sci. Res.* A **5** : 266.
Mills, B. Y. (1952*b*).—*Aust. J. Sci. Res.* A **5** : 456.
Mills, B. Y. (1952*c*).—*Nature* **170** : 1063.
Ryle, M., Smith, F. G., and Elsmore, B. (1950).—*Mon. Not. R. Astr. Soc*, **110** : 508.
Shain, C. A. (1954).—*Aust. J. Phys.* **7** : 150.
Shain, C. A., and Higgins, C. A. (1954).—*Aust. J. Phys.* **7** : 130.
Stanley, G. J., and Slee, O. B. (1950).—*Aust. J. Sci. Res.* A **3** : 234.