RESULTS OF A SURVEY OF GALACTIC RADIATION AT 38 Mc/s

J. H. Blythe

(Communicated by F. Graham Smith)

(Received 1957 July 19)

Summary

A pioneer realization of a new aerial principle has produced a contour map of the sky at 38 Mc/s with a resolving power of about $2\frac{1}{2}°$. The list of sources includes a number with appreciable angular diameters which have not previously been recorded. Some results for H II regions are also given. It is suggested that sources Nos. 18 and 24 represent regions where gas, dust, magnetic fields and relativistic particles occur together.

1. *Introduction.*—A survey of the galactic radio emission at a frequency of 38 Mc/s has been carried out using a new form of pencil beam "radio telescope". High resolution was achieved by means of a new interferometric technique which has been described in a previous paper (**1**), referred to here as Paper I. The results are presented in the form of a contour map (Fig. 1) together with a list of reliably observed sources and features (Table I). Some details of the observations are given in Section 2; the remaining sections comment briefly on the main features revealed by the survey.

2. *Details of the observations.*—The observations cover most of the sky north of declination $-20°$. Some areas have been omitted where the results are untrustworthy due to the proximity of intense sources, so that the total area covered by the map in Fig. 1 is about half the celestial sphere. The width of the beam to half intensity points is $2°\cdot2$ in the east-west direction, and in the north-south direction it varies according to the zenith angle from $2°\cdot3$ at declination 52° to $7°\cdot4$ at declination $-20°$. The observations were made from June to December, 1955.

The temperature plotted in Fig. 1 is the synthesized aerial temperature $T'(\sin\theta)$ obtained by means of equation (5) of Paper I (where θ is the zenith angle). It is equal to the aerial temperature that would be measured with a conventional pencil-beam instrument having the above beamwidth, and will be referred to as aerial temperature, or T_a.

The uncertainties in the map of the sky require careful consideration with the new type of aerial. Reference should be made to Paper I for details, but in the present map we may expect the following type of error:—

(i) At any point there may be a random error in the background temperature of about 200 deg. K.

(ii) Individual intense sources produce spurious features at positions with the same time of transit (approximately along hour circles through the sources) and also on a locus through the star passing round the pole (near the source this locus lies roughly on a line of constant declination). These spurious features will appear with about 4 per cent of the intensity of the source itself.

TABLE I

No.	Position (1950) R.A. h	m	Dec. °	Aerial temperature T_a (deg. K).	Size	Flux density w.m^{-2} (c/s)$^{-1}\times 10^{26}$	
1	00	03	−16	3000	3° × P	350	
2	00	33	− 1	2000	P	150	2C50
3	00	35	−10	5000	$2\frac{1}{2}$° × $2\frac{1}{2}$°	480	An extension joins to No. 1.
4	00	40	40	2000	3° × 3°	390	IAU00N4A
5	00	53	$26\frac{1}{4}$	2000	P	150	2C72
6	00	54	$-1\frac{1}{2}$	1500	P	110	2C73 Superposed on extended feature
7	01	05	$-13\frac{1}{2}$	3500	5° × P	600	
8	01	05	$13\frac{1}{4}$	2000	P	150	2C94 Superposed on larger source
9	01	12	36	1700	2° × $2\frac{1}{2}$°	200	2C99
10	01	21	$-1\frac{3}{4}$	1500	P	110	2C122
11	01 to 02	30 to 55	3 to 5	~3000	21° × 6°	~3000	
12	01	34	$20\frac{3}{4}$	2000	$1\frac{1}{2}$° × $1\frac{1}{2}$°	150	
13	02 to 02	00 to 45	$7\frac{1}{2}$ to 15	~2000	11° × 6°	~ 900	
14	03	00	$15\frac{1}{2}$	2000	3° × 1°	210	
15	03	15	$41\frac{1}{2}$	5000	$\frac{1}{2}$° × P	365	IAU 03N4A
16	02 to 03	40 to 20	60 to 55	~2000			Structure along gal. equator, $l=105° \rightarrow 112°$
17	03 to 04	45 to 10	47 to 51	~2000			Along gal. equator, $l=116° \rightarrow 120°$
18	03 to 05	30 to 30	9 to 19	~4000	P × 5°		BWSS–B; possibly Belt A
19	03	58	$10\frac{1}{2}$	2000	P	150	2C349 Superposed on larger source
20	04	14	$38\frac{1}{2}$	3000	P	220	2C379
21	04	33	$29\frac{1}{4}$	6500	P	480	IAU 04N3A
22	04	56	46	5500	3° × $1\frac{1}{2}$°	440	IAU 04N4A
23	05	00	38	5000	P	370	2C440
24	05	40	1	~3000	10° × 5°	~1300	BWSS–D
25	06	02	15	2500	$2\frac{1}{2}$° × $2\frac{1}{2}$°	320	Along gal. equator $l=160° \rightarrow 164°$
26	05	51	26	2500	P	180	
27	06	03	$-8\frac{1}{2}$	~8000	$2\frac{1}{2}$° × P	~ 300	2C520
28	06 to 08	00 to 00	15 to 20	~2500			Belt A
29	06	14	$22\frac{1}{2}$	9500	P	730	IAU 06N2A
30	06	24	$-6\frac{1}{2}$	3000	P	220	2C553
31	06	42	$-6\frac{3}{4}$	~4000			Along gal. equator $l=184° \rightarrow 187°$
32	07	12	$-15\frac{1}{2}$	~2000			$l=194° \rightarrow 197°$
33	07	20	−8	5000	3° × P	520	
34	08	07	$48\frac{1}{2}$	2800	P	200	IAU 08N4A
35	08	17	$4\frac{3}{4}$	2000	2° × 4°	270	

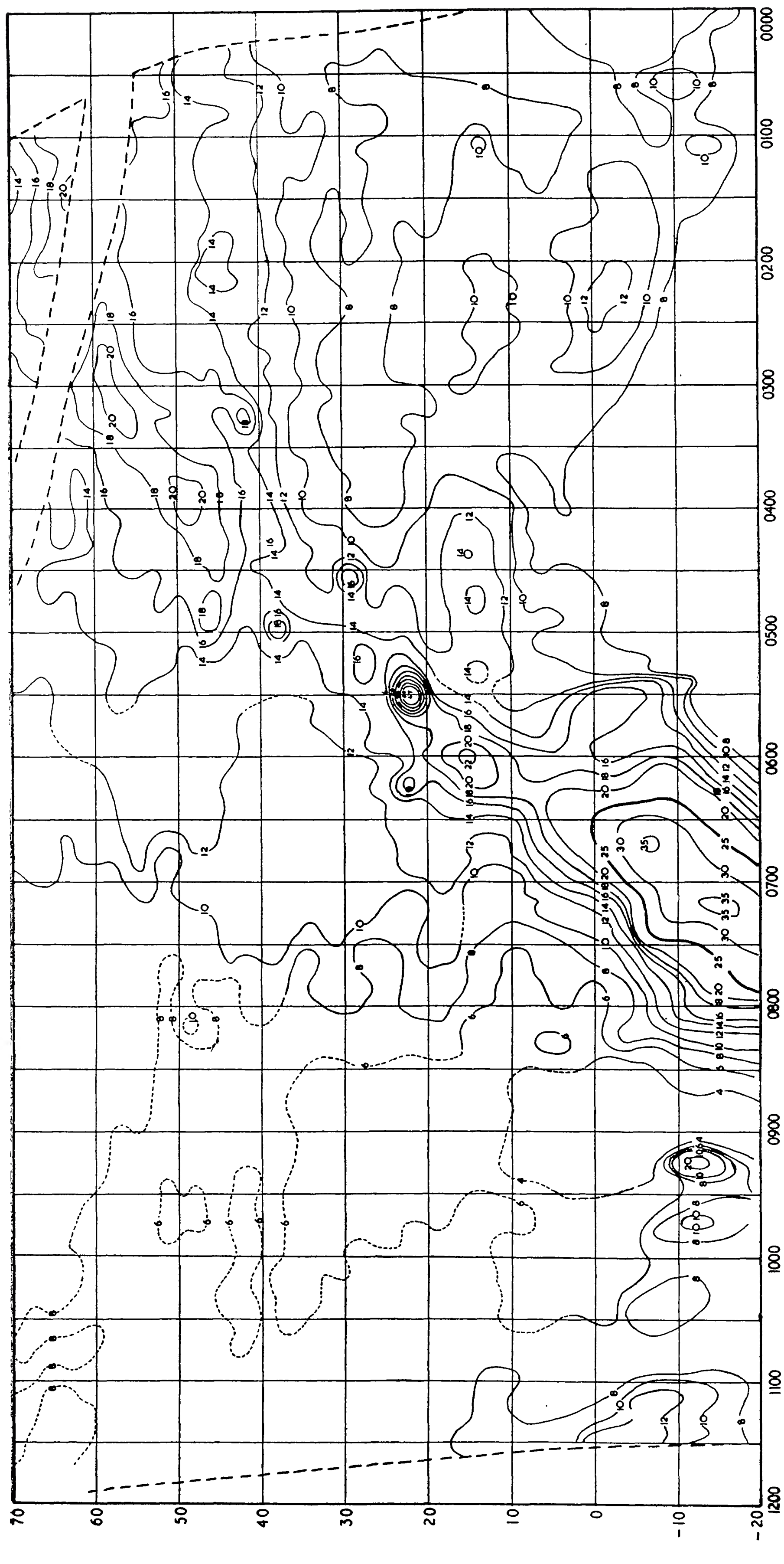

FIG. 1.—*Galactic radio emission at 38 Mc/s (each unit represents 1000 deg. K).*

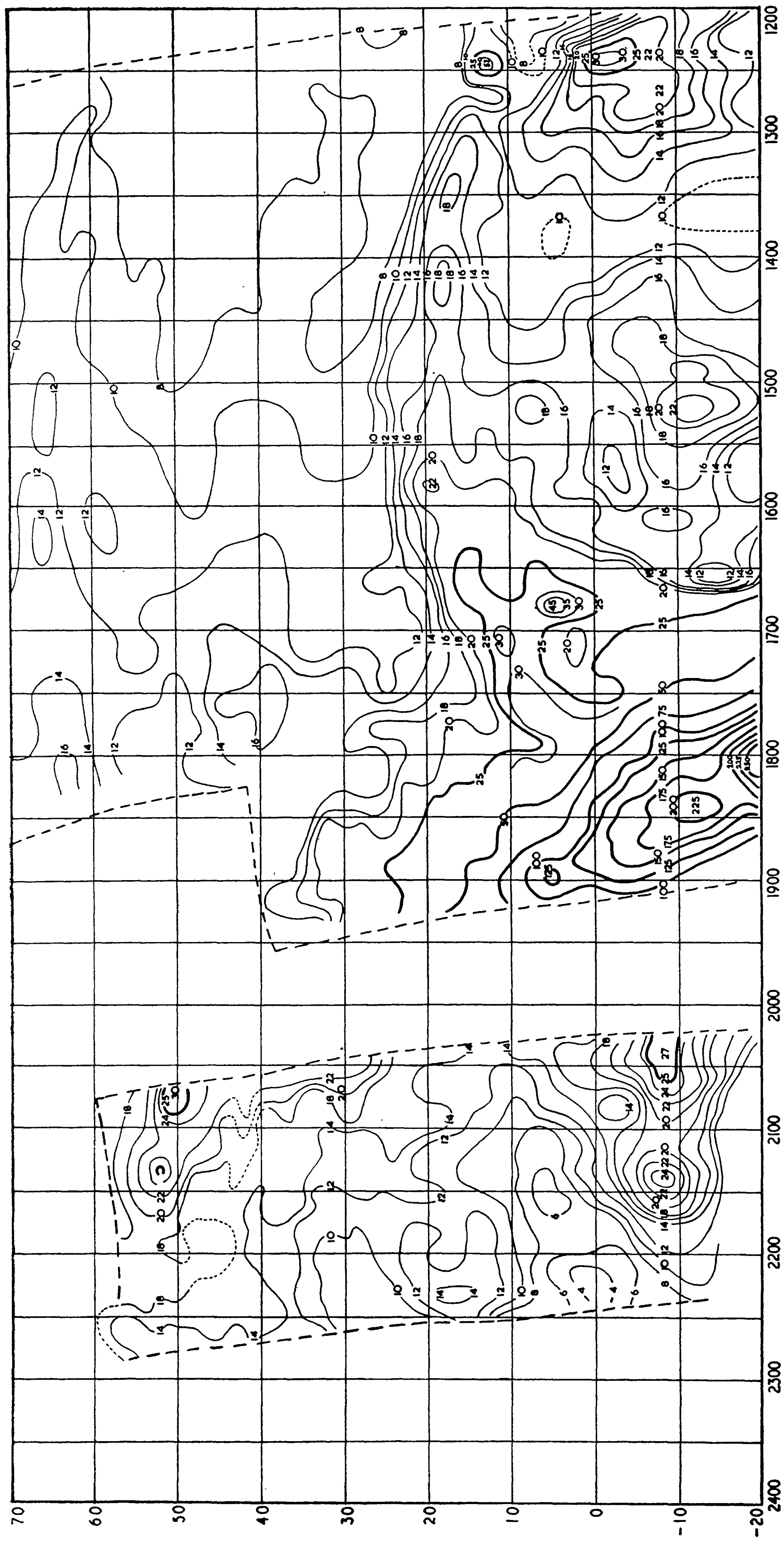

FIG. 1.—*Galactic radio emission at 38 Mc/s (each unit represents 1000 deg. K).*

TABLE I—(*Continued*)

No.	Position (1950) R.A. h	m	Dec. °	Aerial temperature	Size	Flux density w.m⁻² (c/s)⁻¹ × 10²⁶	
36	09	14	−13	19000	P	1400	IAU 09S1A; S 09−1
37	09	18	45½	1700	P	130	2C805
38	09	40	14	2000	4° × 2½°	300	
39	09	43	−12½	4500	2½° × 8°	900	
40	09	43	8	1700	P	130	2C843
41	09	59	28	2000	P	150	2C855
42	10	05	19	2000	3° × 4½°	400	
43	10	22	− 8	4500	7° × 8°	1700	S 10−1
44	10	47	16½	2000	3° × 3½°	270	S 10+1
45	11	12	− 6¾	2500	1° × P	180	
46	12	25	− 2¼	14000	2° × P	1100	
47	12	36	− 2½	~7000	10° × 11°	~5100	BWSS–H; S 12−0
48	12	32	−12½		1° × 1°		
49	12	57	46½	2000	P	150	IAU 12N4B
50	12	57	−17	~6000	3° × P	630	2C1073
51	13	00	6	3000	2½° × 2½°	350	
52	13	03	− 2½	2500	2° × P	200	
53	14	10	52½	2000	P	150	IAU 14N5A
54	13 16 17	00 to 00 53 to	15 20 4		width 6° to 20° length >90°		Belt A
55	14	43	− 4	5000	7° × 7°	1700	
56	14 16	30 to 50	65 66	3000			Belt B
57	15	01	26	~3000	P	~220	2C1259
58	15	12	7½	4000	P	300	IAU 15N1A
59	15	13	−12	7000	3° × 6°	1300	S 15−1
60	15	38	13	~1500	4° × P	180	2C1315 } Structure of Belt A
61	15	40	8	2000	2° × P	180	} Structure of Belt A
62	16	01	1½	3000	P	220	2C1359
63	16	07	− 6	2000	P × 15°	490	
64	16	24	8	2000	2° × P	220	2C1390
65	16	27	39¾	2500	P	180	2C1402
66	16	35	15	4000			Structure of Belt A
67	16	48	5	21000	P	1600	IAU 16N0A
68	17	04	11½	3000	2½° × P	300	2C1454
69	17	16	− 1	8000	P	600	2C1473
70	17	52	− 8	20000	3½° × 4°	3200	
71	18	24	−11¾	50000	3° × 3°	6000	
72	18	30	9½	8000	2½° × P	900	
73	18	54	14½	6500	1½° × P	520	
74	18	58	5½	28000	3° × 2°	3000	2C1607
75	20 22	10 to 20	−7½ −12½	~10000			Belt A. Includes S 21−1
76	20	30	− 7½	4000	6° × P	620	Structure on Belt A
77	20	42	6½	2500	2° × P	240	2C1716
78	20	44	50½	8000	P × 2°	800	2C1725
79	20	47	30	4500	1° × 1°	380	
80	21	20	52	2500			Along gal. equator $l=61°$
81	21	24	− 8	3000	2½° × P	330	Structure of Belt A
82	22	20	17	4000			Complicated object.

The intense sources IAU Nos 05N2A, 12N1A, 19N4A, 23N5A which were used as calibration sources have been omitted from this list.

The sizes are given East–West diameter first, then North–South diameter. P indicates there is no detectable broadening of the polar diagram.

(iii) The individual "side-lobes" of numerous sources of relatively small intensity combine to give a random disturbance of the true distribution. Some features of small angular diameter with aerial temperature up to 500 deg. K, and some larger features up to 700 deg. K, may derive from this experimental error.

It will be seen that with the adopted contour interval of 2000 deg. K appreciable errors can occur in the map due to effects (ii) and (iii). Contours which are uncertain because of the effect of the bright parts of the Galaxy or intense discrete sources are shown dashed. Some sources of low surface brightness do not show clearly on the map, but Table I includes any such sources which appear to be reliable.

3. *Galactic Structure*

3.1 *Halo distribution.*—Westerhout and Oort (2) have drawn attention to the considerable amount of radiation from high galactic latitudes. It has been shown by Baldwin (3) that most of this radiation originates in a spherical halo round the Galaxy. Inspection of Fig. 1 in relation to the model given by Baldwin (3) has shown that this component accounts for most of the radiation at 38 Mc/s from high galactic latitudes.

3.2. *Galactic plane.*—In examining the radiation from regions within about 15° of the plane we may bear in mind that at higher frequencies it has been associated with several different types of source. Thus Westerhout and Oort (2) suggested a source distributed in the same way as mass in the Galaxy. Ionized hydrogen is observed optically within about 2° of the galactic equator, and may be expected to produce a narrow band of emission at high frequencies, and absorption at low frequencies. Ryle and Scheuer (4) observed such a band of emission at 80 Mc/s and 210 Mc/s, but the position may be complicated by the presence of non-thermal sources concentrated near or towards the plane (5).

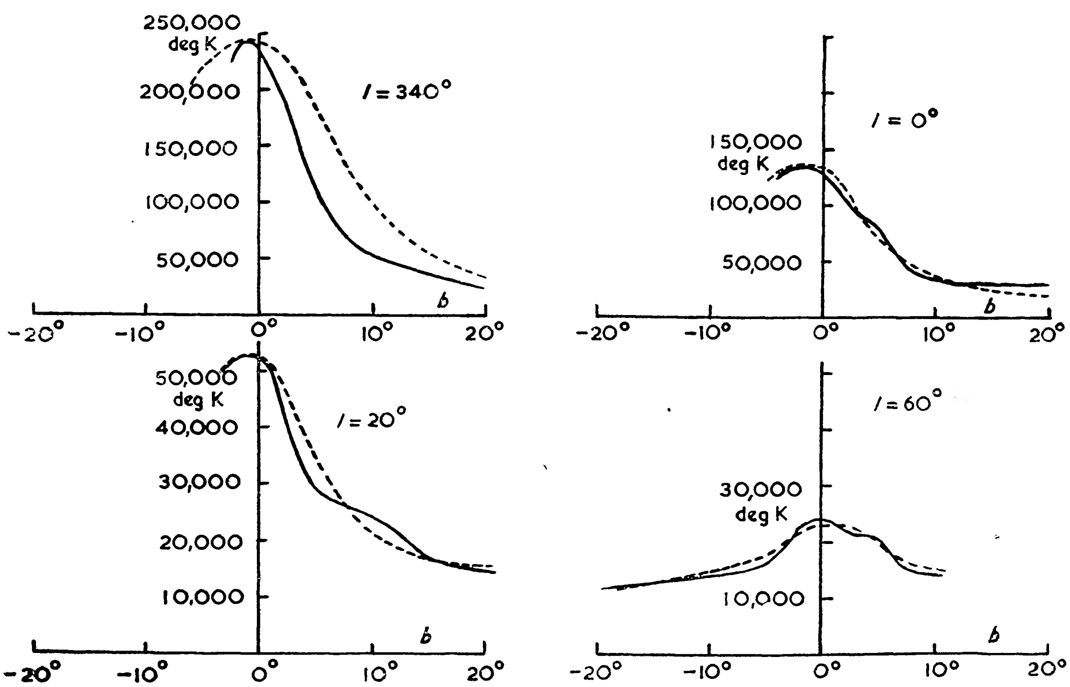

FIG. 2.—*Sections across the galactic equator. The dashed curve is the profile expected from the halo distribution and a source distributed like mass in the galaxy.*

The absence of a band of absorption in the sections across the galactic equator in Fig. 2 confirms the presence of non-thermal sources, for the total absorption through the Galaxy would be considerable if a large part of the band of emission at higher frequencies were emitted by H II regions.

Profiles expected if the radiation originated in a halo distribution and a source distributed like mass are also shown in Fig. 2, based on the curves given by Westerhout and Oort (**2**). Consideration of Fig. 1 shows that the observed distribution is very irregular. The profiles for the mass distribution have therefore been adjusted, both by applying different intensity scale factors and by different translations in latitude. We note that radiation associated with the galactic plane does extend to latitude 15° at most longitudes.

Since the band of emission is highly concentrated towards the galactic plane, and the radiation comes from distant parts of the galaxy, it may be used to locate the galactic pole. On the basis of a survey at 600 Mc/s, Piddington and Trent (**6**) have derived coordinates $b=89°\cdot1$, $l\sim330°$ relative to the Lund pole, with a solar distance of 56 parsecs. The position of the band varies irregularly about that expected on the basis of the above values, so that the present survey lends support to these coordinates.

3.3 H II *regions*.—H II regions are important in the interpretation of the structure along the galactic equator, and a search was made for individual bright regions which might be observed at 38 Mc/s by their absorption of the background radiation. Fifteen regions observed optically are given in Table II: these lie in the area covered by the present survey and have diameters greater than ½°. Smaller regions do not fill a sufficient fraction of the beam to produce a detectable signal.

Table II

Observations of H II *regions*

R.A. h	R.A. m	Dec. °	Diam.	T_l-T_r units of 1000 deg. K	T_l units of 1000 deg. K	τ	*EM*
02	29	61	3°	0±2	17	<0·3	<1000
03	48	36	2°·4×0°·8	0±1	11	...	...
05	14	34	1°·4 }	1·5	14·5	⩾1	⩾3000
05	16	33	0°·6 }				
05	33	11	6°·8	2	13	⩾1	⩾3000
06	33	7	1°·2	0±1	16	...	...
05	34	−6	12°×7°·2	0±1	15	<0·2	< 600
07	05	−11	3°×2°·5	2	33	0·09	300
16	36	−10	10°	7	22	0·6	1800
18	13	−12	1°·5 }	22	180	0·4	1300
18	14	−17	0°·8 }				
18	16	−12	1°·4 }				
18	16	−14	1°·1 }				
18	18	−16	0°·9 }				
22	18	55	1°·5	0±1	19	<0·3	<1000

Optical data were compiled from:

Bok, Bester and Wade, *Daedalus*, **86**, 9, 1955.
Gum, *Mem. R.A.S.*, **67**, 155, 1955.
Sharpless, *Ap. J.*, **118**, 362, 1953.
Sharpless and Osterbrock, *Ap. J.*, **115**, 89, 1952.

Five regions of low brightness appear in the survey: ten of the fifteen H II regions are contained in these regions, some containing more than one H II region owing to the limitation of resolving power. The remaining five regions were not detected.

Details of the regions appear in Table II. T_r is the aerial temperature observed in the direction of the region, and T_l is the aerial temperature observed in local directions. If we assume that T_l is the temperature that would be observed in the absence of the region, then $(T_l - T_r)$ is the reduction of aerial temperature caused by the region. If we make the further assumption that each region is a uniform sphere with angular diameter given by the optical results, then the fraction of the beam which is filled can be calculated. Hence the total absorption or optical depth of the region may be found if its temperature is known; in all cases the theoretically expected value of 10 000 deg. K was taken. By this means limits may be placed on the emission measure, *EM*, which is proportional to the optical depth. The emission measure is defined by

$$EM = \int N_e^2 \, ds$$

where the distance s is measured in parsecs, and the electron density N_e is the number per cc. Values of emission measure derived in this way are given in Table II.

4. *Localized sources.*—For those sources in Table I which have been observed previously the relevant survey numbers are shown. The area covered by the survey of radio stars of Shakeshaft, Ryle, Baldwin, Elsemore and Thompson (**7**, referred to here as 2C) includes the area of the present survey, and stars down to a low sensitivity limit were detected. Comparison of the two surveys provides a check on the expected sensitivity limit. In view of the effect (iii) described in Section 2, there will be spurious stars of size about 500 deg. K, so that stars of aerial temperature less than 1700 deg. K have been ignored except for three at 1500 deg. K which agree with other surveys. An aerial temperature of 1700 deg. K with the present aerial corresponds to a flux of 75×10^{-26} mks units at 81·5 Mc/s, assuming an average spectral index of $-0·7$. There are 40 stars in the 2C list, with flux densities greater than this value, which lie in the area covered by the present survey. Of these 30 have been detected, and 4 lie in areas of the sky where the present sensitivity limit should be increased due to the presence of stronger signals, or lie in complicated regions where identification is difficult. The agreement is therefore 80 per cent.

A number of the sources in Table I give records which are appreciably wider than the natural beamwidth. This broadening enables an estimate to be made of the source diameter at half intensity, if it is assumed to have a particular shape; values assuming a Gaussian source shape are shown in Table I. For diameters less than 3° the broadening produced is small and the values are correspondingly inaccurate.

A short list of broad sources was given by Bolton, Westfold, Stanley and Slee (**8**). Four lie in the area covered by the present survey and all appear in Table I. From the results of a pencil beam survey Shain and Higgins (**9**) recorded eight sources in the area of the present survey, of which seven agree. The other, S12–1, may possibly have been a blend of sources in a complex region which is now resolved.

Since individual galaxies have been identified as radio sources it is of interest to see if any of the broad sources originate in clusters of galaxies. Shane and Wirtanen (**10**) have given a contour map of the number of galaxies per unit area. This shows clustering, but the coincidences between the radio sources and the clusters are not significant.

The present survey has revealed new structure in the extended feature denoted as Belt A in Table I (e.g. Nos. 18, 28, 54 and 75). Baldwin (**11**) has pointed out that this belt extends roughly round a great circle, and the present survey also shows an enhancement of radiation where this belt cuts the galactic equator at $l = 162°$ (No. 25).

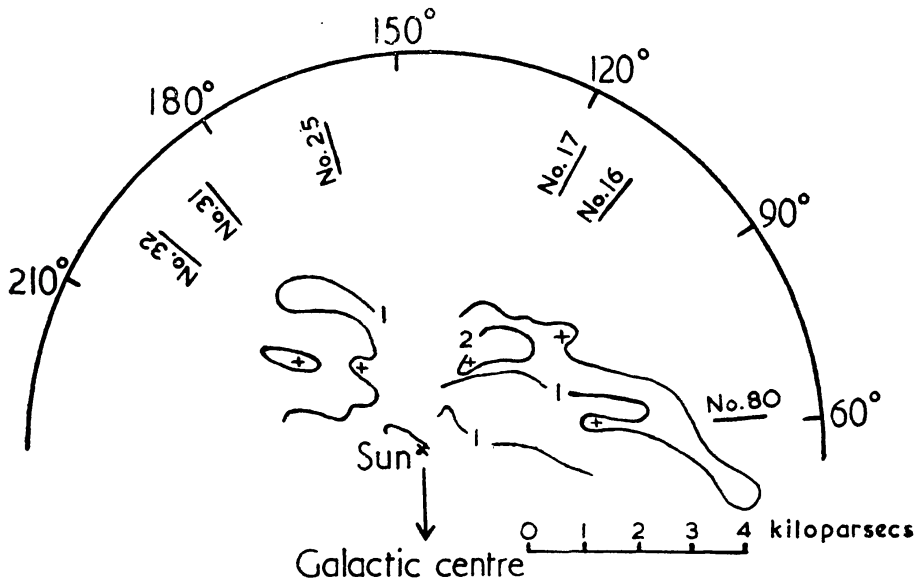

FIG. 3.—*Comparison of sources of* 38 *Mc/s close to the galactic plane and the distribution of* H I *emission. Radiants represent the directions of sources: irregularities in* H I *distribution have been marked with crosses.*

A number of the large diameter sources in Table I (e.g. Nos. 16, 17, 25, 31, 32, 71, 74 and 80) lie closely along the galactic plane, and possibly represent large scale irregularities in emission rather than localized sources. Radiants representing these sources have been plotted in Fig. 3, together with contours of the distribution of the H I emission in the galactic plane as derived by Van de Hulst, Muller, Oort (**12**). The H I contours show structure in the two large spiral arms, and an attempt has been made to distinguish the larger irregularities, which have been marked with a cross. There may be a relation between sources Nos. 17, 31, 32 and 80 and such irregularities at distances of 2, 2, 3 and 3 kiloparsecs respectively. The only other source favourably placed for comparison, No. 16, does not coincide with any similar irregularity. However, such a relation can only be regarded as tentative at this stage.

There also appears to be some correlation between the 38 Mc/s radiation and H I radiation from sources considerably away from the galactic plane. Lilley (**13**) has given profiles of peak H I intensity at $l = 147°$ and also at $b = -15°$, and found a correlation with the extinction of extra galactic nebulae. As may be seen from Fig. 4, sources Nos. 18 and 24 also appear on Lilley's profiles, and both lie in or near extensions of the zone of avoidance. For No. 24 the shape at 38 Mc/s is in good agreement with the shape of the extension. Since neither gas nor dust can produce the radiation at 38 Mc/s, we are led to the hypothesis that sources Nos. 18 and 24 represent regions where gas, dust, magnetic fields and relativistic particles occur together, as has been conjectured to be the case in spiral arms.

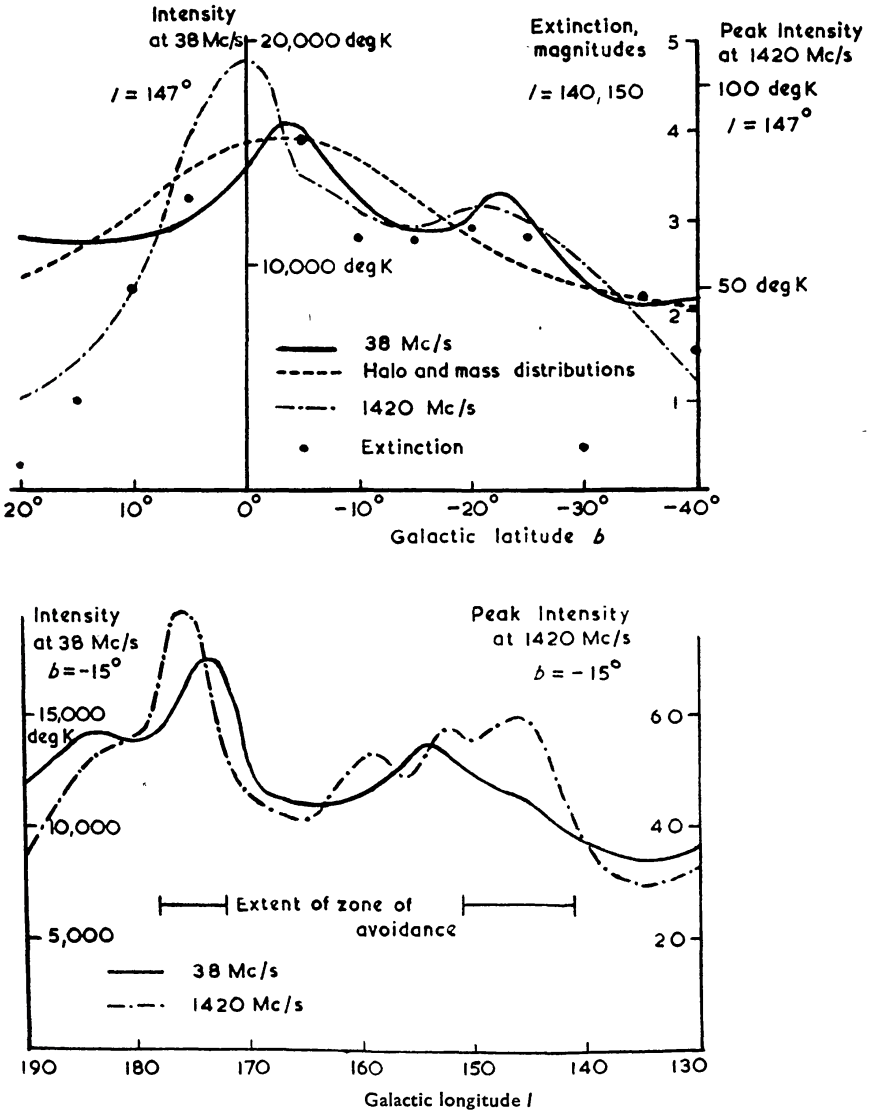

FIG. 4.—*Comparison of distribution at* 38 *Mc/s with peak intensity at* 1420 *Mc/s and with mean total extinction.* (Hubble, *Mt. W. Contr.*, **21**, 139, 1933).

This work was carried out as part of a programme of research at the Cavendish Laboratory supported by the Department of Scientific and Industrial Research, to which I was indebted for a maintenance award. I wish to record my thanks to Mrs J. Sandos who performed most of the analysis, and to Mr M. Ryle and Dr F. G. Smith for invaluable advice and assistance in many ways. In particular the original suggestion was due to Mr Ryle.

Cavendish Laboratory,
Cambridge:
1957 *July.*

References

(1) J. H. Blythe, *M.N.*, **117**, 644, 1957.
(2) G. Westerhout and J. H. Oort, *B.A.N.*, **11**, 323, 1951.
(3) J. E. Baldwin, *M.N.*, **115**, 690, 1955.
(4) M. Ryle and P. A. G. Scheuer, *M.N.*, **113**, 3, 1953.
(5) B. Y. Mills, *Aus. J. Phys.*, **8**, 368, 1955.
(6) J. H. Piddington and G. H. Trent, *Aus. J. Phys.*, **9**, 481, 1956.
(7) J. R. Shakeshaft, M. Ryle, J. E. Baldwin, B. Elsmore and J. H. Thomson, *Mem. R.A.S.*, **67**, Part 3, 1955.
(8) J. G. Bolton, K. C. Westfold, G. J. Stanley and O. B. Slee, *Aus. J. Phys.*, **7**, 96, 1954.
(9) C. A. Shain and C. S. Higgins, *Aus. J. Phys.*, **7**, 130, 1954.
(10) C. D. Shane and C. A. Wirtanen, *Astrom. J.*, **59**, 285, 1954.
(11) J. E. Baldwin, *M.N.*, **115**, 684, 1955.
(12) H. C. Van de Hulst, C. A. Muller and J. H. Oort, *B.A.N.*, **12**, 117, 1954.
(13) A. E. Lilley, *Ap. J.*, **121**, 559, 1955.