A RADIO SURVEY OF THE SOUTHERN MILKY WAY AT A FREQUENCY OF 1440 Mc/s

I. THE ISOPHOTES AND THE DISCRETE SOURCES

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Summary

The 1440 Mc/s isophotes of the Southern Milky Way are presented which were obtained with an aerial beam 50′ of arc at half-power points. The positions and intensities of the discrete sources resolved from the background emission are listed together with their spectral characteristics determined by comparison with the 85·5 Mc/s Mills-Cross survey. Of 74 sources, 54 are found to have spectral indices consistent with the assumption that they radiate thermally. Twelve new identifications of these thermal radio sources have been made with emission nebulae by comparison with the Stromlo Atlas of Hα emission. The remaining twenty sources have nonthermal spectral indices and no new optical identifications have been made. The continuum background emission from the galactic disk is discussed in a second paper.

I. Introduction

Table 1 lists a number of radio surveys of the galactic plane region which have been made over a wide range of frequencies with aerial systems producing pencil beams having half-power widths of approximately one degree. From examination of the 85·5 Mc/s isophotes, Mills (1959) found that a bright band of radiation of width about $\pm 4°$ in latitude exists roughly co-extensive with the visible parts of the Galaxy but more closely concentrated towards the galactic centre. Mills called this component of galactic radio emission, the disk component. The resolution of the surveys was high enough to resolve a number of discrete radio sources distributed along the ridge line of the disk component and closely confined to the galactic plane.

The continuum galactic radio emission is believed to be generated by two processes, commonly called the thermal and nonthermal mechanisms. The radiation produced by these two mechanisms shows quite different spectral characteristics which are discussed in Section V. The thermal radiation increases or remains constant as the frequency increases whereas the nonthermal radiation decreases. Therefore observations of the intensity of the emission at different frequencies have been used by the observers listed in Table 1 to separate the thermal and nonthermal components of the disk radiation and to distinguish between thermal and nonthermal discrete radio sources. Many of the thermal

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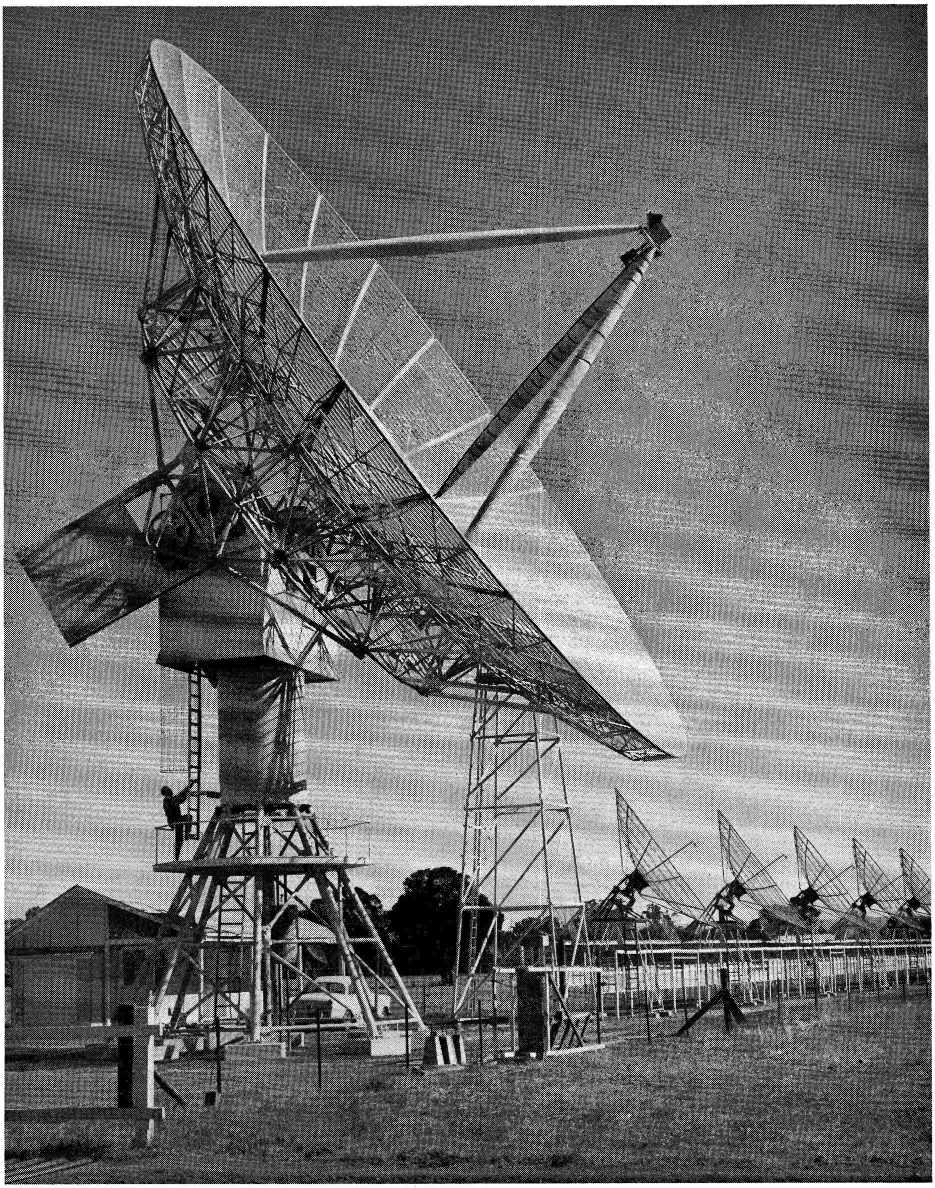
RADIO SURVEY OF SOUTHERN MILKY WAY. I



The 60-ft Kennedy paraboloid at Fleurs Field Station, with the 18-ft paraboloids of the crossed multiple interferometer (Christiansen and Mathewson 1958) in the background.

discrete sources have been identified with Hα emission nebulae (Westerhout 1958) and about a dozen of the nonthermal sources are associated with supernova remnants (Minkowski 1959).

Unfortunately there was a large gap from longitudes 270° to 336° (new galactic coordinate system ; Blaauw *et al.* 1960) where no high frequency information with resolution comparable with that of the other surveys was available. Therefore any determination of the spectral features of the radiation was largely restricted to the Northern Milky Way. However, in November 1960, a 60-ft paraboloid was erected at Fleurs Field Station, near Sydney, and in April–May 1961 this was used at a frequency of 1440 Mc/s to survey a region of the galactic plane from $l^{\mathrm{II}}=258°$ to 0°, $b^{\mathrm{II}}=+9°$ to $-9°$ and so obtain the missing high frequency data for the Southern Milky Way. In the present paper the 1440 Mc/s isophotes are presented and the positions of the radio sources resolved from the background listed together with their spectral characteristics and optical identifications where possible. An attempt to interpret the continuum background emission from the galactic disk is discussed in Part II of this series (Mathewson, Healey, and Rome 1962).

TABLE 1

RADIO SURVEYS OF THE GALACTIC PLANE

Frequency (Mc/s)	Resolution (min of arc)	Longitude Limits (new coordinates)	Observers
19·7	84	258° to 48°	Shain, Komesaroff, Higgins (1961)
85·5	50	256° to 45°	Hill, Slee, and Mills (1958)
408	47	352° to 56°	Large, Mathewson, Haslam (1961)
960	48	336° to 270°	Wilson and Bolton (1960)
1390	34	352° to 90°	Westerhout (1958)
1440	50	258° to 0°	Present survey

II. Equipment

The 60-ft, altazimuth mounted, parabolic reflector (see Plate 1) was fed by a waveguide horn giving a tapered illumination which fell to approximately 10% at the edges of the reflector. The resulting main beam was nearly circular and 50′ of arc between half-power points, while the first side lobe was less than 1% of the main beam.

The receiver was of the comparison type, switching at 400 c/s between the horn and a second horn mounted near the focus but directed away from the reflector. The r.f. switch, crystal mixer, and first i.f. amplifier were mounted together in a box immediately behind the horn, the rest of the receiver was located in a small room directly beneath the dish. The d.c. signal was fed down the tower into a recorder situated in the observation hut at the base of the telescope. The intermediate frequency was 30 Mc/s and, as no image rejection was employed, both sidebands (1410 and 1470 Mc/s) each 5 Mc/s wide, were utilized. The output time constant could be varied from 1 to 8 sec. The stability and sensitivity of the receiver (noise temperature 800 °K) allowed temperature differences to be measured to $\frac{1}{2}$ °K.

III. Temperature Calibration

The general properties of pencil beam aerials have been discussed by Seeger, Westerhout, and van de Hulst (1956) and their procedure has been followed in the measurement of brightness temperatures in this present survey.

They define the "full-beam" directivity $(D')=4\pi/\Omega'$ where the term "full-beam" means the main beam and its near side lobes. The full-beam is enclosed by a circle with diameter five times the half-power diameter of the beam. Ω' is the full-beam solid angle and is defined as

$$\int_{\text{full-beam}} f(\theta,\varphi)\mathrm{d}\Omega,$$

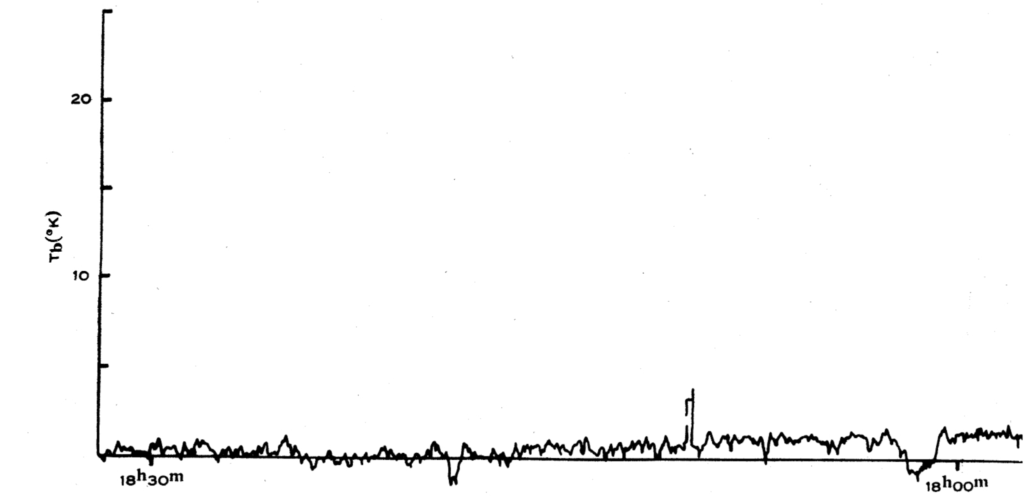
where the power received from a distant unpolarized point source in the direction (θ,φ) is proportional to $f(\theta,\varphi)$, which is normalized by putting $f=1$ at the centre of the beam. The measured excess brightness temperature, ΔT_b, in the direction of the unpolarized point source, is equal to $(\lambda^2/8\pi k)D'S$, where S is the flux density of the source. Hence a point source of flux density $2k\Omega'/\lambda^2$ at the centre of the beam causes an increase of 1 °K in T_b.

The full-beam solid angle (Ω') of the 60-ft paraboloid was measured to be $0\cdot79$ deg^2 from the polar diagram which was obtained from observations of the three well-known radio sources Centaurus A, Crab Nebula, and Virgo A. Therefore an increase of 1 °K in T_b over the "full-beam" is equivalent to an increase of flux density of $15\cdot3\times10^{-26}$ W m^{-2} (c/s)$^{-1}$ at the centre of the aerial beam.

The flux density at 1440 Mc/s of the three standard sources Centaurus A (central part only), the Crab Nebula, and Virgo A was calculated to be 347×10^{-26}, 905×10^{-26}, and 226×10^{-26} W m^{-2} (c/s)$^{-1}$ respectively from their 960 Mc/s flux densities and spectral indices given by Harris and Roberts (1960). Let S_0 denote the flux density of the calibrating sources and ΔD_0 the increase in the recorder deflection above the background deflection when the telescope is directed at the source. Then the excess brightness temperature measured by the aerial beam at a point in the survey region is given by

$$\left(\frac{S_0\lambda^2}{2k\Omega'}\right)\cdot\frac{\Delta D}{\Delta D_0},$$

where k is Boltzmann's constant, λ is the wavelength, and ΔD is the increase in recorder deflection produced at that point above the deflection produced by the region above which the temperatures in the survey region are to be measured. This expression for the measurement of brightness temperatures is not completely accurate because the amount of power in the very wide angle side lobes of the paraboloid may vary depending on their position in the sky. However, if the "reference-regions" above which the temperatures are to be measured lie close to the survey region then this effect should be small.



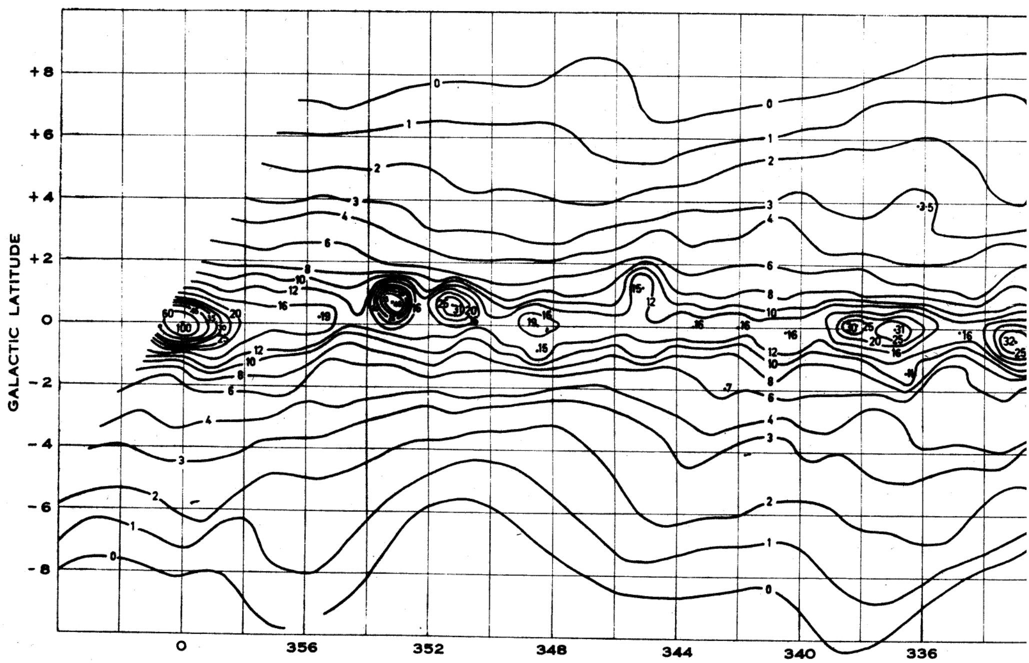


Fig. 2.—The 1440 Mc/s isophotes of the Southern Milky Way obtained with an aerial beam 50′ of
and 60 °K contours have been drawn.

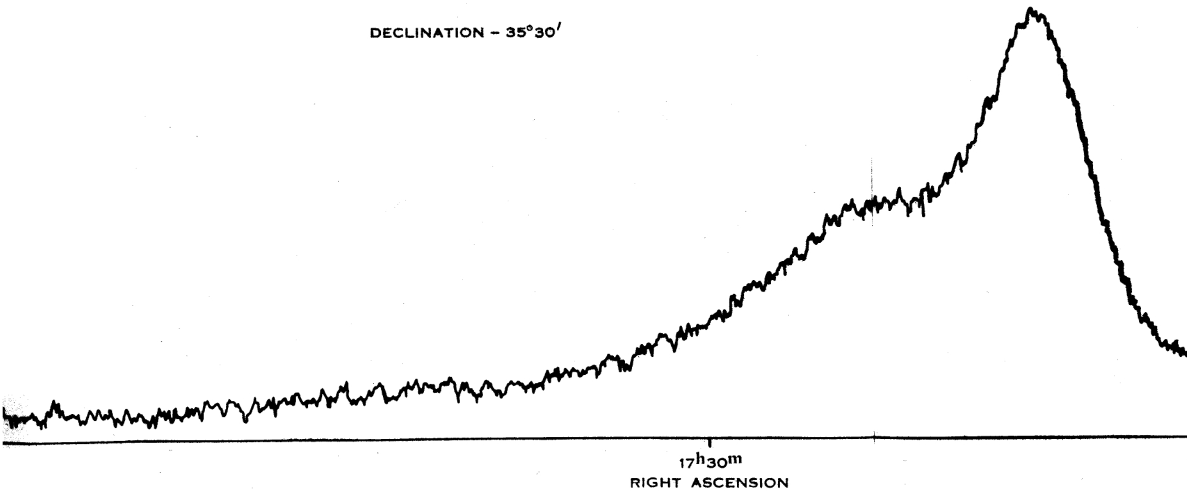
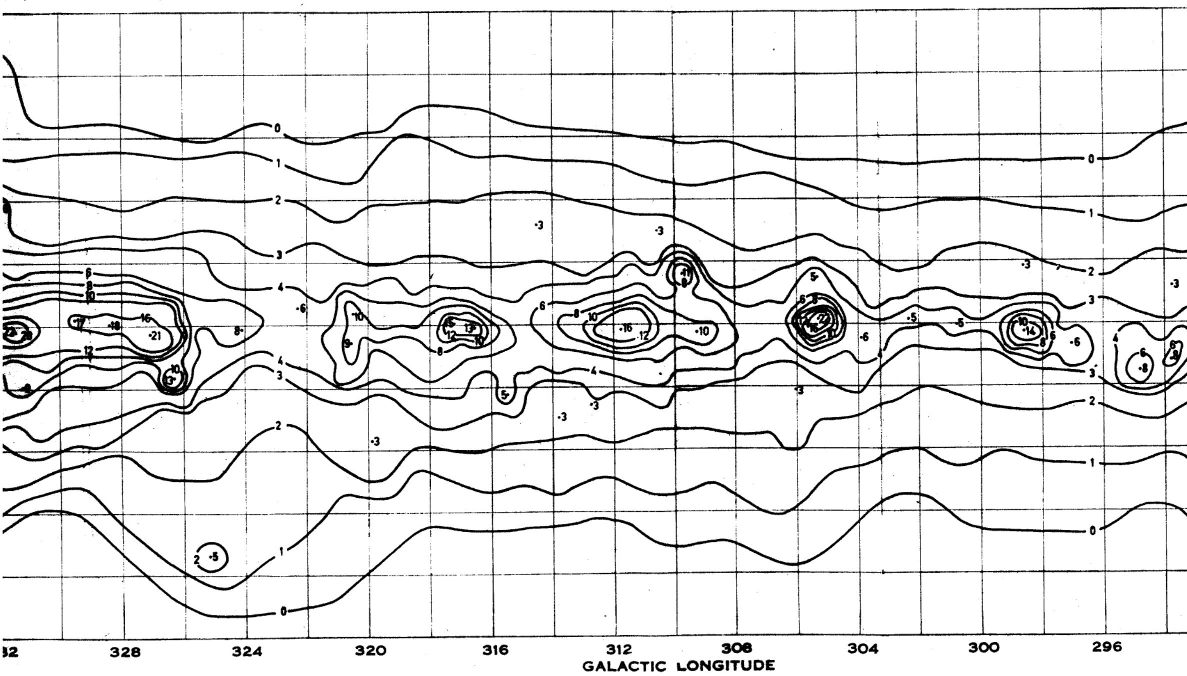


Fig. 1.—A 1440 Mc/s scan at Dec. −35° 30′ across the Milky Way.



arc at half-power points (see shaded area, top right-hand corner). The contour numbers represent the brightness tem
The positions of the discrete sources are marked with dots against which are written the peak brightness temperatu
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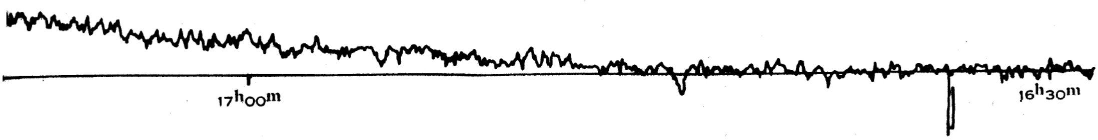

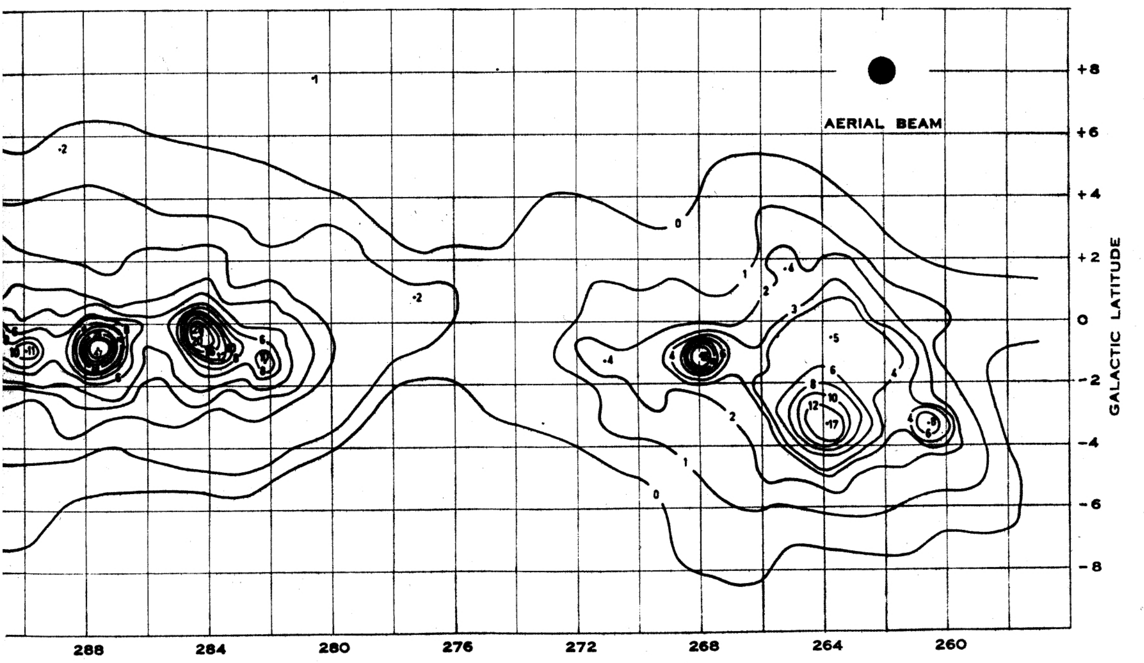

›s in °K above the chosen reference region (Section IV). The 0, 1, 2, 3, 4, 6, 8, 10, 12, 16, 20, 25, 30, 35, 45, he new galactic coordinate system has been used.

IV. Observations

Observations were made at night to avoid interference from the Sun. The positional accuracy of the 60-ft paraboloid was measured to be about 4′ of arc using the three radio sources Centaurus A, the Crab Nebula, and Virgo A. A daily calibration of the system was made by observing at least one of these sources. The receiver sensitivity was checked every few hours by a signal from a standard noise generator fed into the receiver by means of a directional coupler inserted in the cable from the horn feed.

Effects due to variation in ground radiation as the elevation of the telescope was changed were measured by scanning between the zenith and zero elevation across a cold part of the sky. It was found that, provided observations were restricted to elevation angles greater than 35°, variations were less than 1 °K, apart from one sharp step of about 1 °K at 64° elevation. This was allowed for in the reduction of the observations.

The 1390 Mc/s survey by Westerhout (1958) showed that at 10° to 20° from the galactic plane the intensities are uniform to within 1 °K. Several long scans in latitude gave a similar result for the section of the galactic plane covered in the present survey. Also the temperatures of six selected points, whose galactic longitude and latitude positions are 268°, −14° ; 290°, −8° ; 291°, +11° ; 320°, −10° ; 342°, −12° ; and 359°, −15°, were compared and found to be identical within the observational uncertainty of 0·5 °K. The South Pole was about 1 °K colder than the points. The temperatures of these "reference-regions" were used as the zero level of the survey.

The region north of declination −55° and the Vela Puppis region were surveyed by a series of drift scans, that is, constant declination scans separated by half-beamwidth intervals. Figure 1 shows one of these scans at declination −35° 30′. The region between $l^{\mathrm{II}}=277°$ to 338° was surveyed by scanning approximately in galactic latitude at about 1°·5/min using a 1 sec time constant. A trial scan at this speed was first made through Virgo A to ensure that this time constant was short enough so that no positional errors were introduced. The azimuth and elevation of the telescope and the sidereal time were noted at four points on each scan. These data were later fed into the SILLIAC computer of the University of Sydney which produced the galactic longitude and latitude at these check points. Several " tying-down " scans were made approximately at right angles to the latitude scans which allowed the testing of the assigned zero levels by looking for inconsistencies in the intensities of the two sets of scans.

Figure 2 presents the 1440 Mc/s isophotes. The numbers on the contours indicate brightness temperature in °K, above the chosen reference region. In Part II of this series (loc. cit.), a sequel to the present paper, the absolute temperature of the reference region is estimated to be about 1·5 °K. The positions of the radio sources resolved from the background emission are indicated by dots against which are written their peak brightness temperature.

V. The Continuum Spectrum of the Discrete Sources

Figure 3 shows a 1440 Mc/s record obtained by scanning the telescope along a path close to the galactic plane (i.e. $b^{\mathrm{II}}=0$) from $l^{\mathrm{II}}=256°$ to 88°. The variation in intensity of the $85 \cdot 5$ Mc/s radio emission along the galactic plane from $l^{II}=256°$ to $45°$ is also shown in Figure 3. This profile was derived from the $85 \cdot 5$ Mc/s isophotes of Hill, Slee, and Mills (1958). The half-power widths of the aerial beams used in these two surveys were both about $50'$ of arc. The discrete radio sources are clearly seen resolved from the disk emission, which appears as a very broad hump in the radio profiles and is concentrated in the inner regions of the Galaxy symmetrically distributed about the galactic centre.

A number of these radio sources have been identified with Hα emission nebulae (Westerhout 1958) where the ionization of the hydrogen is maintained by the intense ultraviolet radiation of O and B stars. In such nebulae the electron temperature is thought to be usually 10^4 °K (Aller 1953). The emission and absorption of radio waves by the process of free–free transitions in ionized hydrogen has been discussed by Piddington (1951) who concluded that the spectral index of the flux density, α, for these thermal radio sources may range from $+2$ for optically opaque regions to zero for optically thin regions.

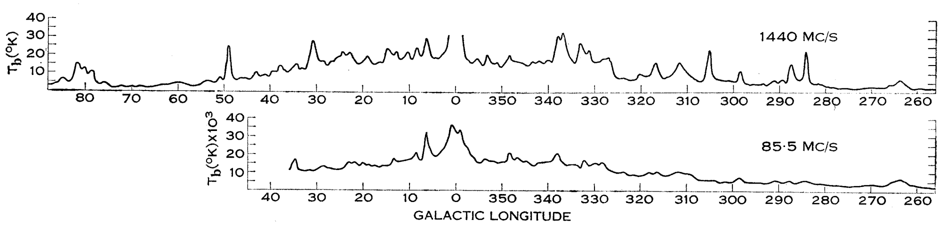

Fig. 3.—The top radio profile shows a 1440 Mc/s record obtained by scanning the 60-ft paraboloid along the galactic plane from $l^{II}=256°$ to $88°$ (new coordinate system). The bottom profile shows the variation in intensity of $85 \cdot 5$ Mc/s radio emission along the galactic plane between $l^{II}=256°$ to $45°$ obtained from the isophotes of Hill, Slee, and Mills (1958).

About a dozen sources have been associated with supernova remnants (Minkowski 1959) which are thought to emit radio waves by a "nonthermal" process which is now believed to be the "synchrotron" mechanism (Shklovsky 1953). Hanbury Brown (1954) and Mills (1959) have suggested that all nonthermal galactic radio sources are remnants of supernovae. The spectral index of flux density of the optically identified nonthermal sources is observed to range between about $-0 \cdot 1$ and $-1 \cdot 0$ (Whitfield 1959), which agrees with that predicted from the synchrotron emission theory. This difference in the spectral indices of the thermal and nonthermal sources is nicely demonstrated in Figure 3, where it is seen that certain sources, which we take to be of thermal origin, appear strongly at 1440 Mc/s (e.g. η Carinae nebula at $l^{II}=287° \cdot 6$) but are very weak or unseen at $85 \cdot 5$ Mc/s whereas the probable nonthermal sources are the more intense at the lower frequency (e.g. $l^{II}=6° \cdot 6$).

The radiation from the disk is thought to be due to the integrated nonthermal emission from the spiral arms of the Galaxy (Mills 1959) and thermal emission from large-scale distributions of ionized hydrogen scattered along the Milky Way (Shain, Komesaroff, and Higgins 1961). Large, Mathewson, and Haslam (1961) have delineated the distribution of the thermal and nonthermal components of the radio emission from the disk for the Northern Milky Way and in Paper II of this series (loc. cit.) the thermal and nonthermal isophotes are presented for the Southern Milky Way.

The discrete source intensities were measured by subtracting the brightness temperature of the disk immediately adjacent to the source from the peak brightness temperature measured in the direction of the source. The ratios of the excess brightness temperatures obtained in this manner at 1440 and 85·5 Mc/s were then used to derive directly a spectral index of brightness temperature and thence the spectral index of flux density for the radio source which is given in Table 2. However, the spectral index determined in this manner is not necessarily the spectral index of the radiation emitted by the source (hereafter referred to as the true spectral index) for it will depend on the amount of absorbing ionized hydrogen between the source and the Earth and, for a thermal source, on the absorption of the background radiation in the source itself (nonthermal sources are assumed not to absorb incident radiation). An attempt has been made below to estimate the magnitude of this effect on the true spectral index of the nonthermal and thermal galactic radio sources.

VI. Nonthermal Sources

The apparent excess brightness temperature of a nonthermal galactic source as measured by the aerial beam at a frequency of 1440 Mc/s is given by

$$\Delta T_{(1440)} = g\overline{T}_{S(1440)} \exp\left[-\tau_{F(1440)}\right], \tag{1}$$

where $\overline{T}_{S(1440)}$ is the mean brightness temperature at the source at 1440 Mc/s, g is the fraction of the aerial beam occupied by the source, and $\tau_{F(1440)}$ is the optical depth of the foreground radiation at 1440 Mc/s (τ is inversely proportional to the square of the frequency). A similar equation holds for 85·5 Mc/s.

The ratio of the observed excess brightness temperature at 85·5 and 1440 Mc/s with aerial beams of similar size is given by

$$\frac{\Delta T_{(85\cdot5)}}{\Delta T_{(1440)}} = \left(\frac{85\cdot5}{1440}\right)^{\beta_t} \exp\left\{\tau_{F(1440)}\left[1-\left(\frac{85\cdot5}{1440}\right)^{-2}\right]\right\}, \tag{2}$$

where β_t is the true spectral index of brightness temperature for the source. (The true spectral index of flux density for the source $\alpha_t = \beta_t + 2$.) It is interesting to note that if observations at a third, intermediate frequency were available then in principle β_t and $\tau_{F(1440)}$ could be calculated and, if the large-scale distribution of ionized hydrogen in the Galaxy were known, then the distance of the radio source could be estimated.

It may be shown using equation (2) that the true spectral index (α_t) of the radio source will differ from the measured spectral index (α_m) by an amount

$$\alpha_t - \alpha_m = \frac{\tau_{F(1440)}\left[1-(1440/85\cdot5)^2\right]}{\log_e(1440/85\cdot5)}, \tag{3}$$

that is,

$$\Delta\alpha \approx -100\tau_{F(1440)}.$$

Results, which are presented in Part II of this series, show that the integrated optical depth of the extended regions of ionized hydrogen along any direction in the Galaxy is unlikely to exceed $0\cdot001$ at 1440 Mc/s. Therefore $|\Delta\alpha|$ should in general be less than $0\cdot1$, which is about the order of accuracy of the spectral-index measurements. Hence it is reasonable to neglect the effect of foreground absorption on the spectral-index measurements of nonthermal sources. It should be noticed that the effect of foreground absorption is always to make the radio source appear " more thermal ". Therefore the sources which are classified in Table 2 as nonthermal on the basis of their measured spectral indices being equal to or less than $-0\cdot2$ are correctly classified irrespective of the amount of foreground absorption.

VII. Thermal Sources

The apparent excess brightness temperature (ΔT) of a thermal galactic source as measured by the aerial beam at a frequency of 1440 Mc/s is given by

$$\Delta T_{(1440)}=g\{T_e-T_{B(1440)}\}\{1-\exp[-\tau_{S(1440)}]\}\exp[-\tau_{F(1440)}], \tag{4}$$

where g is the fraction of the aerial beam occupied by the source, $\tau_{F(1440)}$ is the optical depth of the foreground material at 1440 Mc/s, $\tau_{S(1440)}$ is the optical depth of the source at 1440 Mc/s, T_B is the brightness temperature of the radiation originating behind the source at 1440 Mc/s, and T_e is the electron temperature in the source which is assumed to be 10^4 °K. Equation (4) shows that if T_B is comparable with T_e then the excess brightness temperature measured in the direction of the source is small, and indeed it will appear in absorption (as a negative source) if T_B is greater than T_e. The temperature of the disk component increases rapidly as the frequency decreases (see Fig. 3), and therefore the ratio of observed excess brightness temperature of the source as measured by the aerial beams at $85\cdot5$ and 1440 Mc/s and hence the measured spectral index will depend markedly on the position of the thermal source in the Galaxy and its distance from the Earth. It will also depend critically on the electron temperature assumed for the ionized gas in the source. It may be shown that the true spectral index of the source (α_t) will differ from the measured spectral index (α_m) by an amount

$$\alpha_t-\alpha_m=\frac{\log[T_e-T_{B(85\cdot5)}]-\log[T_e-T_{B(1440)}]}{\log(1440/85\cdot5)}-100\tau_{F(1440)}. \tag{5}$$

If the effect of foreground absorption, which has been shown to be small, is neglected and if it is noted from inspection of the 1440 Mc/s isophotes (Fig. 2) that $T_{B(1440)}$ will always be less than 20 °K, which is small compared with the electron temperature of 10^4 °K, then

$$\Delta\alpha\approx\frac{\log[10^4-T_{B(85\cdot5)}]-4}{1\cdot2}. \tag{6}$$

The brightness temperature of the disk along the galactic plane at $85\cdot5$ Mc/s varies from a few 1000° at $l^{\text{II}}=256°$ to 16,000 °K towards the galactic centre. The magnitude of $\Delta\alpha$ will then depend on the galactic longitude and latitude of the source and its distance from the Earth, the effect being the greatest for the nearby sources in the inner regions of the Galaxy.

The temperature of the disk immediately adjacent to the discrete source has been noted for each source in Table 2 and $\Delta\alpha$ calculated on the assumption that the source is situated in the foreground (i.e. $T_B = T_{(\text{disk})}$), which of course will give the maximum value of $\Delta\alpha$ possible for that particular direction in the Galaxy. These values of $(\Delta\alpha)_{\text{max.}}$ are given in Table 2 for each source.

It should be noticed that $\Delta\alpha$ is always negative, that is, the source will always appear to have a " flatter " spectral index and appear " more thermal ". Therefore the sources are correctly classified as thermal in Table 2 on the basis of their measured flux density spectral indices lying between $-0\cdot1$ and $+2$. However, it will not be possible to classify a source as optically opaque when the measured spectral index of flux density is greater than $+0\cdot4$, if the source is observed towards the inner regions of the Galaxy when $|\Delta\alpha|$ is large. If a source has zero spectral index and lies in that direction in the Galaxy where $|\Delta\alpha|$ is large, one possible conclusion is that it is an optically thin source lying at a large distance from the Earth so that T_B is small.

VIII. The List of Discrete Sources

The criterion adopted to decide whether to claim the existence of a discrete source was that a closed contour could be drawn about a point in the survey within a distance of one aerial beamwidth, that is, a radius of $0°\cdot8$. Table 2 is a list of the discrete sources recognized within the limits of the 1440 Mc/s survey. The columns of the table are :

1. Current catalogue number. The sources are arranged in order of increasing longitude.

2. The number of the object in other catalogues. Abbreviations used to denote the particular catalogue are : MSH, Mills, Slee, and Hill (1960, 1961) ; WB, Wilson and Bolton (1960) ; W, Westerhout (1958) ; LMH, Large, Mathewson, and Haslam (1961).

3 & 4. The galactic longitude l^{II} and latitude b^{II} of the radio source. The probable error of source position over the whole survey is 5′ of arc. The error in the quoted position of the weaker sources may be greater than this value.

5 & 6. The Right Ascension α_{1950} and declination δ_{1950} of the radio source referred to epoch $1950\cdot0$.

7. After subtraction of the background, the widths of the observed cross sections and/or contours at half-intensity. If the source is elliptical the widths of the major and minor axes are given. The abbreviation " p.s." denotes a " point source ", i.e. a source not resolved by the 50′ of arc aerial beam.

8. Flux density of the source at 1440 Mc/s expressed in "flux-units". One flux-unit is $10^{-26}\,\text{W m}^{-2}\,(\text{c/s})^{-1}$. The flux density of a point source was obtained by multiplying the peak brightness temperature measured by the aerial beam by $15\cdot3$ flux units (Section III). If the source was extended, the emission was integrated by planimetry of the isophotes to obtain the total flux density.

9. The excess brightness temperature at 1440 Mc/s as measured by the aerial beam in the direction of the source expressed in °K, $\Delta T(1440)$ (Section V).

Table 2

LIST OF DISCRETE SOURCES

Source No.	Other Catalogue Numbers	l^{II}	b^{II}	α_{1950} h m s	δ_{1950} ° ′	Size (min. of arc)	Flux Density (flux units)	$\Delta T1440$ (°K)	$\Delta T85 \cdot 5$ (°K)	Spectral Index α_m	$\Delta\alpha_{\max}$.	Class	Optical Identification
1	MSH 08–44 ; WB25	260·6	−3·3	08 21 42	−42 55	60×66	180	7	7000	−0·4	−0·1	Nonth.	Puppis A ; IAU 0854A
2	WB 28	263·6	−0·6	08 43 28	−43 42	Extended		3	3000	−0·4	−0·1	nonth.	Vela Y
3	MSH 08–45 ; WB26	263·9	−3·3	08 32 31	−45 35	90×108	920	15	6000	−0·1	−0·2	th.	Vela X
4	MSH 08–48 ; WB32	265·2	+1·7	08 58 52	−43 26		45	3	500	+0·2	−0·3	th.	RCW 36 ; G20
5	MSH 08–47 ; WB31	268·0	−1·1	08 57 26	−47 23	p.s.	250	16	1000	+0·5	−0·1	th. opaq.	RCW 38 ; G23
6		271·1	−1·3	09 09 09	−49 49		30	2	Not seen			th.	
7		277·3	+0·8	09 47 15	−52 31		30	2	Not seen			th.	
8		280·6	+7·8	10 29 34	−48 40		15	1	Not seen			th.	
9	MSH 10–51	282·2	−1·2	10 05 52	−57 05		110	7	1000	+0·2	−0·2	th.	RCW 46
10	MSH 10–54	284·2	−0·4	10 21 28	−57 32	57×70	580	23	1500	+0·5	−0·3	th.	RCW 49, G29, NGC 3247
11	MSH 10–57	287·6	−0·8	10 42 31	−59 34	63×57	950	43	4000	+0·4	−0·2	th.	η Carinae nebula RCW 53, NGC 3372
12		288·8	+5·6	11 10 11	−54 16		15	1	Not seen			th.	
13	MSH 11–61	289·9	−0·9	10 58 46	−60 40		100	7	4000	−0·3	−0·1	nonth.	NGC 3503
14	MHS 11–62	291·6	−0·6	11 12 36	−61 03	p.s.	370	24	1500	+0·5	−0·3	th.	RCW 57 ; G38 ; NGC 3603
15	MSH 11–54	291·8	+1·8				15	1	1000	−0·4	−0·1	nonth.	
16		293·7	+1·2	11 33 31	−60 02		15	1	Not seen			th.	
17		293·8	−1·2	11 28 24	−62 21		75	5	1000	+0·4	−0·2	th.	RCW 60 ; IC 2872
18	MSH 11–65	294·8	−1·5	11 35 57	−62 56		75	5	1000	+0·4	−0·2	th.	RCW 62 ; IC 2944
19		297·0	−0·7	11 56 20	−62 41		45	3	1000	0·0	−0·3	th.	
20	MSH 12–61	298·6	−0·3	12 10 39	−62 34	54×72	270	11	2000	+0·2	−0·3	th.	
21		298·7	+1·8	12 13 59	−60 31	Extended		1	Not seen			th.	

TABLE 2 (*Continued*)

Source No.	Other Catalogue Numbers	l^{II}	b^{II}	α_{1950} h m s	δ_{1950} ° ′	Size (min. of arc)	Flux Density (flux units)	$\Delta T1440$ (°K)	$\Delta T85\cdot5$ (°K)	Spectral Index α_m	$\Delta\alpha_{max.}$	Class	Optical Identification
22		300·8	0·0	12 29 55	−62 31		15	1	Not seen			th.	
	MSH 12–64	301·9	+0·9	12 39 42	−61 42			Not seen	1000			nonth.	
23		302·3	+0·1	12 42 56	−62 30		15	1	Not seen			th.	
24		303·9	−0·5	12 56 57	−63 05		45	3	Not seen			th.	
25		305·3	+0·2	13 08 49	−62 19	p.s.	260	17	1000	+0·6	−0·2	th. opaq.	RCW 74
26		305·4	+1·5	13 08 49	−61 01		30	2	Not seen			th.	
		305·4	−1·6	13 10 00	−64 08			Not seen	1000			nonth.	
27		306·1	−2·1	13 14 12	−63 34		15	1	Not seen			th.	
28		309·3	−0·3	13 43 30	−62 14		60	4	1000	0·0	−0·5	th.	RCW 80 ; BBW 27700
29	MSH 13–62	309·7	+1·6	13 43 27	−60 18	p.s.	130	8	11,000	−0·6	−0·1	nonth.	IAU 1356A
30		310·6	+3·0	13 47 58	−58 44		15	1	Not seen			th.	
31	MSH 14–61	311·8	−0·2	14 03 51	−61 31	60 × 102	380	9	1500	+0·2	−0·8	th.	RCW 83
32		312·8	−2·6	14 18 34	−63 29		15	1	Not seen			th.	RCW 84
33		313·8	−3·0	14 28 12	−63 30		15	1	Not seen			th.	
34		314·5	+3·2	14 15 52	−57 27		15	1	Not seen			th.	
35	MSH 14–63	315·5	−2·2	14 39 08	−62 06		30	2	1000	−0·2	−0·1	nonth.	
36	MSH 14–57	316·5	−0·1	14 39 32	−59 47	p.s.	110	7	2000	0·0	−0·7	th.	
37		317·2	0·0	14 44 13	−59 24	p.s.	120	8	Not seen			th.	
	MSH 14–58	318·0	−0·1	14 50 00	−59 03			Not seen	1500			nonth.	
38		319·9	−3·7	15 17 49	−61 20		15	1	Not seen			th.	
39		320·5	+0·4	15 05 10	−57 31		45	3	Not seen			th.	
40		320·6	−0·6	15 09 37	−58 19	Extended	170	5	Not seen			th.	
	MSH 15–53	321·7	−0·3	15 15 36	−57 30			Not seen	1000			nonth.	
41		322·3	+0·5	15 16 08	−56 30		25	1·5	Not seen			th.	RCW 92 ; BBW 28900
42	MSH 15–54	324·1	−0·1	15 29 20	−56 00		45	3	1000	0·0	−0·8	th.	
43	MSH 16–61	325·2	−7·4	16 11 15	−60 59		75	5	15,000	−0·8	0	nonth.	IAU 1656A
44	MSH 15–56	326·3	−1·7	15 48 47	−55 58	p.s.	130	8	4500	−0·3	−0·1	nonth.	
45		327·1	−0·3	15 47 01	−54 22	60′ × 80′	230	11	In abs.			th.	RCW 97 ; BBW 29401
46	MSH 15–57	328·4	+0·1	15 52 10	−53 15		90	6	4000	−0·3	−0·1	nonth.	

TABLE 2 (*Continued*)

Source No.	Other Catalogue Numbers	l^{II}	b^{II}	α_{1950} h m s	δ_{1950} ° ′	Size (min. of arc)	Flux Density (flux units)	$\Delta T1440$ (°K)	$\Delta T85{\cdot}5$ (°K)	Spectral Index α_m	$\Delta\alpha_{\mathrm{max.}}$	Class	Optical Identification
47	MSH 15–5*8*	329·5	+0·2	15 57 19	−52 28		30	2	1500	−0·3	−0·1	nonth.	
48		331·2	−2·0	16 15 23	−52 57		30	2	Not seen			th.	
49		331·4	−0·2	16 08 16	−51 30	50×63	140	7	In abs.			th.	
50		332·0	+3·8	15 54 39	−48 06		15	1	Not seen			th.	
	MSH 16–5*1*	332·3	+0·1	16 11 30	−50 40			Not seen	3500			nonth.	
51		333·0	−0·4	16 16 31	−50 30	50×66	370	18	In abs.			th.	RCW 106
52		334·8	−0·1	16 23 06	−49 03		15	1	Not seen			th.	
53		336·2	+3·9	16 12 27	−45 14		15	1	Not seen			th.	
54		336·6	−1·5	16 36 48	−48 42		45	3	Not seen			th.	RCW 108 ; NGC 6193
55	WB 33	336·9	−0·1	16 31 49	−47 32	50×78	360	15	Not seen			th.	
56	MSH 16–4*7* ; WB34	338·2	+0·1	16 36 05	−46 27		230	15	5500	−0·1		th.	
57		340·5	−0·2	16 46 03	−44 54		30	2	Not seen			th.	
58	MSH 16–4*8*	342·0	0·0	16 50 34	−43 38		30	2	1500	−0·3	−0·1	nonth.	
59	WB 36	342·4	−1·9	17 00 13	−44 30		15	1	Not seen				
60		343·5	0·0	16 55 44	−42 28		15	1	Not seen			th.	
	MSH 16–4*11*	344·8	+0·3	16 59 00	−41 18			Not seen	2000			nonth.	
61	WB 35	345·1	+1·2	16 56 03	−40 28		110	7	Not seen			th.	
		346·7	+0·1	17 05 44	−39 52			Not seen	3000			nonth.	
62	WB 38	348·4	−0·9	17 15 07	−39 05		75	5	Not seen	(0·0) 960		th.	RCW 121
63	MSH 17–3*3* ; WB 37	348·5	0·0	17 11 40	−38 29	50×66	100	5	5500	−0·5	−0·1	nonth.	
64	WB 39 ; LMH 1	351·3	+0·6	17 17 23	−35 51		400	21	In abs.	(+0·7) 408	(−0·1)	th. opaq.	RCW 127 ; NGC 6334
65	W22 ; WB 40 ; LMH 2	353·2	+0·7	17 22 17	−34 14	p.s.	580	38	In abs.	(+0·3) 408	(−0·1)	th.	RCW 131 ; NGC 6357
	MSH 17–3*7* ; LMH 3	353·8	0·0	17 26 37	−34 12			Not seen	1500			nonth.	
66	W 23 ; LMH 5	355·6	+0·2	17 30 40	−32 31		75	5	Not seen	(+0·6) 408	(−0·1)	th. opaq.	RCW 132 ; NGC 6383

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10. The excess brightness temperature measured in the direction of the source at 85·5 Mc/s, $\Delta T(85 \cdot 5)$. The abbreviation "in abs." denotes a source seen in absorption at 85·5 Mc/s, i.e. a negative source (Section VII).

11. The measured flux-density spectral index (α_m) of the radio source. When a source is not seen at 85·5 Mc/s, a spectral index has been obtained where possible by comparing the 1440 Mc/s brightness temperature with that obtained on one of the higher frequency surveys listed in Table 1 in the region of overlap. The spectral indices derived in this manner are bracketed and the subscripts denote the frequency of the comparison survey. When a source is seen at 85·5 Mc/s but not at 1440 Mc/s it is included in Table 2 for spectral classification purposes but is not given a catalogue number.

12. $(\Delta\alpha)_{\text{max.}}$ is the maximum possible difference due to absorption effects between the true spectral index of the source and the measured spectral index (see Sections VI and VII).

13. Sources are classified according to their spectral index. A source is classified as thermal if the measured spectral index of the flux density (α_m) is greater than $-0 \cdot 1$. If α_m lies between $-0 \cdot 1$ and $+0 \cdot 1$, the source is an optically-thin region. If the true spectral index (α_t) is greater than $+0 \cdot 3$, the source is classified as thermal, optically opaque. If α_m is less than $-0 \cdot 1$, the source is classified as nonthermal. Abbreviations used : th., thermal spectrum ; th. opaq., thermal opaque spectrum ; nonth., nonthermal spectrum (see Sections VI and VII).

14. A search was made in the catalogue of Rodgers, Campbell, and Whiteoak (1960) of Hα emission regions in the southern Milky Way in an attempt to identify optically some of the radio sources. The Stromlo number of an Hα region which was found to coincide with the radio position to within 12′ of arc is given together with other catalogue numbers where possible. Catalogues in column 14 are designated thus : RCW, Rodgers, Campbell, and Whiteoak (1960) ; BBW, Bok, Bester, and Wade (1955) ; G, Gum (1955) ; and NGC, New General Catalogue (Dreyer 1953).

IX. Notes to Table 2

Source No. 3 has been identified by Wilson and Bolton (1960) with a supernova. The spectral index measured between 85·5 and 1440 Mc/s is almost zero, which would suggest that the source is an optically thin thermal emitter, or a nonthermal source with a very flat spectral index. The fact that Shain, Komesaroff, and Higgins (1961) do not observe this source at 19·7 Mc/s whilst clearly seeing the other nonthermal sources in this region tends to support the thermal origin of the source although the possibility exists of foreground ionized hydrogen obscuring the source from view at such a low frequency.

Source No. 56 has a flux density spectral index close to zero, indicating that the source is an optically thin thermal emitter. However, it is seen clearly in emission at 85·5 Mc/s against a disk temperature of 15,000 °K. Therefore if the source is an emission nebula with electron temperature of 10^4 °K it must lie at the back of the Galaxy (Section VII). If the source lay in the foreground its electron temperature would need to be about 2×10^4 °K. Of course it could be a nonthermal source with a flat spectral index, although Shain, Komesaroff, and Higgins do not see it at 19·7 Mc/s.

Sources 28, 31, 36, and 42 also have zero spectral indices and lie in regions of high disk temperatures at 85·5 Mc/s, that is, $|\Delta\alpha_{\max.}|$ is large. From Section VII it may be inferred that if they are assumed to be of thermal origin, they must lie at large distances from the Earth.

Sources 45, 49, 51, 64, and 65 are seen in absorption at 85·5 Mc/s against disk temperatures of about 13,000 °K. From equation (4) it is seen that if the electron temperature of these thermal sources is 10^4 °K then they must all be nearby objects.

Sources 5, 25, 64, and 66, which have been identified with the emission nebulae RCW 38, RCW 74, NGC 6334, and NGC 6383 respectively, appear to have true flux density spectral indices greater than +0·4 indicating a thermal source which becomes optically opaque at the lower frequency of observation. By assuming the electron temperature to be 10^4 °K, and calculating the optical thickness at the lower frequency from the spectral index, it is possible to calculate the brightness temperature of the source. This is compared with the excess brightness temperature measured by the aerial beam in the direction of the source to find the dilution factor in the aerial beam and hence the source diameter. Large, Mathewson, and Haslam (1961) used this technique to determine the diameters of sources 21 and 35 in their catalogue. Using this method, the diameters of the four sources 5, 25, 64, and 66 are estimated as 20′, 16′, 5′, and 3′ of arc respectively. At Parkes on October 28, 1961, a 1440 Mc/s drift scan through source No. 64, using the 210 ft-paraboloid which has a beamwidth of about 14′ of arc, showed no significant broadening of the aerial beam, thus supporting the size estimate based on the above method.

Altogether 54 sources have spectral indices greater than −0·1 and are consequently classed as thermal. Eighty per cent of these lie within 2° of the galactic plane ; the remaining sources at higher latitudes are very weak and were just detectable at 1440 Mc/s. Twenty-two of the thermal sources have been identified with HII regions of which 10 already had identifications.

Twenty sources in Table 2 have spectral indices less than −0·2 and are therefore classed as nonthermal. Nearly all of them lie within 2° of the galactic plane defined by $b^{\mathrm{II}}=0$, particularly if one disregards the sources in the Vela Puppis region which is displaced south of the plane. (This general distortion of the outer regions from the galactic plane is also noticeable at northern longitudes, e.g. the Cygnus X region which is displaced north of the plane.)

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