A SURVEY OF THE GALACTIC PLANE AT 85 AND 150 MHz

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Summary

A survey has been made of the intense emission regions along the galactic plane from $l = 60°$ to $290°$ at frequencies of 85 and 150 MHz with the 210 ft radio telescope at Parkes. Aerial temperatures were accurately measured, essentially in terms of thermal standards, with a known baselevel. The spectrum and "steps" of the observed emission have been investigated.

I. Introduction

The investigation of nonthermal emission from the Galaxy is best carried out at metre wavelengths. To achieve any degree of resolution, which is particularly necessary for observation of the galactic plane region, very large instruments are required. While unfilled aperture instruments achieve good resolution there is also a need for well-calibrated surveys made with instruments of medium resolution. The 210 ft radio telescope at Parkes, N.S.W., was made available for the present investigation, which was carried out at frequencies of 85 and 150 MHz. The measured beamwidths are $3 \cdot 6°$ by $3 \cdot 8°$ and $2 \cdot 2°$ by $2 \cdot 2°$ at 85 and 150 MHz respectively. The aerial temperatures have been accurately calibrated, in terms of absolute thermal standards, with a known baselevel.

Surveys of the galactic plane region have been made at metre wavelengths by a number of observers. The 85 MHz Cross survey with a resolution of 50′ (Hill, Slee, and Mills 1958; Mills, Hill, and Slee 1958) remains, at metre wavelengths, the only such high resolution investigation. Surveys made in Cambridge at 85 MHz by Baldwin (1955), at 178 MHz by Turtle and Baldwin (1962), and at 38 MHz by Kenderdine (1963) have been prevented by geographical position from reaching regions of the galactic plane near the galactic centre. A recent survey at 85 MHz, made at Parkes by Yates, Wielebinski, and Landecker (1967) with the same instrument as the present investigation, concentrated on regions of sky away from the intense galactic plane regions. Even a cursory inspection of this medium resolution survey reveals that the "step" observed by Mills (1959) in the direction $l = 325°$ can be discerned. This observation prompted the present investigation.

There are many high resolution surveys of the galactic plane in the decimetre wavelength range. Surveys by Large, Mathewson, and Haslam (1961) and Komesaroff (1966) at 408 MHz, Moran (1965) at 610 MHz, Wilson and Bolton (1960) and Nicholson (1965) at 960 MHz, Westerhout (1958) at 1390 MHz, and Mathewson, Healey, and Rome (1962) at 1440 MHz are available in this range of wavelengths. All these

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surveys have been made with instruments giving beamwidths smaller than 1°. These high resolution surveys at decimetre wavelengths reveal a wealth of detail, particularly of the thermal radiation observed close to the galactic plane. The separation of the thermal and nonthermal components was carried out by most of the observers making high frequency surveys (e.g. Westerhout 1958; Mathewson, Healey, and Rome 1962). The separation was always based on the use of the 85 MHz high resolution survey of Hill, Slee, and Mills (1958) and on various assumptions about spectra and baselevels.

The present survey was used to derive sky maps at 85 and 150 MHz of a region of the galactic plane that is symmetrical about the galactic centre within the limits $+10° > b > -10°$, $60° > l > 290°$. The absolutely calibrated aerial temperatures and the aerial polar patterns have been used to estimate spectral index. Profiles were drawn at constant galactic latitudes to reveal the structure of emission steps.

II. EQUIPMENT

The aerial used for the survey was the 210 ft fully steerable paraboloidal reflector at Parkes. At 85 MHz the primary feed was a $\lambda/2$ dipole mounted in the focus, $\lambda/4$ below the reflecting area of the aerial cabin. The dipole was matched to an impedance near 50 Ω by adjustment of the dipole length and of the position relative to the reflecting plate. Final matching at 85 MHz was done by means of a matching unit. The primary feed for 150 MHz consisted of two dipoles mounted orthogonally relative to the 85 MHz dipole. The 150 MHz two-dipole feed is a standard configuration used for the Parkes reflector (Minnett and Yabsley 1966). The isolation of the two feeds was measured to be better than 45 dB at both survey frequencies.

The receivers used at both frequencies were switched radiometers of the type described by Yates, Wielebinski, and Landecker (1967). The receiver configuration allowed remote switching to a matched load at ambient temperature and calibration with a monitored noise current. The standards of noise were calibrated in terms of absolute thermal standards. A noise source similar to that described by Harris (1961) was used at 150 MHz, and a well-matched noise diode type CV 2398 was used for the 85 MHz calibrations. The linearity of the receivers was checked for the complete range of deflections encountered in the survey of the galactic plane.

The bandwidth of the 30 MHz i.f. amplifiers in both receivers was 1 MHz, which could be reduced to 150 kHz by a filter in case of interference. During most of the observing period, conditions allowed the use of the full bandwidth of 1 MHz. The output deflections on a pen recorder gave readings of aerial temperature measured above the baselevel, which was obtained by replacing the aerial with a matched termination at ambient temperature (taken to be 285°K).

III. OBSERVATIONS

The observing procedure for most of the scans was to drive in declination through the galactic plane at constant right ascension using a telescope drive rate of 2·5 deg/min. Some of the northern portions of the galactic plane were observed at transit with a telescope zenith-angle drive rate of 5 deg/min. Additional right

ascension scans at a number of declinations were made to provide a check on temperature values. The intervals of scanning were chosen to allow some beam overlap at 150 MHz. South celestial pole calibrations were performed occasionally to check overall system performance. The observations were made during two nights in August 1967.

The sky temperatures determined from the scans were plotted as maps in new galactic coordinates and are shown in Figures 1(a) and 1(b), which correspond to frequencies of 85 and 150 MHz respectively. The graphical method of reduction from paper chart records may introduce up to $0 \cdot 5°$ error in placement of the isophotes.
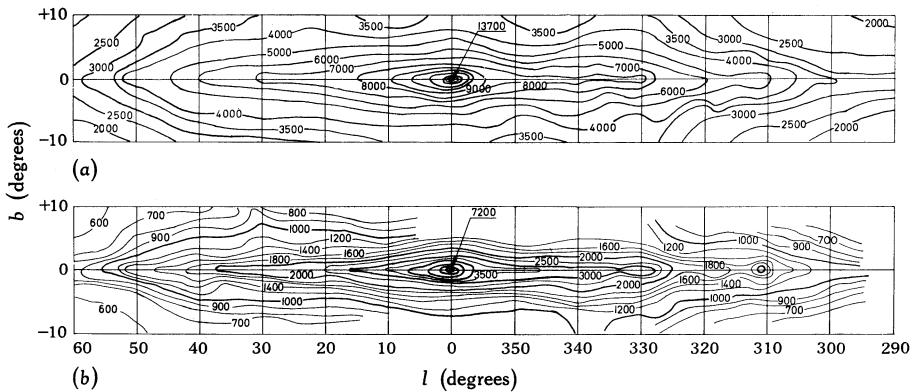

Fig. 1.—Maps of aerial temperatures (°K) along the galactic plane at (a) 85 MHz, $3 \cdot 7°$ beam, and (b) 150 MHz, $2 \cdot 2°$ beam.

The random errors in aerial temperatures are estimated as 3% r.m.s. at both frequencies. This value includes the mismatch error deduced from the scatter of observed south pole temperatures, and the error due to noise fluctuations on records. Systematic errors of 7% at 85 MHz and 4% at 150 MHz must be allowed in the survey temperatures. The systematic errors are the combination of absolute noise diode calibration error, ground effects, and error due to leakage of the reflector, particularly at the lower survey frequency. A leakage of electromagnetic radiation may arise due to the discontinuous nature of the surface of the Parkes reflector. The reflector panels are small in size compared with the wavelength of $3 \cdot 5$ m. The ground elevation dependence was investigated by tracking two areas of sky from zenith down to a zenith angle of 60°. A temperature reduction of 100 degK was observed at 85 MHz for zenith angles near 60°. No ground elevation effects were observed at 150 MHz, at which frequency a more directive primary feed was used. The possibility of a systematic reduction in the sky temperatures at 85 MHz was investigated by comparing the aerial temperatures measured in the survey by Yates, Wielebinski, and Landecker (1967) and the temperatures measured with a broad beam aerial at 85 MHz by Yates and Wielebinski (1966). A systematic reduction of 5% was found to be consistent with the measurements.

IV. TEMPERATURE SPECTRUM

The temperature scales of the galactic plane surveys at 85 and 150 MHz are determined in terms of thermal standards with a known baselevel. The data are therefore suitable for spectral investigations. The temperature spectral index β is given in terms of temperatures T_1 and T_2 measured at wavelengths λ_1 and λ_2 respectively by

$$T_1/T_2 = (\lambda_1/\lambda_2)^\beta. \tag{1}$$

The temperatures T_1 and T_2 in equation (1) should be either "full beam temperatures" or else aerial temperatures measured with aerials that are scaled with wavelength. In the case of the present surveys, the aerial beams are dissimilar and full beam temperatures have not been determined. Therefore a further beam factor k is required in the spectral equations. The spectral equation for the present frequencies becomes

$$(1 \cdot 76)^\beta = k(T_{85}/T_{150}), \tag{2}$$

where k must be determined from a knowledge of aerial polar patterns and temperature gradients.

The aerial temperature T_a is given by

$$T_a = \int_{4\pi} T(\theta,\ \phi)\ f(\theta,\ \phi)\ d\omega \div \int_{4\pi} f(\theta,\ \phi)\ d\omega, \tag{3}$$

where $T(\theta,\ \phi)$ represents the temperature distribution, $f(\theta,\ \phi)$ is the aerial power polar pattern, and $d\omega$ is an increment of the solid angle. To simplify the computation the aerial beam can be divided into n areas. The aerial temperature T'_a, given by the expression

$$T'_a = \sum_{r=1}^{n} T_r a_r p_r \div \sum_{r=1}^{n} a_r p_r, \tag{4}$$

is an approximation of the aerial temperature T_a. In (4) T_r is the mean temperature of the rth region, a_r is the area of this region, and p_r is the mean level of the polar pattern in the rth region. The beam factor k can be determined by convolution of either of the two surveys by the beams at both survey frequencies. This convolution process will yield two values of k:

$$k_1 = \frac{T_{85}(150\ \text{beam})}{T_{85}(85\ \text{beam})} \quad \text{and} \quad k_2 = \frac{T_{150}(150\ \text{beam})}{T_{150}(85\ \text{beam})}. \tag{5}$$

The two beam factors should be identical if temperature gradients are low. A mean value of k_1 and k_2 can be used.

The polar patterns of the survey aerials were obtained from a number of scans through the strong radio sources, Pictor, Fornax, Virgo, and Hydra. These polar patterns in the E and H planes are shown in Figure 2. The scans were made in right ascension and declination at various parallactic angles. The 150 MHz polar pattern was found to be circular with a half-power beamwidth of $2 \cdot 2°$. The corresponding 85 MHz beam was elliptical with half-power beamwidths of $3 \cdot 6°$ by $3 \cdot 8°$. The polar

patterns are taken to be zero, on a linear scale, at beamwidths of 9° at 85 MHz and 5·5° at 150 MHz. In the derivation of the beam correction factors k_1 and k_2, the beam area was divided into 41 squares, each 1° by 1°. Mean values of the power level were assigned to the squares at both frequencies from the knowledge of aerial polar patterns. At the frequency of 150 MHz, 16 of the outer squares were assigned the
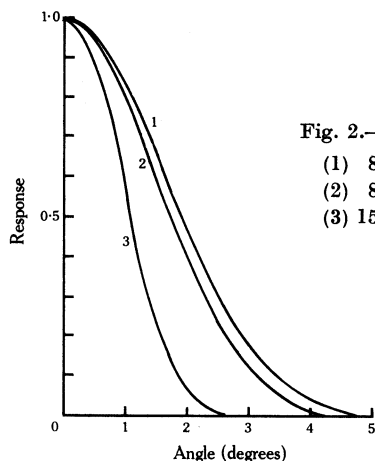
Fig. 2.—Aerial power polar patterns for:

(1) 85 MHz, E plane
(2) 85 MHz, H plane
(3) 150 MHz, E and H planes

power level value of zero. The mean temperature values for each of the 41 points for both survey frequencies were derived from the maps in Figures 1(a) and 1(b) for a number of sky directions away from the galactic centre.

TABLE 1

VALUES OF BEAM FACTOR k AND SPECTRAL INDEX β FOR 12 POINTS AWAY
FROM GALACTIC CENTRE

Point	b (deg)	l (deg)	T_{85} (°K)	T_{150} (°K)	$\dfrac{T_{85}}{T_{150}}$	k	β
1	+5	45	3550	940	3·8	1·04	2·4
2	0	45	4900	1650	3·0	1·09	2·1
3	−5	45	3750	800	4·6	1·05	2·8
4	+5	35	4500	1050	4·3	1·06	2·7
5	0	35	6500	2050	3·2	1·11	2·2
6	−5	35	4200	980	4·3	1·07	2·7
7	+5	325	4000	1000	4·0	1·04	2·5
8	0	325	6500	2000	3·3	1·09	2·2
9	−5	325	4000	1050	3·8	1·04	2·5
10	+5	315	3250	1000	3·3	1·05	2·2
11	0	315	5500	1800	3·1	1·09	2·2
12	−5	315	3250	900	3·6	1·04	2·4

The detailed computations for the derivation of the beam factors k_1 and k_2 were made for 12 points away from the galactic centre. The galactic direction, the temperatures, and the mean value k of the beam factors k_1 and k_2 are given in Table 1. The mean value of k is 1·05 for directions away from the galactic plane, and 1·1 on the galactic plane. The mean value of the temperature spectral

index is found to be $\beta = 2\cdot5\pm0\cdot15$ for directions away from the galactic plane, and $\beta = 2\cdot2\pm1$ on the plane. The lower value of the temperature spectral index on the plane is consistent with the fact that the thermal emission component that has $\beta < 2\cdot5$ is concentrated along the galactic plane. The temperature ratio T_{85}/T_{150}
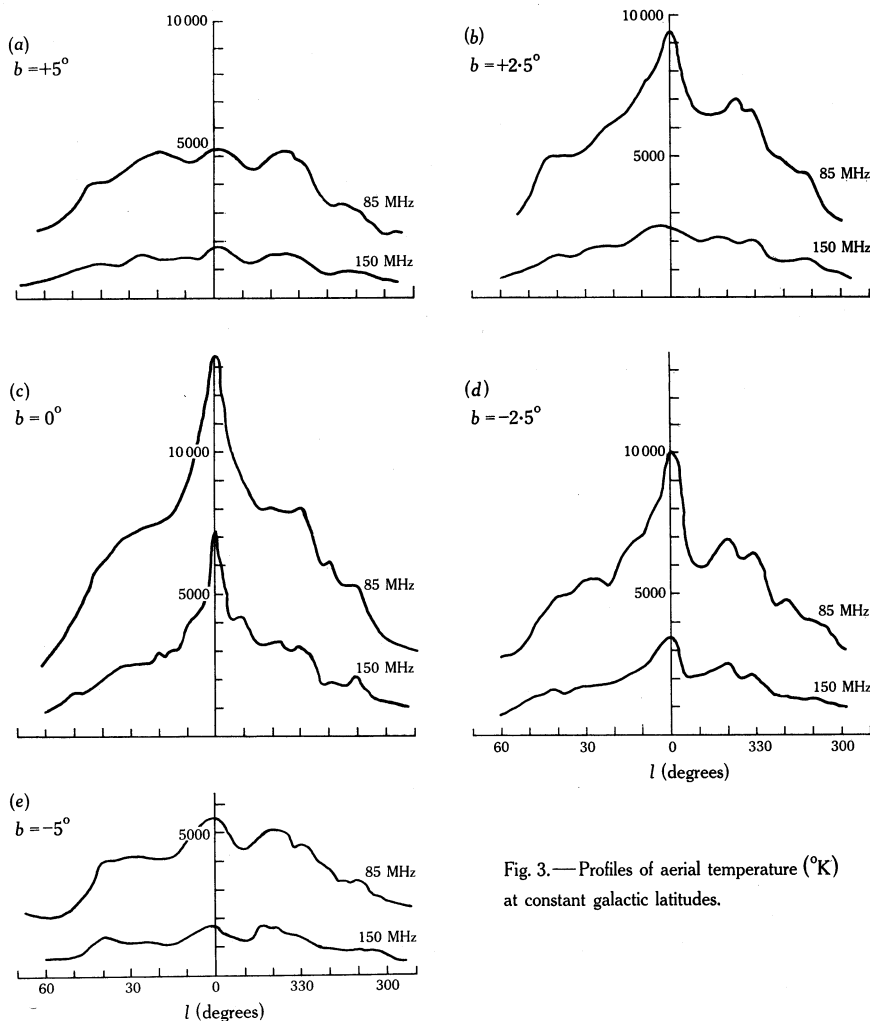

Fig. 3.—Profiles of aerial temperature $(^{\circ}\text{K})$ at constant galactic latitudes.

was computed for some 100 points in various directions. For most of these points the value of the temperature ratio was found to be

$$T_{85}/T_{150} = 3\cdot7\pm0\cdot25.$$

The ratio with the beam factor $k = 1\cdot05$ corresponds to the value of spectral index $\beta = 2\cdot4\pm0\cdot15$. Reduced values of the temperature ratio are found for some points in the directions $l = 340^{\circ}$, $b = -5^{\circ}$ and $l = 335^{\circ}$, $b = +5^{\circ}$. The temperature ratio values are as low as $3\cdot1\pm1$, which is significantly lower than for all other directions.

V. Steps of Emission

Features that are clearly discernible in the maps shown in Figure 1 are the sudden increases in measured aerial temperatures along the galactic plane. These sharp increases or "steps" can be seen towards $l = 305°$ and $325°$ from the sky maps. By producing diagrams of aerial temperatures at constant galactic latitude the steps can be investigated more effectively. Five diagrams have been drawn from the original records rather than from the maps, where some loss of detail is unavoidable. The profiles at $b = +5°$, $+2\cdot5°$, $0°$, $-2\cdot5°$, and $-5°$ are shown in Figures 3(a)–3(e) respectively.

Examination of the temperatures along the galactic plane shown in Figure 3(c) indicates the existence of steps in the directions $l = 305°$, $325°$, $345°$, $14°$, and $35°$. The step effects are more pronounced at 150 MHz, which may be due only to the higher resolution of the beam. The positions of the steps agree well with the positions of the original observations of these features by Mills (1959). The observations also confirm the fact that the features visible in the northern sky are not as well defined as those in the south. The diagrams for latitudes $b = \pm2\cdot5°$ contain much the same information as the galactic plane section. However, in the direction $l = 335°$ both at $b = +2\cdot5°$ and $-2\cdot5°$, a step is replaced by a "bump". This effect is even more pronounced at $b = +5°$ and $-5°$. A further observation is that there is some evidence for a similar bump at $l = 25°$, $b = +5°$ but none is seen at $l = 25°$, $b = -5°$. One conclusion that must be drawn from the diagrams in Figure 3 is that the directions near $l = 330°$ and $30°$ correspond to some special galactic features.

VI. Discussion

The regions of the sky near the galactic plane have been mapped at 85 and 150 MHz. The maps extend over 120° of galactic longitude, symmetrically about the galactic centre. The aerial temperatures have been absolutely calibrated.

The temperature spectral index has been found for a number of points near the galactic plane. The mean value for the directions $b = \pm5°$ (from Table 1) is $\beta = 2\cdot5\pm 0\cdot15$. This value of spectral index is in agreement with that for the galactic spectrum derived from low resolution scaled aerial measurements (Yates and Wielebinski 1966), which was also $\beta = 2\cdot5\pm0\cdot15$ for a somewhat lower frequency range. These values of spectral index indicate a nonthermal emission mechanism. Along the galactic plane the values of spectral index are lower, indicating a mixing of emission from thermal and nonthermal mechanisms. Some reduction in spectral index occurs also in the directions $l = 340°$, $b = -5°$ and $l = 335°$, $b = +5°$. This significant reduction of spectral index away from the plane may be due to the extension of the thermal emission from the plane into higher galactic latitudes.

The steps of emission along the plane are very pronounced in the directions $l = 325°$ and $305°$. The temperature gradient in the direction $l = 35°$ is not very steep. The assertion of the existence of a ring of emission by Komesaroff (1966) requiring symmetrical temperature steps must be questioned. There is, however, evidence from surveys (Baldwin 1955; Yates, Wielebinski, and Landecker 1967) that the directions $l = 30°$ and $325°$ are associated with spurs rising into both hemi-

spheres. The directions $l = 30°$, $b = +20°$ and $l = 330°$, $b = -20°$ are associated with the two most intense spur features in the sky. The possibility of the association of these spurs with the thermal emission in the plane should be further investigated.

The absolute calibration of the present aerial temperatures enables a comparison to be made with the temperatures observed in the high resolution survey of Hill, Slee, and Mills (1958). To achieve this, a convolution procedure similar to that used in the derivation of the spectral index must be used. This was done for eight points away from the galactic centre. The mean ratio of convolved high resolution temperatures to the present aerial temperatures gave a factor of $1 \cdot 27 \pm 0 \cdot 1$. If allowance is made for the possibility of a 5% systematic error that reduced the aerial temperatures of the present survey, then the brightness temperatures of Hill, Slee, and Mills (1958) are 22% $\pm$8% too high. It should be noted, however, that the conversion of the aerial temperatures to beam temperatures (discussed in Yates, Wielebinski, and Landecker 1967) will in fact bring the temperature values into good agreement.

The present survey, although limited by resolution, clearly shows the advantages of galactic observations at metre wavelengths. Observations of other galaxies like M 31 at metre wavelengths, if made with sufficient resolution, could add much to the understanding of our own Galaxy, which we must observe only from within.

VII. Acknowledgments

VIII. References

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