AN INTERPRETATION OF THE DISTRIBUTION OF METRE WAVELENGTH RADIO EMISSION

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Summary

A recent 85 MHz survey of the southern sky had an absolute calibration accuracy and resolution comparable with a number of surveys made for the northern skies. By combining the results of these surveys in both hemispheres a complete sky map has been produced, and in this paper an analysis is made of the distribution of the medium and high latitude emission. A fundamental difficulty encountered is the identification and isolation of the spurs of emission projecting from the galactic plane. Two hypotheses are proposed. The first attributes the spurs to a large-scale feature associated with the galactic core and the remaining emission to a galactic halo. The second postulates the origin of the spurs within the local spiral arm, which is itself considered to contribute significantly to the high latitude background. An upper-limit estimate of the emissivity of the local arm is made from currently available independent data. Using this result a model local arm is proposed, which, together with an isotropic component from beyond the Galaxy and a small additional galactic component, explains the observed distribution.

I. INTRODUCTION

Study of the metre wavelength background brightness distribution is an important source of information on galactic structure. Analysis of the distribution is made by identifying components in the background related to known galactic features. Most of the observed radiation may be explained by superposition of four components, three with galactic symmetries and one that is isotropic. These components are the halo, distributed about the galactic centre; the disk, distributed about the galactic plane; the local arm radiation, distributed about the arm axis; and the isotropic component being the extragalactic emission. Complete synthesis of the observed distribution requires, in addition, components with no obvious symmetries to account for the apparently random features of the background, such as the spur features and the fine detail visible with high resolution instruments. If independent information is available concerning the magnetic field and the electron energy density spectrum of any one of the regions, then synchrotron emission theory may be used to compute the magnitude of its contribution to the background. In the absence of this information the estimation of the relative magnitudes of the components must be made from symmetry arguments alone.

Early metre wavelength surveys (Baldwin 1955*a*; Hill, Slee, and Mills 1958) were confined to sections of the sky that were visible from particular observatories and their interpretation (Baldwin 1955*b*; Mills 1959) was further hampered by the

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absence of reliable data giving independent values for the galactic magnetic field strength and relativistic electron energy distribution. In recent years the position has greatly improved. Polarization measurements, both of the radio background and of sources seen through the Galaxy (Faraday rotation studies), have contributed to knowledge of the order and direction of the local field. Observations of Zeeman splitting of 21 cm spectral lines and of the polarization of starlight, together with the radio polarization data, have set upper and lower limits to the magnetic field magnitude. Moreover, the cosmic ray electron energy spectrum has been measured directly a number of times, giving reasonably consistent results.

A further improvement has been brought about by the recent completion of an 85 MHz survey of the southern sky (Yates, Wielebinski, and Landecker 1967). This survey was made with a beam of $3\cdot5^\circ \times 3\cdot8^\circ$ making it most suitable for studies of large-scale galactic structure. The survey was also comparable in resolution and absolute calibration accuracy with a number of northern surveys. In the present paper a complete sky map is produced by combination of the results from both hemispheres. An analysis is then made of emission distribution away from the galactic plane. Because of the present doubt that has been cast upon the existence of the halo (an account of which is given in Felton 1966), the analysis is based on two alternative prior assumptions about the nature of the halo. These are that the halo contributes either a maximum or a minimum proportion of the background intensity.

The discussion commences with a description of the technique used for the production of the complete sky map, after which the map is used for a study of the spur features. Certain conclusions are reached, leading to an identification and isolation of the spur component. The remaining analysis is then based upon the minimum-halo assumption. The approach taken is to determine the maximum emission contribution from the local arm that is consistent with independent data, and to then make a study of the remaining emission, which on the basis of the simple subdivision referred to earlier, must originate in the halo and beyond the Galaxy.

II. Preparation of Complete Sky Map

Unless an exactly corresponding survey is available, a number of difficulties are encountered in combining northern and southern sky survey results. Combination of surveys made at different frequencies involves an assumption of spectrum, while combination of different resolution involves an imprecise smoothing process. Furthermore, unless the results are corrected to true full beam temperatures in an identical manner, the results are not completely comparable.

Three northern surveys were considered suitable for combination with the southern results referred to above in order to produce a complete sky map of the 85 MHz emission. Although each survey had one of the limitations mentioned, it was possible to combine them in such a way so as to produce minimum error. The $81\cdot5$ MHz $15^\circ \times 2^\circ$ survey of Baldwin (1955*a*) was used to set the minimum temperature in the northern skies without making any assumption about the spectrum. The discrepancy in beamwidth is not important in the slowly changing regions near the minima, although an error associated with beam-temperature correction does remain. After establishing the baselevel, detailed structure visible from the north was filled in by smoothing the 178 MHz contours obtained by Turtle and Baldwin (1962), who used a $4^{\circ} \times 13'$ instrument. The temperature scale was deduced from the direct overlap between the two surveys on the North spur and the ratio of the 178 and 81·5 MHz minimum temperatures. This technique minimized any error from spectrum change between high and low temperature regions. Finally, some modifications were made to the map to account for the different methods of reduction to beam temperatures by scaling the 404 MHz survey of Pauliny-Toth and Shakeshaft (1962) to 85 MHz. The results of this 404 MHz survey are presented as modified beam temperatures of the same form as the southern results.

The complete sky map produced by this procedure is shown in Figure 1. Maximum relative error between directions in opposite hemispheres is estimated to be 10%. Internal consistency of each hemisphere is no doubt much better than this. In some directions the error is increased by further uncertainties. Firstly, the usefulness of the contours in the vicinity of the disk is reduced by the inadequate resolution. Secondly, the area enclosed by the dashed lines represents that portion of the sky observed by neither the 178 nor the 85 MHz surveys. Finally, crosses on the map indicate directions in which an estimate of the galactic background has had to be made because of obscuration by strong sources.

III. Spur Features

The great amount of detailed structure revealed by high resolution surveys has led to a belief that much of the radiation from high galactic latitudes emanates from isolated discrete features rather than from a uniform halo. Many attempts have been made to identify the more obvious features in order to ascertain their contribution to the background radiation. In particular, through lack of suitable high resolution studies elsewhere, the great North spur has received a lot of attention. Theories have been proposed in turn explaining the existence of the spur in terms of a collision between our Galaxy and another system (Johnson 1957), an anisotropic population of electrons radiating in a local ordered field (Tunmer 1958), an interarm link, and emission from a supernova remnant (Hanbury-Brown, Davies, and Hazard 1960).

At present no one theory can claim universal acceptance. The steep outer edge of the spur near $l = 35^{\circ}$, $b = 30^{\circ}$ supports the theory that an incomplete shell of emission is responsible for the feature. In a detailed study, Davies (1964) showed that a supernova remnant of the same age and size as the Cygnus loop, positioned about 30 pc from the Sun would produce such an emitting shell. Previously, van der Laan (1962) had shown that an expanding shock wave associated with the supernova causes a local increase in the magnetic field which is responsible for the increased emission. It was explained that the limited angular extent of the spur could be the result of expansion into a nonuniform medium.

Two experimental results cast doubt on the supernova theory. The first was the absence of any optical evidence for the feature, indicating that it must have a much higher radio to optical brightness ratio than other supernovae such as the Cygnus loop

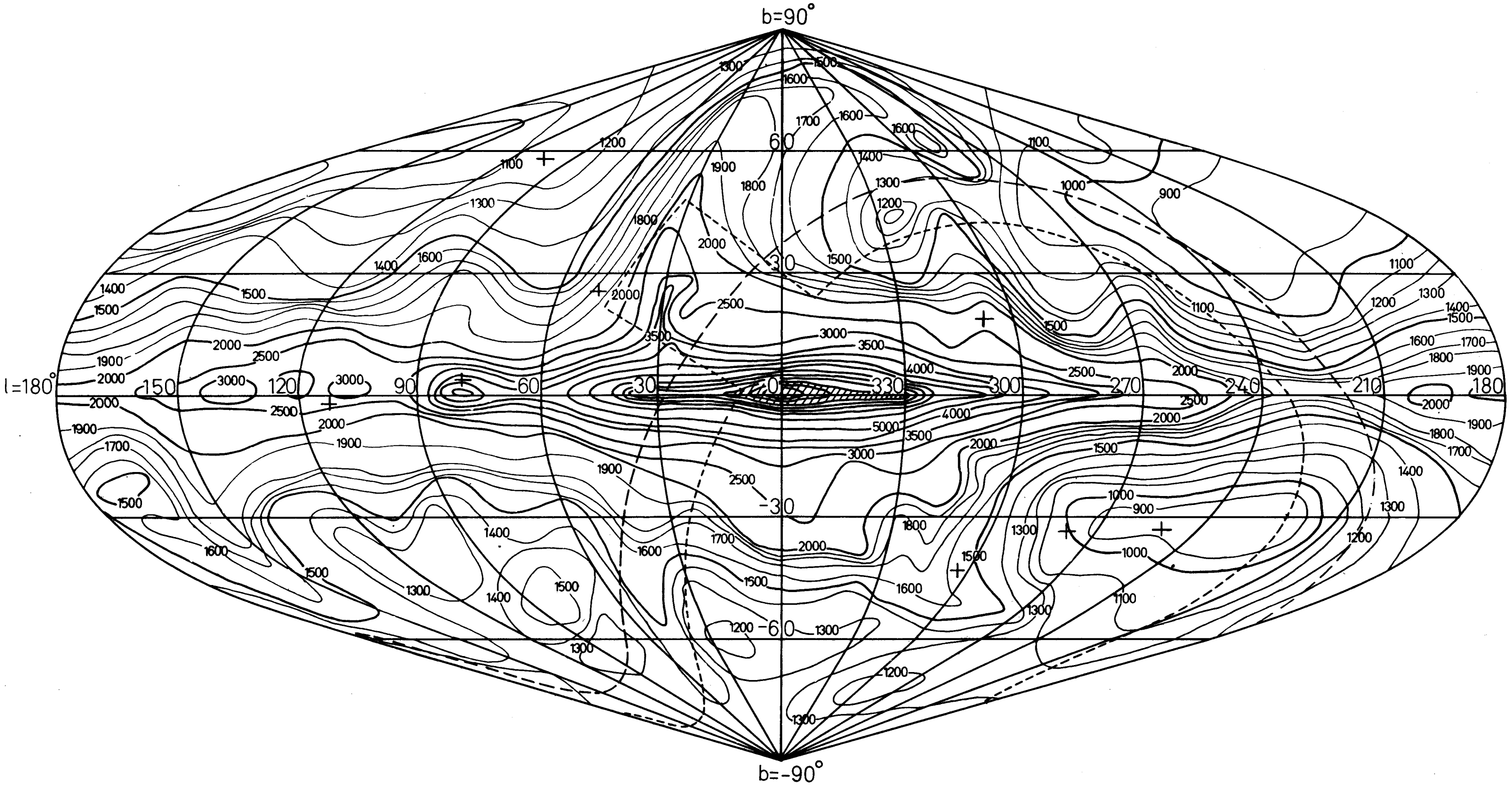

Fig. 1.—Contours of brightness temperature at 85 MHz obtained from the combination of northern and southern surveys. The zone enclosed by the dashed lines and the directions indicated by the crosses have reduced accuracy (see text).

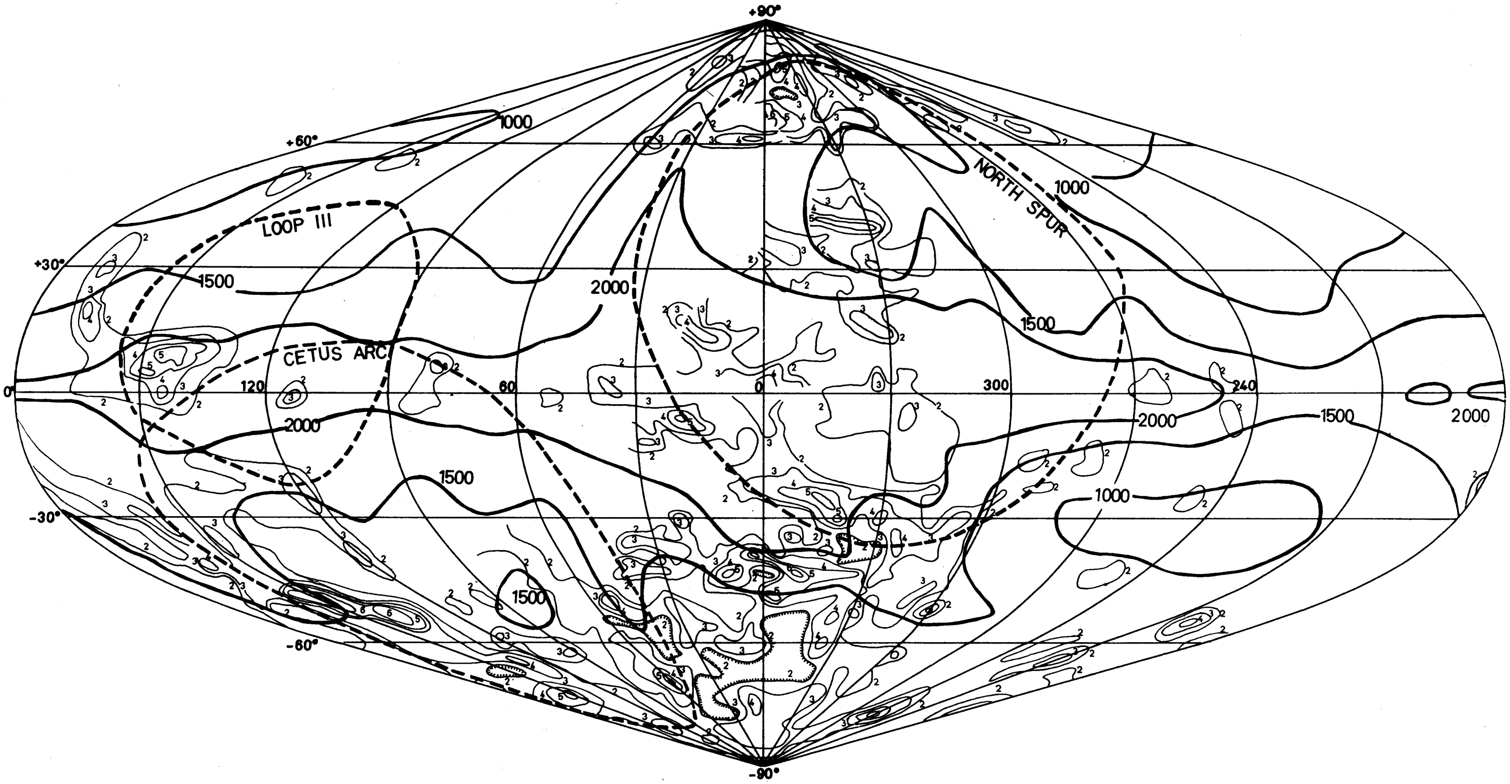

Fig. 2.—Contours of brightness temperature at 85 MHz for T = 1000, 1200, 1500, and 2000°K superimposed on the 408 MHz polarization results of Mathewson and Milne (1965). The dashed lines indicate the small circles associated with the spur features, as defined by Quigley and Haslam (1965).

(Davies, Hanbury-Brown, and Meaburn 1963). The second was the discovery of a feature of similar angular size south of the galactic plane, the so-called "Cetus arc" (Large, Quigley, and Haslam 1962).

The existence of two remnants in the close vicinity of the Sun implies a density in the distribution of such features through the Galaxy that would result in a higher background emission intensity than is observed.

Using results from a number of northern surveys, Quigley and Haslam (1965) were able to show, without suggesting a mechanism, that most of the large spurs of radiation leaving the galactic plane lie either along or within one of three small circles on the celestial sphere: the North spur along a circle with diameter $113°\pm3°$, centred on $l = 330°\pm2°$, $b = 19\cdot5°\pm2°$; the Cetus arc along a circle with diameter $92°\pm3°$, centred on $l = 100°\pm3°$, $b = -33°\pm3°$; and a third feature designated "Loop III" lying along a circle with diameter $71°\pm2°$ and centre $l = 124°\pm1°$, $b = 11\cdot5°\pm2°$. The North spur circle feature was closely examined by Haslam, Large, and Quigley (1964) at a frequency of 237 MHz with resolution of 1° and they demonstrated the existence of a number of concentric ridges and filaments of emission within the bounds of the circle.

Until the present it had not been possible to follow any of the features across the galactic plane with any certainty. Both the Cetus arc and the Loop III circles lie for part of their length along the galactic plane and are thus obscured by disk emission. The North spur circle has been inaccessible below the plane to northern observers.

Against the circle hypothesis of Quigley and Haslam, Rougoor (1966) proposed that the major ridges may be part of a single feature, such as a helix, with axis in the direction of $l = 110°$ and $b = 0°$. Once again, any southern extension of the proposed feature has been hidden from northern observatories.

The recent 85 MHz southern survey used for the production of the galactic map shown in Figure 1 provides the additional information required to obtain an overall picture of the spur phenomena. One large-scale feature having a size comparable with the spurs observed in the north, yet hitherto unrecorded, is visible in the south. This feature is first discernible from the disk emission at $l = 0°$, $b = -25°$. It then extends through $l = -335°$, $b = -37°$ and out to $l = -275°$, $b = -55°$. It is not so obviously a ridge and is much broader than equivalent brightness spurs visible in the north. Along the inner side of the feature further high temperature areas are apparent, particularly at $l = 320°$, $b = -30°$.

The orientation of this southern "arc" lends considerable support to the small-circle theory of Quigley and Haslam as against the theory that the spurs have origin in a single galactic feature such as a helix. This latter theory predicts a spur leaving the galactic plane southwards at $l = 270°$, but in fact this region is observed to be one of the coldest in the sky. In Figure 2, the paths of the three reference circles have been superimposed onto a galactic map showing the main 85 MHz brightness contours and the polarization temperatures observed at 408 MHz (Mathewson and Milne 1965). The strong orientation of the southern feature along the small circle associated with the North spur is apparent out to $l = 330°$, $b = 35°$. Beyond this point the centre line of the spur becomes tangential to the circle.

It has thus been established that features symmetrical about small circles may be followed across the galactic plane.

From a study of the complete sky maps in Figures 1 and 2, the following general remarks about the spur features may be made.

(1) High latitude ridge features broad enough to be detected by $3\cdot5°$ resolution are evident at the following galactic directions:

$l = 90°$, $b = 30°$; $l = 32°$, $b = 30°$; $l = 310°$, $b = 40°$;
$l = 268°$, $b = 25°$; $l = 160°$, $b = 30°$; $l = 160°$, $b = -40°$;
$l = 105°$, $b = -30°$; $l = 75°$, $b = -30°$; $l = 45°$, $b = -50°$;
and $l = 330°$, $b = -35°$.

Of these, all but three either lie along or are tangential to one of the three small circles on the celestial sphere.

(2) The remaining three features lie within one or other of these small circles. If north–south symmetry is assumed there is also considerable evidence for a general increase over the whole of the interior of the Cetus arc circle.

(3) In almost all cases the brightness decreases along the features as galactic latitude is increased. The exception is the bright region on the North spur circle at $l = 285°$, $b = 65°$.

(4) There is a strong concentration of the spur features towards the galactic centre. The strongest features lie within the zone $0 < l < 90°$ and $270° < l < 360°$.

(5) Examination of the polarization results of Mathewson and Milne (1965) reveals some evidence for an enhancement of polarization in the directions of the spurs, and the regions enclosed by the spur "circles". Mathewson and Milne drew attention to the fact that the directions in which polarization of the background has been detected are mainly confined to a 60° band containing the great circle through $l = 340°$ and 160°. The present results indicate that it is possible that at least some of the observed polarized emission has its origins within the spur features. It is also interesting to note that polarization has been detected in the direction $l = 285°$, $b = -22°$, a point on the small circle defined by the North spur at which no brightness ridge is discernible.

(6) For completeness in this study of the spur features it is noted that a difference in spectral index has been detected between the North spur and adjacent regions (Pugh 1964).

Items (1), (2), (5), and the exception referred to in (3) support the theory that the features have common origin and that they are local to the Sun. This is further supported by the fact that of the three discernible circle features, the brightest has the largest diameter. The theory that the features are due to local supernova remnants is attractive, particularly in view of the increased bright structure and polarization within the defined circles, although this explanation has the disadvantage of requiring the Sun to be in a very special location in the Galaxy.

Items (3) and (4), on the other hand, favour more the idea that the visible spurs are associated with features that are a part of the large-scale galactic structure, such as filaments associated with the galactic core, which extend up from the galactic plane. It is not possible to make a definite identification of the features from the data available, and reference must now be made to the basic assumptions referred to in the Introduction. If the minimum-halo assumption is accepted, some alternative to an extended emission distribution away from the galactic plane must be found to explain the observed medium and high latitude radiation intensity. The obvious alternative is emission of local origin. In this case it is reasonable to regard the spur features as being of common local origin, contributing to the background alongside emission from the local spiral arm. The maximum-halo assumption implies an insignificant contribution from local sources and consequently requires the spurs to be manifestations of large-scale features.

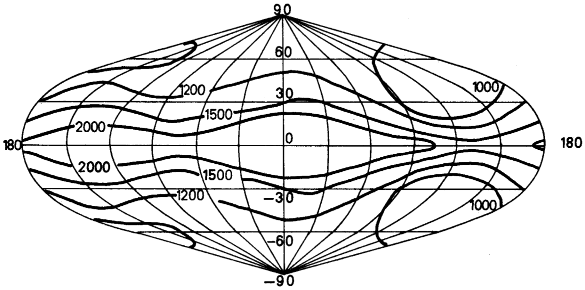

Fig. 3.—Contours of brightness temperature at 85 MHz below $T = 2000°K$ after radiation associated with the spur features has been subtracted from the background in the manner indicated in the text.

The subsequent analysis is based on the assumption of a minimum-halo contribution. It is further assumed that the contribution of the spur features may be subtracted from the observed background in the following manner.

(1) Any components in the background with symmetry about, or associated with, the small circles previously defined are removed.

(2) The temperature of regions enclosed by the small circles is reduced in such a way as to produce symmetry in the background brightness about the galactic plane.

In following this procedure, directions in either galactic hemisphere outside the circular features are useful in setting maximum temperatures. The minimum temperature observed across a feature may be taken as the maximum temperature of the background beyond.

In Figure 3 a map is presented of the 85 MHz background radio emission after removal of the spur features in the manner indicated. Only contours below 2000°K are shown and subsequent analysis will be confined to corresponding latitudes. The magnitude of the radiation subtracted and its distribution about the small circles may be seen in Figure 4. This figure shows constant azimuth profiles of the features, in the range included by circles with diameters 20° either side of the diameter of the reference circle. For comparison, the observed background temperatures are plotted in the same way.

IV. Local Arm Radiation

Some contribution to the background radiation is to be expected from the local arm as a consequence of synchrotron emission by galactic electrons spiralling about the magnetic field aligned along the arm.

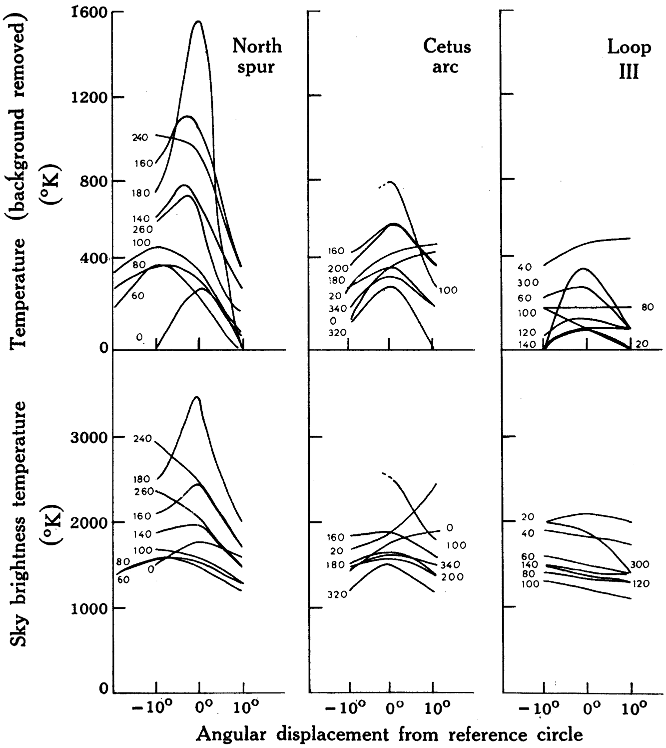

Fig. 4.—Constant azimuth profiles of the spur features showing the observed temperatures (*below*) and the temperatures after removal of the radiation distribution in Figure 3 (*above*).

A direct assessment of its magnitude, using synchrotron emission theory, would require a knowledge of field and electron conditions more detailed than present experimental techniques allow, since, although the existence of a magnetic field associated with the arm has been firmly established, its exact magnitude and form remain uncertain. Present experimental results are inadequate to permit a choice between the number of helical and aligned field models that have been proposed (Hoyle and Ireland 1961; Wentzel 1963; Hornby 1966). At best, the large number of independent investigations may be used to set upper and lower limits to the field and electron parameters required to compute the arm emissivity.

In the subsections that follow current independent results concerning the local field and electron conditions are reviewed as a prerequisite to setting up a model arm with a maximum contribution to the background radiation.

(a) *Local Magnetic Field*

The orderedness of the local arm field near the Sun has been established from the detection of polarized radio emission. Polarization results at 408 MHz from northern and southern hemispheres have been collected by Mathewson and Milne (1965), who found that the polarized emission is confined to a band 60° wide containing the great circle and crossing the plane at $l = 340°$ and 160°. Polarization is expected from nearby synchrotron radiation in directions at right angles to the axis of an ordered local field. The field direction implied by the band of polarization is thus $l = 250°$ and 70°. This direction for the field was supported by the Faraday rotation observations of polarized sources by Gardner and Davies (1966), which showed that for $b > 20°$ reverse rotations occurred in the zone $\sim 160° < l < \sim 340°$ to those in the zone $\sim 340° < l < \sim 160°$.

The radio polarization results give a good indication of conditions out to about 150 pc from the Sun (Mathewson and Milne), but there is evidence that the ordered field extends much further out. Field alignment in directions $l = 242°$, 235°, and 230° are indicated from the optical polarization of stars out to 250, less than 600, and more than 600 pc respectively (Schmidt 1956; Behr 1959; Serkowski 1962). The alignment compares well with the direction $l = 240°$ of the arm itself defined by O, B stars, HII regions, and galactic clusters (Becker 1964).

Hornby (1966) pointed out that radio brightness results also indicated a much more extended ordered field, since a brightness minimum occurs at $l = 240°$. This direction corresponds to a line of sight along the local field. If the order of the field were confined to solar regions and fields were tangled elsewhere (as would be expected from supernovae remnants), then a maximum in brightness would be expected in this direction.

The magnitude of the field may be estimated independently of brightness results by using stellar polarization and the Zeeman splitting of the 21 cm spectral line. The field value determined from optical polarization results depends on the nature of the polarizing particles. Visvanathon (1966) found that the observed wavelength dependence of polarization and extinction favoured dirty ice as the interstellar grains. The field magnitude required in this case has a minimum value of 3×10^{-5} gauss. Zeeman splitting of the 21 cm spectral line allows a completely independent measurement of field strength within neutral hydrogen clouds. Clouds studied so far indicate an upper limit of 10^{-5} gauss and in one case 5×10^{-6} gauss (Davies 1965). Although these results give conditions within clouds only, it seems unlikely that there is much variation in field conditions between cloud and intercloud regions, since the presence of a large-scale ordered field has been established.

The two independent methods of field determination therefore do not permit a choice between a high ($> 10^{-5}$ gauss) and a low ($< 5 \times 10^{-6}$ gauss) value for the magnitude of the aligned field. For the purpose of computing the upper limit of emissivity from the local arm, a value of $H = 10^{-5}$ gauss will be used here. This value is consistent with the conclusions of Okuda and Tanaka (personal communication) based on an analysis of the disk emission. Although a higher value of magnetic field is allowed by the optical evidence, the lower one was chosen to provide some compensation for simplicity of the model used. It is, for instance, most unlikely that the arm field is uniform to its extremities, dropping to zero outside the arm, as we will assume. Furthermore, it is possible that the arm emission originates in patches or filaments rather than uniformly. Both these situations would cause the radiation calculated from the simple model to be unrealistically high, and hence the choice of the lower value of H.

The direction taken for the model arm field will be that implied by the polarization results (that is, $l = 250°$ and $70°$). These results give the most accurate estimate of the alignment near the Sun, which is the region responsible for the medium and high latitude radiation to be studied.

(b) *Electrons within the Local Spiral Arm*

The population of electrons at any galactic location may be described by the function $n(\gamma,\phi,\theta)\,\mathrm{d}\gamma\,\mathrm{d}\Omega$, which specifies the number of electrons per unit volume with energies within the range defined by $\mathrm{d}\gamma$ and velocities directed within $\mathrm{d}\Omega$. For energies of interest here, this function may be approximated by a power law and thus

$$n(\gamma,\phi,\theta)\,\mathrm{d}\gamma\,\mathrm{d}\Omega = \bar{n}(\phi,\theta)\,\gamma^{-m}\,\mathrm{d}\gamma\,\mathrm{d}\Omega \qquad \mathrm{cm}^{-3}, \tag{1}$$

where ϕ and θ define the velocity direction and γ is the electron Lorentz factor ($\gamma = E/m_0 c^2$). Some indication of the values of the unknowns, $\bar{n}(\phi,\theta)$ and m, applicable to the galactic electron population near the Sun is given by the results of high altitude electron flux measurements made from balloons. At low energies these measurements have limited value, since the flux of galactic electrons is distorted by solar modulation and contaminated both by secondaries generated in the overlying atmosphere and by electrons from the re-entrant albedo. These influences, however, become less dominant as electron energy increases and for $E > 2$ GeV the Earth flux, with the exception of its directional distribution, may be taken as being characteristic of a far more extended region.

Observations in the vicinity of the Earth indicate an isotropic distribution of velocity directions, but we are not immediately justified in assuming isotropy throughout the arm because of the possible influence of the Earth's magnetic field on the local flux. The likelihood of a genuine isotropy depends on the origin of the electrons. Although some generation mechanisms do establish an anisotropic flux, small field variations will act to re-establish randomness in the velocity directions and it is therefore unlikely that gross anisotropy exists. The absence of a narrow bright band of emission lying along a great circle in the celestial sphere (Tunmer 1958) further supports this contention, and it will therefore be assumed that the galactic population has an isotropic directional distribution. Equation (1) then becomes

$$n(\gamma)\,\mathrm{d}\gamma = n_0\,\gamma^{-m}\,\mathrm{d}\gamma \qquad \mathrm{cm}^{-3}. \tag{2}$$

Finally, before using the measured flux values to compute the local arm radiation, it is necessary to make the assumption that n_0 and m are constant along each line of sight through the arm. Since this study is confined to latitudes $> 10°$, corresponding to short lines of sight through the arm, this assumption is not unreasonable, even though a difference in m between arm and interarm regions has been reported (Bridle 1967).

We turn now to the flux measurements themselves. In Figure 5 results from a number of balloon experiments, which were made during the recent solar minimum, are presented (Bleeker *et al.* 1965; L'Heureux and Meyer 1965; Waddington and Freier 1965; Okuda and Tanaka, personal communication). The experiments chosen were those in which the differential energy spectrum was measured specifically. Other results of the integral spectrum were not included, since their representation in the differential form is strongly dependent on the value of m assumed (Felton 1966).

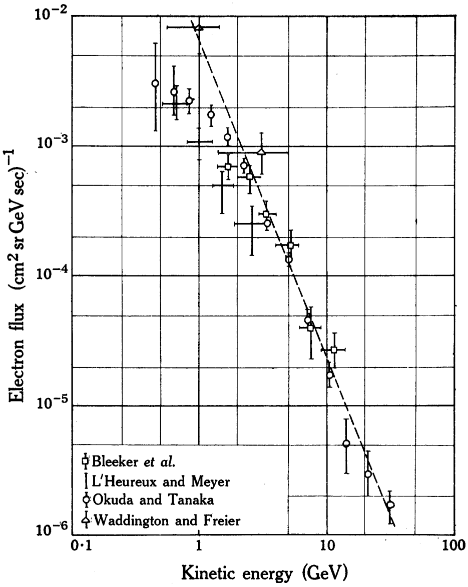

Fig. 5.—Results of balloon measurements of the differential energy spectrum of electrons for $0 \cdot 1 < E < 100$ GeV, made during the recent solar minimum.

Electrons contributing to the radiation at 85 MHz in a field of 10^{-5} gauss have energies centred on $0 \cdot 7$ GeV, which, unfortunately, lies within the zone where the measured flux depends on solar influence and secondary contamination. To overcome this we may extrapolate from the more accurate higher energy results, on the assumption that there is no change of slope in the spectrum for the range $0 \cdot 7 < E < 2$ GeV. The dashed line in Figure 5 shows the flux value to be adopted in this analysis, which corresponds to

$$N(E)\,\mathrm{d}E = 0 \cdot 7 \times 10^{-2} E^{-2 \cdot 4}\,\mathrm{d}E \qquad (\mathrm{cm^2\,sr\,GeV\,sec})^{-1}.$$

(*c*) *Calculation of Radiation from the Local Arm*

The equivalent black body temperature T (°K) observed in the direction of an isotropic synchrotron emission region is given by the expression (Felton and Morrison 1966)

$$T = 5 \cdot 33 \times 10^{11} (4 \cdot 9 \times 10^{2})^{3-m}\, n_0(R)\, H^{(1+m)/2}\, \nu^{-(m+3)/2}, \tag{3}$$

where H (μgauss) is the field, ν (MHz) is the frequency, R (kpc) is the dimension of the emission region, and n_0 is the coefficient of the electron energy density function (equation (2)) in CGS units. When the radiation is from an ordered field region, and $m \simeq 2 \cdot 4$, as in the present case, the term $H^{(1+m)/2}$ in equation (3) is replaced by $1 \cdot 25\, H^{(1+m)/2} \sin^{(1+m)/2} \theta$, where θ is the angle between the line of sight and the field.

In the previous subsections maximum values have been assigned to H and n_0 in accordance with the aim of finding the local arm with maximum emissivity that is consistent with available independent data. It remains to determine R, the dimension of the emitting region of the arm along the line of sight. The value assumed by R, for a particular observing direction, is a function of the profile of the arm, the location of its axis relative to the Sun, and, to a lesser extent, its radius of curvature from the galactic centre. Since this study is restricted to medium and high latitudes the assumption of infinite radius of curvature for the arm may be made without loss of accuracy.

The extent of the arm above the galactic plane may be deduced from the width of the band of radio emission along the galactic plane. A value of 250 pc to the half-power point was derived by Mills (1959), using the results of a high resolution 85 MHz survey. A similar conclusion was reached by McGee and Milton (1964), based on observations of neutral hydrogen. In the present study a simple model arm with uniform emissivity to its extremities is adopted, having a half-width of 400 pc perpendicular to the galactic plane. The axial ratio of the arm is taken to be $< 2 \cdot 5$ (Fujimoto 1961).

The position of the Sun relative to the arm axis may be deduced if the assumption is made that the radiation remaining after subtraction of both spur and local arm contributions from the background intensity is symmetrically distributed about the plane $l = 0°$. It will be recalled that the basic assumption behind this part of the analysis has been that the halo contribution is minimized. This new assumption simply defines the "halo" remaining to be symmetrically distributed about $l = 0°$.

Using equation (3) and the various parameters determined earlier, the radiation from a number of model arms was computed. To fulfil the requirement of symmetry of the remaining radiation two conditions had to be met. The first was that the Sun had to be immersed in the arm, and displaced slightly from its axis in the direction of the anticentre. This configuration was necessary to explain the greater high latitude intensity towards $l = 0°$ compared with that towards $l = 180°$. The second was that the field associated with the arm had to expand slightly about the axis $l = 250°$ instead of being strictly parallel to it. Although there is evidence for the latter situation from the asymmetry of the band of background polarization (Mathewson and Milne 1965), the former condition detracts from the feasibility of the model, since it contradicts neutral hydrogen evidence that the Sun is on the inside edge of the local arm.

The radiation from the model arm that is consistent with the field and electron values and the symmetry condition is shown in Figure 6. The arm profile is also shown in this figure. This has a minor axis of 400 pc and an axial ratio of 2, with the Sun displaced 100 pc from the axis in the direction of the anticentre. The magnetic field associated with the arm has a magnitude of $1 \cdot 2 \times 10^{-5}$ gauss and expands from an axis along $l = 250°$ with $7\cdot5°$ semi-axis angle. The electron energy density spectrum taken for the model was

$$N(E)\,\mathrm{d}E = 0\cdot7\times10^{-2}E^{-2\cdot4}\,\mathrm{d}E \qquad (\mathrm{cm^2\,sr\,GeV\,sec})^{-1}.$$

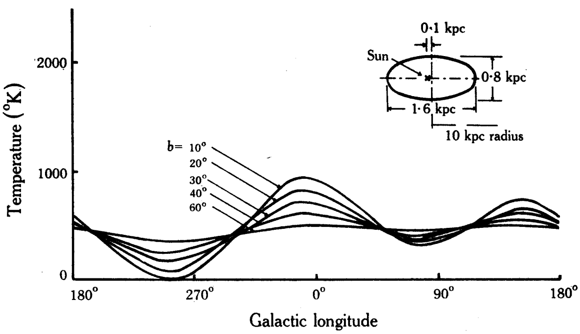

Fig. 6.—Contribution to the background radiation from the model arm adopted for latitudes $b = 10°$, $20°$, $30°$, $40°$, and $60°$.

In Figures 7(*a*) and 7(*b*) the background temperature variation before and after subtraction of the radiation associated with the model is shown. The model satisfies the symmetry conditions to within the accuracy justified by the arbitrariness of the method used to assess the contribution of the spur features. Truly symmetric profiles are indicated by the dashed lines in Figure 7(*b*).

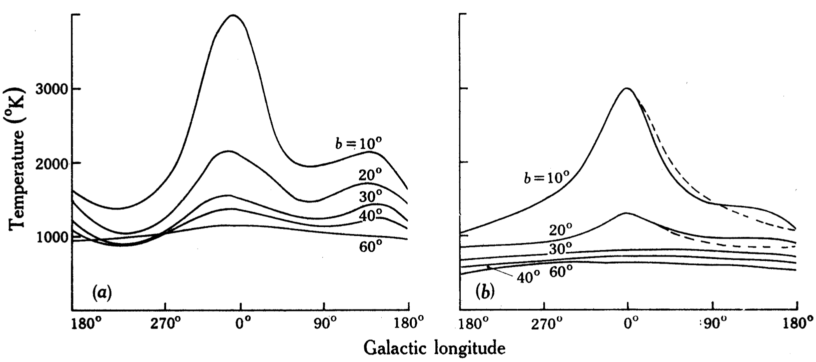

Fig. 7.—Constant latitude profiles of the background brightness temperature (*a*) after radiation from the spur features has been subtracted and (*b*) after radiation from both the spur and the local arm model has been subtracted.

Before proceeding it is worth examining the plausibility of the assumptions that have been made in developing the model. The location of the Sun and the nature of the field have already been referred to. The magnitude of the local arm contribution is very sensitive to the value assumed for the local arm field. A field of $1\cdot7\times10^{-5}$ gauss would result in an arm contribution double the size of the one adopted (derived from a field of $1\cdot2\times10^{-5}$ gauss). On the other hand, a model with a field of 8×10^{-6} gauss and circular cross section with 400 pc radius would have made only a minor contribution to the background. A similar conclusion would follow if synchrotron emission regions were confined to clouds instead of being uniformly spread through the arm. A check on the emissivity value adopted is the temperature of the outer arm and this may be observed as the disk temperature in the direction of the anticentre. The outer arm temperature of 1000°K compares reasonably well with the value of 1800°K, which is the temperature of the model arm observed along its cross section major axis, considering the latter is an upper-limit estimate. The process of elimination of the local arm radiation from the background is also fairly dependent on the orderedness of the field. Mills (1959) found step increases in the disk emission when looking along the spiral arms, indicating some departure of the field from strict alignment with the arms, but in the present study (confined to latitudes of $> 10°$) lines of sight are sufficiently limited for one to be confident of the assumption of orderedness. Some departure from this condition obviously occurs in the spur-feature sources. If any of the major assumptions adopted are in error, i.e. if the arm contributes only a minor proportion to the background or if some other kind of model is more appropriate, then another large-scale emission distribution must be found to explain the asymmetry of the background emission about $l = 0°$.

V. Remaining Radiation—Halo and Extragalactic Components

The distribution shown in Figure 7(a) represents the portion of the background radiation that cannot reasonably be ascribed to either the spur features or the local arm. It consists of a galactic component exhibiting symmetry about the plane $l = 0°$ and an isotropic extragalactic component. The galactic component is not characteristic of a uniform spherical emitting halo since it shows an extended minimum in the direction of the pole.

It is beyond the scope of this discussion to consider a detailed halo model to fit the derived remainder distribution. Nevertheless, it is interesting to note that the remainder distribution that has been derived is consistent with a galactic model proposed by Sciama (1962). According to this theory, the galactic magnetic field is not closed and the halo is that part of the intergalactic gas distribution under gravitational control of the Galaxy. As a result of this gravitational control, electrons and field are concentrated according to the mass distribution of the Galaxy and the halo emissivity of this model thus decreases from the galactic plane and centre. Such a model would produce both the low latitude increase in temperature towards the galactic centre and the high latitude extended minima in the direction of the pole, which are apparent in the present results in Figure 7(b).

A test for the similarity of the derived "remainder" emission and the emission from a *uniform* disk is given by considering the latitude variation of their brightness. For a uniform disk T is proportional to $\operatorname{cosec} b$, where b is the latitude. In Figure 8 brightness temperatures for three longitudes (derived from Fig. 7(b)) are plotted against $\operatorname{cosec} b$. In directions towards the galactic centre, where nonuniformity in the emission is to be expected, there is considerable departure from linearity. However, at $l = 240°$ the linear region extends from 10° to 60°, consistent with a model in which extragalactic sources contribute E and the remainder originates in a disk-shaped "halo" contributing A to the pole temperature, where

$$A \operatorname{cosec} 10° + E = 1340°\mathrm{K}, \qquad A \operatorname{cosec} 60° + E = 580°\mathrm{K}.$$

These equations give $A = 165°K$ and $E = 390°K$. The value for E is well within the range of values for the extragalactic component given by independent measurements (results of which are summarized in Yates and Wielebinski 1966).

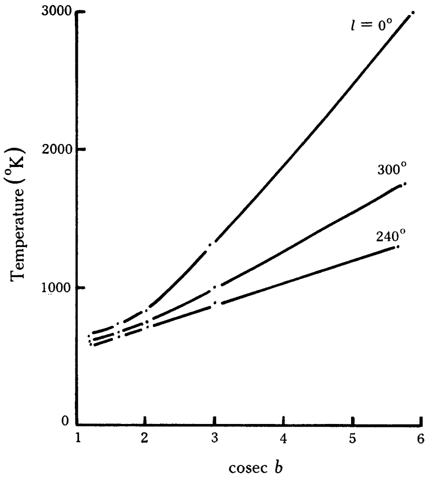

Fig. 8—Variation of cosec b with the brightness temperatures given in Figure 7(b) for $l = 0°$, 240°, and 300°.

VI. Conclusions

A study of the complete sky distribution of the metre wavelength continuum emission has led to the following general conclusions.

(1) Apart from the general concentration of emission towards the galactic plane and centre, the distribution is characterized by a number of ridges or spurs extending from the plane to high latitudes in each hemisphere.

(2) Most of the spurs can be traced along small circles in the celestial sphere, some of which cross the galactic plane. This configuration favours the theory that the spur radiation has local origin. On the other hand, there appears to be a concentration of the stronger features towards the galactic centre, supporting the theory that the spurs are a manifestation of a large-scale galactic phenomenon.

(3) If it is assumed that the spur features are of local origin, the apparent small circle orientation of the features may be used, together with the assumption of symmetry of the remaining emission about the galactic plane, as a basis for the subtraction of the spur contribution from the background.

(4) The remaining emission is not symmetrically distributed about latitude $l = 0°$. It may be explained as being the sum of emission from a model local arm whose emissivity is consistent with the upper limits indicated by independent data, and an additional component that does show symmetry about $l = 0°$.

(5) The additional component has broad minima in the direction of the galactic pole, in which direction it contributes about half the observed intensity. It is satisfactorily explained by the integrated extragalactic emission and a small galactic component, resembling more closely a uniform disk than a uniform spherical halo.

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