PAPER 79

GALACTIC STRUCTURE AT METER WAVELENGTHS

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1. INTRODUCTION

The study of meter-wave radiation from the Milky Way has been hampered, until recently, by the difficulty of obtaining sufficiently high resolution. Observations using interferometers had early indicated the probability of fine structure in the radiation distribution, but the interpretation of these observations was not unique. It was not until the Sydney 3.5-m cross-type radio telescope (beamwidth 50 minutes of arc) was put into operation in 1954 that it became possible to study the distribution of meter wave emission in detail. The observational program with this instrument, together with most of the data analysis relating to the galactic emission, has now been completed and some of the results have already been described [1, 2]. It seems appropriate at this time to give a rather detailed account of the results of this completed work and to discuss its astronomical and astrophysical significance.

It is possible to distinguish three basic components of the galactic emission: (1) an extensive component of small axial ratio, displaying only a moderate concentration toward the plane of the Milky Way and the galactic center, which is here called the corona; (2) a much brighter component, closely confined to the galactic plane and concentrated in the inner regions of the Galaxy (the disk); (3) a population of quite intense radio sources of relatively small angular size distributed along the well-defined ridge-line of the disk component.

Other authors, using instruments of lower resolution, have suggested a different subdivision of the galactic components [3, 4], in particular they have quoted a uniform spherical distribution, or "halo," and a distribution wider than component (2) concentrated toward the galactic center. It seems possible that these two components together comprise the "corona"; but on the basis of the present results such a subdivision does not appear to be justified. Accordingly the corona will be considered as a single physical system. At some longitudes there are discontinuities in the latitude distribution of the disk component which also might suggest a component intermediate between the disk and corona; however, a more satisfactory explanation is that such discontinuities result from the pronounced concentration of the disk component to the spiral arms.

Because of the vast amount of fine detail visible with the 3.5-m cross, it has not proved feasible to construct contour plots of the radio emission over the whole sky. Instead, a map has been prepared of the distribution in

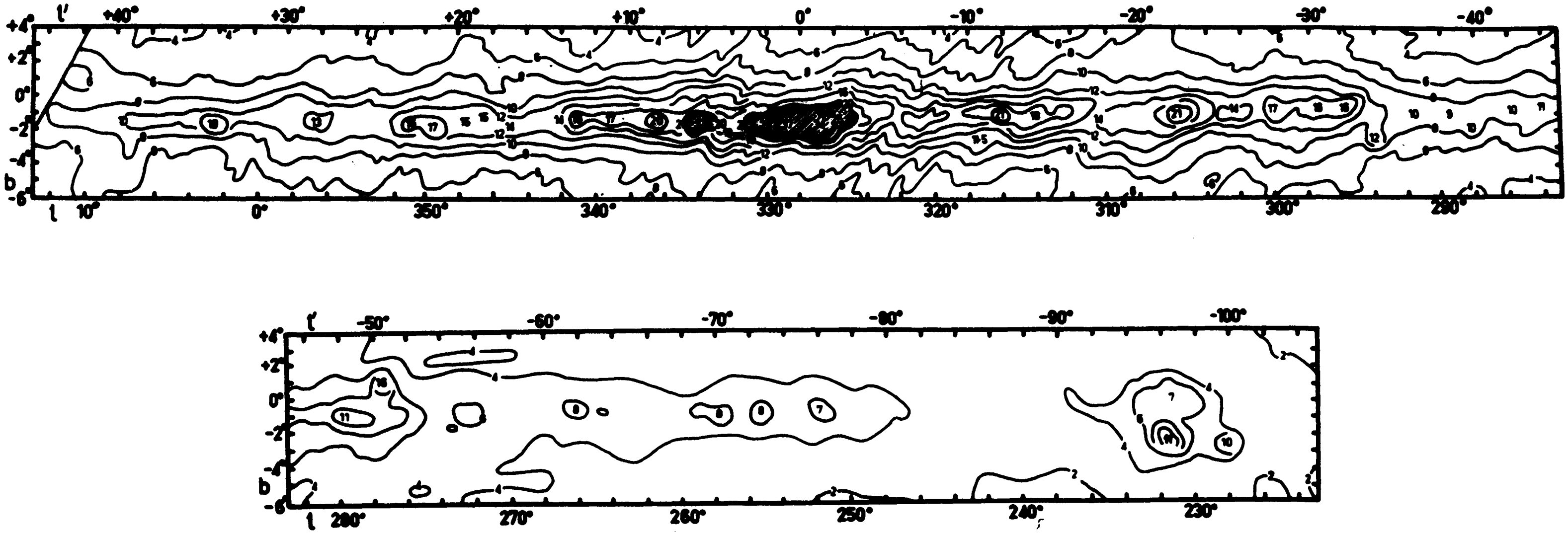

FIG. 1. Contours of apparent brightness temperature, T_b, near the galactic plane between $l = 223$, 0, and 13 degrees; the unit of T_b is 1000 °K. Temperatures not inserted in contours are peak temperatures and generally indicate a discrete source. Within the shaded areas $T_b > 20{,}000$ °K. Conventional galactic longitudes l from the Lund tables are given on the bottom and modified longitudes l' on the top.

a strip 10 degrees wide stretching along the galactic plane between longitudes 223 through 0 to 13 degrees; a simplified reproduction of this map is shown in Fig. 1. Also a " smoothed " contour map over the whole sky has been constructed by plotting the mean brightness observed over areas of a few square degrees centered on a grid measuring $\frac{1}{2}^{h}$ in right ascension by about 5 degrees in declination; this is shown in Fig. 2. The relationship between the disk and coronal components is illustrated in Fig. 3 which displays two constant-longitude sections through the Milky Way at longitudes chosen so as to avoid the strong sources of component (3).

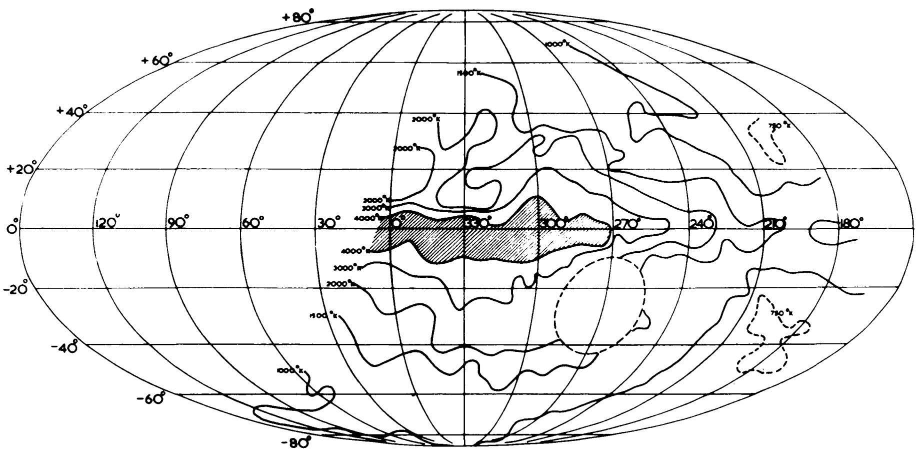

FIG. 2. "Smoothed" contours of apparent brightness temperature, T_b, over the whole region accessible to the instrument. Within the shaded area $T_b > 4000$ °K.

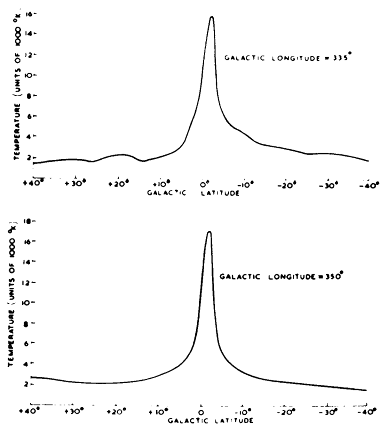

FIG. 3. Some constant longitude sections across the galactic plane, illustrating the relationship between disk and corona.

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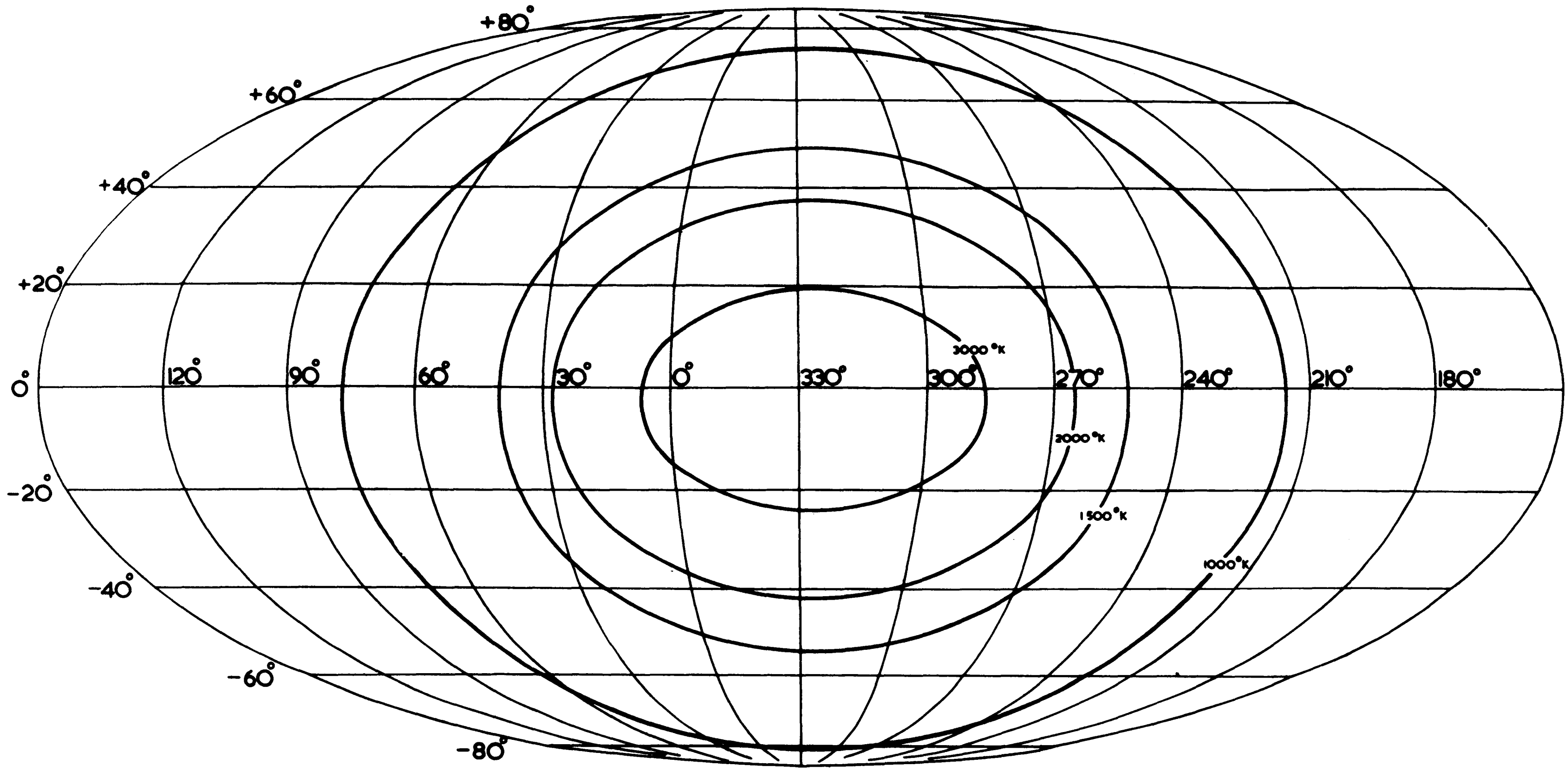

FIG. 4. A family of elliptical contours fitted to the "smoothed" contours of Fig. 2 and representing the large-scale distribution of the corona.

2. THE CORONA

It appears from Fig. 2 that the smoothed distribution of radio emission at high latitudes still shows a great deal of complex structure. Some of this may be the result of instrumental effects which are likely to be significant when using a cross-type or similar aerial. The questions to be answered are: how much of the fine detail is instrumental in origin, how much is galactic, and how much is extragalactic?

An obvious approach is to investigate the variability of the background emission as a function of galactic coordinates. For this purpose a variability index has been derived from the temperature data used in constructing Fig. 2 by a differencing procedure. It is found that the mean value of the index within about 45 degrees of center is nearly double what it is elsewhere. The implication is that the extra contribution either originates in a more or less spherical volume with a radius of approximately 5 kiloparsecs surrounding the galactic nucleus, or is the result of spurious instrumental responses to the high emission near the nucleus. The extra fluctuations observed in this region are of the order of one per cent of the excess-brightness temperatures close to the galactic center so that exclusion of the latter possibility would be a delicate matter with any instrument, particularly so with a cross-type or similar aerial which is rather subject to small spurious responses at large angles from the main beam. This question is best resolved by a detailed comparison between the results obtained with different instruments of comparable performance. But such a detailed comparison is not yet possible over the region analyzed here.

Also it is not clear whether the remaining variability observed over the whole area accessible to the instrument is primarily of galactic or extragalactic origin. At least some of the variability may have an extragalactic origin, since Hanbury Brown and Hazard [5] and Kraus [6] have found a general correlation between concentrations of galaxies and radio brightness, particularly along the belt of the "local supergalaxy." Hill [2] has studied the 3.5-m cross-aerial records in detail in this region but has not confirmed this picture; there are large bright areas that do not correspond with high galaxy density (at least with the limited available optical data for southern galaxies) in addition to galaxy concentrations that show no excess emission.

Thus the question at present remains completely open, and to determine the gross features of the spatial distribution of the coronal component the irregularities will simply be ignored and the contours of Fig. 2 fitted to a family of concentric ellipses as illustrated in Fig. 4. Because of the severe distortions of the observed contours in northern latitudes the ellipses have been defined mainly by the relatively smooth southern contours. Subject to the uncertainties introduced by these processes the contours represent the large-scale distribution of the coronal component. They appear to be centered at $l = 326$ degrees, $b = -3$ degrees rather than at the center defined by the disk component $l = 327\overset{\circ}{.}8$, $b = -1\overset{\circ}{.}4$, but the difference may not be significant.

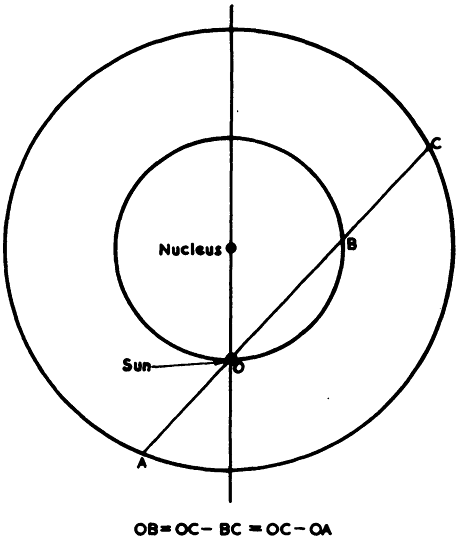

FIG. 5. Illustrating the procedure for obtaining the infra-solar brightness distribution.

The distribution of emission between the sun and the galactic nucleus is obtainable from these elliptical contours on the assumption that the emission originates in a family of uniform concentic spheroids. Separation of the radiation originating outside the spheroid whose surface passes through the sun is possible in any direction by subtracting the brightness temperature observed in the opposite direction. This procedure is illustrated in Fig. 5; it allows also for any isotropic extragalactic component. Fig. 6 shows the estimated distribution in longitude of the coronal component at $b=0$, and the distribution in longitude after subtracting radiation originating outside the solar distance. This may be converted to a radial distribution, assuming circular symmetry, by well-known methods [7, 8]. The resulting radial distribution in the galactic plane is shown in Fig. 7; at the solar distance the emission has fallen to about 2/3 the central emission. The z distribution may be obtained, in general, by fitting to the observed latitude distribution a family of ellipsoids of emissivity defined by the radial distribution and of variable axial ratio. For each ellipsoidal distribution, of constant axial ratio, α, it follows from simple geometrical concepts that the ratio of the brightness temperature at latitude b

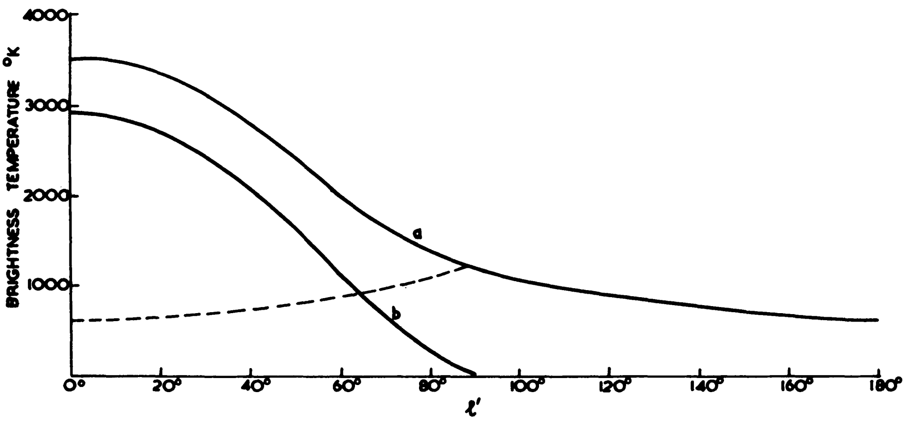

FIG. 6. The longitude distribution of the coronal component at $b=0$: (a) directly observed; (b) the infra-solar distribution.

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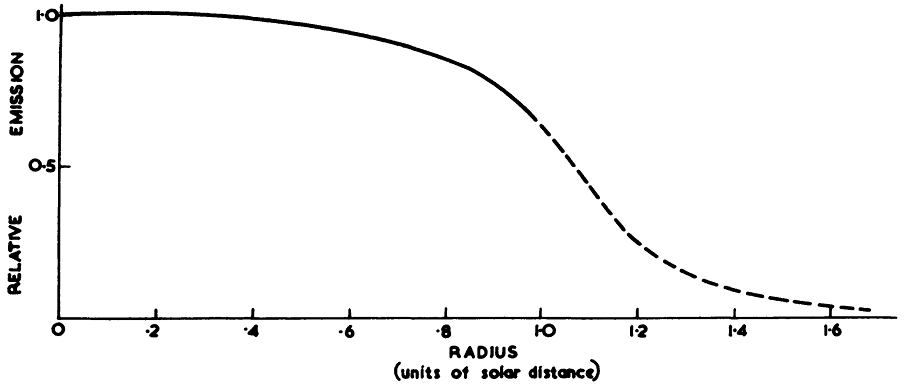

FIG. 7. The radial distribution of the corona calculated on the assumption of radial symmetry. The dotted extension represents an extra-solar distribution consistent with the data: however, it is not unique.

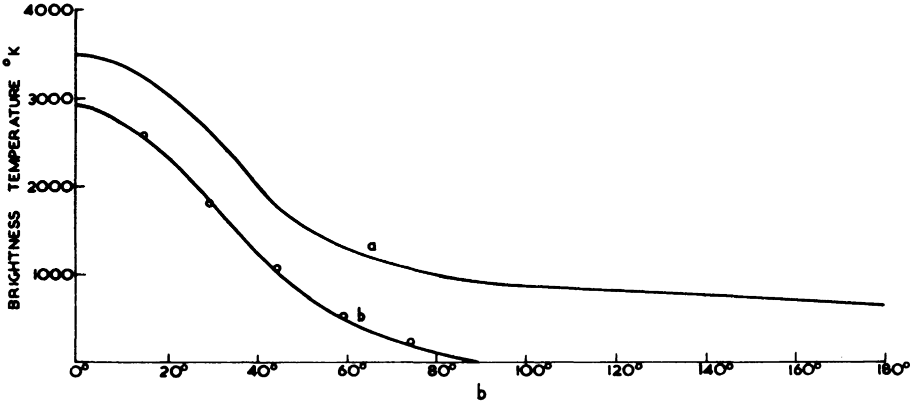

FIG. 8. The latitude distribution of the coronal component at $l' = 0$. (*a*) Directly constructed from the ellipses of Fig. 4. (*b*) The infra-solar distribution. The circles represent temperatures calculated from the radial distribution curve of Fig. 3 on the assumption of an ellipsoidal spatial distribution of axial ratio 1.45.

to the temperature at modified longitude* l', defined by $\alpha \tan|b| = \tan|l'|$, is given by

$$r = \sqrt{\frac{1+\tan^2 b}{1+\tan^2 l'}}\,. \qquad (1)$$

In the present case a constant axial ratio of 1.45 gives a good fit, as shown by the calculated points on the observed latitude distribution curve of Fig. 8.

The problem of deriving the spatial distribution of the coronal emission

* l' is taken to be zero at the galactic center ($l = 328$ degrees) and to take values between 0 and ± 180 degrees (Fig. 1).

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beyond the solar distance is more difficult and does not have a unique solution. It is first necessary to estimate the integrated effect of all extragalactic sources and subtract it from the observed temperatures. This extragalactic component may be estimated, using various cosmological models, by making assumptions about the radio-luminosity function of extragalactic objects. However, the observational data relating to such a luminosity function are very scanty and quite insufficient for a definitive result. A more promising approach has been instituted by Shain, based on observations of remote H II regions at a 15-m wavelength. The most useful object is the giant emission nebula 30 Doradus in the Large Magellanic Cloud and the surrounding H II regions. These form a system of large angular size which is opaque to 15-m radiation therefore eliminating the extragalactic radiation beyond. At the same time it is well outside the galactic corona so that it should be possible to separate the galactic and extragalactic components. Uncertainties arise because of the present lack of knowledge concerning the precise extent of the H II regions and the thickness of the radio-emitting region in the LMC itself. Nevertheless, Shain, in a preliminary analysis (personal communication), has been able to set an upper limit of about 25,000 °K to the extragalactic component at 15 m and to estimate a most probable value of roughly 15,000 °K. These compare with a sky temperature at high galactic latitudes of 50,000 °K, suggesting that not more than one half, and probably about one-third, of the observed emission in the colder part of the sky is of extragalactic origin. It will be assumed that the spectra of high-latitude galactic and extragalactic components are identical, which leads to the conclusion that the most probable extragalactic contribution at 3.5 m is of the order of 250 °K, with a probable upper limit of 400 °K. Subtracting a temperature of 250 °K from the observed temperatures we find that the coronal emission in the direction of the anti-center is of the order of 400 °K, compared with an estimated 1500 °K arising between the sun and the galactic nucleus. The distribution cannot be uniquely determined but various models may be fitted to the data. If, for instance, the emission is assumed to be uniform in the galactic plane out to a certain cut-off distance, then comparison of the temperature at $l' = -90$ degrees (1000 °K) with the temperature at $l' = 180$ degrees (400 °K) yields, from simple geometrical considerations, a cut-off at a radius of about 1.4 solar distances. However, there is a discontinuity at the solar distance and the model is otherwise implausible, the emission undoubtedly falling off smoothly to much greater distances. The dotted extension of the radial distribution of Fig. 7 is consistent with the data.

It remains to compute absolute values for the emission of the coronal component. It is easy to show that, providing there is no absorption,

$$E = \frac{8\pi k \Delta T}{\lambda^2}, \tag{2}$$

where E is the emission per unit bandwidth per unit volume, k is Boltzmann's constant, λ the wavelength, and ΔT the increment in brightness temperature per unit distance along the line of sight. The latter may be obtained at any

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radius in the galactic plane by normalization of the radial distribution curve in Fig. 7 so that

$$2\int_0^{R_o} \Delta T(r)\, dR = 2900\ ^\circ\mathrm{K}\ ,$$

where R_o is the solar distance. Taking R_o equal to 8 kiloparsecs we find that the central emission is 0.2 °K/parsec, which corresponds to a value for E of 5.4×10^9 watts $(c/s)^{-1}pc^{-3}$. By integration through the ellipsoidal distribution, the total emission is then found to be 1.1×10^{22} watts $(c/s)^{-1}$.

3. THE DISK

It appears that the bright band concentrated close to the galactic plane cannot be attributed to the integrated emission of the class of radio sources visible in Fig. 1, for the strong sources are more closely concentrated to the plane than is the emission band. Consequently, it is legitimate to subtract the observable sources as well as the coronal and extragalactic contributions to determine the properties of the disk component alone.

The resulting distribution in longitude of the temperature at the ridge-line of the disk component is shown in Fig. 9: the distribution is rather complicated and also asymmetrical, with higher temperatures at negative l'. The latter feature is also apparent in other surveys (e.g., Piddington and Trent [9]). An analysis based on the assumption of radial symmetry is therefore open to question; however, if we restrict attention to the gross features of the distribution it should not be misleading. An "equivalent" radial distribution has been derived in detail for the southern side of the galactic center and compared qualitatively with the distribution on the northern side, for

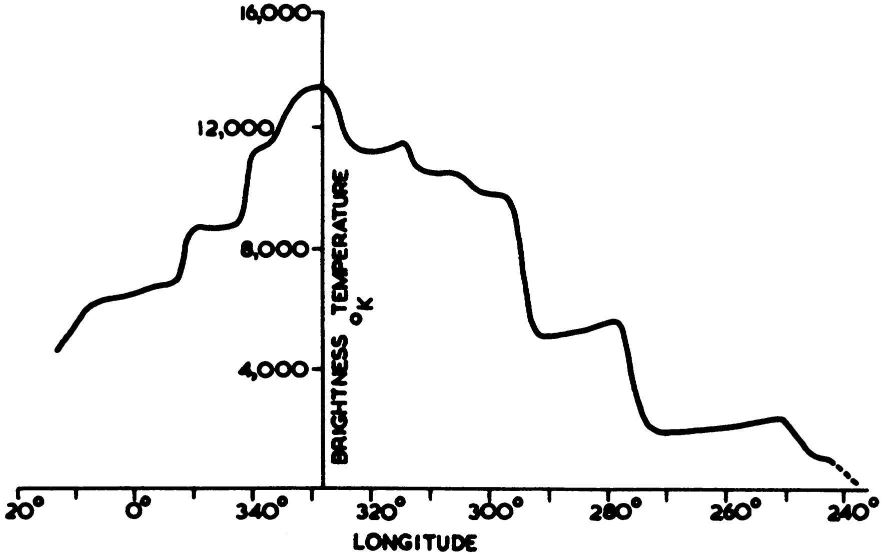

FIG. 9. The longitude distribution of the disk component after subtracting the recognizable sources and the coronal and extragalactic components.

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which the data are incomplete. Another difficulty with this component is that the extra-solar distribution displays irregularities and does not decrease smoothly from a longitude of 238 degrees ($l' = -90$ degrees) to the anti-center, in fact the minimum is at a longitude of about 193 degrees ($l' = -135$ degrees). To obtain an estimate of the infra-solar distribution, a constant temperature of 1000 °K has been subtracted from the total emission: these derived temperatures might be in error by several hundred degrees because of the uncertainty in this figure.

The equivalent radial distribution is shown in Fig. 10. The pronounced "steps" in the observed distribution at longitudes 295 and 277 degrees are reflected in the sharp peaks in the radial distribution at radii of $0.53\,R_o$ and $0.78\,R_o$, where R_o is the solar distance. These peaks correspond closely with the directions in which the line of sight passes tangentially along a spiral arm defined by the 21-cm hydrogen-line radiation [10]. The two peaks are particularly clearcut and suggest that, in the outer regions at least, the "disk" component is confined entirely to the spiral arms, with a radial width to the half-emissivity points of the order of 500 parsecs.

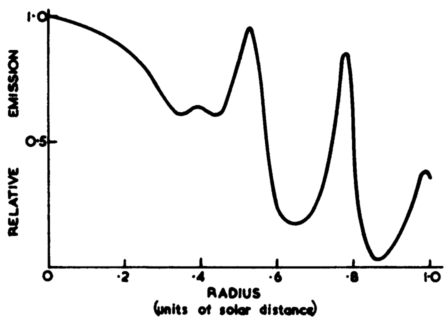

FIG. 10. The radial distribution of the disk component calculated from the longitude distribution south of the nucleus on the assumption of radial symmetry.

The peak at $0.98\,R_o$ is less clear, the relative uncertainties in the temperatures being much larger in this region; however, it also corresponds roughly with the direction of a hydrogen-line spiral arm. It therefore appears that in general one may tentatively identify such "steps" in the 3.5-m radiation with the directions tangential to spiral arms. It is interesting to pursue this idea further.

There is a small but quite definite step visible at a longitude of 312 degrees (equivalent radius $0.26\,R_o$), and a still smaller one at 305 degrees (radius $0.39\,R_o$), but the effect of these has been smoothed out in the analysis of the radial distribution. According to Kerr (personal communication) the latter also corresponds closely with an inner spiral arm visible in the hydrogen line. On the northern side of the galactic center two similar steps are clearly visible, at longitudes of 341.5 and 351 degrees (radii $0.39\,R_o$ and $0.65\,R_o$). All these equivalent radii are regularly spaced, being very close to multiples of $0.13\,R_o$, and this suggests that they may define a regular spiral pattern. This, in fact, appears to be the case, as demonstrated in Fig. 11. Here two equiangular spirals are drawn commencing at equal radii 180 degrees apart and defined by the equation:

$$R = 0.22\,R_o \exp\left(0.12\,\theta + \begin{Bmatrix} 0 \\ \pi \end{Bmatrix}\right). \qquad (3)$$

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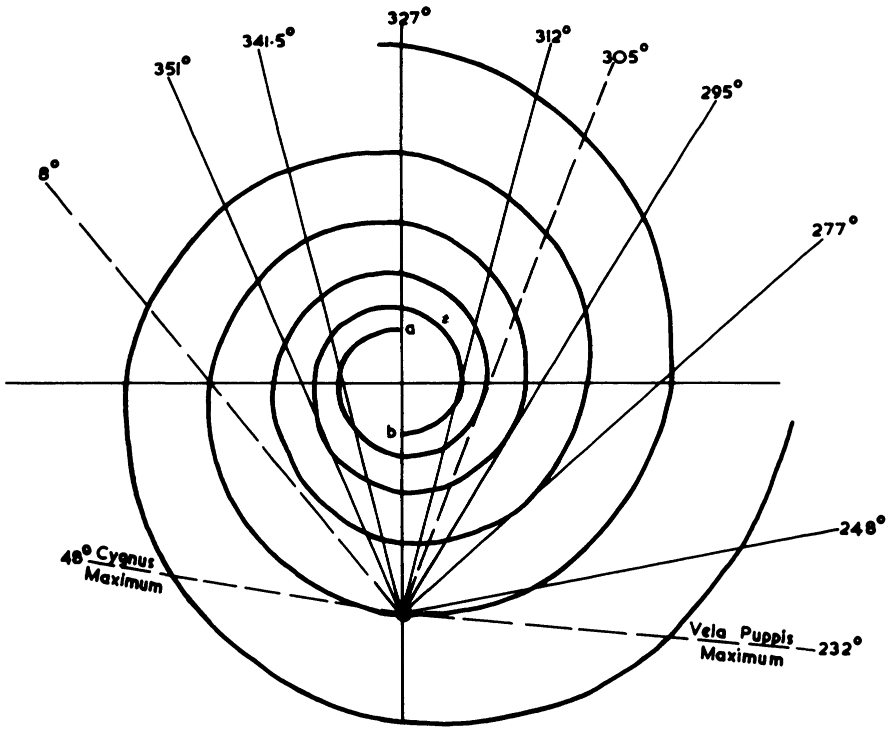

Fig. 11. The spiral pattern of the Galaxy as defined by "steps" in the longitude distribution of the disk component. The directions of the steps are indicated by the lines radiating from the solar position. When the line is dotted, the step is not very pronounced. The directions of the two pronounced maxima in Cygnus and Vela are also shown by dotted lines.

The center of the system is taken at longitude 327 degrees for the best fit, and the directions of "steps" in the 3.5-m radiation are indicated. The step at longitude 305 degrees is shown dotted as it is very small; also dotted is an abrupt change of gradient at longitude 8 degrees. The fit is startlingly good and could be even better if a slightly different exponent were used in the expression for spiral a: it is difficult to avoid the conclusion that we are defining the basic spiral structure of the Galaxy. Further weight is given to this conclusion by the well-known maxima in the meter wave emission in the constellation of Vela with a longitude at the center of the maximum of 232 degrees, and in Cygnus (Cygnus X) with a longitude of 48 degrees. These directions are shown on the figure as dotted lines and it is clear that they closely correspond with the direction of the spiral arm containing the sun; that is, it appears they both represent the integrated emission of the local arm. Their mean inclination to the radius vector from the galactic center is 83 degrees, and the inclination of the equiangular spiral defined by equation (3) is 83°.2.

This model fits quite closely the preliminary hydrogen-line results of Kerr and his colleagues of Sydney [10] although it does not agree so well on the northern side with the Leiden model of spiral structure [11], which is too complex to fit such a simple pattern; however, the reduction of the observational data has been treated differently at the two places.

The parameters of the spiral pattern allow one to classify the Galaxy with some confidence. An inclination of 83 degrees represents a closely wound spiral, consistent with an Sb [12]. Similarly the minimum radius to which the spiral arms may be definitely traced is about 2 kiloparsecs on the assumption of 8 kiloparsecs for the solar distance. This is again consistent with an Sb. There is no bar or ring structure obviously present so that the classification suggested, using de Vaucouleurs' scheme, is SA(s)b.

Because of the complex radial distribution of the "disk" component it is obviously not possible to fit a family of concentric spheroids and determine the axial ratio, as it is with the corona. However, by estimating the width of this component to the half-brightness points and by comparing it with the distribution in longitude, rough estimates of an axial ratio are possible. It is found, for instance, that the width between half-brightness points near the galactic center is about $3\frac{1}{2}$ degrees: the corresponding angle in longitude is about 60 degrees (from Fig. 9). Thus, the axial ratio is of the order $\sin 30^\circ/\sin 1^\circ\!.75 = 15$.

The width of the component increases with increasing l', being about $4\frac{1}{2}$ degrees at $l' = 30$ degrees and very roughly 10 degrees at $l' = -60$ degrees. These angles are consistent with a layer about 500 parsecs thick between the half-emissivity points. Thus it would appear that the spiral arms, as defined by the 3.5-m radiation, have a more or less circular cross-section of 500 parsecs diameter.

The total emission of the disk component may be estimated like that of the coronal component. At this stage, only order-of-magnitude estimates are worth while, and for this we may represent the component by a uniformly emitting spheroid of emissivity equal to that at the component's center, of axial ratio 15 and of thickness along the axis of rotation 500 parsecs. This yields a total emission of 8×10^{20} watts $(\mathrm{c/s})^{-1}$ at a wavelength of 3.5 m, or about 1/10 the total emission of the corona. On the other hand, the emissivity in the inner regions and in the spiral arms is estimated to average about 2 °K/parsec or 10 times the emissivity of the coronal component.

The spectral properties of the "disk" component have already been examined in some detail [1]. It has been shown by comparison with a survey of Westerhout at 22 cm [13], that the emission has a nonthermal spectrum, which indeed had been demonstrated earlier by the author [14]. However, the much improved data now available allow estimates of the proportion of thermal and nonthermal emission, something that had not been attempted with the earlier uncertain data. The separation may be effected by making a number of simplifying assumptions: the spectrum of the nonthermal component is constant within a few degrees of the galactic ridge-line; the effect of ionized hydrogen is negligible at a few degrees from the galactic ridge-line; the ionized hydrogen has a constant electron temperature and is more or less uniformly distributed over the aerial beam; and the ionized hydrogen and sources of nonthermal emission are similarly distributed in the plane of the Galaxy. Under these assumptions the observed brightness temperature at a wavelength λ is given by

$$T_b = (T_\lambda/\tau_\lambda + T_e)(1 - e^{-\tau_\lambda}) , \qquad (4)$$

where T_λ is the brightness temperature due to the nonthermal emission in the absence of absorption, T_e is the electron temperature and τ_λ the total optical depth of the ionized hydrogen.

By selecting longitudes free of sources and comparing T_b at points on and off the ridge-line at different wavelengths it is possible to deduce values for T_λ and τ_λ. A high concentration of ionized hydrogen was found from the galactic center out to $l' \approx +30$ degrees (longitude ≈ 0 degrees). In this area it appeared that about half the total radiation at 22 cm has a thermal origin and that the optical depth at 3.5 m is about 0.2, corresponding to an emission of about 2000 °K. It was also found that, before decreasing, the proportion of thermal radiation reached a maximum between $l' = +20$ degrees and $l' = +30$ degrees. If radial symmetry is assumed, this does not agree particularly well with the spiral pattern defined by the 3.5-m radiation: a plausible explanation is that the excess ionized hydrogen represents in part a local concentration or "knot" within one of the spiral arms. Such features are more characteristic of the distribution of ionized hydrogen in other galaxies than is radial symmetry. Westerhout [13] has carried this analysis much further and, on the assumption of radial symmetry, considers that all the ionized hydrogen within about 4 kiloparsecs of the nucleus is concentrated into a ring, with little or none at less than 3 kiloparsecs. Because of the above argument and the many other uncertainties and *ad hoc* assumptions involved in an analysis of this type his conclusion does not appear to be a necessary consequence of the data.

4. THE DISCRETE SOURCES

A striking feature of Fig. 1 is the collection of quite strong radio sources distributed along and very close to the ridge-line of the disk component. The double source at the galactic center has been discussed elsewhere [15] and will not be considered here. The others are clearly extreme Population I objects, but it is equally clear that they are not related to ionized hydrogen. They do not correspond with known emission nebulae (except in the longitude range 250 to 260 degrees), and their brightness temperatures are, in general, too high for a thermal-emission process. Further confirmation of this conclusion comes from comparison with Westerhout's high-resolution survey at 22-cm wavelength [13]. The bright sources at 3.5 m in the region common to the two surveys all have less emission at the shorter wavelength, which is inconsistent with thermal emission. Conversely, the brighter sources at

22 cm, some of which coincide with known H II regions, are either unobservable at 3.5 m or visible in absorption as would be expected if they are all H II regions. The great majority of the 3.5-m sources are unresolvable with the present instrument; that is, they have sizes less than about ½ degree; two, at longitudes 277 and 334 degrees, may subtend only a few minutes of arc [16].

Some of the sources will be discussed in another paper [17]. Our interest here is in their properties as a class of objects and in their relation, if any, to the other galactic components. It may be stated immediately that only one source is definitely identified with an optically observed object: the source at $l = 228$ degrees, $b = -5$ degrees (Puppis A), previously identified by Baade and Minkowski [18] with a peculiar cluster of bright filaments. However, it now appears probable that the strong northern source in Cassiopeia, which is related to a filamentary nebulosity having certain similarities to the Puppis A filaments, is the remnant of a type II supernova, which is a Population I supernova [19]. Since the observed sources have a Population I distribution it would appear that they could well comprise a homogeneous class of similar remnants. On the face of it, such objects are likely to be radio sources, because type II supernovae probably occur preferentially in regions of relatively high gas concentrations where the conditions would seem appropriate for the production of high-energy electrons, and consequent meter wave synchrotron-type radiation, by any of a variety of suggested mechanisms.

It is possible to investigate this hypothesis by making assumptions about the radio properties of the type II supernova and by comparing the resulting source properties with those observed. For example, if one makes the very artificial assumptions that a radio source connected with such a supernova expands at a constant rate of 5000 km/second, exists as a radio emitter for 5000 years, and then ceases to radiate, and finally, that such radio-emitting supernovae occur at a mean rate of one per galaxy per 50 years, then one can show that within the region of the Galaxy covered by this survey the expectation is that there should be of the order of 50 such objects, of which more than half have angular sizes less than 1/10 degree and only two have sizes greater than ½ degree. The number of distinguishable sources within 3 degrees of the galactic ridge-line is also about 50 (the parameters of the model were chosen to produce equality in these numbers), but from the expected sizes it is evident that higher resolution would be required for measuring angular sizes to test this or other possible models.

The statistics of the source distribution are investigated in another paper [17]; it is sufficient to note here that within about 60 degrees of the galactic center the sources tend to be stronger, smaller, and more numerous than they are near the anti-center. This is simply consistent with the presence of a greater amount of matter in this region. However, the concentration to the center is not as marked as that of the disk component. The obvious clustering near the direction of " steps " in the disk distribution is evidence that the sources are associated with the same spiral structure.

5. ORIGIN OF THE RADIATION

The general distribution and properties of the galactic emission at 3.5 m have been described. No consideration, however, has been given to the origin of the greater part of the emission (excluding the small contribution from ionized hydrogen and recognizable discrete sources); consequently the observed structure has not yet been related to any physical properties of the Galaxy. The assumption in the early days of radio astronomy, that the galactic emission resulted from the integrated output of large numbers of radio sources, has now been largely superseded by the assumption that it originates in a diffuse medium comprising relativistic electrons moving in magnetic fields and radiating by the synchrotron process. This replacement has occurred because of the failure to identify a sufficiently numerous class of galactic sources and the inherent plausibility of the latter picture. It has, however, not yet been proven, and in accepting it as a model for the ensuing discussion this must be borne in mind.

It might be expected that if the radiation is originating in such a diffuse medium the distribution of radio-continuum emission will reflect the large-scale distribution of magnetic fields in the Galaxy. It is easy to show that the time for a typical emitting electron to lose the greater part of its energy is much longer than the time for it to move through a distance of the order of galactic dimensions, so that a homogeneous energy distribution might be expected. The emission will then depend on the electron density and the magnetic field. This problem will not be discussed in detail here, but it is evident from the properties of synchrotron radiation that the magnetic field will be the dominating factor. This leads to a model of the field structure of the Galaxy in which one can recognize the two components corresponding to the coronal and disk distributions. The former apparently extends over a spheroid of axial ratio about $1\frac{1}{2}$ and radius to the half-field circle of about 1.4 solar distances. The latter is probably related to the spiral arms and is estimated to be several times stronger than the coronal field.

It has been suggested earlier that the high-energy electrons might originate in the type II supernovae suspected of being responsible for the majority of discrete sources [1]. The picture is roughly that a discrete source, comprising high-energy electrons and relatively strong magnetic fields, would be formed from a supernova explosion and gradually dissipate itself into the surrounding medium until it had lost its separate identity. Such electrons would be found in the arms where the supernovae occur and they would initially diffuse through the arms, spreading into the corona and interarm regions only when they encountered relatively low fields.

However, a difficulty arises since the average optical emission of all type II supernovae is only of the same order as the total radio emission from the Galaxy ($\sim 10^{31}$ watts). Any electron-accelerating process must be very inefficient, and it therefore would seem necessary to postulate an additional source of energy to maintain or increase the electron energies. While the basic origin of such additional energy is not apparent, high-velocity gas in the galactic corona could well provide the accelerating mechanism [14].

In conclusion, it is worth noting an apparent inconsistency with optical data in the above model. If the spiral arm emission arises from synchrotron-type radiation in the interstellar medium, no emission can be expected when the line of sight passes along a line of force. The observed enhancements in the directions tangential to the spiral arms can therefore not occur if the spiral-arm field is aligned regularly with the direction of the arm. Observations of the interstellar polarization of starlight appear consistent with a field that is approximately co-planar with the spiral arms. This optical evidence for regularity, however, does not appear to be any stronger than the radio evidence for irregularity, and both results would seem to be compatible if the irregularities are more pronounced in the galactic plane. Alternatively, as mentioned earlier, the assumed origin of the radio emission may be incorrect.

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