A SURVEY OF GALACTIC RADIATION AT 38 Mc/s

I. DECLINATIONS +10° TO +45°

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Summary

The results are presented of two surveys of galactic radiation at a frequency of 38 Mc/s; the method of aperture synthesis was used to give a resolution of approximately 1°. The region surveyed covers the range of declination from +10° to +45°, an area of 3.4 steradians. Values of 2300 and 3200 x 10^{-28} w.m^{-2}(c/s)^{-1} for the flux densities of the intense sources Tau A and Vir A were used to derive the scale of brightness temperature.

1. Introduction.—The 38 Mc/s pencil beam instrument at the Mullard Radio Astronomy Observatory uses the method of aperture synthesis to obtain a resolution of approximately 1°. The radio telescope and its method of operation have already been described (Costain & Smith 1960); only a short account is given here. The aerial system comprises a fixed 128λ x 1.5λ element aligned EW used as an interferometer with a 4λ x 1.5λ element which moves to a series of positions on a NS line bisecting the fixed element. The outputs from the aerials are connected to a phase-switching receiver; by a process of time-sharing both in-phase and quadrature components of the correlated signal from the aerials are recorded simultaneously. By combining as a Fourier sum the records obtained at a given sidereal time from each aerial position one obtains the NS distribution of intensity across the strip of sky 5°-8 wide in right ascension and 40° in declination determined by the primary responses of the two aerials.

A number of surveys have been undertaken with this instrument. In the present paper the results of two surveys centred upon δ = +30° are described. A survey of greater resolution centred upon δ = +52° has been completed and the data are in course of reduction; a survey centred upon δ = +07° is in progress. For these later surveys alterations were made to the aerial feeder system which removed the sensitivity to weather conditions in the present observations. The results of these two surveys will be published later.

A preliminary survey centred upon δ = +07° was undertaken in order to study the galactic plane at longitudes towards the centre of the Galaxy, and a map of the area derived from this survey will be presented elsewhere (Kenderdine 1963); detailed results of the remainder of this survey are not given since they are being superseded by the observations now in progress.

In addition to the interferometric observations, a series of total power observations was made using the long aerial alone; this was made to give the low-order Fourier components required for the synthesis but unobtainable by interferometric observations since they correspond to spacings less than the physical
size of the aerials. The interferometric and total power observations are described separately in what follows.

The present observations have provided values of flux density at 38 Mc/s for about 200 sources. Of these 100 have been used in the derivation of the spectra of radio sources by Conway, Kellermann & Long (1963) and the values are quoted in their paper. A complete list will be given later.

2. Total power measurements.—A series of observations using the long EW aerial as a total power instrument was made in 1961 August. The object of these observations was:

(a) to determine from the responses of point sources the reception pattern in declination of the two aerials; this information is needed in order to correct the final map of sky brightness;

(b) to obtain a map containing the low and zero order NS Fourier components which are unobtainable from interferometric observations;

(c) to obtain flux densities for about 60 point sources. These are important for work on source spectra and for calibrating the temperature scale of the synthesis surveys.

The beam width of the aerial when used as a total power instrument is 6°·5 in right ascension and 45° in declination. The aerial was tipped in turn to a series of declinations at intervals of 11° from +07° to +86°. In each position several days’ observations were obtained. The experimental arrangement was similar to that used at this frequency in the low resolution measurements described by Turtle, Pugh, Kenderdine & Pauliny-Toth (1962). Daily calibrations were made by connecting the aerial cable to a diode noise source. To determine the absolute temperature scale it is necessary to allow for the attenuation of the feeder system of the aerial; the structure of the feeder makes measurement of the attenuation difficult and hence the absolute calibration of the new measurements was made by comparison with the low resolution observations. Allowance was made for the different beam shapes; since both high and low resolution observations have the same resolution in declination, it was sufficient to smooth the high resolution observations in one dimension only.

Ionospheric absorption at 38 Mc/s cannot be neglected during the daytime. A comparison of the low resolution observations made in 1960 December and 1961 July enabled the magnitude of the absorption to be derived; during July it reaches a maximum value near noon of 5 ± 2 per cent. Using this result, corrections were made to the sky temperature observed with the high resolution system.

The declination reception pattern derived from the observations of point sources is shown in Fig. 1.

3. Interferometric observations.—Two complete sets of interferometric observations are presented in this paper. The central declination of these surveys was +30°, and each survey gives a map of the sky from declination +10° to +45°; the coverage in right ascension was in each case limited to at most 16 hours by interference from distant transmitters reflected by the ionosphere during the daytime. The surveys are designated I and II and cover the regions of right ascension from 05h to 17h and from 15h to 07h respectively. Thirty aerial spacings were used for each survey, the interval between successive aerial positions being 1°08λ.

The receiver bandwidth is 100 kc/s. The output from the receiver is fed to an integrator unit which records values of the in-phase and quadrature components every 40 seconds.
Small alterations to the equipment and to the observing procedure were made during this programme. During Survey I a calibration loop was permanently connected as shown in Fig. 2. It was used to check the phase and amplitude stability of the system. The attenuation of the aerial signal before the pre-amplifiers was considerable, 14.9 and 14.2 dbs for the N and S aerials respectively of which 6 dbs was contributed by the T-pieces of the calibration loop. As the receiver is fitted with an automatic gain control (Costain & Smith 1960), its gain is determined by the total power received; with this attenuation the aerial

![Diagram of experimental arrangement for Survey I.](https://academic.oup.com/mnras/article-abstract/126/1/41/2602415)
power and preamplifier noise power are comparable so that the recorder sensitivity depends on the noise figure of the preamplifier.

In Survey II, the calibration loop was disconnected and much of the trailing polythene-dielectric cable to the moving aerial replaced by air-spaced cable of less attenuation; a similar length of cable in the lead from the fixed aerial, which had been introduced to compensate changes in phase path due to variation of temperature, was also removed. The attenuation of the aerial power was now 4.7 and 3.0 db for the two aerials and the gain was therefore controlled almost entirely by galactic emission; from measurements of the variation of total aerial power during a 24-hour period described in Section 2, the absolute sensitivity of the survey could be established. Phase and amplitude checks were made by disconnecting the aerial and feeding the cables of the calibration loop directly into the preamplifiers in place of the aerials.

In Survey I the observing time was seriously increased by the necessity of repeating the observations when the presence of moisture on the open-wire feeder system of the long aerial introduced variations in the phase velocity of the feeders and hence phase errors in the excitation of the aerial. The amplitudes and phases of about eight of the more intense sources were recorded daily and observations were repeated until errors in amplitude of less than 15 per cent and errors in phase of less than 10° were found. For Survey II the feeders were enclosed in a 2-inch diameter polythene tube. At the same time the grading of excitation along the fixed aerial was altered from a truncated gaussian distribution to a uniform distribution; the necessary weighting needed to produce a low side-lobe response in the synthesis of the final map was obtained by a process of numerical convolution (Scott, Ryle & Hewish 1961.)

4. Observations at small aerial spacings.—As the NS interval between successive positions of the moving aerial must always be less than the aerial width, the closest position should correspond to the aerials overlapping; neither the zero nor first order terms required in the synthesis can therefore be obtained by direct observation.

The zero order term corresponds to superposing the moving aerial on the centre of the fixed aerial. The spatial frequencies in right ascension which occur under these circumstances are however present with different weighting in total power observations using the long aerial alone. The total power records described in Section 2 were therefore passed through a convolution procedure in order to produce the required weighting function.

For the first order component (r.08λ spacing), observations were made with the moving aerial in its correct NS position which, however, screens part of the central section of the fixed aerial. This screening would give rise to a small error in the mean slope of the temperature distribution in declination; this error can however be nearly removed by adding to the result of the synthesis the NS temperature distribution obtained by scanning with the single aerial.

5. Computation.—The computation was performed by EDSAC II, the digital computer at the Cambridge University Mathematical Laboratory. For each aerial position the best available record was selected and converted to punched paper tape using a manually operated chart reader and digital converter. As the data were read into the computer a correction was introduced for the amplitude and phase errors derived for each aerial position from the observations of intense discrete sources. For Survey II each record was convolved at this stage with a
gaussian function to obtain the desired reception pattern in right ascension. At each interval of sidereal time the readings obtained from all the aerial positions were combined as a Fourier synthesis to give the distribution in declination of intensity received by the aerials. Each point on this distribution was now corrected for the reduction of intensity by the declination polar diagram of the primary aerials. Finally for each interval of sidereal time, all points on the distribution were multiplied by a factor to allow for the diurnal variations of receiver gain.

The output at this stage contains all the Fourier components obtained from the interferometric observations. For each distribution in declination, the zero order component, giving the average value of the sky temperature over the strip, is missing and there is a small error in the mean NS gradient because of the difficulty of obtaining the 1st order component. This output was plotted as a series of profiles; each profile gives the distribution at one value of right ascension and the profiles for successive values are plotted on the same diagram with a displaced zero on the vertical scale. The total power and corrected first order terms were combined with these curves to derive the contour maps.

Values of flux density for discrete sources were obtained from the profiles.

6. Effects of the ionosphere.—The ionosphere affected the observations in three ways.

(a) Scintillation.—This was evident from the observations of radio stars on individual records and from a routine series of scintillation observations. Observations seriously affected by it were repeated.

(b) Refraction.—EW gradients in the ionosphere alter the time of transit of sources, especially at dawn. There is thus a systematic variation with U.T. having a maximum error of approximately 1 minute, with ± ½ minute random day-to-day variations. On the final map the errors in right ascension due to the systematic variation are smaller than this, being smoothed out over the time taken, about four months, for the completion of the survey. The maximum residual error is expected to be less than 0·3 minutes; no correction for this has been included in the map. The effect of the random variations is to broaden the beam in right ascension by about 5 per cent.

The effects of NS gradients in the ionosphere were not detectable because of the poor phase stability of the feeder system of the south aerial; to first order they were compensated by the phase correction in the computation.

(c) Absorption.—The effect of absorption on the total power measurements has been described in Section 2. Most of the interferometric observations used in the final maps were made at night when absorption is negligible. Furthermore even for daytime observations the automatic gain control makes the output of the receiver independent of absorption since both the Fourier component being observed and also the total background radiation received are reduced by the same factor.

7. The performance of the instrument: (a) Reception pattern in right ascension.—In all surveys the response on individual records is the product of the amplitude reception patterns of the two aerials. For Survey I, for which there was no convolution of the data in right ascension, this is also the reception pattern for the final map. For this survey the grading of excitation along the fixed aerial was approximately gaussian giving a reception pattern of 0·8 width to half intensity; the first side-lobe was about 3 per cent; beyond about 6° from the main response the side-lobes were less than 1 per cent.
For Survey II the fixed aerial had a uniform grading of excitation giving a response on individual records of the form $\sin \theta/\theta$ with $0.5^\circ$ width to half intensity. During the computation the records were convolved with a gaussian function of width 2.8 minutes of time. The final reception pattern produced is a function of declination since objects at higher declination move more slowly through the beam of the aerial. For a source at $\delta = +30^\circ$, the width to half intensity is $0.7^\circ$; the first side-lobe is about $-4$ per cent and the side-lobe level at $6^\circ$ away is $1.5$ per cent dropping to less than $0.5$ per cent beyond about $12^\circ$ away. For sources at more northerly declinations the main beam becomes narrower and the side-lobe level worse.

The intense sources Cas A and Cyg A are both at comparatively high declinations. Because of their side-lobes it has not been possible to observe within 40 minutes of Cyg A, or within an hour of Cas A.

(b) Reception pattern in declination.—The size and slope of the principal response in declination is determined by the relative weightings given to the observations obtained at different NS spacings. A gaussian weighting function truncated at 25 per cent was used; the side-lobes produced by truncation are, except for the first, small compared with the 4 per cent side-lobes produced by random errors of amplitude and phase. The beam width to half intensity is $1.3 \text{ sec } \delta$ where the zenith angle $\delta = 52^\circ \ 10^\prime - \delta$.

The position and size of grating side-lobes are determined by the stepping interval between aerial positions and by the declination polar diagram of the individual aerials. The present observations were made before this polar diagram was well known and subsequent measurements have shown it to be broader than had been supposed. Hence the grating side-lobes are worse than expected and constitute a serious limitation to the final accuracy. The positions of the grating side-lobes are given by integral values of $n_0 \ (\sin z' - \sin z)$ where $n_0 \lambda$ is the spacing between aerial positions and $z'$ and $z$ the zenith angles of the main beam and the grating side-lobe. The magnitude of the grating side-lobes for the surveys centred upon $\delta = +30^\circ$ is about 8 per cent for the north half of the strip, rising to 30 per cent at the extreme south. A graph is shown in Fig. 3. The effect has been
eliminated in subsequent observations by using smaller steps between aerial positions. In the present observations it could be made unimportant if a detailed knowledge of the region of sky outside that part surveyed were available; no attempt has been made to do this in the present case.

![Diagram of relative intensity vs. declination.](image)

**Fig. 4.**—Idealized reception patterns of the synthesized aerial in declination, showing effect of procedure for restoring the first order component (a) for a source in the centre of the synthesis strip, and (b) for a source at the edge.

The reception pattern in declination is also affected by the procedure for adding the low order Fourier components using the total power measurements; it varies with the position of the source. Fig. 4 shows the reception patterns obtained for (a) a source at the centre of the declination strip and (b) a source at the edge.
Fig. 5.—Contour map from Survey I. The contours are labelled in units of $900 \cdot K$ of brightness temperature. 1950 o coordinates.
Fig. 6.—Contour map from Survey I. The contours are labelled in units of 900 K of brightness temperature. 1950.0 coordinates.
Fig. 7.—Contour map from Survey 1. The contours are labelled in units of 900 MK of brightness temperature. 1950.0 coordinates.
**Fig. 8.**—Contour map from Survey II. The contours are labelled in units of 900 °K of brightness temperature. 1950.0 coordinates.
Fig. 9.—Contour map from Survey II. The contours are labelled in units of 900 °K of brightness temperature. 1950.0 coordinates.
Fig. 10.—Contour map from Survey II. The contours are labelled in units of 300 K. of brightness temperature. 1950.0 coordinates.
The largest errors arising from this procedure are from the negative side-lobes at the edges of the strip.

(c) Sensitivity scale and noise level.—The sensitivity scale for the interferometric observations was based on the values 3200 and $2300 \times 10^{-26}$ w.m$^{-2}$(c/s)$^{-1}$ respectively for the flux densities of the intense sources Vir A and Tau A. Correction was made for the reduction of receiver gain by the source itself as it passed through the reception pattern of the fixed aerial. The temperature scale was chosen so that for these sources the integral $\int Td\omega$ taken over the principal response and near side-lobes had the values $SN/2k$; the contribution from side-lobes is very small since they are on average as much positive as negative. The calibration of sky brightness is believed to be accurate to within 15 per cent.

The noise level for Survey I is about 700 °K at the centre of the strip rising to about twice as much at the edge; for Survey II the corresponding figure is 400 °K. These figures are approximately 12 per cent and 7 per cent of the minimum sky brightness temperature.

9. The contour maps.—The maps derived from the Surveys I and II are given in Figs. 5–10. The numbers shown against the contours give the brightness temperatures in units of 900 °K. Over most of the map the contour interval is 2 units; exceptions to this are (a) the small region above 40 units where the interval is 5 units; and (b) the Cygnus X and Cygnus Loop regions where some of the contours have been omitted.

The contours for the multiples of 10 units are shown with a heavier line. The symbol (<) drawn inside a small detached contour indicates a region of lower intensity than its surroundings; it is normally only used when the sense of the contour is otherwise ambiguous. At the right ascensions of a number of intense sources the contours are uncertain and are either shown dotted or omitted completely. The contours giving the aerial response to a number of intense sources have been omitted: instead a single dot is shown at the position of maximum response together with a number indicating the peak temperature in units of 900 °K.

The coordinates are for epoch 1950.0.

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References