

SOME HIGH-LATITUDE FEATURES RELATED TO THE NORTH POLAR SPUR OBSERVED AT 1417 MHz

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The intensity gradient of the background radiation has been measured in the region of the North Polar Spur using the 25-metre Dwingeloo telescope equipped with a dual feed system. Besides the main ridge of the Spur, a number of ridges running more or less parallel to the main ridge at lower declinations can be followed over a considerable distance. The main ridge is strongly asymmetric and in some places very narrow. The other

ridges appear to have somewhat different characteristics. As the intensity gradients have been measured in only one direction, they are inadequate for a complete study of the complex low-latitude region of the Spur. However, the stability and sensitivity inherent in gradient observations are useful in following very weak extensions of this structure at high latitudes.

1. Introduction

The North Polar Spur is a narrow belt of radio emission rising vertically from the galactic plane at $l = 30^\circ$. The dominance of this feature in the high-latitude continuum radiation is clearly shown in figure 1, which is taken from PAULINY-TOTH and SHAKESHAFT (1962). Their survey was made at 404 MHz with a $7^\circ.5$ beam, with special care taken to suppress reception outside the primary beam.

Recent observations of various regions in the Spur have been made at Jodrell Bank. These have been reported by DAVIES (1964), HASLAM *et al.* (1964) and LARGE *et al.* (1966). Most of these observations have been made at 240 MHz, although Davies has made three scans at 1415 MHz. In the *Low Declination Survey* by LARGE *et al.* (1966), hereafter referred to as the LDS, the authors found not only the well-known main ridge of the Spur, but also several similar but weaker and less extended ridges running more or less parallel to it at lower declinations. While it is difficult to follow these features on their contour maps, they could be followed on the original observations as small but well-defined increases in intensity above the general background radiation.

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New observations at 1417 MHz obtained with the 25-metre paraboloid of the Dwingeloo Radio Observatory show these features very clearly, due to the unusual observing method which has been used. The intensity gradient along a path defined by the sweep motion of the telescope has been measured by the use of a dual feed system with a synchronous detector. Features are effectively suppressed which are much larger than the beam separation of 2° , whereas the ridges, which have a scale in cross-section of the same order as the beam separation, stand out clearly. In addition to removing the larger features, the observing method permitted an accuracy of considerably better than 0.1°K in difference of antenna temperature per beam separation to be obtained.

The observations reported here cover the declination zone 0° to $+20^\circ$ over six hours of right ascension. The position of this region with respect to the Spur is shown in galactic coordinates in figure 3 (section 4). The contours of figure 3 are taken from the survey of background radiation at 400 MHz by SEEGER *et al.* (1965).

The observations are distinctly more difficult to interpret than measurements of total intensity, since the measured gradient depends on the sweep path of the telescope. Even very narrow ridges are still partially resolved if the telescope crosses them at a small angle, making an estimate of total flux very difficult. Structure running parallel to the sweeps cannot be observed at

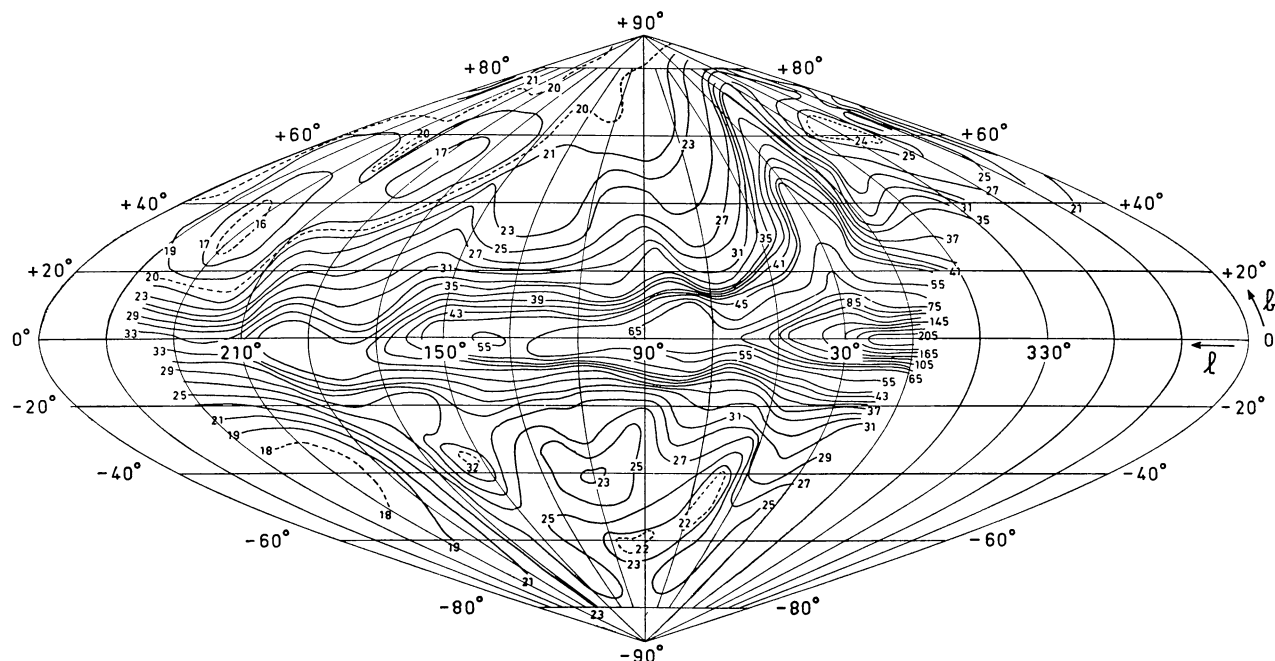


Figure 1. Contours of antenna temperature at 404 MHz, taken from PAULINY-TOTH and SHAKESHAFT (1962).

all. On the other hand, positions of zero gradient provide fairly accurate estimates of the position of the ridge tops, and some information on possible asymmetry of the ridge cross-section can be obtained from a comparison of the positive and negative gradients.

Section 2 of the paper describes the observations and their reduction. In section 3 the resulting contour maps of the intensity gradients are presented. A discussion of these results is given in section 4.

2. Observations

The observations discussed here represent a small part of a survey made in March and April of 1965 for the purpose of detecting discrete radio sources at 1417 MHz. The equipment and observing procedures are discussed in greater detail elsewhere (DAVIS, 1967).

A brief description relevant to the following discussion is given below.

2.1. Telescope and receiver

The 25-metre paraboloid was fitted with two vertically polarized horn feeds which produced primary beams 1° each side of the radio axis of the telescope, at the same elevation. Each primary beam had a width at half-intensity points of $0^\circ.60$. Similar systems have

been used by CONWAY *et al.* (1965) and by BAARS (1966). A circulator was used to switch a 1420-MHz parametric amplifier alternately between the two feeds at 100 Hz. Both sum and difference of the powers measured by the two beams were available from a synchronous detector. The sum channel was recorded in analogue form only, with a short time constant, as a control on equipment performance and interference. The difference channel was recorded both in analogue form and on punched paper tape. A positive output corresponded to a positive gradient in the direction of higher azimuth. A drift curve at the meridian through Virgo A, as it appeared on the analogue record of the difference channel, is shown in figure 3 of DAVIS' (1967) paper.

The noise on the record had an rms value of 0.03°K antenna temperature with the four-second time constant used. The bandwidth was 14 MHz centred at 1417 MHz. Although this includes the 21-cm line of neutral hydrogen, the line is so narrow compared to the bandwidth used that it contributes negligibly to the total measured radiation flux.

2.2. Observation method and scan coordinates

The measurements consisted of sweeps at $2^\circ.5$ of

azimuth per minute, from azimuth 90° to azimuth 43° at an elevation of 28° . At the end of each sweep the telescope returned automatically to azimuth 90° and the sweep was repeated. The interval between the start of the sweeps was exactly 20 sidereal minutes, during which the telescope was actually observing for 18.8 minutes. To obtain a complete coverage of the declination zone 0° to $+20^\circ$ at approximately half-beamwidth intervals, each night's observations started 2.5 sidereal minutes later than the observations of the previous night. Afterwards, the resulting sweeps from eight nights were interleaved. The sweep path in right ascension and declination for the first sweep, beginning at $14^{\text{h}}40^{\text{m}}$ sidereal time, is shown in the right-hand part of figure 2. The other sweeps run parallel but are displaced in right ascension at intervals of $2^{\text{m}}.5$. The last sweep starts at $21^{\text{h}}55^{\text{m}}$. The entire set of observations was repeated during the following eight days.

2.3. Gain and zero-level

The gain was measured at four-hour intervals, with a noise tube connected in parallel with one feed. Possible variations in the noise tube output were checked by daily comparison with the source 3C123 but none were found. As the gain varied only slowly over a period of twenty-four hours, average correction factors were computed for each night's observations. For the observations reported here, the daily gain averages varied so little that our use of a single correction factor for all these observations introduced an error of at most 2 per cent in the intensity gradient scale.

It was essential to determine accurately for each difference measurement the level corresponding to the measurement of equal intensities by the two primary beams. In principle these zero-levels could be determined as an average of the intensities over the entire sweep, since the gain of the positive and negative channels was equal. This average, computed from the digital record, was used as a first approximation. However, a strong point source would occasionally appear at the beginning or end of a scan and hence be seen by only one beam. In addition, the positive and negative peaks of a discrete source could be of differing height. This is due to the sidereal motion of the source in the 0.9-minute interval which elapsed between the observations at a given azimuth by the first beam and by the second beam. The elevation of the source could decrease

by as much as one-fourth beamwidth in this interval, depending on its declination.

To correct for these difficulties a second zero-level was computed from the digital record, excluding all intensities outside a narrow interval centred on the first zero-level. The two zero-levels generally differed by less than 0.02°K . In most cases the second zero-level has been used, but occasionally, particularly where the scan ended close to the galactic plane, the first approximation was so poor that excluding intensities outside a narrow interval meant excluding almost all of the actual scan. In this case the zero-level had to be interpolated from the neighbouring scans or determined planimetrically from the analogue record, omitting the part of the scan that was off-scale. The zero-levels used showed a slow variation over several hours, due to receiver drift. Typical values for this drift were 0.03°K per hour. This value was so small that a constant zero-level could be used for each twenty-minute sweep. In general, only one of the two available records for each scan has been used. Eight of the sixteen days were selected, using as criterion a smaller or more continuous zero-level drift.

It is thought that the resulting zero-levels caused errors of less than one contour interval (0.058°K) in the final contour maps. Larger errors would have caused a corrugated structure in the contours in the direction perpendicular to the sweep motion when the eight days of observations were interleaved, as no adjustment to the zero-levels was made by comparing sweeps made on different days. This accuracy is due primarily to the use of the dual beam comparison method, and to the azimuth sweep motion which eliminated to first order any variations in the ground radiation.

3. The contour maps

Contour maps of the intensity gradient of the background radiation are shown in figure 2. They were derived from the analogue records after these had been smoothed by hand. The direction in which the gradient has been measured corresponds to the curved thick line in the right-hand part of figure 2. The scan direction and the size, orientation and separation of the beams have been indicated at the right of that part. The azimuth scans with the dual beam telescope followed this path from upper right to lower left on the map. The dashed contours correspond to a positive gradient

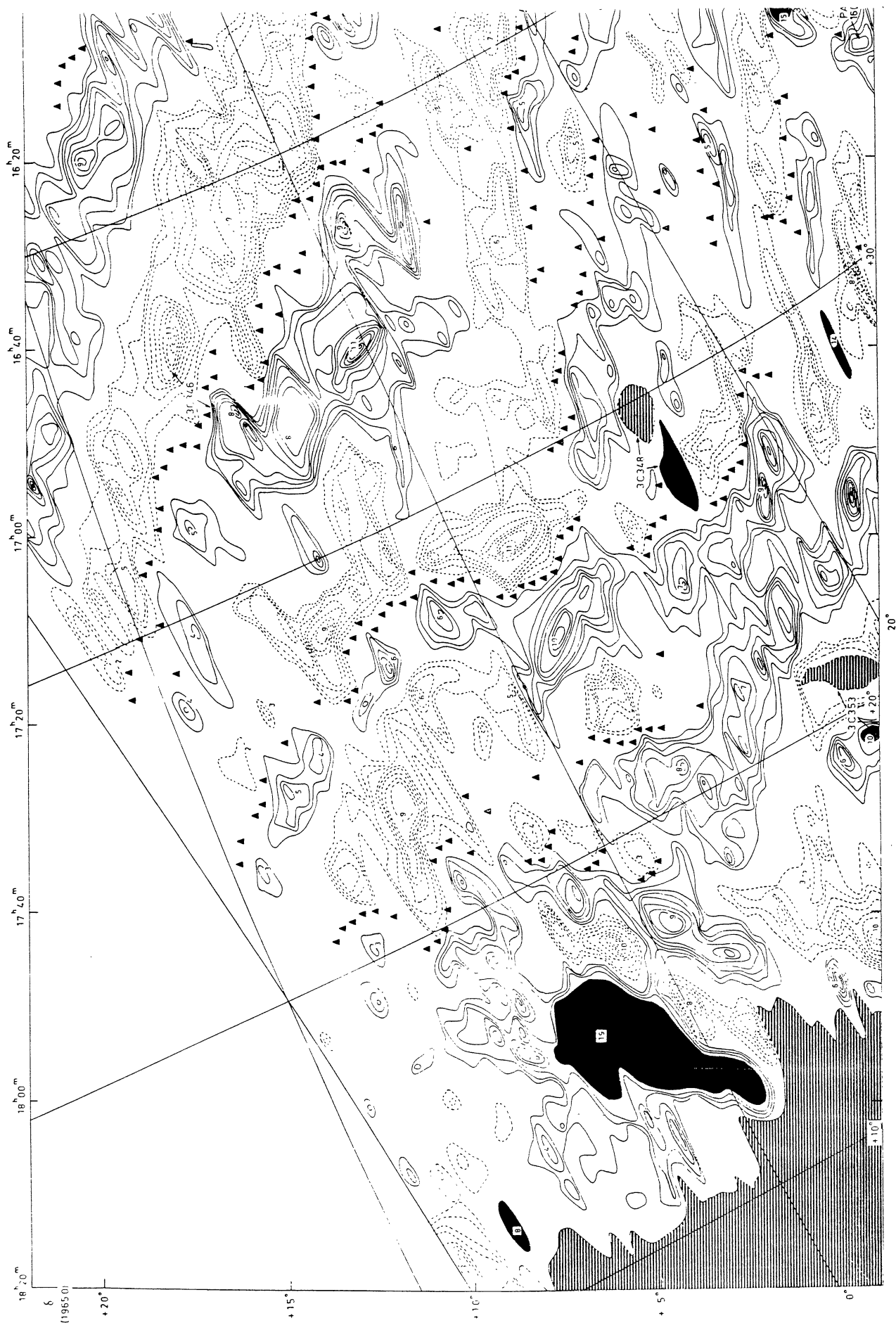
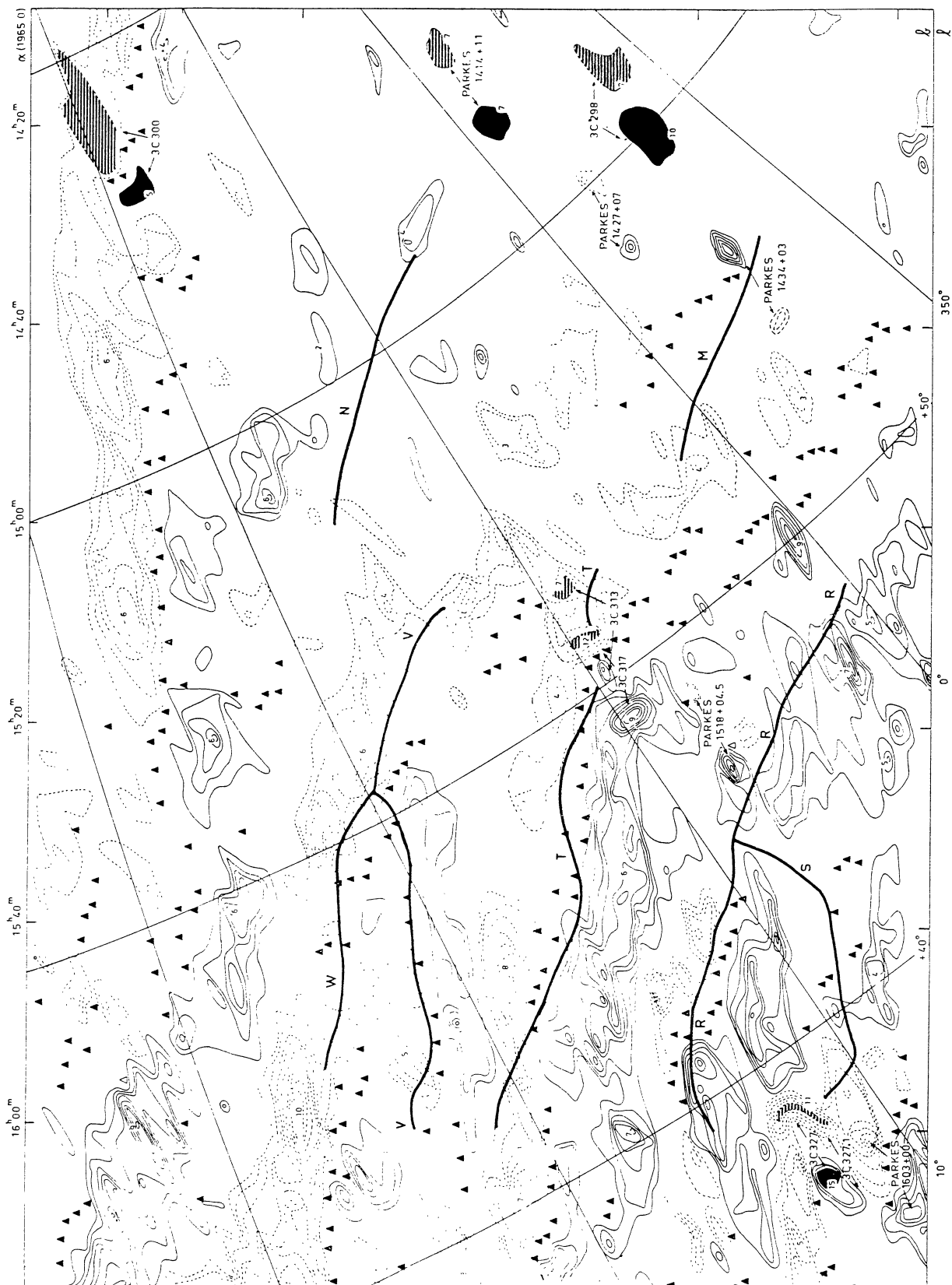
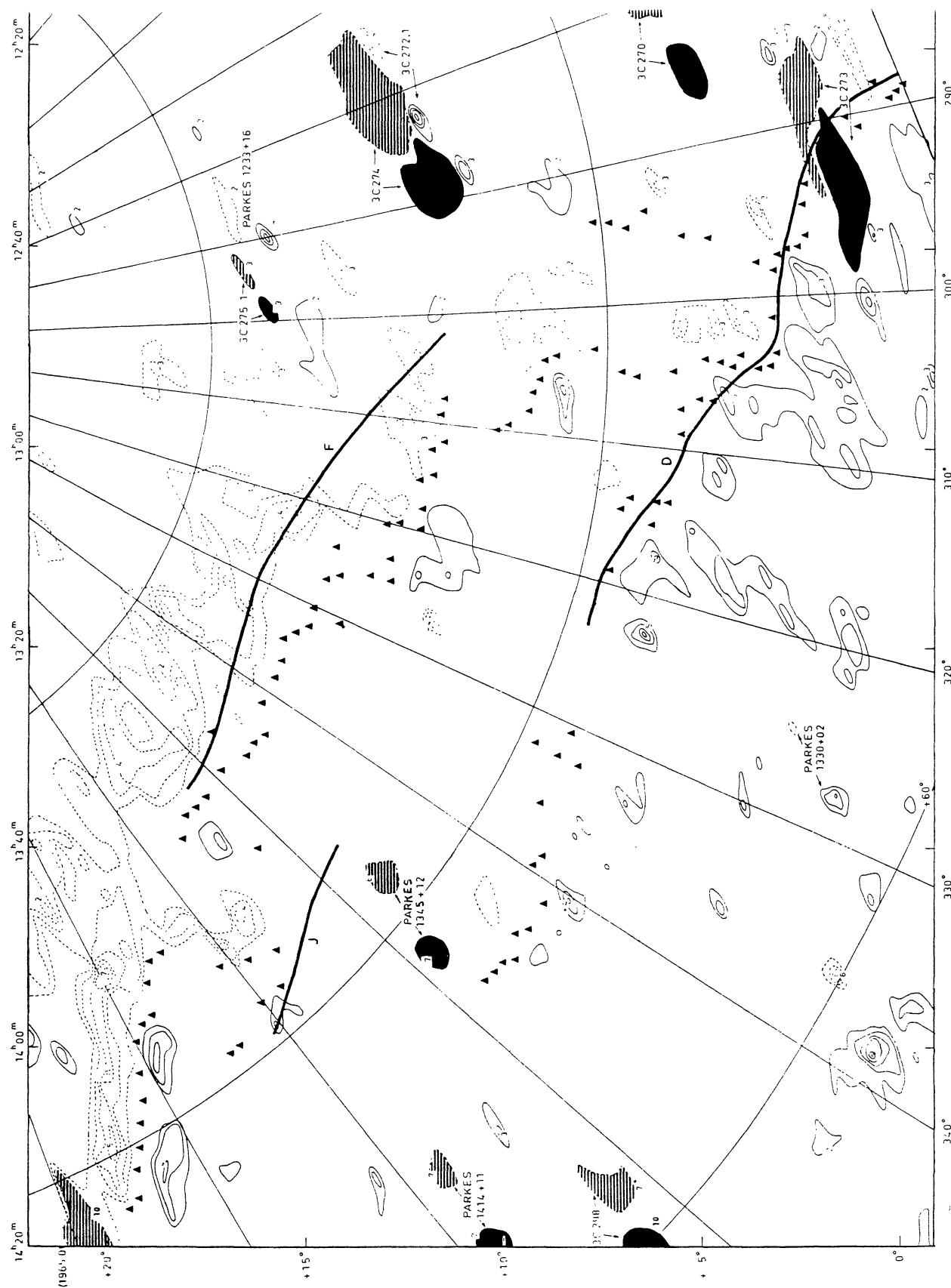


Figure 2. Contour diagram of the intensity gradient of the background radiation in the region of the North Polar Spur. At the extreme right of the right-hand part of the figure the observing method has been indicated. Combining the curved boundary lines at the ends of the two maps gives the scan path; the scan direction is from upper right to lower left and the spacing between two adjoining scans is $2^m.5$ in right ascension. The dashed contours correspond to a positive gradient in the scan direction, the full-drawn contours to a negative gradient. One contour interval equals 0.058°K antenna temperature per 2° beam separation; the contours -1 , 0 and $+1$

are not included in the area of the discrete source gradient chart



are not included as they were strongly affected by noise. For all very bright features (strong gradients) the inner contours were omitted; the area of the feature is hatched for positive gradients and filled in for negative gradients. The peak values are marked and the known discrete sources identified with a source number from either the 3CR, the 4C or the Parkes catalogue. Points where the intensity gradient changes from a positive to a negative value, corresponding to ridge peaks, are indicated by triangles. For comparison, the ridges in this area listed in the LDS are indicated by heavy lines.



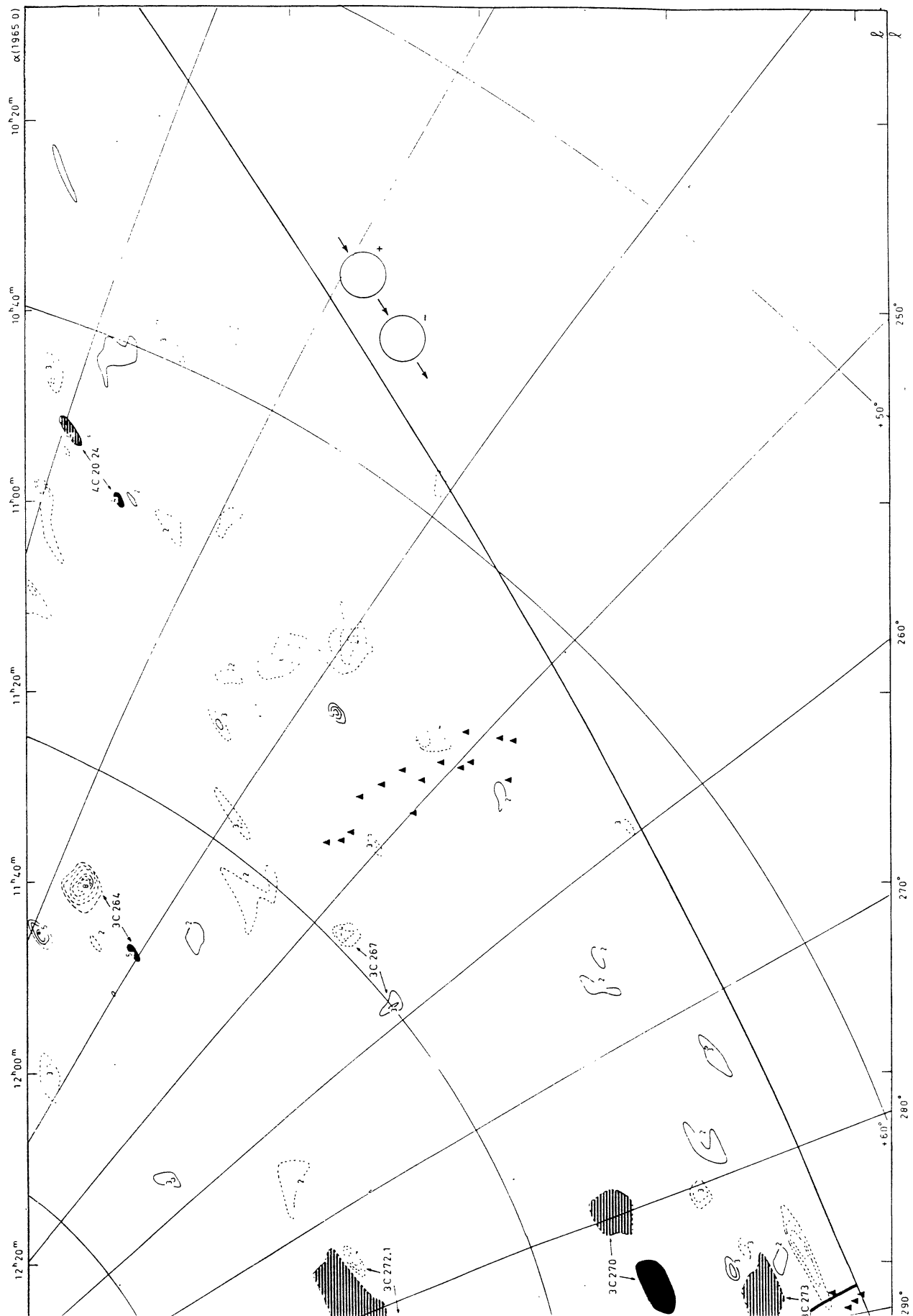


Figure 2 (continued)

towards the bottom of the figure, the full-drawn contours to a negative gradient. One contour interval equals 0.058°K antenna temperature per 2° beam separation, based on a laboratory calibration of the noise-tube signal. The contours 1, 0 and -1 are not included, as they were strongly affected by noise. For those point sources and discrete features giving very steep gradients, all contours have been omitted which lie within the first contour that clearly belongs only to the feature. The area inside this contour is hatched for negative values, filled in for positive values. The peak values are marked (except for those sources that were off-scale on the analogue records) and the known discrete sources identified with a source number from the 3CR catalogue (BENNETT, 1962), the 4C catalogue (GOWER *et al.*, 1967) or the Parkes catalogue (DAY *et al.*, 1966).

Points where the intensity gradient in the direction of higher azimuth clearly changes from positive to negative values, corresponding to ridge peaks, are indicated by triangles. The correct position of the zero gradient was obtained directly from the analogue records. For comparison, the ridges in this area listed in the LDS (LARGE *et al.*, 1966) are indicated by heavy lines. It should be kept in mind that the LDS observations ended at $\alpha = 16^{\text{h}}00^{\text{m}}$, $\delta = +18^\circ$. Because of this, a large part of the Spur at high latitudes was not observed in the LDS.

4. Discussion

The contour maps show a number of quite well-defined ridges. The most conspicuous among these is the main ridge of the North Polar Spur, which can be followed quite easily from the plane through its peak

TABLE 1
Ridges found in the dual feed survey

Ridge no.	Coordinates of ends of ridge				Designation in LDS	Remarks*
	α (1965)	δ (1965)	α (1965)	δ (1965)		
1	$11^{\text{h}}25^{\text{m}}$	9.2	$11^{\text{h}}36^{\text{m}}$	14.2		1
2	at $12^{\text{h}}22^{\text{m}}$	0.0 off map	at $16^{\text{h}}19^{\text{m}}$	22.0 off map	D ($\alpha < 12^{\text{h}}50^{\text{m}}$) F ($\alpha > 12^{\text{h}}50^{\text{m}}$)	2
3	$12^{\text{h}}37^{\text{m}}$	8.0	$12^{\text{h}}40^{\text{m}}$	3.0		3
4	$12^{\text{h}}52^{\text{m}}$	4.3	$13^{\text{h}}12^{\text{m}}$	7.3	D ($\alpha > 12^{\text{h}}50^{\text{m}}$)	4
5	$13^{\text{h}}28^{\text{m}}$	8.3	$13^{\text{h}}53^{\text{m}}$	10.5		5
6	$14^{\text{h}}34^{\text{m}}$	3.8	$14^{\text{h}}48^{\text{m}}$	7.0	M	5
7	$14^{\text{h}}39^{\text{m}}$	0.0	at $17^{\text{h}}36^{\text{m}}$	16.6 off map	T	6
8	$15^{\text{h}}06^{\text{m}}$	9.2	at $17^{\text{h}}22^{\text{m}}$	19.8 off map	V ($\alpha < 15^{\text{h}}28^{\text{m}}$) W ($\alpha > 15^{\text{h}}28^{\text{m}}$)	7
9	$15^{\text{h}}28^{\text{m}}$	12.5	$16^{\text{h}}04^{\text{m}}$	11.5	V	8
10	$15^{\text{h}}30^{\text{m}}$	16.5	$16^{\text{h}}00^{\text{m}}$	20.8		9
11	$15^{\text{h}}31^{\text{m}}$	1.2	$15^{\text{h}}50^{\text{m}}$	2.0	S	10
12	$15^{\text{h}}36^{\text{m}}$	3.8	$15^{\text{h}}58^{\text{m}}$	5.3	R	10
13	$16^{\text{h}}14^{\text{m}}$	12.3	$16^{\text{h}}21^{\text{m}}$	14.2		11
14	$16^{\text{h}}18^{\text{m}}$	6.3	$16^{\text{h}}36^{\text{m}}$	6.8		
15	$16^{\text{h}}43^{\text{m}}$	2.0	$17^{\text{h}}01^{\text{m}}$	5.7		
16	$17^{\text{h}}15^{\text{m}}$	4.0	$17^{\text{h}}43^{\text{m}}$	13.8		
17	$17^{\text{h}}35^{\text{m}}$	5.0	$17^{\text{h}}34^{\text{m}}$	8.1		12

*1. Points of zero gradient are only identification. Very weak.

2. Main ridge of Spur.

3. Joins main ridge at $12^{\text{h}}40^{\text{m}}$. Very weak.

4. Joins main ridge at $12^{\text{h}}52^{\text{m}}$. Very weak.

5. Very weak.

6. The most extended and prominent ridge after the Spur.

7. Prominent. Low-latitude part connected with the main ridge of the Spur.

8. Weak but well-defined.

9. Joins main ridge at $16^{\text{h}}00^{\text{m}}$.

10. No link between R and S here as in the LDS due to direction of the scans in this region. Link if present would run practically parallel to scan direction.

11. Joins ridge 8 at $16^{\text{h}}21^{\text{m}}$.

12. Joins ridge 16 at $17^{\text{h}}34^{\text{m}}$.

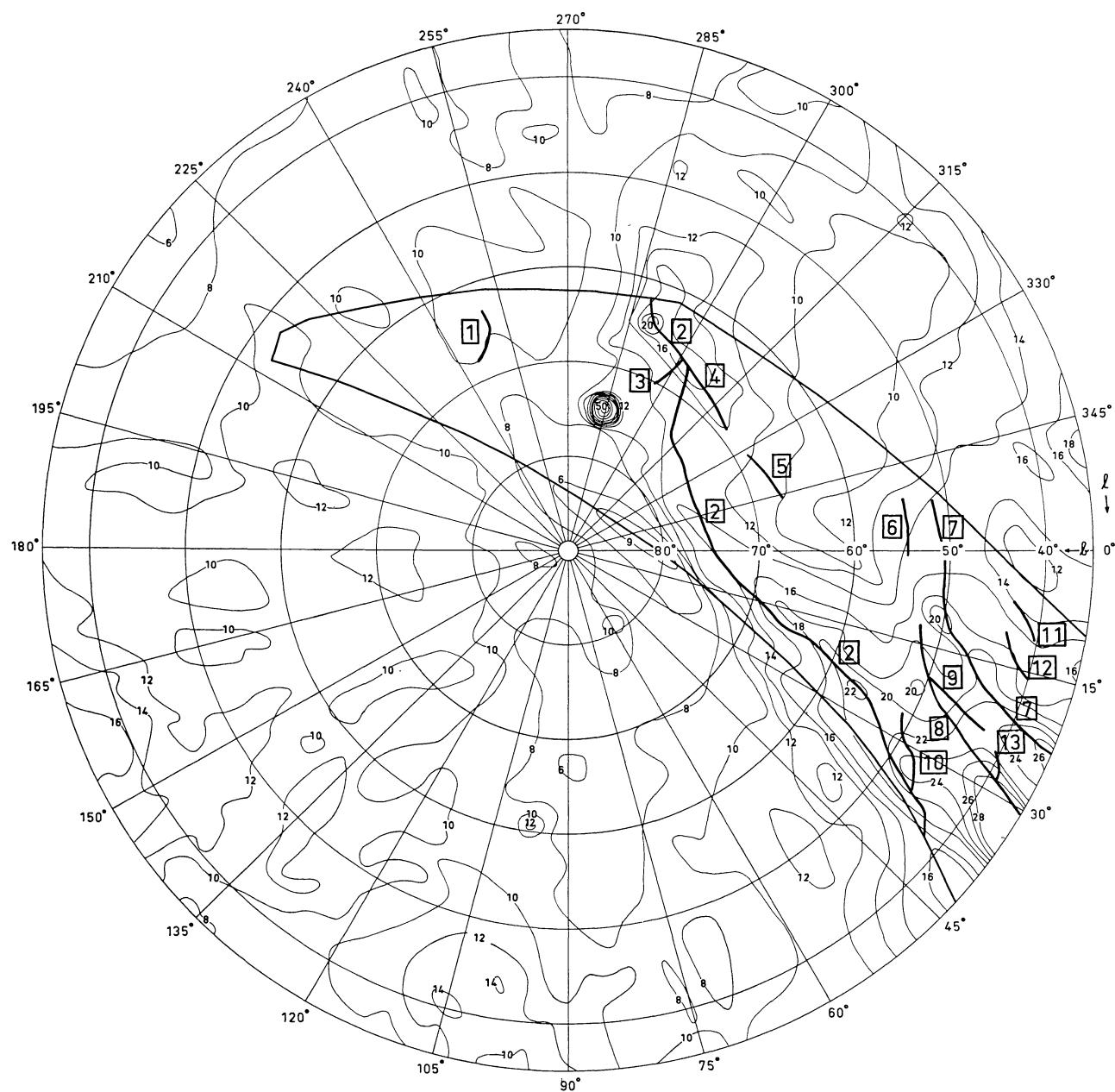


Figure 3. Finding chart for ridges (table 1). The contours of the background radiation have been taken from SEEGER *et al.* (1965).

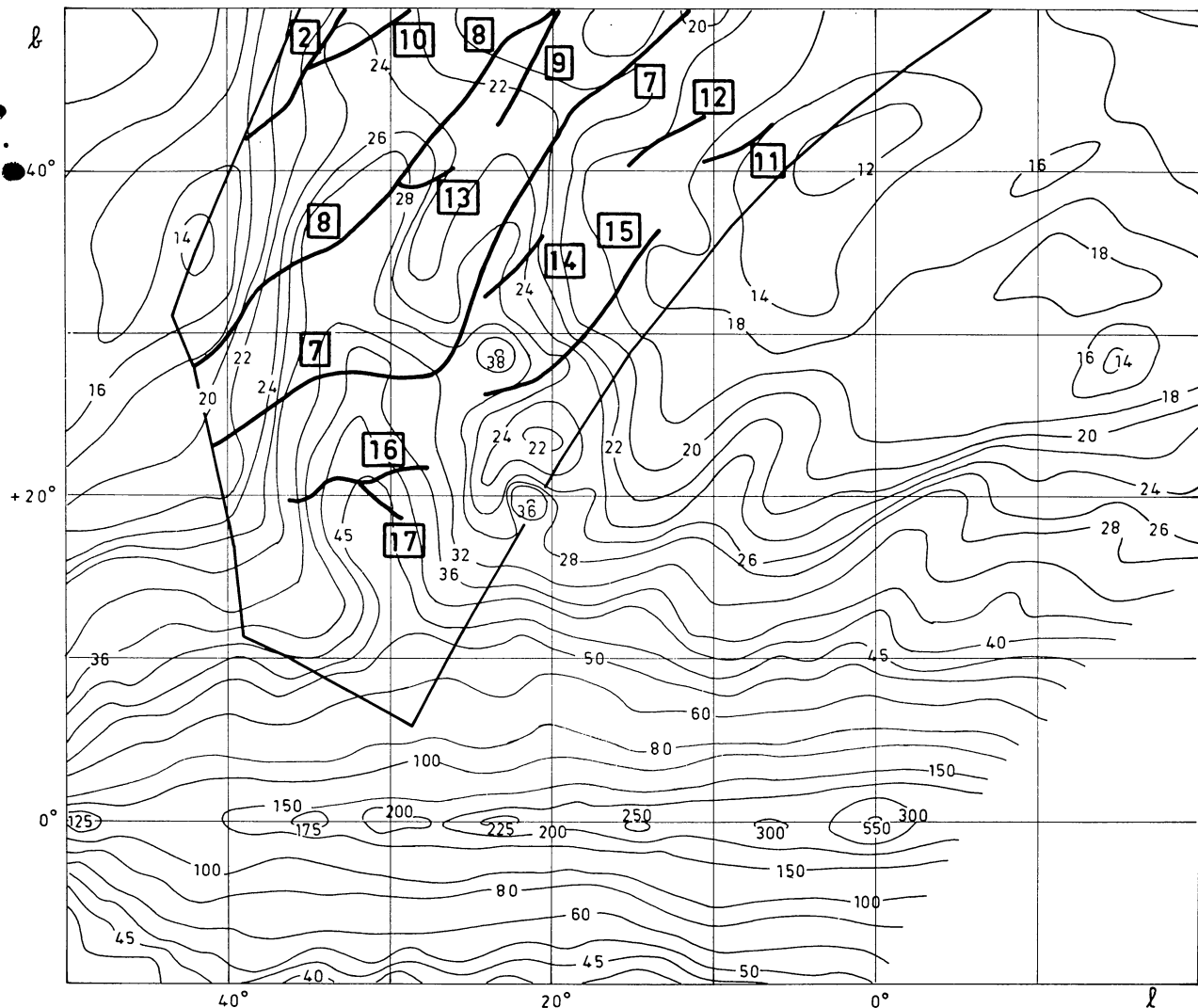


Figure 3 (continued)

galactic latitude of $+75^\circ$ ($\alpha = 13^{\text{h}}20^{\text{m}}$, $\delta = +15^\circ$) down to $b = +62^\circ$ where it runs off the map at $\alpha = 12^{\text{h}}20^{\text{m}}$, $\delta = 0^\circ$. This last ridge section provides a link between the two ridges found in this region in the LDS. Apart from the main ridge, a number of ridges running more or less parallel to it can be followed. The reality of these ridges is fairly certain as the zero-gradient points, which were determined without reference to neighbouring scans, form virtually continuous features in the gradient contour map.

Table 1 lists the ridges found in this survey. The corresponding ridges found in the LDS are given in the sixth column of this table.

4.1. The main ridge of the North Polar Spur

Several authors have put forward the suggestion that the North Polar Spur might be a supernova remnant. The main arguments for suggesting this are: 1) Scans through the Spur give at some places the suggestion of a shock-front, the intensity of the Spur dropping much more steeply on one side than on the other, 2) it roughly describes a semi-circle, and 3) the intensity inside the semi-circle is thought to be somewhat higher than outside.

The present survey can give little information about points 2) and 3). It could be remarked that the Spur is

indeed seen to bend back from high galactic latitudes, but as it runs off the map quite soon the present observations do not seem to be conclusive. The presence of ridges inside the suggested semi-circle could be related to 3), although one very faint ridge was found on the other side. There are unfortunately insufficient observations in the present survey on the other side of the Spur.

With relation to 1), inspection of the contour maps shows that for the main ridge at high latitudes negative gradients are practically absent, evidently there is a marked asymmetry.

The greater detail provided by our primary beam patterns ($0^\circ.6 \times 0^\circ.6$ compared to $1^\circ.1 \times 1^\circ.2$ in the LDS) can be used to advantage in estimating the sharpness of the main ridge of the Spur in the region $\alpha = 12^h40^m$ to $\alpha = 15^h00^m$, where it stands free of other structures except 3C300 at $\alpha = 14^h20^m$. At several points ($\alpha = 13^h59^m$ to 14^h14^m , $\alpha = 14^h54^m$) the gradient is equivalent to one which would be obtained by cutting an infinitely sharp edge at the same angle, indicating that at these points the ridge is not yet resolved by our $0^\circ.6$ beam.

4.2. Other ridges

The most conspicuous ridges indicated in the LDS in this part of the sky were easily found. On the whole, the agreement in position is good. The distances over which the ridges can be followed are somewhat greater than in the LDS. However, several of the weaker ridges which Large *et al.* thought to be related to local bright patches are absent. This is probably due to greater smoothness in the intensity distribution of these features.

The drop in intensity seems to be steep on both sides of the ridges. Apart from the main ridge of the Spur, no ridges were found to have only strong positive or strong negative gradients. In figure 3 the position of the ridges is shown with respect to the 400-MHz brightness contours published by SEEGER *et al.* (1965). It can easily be seen that there is a correlation between the ridges and the 400-MHz contours at low latitudes. Parts of ridge 7 ($b = +30^\circ$ to $+50^\circ$) and ridge 15 ($b < +30^\circ$) are evidently related to Spur-like structures. Another part of ridge 7 ($l > 27^\circ$) corresponds to a "step" in the Spur.

For high latitudes ridge 2 evidently is the main ridge, while between $b = +42.5$ and $b = +35^\circ$ there is a

good agreement between the position of the Spur and the position of ridge 8.

Near the left-hand boundary of the survey the scan direction is practically parallel to the sharp edge of the Spur. As the method is insensitive to structure running parallel to the scan direction this makes it impossible to determine the position of this edge below $b = +45^\circ$ from this survey. Well away from the high-intensity, high-gradient part of the Spur there are no such difficulties. The ridges found in this region appear to be quite well-defined distinct features; traces of most of the ridges could be found in the contour map of Seeger *et al.* in the form of bulges in the contours.

An interesting point about these high-latitude ridges is that at 1417 MHz they seem to be much brighter with respect to the main ridge of the Spur than they are at 240 MHz. This is apparent from a comparison between those parts of the ridges that were measured in both our survey and the LDS. This might be due to a difference in gradient. The sharp features in the main ridge of the Spur may account for a smaller fraction of its total radiation than is the case for the other ridges. Alternatively, it might be due to an intrinsic difference in spectral index.

5. Conclusion

The dual feed system provides a sensitive method for measuring narrow, elongated ridges of enhanced radiation in those parts of the sky where other background radiation is low. The existence of most of the ridges in the LDS in the relevant part of the sky is confirmed and it is possible to follow them over large distances. The data about the main ridge of the Spur tend to confirm that we are dealing with some kind of shock-front. The existence of other ridges inside the supposed arc of the Spur may be related to this, although they are found to have somewhat different characteristics. As the intensity gradients have been measured in only one direction, the present observations are inadequate for a complete study of the complex low-latitude regions of the Spur. A further complication is that recent observations at 1420 MHz show the Spur to be strongly polarized at low latitudes (VAN DE HULST, 1967); as the polarization of the dipoles was parallel to the scan direction throughout the survey, this might well give rise to some spurious effects.

If one would want to study the low-latitude part of the Spur, further observations in two perpendicular scan directions and with circular polarization would be required. In addition to this, the method as described here could be useful in searching for further ridges on the other side of the Spur and in trying to follow the main ridge from where it runs off the map in the present survey to low latitudes.

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