With regard to the planetaries I was very interested to see that Dr. Westerlund finds a centroid within the bar, while the centroid of HI radiation (which agrees with the centre of both radio and optical rotation) lies well outside the bar.

Westerlund: The older population may define a different centroid from that of the gas and the young stars.

Perek: The planetaries do not seem to be very strongly concentrated. Of course, the giant planetaries in the LMC may have a different distribution in space from galactic planetaries.

Tifft: The bar population is probably rather old compared with most of the other types of objects we have been considering. I would not be surprised to see significant shifts in system centroids as a function of age of the systems in view of the rather irregular dynamics of the system.

de Vaucouleurs: The cluster distribution on the south side shows also clearly the part of the outer loop near $-75°$ between 4^h50^m and 6^h10^m which is not covered by the C stars search.

Ambartsumian: I have noted a very strong concentration of M-type stars on your diagram, just within 1 degree from 30 Doradus. Does it coincide with any concentrations of objects of some other type?

Westerlund: It coincides well with groupings of blue stars, generally where there is no or little HII emission visible.

Tifft: Could you say roughly what the apparent visual luminosity of the carbon star group is, and how much spread is seen?

Westerlund: Approximately 15·7 with a spread of about $\pm 0\cdot 5$ mag.

54. CONTINUUM RADIO EMISSION FROM THE MAGELLANIC CLOUDS

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I. Radio Emission from "Normal" Galaxies

Before discussing the results of the radio observations of the Magellanic Clouds in detail, it is worth while to briefly review some of our current ideas about radio emission from "normal" galaxies which would be the classification given to the Clouds by radio astronomers. A "normal" galaxy has no striking visual peculiarity and has a much lower ratio of radio to light flux than the "radio" galaxy.

Hanbury Brown and Hazard (1961*b*) found that in general the ratio of radio to light flux is less for irregular galaxies than for spiral galaxies. This was supported by the surveys of Mills (1959) and Heeschen (1961). A recent survey of 37 "normal" galaxies by Mathewson and Rome (1963*b*) using the 210-foot reflector of the ANRAO at 1410 Mc/s has also confirmed this result. The magellanic-type galaxies NGC 55 and 6822 were amongst the irregular galaxies included in this survey. Table 1 gives radio indices at 1410 Mc/s for these two galaxies together with those for the Large and Small Clouds obtained by integration of the 1410 Mc/s isophotes in Figures 2 and 3. *R*, the radio index, is defined as $m_r - m_{pg}$, where m_r is the radio magnitude at 1410 Mc/s. The 16 Sc galaxies detected in this survey had a mean radio index at 1410 Mc/s of $+ 3\cdot 3$ with an r.m.s. deviation of $0\cdot 6$.

Until now our ideas about the broad-scale structure of radio emission from "normal" galaxies were formed from observations of the Galaxy and M31. Analysis

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of these observations has shown the existence of three main components, the nucleus, the disk, and the corona. From radio observations of M31, Hanbury Brown and Hazard (1959) found that 90% of the radio emission originated in a corona of angular size at half-intensity points about 1·3 times the maximum extent of the visible nebula. Hanbury Brown and Hazard (1961*a*) and other workers have assumed this relationship between the optical and radio size of M31 to hold for other spiral galaxies and they have used this to determine the radio magnitudes of the weaker galaxies whose radio sizes could not be measured. It has gradually become accepted that most "normal" spiral galaxies have radio coronae. However, Mathewson and Rome (1963*a*), from analysis of observations using the 210-foot reflector, have found no coronae for the three optically brightest Sc galaxies in the southern sky NGC 253, 4945, and 5236. Recent observations at 2650 Mc/s with the 210-foot reflector (aerial beamwidth 7·5 min arc) have shown the radio source which is at the centre of each galaxy to have linear dimensions of about 4 kpc or in the case of NGC 4945 even less. This is very much smaller than the visible nebula so that in these cases the radio emission is concentrated almost entirely in the nucleus. It is interesting to note that the ratio of radio to light flux for these three galaxies still lies in the "normal" galaxy range.

TABLE 1
RADIO INDICES OF MAGELLANIC GALAXIES

Galaxy	R(1410 Mc/s)	Galaxy	R(1410 Mc/s)
NGC 55	+5·1	LMC	+4·1
NGC 6822	+4·5	SMC	+4·5

TABLE 2
RADIO CONTINUUM OBSERVATIONS

Frequency (Mc/s)	Aerial Beamwidth (min of arc)	Radio Telescope	Observers
19·7	84	Cross array	Shain (1959)
85·5	50×65	Cross array	Mills (1959)
136	144	210-foot reflector	Mathewson and Healey
408	48	210-foot reflector	Mathewson and Healey
1410	14	210-foot reflector	Mathewson and Healey
2650	7·5	210-foot reflector	Mathewson and Healey

II. Radio Observations of the Magellanic Clouds

Some details of the radio observations of the Large and Small Clouds are listed in Table 2.

The closeness (55 kpc) and therefore large angular extent of the Magellanic Clouds provides an unparalleled opportunity to examine the distribution of radio emission in irregular galaxies of this class. From knowledge of the radio structure

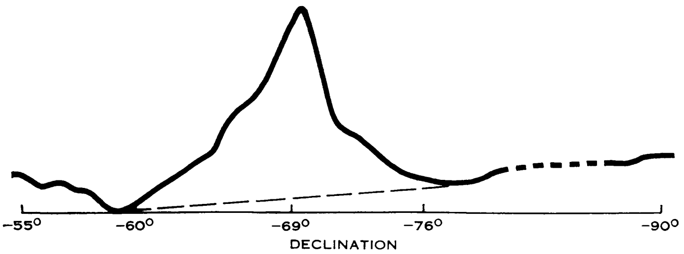

Fig. 1.—A 136 Mc/s declination scan at R.A. 05h 25m through the Large Cloud using the 210-foot reflector.

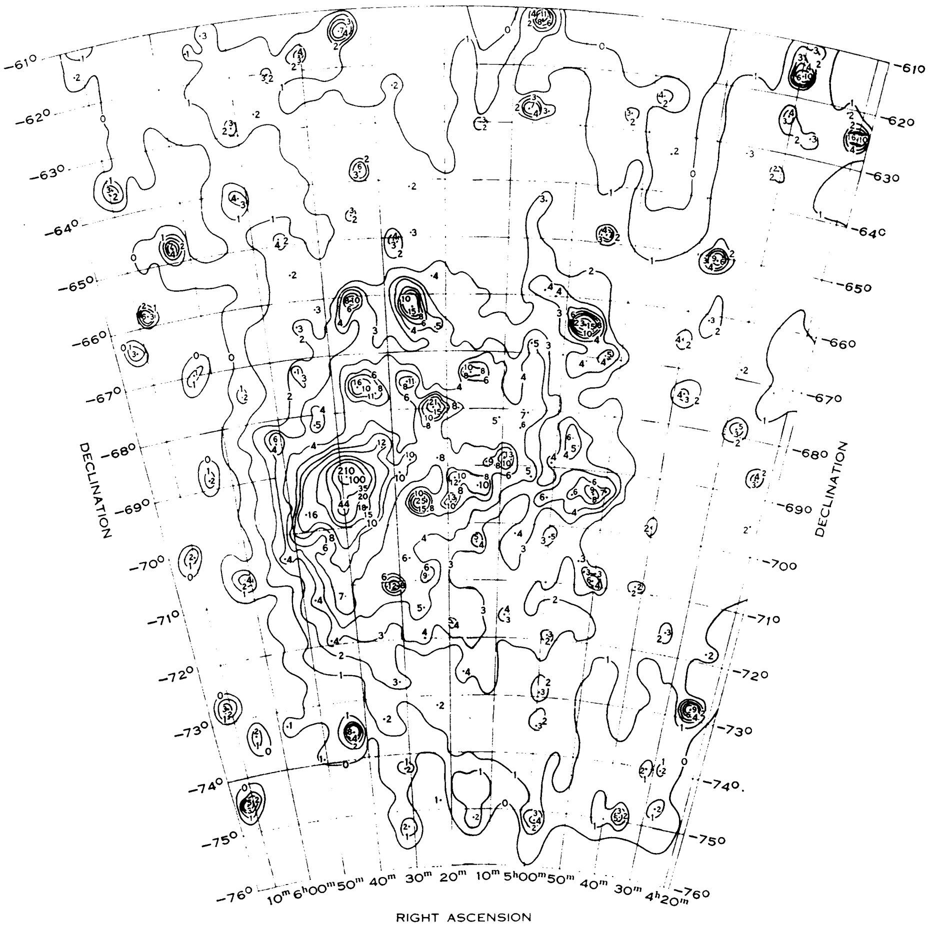

Fig. 2.—1410 Mc/s isophotes of the Large Cloud using the 210-foot reflector. The contour unit of brightness temperature is 0·17 °K.

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in other classes of galaxies, the low-frequency surveys of Mills and Shain, and optical investigations of the Clouds, there may be expected to exist both discrete and extended sources of radio emission of thermal and nonthermal origin. In such cases the 210-foot reflector may be used to great advantage to separate these various components by observing over a wide range of frequencies, as the observed temperatures of point sources (i.e. sources unresolved by the aerial beam) decrease much more slowly with increasing frequency than the extended radio sources.

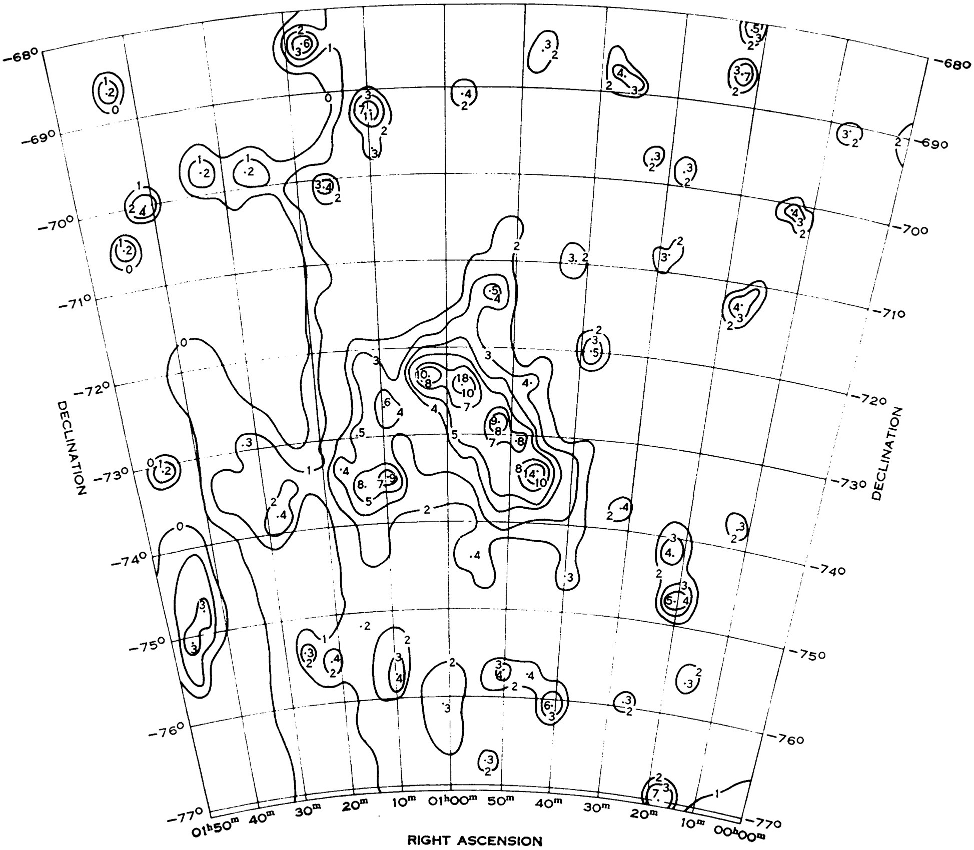

Fig. 3.—1410 Mc/s isophotes of the Small Cloud using the 210-foot reflector. The contour unit of brightness temperature is 0·17°K.

Therefore to detect any extended nonthermal component that may be present, several scans in right ascension and declination were made through the Clouds at the low frequency of 136 Mc/s (e.g. see Fig. 1). However, to delineate any small radio sources the much higher frequency of 1410 Mc/s was used to survey the Clouds and as can be seen from inspection of the isophotes (Figs. 2 and 3), the discrete sources are beautifully resolved from the "background" emission. These sources were also surveyed at 2650 Mc/s where the aerial beamwidth is 7·5 min arc. Most of them are identified with emission nebulae and they will be discussed in a subsequent

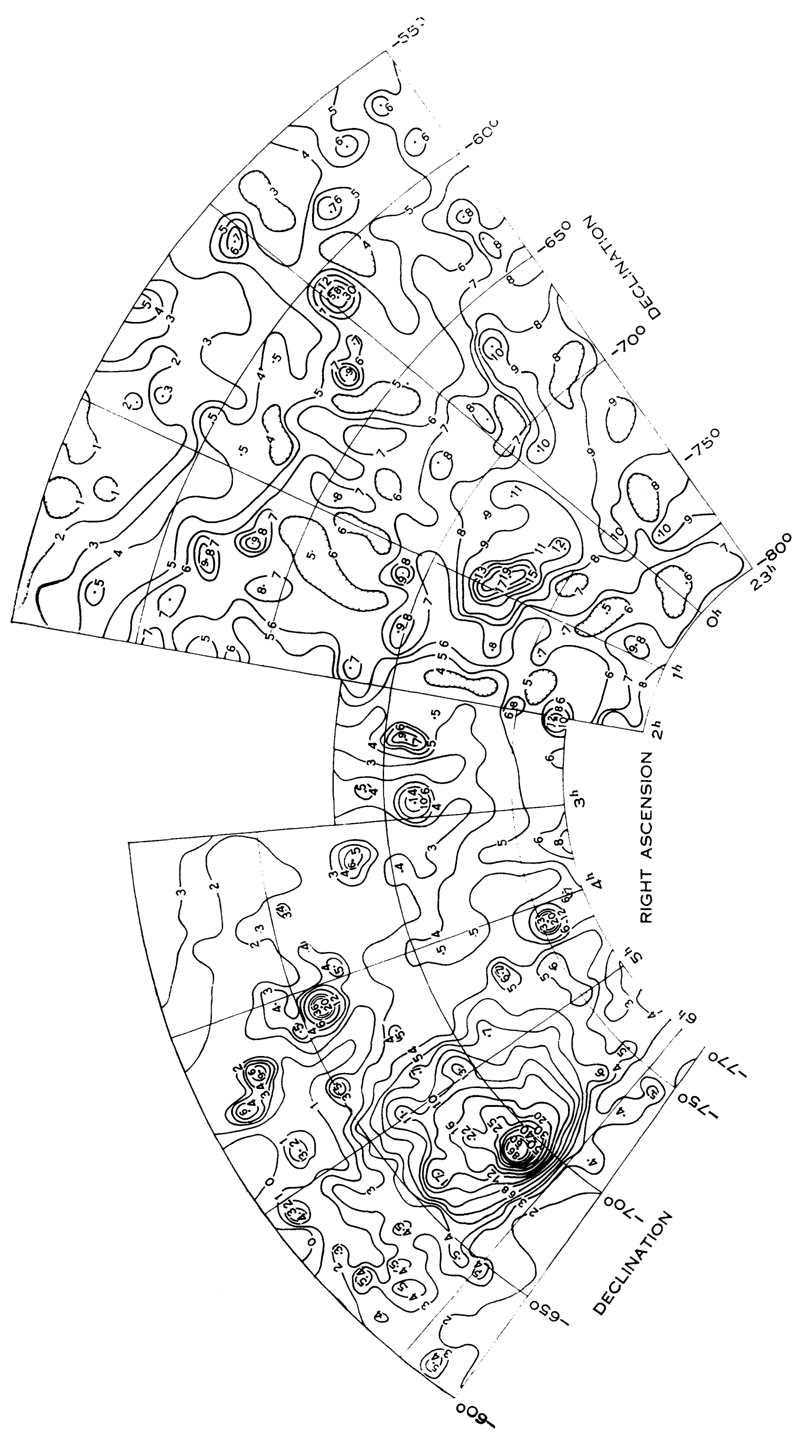

Fig. 4.—408 Mc/s isophotes of the region of the Large and Small Magellanic Clouds — the contour brightness temperature unit is 1·2 °K. The area between R.A. 23h and 02h was surveyed with the primary feed set at a constant p.a. of 30°.

session. 30 Doradus was also surveyed at 3000 Mc/s. The 408 Mc/s isophotes of the Magellanic Clouds obtained with the 210-foot reflector are presented in Figure 4. This intermediate frequency with moderate resolution is very useful for observing both thermal and nonthermal sources although the resolution is not high enough to resolve all the discrete sources in the main body of the Clouds.

Spectral index measurements of the radio emission in regions of complex structure such as the Clouds are most directly made by comparing the observed brightness temperatures at a number of suitably spaced frequencies when using aerial

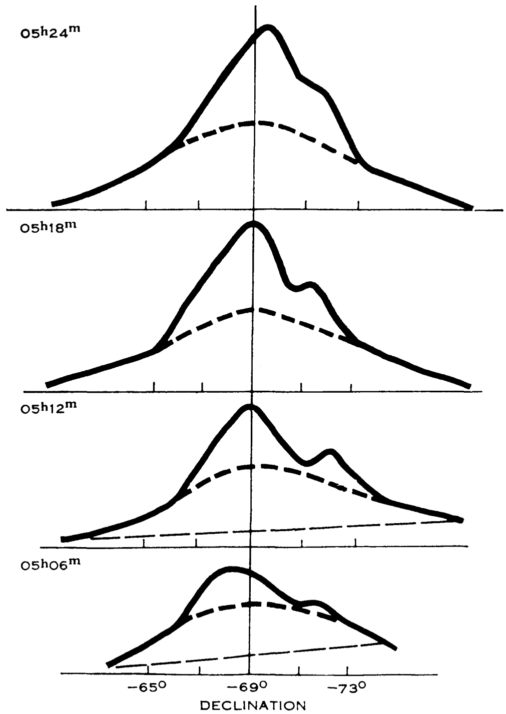

Fig. 5.—408 Mc/s declination profiles through the Large Cloud with the discrete source component removed.

beams of similar size. The 1410 and 2650 Mc/s results were first used to determine the position, intensity, and spectral index of the discrete sources (nearly all the sources are of thermal origin). This source component was then subtracted from the observed 408 Mc/s profiles and the remainder represents the broad-scale radio structure of the Clouds, e.g. Figure 5. The discrete sources were also removed from the 1410 Mc/s isophotes and the remaining isophotes were convolved with a gaussian function to make the resolution equal to that of the 408 Mc/s survey. The spectral index of the radio emission at any point of the Clouds can then be measured directly by comparing the brightness temperatures at 1410 and 408 Mc/s. Similar procedures have been used when comparing the 408, 136, 85·5, and 19·7 Mc/s observations.

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III. Results for the Large Magellanic Cloud

The radio emission from the Large Cloud appears to be concentrated in a region lying between R.A. $04^h\,40^m$ and $06^h\,10^m$, dec. -63 and $-75°$, which is roughly coextensive with the optical object. Very long right ascension and declination scans at 136 Mc/s with the 210-foot reflector show no evidence for a corona. Mills also found no evidence for a corona in his 85·5 Mc/s survey.

The integrated flux density at 1410 Mc/s is 620 flux units of which 120 flux units are contributed by the discrete sources (one flux unit equals $10^{-26}\,Wm^{-2}(c/s)^{-1}$). At 408 Mc/s the integrated flux density is 1100 flux units. The spectral index of the integrated background emission (sources subtracted) between 1410 and 85·5 Mc/s is $-0{\cdot}6$, which is consistent with a nonthermal origin of the radiation. It is very similar to the spectral index of the nonthermal component of the Galaxy.

(*a*) 30 *Doradus*.—Analysis of radio observations of 30 Doradus which have been made at a number of frequencies from 3000 to 19·7 Mc/s (see Table 2) has resulted in the construction of a model which will now be described. There is a strong central thermal source which is observed most clearly at 3000 Mc/s (6·7 min arc aerial beam) and 1410 Mc/s (14 min arc aerial beam) when using the 210-foot reflector. It has a flux density of about 40 flux units at these frequencies. Most of the radio emission originates in a source about 4 min arc in diameter. The intensity and size agrees very well with that predicted by Faulkner (1963) from his $H\beta$ photometric results. This region is "optically opaque" at 85·5 Mc/s. Surrounding this central HII region is a nonthermal source about 24 min arc at half-intensity points which produces most of the emission at 85·5 Mc/s. The flux density spectral index of the radiation is $-0{\cdot}6$. Previous estimates of the mass of 30 Doradus by Johnson (1959) based on the 85·5 Mc/s flux density should therefore be regarded with some caution. Finally there exists an extensive HII region about 45 min arc at half-intensity points which surrounds both the small central thermal source and the nonthermal source. It contributes about 20 flux units at 1410 Mc/s. It has an electron density of 2 and remains "optically thin" even at 85·5 Mc/s.

It is interesting to compare radiowise the galactic centre and 30 Doradus. Firstly, these regions dominate the higher frequency radio surveys of the Galaxy and the Large Cloud. Secondly, if the radio model for the galactic centre proposed by Mills (1956) and Cooper and Price (this volume, paper 40) is adopted, rough calculation shows that at the distance of 30 Doradus, the galactic centre when viewed face on would be very similar to the radio model just derived for 30 Doradus. It would appear to have a small central thermal source of intensity about half that observed in 30 Doradus and an extended nonthermal component about 30 min arc in diameter, i.e. very similar in size and only twice as strong as the nonthermal source in 30 Doradus. The mass of the central thermal component in 30 Doradus calculated from the radio observations is about $3 \times 10^5\,M_\odot$ — very similar to the mass of the galactic centre which Westerhout (1958) calculated to be $2{\cdot}5 \times 10^5\,M_\odot$. This is a most surprising and interesting result, and it is difficult to avoid the conclusion that the galactic centre and 30 Doradus are very similar objects.

(*b*) *Broad-Scale Radio Structure*.—Spectral index measurements of the background radiation with the method outlined in Section II show that the spectral index remains constant at $-0 \cdot 6$ over most of the Large Cloud except in regions about 30 Doradus where thermal emission produces a "flattening" of the spectral index. Several right ascension and declination scans at 136 Mc/s using the 210-foot reflector were made through the Large Cloud to delineate this nonthermal emission. One of these is shown in Figure 1. This scan suggests that the radio emission may be distributed in two components: (i) a central component which appears to be associated with the axial bar which is the characteristic optical feature of this type of galaxy, and (ii) a very extended component roughly the size of the visible galaxy. To investigate this with greater resolution, the contribution of the discrete sources (estimated

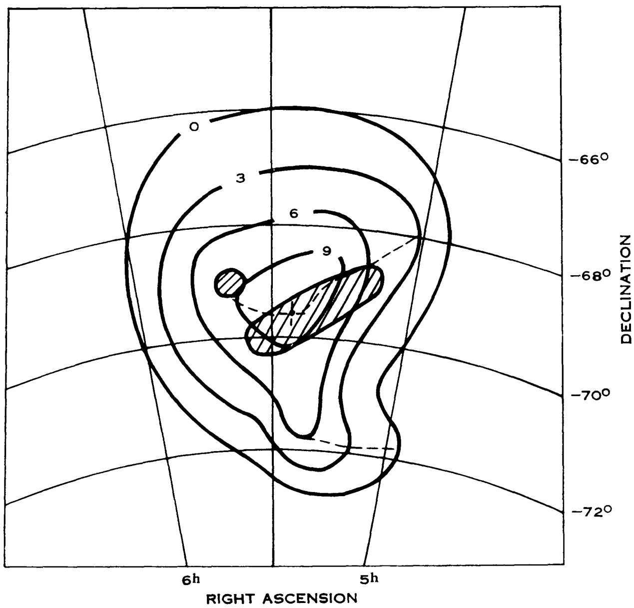

Fig. 6.—408 Mc/s contours of the "axial-bar" non-thermal component. The numbers on the contours represent T_b in °K.

from the 1410 Mc/s isophotes) was subtracted from the observed emission at 408 Mc/s. The four declination profiles shown in Figure 5 represent the distribution of the 408 Mc/s nonthermal emission obtained by this method. These show clearly the two components found more directly by the 136 Mc/s scan, but in addition the increased resolution at 408 Mc/s has revealed a third feature which lies at dec. $-71° \; 50'$, between R.A. $05^h \; 30^m$ and $05^h \; 00^m$. It has a width of about 75 min arc in declination (i.e. 1 kpc). It has an emissivity very similar to a galactic spiral arm and it may well represent a similar feature in the Large Cloud.

(i) *The "axial bar" nonthermal component.*—From a series of 408 Mc/s profiles similar to those in Figure 5, contours have been drawn for this "axial bar" nonthermal component and the spiral arm feature (Fig. 6). The points of maximum emission of these declination profiles form a ridge (dotted in Fig. 6), which starts near 30 Doradus, sweeps down into the axial bar where the emission reaches a peak at $05^h \; 25^m$, $-69° \; 36'$ (very close to the optical centre of the bar), and then moves to the northern edge of the bar which it follows to the end. The observations of this axial bar component can be reproduced if the true isophotes of this component are elliptical with gaussian brightness distributions along both axes. The apparent widths of this distribution are 3°.1 by 2°.2. The optical dimensions of the axial bar are roughly 2°.7 by 1°.0. Some degree of linear polarization has been detected in the 408 Mc/s radiation in the direction of the axial bar but as can be seen from Figure 7

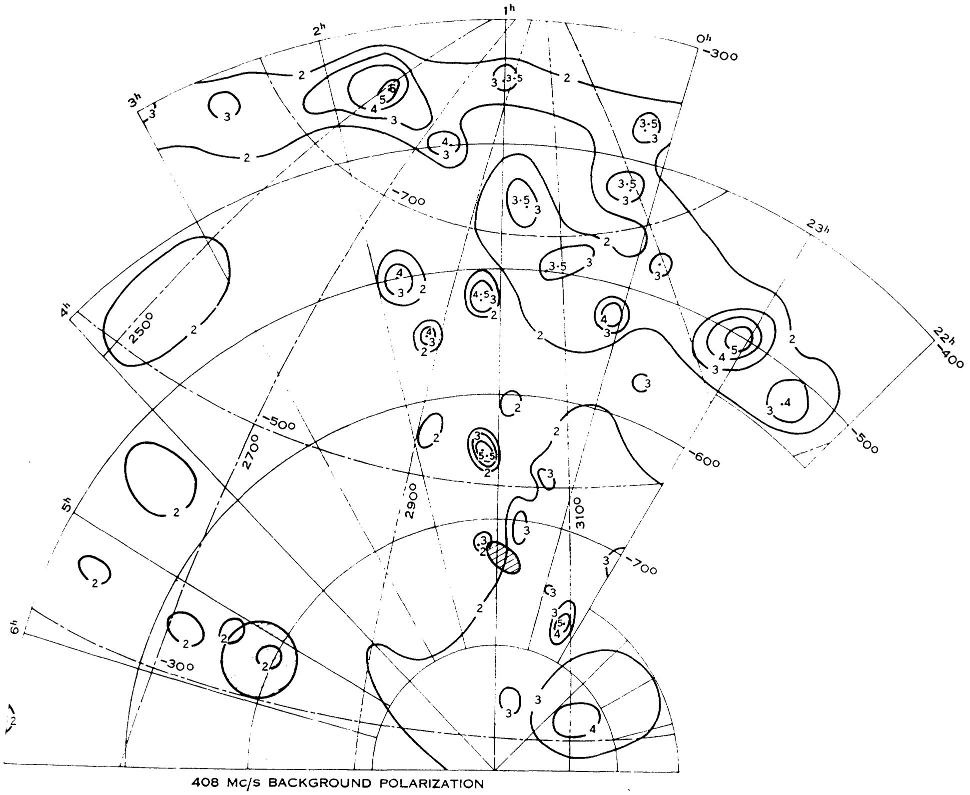

Fig. 7.—Contours of polarization temperature of the 408 Mc/s radio emission. The numbers on the contours represent T_b in °K.

the polarized radiation may not originate in the axial bar. The concentration of radio emission in this region infers the existence of a strong magnetic field, and if the linearly polarized radiation did arise in the axial bar it would also mean that the magnetic field was very ordered. The integrated radio emission at 408 Mc/s from this component is 160 flux units which is about 15% of the total radio emission from the Large Cloud. If the Galaxy was viewed face on, a corresponding feature to this component in the Large Cloud may be produced by the North and South Galactic Spurs (Bolton and Westfold 1950).

(ii) *Extended nonthermal component.*—This component has a width at half-intensity points in R.A. of 5° and in dec. of 7°. It is responsible for about two-thirds of the total radio emission at 408 Mc/s, its integrated flux density being 700 flux units.

IV. Results for the Small Magellanic Cloud

The radiation at 408 Mc/s in the region of the Small Cloud was found to have a linearly polarized component. The 408 Mc/s isophotes in Figure 4 between R.A. 23^h and 02^h were obtained with the primary feed of the 210-foot reflector set at a constant position angle of 30°. The contours in Figure 7 indicate 408 Mc/s polarization temperature, which is defined as the difference of aerial temperature between an aerial so aligned to receive all the linearly polarized radiation and one at right angles to it which receives none. The region from which linearly polarized radiation is detected extends far to the north of the Small Cloud and it therefore appears doubtful that any of this polarized radiation originates in the Small Cloud. It is probably associated with some galactic foreground feature.

The 1410 Mc/s isophotes obtained with the 210-foot reflector are presented in Figure 3. Most of the discrete sources lying in the main body of the Cloud have been identified with emission nebulae in the catalogue of Henize (1956). They will be discussed in a following session. The 1410 and 408 Mc/s isophotes follow closely the bright optical bar and show an extension coincident in position with "the wing" of the Small Cloud. The optical bar is about 2°.4 by 0°.7 and the radio contours show a source of about 2°.5 by 1°.0 coextensive with this optical feature.

The integrated 1410 Mc/s radiation from the Small Cloud is 67 flux units of which 13 flux units are due to discrete sources. At 408 Mc/s the integrated emission is about 110 flux units. The spectral index of the extended component of the radiation from the Small Cloud is $-0{\cdot}7$, similar to that of the Large Cloud.

V. Acknowledgments

The authors would like to thank Messrs. C. D. Smith, D. Gill, and L. F. Fellows for their help during the observations.

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Discussion

Aller: In the Triangulum spiral M33, the emission nebula NGC 604 closely resembles 30 Doradus in appearance and optical spectrum. NGC 604 is fainter than 30 Doradus but otherwise appears to be very similar to it. Yet NGC 604 is located a considerable distance from the nucleus of M33.

Mathewson: It may be possible for some galaxies to have two nuclei.

Davies: The density of sources in your 1410 Mc/s map appeared to be as large outside the Clouds as inside. You associate the radio sources inside the Clouds with optical objects. What is the origin of the sources outside the periphery of the Clouds?

Mathewson: The density of intense sources is higher inside the main body of the Clouds than outside. At the moment I have not attempted to associate the optically unidentified sources with the Clouds, although the sources with thermal-type spectral indices and the extended nonthermal sources found in the outlying regions may well be profitably investigated with optical telescopes.

Ambartsumian: What is the ratio of integrated intensities of nonthermal emission of the central bar and of the region surrounding 30 Doradus, say at 408 Mc/s?

Mathewson: The integrated emission at 408 Mc/s from the central nonthermal bar is about 150×10^{-26} $Wm^{-2}(c/s)^{-1}$ and from the 30 Doradus region about 100×10^{-26} $Wm^{-2}(c/s)^{-1}$.

Arp: Can you say whether the general polarization activity in the region of the Magellanic Clouds is higher than in corresponding galactic latitudes in much different directions?

Mathewson: Healey, Milne, and myself have commenced a general "background" polarization survey at 408 Mc/s of regions south of declination 30°. However, at the moment not a wide enough area in latitude has been surveyed to answer your question.

Oort: This is a tremendous amount of material of very great interest which you have presented. In reply to Dr. Arp's question, concerning the foreground polarization you observe in the general direction of the Small Cloud, I want to point out that distribution of the galactic polarization in high latitudes is so chaotic that one cannot hope to predict what it would be in front of the Small Cloud.

Have you any information on the direction of the magnetic field in the bar of the Large Cloud?

Mathewson: The observed position angle of the plane of polarization has not yet been corrected for Faraday rotation in the ionosphere. If the direction of the magnetic field obtained from the radio measurements agreed with that derived from the optical polarization measurements, one would have more confidence in associating the polarized radio emission with the Clouds.

Buscombe: Has any comparison been made of the space distribution of radio emission in the SMC with (*a*) early-type supergiants, and (*b*) the star clusters, which delineate quite a different distribution both in position and velocity from the bright stars?

Mathewson: No such comparison has been made.

55. NOTES ON THE STRUCTURE OF THE SMC AS OBSERVED IN 21-CM LINE RADIATION FROM NEUTRAL HYDROGEN

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I. Introduction

Earlier surveys of the line radiation from neutral hydrogen in the Magellanic Clouds (Kerr, Hindman, and Robinson 1954; Hindman, Kerr, and McGee 1963; Hindman *et al.* 1963) have shown that the amount of gas associated with these extragalactic bodies is relatively large. The gas appears widespread, surrounding the stellar bodies in a single continuous and very tenuous envelope with a marked bridge in the vicinity of the optical wing of the SMC linking the two main concentrations.