Discussion

Davies: Measurements have been made at Jodrell Bank with 200 kc/s bandwidth to determine the neutral hydrogen distribution in M31. The prominent feature is a ring of neutral hydrogen at $\sim$ 10 kpc from the centre. The northern part of this ring contains more neutral hydrogen than the southern part.

Blaauw: How large are the differences between the rotational velocities one finds for given distances from the centre?

Burke: This depends on the velocity of the centre of mass. There appear to be velocity differences of about 20–40 km/sec within 6 kpc of the centre.

Davies: M33 shows a similar neutral hydrogen concentration in a ring $\sim 15'$ in radius.

Burke: This agrees with our result.

25. THE RADIO CONTINUUM EMISSION FROM THE GALAXY

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Study of the radio continuum emission from the Galaxy is of interest both from the viewpoint of the physics of the radiating processes and the light which these shed on physical conditions within the Galaxy, and also because the large-scale organization of the emitting regions gives information about the structure of the Galaxy as a whole. We are concerned here particularly with the latter aspect, that is, the question of galactic structure, and for this we need to know the distribution of the emitting regions throughout the Galactic System.

There is no inherent distance scale yet available for the continuum radiation and to determine its distribution along a given line of sight one must rely heavily on assumptions of similarity and the measurement of angles. For example, we assume that the thickness and general properties of the spiral arms are a function only of their distance from the nucleus. Thus the direction of the galactic centre is taken as origin and one must be able to make measurements all around it; this kind of investigation is therefore particularly suited for the southern hemisphere. Another possibility is a distance scale based on low-frequency spectral measurements and the differentiation of thermal and nonthermal components; this has not yet been fully explored, but may become important in the future.

It is now customary to think of three basic galactic distributions of the emission. These are the discrete sources (including HII regions), the corona (or halo), and the disk (principally spiral arm emission).

Discrete Sources

The galactic discrete sources comprise a population of localized emitting regions distributed along and very close to the galactic plane. They now appear to have separated out fairly clearly into two classes, supernova remnants, which emit by the synchrotron process, and HII regions emitting thermally. Both appear to be well concentrated towards the spiral arms. Recent high-resolution observations of these objects are discussed in other papers and so they will not be considered here.

Corona

While any consideration of the general properties of the corona has been specifically excluded from this symposium, some very recent queries as to its very existence require some discussion. The principal evidence for a corona comes directly from the southern hemisphere work. Here it is a simple matter to observe that the radio emission falls off in all directions as we look away from the direction of the galactic centre. Certainly there are some major irregularities, but the general trend is clear and the irregularities themselves decrease at large angles.

This evidence was presented in detail at the Paris Symposium on Radio Astronomy (Mills 1959). It appears that no new results of this kind have been obtained, so that it is reasonably clear that an extensive corona exists which extends from the galactic nucleus out to at least the solar distance, in the form of a somewhat irregular oblate spheroid with axial ratio of about 1·5. At larger distances the evidence is all more indirect and it seems impossible to give definitive answers. However, the results presented at the Paris Symposium indicated a quite rapid decrease in emissivity beyond 10–12 kpc from the nucleus.

It seems likely the radiation is produced almost entirely by the synchrotron process. Certainly any thermal component is likely to be very small at normal frequencies. This follows from recent low-frequency observations by Ellis, Waterworth, and Bessell (1962). As shown by Hoyle and Ellis (1963) the observed low-frequency cut-off in the spectrum is consistent with absorption of distant nonthermal radiation by a thin layer of ionized hydrogen in the local spiral arm.

Disk Radiation

The disk radiation comprises the band of unresolved emission concentrated closely to the galactic plane. Various authors have attempted to separate this into its thermal and nonthermal components; in fact the basic idea of this separation originated with Piddington more than a decade ago, although the data then were inadequate for a useful analysis. In 1958, however, the availability of galactic survey results of reasonably high resolution at 85 Mc/s allowed considerable advances to be made (Mills, Hill, and Slee 1958; Westerhout 1958; Large, Mathewson, and Haslam 1961; Mathewson, Healey, and Rome 1962).

Recent analyses have assumed (i) complete mixing of the thermal and nonthermal components and (ii) a nonthermal spectrum which is constant throughout the Galaxy and in which the emissivity is related to the frequency through a simple power law. Departures from assumption (i) are relatively unimportant at frequencies above about 100 Mc/s, although they could have drastic effects at low frequencies. Assumption (ii), however, is crucial to the whole method and is certainly open to question.

It does appear that, at latitudes greater than a few degrees, at least the first part of assumption (ii) is not greatly in error, although it is now clear that the second part is true only over limited frequency ranges because the slope of the spectral curve decreases with decreasing frequency (Turtle *et al.* 1962; Hoyle and Ellis 1963). However, these results apply only to the corona, the local spiral arm, and perhaps the nearer parts of the Sagittarius arm; we have not yet any conclusive evidence that the inner spiral arms, which lie close to the galactic plane, have the same spectrum.

In order to test the consistency of recent attempts to separate the thermal and nonthermal components, Table 1 has been prepared. Regions have been selected from recent maps of the derived HII distribution (Large, Mathewson, and Haslam 1961; Mathewson, Healey, and Rome 1962) in which the ionized hydrogen is essentially absent and its effect on the spectra between 19·7 Mc/s and 85·5 Mc/s should be negligible. The published data at these frequencies (Hill, Slee, and Mills 1958; Shain, Komesaroff, and Higgins 1961) have been used to derive spectral indices x, defined by $T \propto f^{-x}$.

TABLE 1

COMPARISON OF SPECTRAL INDICES AT PLACES WHERE THE EFFECTS OF IONIZED HYDROGEN SHOULD BE SMALL

l^{II}	276	286	314	322	340	0	20	30	38
b^{II}	0	−3	−3	−3	−2	−3	−3	−3	−2
x	2·75	2·50	2·50	2·30	2·00	2·51	2·44	2·56	2·54

Inspection of the table reveals a fair scatter in x which, if the initial assumptions are correct, should have a constant value of 2·6. Some of the scatter is likely to be due to inaccuracies in reading from a contour diagram, but such errors must have been also present in the original analysis. Consequently it appears that the detailed picture of the distribution of ionized hydrogen may not be accurate. The most significant result of these analyses, however, is the apparent concentration of ionized hydrogen towards the central parts of the Galaxy where the spectral slope is much less than the 2·6 observed at higher latitudes. Taking into account the small range of latitudes over which this effect is observed, an interpretation requiring the presence of large quantities of ionized hydrogen is certainly the most plausible. However, it does not yet seem possible to make any confident statements about the details of the assumed HII distribution, whether it is in the form of a ring as proposed by Westerhout (1958), whether it is concentrated to the inner spiral arms as suggested by Mathewson, Healey, and Rome (1962), or whether it has some other configuration.

Further progress would seem to need high-resolution observations at quite low frequencies where the hydrogen, if present, might be observed in absorption, or at least with a very much modified spectrum.

Spiral Arm Pattern

Finally let us consider the possibility of deriving the galactic spiral arm pattern from the continuum observations. This was discussed at the Paris Symposium on Radio Astronomy (Mills 1959) but, since then, several more surveys have become available.

In Figure 1 it is shown how the spiral arm directions are defined by various methods. For the continuum radiation the longitudes of observed "steps" in the distribution are indicated; it is assumed that we are there looking tangentially to the spiral arms. The same criteria for the recognition of such steps have been used throughout. No attempt has been made to separate the thermal and nonthermal components because the details of this separation may be rather uncertain and it is the details which are needed here. The HI results have been taken from Kerr (1962) and the optical results from Elsasser and Haug (1960).

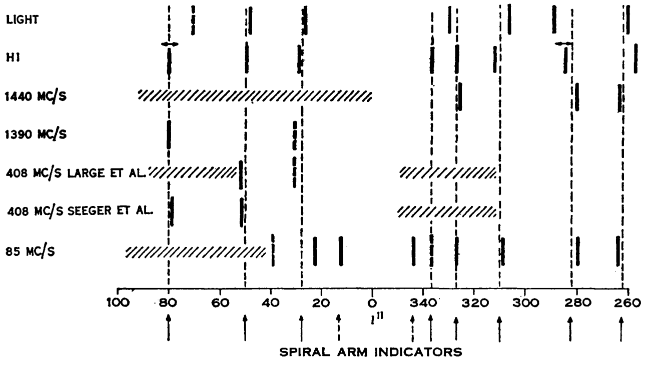

Fig. 1.—Spiral arm indicators—the arrows represent the inferred directions of the tangential points.

Most of the indicated longitudes are in good agreement. The apparently bad discrepancy at 85·5 Mc/s, in the direction of the 50° arm, arose simply because the survey was terminated at about this point, but the arm does seem to be very wide.

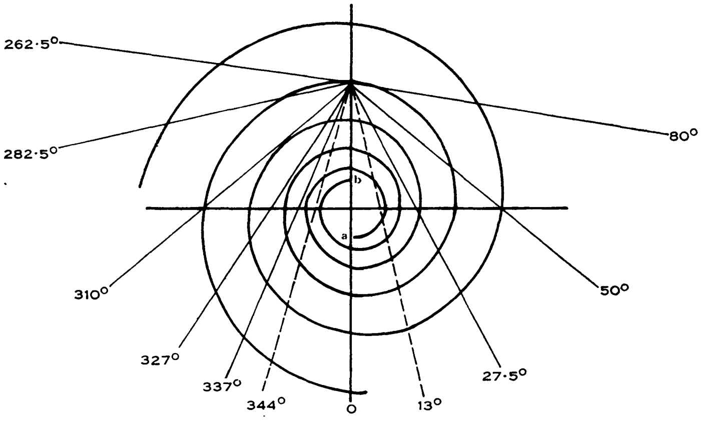

Fig. 2.—A possible form of spiral pattern (a two-start equiangular spiral of angle 83°.2); the inferred directions of the tangential points are shown.

Otherwise, it appears that the spiral arms might be delineated most clearly at relatively low frequencies. The 111 Mc/s results from our new Cross (Mills *et al.* 1963) may therefore help considerably (beamwidth ≈ 10 min arc).

In Figure 2 an attempt is made to fit a spiral pattern to these arm directions. The pattern, a two-start equiangular spiral, is the one presented before at Paris (Mills 1959) and one can see immediately that the new results do not necessarily cause any major changes, although it is clear that the Sagittarius arm does not lie exactly in the predicted direction. This has not invalidated the model, as divergences from a completely regular spiral are only to be expected, but the precise agreement found before is lost and so one should seriously consider other ways of joining the spirals around. Elementary considerations of topology indicate that this is the only way of joining up a two-start spiral, but three- or even four-start spirals are not excluded and would lead to a greater inclination of the spiral arms.

The feature of the two tangents to the local arm at 262°.5 and 282°.5 is easily understandable as the result of a local irregularity which shows also in the optical and HI results.

These results have been presented largely to demonstrate the potentialities of the continuum emission in delineating the spiral pattern. High-resolution surveys will help still further in allowing separation of the sources and better estimates of the angular widths of the suggested arms; the latter would serve as additional indicators of their distance.

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Discussion

Bolton: It seems to me that Dr. Mills' apology for an adequate distance scale for the radio observations was somewhat unnecessary. Nearly every speaker in the conference has made a similar apology for his observations.

Oort: Dr. Mills mentioned that at a recent Herstmonceux Conference it had been suggested that there was not yet good evidence for the existence of a radio halo. I do not believe that this suggestion could have been meant too seriously. If there were no halo, the irregular radiation observed in high latitudes would have to be ascribed to radiation from nearby regions in the disk. But in that case we should expect to see much higher intensities of nonthermal radiation in the plane of the disk than have actually been observed.