THE RADIO SPECTRUM OF THE ANDROMEDA NEBULA

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Summary

Some new observations of the Andromeda nebula have been made at frequencies of 38 and 178 Mc/s. At 178 Mc/s both fan-beam and interferometric measurements have allowed a number of point sources superimposed on the nebula to be distinguished; a comparison of the number of these sources with those found in neighbouring areas of sky suggests that they are not related to the nebula.

By comparing the observations at 38 and 178 Mc/s with those previously made at Jodrell Bank at 408 Mc/s, it has been possible to show that all parts of the nebula have a similar spectrum, the brightness temperature varying at $\nu^{-2.8\pm0.1}$ a figure close to that for the Galaxy.

Introduction

A number of observations of the radio emission from the Andromeda nebula have been made in the frequency range 81.5–408 Mc/s (1, 2, 3, 4, 5). The overall distribution of emission from the nebula is now well established, most of the radiation originating in an extended halo about $10^\circ \times 6^\circ$ in size. On the other hand, no satisfactory value has been obtained for the spectrum of the radiation, mainly because of the difficulty of separating the radiation from M31 from the superimposed galactic emission. Different observers have subtracted the galactic emission in differing arbitrary ways and the resulting flux densities cannot usefully be compared. Values of the spectral index ranging from $-1.6$ (6) to $-1.1$ (5) have been quoted. A more reliable way of deriving the spectral index, and one which shows up clearly the probable errors of the determination, is to compare scans across M31 over a range of frequencies using beams of similar shapes. Recent measurements at Cambridge at frequencies of 38 Mc/s and 178 Mc/s combined with the observations of Large, Mathewson and Haslam (4), enable this procedure to be used, giving the spectral index of the radiation from M31 over the range 38–408 Mc/s. The 178 Mc/s observations also provide new information concerning the distribution of brightness over the nebula, particularly with regard to the 'point' sources of radio emission in this region of the sky.

178 Mc/s observations

Recordings of the total power received by one element of the 178 Mc/s interferometric radio telescope at Cambridge have been made with the aerial beam centred on $\delta = +40^\circ 0$. The beam widths at half power points are $4^\circ 6$ in $\delta$ and $13^\circ 5$ in $\alpha$. Fig. 1 shows the mean of two recordings on successive days. From measurements of the polar diagram, the aerial efficiency is known to be $0.75$ and the observed temperatures have therefore been multiplied by $1.33$ to give true brightness temperatures. The halo of M31 extends from $00^h 25^m$ to $00^h 57^m$, superimposed on which there are several features whose
width in right ascension is that expected for a radio source $\leq 13'5$ in diameter. Many of these sources appear on an interferometric record made using both portions of the radio telescope at an E–W spacing of $465\lambda$, and are therefore $\leq 3'\text{ arc}$ in size. In particular the sources at right ascensions $00^h 28^m$, $00^h 31^m 45^s$, $00^h 46^m$, $00^h 52^m$, $00^h 54^m$ are all of small angular size. Part of the area of sky close to $\text{M}_31$ has recently been surveyed at $178\text{ Mc/s}$ using the aperture

![Graph](attachment:image.png)

**Fig. 1.**—Drift curve of the variation of brightness temperature at $178\text{ Mc/s}$ across the Andromeda nebula. The aerial beam was centred on $\delta = +40^\circ$. The plotted curve is the mean of two readings.

synthesis technique (7), giving positions of sources of small angular size down to flux densities of about $2 \times 10^{-26}\text{ w.m.}^{-2}\text{ (c/s)}^{-1}$. In the region of sky $44^\circ \leq \delta \leq 39^\circ 30', 0020 < \alpha < 0100$ the following sources have been located by P. F. Scott and D. R. Marks, who have kindly allowed us to make use of the information.

<table>
<thead>
<tr>
<th>$\alpha$</th>
<th>$\delta$</th>
<th>$S \times 10^{-26}\text{ w.m.}^{-2}\text{(c/s)}^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$00^h 28^m 07^s$</td>
<td>$+40^\circ 53'$</td>
<td>2.5</td>
</tr>
<tr>
<td>$00^h 33^m 56^s$</td>
<td>$+42^\circ 36'$</td>
<td>1.9</td>
</tr>
<tr>
<td>$00^h 39^m 34^s$</td>
<td>$+39^\circ 48'$</td>
<td>2.3</td>
</tr>
<tr>
<td>$00^h 41^m 55^s$</td>
<td>$+42^\circ 30'$</td>
<td>1.9</td>
</tr>
<tr>
<td>$00^h 45^m 26^s$</td>
<td>$+40^\circ 06'$</td>
<td>3.1</td>
</tr>
<tr>
<td>$00^h 46^m 07^s$</td>
<td>$+43^\circ 56'$</td>
<td>1.6</td>
</tr>
<tr>
<td>$00^h 51^m 39^s$</td>
<td>$+40^\circ 26'$</td>
<td>3.1</td>
</tr>
<tr>
<td>$00^h 53^m 59^s$</td>
<td>$+43^\circ 58'$</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Two of these sources are probably the same as those observed by Large, Mathewson and Haslam (4) at $00^h 46^m 15^s$, $+40^\circ 24'$ and $00^h 52^m 00^s$, $+40^\circ 30'$. The source at $00^h 39^m 34^s$, $+39^\circ 48'$, lying just over $1^\circ$ south of the centre of $\text{M}_31$, appears on the total power curve (Fig. 1) with a flux density of $4 \times 10^{-26}\text{ w.m.}^{-2}\text{(c/s)}^{-1}$, but its flux density is too small for a reliable angular
diameter to be quoted for it. No source has been detected coinciding with the optical nucleus of M₃₁.

The average density of radio stars down to flux densities of $2 \times 10^{-26}$ W.m.$^{-2}$ (c/s)$^{-1}$ over the area of M₃₁ is not significantly different from the density in other samples of sky nearby. Most of the radio sources superimposed on M₃₁ are thus not physically connected with it but remain as a confusing feature in the determination of the spectral index.

38 Mc/s observations

The 38 Mc/s interferometer at Cambridge, employing the principle of aperture synthesis, has been used to observe the region in the vicinity of M₃₁ with a beam width of $0^\circ.8$ in $\alpha$ and $4^\circ.4$ in $\delta$. The beam width in $\delta$ is determined by the total North–South movement of the small section of the interferometer; observations at this declination using spacings up to 12$\lambda$ are at present available.

![Graph showing the distribution of brightness at 38 Mc/s across the Andromeda nebula at $\delta = +40^\circ$.](https://example.com/graph.png)

Fig. 2.—Synthesised distribution of brightness at 38 Mc/s across the Andromeda nebula at $\delta = +40^\circ$.

The results obtained are in the form of scans in declination at successive minutes of right ascension with a declination beam width of $4^\circ.4$ to half power points. The values at $\delta = +40^\circ.0$ are plotted in Fig. 2. Examination of the scans in $\delta$ suggests that the feature in Fig. 2 at $\alpha = 00^\text{h} 52^\text{m}$ is associated with the 178 Mc/s source at $\delta = +40^\circ.26'$.

The radio spectral index of M₃₁

The radio data provide two distinct kinds of information relating to the spectrum of M₃₁ which are affected in different ways by errors in measurement:

(i) The spectral index of the radiation from the whole of M₃₁. The accuracy of this determination depends on the accuracy of the absolute scales of temperature employed by different observers and an accurate knowledge of the aerial efficiency.
(ii) The variation of spectral index across M31. This depends only on a comparison of the shapes of the scans at different frequencies and is independent of any assumed scale of temperature.

To reduce the observations at 38 Mc/s and 178 Mc/s and the Jodrell Bank observations at 408 Mc/s to a common beam width, the 178 Mc/s observations have been smoothed in right ascension to give an effective $40' \times 4^3$ beam whilst the 408 Mc/s observations have been smoothed in declination to give a similar beam. The beam width of $48' \times 4^3$ at 38 Mc/s is sufficiently similar for the present discussion.

The three curves derived in this way are shown together in Fig. 3, the scales of temperature having been chosen to give the best overall fit between the curves. There is good general agreement between the curves except at $\alpha = 00^h 32^m$ and $\alpha = 00^h 52^m$ where it is evident that the radio sources at these right ascensions have flux densities falling off more steeply towards higher frequencies than M31 itself.

![Fig. 3.—Brightness temperatures at 38, 178 and 408 Mc/s scaled to give the best overall fit between the curves. All the observations have been smoothed to a beam width of 40' in right ascension by 4$^3$ in declination.](https://academic.oup.com/mnras/article-abstract/121/4/413/2602336)

Brightness temperatures taken from the temperature scales in Fig. 3 are plotted in Fig. 4. These points define the mean spectral index of M31. The slope of the line is $-2.5 \pm 0.1$. The flux density of M31 thus varies with frequency, $\nu$, as $\nu^{-0.5}$ i.e. the spectral index of M31 is $-0.5$. For the spectral index of the galactic radiation Adgie and Smith (8) obtained a value of $-0.5 \pm 0.1$, in good agreement with the result for M31. More recent measurements by Costain (9) on the galactic radiation have given a spectral index of $-0.37 \pm 0.04$, which is just consistent with the M31 value.

Adgie and Smith (8) and Costain (9) also found that, except in regions of sky very close to the galactic plane, the spectral index of the galactic radiation is independent of direction. Examination of Fig. 3 suggests that, within the

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errors of measurement, the spectral index of M31 is constant across the nebula. Using the 178 Mc/s and 408 Mc/s results, the variation in spectral index between $00^h30^m$ and $00^h50^m$ is $\pm 0.2$. Similarly using the 38 Mc/s and 408 Mc/s results together, the variation in spectral index between $00^h30^m$ and $00^h50^m$ is $\pm 0.15$

![Graph showing the mean spectrum of M31](image)

**Fig. 4.—Plot of the mean spectrum of M31 derived from the relative temperature scales in Fig. 3.**

The close agreement between the spectral index of the radio emission from the Galaxy and M31 and the constancy of this spectral index throughout each galaxy suggests that these may be typical features of the radio emission from normal galaxies.

We should like to thank Professor M. Ryle for his help with the observations and his continued interest in the investigation.

_Mullard Radio Astronomy Observatory, Cavendish Laboratory, Cambridge:_

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**References**