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RADIO EMISSION FROM THE ANDROMEDA NEBULA

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Summary

A detailed account is given of the measurement of the radio-frequency radiation from the Great Nebula in Andromeda (M31) using a wave-length of 1·89 m. It is shown that the measured intensity is in good agreement with that to be expected on the assumption that the generation of the radiation is similar to that in the Galaxy. From these results it is estimated that the total extra-galactic radio emission amounts to about 1 per cent of the whole radio flux observed on the Earth.

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1. *Introduction.*—The experiments of Jansky (1) in 1931 showed that radio-frequency radiation is reaching the Earth from the general direction of the Milky Way. Subsequent measurements by Hey, Parsons and Phillips (2), by Reber (3) and by Bolton and Westfold (4) have shown that the intensity contours of this radiation correspond well with the structure of the Galaxy derived from visual observations. Although the source of the radiation remains unknown, it is generally accepted that the major part of the radiation must be generated by some mechanism which is widespread in the Galaxy.

Attempts have been made in the past to discover whether or not the extra-galactic nebulae generate similar radio emissions. For example, Reber (3) used a paraboloid of 30 feet aperture on a wave-length of 1·87 metres, but failed to find any conclusive evidence of radiation from the nebula M31. During the last few years, however, a much larger paraboloid of aperture 218 feet has been available at the Jodrell Bank Experimental Station. Calculations of the intensity to be expected from M31 based on the assumption that it radiates in a similar way to the Galaxy suggested that with this paraboloid, used in conjunction with the best available receiver, it might be possible to detect the radiation if it existed.

This paper describes the results of an experiment designed to test if such radio-frequency radiation is being emitted by the Great Nebula in Andromeda (M31). A short account of the results has been published previously (5).

2. *Description of apparatus.*—Fig. 1 shows a block diagram of the apparatus. The aerial is a paraboloid of diameter 218 feet and focal length 126 feet. The reflecting surface is formed by long wires which are spaced 8 inches apart and which run parallel to one fixed plane of polarization.

Electromagnetic waves of wave-length large compared with 8 inches and whose polarization is parallel to the wires are reflected by this surface and are focused on to the primary feed which consists of two dipoles and their reflectors mounted on a central mast 126 feet high. This mast is pivoted at its base in such a way that it may be tilted in the north–south plane to 15 degrees on either side of the vertical. The latitude of the system is N. 53° 14′ and it is therefore possible to direct the beam to declinations between N. 38° and N. 68°. The direction of the beam is estimated by measuring the angle through which the primary feed is displaced from the vertical and applying to this angle a correction established from experiments (6) carried out with small paraboloids.

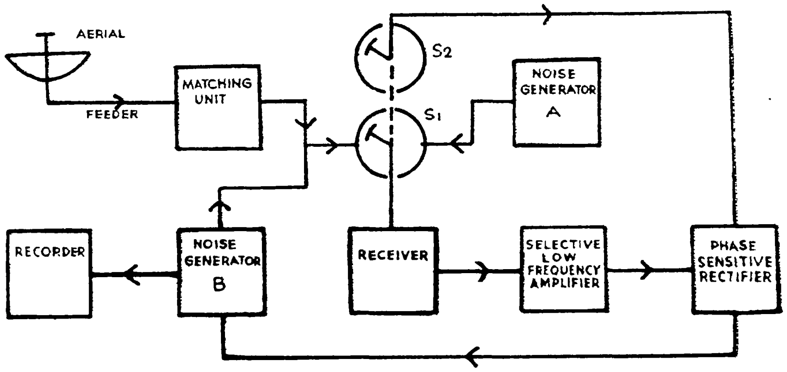


Fig. 1.—*Block diagram of apparatus.*

The gain and beam-width of the aerial have been calculated for various wave-lengths, taking into account the polar diagram of the primary feed, the actual shape of the reflecting surface and the reflection coefficient of the system of wires. They have also been measured at 4·2 metres using an aircraft as a transmitting source. The beam-width at 1·89 metres has been measured by observations of the radio source in Cygnus. The values obtained are shown in Table I.

Table I

Characteristics of Aerial System

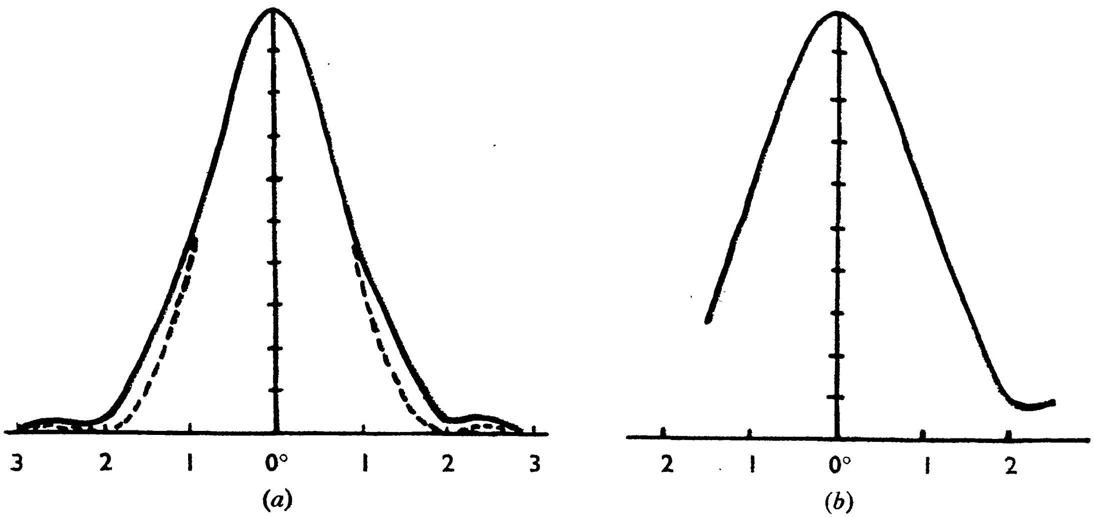
	72 Mc./s.		158·5 Mc./s.	
	Theoretical	Measured	Theoretical	Measured
Gain (over half-wave dipole)	690	700	2130	...
Beam-width to half power	4° 30′	4° 20′	2° 00′	1° 58′

Fig. 2 shows the shape of the beam measured in both planes by observations of the source in Cygnus, that is with the beam tilted about 14 degrees from the vertical. The broken line in Fig. 2 (*a*) shows the theoretical beam shape when the beam is directed to the zenith.

The aerial system is connected to the receiver through 294 feet of coaxial feeder which has a loss of 2·7 decibels at 1·89 metres.

The receiving equipment is based on that described by Ryle and Vonberg (7). Their arrangement has been modified to allow the measurement of aerial temperatures below room temperature. A rotating switch S_1 (Fig. 1) revolves at about 1200 r.p.m. and switches the receiver alternately to a noise generator A and to the aerial in parallel with a noise generator B. Both noise generators are tungsten filament diodes type CV 172. Any difference between the power received in the two positions of the switch appears as a low-frequency modulation of the receiver output. This low-frequency component is amplified by a selective low-frequency amplifier and is applied to a phase-sensitive rectifier operated from a switch S_2 which is synchronous with the aerial switch. The output of the phase sensitive rectifier controls the power delivered from the noise generator B which is in parallel with the aerial. The system automatically maintains a balance such that the power from the aerial plus that from the generator B balances the power from the generator A. The power from the generator A is kept constant and the variations in the power from the aerial are recorded as variations in power output from the generator B. These variations are recorded continuously by a standard recording milliammeter on a moving chart.

In the region of sky around M31 the effective aerial temperature remained below room temperature and, except when calibrating, the output from the generator A was simply that of a resistance at room temperature. The load impedance of the generator A is accurately pre-set and an adjustable matching unit is used to equalize the impedances of the two branches at the switch S_1. As a further precaution the output of the generator B is calibrated by means of the generator A.



(*a*) (*b*)

FIG. 2.—*Polar diagrams of* 218-*ft. aperture paraboloid.* ($\lambda = 1{\cdot}89$ *metres.*)

(*a*) *Beam shape in right ascension.*
(*b*) *Beam shape in declination.*
Ordinates: Intensity in arbitrary units.
Abscissae : Degrees.

The receiver has a midband frequency of 158·5 Mc./s. determined by a crystal-controlled local oscillator. The pre-detector band-width is 1·5 Mc./s., and the radio-frequency amplifier is a "cascode" (**8**) with a noise factor of 3·5. The time constant of response of the whole system is about 10 seconds which is small compared with the 10 minutes taken by a point source at declination N. 40° to transit the aerial beam.

The minimum power incident on the aerial, which can be detected by such an equipment, can be estimated theoretically, assuming that the limit is set by the random fluctuations inherent in the equipment, and not by external interference.

Assuming that

N = noise factor of the receiver,
B = band-width of receiver in cycles per second,
t = time constant of response of the equipment,
T = total effective temperature at input to receiver,
ΔT = r.m.s. fluctuations of output meter,

it can be shown (**9**) that

$$\Delta T \sim NT \sqrt{\left(\frac{2\pi}{Bt}\right)}. \qquad (1)$$

Substituting the parameters of the equipment described above, $\Delta T \sim 0{\cdot}7$ deg. C. Practical experience shows that under the conditions of this experiment the minimum deflection which can be detected on a single trace is about twice the r.m.s. fluctuation of the output indicator. Using the theoretical value of ΔT derived above, the minimum change of aerial temperature which can be detected should be about $1{\cdot}4$ deg. C.

Allowing for the loss in the feeder cable and for the decrease in gain of the aerial system when the beam is tilted 14 degrees from the zenith, this value of ΔT corresponds (at $1{\cdot}89$ metres wave-length) to an incident randomly polarized flux of 10^{-25} watts/square metre/c.p.s. Practical experience shows that the minimum detectable flux depends upon the time of day and on the weather. During the day, and in fine weather, the noise level of the equipment is controlled by reception of the "quiet" Sun in minor lobes of the aerial, and by man-made static. Charged rain, electrical disturbances in the atmosphere and radiation from the "disturbed" Sun overload the equipment. During the night the noise level falls off gradually until about midnight and increases again at sunrise. Between midnight and sunrise the minimum detectable flux appears to be controlled sometimes by the theoretical limits discussed in equation (1) and sometimes by unidentified signals which appear to vary with the weather and which probably have a terrestrial origin. On favourable nights it is about 10^{-25} watts/square metre/c.p.s., which is the limit estimated theoretically. By averaging the results of several independent observations it is possible to extend this limit by an amount which has not yet been established by a quantitative experiment. In the present work the limit has been successfully reduced to 5×10^{-26} watts/square metre/c.p.s. by averaging four records.

3. *Method of observation.*—The experiment was carried out by fixing the beam at a number of different elevations corresponding to the region around M31, so that for each diurnal rotation of the Earth the beam swept out a strip of sky 2 degrees wide in declination and 24 hours in right ascension. For each elevation of the beam the intensity of the radio flux received was recorded continuously for about 100 to 200 hours. Altogether, recordings were made for several elevations of the beam, corresponding to declinations between N. 38° 47′ and N. 43° 00′. The variation with right ascension of the flux received at each declination was found by averaging the results obtained on several successive sweeps.

4. *Results.*—The total number of records obtained by the method described above was 90, of which 20 were spoiled by the effects of heavy rain which persisted throughout 1950 August and September. Of the remaining records 50 showed the existence of a localized source of radio-frequency radiation at $00^{\mathrm{h}}40^{\mathrm{m}}$ R.A. Plate 4 shows one of these records taken with the beam at declination N. 40° 11′. The remaining 20 were either taken when the beam was directed to declinations N. 38° and N. 43°, or interpretation of the records was made difficult by interference in the period $23^{\mathrm{h}}30^{\mathrm{m}}$ R.A. to $01^{\mathrm{h}}40^{\mathrm{m}}$ R.A. The curves shown in Fig.
were constructed from 30 records which were undisturbed by interference In order to show clearly the change in intensity with right ascension along eac sweep the records have been displaced by an arbitrary amount, corresponding t different declinations, so that the ordinate represents only the relative intensitie for the points in each sweep. The sweeps between declinations N. 39° 48 and N. 41° 58′ indicate a localized source of radiation about $00^{\mathrm{h}}40^{\mathrm{m}}$ R.A., super imposed on a slow change of intensity which reaches a minimum betwee

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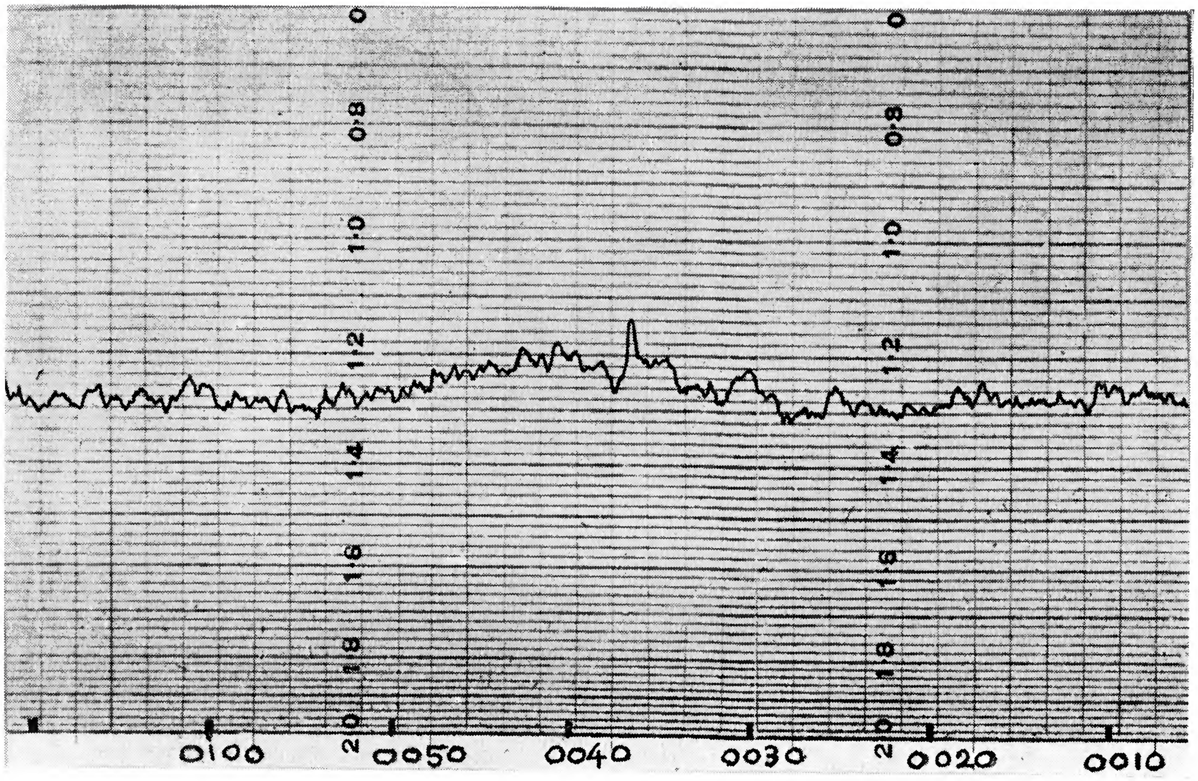

Facsimile of a single record of the transit of the source in Andromeda taken on 1950 *October* 31 *with the aerial beam directed to declination* 40°11′*N.*
Ordinates : Intensity in arbitrary units.
Abscissae : Hours and minutes of right ascension.

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$00^{h}20^{m}$ and $00^{h}30^{m}$ R.A. This slow change corresponds to a gradient of the galactic background radiation, which reaches a minimum when the beam is near its maximum southern galactic latitude.

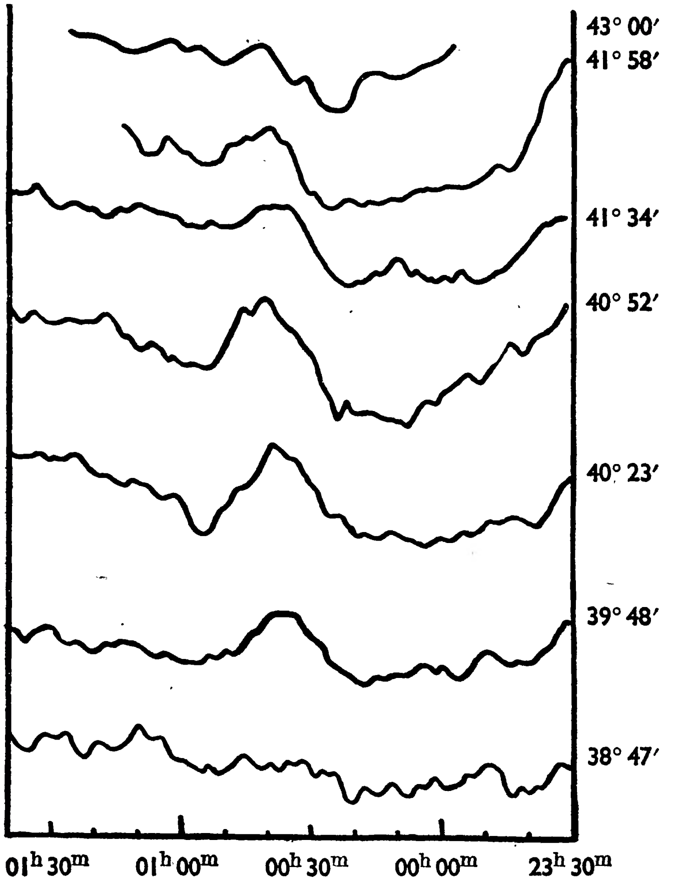

FIG. 3.—*Intensity recorded during transit of the source in Andromeda with the aerial beam directed to different declinations.*

Ordinates : Relative intensity in arbitrary units.
Abscissae : Hours and minutes of right ascension.

These curves cannot be converted into true contours of the intensity from this region because the change of aerial impedance with beam tilt did not permit the difference in absolute intensity between observations at different declinations to be measured reliably. Therefore the background intensity was extrapolated to $00^{h}40^{m}$ R.A. for each curve and the intensity of the background radiation at this point was taken as the zero for each curve when plotting the contours shown in Fig. 4. The contour system (Fig. 4) therefore represents the intensity relative to the background intensity at $00^{h}40^{m}$ R.A., the gradient in declination of the galactic radiation having been removed. The gradient in right ascension has not been removed and so causes a distortion of the contours.

Analysis of the results yields the data shown in Table II. The source has a finite apparent width in right ascension and declination, as can be seen by comparing the apparent widths with the corresponding widths of the intense source in Cygnus, which is at approximately the same declination as the observed source, and whose apparent width is known to be less than $1'\cdot 5$ of arc (**10**). This comparison eliminates any uncertainty due to possible distortion of the beam. The appropriate curves are shown at (*a*) and (*c*) in Fig. 5. Record (*b*) in Fig. 5

shows the intensity received from another weak source at approximately the same declination as the observed source.

The intensity given in Table II is an integrated value over the source and is twice the intensity observed on one polarization, as it is assumed that the radiation

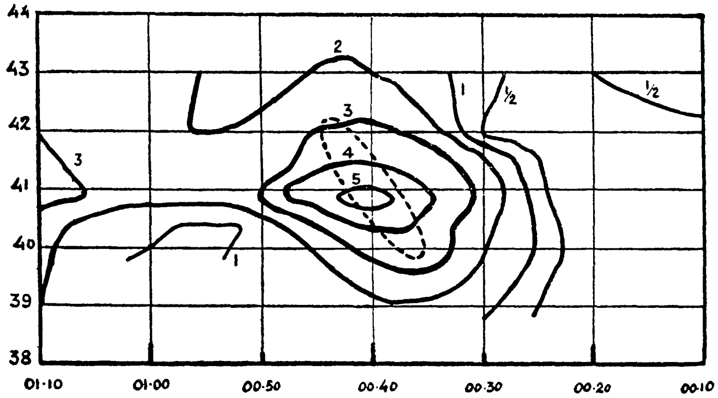

FIG. 4.—*Contours of radio-frequency flux observed near the source in Andromeda with a 2-degree beam.* (1 *unit* = 10^{-25} *watts/square metre/c.p.s.* $\lambda = 1{\cdot}89$ *metres.*)

The contours do not represent the absolute intensity of the radio flux at each point. As explained in the text the gradient of background flux in declination has been removed and the contours show the intensity for each point above the background flux at $00^{\mathrm{h}}\,40^{\mathrm{m}}$ *R.A. The gradient of background flux in right ascension has not been removed and therefore distorts the contours.*

The broken line shows the outline of the nebula derived from a photograph.

Ordinates : *Declination* (*degrees north*).

Abscissae : *Right ascension* (1 *division represents* 10 *minutes*).

TABLE II

Data on Source in Andromeda

Right Ascension	$00^{\mathrm{h}}\,40^{\mathrm{m}}\,15^{\mathrm{s}} \pm 30^{\mathrm{s}}$
Declination	$40°\,50'$ N. $\pm 20'$
Apparent widths to half-power	3° (dec.) × 3½° (R.A.)
Apparent widths to half-power of the source in Cygnus	2¼° (dec.) × 2° (R.A.)
Intensity (integrated over source)	10^{-24} watts/sq. metre/c.p.s. ± 25 per cent

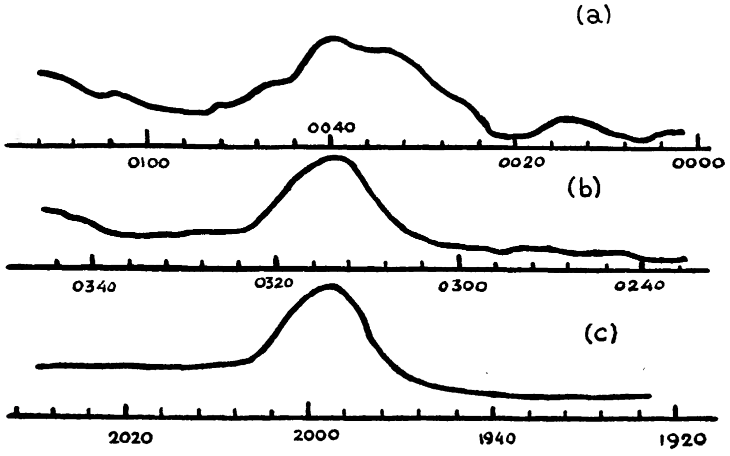

FIG. 5.—*Intensity recorded during transit of three sources through the aerial beam. The scale of intensity for each diagram has been adjusted so that the widths in right ascension can be compared easily.*

(*a*) *Source in Andromeda.*
(*b*) *Weak source in Perseus.*
(*c*) *Intense source in Cygnus.*

Ordinates : *Intensity* (*arbitrary units*).

Abscissae : *Hours and minutes of right ascension.*

is randomly polarized. The previously published (**5**) value of 4×10^{-25} watts/square metre/c.p.s. was calculated assuming the apparent diameter of the source to be small compared with the beam-width, and radiation from the outer regions of the source was neglected. Further measurements and analysis showed the extension of the source to be so great that this assumption was not justified.

The intensity of the source is so small compared with the background radiation and with the random fluctuations in the receiver that the difficulty in interpreting the records is the main cause of errors in the data in Table II. There is no significant systematic error in right ascension as the position of the beam in this coordinate was checked by reference to the intense source in Cygnus whose right ascension is well established. As the declination of the source in Cygnus is not yet known with satisfactory accuracy (**10**) it was not possible to check the position of the beam in declination in the same way. This introduces an additional error into the determination of declination, as the relationship between the angle of tilt of the mast and the angle of the beam is not yet known to better than 1 per cent. Therefore there may be a systematic error of the order of $\pm 10'$ in the measurements of declination. The error in measuring the actual tilt of the mast was negligible.

The error in the measurement of intensity is caused partly by the weakness of the source and partly by inaccuracy in the calibration, these two errors being of comparable magnitude.

5. *Discussion of results.*—The coordinates of the observed source lie close to the centre of the Great Nebula in Andromeda M31 (R.A. $00^{h}\,40^{m}$, declination N. $41^{\circ}\,00'$, Epoch 1950). The apparent dimensions of the source are consistent with a source of radio-frequency radiation of size comparable with the main body of the nebula M31.* It is possible that these results could be due to a fortuitous grouping of two or more point sources with their effective centre coincident with that of M31. From a consideration of the number of observed point sources of intensity comparable to 10^{-24} watts/square metre/c.p.s. and, assuming a random distribution of sources, it can be shown that the probability of observing two sources simultaneously in the beam is about $\frac{1}{4000}$. It is therefore improbable that the finite width of the source is due to a coincidence of two point sources.

The celestial coordinates and finite size of the source indicate with a high degree of probability that the source may be identified with the nebula M31. It is assumed that the two companion nebulae NGC 205 and NGC 221 (which have apparent photographic magnitudes of 10·8 and 9·5 respectively compared with the apparent photographic magnitude 5 of M31 (**11**)) are not contributing substantially to the radiation received.

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* *Note added in proof.*—The apparent extension of the source can, in principle, be deduced by applying to the observed results a correction for the finite beam-width of the aerial. However, the low intensity of the source in comparison with the gradient of background radiation precludes an accurate analysis of the extension, particularly in right ascension. The values for the extension of the source given in a previous publication (**5**) were underestimated. A subsequent analysis showed that the observed variation of intensity with declination could be accounted for by a source in which the intensity is a maximum at the centre and decreases to 10 per cent of the central intensity at points separated by 150′. The apparent extension of the source in right ascension appears to be of the same order, but the gradient of background radiation makes this result unreliable.

Inspection of the contour system given in Fig. 4 shows that, when allowance is made for the distortion in right ascension of the contours by the gradient of background radiation, it is possible to interpret the results as due to an elliptical source orientated in a similar manner to M31.

The authors are obliged to Mr J. H. Piddington of the Radiophysics Laboratory, Sydney, whose criticisms have led to the inclusion of this footnote.

6. *Comparison of the radio emission from M31 and the Galaxy.*—From the results described above it appears evident that radio emissions from M31 are being received on the Earth. In this section we compare the measured intensity of this emission with that to be expected if M31 is similar to the Galaxy. An estimate of the intensity to be expected from M31 has been made in two ways, (*a*) by consideration of the luminosities and (*b*) by analysis of the contours of radio flux from the Galaxy.

(*a*) *Comparison of radio flux and light flux.*—This method makes the assumption that the ratio of the radio flux from M31 to the radio flux from a volume near the Sun equals the ratio of the light flux from M31 to the light flux from the same volume near the Sun.

The aggregate luminosity per cubic parsec near the Sun is known to be 0·045 suns. The radio flux from the same volume can be estimated from the temperatures observed (**4**) in the directions of the galactic poles, if it is assumed that the radio flux originates in bodies distributed in a manner similar to the visible stars and that absorption is negligible. The temperatures of the galactic poles have been used because in these directions the estimates of stellar distribution are the most reliable.

Consider an aerial with a beam of solid angle ω, effective area A and gain G directed towards a galactic pole and receiving radiation of wave-length λ metres.

Let

ρ_r = the density of sources per cubic metre at a distance r metres from the Sun,
ρ_0 = the density of sources near the Sun,
$4\pi\alpha$ = the total power radiated by an average source (watts/c.p.s.),
I = the intensity of the radio flux at the Earth (watts/square metre/c.p.s.),
P = the power received by the aerial (watts/c.p.s.),
T = the effective temperature of the aerial (deg. K.),

then

$$I=\int_0^R \frac{\alpha}{r^2}\rho_r\frac{\omega}{4\pi}\,.\,4\pi r^2\,dr=\alpha\omega\int_0^R \rho_r\,dr, \tag{2}$$

where R is the distance from the Sun to the boundary of the Galaxy in a direction perpendicular to the galactic plane, the boundary being taken as the distance at which the stellar density falls to 1 per cent of that near the Sun. Therefore

$$P=kT=\frac{\alpha\omega A}{2}\int_0^R \rho_r\,dr,$$

where k is Boltzmann's constant (the factor $\frac{1}{2}$ is included because the aerial receives radiation in one polarization only), but

$$G=\frac{4\pi A}{\lambda^2}=\frac{4\pi}{\omega}. \tag{3}$$

Hence

$$kT=\frac{\alpha\lambda^2}{2}\int_0^R \rho_r\,dr. \tag{4}$$

The integral $\int_0^R \rho_r\,dr$, evaluated by using the star density/distance tables given by Bok (**12**), equals $1{\cdot}4\times10^{19}\rho_0$.

Taking (**4**) $T=600$ deg. K. and $\lambda=3$ metres,

$$\alpha\rho_0=1{\cdot}3\times10^{-40}\ \text{watts/steradian/cu. metre/c.p.s.}$$
$$=3{\cdot}8\times10^{9}\ \text{watts/steradian/cu. parsec/c.p.s.,}$$

it has been shown that the law connecting the intensity (I) of the background radiation with wave-length (λ) is $I = \text{constant} \times \lambda^a$, where $0{\cdot}35 < a < 0{\cdot}65$ (**10**).

By assuming $I :: \lambda^{0\cdot5}$,

$$\alpha\rho_0 = 3 \times 10^9 \text{ watts/steradian/cu. parsec/c.p.s.}$$

at a wave-length of 1·89 metres. This is the radio flux per steradian from a cubic parsec near the Sun.

The ratio of the light flux from M31 to that from a cubic parsec near the Sun is $2{\cdot}2 \times 10^{10}$. (The luminosity of M31 is taken as 10^9 suns and that of a cubic parsec near the Sun as 0·045 suns.)

Assuming this same ratio for radio-frequency radiation, then the total radio-frequency radiation from M31 is $2{\cdot}2\alpha\rho_0 \times 10^{10}$ watts/steradian/c.p.s. The intensity of this radiation at the Earth should therefore be

$$\frac{2{\cdot}2\alpha\rho_0 \times 10^{10}}{l^2} \text{ watts/square metre/c.p.s.,}$$

where l is the distance of M31 in metres.

If $l = 230{,}000$ parsecs, then $I_{\mathrm{M31}} = 1{\cdot}2 \times 10^{-24}$ watts/square metre/c.p.s. which is of the same order as the observed value.

(*b*) *Analysis of contours of radio flux from the Galaxy.*—The contours of radio-frequency radiation over most of the celestial sphere have been measured by Bolton and Westfold (**4**) at a wave-length of 3 metres. These have been used to construct a rough model of the Galaxy as it would appear from the distance of M31.

If absorption is negligible, then the intensity of the radiation observed from this distance will be approximately independent of the orientation of the Galaxy with respect to the observer. In this analysis the Galaxy was assumed to be viewed along the equatorial plane. The observed contours were projected on to a cross-section of the Galaxy through the galactic centre and perpendicular to the observer. The Galaxy was assumed to be a spheroid with dimensions 30,000 × 5,000 parsecs and to have a distribution of mass symmetrical about its minor axis. The projection was made on the assumption that the radiation from any volume of the Galaxy is proportional to the mass in that volume. From these projected contours $\int T(\Omega)\,d\Omega$ was evaluated over the whole cross-section of the Galaxy, where $T(\Omega)$ is the effective temperature observed over an elementary solid angle $d\Omega$ subtended at an observer at a distance of 230,000 parsecs. The intensity (I_G) observed at this distance will be *

$$I_G = \frac{2k}{\lambda^2}\int T(\Omega)\,d\Omega.$$

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* This expression can be derived as follows :—

Consider a beam of solid angle ω where ω is large compared with the apparent diameter of the source. The effective temperature (T_ε) of this beam will be given by

$$T_\varepsilon = \frac{\int T(\Omega)\,d\Omega}{\omega}$$

using the same notation as in the text. The power (P) received by the beam is given by

$$P = kT_\varepsilon = \frac{k\int T(\Omega)\,d\Omega}{\omega} = \frac{I_G}{2} . A,$$

$$I_G = \frac{2k\int T(\Omega)\,d\Omega}{A\omega} .$$

From equation (3) $A\omega = \lambda^2$,

$$\therefore \quad I_G = \frac{2k}{\lambda^2}\int T(\Omega)\,d\Omega .$$

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Evaluating the integral as described above, the value of I_G is found to be 9×10^{-24} watts/square metre/c.p.s. at a wave-length of 3 m. Then, assuming $I::\lambda^{0\cdot5}$ as before, the intensity on the wave-length of 1·89 m. used in the present work should be 7×10^{-24} watts/square metre/c.p.s. for the Galaxy observed at the distance of M31.

By assuming, as above, that the radio flux is proportional to the mass, then the intensity to be expected from M31 can be estimated by comparing its mass with that of the Galaxy. Estimates of the mass of M31 vary from 3×10^{10} to 10^{11} solar masses compared with an estimate of 10^{11} to 2×10^{11} for the Galaxy. The intensity of the radio-frequency radiation from M31 observed on the Earth would thus be expected to be within the range 1×10^{-24} to 7×10^{-24} watts/square metre/c.p.s. which, in fact, includes the observed value.

The agreement between the theoretical values calculated above and the measured intensity suggests that as far as radio-frequency emission is concerned M31 possesses similar characteristics to the Galaxy.

7. *The total radiation from extra-galactic nebulae.*—The contribution to the radio flux incident on the Earth from extra-galactic nebulae has been calculated for a very simple model of the universe, assuming that the ratio of radio flux to light flux found for M31 is true for all nebulae independent of type.

The intensity of the radio flux from M31 observed on the Earth at a wave-length of 1·89 metres is 10^{-24} watts/square metre/c.p.s. and therefore assuming it to be an isotropic radiator the total radio flux emitted is 5×10^{19} watts/steradian/c.p.s. M31 has an absolute visual magnitude of $-17\cdot5$ compared with $-15\cdot2$ for the average nebula. Therefore the radio flux from an average nebula will be about 5×10^{18} watts/steradian/c.p.s.

If σ = the average space density of nebulae (assumed isotropic),
$4\pi\gamma$ = the total radio flux from an average nebula,
I_E = the intensity at the Earth of extra-galactic radiation per steradian,

then if radiation is received from nebulae in a sphere of radius D and the effects of absorption and recession are neglected,

$$I_E=\gamma\sigma D \qquad \text{(from equation (2)).}$$

Putting $\gamma=5\times10^{18}$ watts/steradian/c.p.s., $\sigma=1\cdot9\times10^{-19}$ nebulae per cubic light year, then for a universe of radius 5×10^{8} light-years (corresponding to the rang of the 100-inch telescope), $I_E=4\cdot75\times10^{-24}$ watts/square metre/steradian/c.p.s If the radius of the visible universe is taken as $1\cdot8\times10^{9}$ light-years, as suggeste by the apparent recession of the nebulae,

$$I_E=1\cdot7\times10^{-23}\ \text{watts/square metre/steradian/c.p.s.}$$

This latter value of I_E corresponds to an effective aerial temperature 1·89 metres of about 2 deg. K. The average aerial temperature observed ov the whole celestial sphere at this wave-length is about 200 deg. K., and th calculation therefore suggests that the extra-galactic radiation contributes abo 1 per cent of the total radio flux incident on the Earth.

8. *Acknowledgments.*—The work has been carried out at the Jodrell Ba Experimental Station of the University of Manchester. The aerial system w designed by Dr J. A. Clegg. The construction of the aerial and apparatus w made possible by financial assistance from the Department of Scientific a Industrial Research. We wish to thank Dr A. C. B. Lovell for his interest

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