THE LINEAR POLARIZATION OF RADIATION FROM JUPITER AT 6 CM WAVELENGTH

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Summary

At a wavelength of 6 cm the degree of linear polarization of the radiation from Jupiter is $0\cdot076\pm0\cdot002$. The variation of the direction of polarization with longitude of the central meridian is consistent with the increased period of rotation determined by Komesaroff and McCulloch (1967). There is evidence of an asymmetrical beaming of the nonthermal radiation with longitude in addition to the latitude asymmetry that was detected previously by Roberts and Komesaroff (1965). The mean flux density normalized to a distance of 4·04 a.u. is $10\cdot7\pm0\cdot2$ f.u. The small nonthermal contribution (3·7 f.u.) is further evidence for a high frequency cutoff in the synchrotron radiation; the thermal component corresponds to a brightness temperature of about 250°K.

I. INTRODUCTION

Observations of the linear polarization of the 6 cm radiation from Jupiter were obtained with the 210 ft radio telescope at Parkes during the period December 10–13, 1966. The receiver utilized polarization switching. Its initial stages were attached to the feed platform of the telescope and therefore rotated with the feed during polarization observations. The dual-mode feed consisted of a circular waveguide with an expanded entrance designed to provide a circular beam. This was followed by a ferrite waveguide switch which, operating at a frequency of 40 Hz, varied the direction of polarization of the incident radiation by ±45° before analysis by a linearly polarized probe. With a tunnel diode preamplifier the resulting system noise temperature was 900°K. The r.f. bandwidth was 200 MHz, centred at 4995 MHz. The amplitude of the 40 Hz signal at the detector output provided a measure of the linearly polarized flux, while the d.c. component contained a contribution corresponding to the total flux density. The relative gains of the a.c. and d.c. channels were established by the use of an argon discharge tube which provided linearly polarized radiation in the waveguide ahead of the ferrite switch. Both the switched and total power outputs were recorded on paper tape, and subsequent analyses were effected with a CDC 3200 computer.

II. OBSERVATIONS

A single polarization measurement consisted of a set of observations made with the orientation of the feed at a succession of angles at 30° intervals. A complete observation at each angle consisted of 50 sec integrations with the telescope directed near the source, at the source, and near the source, terminating with a measurement of a calibration signal from the discharge tube.

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The instrumental polarization, a function of feed orientation and zenith angle of the telescope, was obtained by observation of several bright HII regions. For the observations of Jupiter, the zenith angle ranged between 53° and 60° and the instrumental polarization was essentially constant at 0·6%. The approximate zero of the position-angle scale for the feed was established from observations of a linearly polarized c.w. signal radiated from the apex of the paraboloid. The scale of flux density is based on a value of 13·0 f.u. for Hydra A, as adopted by Kellermann (1964). The errors quoted do not contain any allowance for a systematic error in the flux density scale.

III. RESULTS

Figure 1 shows the variation of flux density, percentage polarization, and position angle of the electric vector as a function of the system III (1957·0) longitude of the central meridian of Jupiter (Morrison 1964). For comparison purposes, all flux densities refer to the standard distance of 4·04 a.u. The continuous curves represent sinusoids fitted to the observations by the method of least squares. For the analyses of percentage polarization and position angle, a second harmonic term has been fitted, although the limited number of observations barely justifies its inclusion. For the analysis of flux density it was felt that the accuracy of the observations did not warrant the addition of the higher harmonic, despite its observation at longer wavelengths. The computer programme for the fitting was kindly provided by Mr. M. M. Komesaroff.

The solutions to the observations are:

Normalized flux density $S = S_0 + S_1 \sin(l - \alpha_1)$;

Percentage polarization $M = M_0 + M_1 \sin(l - \beta_1) + M_2 \sin 2(l - \beta_2)$;

Direction of polarization $P.A. = A_0 + A_1 \sin(l - \theta_1) + A_2 \sin 2(l - \theta_2)$;

where

$$S_0 = 10{\cdot}68 \pm 0{\cdot}04, \quad S_1 = 0{\cdot}07 \pm 0{\cdot}06, \quad \alpha_1 = 140^\circ \pm 40^\circ;$$

$$M_0 = 7{\cdot}63 \pm 0{\cdot}14, \quad M_1 = 0{\cdot}52 \pm 0{\cdot}28, \quad \beta_1 = 165^\circ \pm 28^\circ, \quad M_2 = 0{\cdot}21 \pm 0{\cdot}28, \quad \beta_2 = 65^\circ \pm 53^\circ;$$

$$A_0 = 110{\cdot}5 \pm 0{\cdot}6, \quad A_1 = 8{\cdot}8 \pm 1{\cdot}0, \quad \theta_1 = 22^\circ \pm 6^\circ, \quad A_2 = 1{\cdot}2 \pm 1{\cdot}0, \quad \theta_2 = 113^\circ \pm 40^\circ.$$

Each calculated value is accompanied by its corresponding standard deviation.

(a) *Variation of Direction of Polarization with Longitude*

The mean direction of the maximum electric vector, 110°·5, differs from the orientation of the Jovian equator during the period of observations (105°·2), but the difference probably indicates a zero error in the calibration of position angle.

The amplitudes and phases of the harmonics determined from 11 cm observations by Komesaroff and McCulloch (1967) are:

1st harmonic	$A_1 = 9\cdot6\,(8\cdot8\pm1\cdot0)$,	$\theta_1 = 21\cdot8\,(22\pm6)$;
2nd harmonic	$A_2 = 1\cdot0\,(1\cdot2\pm1\cdot0)$,	$\theta_2 = 81\cdot9\,(113\pm40)$.

The values in parentheses are the corresponding values from the present observations.

The agreement of the phases of the first harmonic is excellent. The present results therefore support the conclusion of Komesaroff and McCulloch that the period of rotation of Jupiter exceeds that adopted in the I.A.U. system III (1957·0) definition by $0^{\mathrm{s}}\cdot5$ (Morrison 1964). In contrast, Dickel (1967) obtained a lower first harmonic phase at 6 cm (14±10) and concluded that the period is within $0^{\mathrm{s}}\cdot2$ of the I.A.U. value. However, the uncertainties in his results do not preclude the existence of the larger period.

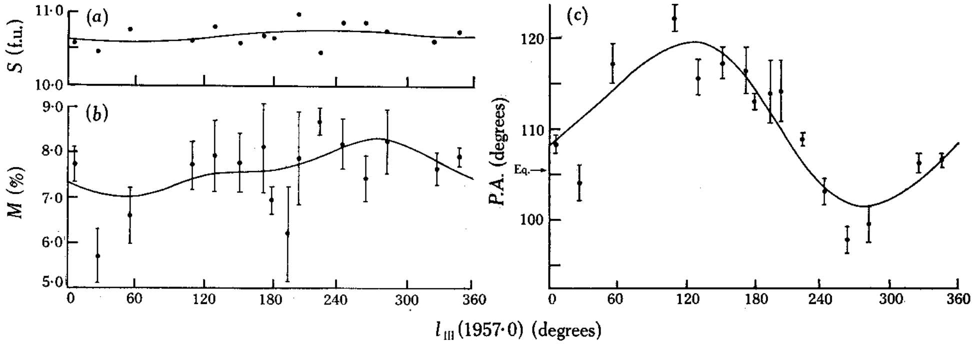

Fig. 1.—The 6 cm variation of (*a*) normalized flux density S, (*b*) percentage polarization M, and (*c*) direction of polarization $P.A.$ with longitude of the central meridian of Jupiter (l_{III}). Error bars represent standard deviations.

The first harmonic amplitude (8°·8±1°·0), assumed to correspond to the angle between the rotational and magnetic axes of Jupiter, agrees well with those determined by Komesaroff and McCulloch at 11 cm (9°·6) and Dickel at 6 cm (8°·3).

(*b*) *Variations of Intensity and Percentage Polarization with Longitude*

The present observations yield only an upper limit of about 3% for the peak-to-peak variation in the total flux from the planet. Previous observations at longer decimetric wavelengths (Roberts 1965; Roberts and Komesaroff 1965; Barber 1966) have shown a large second harmonic term due to a beaming of the radiation into the magnetic equator of Jupiter. A smaller first harmonic variation was also present, due in part to the tilt of the rotational axis of the planet to the plane of the sky and in part to a north–south asymmetry in the beaming. In the present case the tilt is small (0°·8), and any first harmonic is due to asymmetries in the beaming pattern.

The variation of percentage polarization with longitude shows evidence of first and second harmonic terms. As was the case in the observation of total flux, the presence of the first harmonic reflects an asymmetry in the beaming pattern. The similarity of the phases for the variations of flux and percentage polarization suggests that both types of observations are affected by the same asymmetry. Since the phase of the first harmonic (165°±28°) is not that expected of a north–south asymmetry alone (112°), the radiation pattern appears to be asymmetrical in longitude as well as latitude.

(c) *Thermal and Nonthermal Contributions to the Radiation*

The mean flux density corrected to 4·04 a.u. is 10·7±0·2 f.u., in good agreement with Dickel's (1967) value of 10·8±0·6 f.u. (Dickel also used the flux density scale established by Kellermann 1964.) The radiation is composed of nonthermal emission from the radiation belts and a thermal component from the planetary disk. Assuming that the degree of polarization of the nonthermal component is 0·22 at 6 cm, as applies at longer wavelengths, the nonthermal and thermal contributions are 3·7 and 7·0 f.u. respectively. The thermal contribution corresponds to a brightness temperature of about 250°K, a value in reasonable agreement with Dickel's estimate of 224°K at 6 cm, and with Berge's (1966) value of 260°K at 21·2 cm. The nonthermal flux density is significantly lower than at longer decimetric wavelengths, where a value of 6·7 f.u. prevails (Roberts and Komesaroff 1965). It confirms the high frequency cutoff reported by previous observers (see Fig. 1 of Roberts 1965). The actual value should be treated with caution, since the assumption that the degree of polarization is independent of frequency may be erroneous. In this connection, Komesaroff and McCulloch (1967) have suggested that at 11 cm the degree of polarization is decreasing secularly.

Additional evidence for the low nonthermal flux can be obtained from the observations of the beaming of the total flux at 6 cm. An upper limit of 3% variation has been set for the present measurements. At longer wavelengths, the variation is about 10%. Hence, if the nonthermal emission has a similar radiation pattern to that observed at 11 and 21 cm, then no greater than three-tenths of the total flux at 6 cm can be of nonthermal origin.

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V. REFERENCES

BARBER, D. (1966).—*Mon. Not. R. astr. Soc.* **133**, 285.
BERGE, G. L. (1966).—*Astrophys. J.* **146**, 767.
DICKEL, J. R. (1967).—*Astrophys. J.* **148**, 535.
KELLERMANN, K. I. (1964).—*Astrophys. J.* **140**, 969.
KOMESAROFF, M. M., and MCCULLOCH, P. M. (1967).—*Astrophys. Lett.* **1**, 39.
MORRISON, B. L. (1964).—U.S. Naval Obs. Circ. No. 94.
ROBERTS, J. A. (1965).—*Radio Sci.* **69D**, 1543.
ROBERTS, J. A., and KOMESAROFF, M. M. (1965).—*Icarus* **4**, 127.