INTERPRETATION OF THE RADIO ROTATION PERIOD OF JUPITER IN TERMS OF THE CYCLOTRON THEORY*

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Since 1961 the most intense source of Jovian decametric emission has drifted with respect to system III longitude by about +10° per year (Douglas and Smith 1963; Smith *et al.* 1965). Interpreted as a change in the rotation rate, this would imply that the period increased by approximately 1·1 sec around 1960. Runcorn (1967) and Hide (1967) have interpreted this as a change in the rotation rate of the solid body of Jupiter, in which angular momentum is exchanged between Jupiter's core and the Great Red Spot.

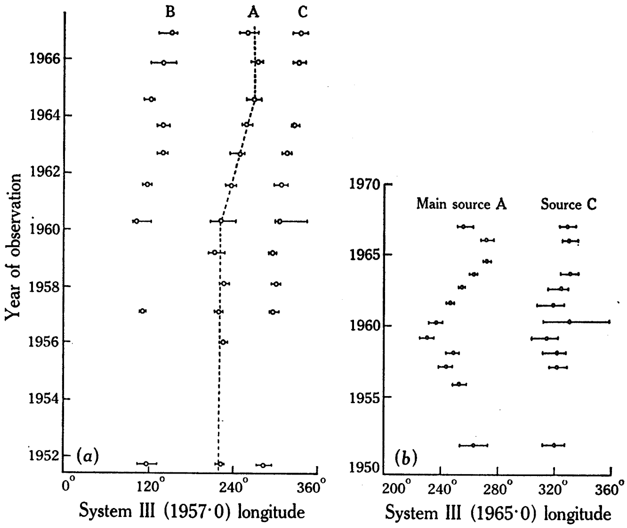

Fig. 1(*a*).—Estimated I.A.U. system III (1957·0) longitude positions of the three main sources in the longitude profiles at 18 MHz are plotted for each year of observation since 1951. The data are taken from Gulkis and Carr (1966) and Williams *et al.* (1967).

Fig. 1(*b*).—Data of Figure 1(*a*) for sources A and C are replotted on a revised system III (1965·0) longitude, which coincides with system III (1957·0) at 0^{h} U.T. on January 1, 1965 and has a rotation period of $9^{h}\,55^{m}\,29^{s}{\cdot}67$.

A more plausible interpretation has recently been advanced by Gulkis and Carr (1966). They show that the results are consistent with a constant rotation period about 0·3 sec longer than the system III period, together with a cyclic drift in the longitude of source A.

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Douglas (1960) and Carr *et al.* (1961) both analysed data obtained prior to 1961 and found that the rotation period was constant at about $9^h 55^m 29^s{\cdot}37$ (system III). However, observations made since 1961 indicate that the rotation period has fluctuated. Between 1961 and 1965 the mean period was approximately 1·0 sec longer than the system III period quoted above, and since 1965 the period appears to have returned to near its former value. Figure 1(*a*) shows the estimated positions of the three main sources in the longitude profiles at 18 MHz since 1951. The drift in the main source A is quite distinct, while the points for sources B and C are not as consistent.

Gulkis and Carr (1966) have suggested that the apparent rotation period of Jupiter drifts cyclically about a constant mean value which is about 0·3 sec longer than system III. Figure 1(*b*) shows the data of Figure 1(*a*) for sources A and C replotted on a system III (1965·0) longitude scale, which is defined to coincide with system III (1957·0) at 0^h U.T. on January 1, 1965 and has a rotation period of $9^h 55^m 29^s{\cdot}67$. The points for source A define a sine wave with an amplitude of about 18° and a period of about 12 years, in close agreement with Jupiter's orbital period and the length of the sunspot cycle. The points of source C also define a sine wave which is in phase with that defined by source A but has an amplitude of only about 8°. The data from the two early sources B1 and B2 have not been analysed in this way because they are not sufficiently well defined on the majority of longitude profiles.

Several estimates of the rotation period have been made from decimetric observations (Bash *et al.* 1964; Komesaroff and McCulloch 1967). These estimates give periods significantly larger than system III and agree with the mean period of Gulkis and Carr (1966) within the quoted errors.

The cyclotron theory of the Jupiter decametric emissions was first proposed by Ellis (1962, 1963) and was later developed in detail by Ellis and McCulloch (1963) and Ellis (1965). Radiation is emitted at the local electron gyrofrequency by electron streams in Jupiter's magnetic field. The observed frequency is Doppler shifted owing to the longitudinal motion of the electrons. The propagation of the radiation is controlled by the medium so that only radiation in the extraordinary mode in the forward direction escapes. In this case the observed frequency is slightly above the local gyrofrequency. The emission is concentrated onto the surface of a cone about the magnetic field direction, where the cone angle depends on the ratio of the gyrofrequency to plasma frequency at the emission point and the pitch angle of the electrons.

The electron streams are assumed to be confined to field lines that intersect the surface of Jupiter at latitudes greater than 75°, with the probability of finding an electron stream at 75° being zero but increasing linearly with magnetic latitude. All magnetic longitudes are assumed to be equally probable. The characteristics of the model are such that the probability of occurrence and power of the emissions depend on the angle between the observer's line of sight and the axis of the emission cone. As the cone angle is fixed for a given distribution of electron streams, the probability of occurrence as a function of longitude can only be varied by changing the inclination of the magnetic field (Fig. 2).

The main peak in the longitude profiles for frequencies above 15 MHz was explained by a local dip anomaly in Jupiter's magnetic field. The maximum tilt of the field lines from those of a dipole necessary to account for the observations was found to be about 15°.

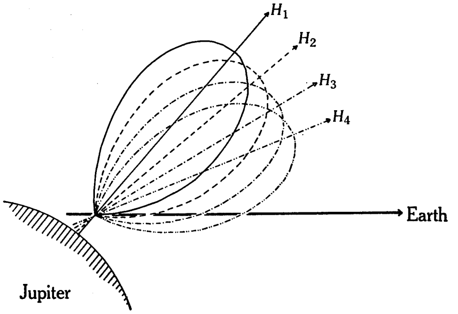

Fig. 2.—Probability-of-occurrence emission cones are illustrated for four different inclinations of Jupiter's magnetic field. The relative probability of occurrence at any time is given by the intersection of the cones with the Earth–Jupiter line.

As Jupiter revolves about the Sun the tilt D_E of its rotation axis to the Earth–Jupiter line changes cyclically. This results in a cyclic variation in the range of magnetic latitudes from which emission can be seen at any time. Hence, if the longitude of the maximum dip deviation changes with magnetic latitude, we would expect to see a cyclic change in the longitude of the corresponding emission region. The change in main source position can then be interpreted as a change in longitude of the maximum dip angle deviation with magnetic latitude. The dip anomalies needed at different latitudes to explain the observed main source positions are shown in Figure 3.

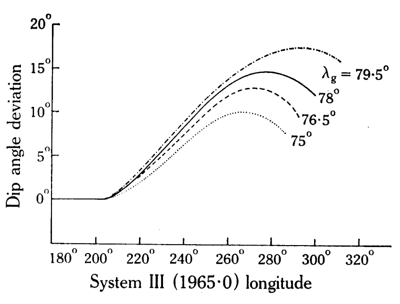

Fig. 3.—The proposed dip angle deviations at 18 MHz in the vicinity of source A are plotted for various values of λ_g, the magnetic latitude at which the undistorted field line intersects the surface of Jupiter.

The consequence of this explanation of the main source position drift is that each of the four individual sources in the longitude profiles could change positions in different ways, depending on the local dip anomalies. The sources associated with the magnetic poles would not be expected to change their positions appreciably. The small in-phase variation of source C can be explained on the basis of overlapping by source A, which is much larger and has a larger position variation. The earlier of the two B sources could change in position with appropriate dip angle deviations similar to those for source A. However, the present observations are not sufficiently accurate to demonstrate any such variation.

The different rotational periods determined by Dulk (1965) by analysing spectral data in different ways may be explained on the basis of the above discussion. The correlation or comparison of longitude profiles gives periods that are dominated by the period of the strongest source A in the longitude profiles. Comparison of individual features on dynamic spectra on the other hand are biased in favour of the early B source, as this is the region where the majority of repeatable dynamic spectra are obtained.. We have seen that, according to the cyclotron theory, there is no need for the periods of sources A and B to be the same. These two types of observation give information about the configuration of Jupiter's magnetic field in two different longitude ranges.

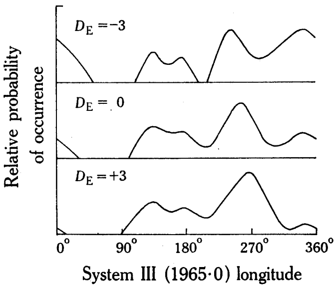

Fig. 4.—Theoretical profiles showing the relative probability of occurrence at 18 MHz are plotted for various values of D_E, the inclination of Jupiter's rotation axis to the Earth–Jupiter line.

Duncan (1967) has recently made a statistical analysis of Jupiter data at frequencies above 20 MHz (where possible) for the period 1957–66. He has found that the commencement of main source storms has recurred with a period that has been constant from 1951 to 1966, being $9^h 55^m 29^s \cdot 70 \pm 0^s \cdot 05$, in good agreement with that obtained by Gulkis and Carr.

The cyclotron theory predicts that the width in longitude of an emission peak depends on the penetration of the observer's line of sight into the emission cone. The width of the emission regions then vary cyclically with D_E. Figure 4 shows probability-of-occurrence longitude profiles of source A for various values of D_E. A most interesting feature of these profiles is that the increase in width of the peak is just sufficient to compensate for the change in longitude of the peak. Hence the leading section of the source always occurs at the same longitude regardless of the value of D_E. There is then no contradiction between the observations of Duncan and those of Gulkis and Carr, as the starting times are exactly compensated by the change in source width. Hence the centre of the emission region is the important feature and not the storm commencement. This is further emphasized by the observation of Duncan (1966) that Io's influence is sharpest for the peak in the emission region and is not as well correlated with the commencement time.

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