Reports

Radio Rotation Period of Jupiter

Abstract. *The results of observations of Jupiter at 18 megacycles per second indicate that the apparent rotation period drifts cyclically about a constant mean value. The most probable drift period appears to be 11.9 years, Jupiter's orbital period. The mean rotation period during one orbital period is about 0.3 second longer than that of the system III (1957.0) period. This is in close agreement with the rotation period deduced from decimetric observations and probably represents the true rotation period of the magnetic field. The cyclic drift in the rotation period of source A at 18 megacycles per second is explained on the basis of beaming of the escaping radiation at an angle 6 degrees north of the magnetic equator. The apparent rotation period of source A depends on the rate of change of the Jovicentric declination of Earth.*

Since 1955 various determinations of Jupiter's rotation period have been made from observations of the radio emissions by the planet at decameter (*1–3*) and decimeter (*4*) wavelengths. The localized "sources" at decameter wavelengths appear to rotate with a period which is close to, but not identical with, the optical system II period, $09^h55^m40.632^s$. At frequencies in the vicinity of 18 Mc/s, four such sources have been recognized; they have been designated A, B_1, B_2, and C, in the order of decreasing activity (*5*). The estimates of the decametric period have all been based on the values which most nearly keep one or more of these sources at the same longitude year after year.

Over the approximately 9 years during which decametric rotation period measurements have been possible with accuracies on the order of a second, the period has apparently changed from $09^h55^m28.5^s$ to $09^h55^m30.5^s$. With the exception of an apparent increase of 1^s about 1960, the transition to longer and longer periods has not aroused much curiosity, since it was thought that the changes were due simply to improvements in the precision of measurement. The generally accepted decametric period prior to 1961 was about $09^h55^m29.37^s$. System III (1957.0) was designated by the International Astronomical Union in 1962 as the Jovian longitude system which rotates with the above period and which coincided with system II at 0^h U.T. on 1 January 1957 (*6*). Figure 1 shows the system III (1957.0) longitude λ of the center of source A at 18 Mc/s for each of nine apparitions of the planet since 1951. It appears that the rotation period remained essentially constant at the system III (1957.0) value until 1960, but that there was an unmistakable drift toward higher longitudes after 1960. This effect was observed independently by Douglas and Smith (*3*) and by Smith *et al.* (*5*), who concluded that a lengthening of the rotation period of approximately 1^s had taken place rather abruptly. There has subsequently been considerable discussion as to whether or not this represented an actual slowing of the rotation of the magnetic field. We believe that it did not, but that the apparent decametric period undergoes a cyclic drift about a mean value which is slightly longer than the system III (1957.0) period.

If there is a cyclic drift, the average rotation period at 18 Mc/s can be deduced from the data of Fig. 1, provided the drift period is known. Figure 1 is from the data of Smith *et al.* (*5*) and, with the exception of the point at 1951.7, is based on observations at the University of Florida. It seems likely that the drift in the rotation period is related either to the solar activity cycle or to Jupiter's orbital motion, and that the drift period is the same as the period of one or the other of these phenomena. The interval between the two most recent principal minima in the running average of the Zurich sunspot numbers was about 10.5 years, while Jupiter's orbital period is about 11.9 years. In any study of the drift in rotation period at 18 Mc/s over such intervals, use must be made of the mean position of source A as deduced from Shain's early measurements (*1*), which in terms of λ_{III} (1957.0) is indicated by the point for 1951.7 in Fig. 1. If a drift period of 10.5 years is assumed, then a good approximation to the average rotation period can be made from the observed drift in λ_{III} (1957.0) for source A between 1951.7 and 1962.7. This drift was 21.0° ± 7.0° over 11.0 years. The equation

$$\Delta T = 0.1124\,\Delta\lambda$$

gives the correction ΔT, in seconds, which must be applied to the system III (1957.0) period if the source A drift was $\Delta\lambda$ degrees per year. The correction in this case is thus $+0.21^s \pm 0.07^s$, and the average rotation period over the 11.0-year interval was $09^h55^m29.58^s \pm 0.07^s$.

On the other hand, if a drift period of 11.9 years is assumed, a better approximation to the rotation period can be made from the observed drift in source A between 1951.7 and 1963.6. In this case the drift was 32.0° ± 7.0°, and the time interval was just 11.9 years. The correction to the system III (1957.0) period now becomes $0.30^s \pm 0.07^s$, giving $09^h55^m29.67^s \pm 0.07^s$ for the average rotation period over 11.9 years. The difference in the two estimates is hardly significant. Both agree with the period $09^h55^m29.70^s \pm 0.04^s$ deduced by Bash *et al.* (*4*) from decimetric observations. These values are probably close to the true rotation period of the Jovian magnetic field.

It is convenient to define a revised system III for the epoch of 1965.0. For reasons which will become apparent, we define the new system on the basis of the second of the above two values for the average decametric rotation period. We thus designate as λ_{III} (1965.0) the longitudes in a coordinate system which has the rotation period $09^h55^m29.67^s$, and which coincided with λ_{III} (1957.0) at 0^h U.T. on 1 January 1965.

Figure 2 shows successive positions of the center of source A at 18 Mc/s replotted in terms of λ_{III} (1965.0). This slight revision in the rotation period has changed the unlikely drift pattern shown in Fig. 1 into what appears to be a regularly cyclic drift. The solid

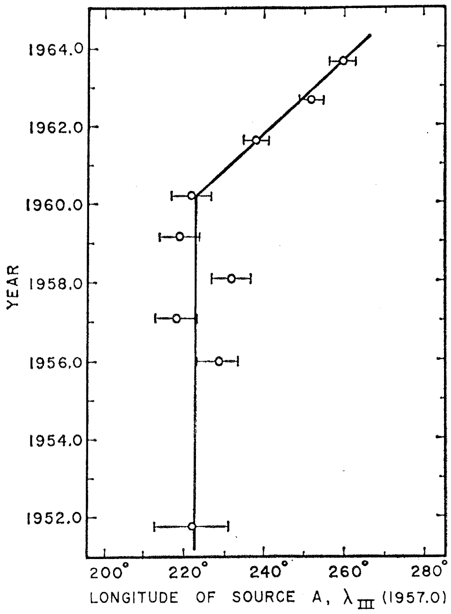


Fig. 1. Yearly variation of the apparent central meridian longitude, λ_{III} (1957.0), of Jovian source A at 18 Mc/s [after Smith *et al.* (5)].

line through the source A points in Fig. 2 is the weighted least-square fit of the equation

$$\lambda_A = A_1 + A_2 \sin\left[\frac{(\text{Year-}A_3)}{11.9}\ (2\pi)\right]$$

to the experimental data. With weights chosen to be the reciprocals of the squares of the lengths of the error bars for the source A points, the values of A_1, A_2, and A_3 are 253.5°, −17.8°, and 1956.25, respectively. The root mean square of the differences between the empirical function and the experimental data is 4.48°. The value of λ_{III} (1965.0) at 0^h U.T. on any Julian date J can be found from either λ_{III} (1957.0) or λ_{II} at the same time by means of the formulas

$$\lambda_{III}(1965.0) = \lambda_{III}(1957.0) - 0.00731\,(J - 2438761.5)$$

$$\lambda_{III}(1965.0) = 81.5° + \lambda_{II} + 0.2670\,(J - 2438761.5)$$

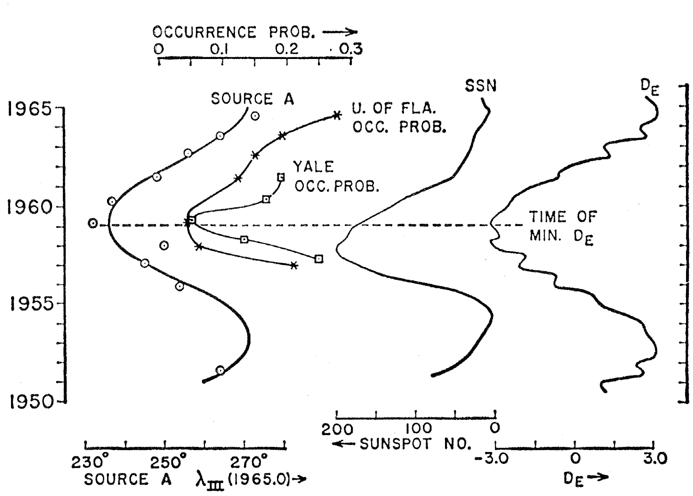
In addition to the drift of source A, Fig. 2 also indicates the time variation in the declination of Earth as seen from Jupiter (D_E), the smoothed Zurich sunspot number (SSN), and the probability of occurrence of radiation from Jupiter for each apparition. Two occurrence-probability curves are shown, one obtained by Smith *et al.* at 18 Mc/s for all longitudes (5) and the other by Douglas and Smith at 22.2 Mc/s for only source A longitudes (7). It appears significant that the source A longitude and the yearly occurrence probability reached their minimums at about the same time (1959.2), and that this time was decidedly closer to the time of minimum D_E than to that of maximum sunspot number. This suggests that it is the variation in D_E rather than the sunspot number which is responsible for both the longitude drift and the variation in occurrence probability.

The variation of occurrence probability has long been attributed to the solar activity cycle. However, it has never been satisfactorily explained why the two effects should not be correlated, nor why the Jupiter activity minimum should lag the solar activity maximum by a year. On the other hand, if the variation in D_E is responsible, a narrow beaming of the escaping radiation is implied, because the total range of variation in D_E is only slightly more than 6°. If the latter hypothesis is correct, the northern hemisphere must be the more active one, since it is tipped toward Earth during years of greatest activity (8). This is supported by the decimetric observations (9), which indicate that at central meridian longitudes in the neighborhood of the decametric sources A and B, the pole in the northern hemisphere is tipped toward Earth, and therefore, this must be the more active hemisphere for decametric emission.

We also have additional evidence for sharp beaming of the decametric radiation, and for a dependence on D_E rather than on sunspot number. The Jovicentric magnetic latitude of Earth, Φ_E, is the angle between the radius vector to the earth and the equatorial plane of an assumed magnetic dipole inside Jupiter. If the dipole is tipped by an angle β with respect to the rotational axis and the magnetic pole lies in the northern hemisphere on the meridian λ_N, then the relation between Φ_E and the central meridian longitude λ is given with sufficient accuracy for our purpose by

$$\Phi_E = D_E + \beta \cos(\lambda - \lambda_N).$$

On the basis of the best decimetric determinations of the relative orienta-



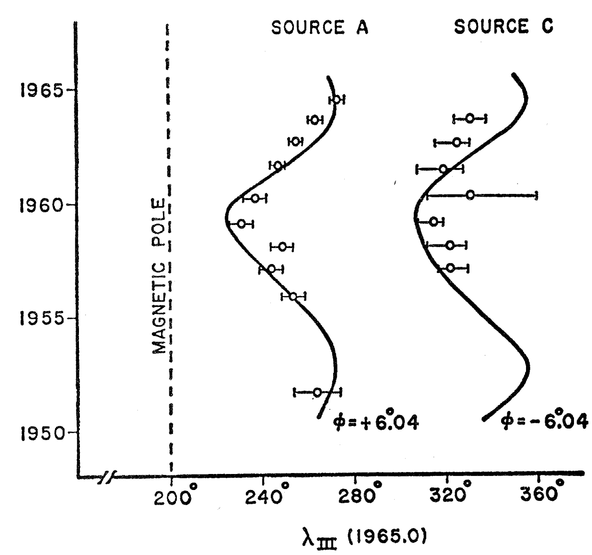


Fig. 2 (left). Yearly source A longitudes from Fig. 1 replotted in terms of the new system, λ_{III} (1965.0). Also shown are curves of occurrence probability, sunspot number (SSN), and Jovicentric declination of the earth (D_E). Fig. 3 (right). Curves indicating λ_{III} (1965.0) values for which rays escaping at ± 6.04° with respect to Jupiter's magnetic equator would reach the earth. The points are derived from the data of Smith *et al.* (5) and Hayward (10).

tion of the dipole axis (9), λ_N is 200° in terms of system III (1965.0). If our assumptions are correct, the pole will remain at this longitude indefinitely, whereas it will drift slowly in terms of the older system III (1957.0). The accepted value of β is 10°. We now postulate that, to a first approximation, decametric radiation escaping from Jupiter is beamed parallel to a cone of radius vectors having constant magnetic latitude, Φ_0. The radiation will reach the earth whenever Φ_E is equal to Φ_0. The central meridian longitudes at which this occurs are given by

$$\lambda° = 200° + \arccos \left[\frac{\Phi_0 - D_E}{10} \right]$$

If the radiation escaping the northern hemisphere is beamed at magnetic latitude Φ_0, that from the southern hemisphere should be beamed at $-\Phi_0$. The simple model thus predicts for a given value of D_E four values of λ at which radiation should reach the earth. Figure 3 shows, as a function of date, the values of λ_{III} (1965.0) for the centers of sources A and C, and also two curves representing solutions of the above equation for λ for a particular pair of values $\pm\Phi_0$. The source C points were obtained from Hayward's analysis of University of Florida data (10). The best fit to the observed points was obtained with $\Phi_0 = \pm 6.04°$. The fit is remarkably good. The fact that sources A and C lie on opposite sides of the magnetic equator is in agreement with the results of polarization measurements (11). It was expected that the third and fourth solutions of the above equation for λ for the same $|\Phi_0|$ would have fit the source B_1 and B_2 points, but this was not the case; these curves and points were not included in Fig. 3.

The results seem to indicate that while the field at longitudes near sources A and C is approximately that of a dipole, it is greatly distorted in the source B region. The positions of sources B_1 and B_2 could perhaps be accounted for if the shape of the field in this region were known. In further support of this idea, we again call attention to the results of Roberts and Komersaroff (9) at decimetric wavelengths. They concluded that departures from a dipole field are most pronounced at the early system III (1957.0) longitudes, that is, in the decametric source B region.

The evidence thus appears strong that in the vicinity of 18 Mc/s the source A radiation from Jupiter is beamed into a thin curved sheet which is inclined 6° north of the same magnetic equator deduced from decimetric observations. Although the rotation period of the magnetic field probably remains constant, the apparent source A period differs from it by a small amount which depends on the rate of change of the Jovicentric declination of the earth. The observed width of source A indicates that the thickness of the beam is about 10°. The magnetic latitude corresponding to the beam center is probably a function of frequency; observations by Hayward at the University of Florida (8) have indeed indicated that the apparent rotation period of source A depends somewhat upon frequency. It should be possible to account quantitatively for the long-term variation in occurrence probability and source width on the basis of beaming. As D_E approaches its most negative value, less of the source A beam can reach the earth, and as a result, both occurrence probability and source width approach minimum values.

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Atomic Nuclei: Moments of Inertia and Quadrupole Moments

Abstract. *Moments of inertia and quadrupole moments of deformed even-even nuclei were calculated in the closely packed spheron model.*

In Pauling's extremely simplified classic and static spheron model of atomic nuclei (1), nuclei are considered as aggregates of closely packed, rigid clusters. In spite of its simplicity the model reproduces well the magic numbers, the proton : neutron ratio, the onset of spheroidal deformation, and such. Of interest is calculation from this model of other static properties of nuclei, such as moments of inertia and quadrupole moments.

The moment of inertia γ and the quadrupole moment Q of a given nucleus may be calculated by use of one of the microscopic theories (2). Crude approximations are obtained with phenomenological models: the rigid-body model (which gives the same results as the cranking model) and the liquid-drop model.

I consider the nucleus as an aggregate of spherons. In calculating the moment of inertia I assume that the moment of inertia of a spheron around an axis through its center-of-mass is zero, as it should be in quantum mechanics for spherical objects (3). The origin of the coordinate system is put in the center-of-mass of the nucleus, which is axially symmetrical around the axis z. The moment of inertia around the axis y is

$$\gamma = \Sigma\, m_i (x_i^2 + z_i^2) \qquad (1)$$

where x_i, y_i, and z_i are the coordinates of the center-of-mass and m_i is the nucleon number of the ith spheron. The sum runs over all spherons in the nucleus.

I consider that rare-earth nuclei have two spherons in the inner core; this holds best for maximally deformed nuclei—those away from closed shells. Two of the 17 spherons of the outer core are arranged in a straight line with the spherons of the inner core. The remaining 15 spherons form three rings of five spherons in the interstices between the two spherons in the line. The spherons of the mantle form rings with, maximally, nine spherons in the interstices of two rings of the outer core, and form caps with six or three spherons at the poles.

For a given nucleus, the α-particles,