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10-CM OBSERVATIONS OF JUPITER, 1961–1963

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ABSTRACT

Jupiter was observed at 10-cm wavelength with the N.R.A.O. 85-foot radio telescope on 40 days between May 1 and August 8, 1961, and on 91 days between September 17, 1962 and February 25, 1963. A total of about 3930 observations of about 5 minutes' duration each is available. From these it has been determined that (1) the mean equivalent disk brightness temperature was about 690° K; (2) the mean total planetary 10-cm emission did not vary by more than 3 per cent over the observing periods; (3) the period of rotation of the decimeter source system is $9^h55^m29^s.70 \pm 0^s.04$ (m.e.), probably the same as the rotation period of the decameter sources; (4) the magnetic axis defined by 10-cm radiation is tilted $24^\circ.3$ with respect to the rotational axis; (5) the north pole of the magnetic axis is located at $\lambda^{III} = 186^\circ.8$; (6) the percentage polarization of the radiation is 7.8 per cent; (7) the data indicate that the polarized component of the radiation is strongly concentrated in directions close to the equatorial plane of the polarized radiating system.

I. INTRODUCTION

It has been known for some time that Jupiter possesses an extensive system of radiation belts which radiate strongly at decimeter wavelengths (Drake and Hvatum 1959; Radhakrishnan and Roberts 1960). Sloanaker and Boland (1961) reported large variations in the 10-cm emission of the planet from 1958 to 1959, while Morris and Bartlett (1963) in April, 1962, found the intensity to be about the same as Sloanaker and Boland had found in 1958, but different from the 1959 value. Roberts and Huguenin (1963) have given an analysis indicating that the Jovian radiation at 22 cm correlates with solar activity. Polarization phenomena have been measured on several wavelengths, and an indication that Jupiter is not an isotropic radiator has appeared in several studies made at the California Institute of Technology (Morris and Berge 1962; Morris and Bartlett 1963) and the Naval Research Laboratory (McClain 1959; Miller and Gary 1962; Gary 1963). It has been suggested, but not proven, that the decimeter and decameter source systems rotate in synchronism. All of these facets of the Jovian decimeter phenomenon bear directly on theories of the emission, such as those given by Field (1961) and Chang (1960, 1962) and Chang and Davis (1962).

To clarify these problems, Jupiter was observed at a wavelength of 10 cm extensively in 1961, 1962, and 1963, with the object of obtaining a large set of homogeneous data covering a long period of time, from which to extract as much information relevant to the above problems as possible.

II. OBSERVATIONS

Jupiter was observed on 40 days between May 1 and August 8, 1961 (called here the "1961 observations") and on 91 days between September 17, 1962, and February 25, 1963 (called the "1962 observations"). The radiometer used and the observational technique have been described previously (Drake 1962). One observation consisted of 30 seconds of integration with the antenna pointed on the sky 30′ east of Jupiter, followed by 30 seconds on the planet, then 30 seconds on a point 30′ west of Jupiter, and back to the planet, etc., until a total of five measurements of the sky and four measurements of Jupiter was made. The procedure was then repeated using comparison positions north

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and south of the planet. About 30 such observations were made on the typical observing day, so that in 1961 about 1200 observations of Jupiter were made, and in 1962 approximately 2730 observations were completed, giving a total of about 3930 observations for the observing program. Interspersed with the Jupiter observations were calibration observations of an argon noise-discharge tube and the radio source 04N3A (3C 123). The relevant parameters of the traveling-wave tube radiometer used were: an operating wavelength of 10.0 cm, a band width of 200 mc, and an over-all system noise temperature of 1200° K. The 30-second integration time used resulted in r.m.s. output fluctuations of about 0.09° K for most of the observations.

The observations were made with the N.R.A.O. 85-foot radio telescope which was equipped with a linearly polarized feed horn aligned so that the telescope was polarized with the E-vector north-south. All data were reduced to give a ratio of the flux density from Jupiter to the flux density from the calibration source 04N3A. The flux density at 10.0 cm adopted for 04N3A was

$$S = 23.7 \times 10^{-26}\ \mathrm{w/m^2/cps}\,,$$

which was obtained from the accurate calibration horn flux of Cassiopeia A at 1440 mc found by Findlay and Hvatum, in turn converted to a flux density at 3000 mc using the well-known spectral index of Cas A, and which in turn gives the flux density of 04N3A from the ratio Cas A/04N3A (Heeschen and Meredith 1961) at 10.0 cm. The maximum systematic error in the flux density is estimated to be 8 per cent (Drake 1962).

The brightness temperature of Jupiter implied by each observation was computed using the solid angle subtended by the oblate optical disk of the planet and the usual radiation formulae. This brightness temperature has, of course, no close relationship to any real temperatures because it is known that some of the 10-cm radiation originates in the radiation-belt system. The use of "brightness temperature" is merely a way of eliminating the effects of the changing earth-Jupiter distance from the data. The brightness temperature data were analyzed in two ways. First, in order to see if the brightness temperature at 10 cm was a function of time, it was averaged over 6-day intervals for the whole 1961 data period and for the first 58-day observing period of the 1962 observations. Since the Jovian brightness temperature varies with the rotation of the planet, 6-day intervals were chosen in an attempt to get a value which is a good average over all planetary longitudes. Figure 1 presents these results for 1961 and 1962. No correction has been made for polarization effects. The 1961 peak-to-peak temperature fluctuations are about 6 per cent, the 1962 peak-to-peak fluctuations are nearly 4 per cent, and the means of the 1961 and 1962 data points differ by 3 per cent. We take this last value to be the upper limit on any real long-term variations, since it includes any systematic calibration errors from 1961 to 1962. This is a much smaller variation than that reported by Sloanaker and Boland (1961) between 1958 and 1959, who observed with the same telescope polarization as in the present observations. The mean temperature here is very close to the value found by Sloanaker (1959) in 1958. These results do not support a correlation at 10 cm between solar activity and the decimeter emission such as reported by Roberts and Huguenin (1963) for the 22-cm Jovian emission. However, the results cannot be said to rule out such a correlation, because this was a period of relatively constant low solar activity and the antenna was polarized so as to discriminate somewhat against the polarized component. Nevertheless, the lack of long-term variation imposes strong constraints on theories of the decimeter emission, as emphasized in the papers of Field.

Second, the brightness temperature of Jupiter has been analyzed as a function of the longitude of central meridian. A systematic variation with longitude is found. This effect was first reported by McClain (1959). His work indicated that the brightness temperature varied following either the System II or System III rotational period. Sloan-

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aker and Boland (1961) also found indications of a variation with rotation. Morris and Berge (1962), observing at 31-cm and 22-cm wavelengths, also observed the variation of the Jupiter brightness temperature as Jupiter rotated. They suggested that System III probably applies to the decimeter radiation because a "magnetic pole" found by them coincides with the principal decametric radio source, and thus the decimeter and decameter systems probably rotate together. More recently Morris and Bartlett (1963), observing at 10.6 cm, and Miller and Gary (1962), observing at 20.8 cm, have seen the brightness temperature vary with rotation. Our observations are reduced with respect to the System III longitude of central meridian, where, specifically, we average the brightness temperature of Jupiter observed over a range of 20° of System III longitude. The validity of the use of the System III period is examined in Section IV. Figures 2 and 3 present the run of brightness temperature with the System III longitude of central meridian for the 1961 and 1962 observations, respectively, where the vertical bars show the mean errors of the points.

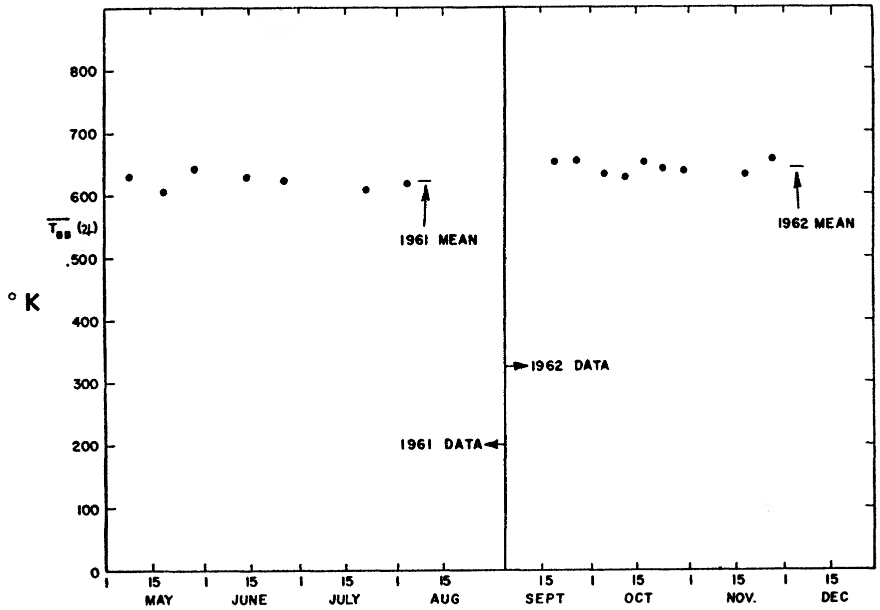

FIG. 1.—Brightness temperatures of Jupiter averaged over 6-day intervals for the 1961 and 1962 observing periods.

III. THE ROTATION PERIOD OF THE DECIMETER RADIATION SYSTEM

Reducing the observations with respect to either the System II or System III rotational period makes little difference in the general appearance of Figures 2 and 3, except that the peaks and dips are shifted due to the difference between the System II and III longtiudes at a given instant. It is clear from the data that either System II or III is near the rotation period of the decimeter source system, but it might be that neither is the exact period of the variation.

The data give two independent sets of the brightness temperature of Jupiter reduced with respect to the System III longitude of central meridian ($\lambda_{\text{cm}}^{\text{III}}$), which sets are separated in time by about 18 months. If the decimeter temperature variation does not rotate with the System III period exactly, then the significant features of Figure 2 and 3, particularly the major maximum near $\lambda_{\text{cm}}^{\text{III}} = 280°$, should apparently move with time. The major maximum will not be at exactly the same System III longitude of central meridian in the 1962 data as it was in 1961. Accordingly, we have examined the relative locations of features on the 1961 and 1962 data-curves. Probably the most sensitive way to do this is to cross-correlate the two sets of data. Consequently, a cross-correlation of the 1962 data with the 1961 data was performed. The resulting cross-correlation function has a strong maximum shifted slightly from phase zero. A $\cos^2$ curve was fitted to the peak using only the range of shifts from $\Delta\lambda_{cm}^{III} = -25^\circ$ to $+25^\circ$. The result of this least-squares fit was that the best cross-correlation occurs when

$$\Delta\lambda_{cm}^{III} = 3\overset{\circ}{.}97 \pm 0\overset{\circ}{.}42 \text{ (m.e.)}$$

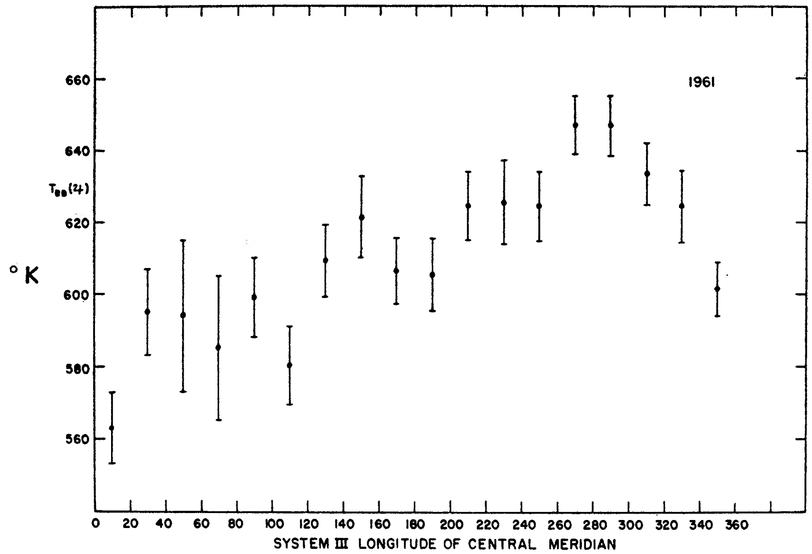

FIG. 2.—The variation of the brightness temperature of Jupiter with the System III longitude of central meridian for the 1961 observing period.

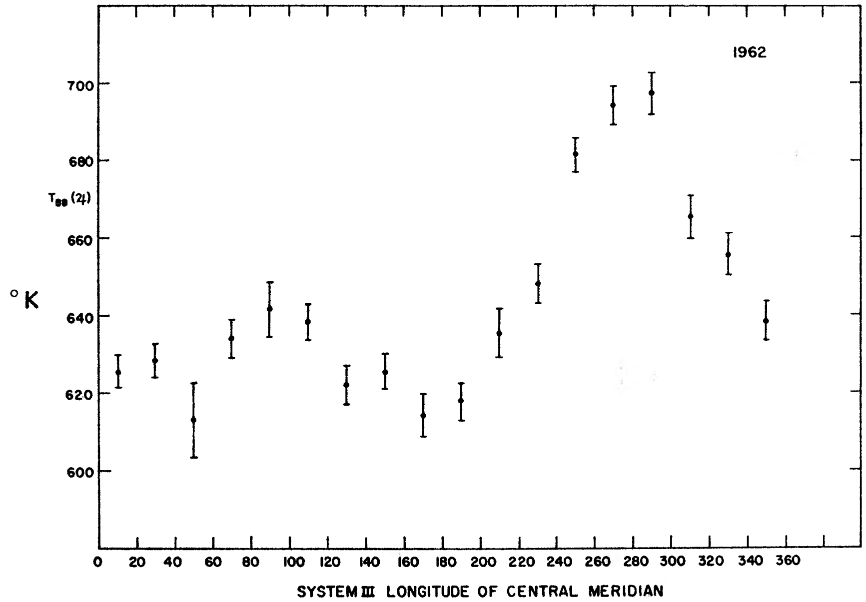

FIG. 3.—The variation of the brightness temperature of Jupiter with the System III longitude of central meridian for the 1962 observing period.

and is in the sense that the features in the 1962 data lie at larger $\lambda_{\mathrm{cm}}^{\mathrm{III}}$ than in the 1961 data. The mean error is calculated for the least-squares analysis in the usual way and includes no systematic errors. This indicates that the rotation period of the decimeter sources is very slightly longer than the System III period used, and that this has led to an error of about 4° in $\lambda_{\mathrm{cm}}^{\mathrm{III}}$ over the 18-month period of observations. This longitude difference was converted accurately to a correction to the System III period by computing the increase in the System III period which would cause $\Delta\lambda_{\mathrm{cm}}^{\mathrm{III}}$ to be zero over the time difference, 11892 hours, between the mean dates of the 1961 and 1962 observing periods. The cross-correlation function is shown in Figure 4, with the abscissa expressed in units of the implied correction to the System III period. The computed correction to the System III period was

$$\Delta P^{\mathrm{III}} = +0^{\mathrm{s}}.33 \pm 0^{\mathrm{s}}.04 \text{ (m.e.)} .$$

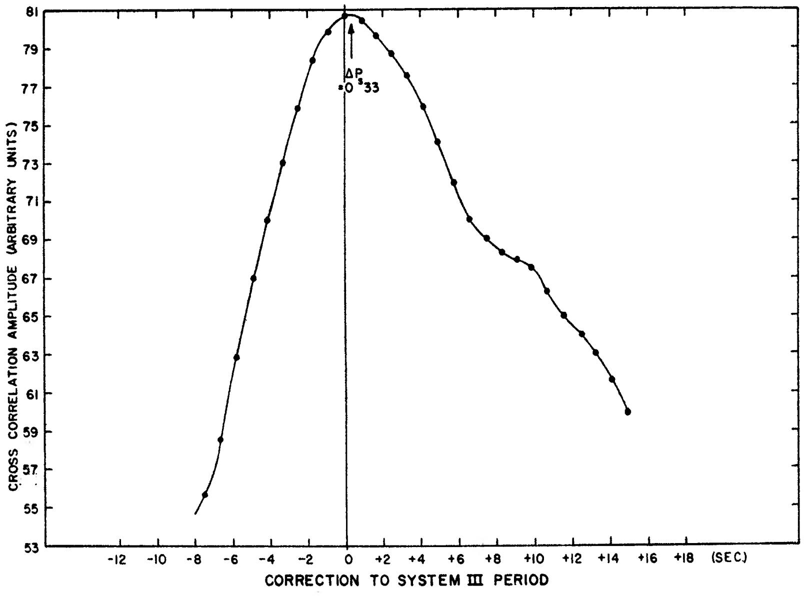

FIG. 4.—Cross-correlation of the 1961 with the 1962 variable component of the Jovian brightness temperature as a function of System III longitude of central meridian. The abscissa is expressed as the correction to be added to the adopted System III rotational period to obtain the rotational period of the decimeter source system.

This correction, when applied to the System III period of $9^{\mathrm{h}}55^{\mathrm{m}}29^{\mathrm{s}}.37$ (Douglas 1960), gives the rotational period for the decimeter source system:

$$P_{\mathrm{cm}} = 9^{\mathrm{h}}55^{\mathrm{m}}29^{\mathrm{s}}.70 \pm 0^{\mathrm{s}}.04 \text{ (m.e.)} .$$

This result was checked by fitting a $\cos^2$ curve to the major peak near $\lambda^{\mathrm{III}} = 280°$. The difference in the positions of the peaks so found leads to $\Delta P^{\mathrm{III}} = 0^{\mathrm{s}}.19 \pm 0^{\mathrm{s}}.61$, consistent with the more accurate cross-correlation determination. The error is determined in the same manner as in the cross-correlation analysis, and does not include systematic errors.

The derived period for the variation of the decimeter radiation is changed, if Jupiter does not radiate isotropically, because the apparent orientation of the Jovian axis differed slightly between the two sets of observations. It may be shown that a high upper limit on the error in $\Delta\lambda_{\mathrm{cm}}^{\mathrm{III}}$ due to this effect is $\Delta\delta \cot \phi$, where $\Delta\delta$ is the change in the declination of the earth, δ_0, as seen from Jupiter between the two sets of observations, and ϕ is the inclination of the magnetic equatorial plane to the equator of Jupiter. In 1961, δ_0 was $-0\overset{\circ}{.}62$; in 1962, $+1\overset{\circ}{.}16$. With the value of ϕ found later in this paper, the maximum error in $\Delta\lambda_{\text{cm}}^{\text{III}}$ due to this effect is about 4°, which would occur only if the polarized radiation occurs entirely in the magnetic equatorial plane. The observed concentration is less than this. This effect would cause us to observe a period shorter than the true period, meaning that the observed period is a minimum value. Thus, the true $\Delta\lambda_{\text{cm}}^{\text{III}}$ and ΔP^{III} may be as much as twice the values derived here, but are probably very close to the derived values.

The decameter rotation period, $9^{\text{h}}55^{\text{m}}29\overset{\text{s}}{.}37 \pm 0\overset{\text{s}}{.}13$ (m.e.) is derived from inhomogeneous data and the decimeter period derived here, $9^{\text{h}}55^{\text{m}}29\overset{\text{s}}{.}70 \pm 0\overset{\text{s}}{.}04$ (m.e.) may be influenced by undetected systematic effects such as time variability and non-isotropic radiation, which may lead to an underestimation of the errors in the derived periods. Because of this, we consider the near-coincidence of the two periods to be remarkable, and a very strong indication that the periods are, in fact, identical, as may well be shown by better data. There appears to be good evidence here that both the decimeter and decameter sources are associated with the same physical aspect of Jupiter, the magnetic field, already suggested repeatedly, being the obvious choice.

TABLE 1

THREE-PARAMETER SOLUTION FOR 1962 DATA

A	616° ±5° K
B	64° ±8° K
ϕ	56° ±9°
Polarization	5 0 per cent ±0.6 per cent
M.E.	11 0

IV. ANALYSIS OF THE VARIATION WITH LONGITUDE OF THE BRIGHTNESS TEMPERATURE

Following Miller and Gary (1962), we may write for the temperature variation as a function of the System III longitude of central meridian, where our antenna is polarized N–S,

$$T_{BB}(\lambda_{\text{cm}}^{\text{III}}) = A + B\sin^2[\alpha + \phi\sin(\lambda_{\text{cm}}^{\text{III}} - \lambda_0^{\text{III}})]\,, \tag{1}$$

where A is the brightness temperature of the randomly polarized component, B is the brightness temperature contribution of the polarized component, ϕ is the angle between Jupiter's rotational axis and the axis of its magnetic field, α is the angle between the earth's and Jupiter's rotational axes, measured in the plane of the sky, and λ_0^{III} is the longitude of the point where the magnetic-field axis cuts Jupiter's northern hemisphere. This equation assumes that the axis of Jupiter is perpendicular to the line of sight to the earth. The plane of polarization of the Jovian radiation is rotated upon passing through the earth's ionosphere by the Faraday mechanism; however, at our observing wavelength of 10.0 cm, this rotation amounts to only about 1°, and is therefore neglected. Assuming that the radiation is emitted isotropically, and that the polarization vector of the emitted radiation remains parallel to Jupiter's magnetic equator as it turns, then equation (1) reflects the amount of the polarized radiation accepted by the antenna as a function of $\lambda_{\text{cm}}^{\text{III}}$.

Equation (1) was fitted to the data using a least-squares technique in which the equation is linearized by writing it as a Taylor series and retaining only the first-order terms. The parameters A, B, and ϕ were solved for, the value of λ_0^{III} being set equal to the value found for the location of the major peak minus 90°, and the value of α being taken from the American Ephemeris and Nautical Almanac. Figure 5 shows the three-parameter solution fitted to the 1962 data (see also Table 1).

The stated mean errors here and in Tables 2–4 are computed from the least-squares analysis in the usual way, and include only accidental errors.

The polarization is defined as $(T_{\max} - T_{\min})/(T_{\max} + T_{\min})$ or $B/2A + B$, and the quantity M.E.^{2} is given by the sum of the squared residuals between the least-squares curve and the data points divided by the number of data points minus the number of parameters solved for. The quantity M.E. is a measure of the quality of fit of the least-squares curve to the data.

Morris and Berge (1962) found an indication, and later Gary (1963) found strong evidence, that the radiation from Jupiter's Van Allen belts may be emitted more strongly in directions close to the magnetic equatorial plane, so that when the earth is in this plane the received flux is a maximum. It was of interest, therefore, to attempt to fit an equation including this effect. We have assumed that this radiation pattern from the Jovian radiation belts may be represented as the function cosine^{F} of the angle between the observer's line of sight and the Jovian magnetic equatorial plane. For this case we write the run of $T_{BB}(\lambda_{\rm cm}^{\rm III})$ with $\lambda_{\rm cm}^{\rm III}$ as

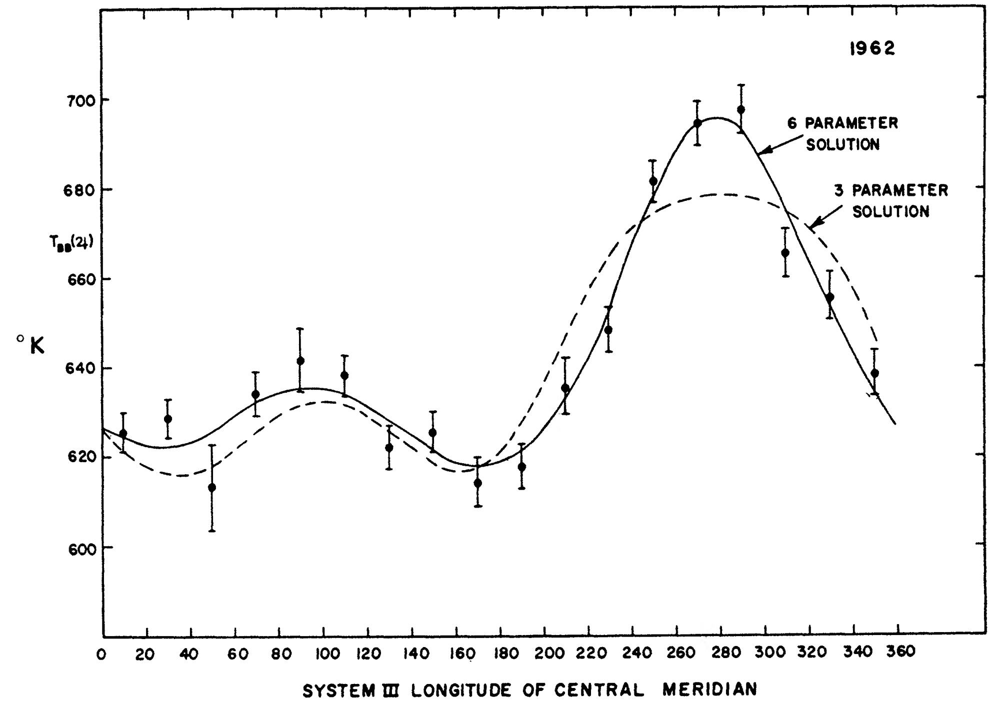

FIG. 5.—Six-parameter least-squares fit, including a non-isotropic radiation pattern, and a three-parameter fit, not including this effect, to the 1962 brightness-temperature variation data.

$$T_{BB}(\lambda_{\rm cm}^{\rm III}) = \cos^{F1}[\delta_0 + \phi\cos(\lambda_{\rm cm}^{\rm III} - \lambda_0^{\rm III})]A + B\cos^{F2} \times[\delta_0 + \phi\cos(\lambda_{\rm cm}^{\rm III} - \lambda_0^{\rm III})]\sin^2[\alpha + \phi\sin(\lambda_{\rm cm}^{\rm III} - \lambda_0^{\rm III})]\,, \tag{2}$$

where we have separated the unpolarized and polarized components and assigned them different exponents F1 and F2, respectively, for generality, and where δ_0 is the declination of the earth as seen from Jupiter. The other symbols have been defined above.

Equation (2) was fitted to the 1962 data in a solution solving for the six parameters $A, B, \phi, \lambda_0^{\rm III}$, F1, and F2. The solid line on Figure 5 shows this six-parameter least-squares curve. The values of the above six parameters given by the solution are shown in Table 2.

A comparison of the quantity M.E. for the six-parameter and three-parameter solutions shows that the six-parameter solution fits the data very much better than the three-parameter solution. An examination of Figure 5 clearly reveals that the peak near $\lambda_{\mathrm{cm}}^{\mathrm{III}} \simeq 280°$ is poorly fitted by the solution which neglects the radiation pattern of the Jovian Van Allen belts. The effect of the radiation pattern of these belts is to sharpen the peak at $\lambda_{\mathrm{cm}}^{\mathrm{III}} \simeq 280°$, because, in addition to the fact that at this $\lambda_{\mathrm{cm}}^{\mathrm{III}}$ the maximum component of the polarized radiation is accepted by the antenna, the observer is in the magnetic equatorial plane. Figure 5 gives good evidence that non-isotropic radiation is occurring and must be taken into account.

Due mainly to the shorter observing time used, the 1961 data are not as smooth as the 1962 run of T_{BB} with $\lambda_{\mathrm{cm}}^{\mathrm{III}}$. Figure 6 shows the fit of equation (1) to the 1961 data. This solution is marked as "Three-Parameter Solution No. 1." Again λ_0^{III} was set equal to the value of $\lambda_{\mathrm{cm}}^{\mathrm{III}}$ found for the 1961 major peak minus 90°, and the 1961 value of a was found in the Ephemeris. The values found are shown in Table 3.

The inaccuracies of the 1961 data prevented a meaningful solution for six parameters

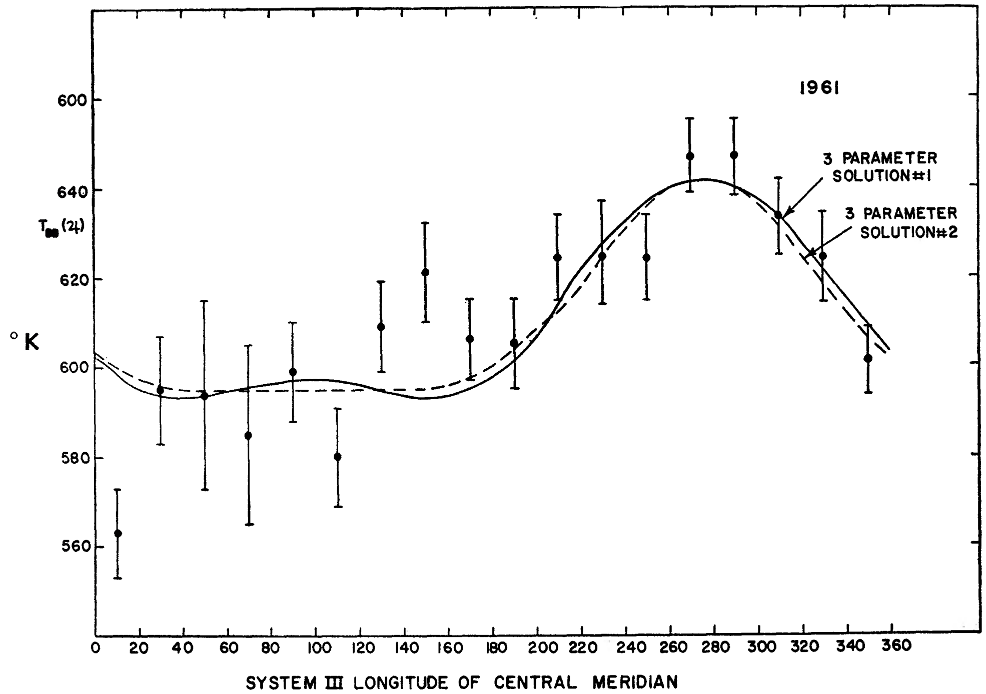

FIG. 6.—Two three-parameter least-squares fits to the 1961 brightness-temperature variation data. Solution No. 1 does not include the effects of the radiation pattern of the Jovian radiation belts. Solution No. 2 includes radiation pattern effects.

TABLE 2

SIX-PARAMETER SOLUTION FOR 1962 DATA

A	635° ± 4° K
B .	106° ±30° K
ϕ .. .	24°.3 ± 1°.5
λ_0^{III}	186°.8 ± 2°.4
F1	0.4 ± 0.05
F2	6.8 ± 5 7
Polarization	7 8 per cent ±2 2 per cent
M.E. .	6.6

simultaneously. To ascertain whether the assumption of a non-isotropic radiation pattern for the Jovian radiation belts allowed a better fit to the 1961 data than equation (1) gave, equation (2) was fitted to the 1961 data with three free parameters A, B, and ϕ, and F1 was set equal to zero, F2 set equal to 6, and λ_0 as before. This solution appears on Figure 6 as "Three-Parameter Solution No. 2" (see also Table 4).

This solution with equation (2) does not fit the 1961 data better than equation (1), and thus the 1961 data give no further information about the non-isotropic nature of the emission.

Because the weight of the 1962 data is about 5, if the 1961 data are considered weight 1, a properly weighted solution based on both the 1961 and 1962 data would not have differed significantly from the results derived from the 1962 data alone. Because of this and the fact that it is not certain that the Jovian emission was the same in 1961 and 1962, no over-all solution from all the data was made. We conclude that the six-parameter solution for the 1962 data (Table 2) gives the most accurate picture of the 10-cm Jovian emission derivable from our data.

TABLE 3

THREE-PARAMETER SOLUTION NO. 1, 1961

A	593° ± 5° K
B	113° ±61° K
ϕ	25°.6 ±13°.4
Polarization	8 7 per cent ±4 7 per cent
M.E.	14 6

TABLE 4

THREE-PARAMETER SOLUTION NO. 2, 1961

A	595° ± 5° K
B	154° ±73.5° K
ϕ	19°.1 ± 9°.4
Polarization	11 5 per cent ±5 5 per cent
M.E.	14 4

Comparison of the present results with those of other observers shows a fairly consistent picture. Our results, and the most detailed published measures, are shown in Table 5. The errors quoted here are those given by the various authors, except that we have converted the errors to mean errors where the author has stated that his published error is expressed differently.

Comparing our results to those of Rose, Bologna, and Sloanaker (1963) and Morris and Bartlett (1963) at nearly the same wavelength, we see that the results of Morris and Bartlett are consistent with ours, except that they observe a higher percentage of polarization. The difference in disk temperature is expected from the Jovian spectrum. The results of Rose, Bologna, and Sloanaker differ in both ϕ and the percentage of polarization. The differences here are probably a result of the difference in observing technique and analysis used, and the inclusion of the non-isotropic radiation effect in our analysis. In particular, our mathematical model for the non-isotropic radiation effect may be inaccurate and may lead indirectly to an inaccurate value for ϕ and/or the percentage of polarization. There is a strong indication that the magnetic field may be quite asymmetric, in which case a more complex treatment than ours of the radiation directionality is called for. We have used as complex a model as appears justified by the data.

The results of Gary at 22 cm are of particular interest, because they were obtained with a similar observational technique and method of analysis; however, Gary has defined his quantities A and B differently from our definition of A and B. His values

TABLE 5

	Wavelength (cm)	A(° K)	B(° K)	ϕ	λ_0^{III}	F1	F2	Polarization (Per Cent)
This paper	10.0	635° ±4°	106° ±30°	24°3± 1°5	186°8± 2°4	0.4±0.05	6.8±5 7	7.8±2.2
Rose, Bologna, and Sloanaker (1963)	9 4	$A+\frac{1}{2}B\approx$	658± 58	12	190	...	...	21
Morris and Bartlett (1963)	10.6	$A+\frac{1}{2}B\approx$	800±100	20 ±11	260 ±70	...	...	20 ±5
Gary (1963)	22	2296	1465	10.1± 1.2	195 ± 4.5	0.8±2.5	6.8±1.9	22 ±2
Morris and Berge (1962), June–July 1961	22	$A+\frac{1}{2}B\approx$	3380±500	7 7± 3	198 +18	...	...	28 ±6
Morris and Berge (1962)	31	$A+\frac{1}{2}B\approx$	5500±740	7.3± 5	225 +19 −45	...	...	33 ±7

quoted in Table 5 have been modified so as to agree with our definition; that is, here his A represents the unpolarized component of brightness temperature and B represents the amplitude of the polarized component. It is of interest that Gary's values for F1 and F2 are virtually identical to ours, suggesting that the radiation pattern of the Jovian non-thermal system does not vary rapidly with frequency. Furthermore, the well-determined values of λ_0^{III} are in very good agreement, indicating no change in λ_0^{III} with frequency, and indicating that the true value of λ_0^{III} is very probably within a few degrees of $\lambda^{\mathrm{III}} = 190°$. This is close to, but significantly different from, the center of the main radiation lobe of the decameter sources, $\lambda^{\mathrm{III}} = 212° \pm 7°$ (Douglas and Smith 1963). Thus the exact coincidence that was suspected between λ_0^{III} and the decameter maximum apparently does not exist.

Table 5 suggests that the percentage polarization decreases gradually, and that the tilt of the axis of the decimeter system increases markedly with decreasing wavelength. The former feature can be understood in the context of the theory of Chang (1960, 1962) and Chang and Davis (1962), who suggest that decimeter emission emanates from electrons moving in flat helices near the equatorial plane, if one adds the hypothesis that the higher frequencies originate nearer the poles. This is to be expected, since the field becomes stronger near the poles, and thus particles will radiate higher synchrotron frequencies when nearer the poles. In this case, since the lines of force near the several poles of the planet will deviate both from the mutual parallelism of the equatorial regions and also rapidly in direction, we would expect a mixing of polarizations and a decrease in the net polarization for the radiating system. The change in ϕ with frequency could also be a result of different frequencies being radiated preferentially from different regions. An asymmetric magnetic field system would be required, which is consistent with the explanations offered by Warwick (1961*a*, *b*) for the asymmetry of the decameter radiation. It is probable that a clear solution to these problems will have to await high-resolution polarization studies of the planet.

We are indebted to the N.R.A.O. telescope operators, who made the many observations discussed here, and to Mr. B. L. Gary for providing us with his results in advance of publication.

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