Simultaneous Observations of Jupiter on Three Frequencies

I. Kazes [1]

Arecibo Ionospheric Observatory, Arecibo, Puerto Rico [2]

The planet Jupiter was observed at 41.7 Mc/s, 195 Mc/s, and 430 Mc/s during the month of September 1964 at the Arecibo Ionospheric Observatory [Gordon and Lalonde, 1961]. Each feed consisted of a pair of folded dipoles with reflectors separated by one-half wavelength. The three systems of feed were installed under carriage house No. 2 and centered approximately along a radius of the spherical reflector. The 195-Mc/s and 430-Mc/s feeds were centered to better than 5 min of arc. With respect to the 430-Mc/s dipoles, the 41.7-Mc/s dipoles were parallel while the 195-Mc/s dipoles were perpendicular. The illumination of the surface corresponds to a beam width of 18 min of arc at 430 Mc/s, 37 min of arc at 195 Mc/s, and approximately 2° at 41.7 Mc/s.

The motion of the planet through the beam agreed to ±2 min of arc with that predicated from the ephemerides. The whole region was later surveyed and no source stronger than 10 percent of the flux of Jupiter was observed. Furthermore, on 12 November 1964 with Jupiter completely out of the beam, the beam was again pointed at the position of 15 September 1964 and again no confusing source was observed. Altogether more than 30 drift curves and declination scans of Jupiter were taken; of this number only 26 observations exist at all three frequencies simultaneously. For these observations to within 10°, the 41.7-Mc/s dipoles as well as the 430-Mc/s dipoles were oriented east-west, while the 195-Mc/s dipoles were oriented north-south.[3]

Whenever Jupiter was observed, the nearest radio source 3 C79 was also observed for calibration. The fluxes assumed for 3 C79 were $70.\times 10^{-26}$ Wm^{-2} $(c/s)^{-1}$ at 41.7 Mc/s, $25.\times 10^{-26}$ Wm^{-2} c/s^{-1} at 195 Mc/s, and $13.\times 10^{-26}$ Wm^{-2} $(c/s)^{-1}$ at 430 Mc/s. The antenna temperature of Jupiter for each day was converted into flux using the antenna temperature of 3 C79 measured the same day. All fluxes were then normalized to the standard distance corresponding to a semipolar diameter of 22.75″.

The mean value and the observed rms deviation are as follows:

$$S_{430} = (7.2 \pm 1.6)\ 10^{-26}\ Wm^{-2}(c/s)^{-1}$$
$$S_{195} = (6.2 \pm 0.7)\ 10^{-26}\ Wm^{-2}(c/s)^{-1}$$
$$S_{41.7} \leqslant (35.)\ 10^{-26}\ Wm^{-2}(c/s)^{-1}.$$

During the 15 to 20 min of each observation, there was no activity equal to or greater than $35.\times 10^{-26}$ Wm^{-2} $(c/s)^{-1}$ recorded at 41.7 Mc/s although on some occasions System III radio longitude of the central meridian of Jupiter was favorable for decametric activity.

For comparison with the observed rms deviations of 22 and 11 percent on the flux at 430 Mc/s and 195 Mc/s respectively, we estimated the errors due to calibration and to signal-to-noise ratio. The total errors are 13 percent at 430 Mc/s and 8 percent at 195 Mc/s. These results suggest a variation of the flux of Jupiter which is smaller at the lower frequency. An analysis of the flux plotted against System III longitude (λ III) shows that the best fit for both frequencies would be periodic rather than linear (fig. 1).

Furthermore, to investigate the apparent existence of a relation between the variations of the fluxes at the two frequencies, the correlation coefficient has been calculated for simultaneous observations only. The value of this coefficient is equal to 0.5. The correlation coefficient calculated in the same way for the variations of 3 C79 is equal to −0.3.

After the discovery of the polarization of the planetary emission [Radhakrishnan and Roberts, 1960] most of the variations of Jupiter's flux, from about 10 to 30 cm of wavelength reported have been attributed to the rotation of the planet [McClain, 1959; McClain and Sloanaker, 1959; Sloanaker, 1959; Sloanaker and Boland, 1961; McClain, Nichols, and Waak, 1960; Morris and Bartlett, 1963; Morris and Berge, 1962] which causes the plane of polarization to rock through ±9° [Morris and Berge, 1962]. While the thermal emission (for $\lambda < 10$ cm) is expected to be unpolarized and come from the visible disk of the planet, the nonthermal, approximately flat spectrum emission (for $\lambda < 10$ cm) is polarized and comes from an elliptical source [Morris and Berge, 1962]. In

[1] On leave from Meudon Observatory – France.

[2] The Arecibo Ionospheric Observatory is operated by Cornell University with the support of the Advanced Research Projects Agency under a research contract with the Air Force Office of Scientific Research.

[3] In September 1964, Jupiter's declination varied very closely around 18° which is approximately the latitude of the site at the AIO.

addition, the suggestion of a beaming effect has been pointed out [Morris and Berge, 1962]. The beaming [Gary, 1963; Bash, Drake, Gundermann, and Heiles, 1964] of the radiation which manifests itself as a variation of the total intensity as the planet rotates, is now unambiguously demonstrated [Roberts and Komesaroff, 1964].

Furthermore, it has been shown [Berge and Morris, 1964; Roberts and Komesaroff, 1964] that there is a physical displacement of the emitting region due to a displacement of the magnetic dipole from the center of the planet.

If the variation described at 430 Mc/s and 195 Mc/s have the same origin, then the linearly polarized wave should be affected by Faraday rotation in the ionosphere. A preliminary analysis of figure 1 suggests cyclic variations in particular from λ III $=0$ to λ III $=200°$. When limited to this range of longitudes, the calculated correlation coefficient for simultaneous observations at the two frequencies is 0.6. This number suggests that the variations of Jupiter's flux at 195 Mc/s and 430 Mc/s are reasonably well in phase. On the other hand the phase of a variation is a function of the position angle θ of the E plane of the dipole diminished by the effect of Faraday rotation φ. Considering that the variations are in phase, we can write.

$$(\theta-\varphi)_{430}=(\theta-\varphi)_{195} \text{ with } \varphi_{195}=\varphi_{430}\left(\frac{430}{195}\right)^2,$$

$$\theta_{430}=90° \text{ and } \theta_{195}=180°. \quad \text{Then } \varphi_{430}\cong 23°.$$

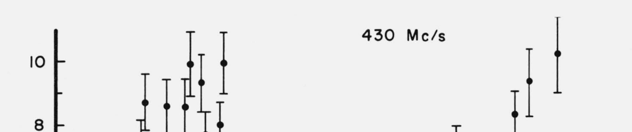

FIGURE 1. *Flux density at 430 Mc/s and 200 Mc/s plotted against System III longitude.*

The values of θ are only known to $\pm 5°$ since the 430-Mc/s and 195-Mc/s dipoles were not always exactly east-west and north-south respectively. The perpendicularity of the two sets of dipoles could be off by 5° due to construction inaccuracy.

According to a recent paper [Lawrence, Little and Chivers, 1964], the Faraday rotation at 100 Mc/s is typically 6.6 rad. With this result the corresponding rotations in degrees at 430 Mc/s and 195 Mc/s are approximately 20° and 98° respectively. Furthermore observations on polarization of the galactic 75-cm radiation [Van de Hulst, 1961] suggest possible Faraday rotation in the ionosphere of 10° to 20° in the middle of the night. Finally, the measurements of Faraday rotation made at the AIO by radar means [Morgan, 1965] on 430 Mc/s in September 1964 between 11:00 and 16:00 AST give values between 50 and 90 deg. round trip. The probability is highest around 60 to 70 deg. A one-way transit of the ionosphere would thus give about 35 ± 10 deg. Since the observations described in this paper have been made between 03:00 and 06:00 AST, it is reasonable to adopt a value of 25° rotation at 430 Mc/s and 120° at 195 Mc/s.

If the given interpretation is correct, there is an experimental evidence to consider that the polarized Jovian decimeter radiation extends until a wavelength of at least 1.5 m. Furthermore, from observations at two or more frequencies, a reasonably good value of the Faraday rotation can be given.

Further analysis of figure 1 shows that the relative variations of the E-W flux at 430 Mc/s are more important than those of the N-S flux at 195 Mc/s. This difference could be explained supposing that the observed 430-Mc/s radiation comes in particular from the highly polarized equatorial region while the observed 195-Mc/s radiation is supposed to be the contribution of the polarized component in a direction perpendicular to the equator of the planet.

This supposition can only be true if the Jovian emission at 430 Mc/s and 195 Mc/s have the same origin as that observed in the range of 3000 Mc/s to 960 Mc/s by other observers,

In similar conditions, though not simultaneously, [Gary, 1963] observed the E-W and N-S flux of Jupiter at 1400 Mc/s. When a comparison is made between the E-W flux at 1400 Mc/s to the E-W flux at 430 Mc/s and between the N-S flux at 1400 Mc/s to the N-S flux at 195 Mc/s it follows that there exist mean flux differences of the order of 7 to 10 percent; also the observed variations at 430 Mc/s and 195 Mc/s can be as great as twice or more the corresponding variations at 1400 Mc/s. The differences in mean flux could be mainly due to the use of different calibration sources. The differences in the variations could be explained by the beaming of the radiation of the Jovian Van Allen belts. The beaming will have a certain influence on the fractional polarization as well as on the total flux. Hence it will be difficult to establish a variability of Jupiter's decimeter radiation with frequency unless more simultaneous observations are made at as many frequencies as possible.

References

Bash, F. N., F. D. Drake, E. Gundermann, and C. E. Heiles (1964), 10–CM observations of Jupiter, 1961, 1963, Astrophys. J. **139,** No. 3, 975–985.

Berge, G. L., and D. Morris (1964), Decimeter Measurements relating to the possible displacement of Jupiter's magnetic dipole, Astrophys. J. **140,** No. 3, 1330–1332.

Gary, B. L. (1963), An investigation of Jupiter's 1400 Mc/sec radiation, Astron. J. **68,** No. 8, 568–572.

Gordon, W. E., and L. M. Lalonde (1961), The Design and capabilities of an ionospheric radar probe, IRE Trans. Ant. Prop. **AP-9,** No. 1, 17–22.

Lawrence, R. S., C. G. Little, and H. J. A. Chivers (1964), A survey of ionospheric effects upon earth-space radio propagation, Proc. IEEE **52,** No. 1, 4–27.

McClain, E. F. (1959), A test for non-thermal radiation from Jupiter at a wavelength of 21 cm, Astron. J. **64,** 339–340.

McClain, E. F., J. H. Nichols, and J. A. Waak (1960), Possible variations in the centimeter wave emission from Jupiter, Paper presented at the 13th General Assembly of URSI London.

McClain, E. F., and R. M. Sloanaker (1959), Preliminary observations at 10-cm wavelength using the NRL 84-foot radio telescope, Proc. IAU–URSI Paris Symposium on Radio Astronomy 61, ed. R. N. Bracewell (Stanford Univ. Press, Stanford, Calif.).

Morgan, G. (1965), Cornell University, Research Report (in press).

Morris, D., and J. F. Bartlett (1963), Polarization of the 2840 Mc/s radiation from Jupiter, Mem. Soc. Roy. Sci. Liege **7,** 564–568.

Morris, D., and G. L. Berge (1962), Measurements of the polarization from Jupiter, Astrophys. J. **136,** 276–282.

Radhakrishnan, V., and J. A. Roberts (1960), Polarization and angular extent of the 960 Mc/s radiation from Jupiter, Phys. Rev. Letters **4,** 493–494.

Roberts, J. A., and M. M. Komesaroff (1964), Evidence for asymmetry of Jupiter's Van Allen belt, Nature **203,** No. 4947, 827–830.

Sloanaker, R. M. (1959), Apparent temperature of Jupiter at a Wavelength of 10 cm, Astron. J. **64,** 346.

Sloanaker, R. M., and J. W. Boland (1961), Observations of Jupiter at a wavelength of 10 cm, Astrophys. J. **133,** 649–656.

Van de Hulst, H. C. (1961), Polarisatie van de Radiostraling ven het Melkwegstelsel, Versl. Afd. Naturk. Kon. Ned. Ak. Wet. Amsterdam **70,** No. 2, 23–27.

(Paper 69D12–591)

A Report of Measurements

D. Barber [1] and J. F. R. Gower [2]

Summary: The main results are values of the flux density for Jupiter at 610 Mc/s (normalized to 4.04 A.U.):

Flux density $=6.6\pm0.3\times10^{-26}$ Wm^{-2} $(c/s)^{-1}$ at 610 Mc/s

Flux density $=5.1\pm0.8\times10^{-26}$ Wm^{-2} $(c/s)^{-1}$ at 178 Mc/s.

[1] Royal Radar Establishment, Ministry of Aviation, Great Malvern, England.

[2] Mullard Radio Astronomy Observatory, Cavendish Laboratory, Cambridge, England.

(Paper 69D12–592)