18·3 Mc/s RADIATION FROM JUPITER

By C. A. Shain*

[*Manuscript received August 23, 1955*]

Summary

Burke and Franklin's discovery of radio emission from Jupiter has been confirmed. Examination of old records has shown that in 1950–51 the radiation came in groups of bursts of very high intensity. Bursts have durations of the order of a minute or less; groups, of an hour. Because of the remarkably close relation between active periods and the period of rotation of Jupiter, it is inferred that the source at the time was very localized. Its identification with a visual disturbance in the South Temperate Belt is very probable.

It is pointed out that occultation by Jupiter's satellites may help to locate the sources of radiation, both in position and in height relative to the visible surface, and that Jupiter radiation should be a valuable tool for studying the outer regions of the solar corona.

I. Introduction

During the rapid development of radio astronomy in the last 10 years, the question has sometimes been raised as to whether radiation from any of the planets could be detected. The detection of thermal radiation would appear to be at present impracticable, but it has been suggested (Higgs 1951) that electrical discharges analogous to terrestrial lightning flashes may occur in the atmosphere of Venus and that radiation from such discharges may be detectable. In 1955, however, came the quite unexpected announcement by Burke and Franklin (1955) that very intense radiation at 22 Mc/s had been received from a direction in the sky which was close to the position of Jupiter, the Right Ascension of the source changing with that of the planet.

Following this remarkable discovery of radio radiation from Jupiter, observations were begun in this Laboratory and at the same time records of cosmic noise which had been made during the past few years were searched for signs of Jupiter radiation. Although there was no trace found of any radiation from Jupiter on records at higher frequencies, some records taken at 18·3 Mc/s in 1950–51 showed series of bursts which had previously been passed over as terrestrial interference. Detailed analysis has now shown these to be radiation from Jupiter, thus confirming Burke and Franklin's discovery. Study of the same observations has added an important new fact; for a period of at least one and a half months in 1951 the radiation came from a very localized region on Jupiter.

The new observations are few and will not be described here in detail; they too show Jupiter radiation, though less frequently than the earlier records.

* Division of Radiophysics, C.S.I.R.O., University Grounds, Sydney.

The present paper discusses the older observations. After a general description of the records and of the equipment used, two series of records are considered in detail. These give evidence that the radiation came from a small region of the planet. A probable identification of one such region is put forward. Finally, the usefulness of Jupiter radiation for the study of radio propagation conditions near the Sun is pointed out.

II. Observations

(a) *Circumstances*

The records discussed in this paper were made in the course of a study of cosmic noise at 18·3 Mc/s ; the equipment used has been described previously (Shain and Higgins 1953). The aerial consisted of an array of 30 half-wave dipoles and the direction of maximum sensitivity in the meridian plane could be changed. The beamwidth to half-power was 17°. The feeders were arranged so that two receivers could be connected to the aerial, one using the aerial with the maximum response in the meridian plane, the other with zero response in the meridian. When suitable records were available from both receivers, a comparison of the signal powers received in the two receivers could be used to find the direction of the source of the signal.

With this system records were taken almost daily for about a year up to June 1951. The aerial direction was changed at frequent but irregular intervals in the course of the cosmic noise programme, and a watch was kept for peculiarities on the records, especially for bursts of solar noise and for variations caused by abnormal ionospheric attenuation. Quite frequently there was interference from atmospherics and radio stations ; thus no particular significance was attached to the occurrence of occasional groups of bursts during the night. However, after the announcement by Burke and Franklin, a review of these records showed that on a number of occasions groups of large bursts occurred when Jupiter was in the aerial beam. In the periods October 16–November 30, 1950 and February 9–April 18, 1951, there were 64 days on which records were suitable for the detection of Jupiter radiation (correct aerial direction, no obvious interference, etc.).*

Study of these records identified the source of the radiation as Jupiter and facilitated recognition of Jupiter radiation in a second series of records, from August 15 to October 2, 1951, taken under somewhat different conditions. In June 1951 part of the original aerial had been dismantled, but a single receiver was used to measure the noise picked up by the remaining 10 dipoles, which had an aerial diagram narrow in the north-south direction but very broad in the east-west direction. These records, which permitted the observation of Jupiter for almost a whole rotation on any one day, have provided information which has led to the conclusion that the radiation originated in an area of small extent on the surface of Jupiter.

The two series of observations will be discussed in turn.

* All dates and times in this paper are given in 150° E. time unless otherwise stated.

(b) *First Series—Identification of the Source with Jupiter*

Figure 1 shows six selected records, for which the aerial had maximum sensitivity in the meridian, so arranged that for each the time of transit of Jupiter lies on the line joining the two arrows. It will be seen that the records are smooth except for the short interval of about 2 hours during which Jupiter was passing through the aerial beam. It is apparent that over several months the time of maximum noise changed from late evening to midday. The changing time interval between the groups of bursts and the passage of part of the Milky Way through the aerial beam (on the right of the records) can also be seen, indicating that the Right Ascension of the source is changing.

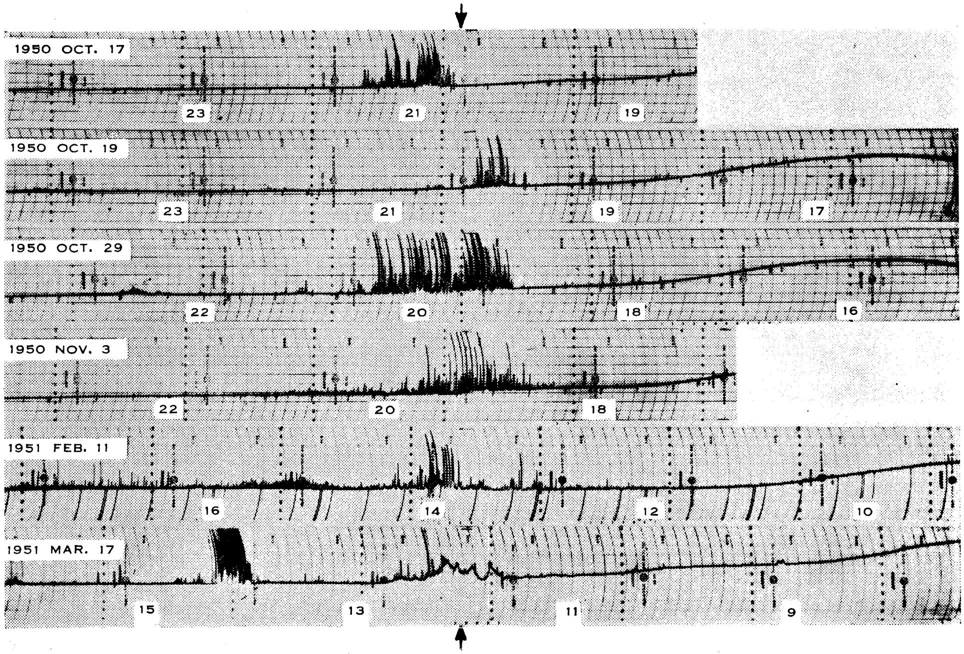


Fig. 1.—Records showing strong bursts near the time of transit of Jupiter. Dates and times are given on each record. The records have been arranged so that the times of transit of Jupiter are on a line joining the arrows. Atmospheric noise is present on February 11, 1951, from 15^h onwards, and radio station interference on March 17, 1951, between 14^h and 15^h.

Most of the records show violent fluctuations, often going off-scale at an intensity greater than 5×10^{-21} W m^{-2} (c/s)$^{-1}$, but the appearance changed for the later records, which were taken when the time of transit of the source was near midday. This change of appearance will be referred to again later. The records were made by a meter having a time constant of the order of 1 sec ; thus transients of shorter duration, if present in the radiation, would not be recorded. Notes written on some records indicate that many bursts sounded like " swishes " (similar to solar noise bursts, with which they were confused) and therefore the recorder followed these noise variations faithfully. On some other occasions there were sounds suggesting the presence of short impulses which the recorder would not follow.

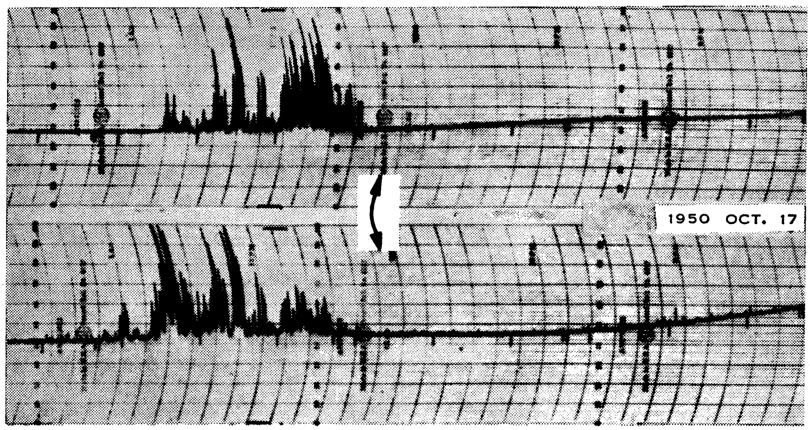
As mentioned above, there were 64 records which were suitable for the detection of bursts near the time of transit of Jupiter. On 17 of these there were intense bursts having characteristics as shown in Figure 1, and on a further 17 there were definite but weaker bursts. On the remaining days no sign of such fluctuations could be detected. This appearance of bursts on only about half the days agrees with another deduction from Figure 1, namely, that on those days on which bursts were received they were not generally present on the records for the full time that the system was sensitive to radiation from a source moving through the aerial beam.

Confirmation of the tentative conclusion that the records were of radiation which had originated on Jupiter came from the detailed comparison of the records from the two receivers, which gave fairly accurate positions of the source of the noise on a particular day. Two pairs of records are shown in Figure 2. For the upper record in each case the aerial had maximum sensitivity in the meridian, while for the lower records there was a zero in the meridian. In Figure 2 (*b*) the bursts commenced before the source had reached the central plane of the aerial and the passage of the source across this central plane can be seen by the absence of bursts below the arrow on the lower record. In Figure 2 (*a*) the bursts did not begin until after the source had passed the central plane of the aerial and the time of zero response cannot be read off directly from the record. However, by finding the ratio of the amplitudes of individual bursts on the two records and comparing these with the ratio to be expected at the same times by calculation from the known aerial diagrams, the time of passage of the source across the central plane of the aerial could be deduced with an accuracy of better than ± 4 min (an angular accuracy of $\pm 1°$). This direction-finding method was checked by application to cosmic noise sources and the Sun. It was not always possible to use this technique as it required good records, free of interference, from both receivers, but on the 13 days for which there were suitable records the origin of the bursts was located within 1° of Jupiter. In this way some solar bursts could be distinguished from Jupiter radiation ; the few bursts of short duration on the record for March 17 (Fig. 1) were found to be from the Sun whilst the large slow variations came from Jupiter.

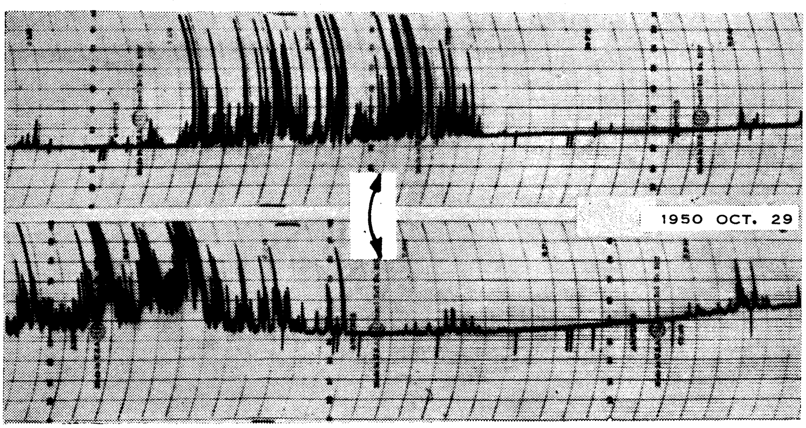
Some correlation was found between the times of appearance of the noise and the appearance on the visible disk of Jupiter of certain regions of longitude. When all the records were taken together, there was a greater chance of receiving the noise when longitude 110° (System II)* was the central meridian on Jupiter's disk. The correlation was not strong enough for detailed study, but it did show that the Red Spot was not a prominent source of radio noise.

* The equatorial regions of Jupiter rotate faster than the remainder of the planet and within each region there are slight variations in period. Two conventional systems of longitude are therefore used. System I is applicable to the equatorial regions and System II to the remainder of the planet. The adopted daily motions and rotation periods of the zero meridians of the two systems are :

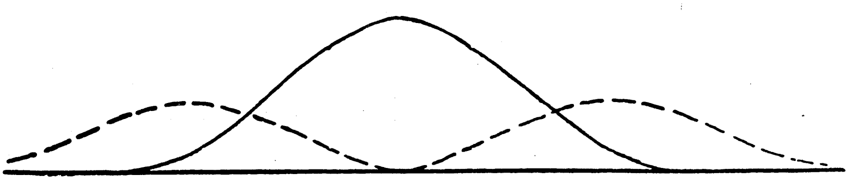
System I	.. 877°·90	$9^h\ 50^m\ 30^s{\cdot}003$
System II	.. 870°·27	$9^h\ 55^m\ 40^s{\cdot}632$



(a)



(b)



(c)

Fig. 2.—Radiation from Jupiter, recorded with two aerials simultaneously, on (*a*) October 17, 1950 and (*b*) October 29, 1950. (*c*) shows the aerial sensitivity. In each case the upper record was made using an aerial with maximum sensitivity in the meridian plane (full curve in (*c*)), while for the lower records there was a zero in the meridian plane (dashed curve in (*c*)). Time of transit of Jupiter is indicated by the arrows.

Having established the characteristics of the radiation from Jupiter, one could recognize with reasonable certainty the same radiation on the records of the second series, made with the broader aerial beam.

(*c*) *Second Series—August 15 to October 2, 1951*

(i) *Description of the Records.*—After modification in June 1951 the aerial was capable of receiving signals from an extraterrestrial source for nearly 8 hours per day. The beam was still narrow in the north-south direction so

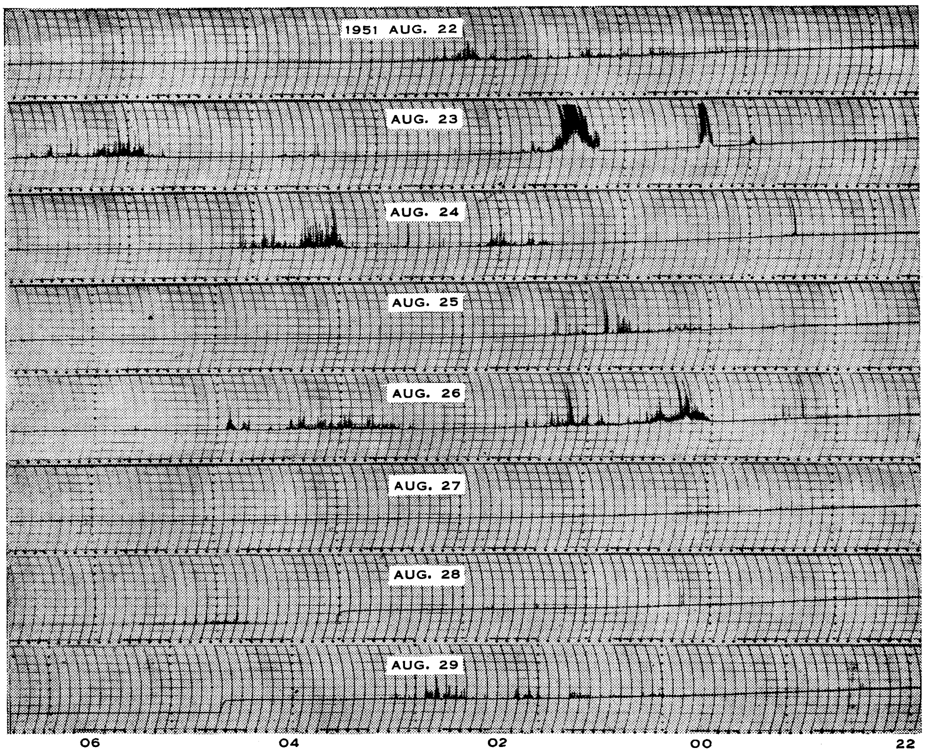


Fig. 3.—Records taken with a very broad aerial beam on successive days (the dates refer to the times after midnight). The time of transit of Jupiter is roughly in the centre of each record.
There is station interference on the record for August 23 at about 00^{h} and 01^{h}, and also probably from about 00^{h} to $00^{h}\,30^{m}$ on August 26. All the other groups of bursts are believed to be from Jupiter. During the later part of the records for August 28 and 29 the receiver sensitivity was low.

that there was discrimination between sources at different declinations, but there were no facilities for accurate direction-finding in the east-west direction.

During the period under consideration the aerial was sensitive to noise from a source on Jupiter's declination and examination of the records showed that again there were groups of bursts near the time of transit of Jupiter. A series of records is shown in Figure 3. These groups of bursts were similar in appearance to those on the earlier records which had been shown to come from

Jupiter, and our experience has shown it to be most unlikely that terrestrial interference would be recorded so regularly at midnight during winter and spring. There were two direct checks that these groups of bursts were actually from Jupiter. Firstly, although the broad aerial beam made useful direction-finding impossible on any one day, the time of transit of Jupiter changed by nearly 4 hours between the middle of August and the beginning of October, and the time of occurrence of the bursts did the same. Secondly, as will be shown later, there was a very close relation between the occurrence of these bursts and the rotations of Jupiter.

With the broad aerial beam, Jupiter was in the beam for a time which permitted almost a complete rotation of the planet. Even if only a fraction of the planet were radiating, it would be expected that noise would be received on a greater proportion of days than was found with the narrower beamed aerial.

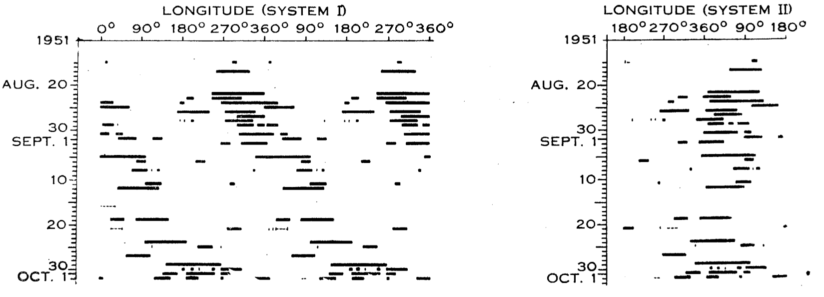


Fig. 4.—Periods of occurrence of 18·3 Mc/s radiation from Jupiter plotted against longitude of the central meridian at the time of observation.

This was found to be the case, noise being detected on 27 out of the 30 days on which there were suitable records. Figure 3 clearly shows that the groups of noise bursts were generally only one or two hours long. Since this is only a small fraction of the rotation period of Jupiter, there must be hour-to-hour variations in the intensity of the noise radiated by the planet.

(ii) *The Relation between the Times of Occurrence of Bursts and the Rotation of Jupiter.*—For each record the times of activity were noted and charts, shown in Figure 4, were drawn up to indicate any correlation with the rotation of Jupiter. For each day a thick line has been drawn under the longitude of the central meridian during the times when bursts were observed. It will be seen that these lines are almost directly under one another when plotted against System II longitudes and show a steady drift towards increasing longitudes in System I. Closer examination shows that there is actually a small negative drift in the System II diagram. These drifts imply that the source of radiation had a rotation period slightly shorter than that adopted for the calculation of System II longitudes ; the period of rotation is found to be $9^h\,55^m\,13^s$ with an estimated probable error of $\pm 5^s$.

Allowing for the slight drift in longitudes, all the lines in Figure 4 were superimposed to give a histogram of the frequency of occurrence of the noise for 5° intervals of central meridian longitude. This is shown in Figure 5, the longitudes being System II longitudes on August 14. It is seen that for a band of longitudes centred on 67° and extending from about 0 to 135° the frequency of occurrence was much greater than outside this band. It should be pointed out that there were about 120 rotations of Jupiter during the period of the observations on which this diagram is based, so that the probability that the effect observed was due to chance is extremely small.

The observations for the period February to April 1951 also indicated the same rotation period, within the experimental uncertainty, but the actual longitudes concerned were about 80° smaller than would have been obtained by extrapolation backwards from the second series observations.

III. Discussion of the Observations

(a) *Size of the Source*

If the radio noise came from a single source radiating in all directions, one would expect that the histogram in Figure 5 would have a flat maximum, cutting off sharply at longitudes 180° apart. Figure 5 does show a fairly flat maximum, but the boundaries are separated by only about 135°. There are several possible reasons for this restriction of the angle during which radiation may be received at the Earth. One possibility is that the emission of radio

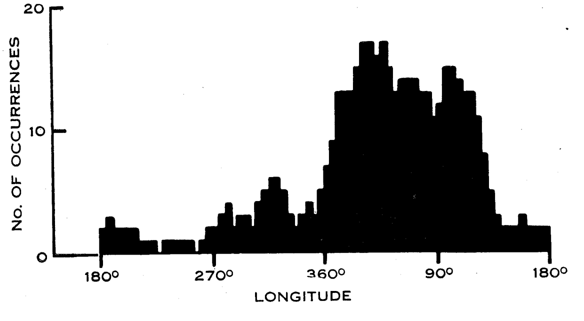


Fig. 5.—Frequency of occurrence of 18·3 Mc/s radiation from Jupiter for intervals of 5° in longitude (based on a rotation period of $9^h\ 55^m\ 13^s$). The longitudes are System II longitudes on August 14, 1951.

bursts is stimulated by solar visible (more probably ultraviolet) radiation. Viewed from Jupiter, the Earth is always close to the Sun so that the Sun rises at any point on Jupiter at very nearly the same time as the Earth comes into view. Therefore, if there were any delay after sunrise before the source radiated strongly, this would be shown as a restriction in the range of central meridian longitudes for which the noise was received.

Depending on the height of the source of the radiation, atmospheric refraction may be more important on Jupiter than on the Earth. Refraction would tend to extend the time during which the noise source would be " visible ", but this effect may be counteracted by the action of the atmosphere as a diverging lens, decreasing the intensity when the source is near the edge of the disk. A further possibility is that an ionosphere on Jupiter would cut off radio radiation when the Earth was at low altitudes as seen from the source.

Alternatively, if the source were actually in the ionosphere and near the level of maximum ionization density, refraction would operate in the correct direction. Jupiter probably has an ionosphere, but at present its characteristics are quite unknown.

In any case the emitting region was probably small in extent to give an "emission polar diagram" of much less than 180°. It therefore appeared worth while to attempt to identify the source with visual features of Jupiter.

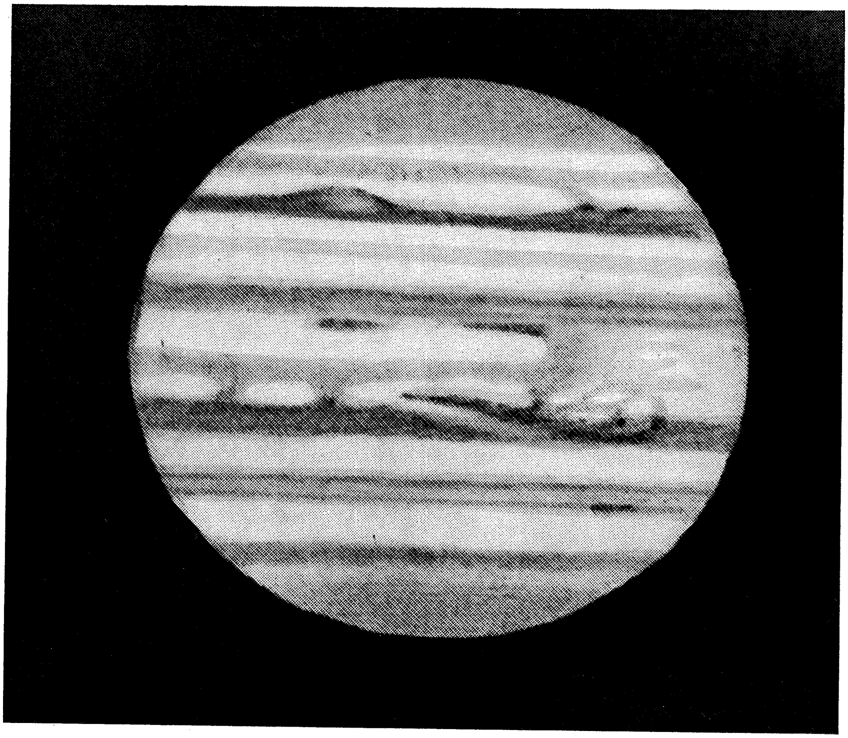


Fig. 6.—Jupiter on September 22, 1951 at 02^{h} U.T. The longitudes on the central meridian are 161° (System I), and 41° (System II). South is at the top.

(*b*) *Identification of the Radio Emitting Region*

The basic data were that the longitude of the source on August 14 was 67° (System II) and the rotation period was 9^{h} 55^{m} 13^{s}, the region being still active when observations ceased on October 2. The rotation period is important; it should be remembered that the two systems of longitude are fixed by convention and actual visible markings commonly drift at differing rates.

A drawing of Jupiter by du Martheray (du Martheray and Antonini 1952) is shown in Figure 6. Fox (1952) has given a summary of contemporary observations of Jupiter which were communicated to the Jupiter Section of the British Astronomical Association, and from this it appears very likely that the source of the radiation was located in the South Temperate Belt (the dark belt near the top of the drawing in Figure 6). A group of spots in this belt, which were observed for several months, and which were considered to be of a long-enduring character, had an observed rotation period of $9^h\,55^m\,13^s$, just the same as that of the radio source. All the other regions which move with System II were either faint with no certain markings or moved slightly slower than System II. The most prominent belt, with many markings, was the North Equatorial Belt, but this rotates with System I. Fox gave a sketch by E. J. Reese (reproduced in Fig. 7) which shows the most visually active region of the South Temperate Belt at the end of November 1951. The radio observations ceased on October 2, but, allowing for the continual drift in longitude, the longitude of the radio source on November 30 would have been 354° (System II); this corresponds with the longitude of the white spot labelled DE in Figure 7. This spot appears in Figure 6 as the indentation near the central meridian in the southern edge of the South Temperate Belt. Also, reference to Figure 5

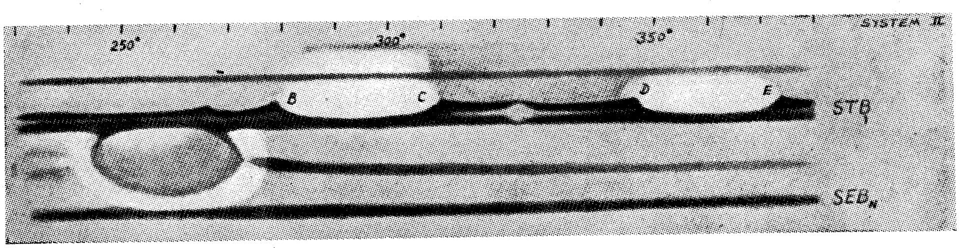


Fig. 7.—A drawing of part of Jupiter's disk on November 29–30, 1951 U.T. An extrapolation of the position of the radio source to November 30 would give its longitude as 354°.

shows that there was some radio noise from sources at smaller longitudes than the main source. The positions of these minor sources would have extended to longitude 260° (System II) by November 30. Therefore, although the identification is not proved beyond doubt, it seems very probable that the visually disturbed region in the South Temperate Belt was responsible for the radio radiation, the most intense source lying in one of the white spots in the southern edge of the belt.

(c) *Occultation by Satellites*

During the period for which observations were available there were three passages of Galilean satellites across the meridian containing the radio source. The records at these times were examined to see whether there were any marked changes, corresponding to occultations, which would help to locate the source. On one occasion there was no effect at all, and on a second occasion there was only a very doubtful suggestion of an occultation. In both cases the position of the satellite was always far from the position of the source deduced in the preceding section.

On the third occasion, during the transit of Satellite II on September 24, there was a sudden cessation of the noise as the satellite reached the meridian of the source, at $03^h\,10^m$. This may have been a coincidence, since the noise had already been received for over 2 hr, but on one or two other days noise had been received continuously for over 4 hr. At $03^h\ 10^m$ the source was still within 25° of the central meridian and as there was weak noise again 32^m later, there is a reasonable probability that the sudden decrease in intensity was due to an occultation of the source. The portion of the visible disk covered by the satellite was almost exactly the probable position of the source deduced previously.

If an occultation did occur, its duration, for a source of small extent, should have been only 16^m; in fact there was no noise for about half an hour. The obvious explanation of this discrepancy would be that slow fading in the intensity of the radiation masked the actual end of the occultation. An interesting alternative possibility is that the source was located well above the visible surface of the planet. The duration of the occultation would be extended to 32^m if the source were at a height of $0 \cdot 1R$, R being the radius of the visible surface; that is, at a height of about 7000 km. Also, there was no effect during the passage across the source of the shadow of the satellite, which occurred at about $01^h\ 20^m$. If this result were genuine it would rule out direct solar stimulation of the source of the radiation.

(*d*) *Propagation Conditions between Jupiter and the Earth*

The detection of radiation from Jupiter leads to the possibility of finding information concerning propagation conditions in interplanetary space near the plane of the ecliptic and especially along ray paths which pass near the Sun. Up to the present time the only information has come from the occultation of the discrete source Taurus-A by the Sun, a phenomenon studied in some detail by Hewish (1955). The large, and at present unpredictable, variations in intensity of the emission from Jupiter would seem to suggest that as a source of radiation for studying this problem Jupiter would not be satisfactory, but its appearance in bursts may actually be useful. In addition, its intensity is very high, frequently greater than that of any known discrete source, and a very small upper limit of about 1 min of arc is set to the angular size of the source. The observations described in this paper did not cover a very long period of time but in the course of the year there were noteworthy changes in the characteristics of the radiation from Jupiter.

Although no detailed study of the average daily intensity was made, it was apparent that during the period February-April 1951, when Jupiter's transit occurred near midday, the intensity was generally lower, by a factor greater than 3, than in the other periods, when transit occurred at night. Variations in ionospheric absorption would change the received intensity by a factor of less than $1 \cdot 2$ (see, for example, Mitra and Shain 1953) and the change in the Earth-Jupiter distance would account for a further factor of about $1 \cdot 8$. The remaining factor of $1 \cdot 4$ or more may have been due to the close approach of the ray paths to the Sun. If a simple, spherically-symmetrical, model of the corona is assumed, then at 18·3 Mc/s a source should be occulted by the solar corona at an angular distance of about $2^\circ \cdot 2$ from the centre of the Sun (Bracewell and Preston, unpublished data). Jupiter was certainly detected (records being available for direction-finding) on March 7 at 13^h and on March 17 at 10^h, the distances of Jupiter from the centre of the Sun being then $3^\circ{\cdot}0$ and $4^\circ{\cdot}6$ (11 and 17 solar radii) respectively. In each case there was no evidence of refraction in the corona, within the experimental uncertainty. The record on March 9 showed features similar to those on March 7 and 17 and, although the direction-finding facility could not be used on this occasion, it was almost certainly radiation from Jupiter at a distance of $1^\circ{\cdot}6$ (6 solar radii) from the centre of the Sun. These results agree with those of Hewish, who also found that radiation could be observed at a time when, according to the simple model of the corona, the source should have been occulted. The fact that radiation could not be observed, although conditions were favourable, for 5 days after conjunction on March 12 suggests that there may have been asymmetry in the southern half of the outer corona.

A point of some interest is the changing appearance of the records, as shown in Figure 1. During October-November 1950 (and later in August-September 1951) the bursts were very short, with durations less than a minute. In February and April 1951 durations of several minutes were common, whilst for a few weeks near the time of conjunction the records often showed only slow variations such as can be seen on the record for March 17. Jupiter has a small angular size and might be expected to show rapid scintillations of large amplitude, arising in the passage of the radiation through the Earth's ionosphere, but none of the discrete cosmic sources has shown such marked variations in the characteristics of scintillations near midday.

The explanation of this lengthening of the bursts probably lies in the scattering of the radiation in the outer corona. Even on a simple model of the corona each radiated burst could reach the receiver by two paths, one direct and the other reflected from the Sun. As an example of the time differences involved, the separation in time of the direct and reflected rays would be about 2^s for an angular separation between the source and the centre of the Sun of 5°, with the delay nearly proportional to the square of the separation. As the refractive index of the corona is less than unity, there will be a further delay due to the slowing down of the reflected ray but this would be extremely small (of the order of 10^{-5} s at a separation of 5° and varying inversely as the fifth power of the separation). These delays would be too small to extend the bursts sufficiently, but much longer delays could arise due to such scattering processes as those considered by Hewish. A study of the short-period variations in the radiation from Jupiter should be a useful supplement to the work on the intensity variations of Taurus-A near occultation.

IV. Conclusions

As a result of the investigation described in this paper two facts have been clearly established. Firstly, the discovery by Burke and Franklin of radio radiation from Jupiter has been confirmed, and secondly, in 1951 the radio emission came from a very small portion of the planet. The active region is very probably identified with a visually disturbed region in the South Temperate Belt.

The study of Jupiter radiation should certainly be extended to observations at a number of frequencies. Such work would help, for example, in sorting out the effects of a possible Jovian ionosphere and might throw more light on the mechanism of origin of the radiation. It is also clear that, as a powerful source of short bursts of radiation, and with its known position and small angular size, Jupiter should be a useful object of study for obtaining information concerning the outer regions of the solar corona.

V. Acknowledgments

The author is indebted to Dr. B. F. Burke for the early communication of his results, which stimulated this investigation. Thanks are due to Dr. G. de Vaucouleurs of the Yale-Columbia Southern Station, and to Mr. J. Robertson of the Sydney Observatory, who gave much help in obtaining information concerning visual observations of Jupiter, and also to Dr. A. F. O'D. Alexander, the Director of the Jupiter Section of the British Astronomical Association, who in personal communications added further comments to the published work of the Section.

VI. References

Burke, B. F., and Franklin, K. L. (1955).—*J. Geophys. Res.* **60** : 213–7.
Fox, W. E. (1952).—*J. Brit. Astr. Ass.* **62** : 280–2.
Hewish, A. (1955).—*Proc. Roy. Soc.* A **228** : 238–51.
Higgs, A. J. (1951).—*Science News* **21** : 39–60.
du Martheray, M., and Antonini, E. (1952).—*Docum. Observateurs* **5**, No. 7.
Mitra, A. P., and Shain, C. A. (1953).—*J. Atmos. Terr. Phys.* **4** : 204–17.
Shain, C. A., and Higgins, C. S. (1953).—*Aust. J. Phys.* **7** : 130–49.