II. RADIO ASTRONOMY*

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A. OH INTERFEROMETRY

In order to investigate further the physical conditions responsible for the anomalously intense sources of 18-cm line emission at radio frequencies, an interferometric study was undertaken jointly with M. L. Meeks and G. M. Hyde of Lincoln Laboratory, M.I.T., to determine the angular dimensions of the emitting regions. The interferometer was composed of the Millstone (84-ft) and Haystack (120-ft) antennas of Lincoln Laboratory, with a baseline of approximately 3800 λ at 18 cm, along a line nearly 20° east of north. Most of the observations were made with both antennas circularly polarized in the same sense.

The signals from the two antennas were effectively crosscorrelated by a phase-switching scheme. The sum and difference of the IF outputs from the two receivers were autocorrelated, and the difference between these autocorrelation functions was taken. A common local-oscillator signal was derived from reference signals carried along a transmission line that was servo-controlled to maintain constant electrical length. An IF delay for white-fringe compensation was unnecessary, since the delays were reconstructed in the autocorrelator.

Fringe amplitude and phase information, as a function of frequency, was extracted from the autocorrelation functions by means of a least-squares-fit technique executed by a digital computer. After calibration of the baseline parameters with continuum radio sources of small diameters and known positions, the positions of the emission lines were obtained from fringe phase as a function of hour angle.

The observations have been concentrated, thus far, on the emission regions near the continuum radio sources W3 (IC 1795), W49, Sgr A, and NGC 6334. Table II-1 shows, for the five strongest lines at 1665 MHz in W3, the size limits (under the assumption of a uniformly bright circular disc) of the emitting source derived from the observed fringe amplitude. The uncertainty in fringe amplitude represents the peak observed deviation

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Table II-1. Angular sizes and separations of emission features observed adjacent to W3.

Line Velocity[a] Km/s	Polarization (I.R.E. Convention)	Fringe Amplitude	Effective Source Diameter	Separation from −45.1 Km/s Line
−45.1	Right	1.01 ± 0.05	<15"	
−43.7	Right	1.0 ± 0.1	<20"	<3"
−41.7	Right	1.0 ± 0.2	<25"	<3"
−45.4	Left	1.0 ± 0.1	<20"	<3"
−46.4	Left	1.0 ± 0.1	<20"	<3"

[a]Velocity relative to the local standard of rest under the assumption that rest frequencies are those of the $2\Pi_{3/2}$, $J = 3/2$, Λ-doublet of $O^{16}H^{1}$.

for 15-minute integration intervals over all local hour angles. All lines had nearly the same phase which allows us to put an upper limit on the angular separation of the individual lines. No significant resolution of the emitting source could be detected, and all of the radiation appears to originate from the same region. More limited observations of the 1667-MHz lines gave the same position for the lines at −42.2 Km/sec and −44.7 Km/sec within 10 seconds of arc, subject to a possible lobe ambiguity owing to the small local-hour-angle coverage of the observations at this frequency.

Since all hour angles were covered at 1665 Mhz, the position was unambiguously determined from the observations made June 7th through June 19th (Epoch 1950.0) to be

$$\alpha = 02^h\ 23^m\ 14.3^s \pm 1.5^s$$

$$\delta = 61°\ 38'\ 57'' \pm 10''.$$

The dominant contribution to these errors arises from uncertainty in the derived interferometer baseline. The rms fluctuations (for a 15-minute integration) because of noise in the observations of the strongest line (−45.1 Km/sec) was 3 per cent in fringe amplitude and 3° in fringe phase.

A search was made in the Palomar Observatory Sky Atlas, for possible optical identifications. The observed position falls just within the boundary of the nebulosity, midway between two faint stars, neither of which is within the position uncertainty.

The source of the line emission is clearly of an unusual nature. For example, the observed angular size limit implies a brightness temperature of at least 2×10^6 °K for the line at -45.1 Km/sec. The apparent linear dimension of the source, under the assumption that it is located at the distance of W3 (1700 parsec), is less than 0.1 parsec. Sgr A is also a single point source, less than 20" in size. W49 and NGC 6334 each appear to be slightly more complex, and are apparently each double. The individual components are, however, unresolved by the interferometer.

In summary, all OH emission sources observed thus far are of very small angular size, although more than one point source can be associated with a given H II region. Each point source usually has more than one velocity component associated with it.

B. F. Burke, J. M. Moran, A. E. E. Rogers

B. LOW-FREQUENCY APERTURE SYNTHESIS OF DISCRETE RADIO SOURCES

A program of observations has just been completed at the National Radio Astronomy Observatory, Green Bank, West Virginia. We measured the fringe visibilities of approximately 24 of the brightest radio sources, at a frequency of 234 MHz, using the long-baseline interferometer with additional equipment constructed at M.I.T.

From the results of these observations, the structures of many of these sources are being obtained by a variety of digital-computer processings, including smoothing, interpolation, inverse Fourier transformation, and model fitting.

The NRAO interferometer consists of two radio telescopes, of 85-ft diameter, capable of operating at any of 6 baselines from 1200 m to 2700 m in separation, along an azimuth of ~50° ($H = 4^h 50^m$, $D = -22° 07'$ approximately). The receiver is of the double-sideband variety, with an intermediate frequency band of 2-12 MHz (Read, 1963). We fitted the telescopes with 234-MHz feeds and front-end electronics, which we then led into the NRAO IF delay and correlation system. The first stage in the processing of the data was finished at NRAO, and the remaining work will be done here during the next 6-8 months.

We selected, for the most part, small extragalactic sources for this program in an attempt to detect larger-scale diffuse halos around the major components that might be depositories for old, lower-energy electrons or the residues of events that preceded those responsible for the major components of the radio sources observed at present. Our ultimate angular resolution (for those sources for which maps can be obtained) will be of the order of 1 min (arc), compared with the 2-5 min (arc) sizes of the major components. In some cases the primary beam of the telescopes (diameter = 3° (arc)) included other comparable sources besides the one of interest, and the large minimum spacing of the interferometer (1200 m = 960 wavelengths) will not allow the several sources to be separated (a problem analogous to the multiple responses of a grating array). It is hoped that next year, when a third telescope will have been constructed at NRAO that will afford a spacing as small as 100 m (80 wavelengths), the missing region of the fringe-visibility plane can be filled in and these complicated areas can be mapped completely. In the meantime, we are analyzing those sources whose structure can now be determined with some certainty.

S. H. Zisk

C. SPECTRUM MEASUREMENTS OF VENUS AND JUPITER

Microwave spectroscopy can provide information about the identity, abundance, and distribution of any atmospheric constituents which have appropriate microwave resonances. As part of a search for atmospheric spectral features, the planets Venus and Jupiter were observed from January to March, 1966, at wavelengths near 1 centimeter.

The observations were made with the 28-ft antenna[1] at Lincoln Laboratory, M.I.T.; and a five-channel microwave radiometer[2] operating simultaneously at 19.0, 21.0, 22.235, 23.5 and 25.5 GHz. The system sensitivity evaluated at the antenna feed, and including baseline drift, was 2.5°K for a 1-sec time constant.

The planetary observations were calibrated by comparison with lunar observations.

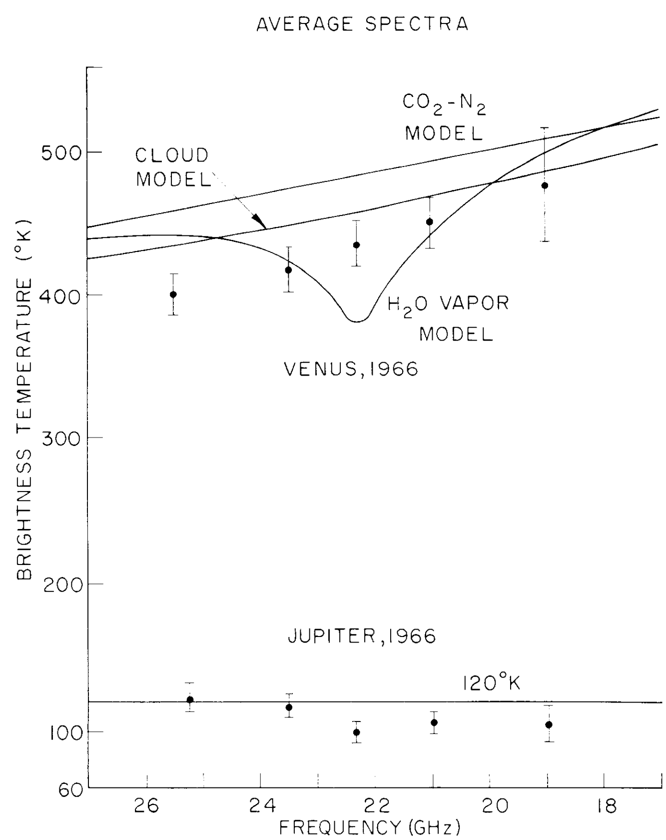

Fig. II-1. Observed and theoretical average spectra of Venus and Jupiter.

The comparison was made utilizing the measured antenna patterns, as described earlier[3,4]. The measurements were corrected for atmospheric absorption with an accuracy of approximately 1 or 2 per cent.[3] The atmospheric absorption was determined by means of a concurrent series of solar-extinction atmospheric absorption measurements and measurements of ground-level humidity.

Venus was observed on 13 days between January 11 and March 15, 1966. The average spectrum is shown in Fig. II-1 and is listed in Table II-2. The error brackets represent the relative rms accuracies of the measurements. The results tabulated in Table II-2 include the absolute accuracies, which incorporate uncertainties in the antenna pointing, in the measured antenna patterns, and in the assumed lunar brightness temperatures.

The observed spectrum can be compared with the theoretical spectra shown in Fig. II-1. The illustrated water vapor spectrum corresponds to an N_2-CO_2-H_2O model atmosphere with 50 atm surface pressure and 650°K surface temperature. The water-vapor density was assumed to be 60 gm/m^3 at the surface and to have a constant mixing

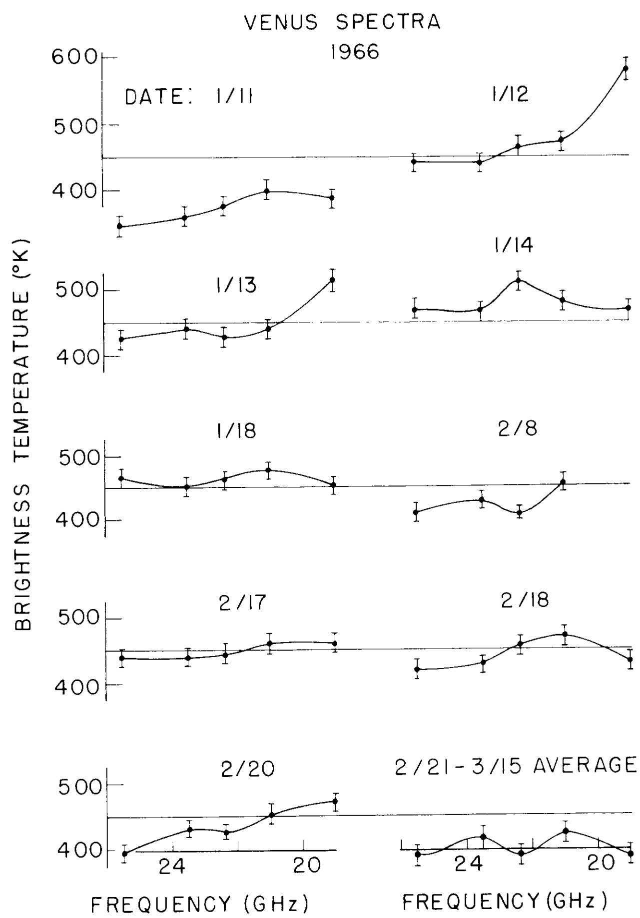

Fig. II-2. Observed spectrum of Venus as a function of date.

Table II-2. Results of spectrum measurements.

Frequency	Venus	RMS Error		Jupiter	RMS Error	
	$\overline{T}_B$	Rel.	Abs.	$\overline{T}_B$	Rel.	Abs.
(GHz)	(°K)	(%)	(%)	(°K)	(%)	(%)
19.0	477	±8	±12	105	±20	±20
21.0	451	±4	±9	106	±9	±10
22.235	436	±4	±9	98	±10	±11
23.5	418	±4	±9	116	±8	±9
25.5	400	±4	±9	123	±7	±9

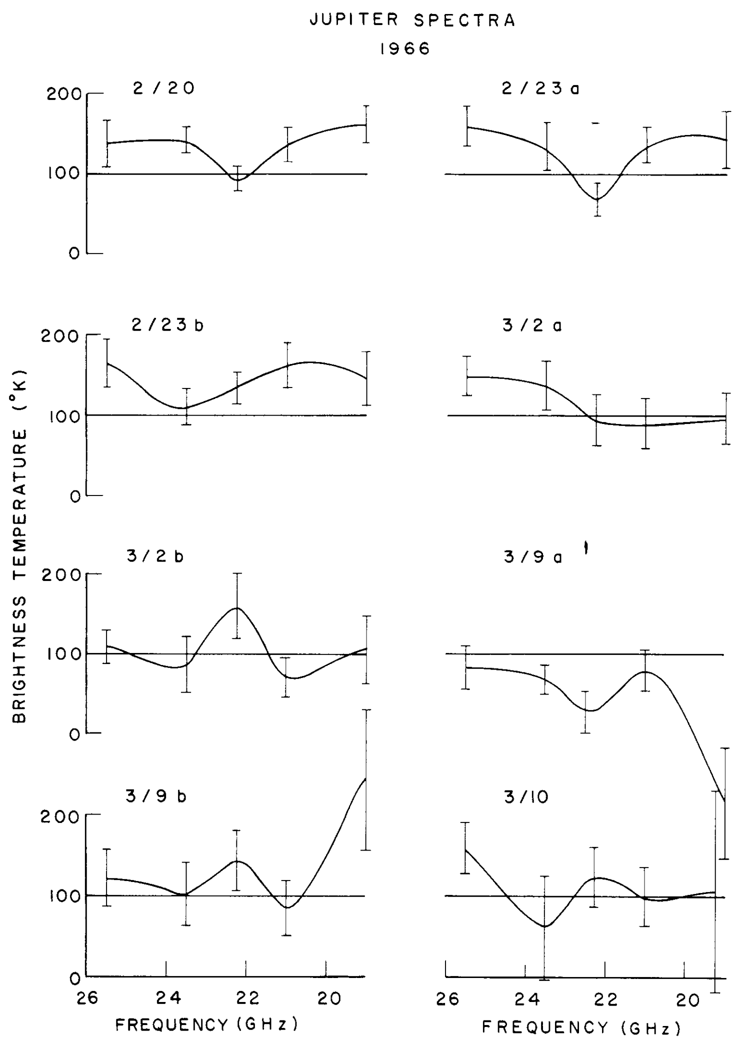

Fig. II-3. Observed spectrum of Jupiter as a function of date.

ratio in all regions hotter than 273°K. This mixing ratio corresponds to a typical winter day. Both of the nonresonant model spectra are consistent with the observed spectrum and the absolute error brackets.

The observed spectrum of Venus is shown as a function of date in Fig. II-2. The error brackets correspond to receiver noise only. There are no apparent fluctuations in spectral shape which are not consistent with either the illustrated error brackets or with instrumental effects such as antenna-pointing errors.

Jupiter was observed on 7 days, yielding the average spectrum shown in Fig. II-1 and tabulated in Table II-2. The observed average spectrum is consistent with a flat spectrum near 110°K. The observed spectra are plotted as a function of date in Fig. II-3; the fluctuations appear greater than the fluctuation of Venus. Although this effect could be instrumental, it could also originate from the very rapid rotation of Jupiter, one revolution every 9.9 hours. The sub-Earth point of Jupiter is plotted as a function of time in Fig. II-4, using System II coordinates. Comparison of Figs. II-3 and II-4 shows that the three

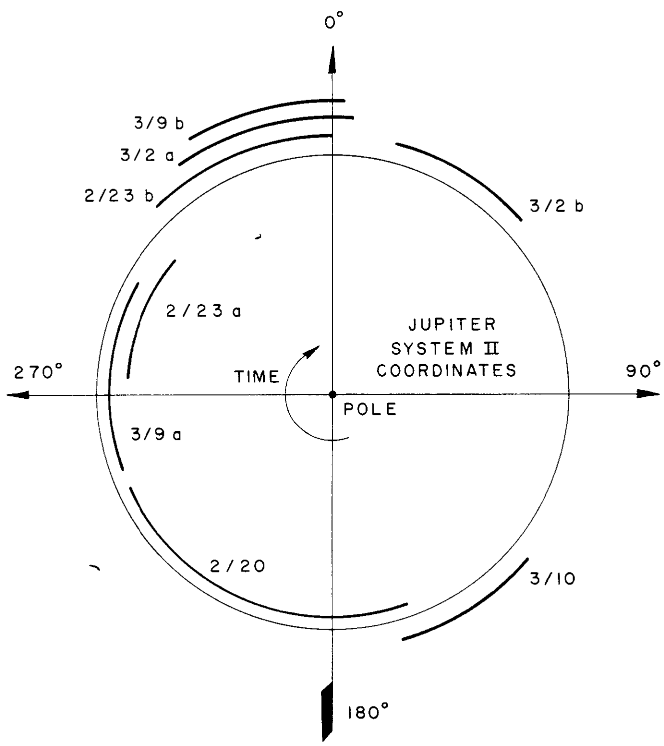

Fig. II-4. System II Longitude of the Jovian sub-Earth point.

spectra exhibiting dips near 22.235 GHz occurred on the same side of Jupiter, and the remainder occurred on the other side. Future observations would be necessary to confirm this Jovian meterological effect. Such an effect could be due to NH_3, which is known to be present on Jupiter. NH_3 has many strong molecular inversion lines in this spectral region, including the J = 3, K = 1 line at 22.2345 GHz.

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References

1. D. H. Staelin, Quarterly Progress Report No. 69, Research Laboratory of Electronics, M.I.T., April 15, 1963, pp. 23-25.

2. D. H. Staelin and A. H. Barrett, Quarterly Progress Report No. 78, Research Laboratory of Electronics, M.I.T., July 15, 1965, pp. 21-24.

3. D. H. Staelin, Sc.D. Thesis, Department of Electrical Engineering, Massachusetts Institute of Technology, January 1965.

4. D. H. Staelin and A. H. Barrett, Astrophys. J. 144, 352 (1966).