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Microwave Observations of Venus, 1962–1963

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Venus was observed at 10.0-cm wavelength on 40 days during the period 15 September 1962 through 1 March 1963. The NRAO 85-ft telescope was used with the same radiometer, calibration procedure, and observing technique as in similar 1961 observations. The results give an intensity versus phase-angle relation which is identical, within the errors, with the result obtained in 1961. This indicates that either Venus has a small pole-to-equator temperature differential, or that its pole is very nearly perpendicular to the ecliptic. The data of 1961 and 1962 give a statistical probability of 0.991 that the minimum brightness temperature is observed after inferior conjunction, a situation to be expected with retrograde rotation.

Venus was observed at 21.4- and 40-cm wavelengths during the period 21 November through 4 December 1962 with the NRAO 300-ft radio telescope. Good measurements were possible at 21.4 cm, leading to a mean equivalent disk brightness temperature of 528±33 (m.e.)°K. The observations at 40 cm were appreciably harmed by sidelobe reception of solar emission, but lead to a preliminary value of the equivalent blackbody disk temperature of 400°K at that wavelength.

I. 10.0-CM OBSERVATIONS

The author has previously reported observations of Venus made over a time interval including the inferior conjunction of 1961 (Drake 1962). These results will hereafter be referred to as the 1961 experiment. They indicated the existence of a small variation in the equivalent blackbody disk temperature T_{BB} of the planet with the phase angle, the angle between sun and earth as viewed from Venus. They also indicated that the minimum value of T_{BB} occurred after inferior conjunction, a situation consistent with retrograde rotation of the planet, barring the presence of a peculiar meteorology.

To verify these results, and to search for any long-term variations in the Venus emission, similar measurements were made on 40 days during the period 15 September 1962 through 1 March 1963 near the time of the 1962 inferior conjunction. The National Radio Astronomy Observatory 85-ft radio telescope with a traveling-wave-tube radiometer was used for both the 1962 and the 1961 observations. The 1962 observing procedure was the same as in the 1961 experiment, and consisted of observing a point 30′ from Venus for 30 sec, then Venus, then a point symmetrically opposite Venus for 30 sec, and so on until four observations of Venus, sandwiched between five observations of comparison positions, were obtained. The pairs of comparison positions used were either 30′ east and west, or north and south of the planet. After eight such sets of observations were made, a similar observation was made of an argon gas discharge tube. Once a day, three such sets of observations were made of the radio source 04N3A(3C123). All data were recorded digitally. The observations thus taken could be reduced to give the ratio of flux densities of Venus to 04N3A for the day's observations. Using a flux density for 04N3A of 23.7 flux units, as with the 1961 observations, and the standard radiation formulas, a value of T_{BB} for the day's observations could be readily obtained. Details of this procedure are given in the description of the 1961 experiment (Drake 1962).

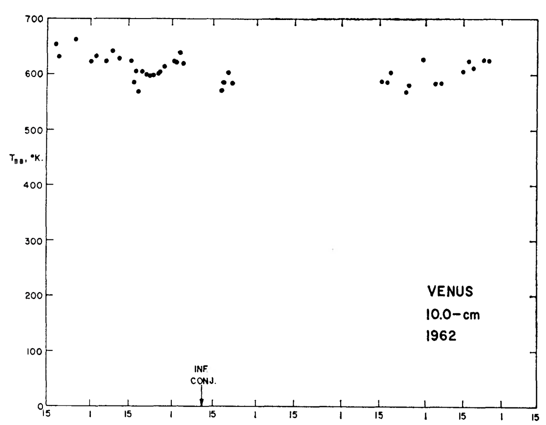

FIG. 1. Daily mean value of equivalent blackbody disk temperature observed at 10.0 cm, 1962–63.

The resultant daily mean values of T_{BB} are shown in Fig. 1. The gap in the data between 24 November and 15 January resulted from the telescope being assigned to other projects. The results show again the high values of T_{BB} of about 600°K, which occur at centimeter wavelengths, and the small variation in T_{BB} with time again appears.

The daily values of T_{BB} are plotted as a function of the phase angle i in Fig. 2. To these points has been fitted, by least-squares, the first two terms of a Fourier series in i, as was done with the 1961 data. The resultant best-fitting phase curve is indicated by a solid line in Fig. 2, and is expressed by

$$T_{BB\ 1962}=\underset{(6)}{622}+\underset{(12)}{43}\cos(i\pm\underset{(20)}{35})°K, \quad (1)$$

where the plus sign is taken for values of i occurring after inferior conjunction, and the minus sign for values occurring before. The numbers in parentheses are the mean errors of the values immediately above them. Again, a statistically significant phase effect appears, and the minimum temperature occurs significantly after inferior conjunction. For comparison, the similar equation given by the 1961 data is

$$T_{\mathrm{BB}\,1961}=\underset{(9)}{622}+\underset{(15)}{39}\,\cos(i\pm \underset{(11)}{17})^{\circ}\mathrm{K}. \tag{2}$$

This result is shown by a dotted line in Fig. 2. It is evident that the two results do not differ significantly, and that T_{BB} varied in 1962 in the same manner as in 1961 to a very high accuracy.

Since we observe Venus in different orientations in an inertial frame of reference from one conjunction to the next, we would expect systematic differences in the run of T_{BB} observed at different conjunctions if the pole of Venus was markedly tilted and there was an appreciable pole-to-equator temperature difference. The lack of such a systematic difference indicates either that the pole is nearly perpendicular to the ecliptic, or that there is a small pole-to-equator temperature difference at the planetary surface. It is also evident that the radio emission from Venus changes very little over periods of at least 18 months, a situation consistent with either the greenhouse or aeolosphere theories, but unlikely with an ionospheric theory.

Assuming that the run of T_{BB} was identical in 1961 and 1962, it is possible to combine the data from the two conjunctions to produce a more accurate mean phase curve for Venus. This is

$$T_{\mathrm{BB}}=\underset{(6)}{622}+\underset{(12)}{41}\,\cos(i\pm \underset{(9)}{21})^{\circ}\mathrm{K}. \tag{3}$$

Mayer, McCullough, and Sloanaker (1963) have made a similar analysis of their data and obtain for a wavelength of 3.15 cm

$$T_{\mathrm{BB}}=\underset{(7)}{621}+\underset{(9)}{73}\,\cos(i\pm \underset{(33)}{11.7})^{\circ}\mathrm{K}.$$

Thus there is remarkably good agreement between the values of the constant term found at 10- and 3-cm wavelengths, indicative that the radiation is emitted from a solid surface whose emissivity does not vary at centimeter wavelengths.

However, there is a statistically significant difference in the amplitude of the variable term. This implies that Venus is not in synchronous rotation. The phase effect is a measure of the diurnal temperature variation in the radiating layers. Were the planet in synchronous rotation, any element of the surface would be subjected to virtually the same ambient temperature at all times, and the element of surface would acquire this temperature to great depths. We would thus observe this temperature at all wavelengths, despite the fact that radiation at different wavelengths emanates from different depths below the surface. The mean disk temperature at a given i, the net effect of many such elements, would then be independent of wavelength. The same phase effect would be observed on all frequencies. However, when a planet is not in synchronous rotation, a surface element is subjected to a diurnal temperature variation, causing a temperature wave to be transmitted below the surface. The amplitude of this wave decreases with depth, so that deeper layers have a smaller diurnal temperature variation. Since longer wavelengths emanate from deeper layers, we would observe a smaller phase effect at longer wavelength. This is the situation observed, arguing strongly for nonsynchronous rotation.

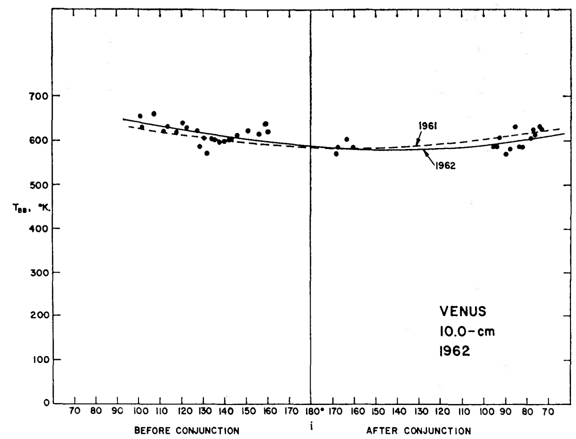

FIG. 2. Observed values of equivalent blackbody disk temperature vs phase angle i, 1962 inferior conjunction.

The mean error of the observed phase lags can be used to determine the probability that the minimum T_{BB} occurs after inferior conjunction. This probability is 0.96 for the 1962 data, and 0.94 for the 1961 data. The probability given by the combined data of 1961 and 1962 is 0.991. Thus it is extremely probable that the minimum T_{BB} occurs after inferior conjunction. This is consistent with retrograde rotation, if the planetary meteorology is similar to terrestrial meteorology, in which the maximum daily temperature usually occurs after noon, and the minimum temperature usually after midnight. Thus, unless a peculiar meteorology exists, retrograde rotation is indicated by the data, consistent with the radar results of Carpenter, presented in a companion paper in this issue.

II. 21.4- AND 40-CM OBSERVATIONS

During the period 21 November through 4 December 1962, Venus was observed at 21.4 and 40 cm with the NRAO 300-ft transit radio telescope. Conventional Dicke radiometers with superheterodyne receivers were used, except that a tunnel-diode amplifier with a noise temperature of about 300°K was used as a preamplifier with the 21.4-cm radiometer. Observations consisted of drift curves as the planet crossed the antenna beam. An argon noise tube calibration signal was measured immediately before and after each observation. The source flux density was computed by measuring the area under the response curve generated by the source transit, and comparing this integral with the integrals obtained in a similar manner for the radio sources 3C123, 3C348,

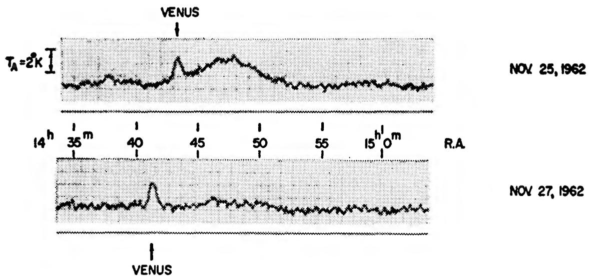

FIG. 3. 21.4-cm wavelength drift curves at the declination of Venus, NRAO 300-ft telescope, 5-sec time constant.

and 3C353. The flux densities assumed for these sources, in flux units, were at 21.4 cm: 3C123, 50.1, 3C348, 44.7, and 3C353, 56.2; at 40 cm they were 3C123, 78.0, 3C348, 89.0, and 3C353, 96.0. The gain of the 300-ft telescope varies by as much as 10% with changing declination; the gain versus declination function has been established by the observation of many sources. Corrections were made to the observed source intensities for this effect. Since the calibration sources were at declinations close to those at which Venus was observed, errors in the gain-declination relation will introduce negligible errors in the computed values of T_{BB}.

Figure 3 shows two of the 21.4-cm analogue tracings of Venus made with a 5-sec time constant. The response caused by the Venus radiation is readily visible. The tracings also contain large "zero drifts" or apparent "extended sources" centered near right ascension 14 h, 47 min. These are a result of sidelobe pickup of solar radiation. They produced considerable uncertainty in the records of 21 to 25 November at 21.4 cm and these records were discarded. Seven excellent records, with no significant solar effects, were obtained during the period 27 November through 4 December. The values of T_{BB} given by these records range between 447° and 580°K. The mean of all the values of T_{BB} from acceptable records is

$$T_{BB\ 21.4}=528\pm33°\mathrm{K}\,(\mathrm{m.e.}).$$

The mean phase angle for the observations used was $i=142°$K, after inferior conjunction.

All of the 40-cm records were considerably confused by sidelobe pickup of solar radiation. The observed values of T_{BB} varied between 260° and 720°K during the period 29 November through 4 December when the solar interference was least. The mean value of T_{BB} from six observations of this latter period is $T_{BB}=400\pm60°$K (m.e.). Because of the small number of observations, and the solar interference, the statistical error of 60°K given by the observations should be treated with suspicion, and may be an underestimate of the true error in the above value of T_{BB}.

Nevertheless, the results here indicate that the Venus spectrum approximates closely to a blackbody spectrum to wavelengths of 40 cm. Gibson and Corbett (1963) have measured $T_{BB}=520\pm40°$K (p.e.) at 1.35-cm wavelength. This, with the above results, shows that the Venus microwave spectrum is a very close approximation to a blackbody spectrum over a wavelength interval of 30/1. As previously discussed in the 1961 paper, this is a strong argument for the idea that the emission originates at the planetary surface. Lastly, these results give no evidence for nonthermal radiation from radiation belts, such as are observed with Jupiter. This is to be expected, in view of the lack of magnetic field indicated by the Mariner 2 magnetometer observations.

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