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10 CM OBSERVATIONS OF VENUS IN 1961

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ABSTRACT

Results are given of observations of Venus made at 10.0 cm wavelength on 68 days during the period March 15 - August 2, 1961. On each observing day, observations were made at approximately eight minute intervals for a period of several hours. Intensity calibrations were controlled using auxiliary observations of the source 04N3A, Jupiter, and an argon tube noise source. No evidence for variations in the Venusian radiation over eight minute intervals was found, and an upper limit of 7 per cent was set on such variations. Similarly, no evidence for variations in the emission from one day to the next was found, with the upper limit on such variations being set at 2 per cent. There is some evidence for a long term variation, with the minimum observed disk brightness temperature occurring very near the time of inferior conjunction. A least-squares fit of the first two terms in a Fourier Series representation of the Venus mean equivalent black body disk temperature T_{BB} as a function of phase angle i gives

$$T_{BB} = 622 + 39 \cos (i \pm 17^\circ)\ ^\circ\mathrm{K} ,$$

where the + sign is taken for values of i occurring after inferior conjunction, and the - for values occurring before. If the Venus reflectivity is 0.12 at 10 cm, then the equivalent mean disk temperature T_D follows the relation

$$T_D = 707 + 44 \cos (i \pm 17^\circ)\ ^\circ\mathrm{K} .$$

If the planet is synchronously rotating, and the variation in temperature with longitude L is approximately sinusoidal, then the mean surface temperature, T_L, at a given longitude is given approximately by

$$T_L = 707 + 56 \cos L\ ^\circ\mathrm{K} .$$

The Venus radio spectrum between 3 and 10 cm wavelength is found to be proportional to $\lambda^{-1.97}$. This very close agreement with the spectrum of an opaque, solid, black body argues against the Ionospheric Theory of the Venus radio emission. With this theory we would expect the radiation to originate from different depths, of different temperatures, at different frequencies, and thus would expect the equivalent black body temperature to vary with frequency. It is concluded, therefore, that the radiation does not originate in the planetary ionosphere. This is supported by the absence of short term variations. The observed variations in temperature with phase angle are contrary to the Aeolosphere Theory, leaving only the Greenhouse Theory consistent with the data.

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Finally, it is estimated that the highest temperature on Venus, near the subsolar point, is about 775 °K. The lowest temperature, near the dark pole, is estimated to be about 540 °K.

I. INTRODUCTION

Lengthy observation of Venus at 3 and 10 cm wavelengths by Mayer, McCullough, and Sloanaker (1958, 1960 a, b,) has shown that Venus radiates a very nearly thermal spectrum at centimeter wavelengths. The equivalent mean black body disk temperature is the very high value of about 600 °K. These observations have suggested three currently popular theories of the Venusian radio emission: 1) The Aeolosphere Theory (Öpik, 1961), which admits only very minute changes in temperature across wide separations on the planet and over periods of time of the order of years; 2) The Greenhouse Theory (Sagan, 1961, 1962), which allows diurnal and seasonal variations in temperature, as well as temperature variations with latitude. No variations in time intervals of less than a few days are admitted; and 3) The Ionospheric Theory, (Jones, 1961; Sagan, Siegel and Jones, 1961) which, because of its hypothesis that the ionosphere is excited by solar corpuscular streams, admits variations in the observed Venusian temperature in the order of minutes as a result of solar activity.

The above circumstances surrounding the leading theories suggest that a study of temporal variations in the Venus radio emission can lead to the rejection of some of the theories, or at least show wherein the theories must be modified to encompass a more complete set of observational data. With this in mind, Venus was observed regularly at 10 cm during the months surrounding the inferior conjunction (April 10) of 1961. Particular emphasis was placed on accurate calibration of the Venus flux density, so that time variations, if any, could be detected and measured accurately. The choice of 10 cm wavelength was dictated by the fact that the available telescope was instrumented for that wavelength. Although the spectrum of Venus does not make this wavelength propitious, signal-to-noise ratios could be maintained at a satisfactory level over the period of observations. It may then be considered advantageous to use this wavelength, since these longer centimeter wavelengths have been more poorly observed than the short centimeter wavelengths.

II. OBSERVATIONS AND DATA REDUCTION

Observations of Venus were made with the NRAO 85-foot radio telescope on 68 days during the period March 15 - August 2, 1961. The radiometer used was a travelling wave tube radiometer of the type described by Drake and Ewen (1958). It operated at a wavelength of 10.0 cm, a bandwidth of 200 mc., and an over-all system noise temperature of about 1200 °K throughout the course of the observations. A digital integrator consisting of a voltage-to-frequency converter and counter was used to make true integrations of radiometer output over the integration period, which was 30 seconds throughout the observations. The r.m.s. radiometer fluctuation for this integration time was about 0.09 °K throughout most of the observations. This fluctuation is almost entirely due to short period variations in radiometer gain, as has been shown by Wade (1961). All data were recorded digitally in printed form and on punched tape in a format compatible with the

NRAO Bendix G-15 computer.

The observational procedure consisted of setting the telescope so as to track a point thirty minutes of arc east of Venus, and then integrating the radiometer output for thirty seconds to establish the radiometer zero level. The telescope was then caused to track while pointing directly at Venus, and another thirty second measurement made. The telescope was then moved thirty minutes of arc west of Venus, and other measurement made. It was then moved to Venus, to the east, to Venus, to the west, to Venus, and to the east, each time making a thirty second integration. This procedure gave a set of four measurements of Venus, surrounded symmetrically in time by a comb of five measurements on comparison positions placed symmetrically in space about the planet. The difference between the four readings on Venus and the five readings off Venus then produced a measure of the flux density from the planet during the period of observation, which was about eight minutes when antenna setting times are taken into account. Such a set of nine measurements will hereafter be called an "observation". The r.m.s. error in the antenna temperature given by such an observation was about 0.06 °K throughout most of the observations.

This observing procedure has several advantages:

1) Radiometer zero drifts that are linear in time, and linear changes in radiometer ground pickup or sky background with position will not introduce errors into the measured flux density.

2) The method is suited to digital recording and the rapid reduction of data on a digital computer.

3) The information acquisition rate is nearly the maximum permitted by the antenna collecting area and radiometer noise, since the telescope spends almost half the observing time receiving maximum power from the planet, and roughly the other half observing the radiometer zero level. Thus both the pertinent radiometer output levels are measured to about the same accuracy, and no antenna time is spent with the telescope pointed so as to give less than peak source intensity, or best signal-to-noise ratio on the source.

4) The method avoids the systematic inaccuracies in intensity that can occur with the drift-curve technique when low signal-to-noise ratios are present. These inaccuracies have been noticed by Mills, Slee, and Hill (1960), who have found that a systematic overestimate of flux density can occur with drift curve observations, with the error being as much as 10 per cent with a signal-to-noise ratio of about 5, and 30 per cent when the signal-to-noise ratio is about 2.5. This effect must be completely eliminated in observations of Venus, of course, as otherwise it will lead to a phase effect giving a minimum in equivalent mean disk temperature at the time of inferior conjunction, a very plausible, but spurious, result.

A disadvantage of the method is that antenna pointing errors are not detected easily from the data. To prevent pointing errors from affecting the data, the antenna pointing calibration curves must be frequently checked. This was done in the course of the observations.

Additional safeguards were instituted in the observing procedure by using comparison points 30' north and south of the source. One observation was made using the east comparison point as a starting point, followed by an observation starting with the north comparison point and alternating between the north and south points, etc. Comparison of the Venus intensity obtained using east and west comparison points with that from the north and south comparison points can reveal the presence of interfering radio sources at any of the comparison points. It can be shown that the probability of a significant interfering source occurring at any of the many comparison points used in the course of the observations is very small. Inspection of the data indicated that, in fact, no such interference occurred.

A run of observations of Venus was started by observing the signal from an argon discharge noise source, with the observation containing four thirty second observations of the noise tube interleaved with five comparison readings. Eight observations were then made on Venus, so that an equal number of east-west and north-south observations were made. The noise tube was then again observed, eight more sets were made on Venus, and the run concluded by observing the noise source for the third time. The mean radiometer deflection caused by the noise tube signal could then be computed for this period, and from this an accurate ratio Venus/noise tube computed, either for the mean Venus deflection for the period, or for individual Venus observations by taking any observed drift in gain into account. By interleaving the noise tube calibrations and Venus observations, as done here, the effects of any linear changes in radiometer gain with time are completely eliminated in the data reduction, and even non-linear changes partially compensated.

It remained to calibrate the over-all system gain, or to relate the radiometer deflections to flux density. This was done by observing the radio source 04N3A at three hour intervals. These observations consisted of one observation of the noise tube, three of 04N3A, and one more of the noise tube. The telescope was pointed at one of the 04N3A comparison positions while observing the noise tube. Again, this procedure eliminates the effects of linear zero level changes, and produces a value of the ratio 04N3A/noise tube. The ratios Venus/noise tube and 04N3A/noise tube may then be combined to give the ratio Venus/04N3A. All deflections due to sources were corrected for atmospheric extinction using the usual secant z relation, where z is the zenith angle, and an adopted extinction at the zenith of 1.0 per cent.

In the course of the observations, the antenna temperature of Venus was in the range 0 to 1.0 °K, the antenna temperature of 04N3A was about 2.5 °K, and the signal from the noise tube about 4.5 °K. These were all small enough that no correction for receiver non-linearity was required.

An accurate value of the flux density of 04N3A, taken with the ratio Venus/04N3A, now leads to an accurate value for the Venus flux density. The value of the flux density of 04N3A adopted here was

$$S = 23.7\ (10^{-26})\ \mathrm{w/m^2/cps}\ .$$

This has been obtained by Heeschen in the following way: The accurate flux density for Cassiopeia A, 2500 (10^{-26}) $\mathrm{w/m^2/cps}$, found at 1440 mc by Findlay and Hvatum with the large NRAO calibration horn, has been converted to a flux density at 3000 mc using the well-determined Cassiopeia A spectral index. The ratio Cas A/04N3A (Heeschen and Meredith, 1961) has then been used to give the flux density of 04N3A at 10.0 cm wavelength. This leads in turn to the Venus flux density. The equivalent mean black body disk temperature, T_{BB}, for Venus may then be determined using the standard radiation formula and the ephemeris planetary semi-diameter. The systematic error in these results depends almost entirely on the error in the calibration horn measurement, perhaps 3 per cent, the error due to uncertainty in the Cas A spectral index, perhaps 3 per cent, and the error in the Cas A/04N3A ratio, 2 per cent. This gives an over-all limit on the systematic error in these results of about 8 per cent.

All of the above reductions were carried out on the Bendix G-15 computer, starting directly with the data tapes prepared by the radiometer, and using a single set of computer programs throughout the analysis.

III. SHORT TERM VARIATIONS

In a search for short term variations in the Venus emission, histograms of the individual observations of Venus have been prepared. These give the frequency with which a given value of T_{BB} was found during an observing period. In the absence of variations in the Venus emission, we would expect these histograms to be gaussian in shape, with their dispersions governed by the magnitude of the radiometer fluctuations. If Venus is variable, with the variations not following a gaussian law, we would expect the shape of the histograms to be distorted from the gaussian shape. None of the histograms plotted departs significantly from a gaussian law. It is also possible that Venus will vary in a random, gaussian manner which will result in histograms that are of gaussian shape, but possessing a greater dispersion than that due to the radiometer alone. Since the actual noise fluctuations of the radiometer are not known with great accuracy, a simple measurement of the gaussian dispersion will not provide good evidence for the presence or absence of random radiation variations. It is possible to make progress in such circumstances by comparing the histograms obtained at one time with those of other times, when the flux density was markedly different. If there is a gaussian variation in the radiated flux, then there should be a correlation between dispersion and observed flux density. No such correlation will occur if the fluctuations are completely a result of radiometer noise.

Figure 1 gives three histograms which make this comparison. Those of April 1 and 3, and April 4, 5, 6 were made very near the time of inferior conjunction, when the Venus flux was most intense. The data of July 28 lead to nearly the faintest antenna temperature observed, and were chosen because more observations were made on this day than any of the other latter days of the observing period. The antenna temperature on July 28 was only about 11 per cent of that of the period April 1-6. If there is any significant variation in the Venus radiation in the period April 1-6, we would expect the dispersion in the histogram from July 28 to be less than the April 1-6 dispersion. The actual dispersion ΔT_A for April 1-6 is

$$\Delta T_A = 0.067\ °K\ ,$$

and the dispersion for July 28 is

$$\Delta T_A = 0.072 \text{ °K} .$$

This is nearly identical with the dispersion of April 1-6, and in fact slightly greater than it, this difference being due to statistical averaging and small radiometer sensitivity variations. We conclude that there was no significant variation in the Venus radiation during the interval April 1-6, and that the dispersion observed on these days is a high upper limit on the true dispersion in the Venus radiation.

It is possible to increase confidence in this result by comparing the dispersion in the Venus data with the dispersion in similar data taken on the same day from a source of about the same intensity. Figure 2a gives histograms for Venus and Jupiter on May 14, 1961. As is seen from the figure, the dispersions in the two sets of data are virtually identical, suggesting strongly that neither source was varying significantly. (It should be noted that the radiometer was giving impaired performance on May 14, resulting in a greater than normal dispersion). It is still possible, of course, that both sources were varying randomly with the same percentage variation. Since both had nearly the same antenna temperature, this would lead to the same dispersion in T_A in both sets of data. This possibility can be eliminated by observing the two sources at another time when the antenna temperatures were quite different. Data for such an epoch are given in Figure 2b. Here, the Venus antenna temperature is only about 1/3 that of Jupiter; if the percentage variation in each source were the same, we would expect now to find the dispersion in the Venus histogram to be less than that of the Jupiter histogram. In actual fact, the dispersions are identical, making implausible the possibility that both sources were varying on May 14. The dispersion in the histogram of May 14 again sets a high upper limit on any true variation in the Venus emission.

We conclude that several approaches give no evidence for variations, ΔT_{BB}, in the Venus equivalent black body disk temperature over time intervals t of about eight minutes to one day. The most restrictive high upper limit on such variations is set by the data of April 4, 5, 6, and can be expressed

$$\frac{\Delta T_{BB}}{T_{BB}} < 0.07 \text{ r.m.s.}, \quad 8 \text{ min} < t < 1 \text{ day} .$$

No useful limit can be set on shorter term variations with present NRAO telescope sensitivities.

IV. LONG TERM VARIATIONS

To reveal longer term variations, the daily mean values of T_{BB} have been plotted in Figure 3, with the exception that points from dates later than May 17 are actually the mean values of data from three to five days' observations. This combination of data for the latter dates was performed to give a set of points of about the same probable error. Figure 4 is a plot of the same data as a function of the phase angle, i, as defined in the American Ephemeris and Nautical Almanac.

It is evident from Figure 3 that the day-to-day variations in the emission are very small indeed. If we take the group of points obtained before inferior conjunction, for which the average probable error is smallest, we find that the r.m.s. deviation ΔT_{BB} from the mean value of T_{BB} given by these points is about 2 per cent of T_{BB}. This sets

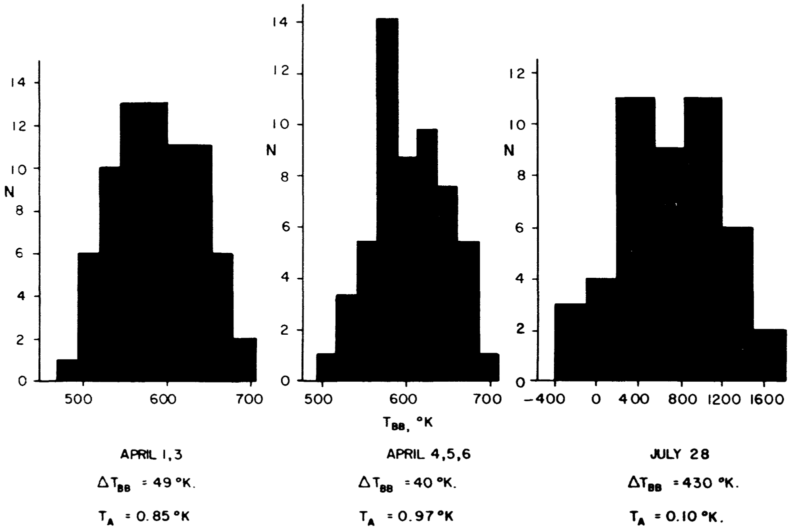
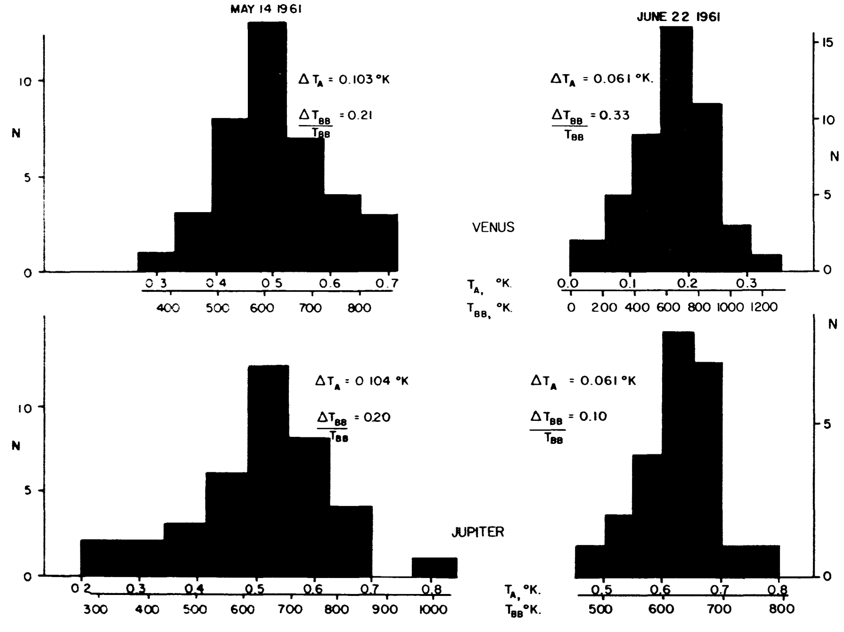


Fig. 1. —— Histograms giving the frequency of occurrence N of observed values of equivalent black body disk temperature, T_{BB}, during various periods of observation.



a

b

Fig. 2. —— a) Histograms of the frequency of occurrence of observed values of T_{BB} for Venus and Jupiter on May 14, 1961. b) The same for June 22, 1961.

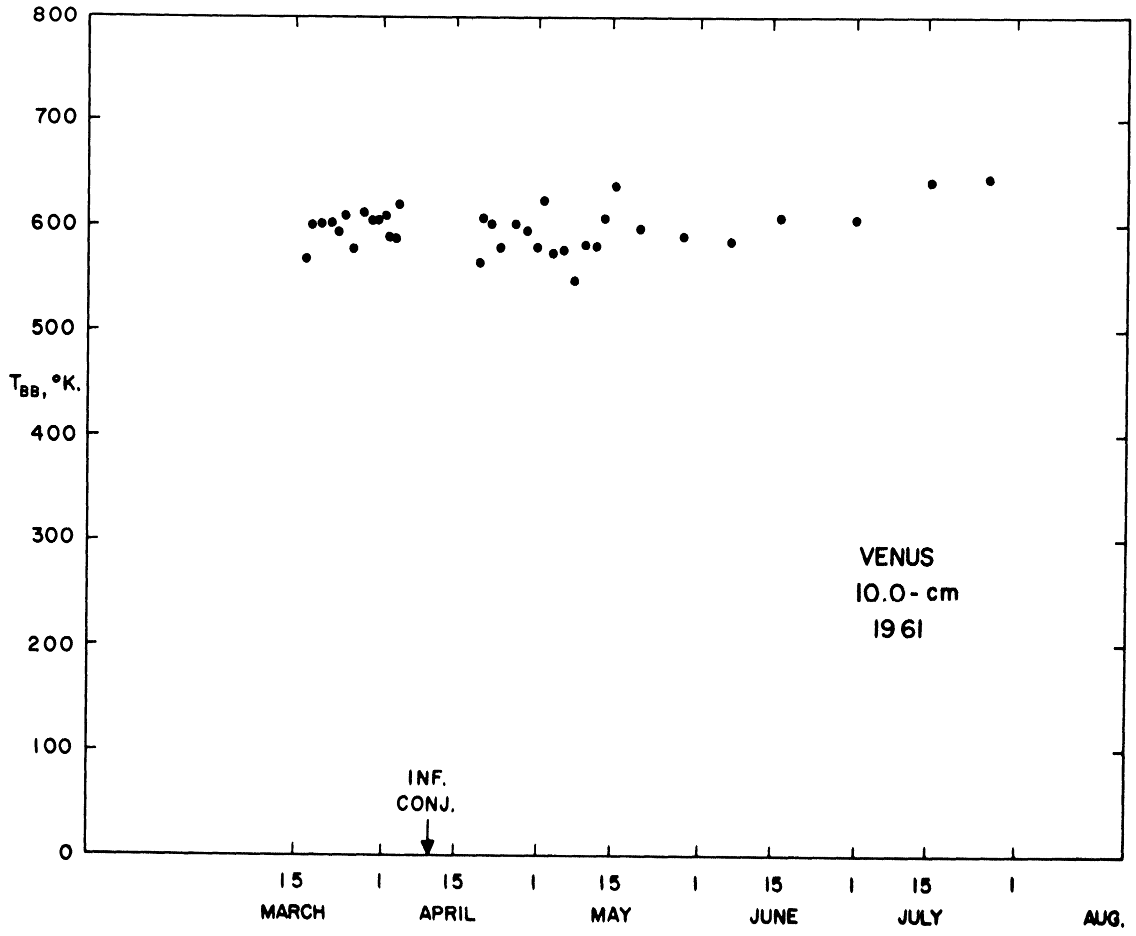


Fig. 3. —— Observed daily mean values of T_{BB}. For dates after May 17, the plotted points are the mean of three to five days' observations.

a better high upper limit on the variation in T_{BB} over time intervals of the order of a day,

$$\frac{\Delta T_{BB}}{T_{BB}} < 0.02, \ 1 \text{ day} < t < 5 \text{ days} .$$

This is in strong disagreement with the results of Kuzmin and Salomonovich (1961) obtained at 9.6 cm during the same time interval. They report variations of a few hundred degrees in T_{BB} from day to day, with their maximum observed $T_{BB} = 1000$ °K, and the minimum $T_{BB} = 450°$ over the period from the middle of March to the beginning of June. During the same time interval, our results contain a maximum daily mean T_{BB} of 637° and a minimum of 547°, and we attribute virtually all this variation to instrumental noise. Over our entire observing period, the highest daily mean T_{BB} observed was 740 °K, and the lowest 485 °K, both of these extreme values occurring when the signal intensity had dropped to a very low value and the measurements were strongly affected by radiometer noise.

Figure 4 shows that the very long term variation, or "phase effect" is small at 10 cm wavelength. There is evidence that a minimum in black body disk temperature occurs near the time of inferior conjunction. Such a minimum has been suggested by Mayer, et al (1960 b). The actual phase relation can be established quantitatively by expressing the function T_{BB} (i) as a Fourier series in i, and using the observational data to solve for the coefficients of the terms in the Fourier series. However, it is obvious that the data are too uncertain to allow a solution for more than the fundamental component of the series; therefore, a least squares fit to the data has been made with the function

$$T_{BB} = T_0 + T_1 \cos (i + \theta). \qquad (1)$$

The least squares solution is

$$T_{BB} = 622 + 39 \cos (i \pm 17°) \text{ °K} \qquad (2)$$

where the plus sign is taken with values of i after conjunction, and the minus sign taken with values of i before conjunction. This function is plotted as a solid curve in Figure 4.

The peak-to-peak variation in T_{BB}, 78 °K, is quite small, and considerably less than that found in some of the older measurements at 10 cm and 3 cm (Mayer, et al, 1958). However, the probable error is large enough in these older observations to allow them to be consistent with (2). Measurements made at the Naval Research Laboratory during the 1961 conjunction are closer to the above relationship (Mayer, private communication).

The near coincidence between the minimum temperature of (2) and inferior conjunction is quite striking, and somewhat surprising in view of the limited span of i for which data are available. It is obvious that the deviation of 17° from exact synchronism can be a result of random errors in the results, and an exact coincidence between the minimum and inferior conjunction, as already suggested by Mayer, et al (1960 b), is admitted by the data. Such a coincidence is a probable result, if the radar measurements indicating synchronous rotation of the planet are correct (Victor and Stevens, 1961, and Staff of the Millstone Radar Observatory, 1961). The radar measurements of Kotelnikov (1961), indicating more rapid rotation, would favor a displacement of the minimum.

A radar reflectivity of about 12 per cent has been measured at about 13 cm wavelength (Victor and Stevens, 1961), and a similar value at 68 cm (Staff of the Millstone Radar Observatory, 1961), suggesting that this value is a very good approximation to the reflectivity at 10 cm. Adopting this value, from Kirchoff's Law we obtain the relation for the true mean disk temperature, T_D,

$$T_D = 707 + 44 \cos (i \pm 17°)\ °K. \tag{3}$$

V. SUMMARY OF OBSERVATIONAL RESULTS

The above results may be summarized as follows:

$$T_{BB} = 622 + 39 \cos (i \pm 17°)\ °K.$$
$$T_D = 707 + 44 \cos (i \pm 17°)\ °K.$$

(+ taken with i after inferior conjunction, — with i before conjunction)

$$\frac{\Delta T_{BB}}{T_{BB}} < 0.07 \text{ r.m.s.} \qquad 8 \text{ min} < t < 1 \text{ day}$$

$$< 0.02 \text{ r.m.s.} \qquad 1 \text{ day} < t < 5 \text{ days}$$

where both the limits on variability are probably high upper limits. The systematic error in the above temperatures is estimated to be less than 8 per cent.

VI. DISCUSSION

Again, an equivalent black body disk temperature of nearly 600 °K has been found, in close agreement with almost all of the centimeter wave temperature measurements made previously. This is also suggestive of a nearly perfect black body spectrum in this wavelength region. Such a perfect black body spectrum is consistent with the Greenhouse and Aeolosphere Theories of the Venus radiation, assuming Venus is rotating slowly.

However, it is not consistent with the Ionospheric Theory, except in very special circumstances. With an optically thick ionosphere, as demanded by that theory, the radio telescope will in effect observe, as the wavelength of observation is decreased, a brightness temperature which is the electron temperature at deeper and deeper ionospheric levels. Unless the ionosphere is isothermal, an extremely improbable situation, different brightness temperatures will be observed at different wavelengths, and the spectrum will not follow the λ^{-2} black body law. The situation can be more complex if a ray entering the Venus ionosphere encounters, before traversing high optical depth, electron densities so high that the critical frequency is higher than the radiation frequency. In such a case, which does occur in the sun at some frequencies, there is a reflecting layer which prevents us from observing high optical depth at the radiation frequency; the bright-

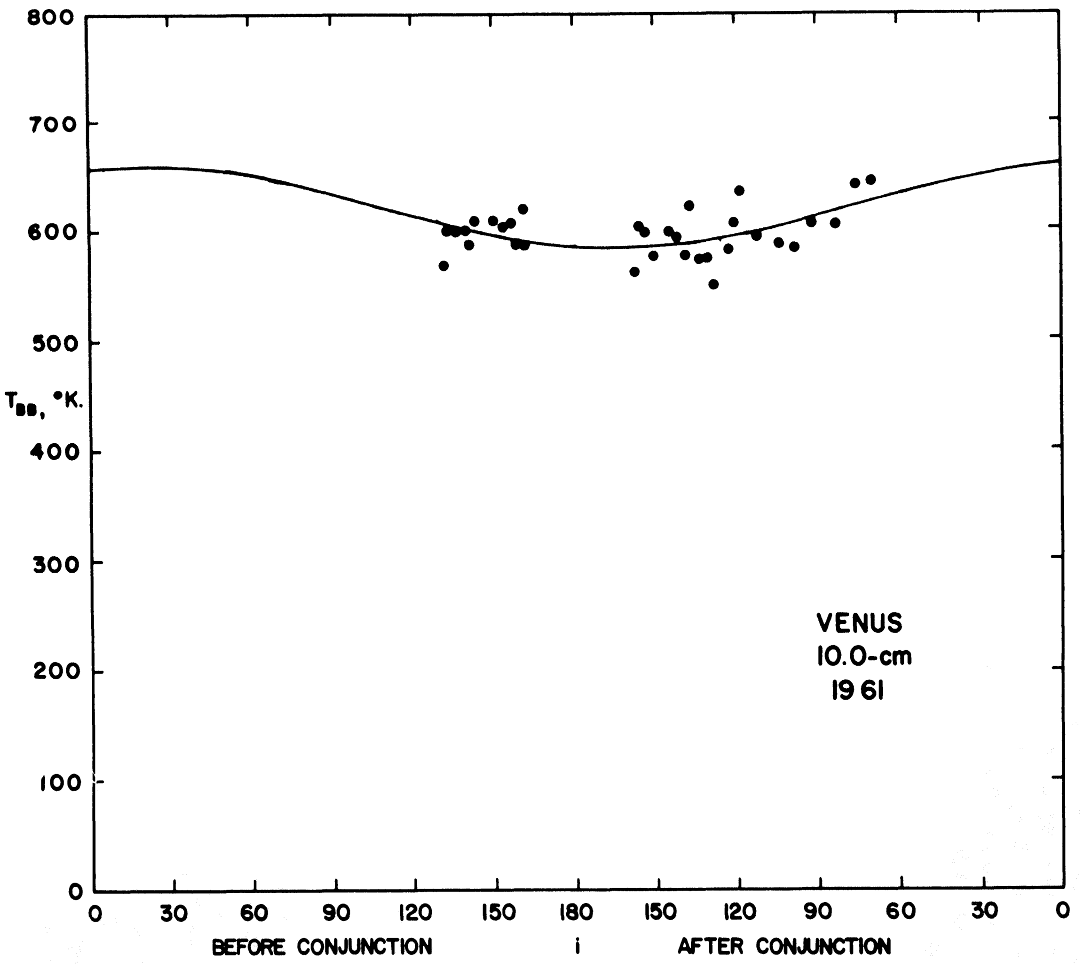


Fig. 4. —— Observed mean daily values of T_{BB} plotted as a function of phase angle i.

ness temperature observed will be less than if these sufficiently high critical frequencies were not associated with the plasma. In such circumstances, we would expect the position of the reflecting layer to change greatly with frequency, and the relationship between observed brightness temperature and frequency to be complicated, departing markedly from the black body law. It is possible, of course, to find a run of temperatures and electron densities with height that will lead to a λ^{-2} relation in the radio emission escaping the ionosphere. However, there is no known process acting to bring about such a system of densities and temperatures, and therefore such an arrangement appears improbable in the ionosphere according to our present knowledge. The fact that ionospheric radiation at different wavelengths comes from different depths, and is perhaps further affected in spectrum by reflecting regions, leads to the conclusion that a Venus ionosphere is very unlikely to emit a true black body spectrum. The presence of such a spectrum would militate against the Ionospheric Theory.

With this in mind, it is desirable to review the existing data on the spectrum at centimeter wavelengths, where it is best defined. Observations were made at the NRAO during the 1959 conjunction, at 3.75 cm, using nearly the same procedure as in the observations given here. These were grouped around an effective phase angle of 130°, and gave a mean value for T_{BB} of 582 °K. The mean value at 10.0 cm at $i = 130°$, from the present work, is $T_{BB} = 596$ °K. If we assume that data from different conjunctions may be combined without significant error, and that the Venus radiation follows a relation λ^{-x}, where the spectral index x is a constant at centimeter wavelengths, we find from these data

$$x = 1.97 \ .$$

If we take these data, and apply the estimated errors in such a way as to enhance to the maximum the error in the value of x, an unlikely situation, we find that the spectral index must still lie in the range

$$1.79 < x < 2.16 \ .$$

These results may be compared with the values of x given by the NRL measures. Mayer, et al (1960 b) obtained a value $T_{BB} = 575$ °K at $\lambda = 3.4$ cm, with i about equal to 133° during the 1958 conjunction, and $T_{BB} = 600$ °K at $\lambda = 9.4$ cm, at about the same value of i, during the 1959 conjunction. These data combine to give

$$x = 1.96 \ .$$

The quoted error of about 60 °K in the values of T_{BB} requires that x lie within the range

$$1.75 < x < 2.17 \ .$$

The two derived values of x are in excellent agreement, and do not differ significantly from the black body value $x = 2$.

A value of x slightly less than 2, as found above, may be easily understood in the context of the Greenhouse and Aeolosphere Theories to be the result of either 1) a very low atmospheric opacity near 3 cm wavelength, or 2) slightly less emissivity at 3 than at 10 cm wavelength. In the former case, if we assume the derived exponent to be exact, the required opacity would be about 5 per cent. In the latter case, the 3 cm emissivity would have to be 3 per cent less than the 10 cm emissivity, a plausible difference. Radar measurements at short centimeter wavelengths could test this latter possibility. However, in accordance with our previous discussion, an exponent so nearly equal to 2 is very unlikely with the Ionospheric Theory. Even the extremes in x permitted by the observational errors are perhaps too near the black body exponent to be consistent with the theory. We conclude that the best data are not consistent with the Ionospheric Theory.

This conclusion is further supported by the absence of short term variations in the emission. Such variations would be expected with an ionosphere supported by sometimes variable solar phenomena, as is presently required in the Ionospheric Theory.

The fact that data from different conjunctions apparently can be combined with consistent results suggests that either the axis of Venus is very nearly perpendicular to the orbital plane, or the variation in brightness temperature with latitude on Venus is very small. Otherwise, we would observe systematic differences in temperature from one inferior conjunction to another, since we observe Venus from different vantage points in an inertial frame during different conjunctions. The possibility of differences in the disk temperatures measured at different conjunctions arising due to latitude and seasonal variations in temperature on Venus has been raised previously by the author. Such effects are not detectable in the existing data. Accuracy of measurement has apparently not reached the level required to detect them.

Turning now to a discussion of the Aeolosphere Theory, let us assume that the planet rotates synchronously and that the axis of rotation is nearly perpendicular to the orbit. If we further assume that the mean temperature T_L at a given planetary longitude, L, follows a sinusoidal law, we may write the law governing T_L simply by increasing the varying term in (3) by a factor $4/\pi$. Defining the zero of longitude L at the subsolar point, making the phase angle i and the longitude of central meridian identical, we obtain

$$T_L = 707 + 56 \cos L \ . \tag{4}$$

The displacement angle of 17° in (3) has been neglected in view of the number of approximations and assumptions already made in obtaining (4). It is evident that (4) will also be a good approximation if the pole is slightly inclined, and in the case that the rotation period is long, but not synchronous.

With regard to the surface temperature of Venus in the present Aeolospheric Model, Öpik (1961) has stated that the large heat capacity of the aeolosphere, and the necessity that the adiabatic lapse rate strictly occur, lead to a constant temperature at a given atmospheric level. This in turn leads to a nearly constant temperature all over the planet. Temperature is to be function of altitude only, and "climatic and diurnal differences in temperature can occur only at the cloud level". Öpik computes the maximum variation in T_L to be of the order of 0.04 °K, if the time scale of the atmospheric circulation is of the order of 20 days. Even with a much longer time scale, this result is not consistent with (4), which shows a maximum variation of 112 °K. The present observations then disagree grossly with the Aeolospheric Model as it now stands.

Only the Greenhouse Model is consistent with the observations reported here and elsewhere. Even it must be embellished to the extent that atmospheric circulation must be added to the model to provide for heating of the night side of the planet. However, since the heat capacity of the hypothesized greenhouse atmosphere is quite large, only a small, reasonable atmospheric circulation is demanded. This represents no significant conceptual change in the Greenhouse Theory. Our conclusion is that the data presently support only the ideas that the Venus radio emission is thermal, and emanates from the surface of Venus, where a very high temperature is maintained by the greenhouse effect.

Lastly, it is possible to estimate the extremes of temperature that occur on Venus. To do this, we assume that the variation in temperature with latitude on Venus is the same as that on Earth, as given by Byers (1954). Using these data and (4), one may estimate that the approximate maximum temperature, near the subsolar point, is 775 °K. The minimum temperature, near the dark pole, is 540 °K. This suggests a peak-to-peak variation in temperature of roughly 36 per cent of the mean temperature, which is quite reasonable when one compares it with the rapidly rotating planets Earth, with a peak-to-peak variation of 28 per cent, as found from Byers, and Mars, with a variation of 31 per cent, as found from the work of Pettit (1961). It therefore appears probable that the above values will not differ markedly from the true ones.

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