Mariner II: Preliminary Reports on Measurements of Venus

The Mariner II spacecraft successfully completed its 109-day journey through interplanetary space and on 14 December 1962 passed Venus at a minimum distance of approach to the planet's center of 41,000 kilometers (6.6 radii of the solid body of the planet). The achievement permitted the first *in situ* scientific measurements in the vicinity of any planet other than Earth. The results of some of these measurements are reported in the papers that follow.

Charged Particles

Abstract. *There was a complete absence of charged particles associated with the planet Venus at radial distances as small as 41,000 km on the sunward side of the planet. This result is taken to mean that the magnetosphere of Venus, if any, does not extend to that great a distance. The most plausible interpretation is that* $(M_V/M_E) \lesssim 0.18$, *where* M_V *and* M_E *are the dipole magnetic moments of Venus and Earth, respectively. The results are consistent with* $M_V/M_E = 0$. *Certain qualifications prevent this interpretation from being a definitive one.*

This experiment was the pioneering attempt to search for charged particles magnetically trapped in the vicinity of the planet Venus and, if such particles were found, to obtain measurements of their spatial distribution and intensity. The equipment comprised a thin-window Geiger-Mueller tube which was included in the scientific payload of the Mariner II spacecraft of the Jet Propulsion Laboratory.

Table 1. Properties of the Iowa detector.

Detector: Anton type 213 Geiger-Mueller tube
Weight of detector assembly: 60 g
Window thickness: 1.2 mg cm^{-2} mica
Full angle of collimator: 90°
Directional geometric factor: 0.2 cm^2 sterad
Efficiency for electrons:
  $\sim$ 1.0 for $E > 70$ kev
  0.35 for $E = 40$ kev
  0.1 for $E = 34$ kev
  0.01 for $E = 29$ kev
  10^{-3} for $E = 27$ kev
  10^{-6} for $E = 5$ kev (nonpenetrating)
Efficiency for protons: $\sim$ 1.0 for $E > 500$ kev
Side shielding: 0.35 g cm^{-2} of stainless steel and magnesium
Omnidirectional geometric factor: 0.2 cm^2
Maximum apparent counting rate: 50,000 count sec^{-1}
Maximum observable true counting rate by use of laboratory calibration curve: 10^7 count sec^{-1}

A description of the Iowa equipment and a preliminary account of the interplanetary observations during September and October 1962 have been published (*1*). The low-energy particle detector consisted of a collimated Anton type 213 Geiger-Mueller tube having a 1.2 mg cm^{-2} mica window (nominal range of 40 kev electrons or 500 kev protons). Throughout the flight, including the planetary fly-by, the axis of the detector's conical field of view (90° full angle) was directed at 70 ± 1° to the spacecraft-sun line, lay in the plane containing the sun, earth, and spacecraft, and was on the earthward side of the spacecraft.

A summary of detector characteristics is given in Table 1.

Observations. In the upper portion of Fig. 1 is plotted the true counting rate R of the detector as a function of Universal Time during the planetary "encounter" period as well as during periods of about 30 hours before and after the time of closest approach. Also shown on the same time scale are the Sun-Venus-probe angle L_{SVP} and the radial distance from the probe to the center of the planet R_V. During the interplanetary, or "cruise," mode of operation of the spacecraft, the accumulated number of counts from the detector during a 9.60-second interval was read out once each 887 seconds. During the "encounter mode" the accumulated number of counts during a 9.60-second interval was read out once each 484 seconds. Each plotted point in Fig. 1 represents a single sample and has, therefore, a statistical uncertainty of about 25 percent. Closest approach occurred at 20:00 UT on 14 December 1962, at a radial distance from the center of the planet of 41,000 km, at a Sun-Venus-probe angle of 71°, and at a Venus-referenced declination of −38°. The latter angle was measured from a plane through the center of Venus parallel to the plane of the ecliptic. The "encounter mode" of spacecraft operation was in effect from 13:35 UT to 20:40 UT on 14 December.

The most striking feature of Fig. 1 is the absence of any discernible increase in counting rate during passage by Venus.

This impression is made more quantitative by reference to Table 2 and to the following discussion. For the 50 samples obtained during the encounter mode, the observed root-mean-square deviation from the mean counting rate was 0.28 count sec^{-1}, and the statistically expected value σ was 0.33 count sec^{-1}.

Fifteen of the 50 sample rates differed from the mean rate 1.125 count sec^{-1} by an amount equal to or greater than σ, and none differed by as much as 2 σ. Of those which differed by as much as, or more than, σ, nine exceeded the mean and six were less than the mean. Both positive and negative deviations appeared to be randomly distributed through the period of the encounter mode.

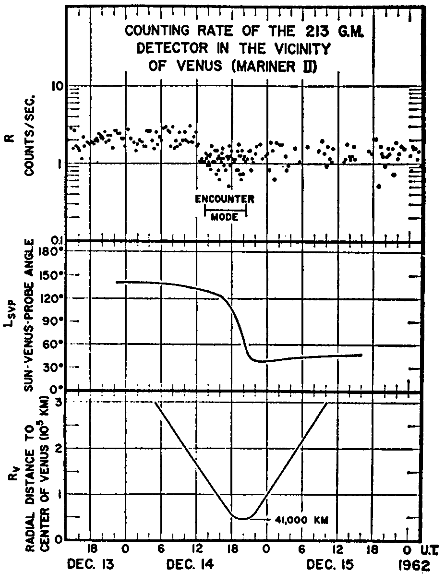

Fig. 1 Plot of the counting rate of the detector in the vicinity of Venus. Each plotted point represents the average counting rate over a time interval of 9.60 seconds. The two lower graphs show, on the same time scale, the time dependence of two coordinates of the trajectory of the spacecraft.

Thus it appears that the absence of a discernible effect in the vicinity of the planet was as complete as was possible on statistical grounds.

A somewhat broader view of the matter can be obtained from an examination of Fig. 1 and Table 2. The mean counting rate during the encounter mode was actually significantly less than that during either the prior period of flight or, to a lesser extent, the subsequent period. There are three conceivable explanations for this effect: (i) an instrumental effect peculiar to the encounter mode of spacecraft operation; (ii) an incidental decrease in the intensity of low-energy particles in interplanetary space, such decrease having no relationship to the proximity to the planet; (iii) a geometric or magnetic "shadowing" effect by the planet.

With the help of Hugh Anderson and several other persons at the Jet Propulsion Laboratory we have examined the first explanation by using the telemetered "engineering data" and other knowledge of the spacecraft's operation. No plausible foundation for this explanation has been found. Moreover, Fig. 1 and Table 2 show that the sharp drop in counting rate occurred at about 12:20 UT during the "cruise mode" and over an hour before the "encounter mode" was actuated. No discontinuity in counting rate occurred at either the beginning or the end of the "encounter mode." Hence we have rejected the first explanation.

In order to accept the third explanation, that the planet had a geometrical or magnetic "shadowing effect," some reasonable physical mechanism must be proposed. For example, one might expect a reduced intensity of particles in the solar wind within a region of finite dimensions on the leeward, or antisolar, side of a nonmagnetic planet. But the rapid reduction in the counting rate of our detector occurred at a position 164,000 km (26.4 planetary radii) from the center of the planet at a Sun-Venus-probe angle of 133° and a planet-referenced declination of +19°. At this time the detector's cone of acceptance was directed generally away from the planet. Thus, such a shadowing seems to be a most unlikely possibility, even if the planet were magnetic and had an effectively greater cross-section. Moreover, there was no evidence for a subsequent return of the counting rate to its "unshadowed" value.

For the reasons cited, we judge that only the second explanation—that is, that there was an incidental decrease in the intensity of low-energy particles in interplanetary space—is acceptable. It is a matter of some comfort that sharp changes in counting rate of similar magnitude were observed at several other times during the 2½ months of interplanetary flight under constant operating conditions at positions very remote from either Earth or Venus. The counting rate due to galactic cosmic rays alone was 0.6 sec^{-1}.

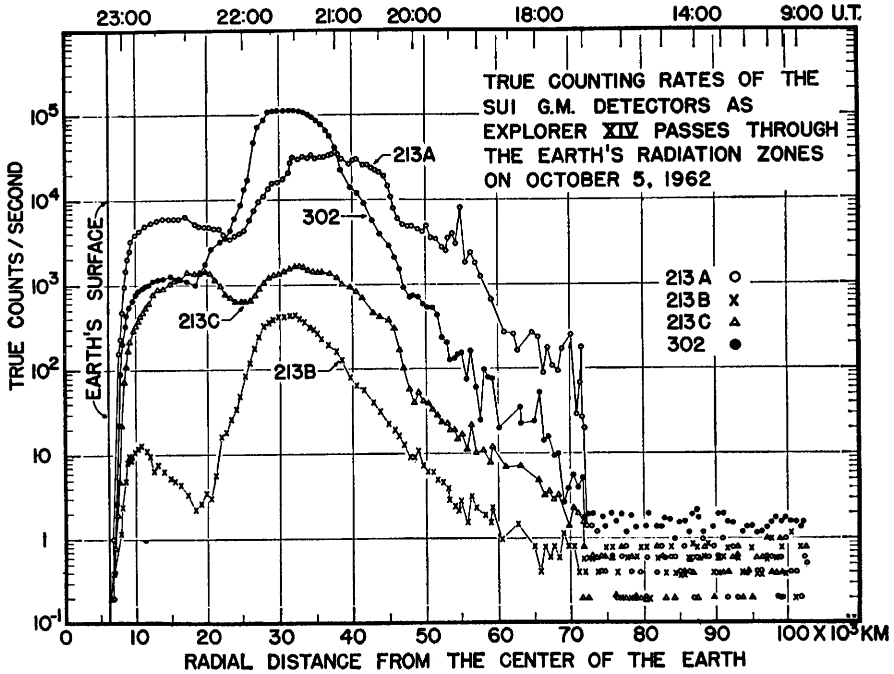

Fig. 2. A graph of experimental results from Explorer XIV on the radiation belts of Earth, after Frank *et al.* (*2*). These data form the basis of a similitude argument for determining an upper limit on the magnetic moment of Venus from the Mariner II observations shown in Fig. 1.

It may be noted here that at no time during the planetary fly-by did the planet fall within the conical field of view of the detector.

Significance of the observations. It may be presumed that the foregoing observations provide a foundation for determining an upper limit to the dipole magnetic moment of Venus. Our attempt to do so is in the form of a similitude argument, utilizing existing knowledge of the radiation environment of Earth.

A detector similar to that in Mariner II but with a smaller opening angle (30° full angle) and a much smaller geometric factor (2×10^{-3} cm^2 steradian) was flown in the earth satellite Explorer XIV out to radial distances of 16.5 earth radii. Figure 2 is reproduced from a report on that work (*2*). The curve marked 213A is the counting rate curve for the detector in question. It can be inferred from Fig. 2 that if the Iowa detector in Mariner II was placed at a radial distance of 41,000 km from the center of Earth

Table 2. Summary of count-rate data in the vicinity of Venus.

Time period (UT) (Dec. 1962)	Radial distance range (10^3km)	Mean counting rate and its statistical uncertainty (count sec^{-1})	Spacecraft mode
16:03/13 Dec. to 12:15/14 Dec.	569 to 167	2.097 ± 0.058	Cruise
12:33/14 Dec. to 13:14/14 Dec.	161 to 147	1.15 ± 0.17	Cruise
13:35/14 Dec. to 20:40/14 Dec.	140 to 41 to 45	1.125 ± 0.049	Encounter
20:55/14 Dec. to 03:07/15 Dec.	48 to 160	1.366 ± 0.086	Cruise
03:19/15 Dec. to 11:51/16 Dec.	163 to 809	1.329 ± 0.031	Cruise

in the magnetic equatorial plane with its axis orthogonal to the *B* vector, then its true rate would be of the order of 10^6 count sec^{-1}; and that even at 65,000 km it would be of the order of 10^4 count sec^{-1}. Thus, it is clear that the radiation environment of Venus is vastly different than that of Earth. However, the nonlinear character of the similitude argument is evident from the precipitous decline in trapped particle intensity at 72,000 km, shown in Fig. 2. If our Mariner II equipment had been flown past Earth at a minimum distance of approach of 75,000 km on the sunward side of the magnetosphere on 5 October 1962, then the results would have been as negative as were those from the Venus fly-by on 14 December.

By means of Explorer XII (*3*) and Explorer XIV (*2*) it has been found that there is often a sharp outer boundary of the magnetosphere (such as exemplified by Fig. 2) as defined by the intensity of electrons of $E > 40$ kev and a nearly coincident discontinuity in the magnitude and direction of the magnetic field. The radial distance to this outer boundary is typically 8 to 11 earth radii. On some occasions, even on the sunward face of the magnetosphere, there is no sharp discontinuity and the intensity of low-energy, trapped electrons dwindles gradually with increasing distance to a radial distance as great as 14 or 15 earth radii.

For the purposes of an exemplary calculation, let it be assumed that the magnetic moment of Venus is perpendicular to the plane of the ecliptic, and that the solar wind which was impinging on the magnetosphere of Venus on 14 December was similar to that responsible for the termination of the magnetosphere of Earth on 5 October (Fig. 2) (the latter assumption is supported by auxiliary geomagnetic data for the two periods in question). If it is further assumed that the magnetospheric boundary occurs at a given value of planetary magnetic field, under given solar wind conditions, then the Mariner II results imply the following upper limit for the ratio of the magnetic moment of Venus M_V to that of Earth M_E.

$$\frac{M_V}{M_E} \leq \left(\frac{41{,}000}{72{,}500}\right)^3 = 0.18$$

We regard this estimate as reasonable but do not regard it as definitive. For example, if the magnetic moment of Venus was in the plane of Mariner II's trajectory and perpendicular to the trajectory at its point of closest approach the fly-by at 41,000 km would have just reached the dipole line of force which crosses the magnetic equator at 106,600 km. This line of force on the sunward side of the earth has never been observed to be populated by a detectable intensity of trapped particles of energy to which our Mariner II detector was sensitive. Hence, in this case M_V/M_E might be equal to or somewhat greater than unity.

It is probable that the heliocentric variation of the dynamic pressure of the solar wind between the orbit of Venus (0.72 astronomical unit) and the orbit of Earth (1.00 A.U.) is less than the day-to-day and week-to-week variations at Earth. Hence no attempt has been made to invoke this consideration, which is in effect buried among other uncertainties previously mentioned.

It may be remarked that our Mariner II detector, though having a wide angle (90°) collimator, was a directional one and was carried past Venus in an oriented vehicle. Since the angular distribution of magnetically trapped particles is always anisotropic, it is of importance to inquire whether the observed null result could have been a false one due simply to the fact that the detector had an unfavorable aspect during its passage through a field of radiation. We examined this possibility for various orientations of the planetary magnetic moment with the help of a model and concluded that such a result was exceedingly unlikely.

The results of the magnetometer observations made with Mariner II may contribute to the determination of an upper limit to M_V, but the interpretation of a null effect on a magnetometer is closely related to the interpretation of the absence of magnetically trapped, charged particles and it is doubtful that anything essentially different can be derived from the magnetic observations. It is assumed implicitly in our interpretation that the processes leading to the development of the radiation belts of Earth also occur in the magnetospheres of other magnetized planets and that the important processes scale in some continuous manner and not discontinuously with the magnitude of the magnetic moment of the planet in question.

In the spirit of the theory of planetary magnetism, our results are consistent with the radar astronomical evidence that the rotational period of Venus is approximately equal to its period of revolution about the sun (*4*, *5*).

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5. This work was supported in part by the Jet Propulsion Laboratory and by our NASA grant NsG-233-62. We are particularly indebted to Conway W. Snyder, Hugh R. Anderson, and Leonard G. Parker (J.P.L.) for essential assistance with many aspects of the work and to C. S. Wang (State University of Iowa) for assistance with data reduction. Two of us (L.A.F. and H.K.H.) are graduate research fellows of the National Aeronautics and Space Administration.

26 February 1963

Infrared Radiometer

The infrared radiometer which was flown on Mariner II in conjunction with the microwave radiometer was designed to measure, with high geographical resolution, the infrared radiation from Venus in two wavelength regions. One of these was centered on the 10.4-μ carbon dioxide band, while the other was selected to correspond to an infrared window centered at 8.4 μ.

The characteristics of the two-channel instrument, which was built by the Barnes Engineering Company, follow: weight, 2.88 lbs; power, 2.4 watts; field of view, 0.9 by 0.9 deg; integration time, 3 seconds between 10 and 90 percent points. The detectors were 0.15- by 15-mm thermistor bolometers immersed in germanium. Channel 1 operated in the spectral region 8.1 to 8.7 microns, channel 2 in the region 10.2 to 10.5 microns. The radiometer, designed to measure radiation temperatures between 200°K and 600°K, chopped the planetary radiation against dark space by means of a mirrored chopper operating at 20 cy/sec. Two essentially identical optical systems looking 45 deg apart were utilized.

The infrared radiometer was mounted

upon and bore-sighted with the microwave radiometer described in the accompanying article. Both instruments therefore executed the same scan pattern caused by the combined effects of the probe motion and a rotation of the radiometers in a plane normal to the probe-sun line. It was originally planned to have approximately 15 scans of the planet, but a failure of the scan reversal system reduced this number to three. Five pairs of radiation temperatures were obtained on the dark side, five on the sunlit side, and eight along the terminator.

The radiometer was calibrated at the Jet Propulsion Laboratory by using two cylindrical black bodies; one was maintained at liquid nitrogen temperature, while the other was variable over the expected planetary temperature range. In addition, a one-point check was obtained during encounter by having the radiometer view a plate, located on the spacecraft structure, whose temperature was independently measured.

The data are consistent with an equality of the 8- and 10-μ radiation temperatures. This apparent equality would indicate that there was little CO_2 absorption in the light path. The implications are that the measured temperatures were cloud temperatures, that the clouds were quite thick, and that essentially no radiation was transmitted from the surface.

A definite limb-darkening was observed in both spectral channels; the radiation temperatures showed a monotonic decrease of approximately 20°K between the central region and the limbs. Central radiation temperatures are estimated to have been on the order of 240°K; an evaluation of the accuracy of the absolute calibration is currently underway. The data do not show any clear-cut evidence of asymmetry in the limb-darkening, except for an anomaly on the southern part of the terminator scan. In particular, the light- and dark-side temperatures were qualitatively the same. The anomaly was about 10°K cooler than expected on the basis of symmetrical limb-darkening (*1*). One obvious interpretation of this temperature anomaly is that the clouds were locally higher or more opaque, or both. An interesting possibility is that this was associated with a surface feature.

A detailed analysis of the data, including a simulation of the Mariner flight equipment, is being carried on in an effort to place realistic limits on the accuracy of the measurements and to understand anomalies which appeared in the science subsystem during calibrations made in flight but before encounter. Until these difficulties are resolved the results must be considered tentative (*2*).

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Notes

1. Cool features have also been reported by Sinton and Strong, *Astrophys. J.* 131, 470 (1960), and by Murray, Wildey, and Westphal, talk at Am. Geophys. Union meeting, Stanford, Calif., Dec. 1962.
2. We acknowledge the help of Carl Sagan, who was an active participant during the conception and initial planning of this experiment. We thank the engineering staff of the Jet Propulsion Laboratory whose skill and perseverance made the Mariner II spacecraft successful. We especially thank M. Eimer, T. Harrington, K. Heftman, K. Hoyt, J. Martin, and W. Valentine of the Jet Propulsion Laboratory, and F. Schwarz, F. Weeks, and A. Ziolkowski of the Barnes Engineering Corporation for their contributions to this experiment.

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Microwave Radiometers

Earth-based measurements of the radio emission of Venus have indicated that the planet's temperature is approximately 600°K for wavelengths in excess of 3 cm. This temperature may be contrasted with infrared measurements of Venus, which yield values somewhat less than half those obtained by radio. The radio data, which are critical to our understanding of the Venusian environment, rest on terrestrial observations which suffer from lack of resolution and insufficient precision. Fly-by planetary probes offer the possibility of precision and resolution with modest radiometers. Accordingly, the Mariner II spacecraft was instrumented with a two-channel microwave radiometer operating at wavelengths of 13.5 and 19.0 mm (*1*). The radiometer's total weight was 22 lb. Its average power consumption was 4 watts; its peak power consumption was 9 watts.

The radiometers were of the crystal video type; the Dicke switching technique was used. Comparison horns, oriented to avoid pointing toward Venus and the sun, provided reference temperatures. The radiometers operated with a common antenna having a diameter of 48.5 cm. The pertinent equipment performance parameters are given in Table 1. The effective antenna gain was calibrated by using a black disk of known temperature whose angular size was designed to be approximately the size of Venus at encounter. This calibration was performed on Table Mountain near Wrightwood, Calif., in March 1962.

During the 110-day flight 23 noise calibrations were made, and thus the gain, base-level, and time constant performance of the radiometers could be monitored en route.

The radiometers were energized and the antenna scan motion was activated about 6½ hours before encounter. The scan motion had an angular extent of 123.5° and a nominal scan rate of 0.1° per second. The microwave radiometer beams first made contact with the planet Venus at 18:59 GMT (spacecraft time) 14 December 1962. During the next 35 minutes three scans across the planetary disk were obtained. The approximate angular extent of each scan was: scan 1, 10 deg; scan 2, 15 deg; scan 3, 10 deg. The altitudes at mid scan were: scan 1, 40,200 km; scan 2, 37,750 km; scan 3, 35,850 km. Scan 1 was located on the dark side, scan 2 was located near the terminator, and scan 3 was located on the light side.

Telemetered digital data points, presented as voltages as a function of time, are the basic data. The data must be corrected for a number of effects before they may be considered as yielding the microwave temperature distribution across the planet. Among these corrections are the more important effects of the post-detection time constant, and a detailed consideration of the antenna pattern.

The noise tube calibrations obtained en route to Venus have enabled us to determine the in-flight time constant and gain of the radiometers. The gain of both channels decreased during the cruise, and the zero levels had systematic variations. These effects were more serious in the 13.5-mm radiometer, and a more exhaustive analysis must be made before the results from this channel can be reported. Accordingly, we present now only a preliminary analysis of the 19-mm channel (*2*).

Preliminary estimates of the peak brightness temperatures of the three

Table 1. Radiometer characteristics.

Item and unit	Channel 1	Channel 2
Center wavelength (mm)	19	13.5
Center frequency (Gcy/sec)*	15.8	22.2
Predetection bandwidth (Gcy/sec)*	1.5	2.0
Sensitivity, rms (°K)	15	15
Calibration signals (°K)	1500	800
Time constant (sec)	40	40
Beamwidth (deg)	2.5	2.2
Side lobes (db)	−23	−23
Reference frequency (Cy/sec)	950	1050

* 1 Gcy = 1 gigacycle = 10^9 cycles.

scans follow. (The temperatures are based on calculations which account for the effects of the antenna beam and the post-detection time constant.) For scan 1 (dark side), 460°K; for scan 2 (near terminator), 570°K; for scan 3 (light side), 400°K. The errors of the quoted temperatures are estimated to be 15 percent.

The possibility of interference between the Mariner radiometer data channels is being investigated. This effect is not expected to alter significantly the tentative conclusions we have given. To date, the analysis of the preliminary results suggests that there is no significant difference in the microwave temperatures on the light and dark sides of the planet. In addition, the results suggest a limb darkening, an effect which presents cooler temperatures near the edge of the planetary disk. The ionosphere model of Venus, which permits earth-like temperatures, appears to be ruled out by these observations. On the other hand, the observed limb darkening is consistent with a model of the Venusian environment which has high temperatures originating deep in the atmosphere or at the surface of the planet.

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1. The radiometer was designed and built at the Jet Propulsion Laboratory. It was based on a larger, four-channel flight instrument developed by the Ewen Knight Corp.
2. A detailed report is in preparation.

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Magnetic Field

Abstract. *Mariner II magnetometer data gave no indication of a Venusian magnetic field. This implies, by comparison with spacecraft measurements near Earth and with theoretical models, that the magnetic dipole moment of Venus is at most 1/10 to 1/20 that of the earth.*

Magnetometer data, obtained as Mariner II passed Venus, gave no evidence of a Venusian magnetic field at any point on the trajectory. No rise in the average value of the magnetic field above the value of the interplanetary field was detected which could be attributed to the planet. The sensitivity of the magnetometer is such that a field change as large as about 4 gamma on any axis would have been detected. (One gamma is 10^{-5} gauss. The magnitude of the earth's field at the equator is about 30,000 gamma.) During encounter, a slow change no larger than about 10 gamma was observed. However, this change should be attributed to a temporal change in the interplanetary magnetic field because it did not have the character of a planetary field. We did not detect the continuous fluctuations with periods from 1 second to 1 minute and amplitudes of the order of 3 gamma, that seem characteristic of the interplanetary region just outside the geomagnetic field. Simultaneous measurements by other Mariner experiments also failed to reveal any effect associated with a planetary field such as trapped particles or a modification in the flow of solar plasma (*1*).

These results do not necessarily mean that Venus has no magnetic field, for the solar wind would confine a weak field to a limited region close to the planet (*2*). The observations indicate that the field does not extend out to the Mariner trajectory, for which the distance of closest approach from the center of Venus was approximately 41,000 kilometers. The results are consistent, however, with the possibility that Venus has no magnetic field.

Since the planetary field does not extend out to the Mariner trajectory, an upper limit for the magnetic dipole moment of Venus can be estimated. Theoretical models of the interaction of the solar wind with a dipole magnetic field, including a crude estimate of the extent of the disturbed region outside the magnetosphere, indicate that the dipole moment of Venus, if it is approximately perpendicular to the Sun-Venus line, is less than 1/10 that of the earth. Comparison of the measurements made near Venus with those made by other spacecraft near the earth leads us to the conclusion that the dipole moment of Venus is less than 1/10, or perhaps 1/20, that of the earth. If the dipole moment of Venus is the dominant field source, the magnitude of the surface field is less than 5 to 10 percent of the geomagnetic surface field. If Venus has a more complicated magnetic structure than the earth, so that higher-order multipoles are important, the surface field in places could be larger than the earth's field without increasing the strength of the field along the Mariner trajectory to an observable value.

Phenomena associated with the geomagnetic field, such as the trapping of particles in radiation belts and the aurora, are likely to be greatly modified, less important, or completely absent on Venus because of its weaker field. The cosmic ray flux at the top of the Venus atmosphere may everywhere correspond to the high level found on earth only in the polar regions.

The Mariner data now add Venus to the other members of the solar system whose magnetic properties are partially known. Recent interpretations of the polarized radio noise from Jupiter indicate that the magnetic field of the surface is 5 gauss (*3*). The Lunik II magnetometer showed that the surface field of the moon, on the sunlit hemisphere, is less than 100 gamma (see *4*).

Jupiter rotates rapidly, twice in an earth day, and is 10 times as large as the earth. The moon rotates once each 28 days, and astronomical observations indicate that Venus, too, may be rotating slowly. These observations suggest that planets and satellites that rotate much less rapidly than the earth have small magnetic fields. This is consistent with theories (*5*) which ascribe planetary magnetic fields to a dynamo action inside the molten core of a rotating planet (*6*).

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6. The three-axis flux gate magnetometer electronics were designed and built by Marshall Laboratories of Torrance, Calif., under the supervision of the Jet Propulsion Laboratory, represented by Benjamin V. Connor, the magnetometer project engineer. The experiment is supported by the National Aeronautics and Space Administration under contracts NASw-6 (E.J.S.), NsG 151-61 (L.D.), and NsG 249-62 (P.J.C.). The sensor was designed and fabricated by Institut Dr. Förster, Reutlingen, Germany.

25 February 1963

Rotation of Venus: Period Estimated from Radar Measurements

Abstract. *Venus may rotate in a direction opposite to that of the earth at a rate of only one revolution in 240 days. The estimated period is accurate within 20 percent if the axis of rotation of Venus is perpendicular to the plane of the planet's orbit.*

Between 1 October and 17 December 1962 we established radar contact with Venus and found that the planet may rotate in a direction opposite to that of the earth at a rate of only one revolution in approximately 240 days. The result has been checked by two independent methods, a range-gated spectrum experiment and a continuous-wave spectrum experiment. We believe this rotation period is accurate within 20 percent if the axis of rotation is nearly perpendicular to the orbit plane of Venus.

Continuous-wave spectra were obtained by transmitting a 13-kilowatt signal of frequency 2388 megacycles per second toward Venus and computing the frequency spectrum of the received echo. An 85-foot parabolic antenna was used alternately for transmission and reception. It was switched between the two modes in accordance with the time required for the signal to make a round trip. An ephemeris-controlled receiver was used to remove from the echo the Doppler shift due to the relative velocity between Earth and Venus. The transmitted signal was less than 1 cycle wide, and any broadening of the echo received was due to the relative velocity of different parts of the planet. The differences in width between the transmitted and received signals may be attributed to the apparent rotation of Venus.

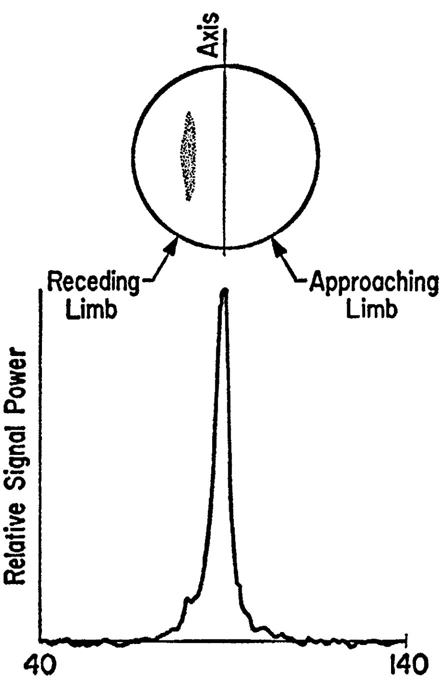

Fig. 1. Continuous-wave radar spectrum of Venus, 10 November 1962.

Figure 1 shows the spectrum obtained on 10 November 1962. It was computed on the I.B.M. 7094 computer from data recorded for about an hour. The ordinate is relative signal power (per unit bandwidth), and the abscissa is frequency shift. The plot can be interpreted equally well as signal power versus radial velocity relative to the center of the planet. The peak corresponds to zero radial velocity. The spectrum has a resolution of 1 cy/sec or a radial velocity resolution of about 6.3 cm/sec. The sketch above the spectrum shows the relation between the spectrum and the regions of Venus from which the signal may have been reflected. It is based on the important assumptions that the axis of rotation is perpendicular to the planet's orbit and that energy was received almost to the limb.

Of particular interest is the detail on the lower left side of the spectrum. At least a suggestion of a similar detail was found on all but two of the spectra obtained in the month preceding conjunction. Figure 2 shows the position of various details relative to the peak of the spectrum. The ordinate is the date of the observation, and the abscissa is the frequency difference between the peak and detail in cycles per second. The widths of the boxes correspond to the approximate width of the detail. The filled boxes are considered good identifications, while the unfilled and dotted ones are fair and poor, respectively. There is an obvious continuity in the position of the best identified details which strongly suggests that the details represent one and the same spectral detail which has moved slowly across one side of the spectrum. If this detail is the result of an actual topographic structure on the surface of Venus, then the rate at which it moves may be used to estimate the planet's rotation period. To obtain the rotation rate, the position of the detail on Venus must be known. The longitude of the detail, relative to the center of the planet's disk, may be

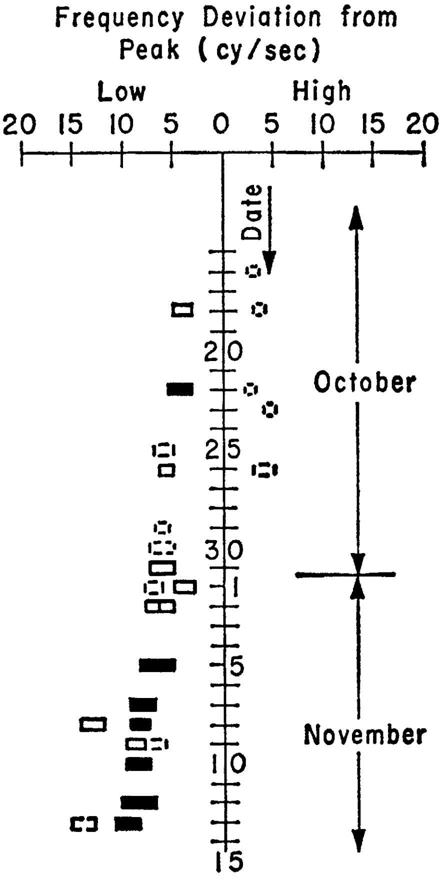

Fig. 2. Position of details on spectrum relative to the central peak. The dates read downward.

estimated by measuring its position relative to the maximum observable half-width of the spectrum's base. This assumes that the spectrum extends to the limb of the planet. If this is not the case, the longitude of the detail will be overestimated, and thus we will overestimate the rotation rate.

Using a composite spectrum constructed by averaging the spectra of 7, 8, 9 and 10 November, we estimate that the longitude of the topographic detail is 23° ± 3°. The given set of spectra was chosen because it fell in the middle of the period of the best position estimates of the detail. The latitude of the detail cannot be estimated from current data, but we have assumed that it is 23° as well. Fortunately, the derived rotation rate varies as the square root of the secant of the latitude and longitude; hence the rate is insensitive to the detail's position if the detail is within 45° of the center of the disk.

The estimated rate at which the detail was moving across the spectrum for the week prior to conjunction is

$$0.28 \begin{matrix} +0.30 \\ -0.10 \end{matrix} \text{ cy/day.}$$

This rate corresponds to an apparent angular velocity of

$$\left(2.0 \begin{matrix} +0.87 \\ -0.41 \end{matrix}\right) \times 10^{-7} \text{ radian/sec.}$$

Synchronous rotation would be approximately 4.4×10^{-7} radian/sec. The apparent angular velocity of Venus is the projection onto a plane perpendicular to the line of sight of the sum of two components: (i) a component due to the rotation of Venus on its own axis and (ii) a component due to an apparent rotation caused by Venus passing the earth in space. If it is assumed that the axis of Venus is perpendicular to its orbit, then the angular velocity found corresponds to a sidereal rotation period of over 1000 days forward or 230 (+40 or −50) days retrograde. The 1000 days forward can be rejected because it leads to spectral bandwidths of about 20 cy/sec for periods of several weeks before and after conjunction, and such a narrow bandwidth was not observed.

The effects of different orientations of the axis are under study; however, a tip of nearly 70° toward the earth would be required to give the same apparent angular velocity if Venus were rotating synchronously (227 days forward). The axis would have to be tipped even more for faster rotation rates.

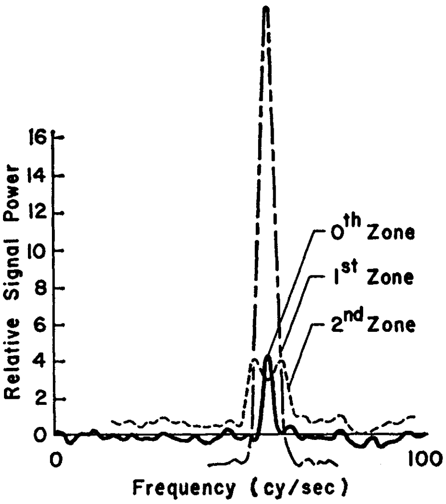

Fig. 3. Spectra of the range-gated zones.

Combining a range-gate with spectral analysis enables one to measure directly the component of Venus rotation which is perpendicular to the line of sight. This is so because the range-gate (a device which accepts echoes from a specified distance, but rejects closer and farther echoes) selects a known portion of the surface of Venus; and the spectrometer, utilizing the Doppler effect, measures the line-of-sight velocity of that portion.

The range-gate operates by modulating the transmitter with a wide-band waveform and modulating the received signal by the waveform's inverse (delayed by the time of flight). Echoes from the proper distance thus pass through the system unaltered, but they remain wide-band from other distances and may be removed with filters.

The true period of rotation of Venus is inferred from several measurements of the perpendicular component, spaced over an interval of several weeks. A rotation period of 250 days, retrograde, fits the data very well, under the assumption that the axis of rotation is perpendicular to the orbit.

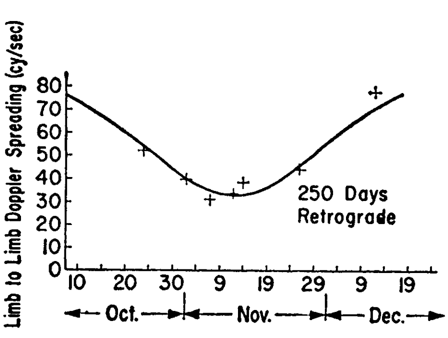

Fig. 4. The limb-to-limb Doppler spreading derived from the spectra of the range-gated zones. The curve shows the expected change assuming a period of 250 days retrograde.

Figure 3 is a sample of the raw data. The reflection from the cap, or zone one, contains most of the power. The bandwidth is remarkably narrow. The echo from the first annular ring, zone two, shows the characteristic double hump and increased Doppler broadening. We used the width of this curve to determine the angular velocity component. Zone zero is the area just ahead of the planet. Normally there would be no power from this zone. However, the range-gate was misaligned slightly to allow the position of the range-gate to be calibrated from the amount of power in zone zero. The distance between zones was 111 miles. These spectrograms required 3 hours of integration time.

Figure 4 shows how well the theoretical curve, calculated from the earth and Venus ephemerides, fits the data. The ordinate is angular velocity, measured in cycles per second of Doppler spreading (limb to limb).

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Nuclear Explosions: Some Geologic Effects of the Gnome Shot

An unusual byproduct of the underground nuclear explosion at Project Gnome was the development of intrusive breccia veins composed of black salt containing minerals created by the blast. They are associated with complex thrust faulting in the rocks adjacent to the shot-formed cavity. These veins closely resemble ore-bearing breccia pipes, dikes, and veins in some of the western mining camps.

Project Gnome was a multiple-purpose experiment conducted by the U.S. Atomic Energy Commission as part of the Plowshare Program to develop peaceful uses for nuclear explosives. The experiment consisted of the explosion of a nuclear device of about 3-kiloton yield (equivalent to 3,000 tons of TNT) on 10 December 1961. The device was detonated at a depth of about 1200 feet below the surface in a thick salt deposit about 25 miles southeast of Carlsbad, New Mexico.

The device was placed in a 7- by 7-