References and Notes

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4. S. Sh. Dolginov, E. G. Yeroshenko, L. N. Zhuzgov, N. V. Pushkov, *Geomag. i Aeronomiya* **1**, 21 (1961).
5. D. R. Inglis, *Rev. Mod. Phys.* **27**, 212 (1955); R. Hide and P. H. Roberts, in *Physics and Chemistry of the Earth* (Pergamon, New York, 1961), vol. 4.
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.

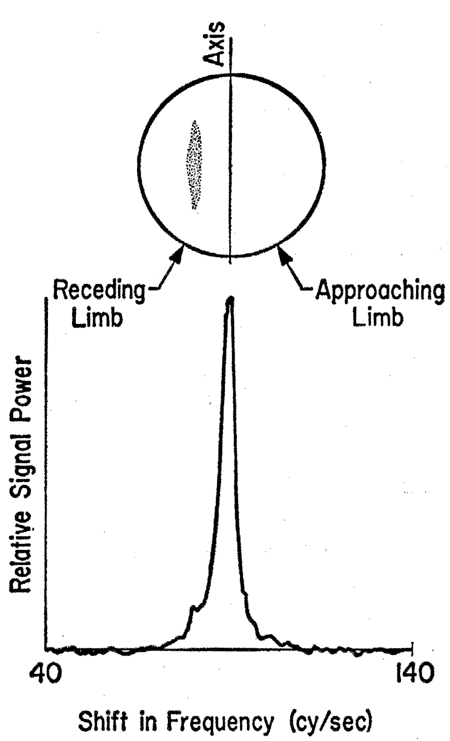

Fig. 1. Continuous-wave radar spectrum of Venus, 10 November 1962.

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

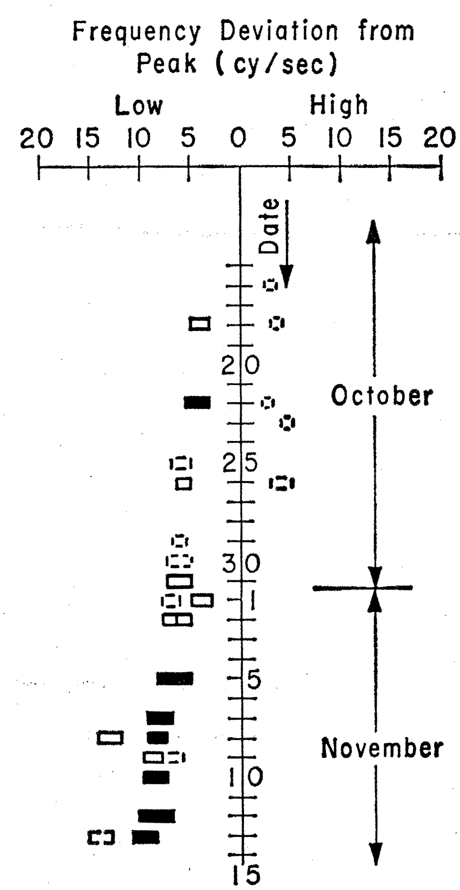

Fig. 2. Position of details on spectrum relative to the central peak. The dates read downward.

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 $23° \pm 3°$. 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

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

This rate corresponds to an apparent angular velocity of

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

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.

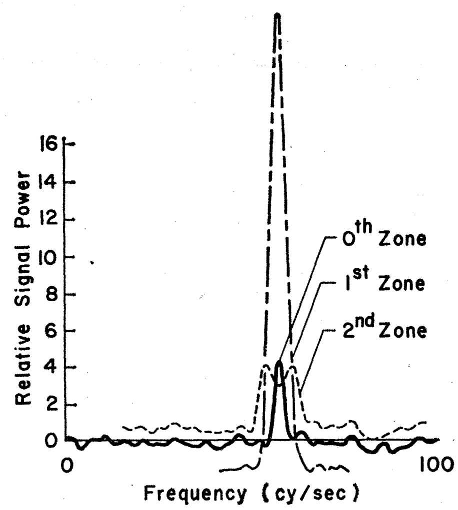

Fig. 3. Spectra of the range-gated zones.

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,

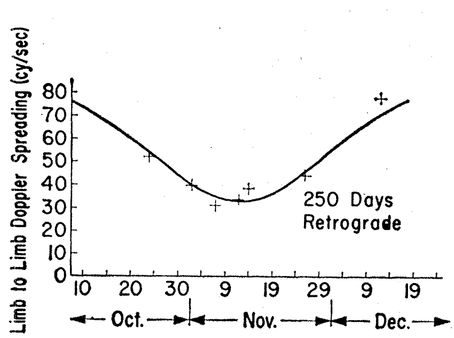

Fig. 4. The limb-to-limb Doppler spreading derived from the spectra of the range-gated zones. The curve shows the expected change assuming a period of 250 days retrograde.

fits the data very well, under the assumption that the axis of rotation is perpendicular to the orbit.

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-