New Radar Image of Venus

Abstract. *A new radar image of Venus covering the latitude range 46° to 75° and the approximate longitude range 290° to 10° is shown. The resolution is approximately 20 kilometers.*

As our nearest neighbor in the solar system, Venus has always excited great interest; but it is its similarity to the earth in size and average density that makes it of special interest for comparative studies of the two planets. Many of these studies have been frustrated by our inability to observe the surface through the heavy cloud cover. However, with the first detections of the surface of Venus by earth-based radars in 1961 there opened up the possibility that surface reflectivity maps (*1*) at radio wavelengths could be used to study the surface morphology. Initial maps showed only the position and approximate size of a half-dozen areas which backscattered significantly more power than their surroundings. While these limitations were partly due to lack of adequate sensitivity, the major problem was the so-called delay-Doppler ambiguity (*2*) which, when the beam width of the antenna used is larger than the angle subtended by the planetary disk, causes each point in a radar map to contain the superposition of backscattered power from two points on the planet. Several techniques have been used in attempts to resolve this ambiguity problem, the most successful of which has been interferometry, which was first tried in 1967 (*3*). Since then, several maps with resolutions of approximately 150 km have been produced covering a significant fraction of the visible face of Venus during inferior conjunction (*3, 4*), plus a series of high-resolution (approximately 10 km) maps covering small areas in the equatorial region (*5*).

The upgrading of the Arecibo Observatory's 330-m antenna to operate down to centimeter wavelengths offered the opportunity for an improvement by a factor of about 50 in sensitivity over existing planetary radar systems for observations of Venus. A 400-kw continuous-wave transmitter operating at 2380 Mhz (12.6 cm) was installed late in 1973. To form a receiving interferometer, a second antenna consisting of a 30-m equatorially mounted reflector was constructed at a site 10.7 km north-northeast of the main 330-m reflector. Calculations predicted that this system would be able to map the equatorial region of Venus at a resolution of about 4 km. At latitudes above ± 30°, the resolution would degrade slowly to about 20 km at ± 60° latitude. The limited hour-angle coverage afforded by the Arecibo antenna gives insufficient total baseline variation to allow determining topography simultaneously with the reflectivity maps.

Data were taken during a series of 2-hour observing sessions each day over a 2-month period around the inferior conjunction of Venus in late August 1975. The transmitted and received signals were linearly polarized in the same direction. No cross-polarized data were taken. The basic time resolution varied between 45 and 125 μsec, yielding resolutions on the surface of Venus between 10 and 20 km (*6*). During processing, the frequency resolution is typically matched to the time resolution, so that a resolution element on the surface of the planet is approximately square.

To develop and test the data reduction procedures, we initially concentrated on data from 2 days, 7 and 10 September, which appeared to be of high quality. The preliminary results are presented in this report. For these days, the time resolution used was 125 μsec, corresponding to an average resolution of about 22 km over the area mapped between latitudes 45° and 75°. The subearth point was at 327° longitude and 9.5° latitude on 7 September and at 331° longitude and 9.1° latitude on 10 September. Data reduction procedures were similar to those described in (*3*) and (*4*).

To compensate for the average change in backscattered power as a function of incidence angle (the scattering law) the power in each delay-Doppler cell was divided by $\cos^{1.5}\theta$, where θ is the angle of incidence. After conversion from delay-Doppler coordinates to planetary coordinates, the results for both days were combined. The projection chosen was partially dictated by convenience in handling the data and is an equal-area projection with the parallels of latitude equally spaced and the meridians of longitude a cosine function of the latitude.

Figure 1 is a map of the relative backscattered power between latitudes 46° and 75° and covering the approximate longitude range 290° to 10° (*7*). Two features seem to dominate this region. One is the large low-contrast area with the well-defined rim on its southern side and with two high-contrast features forming its northern and northwestern edges. Despite the implications, for convenience we refer to this as the northern basin. The other consists of the same two small high-contrast features on the northern edge of the basin and the large, very high contrast feature straddling the 0° meridian and extending from 60° to 70° latitude. The last feature was observed previously under low resolution with the Arecibo

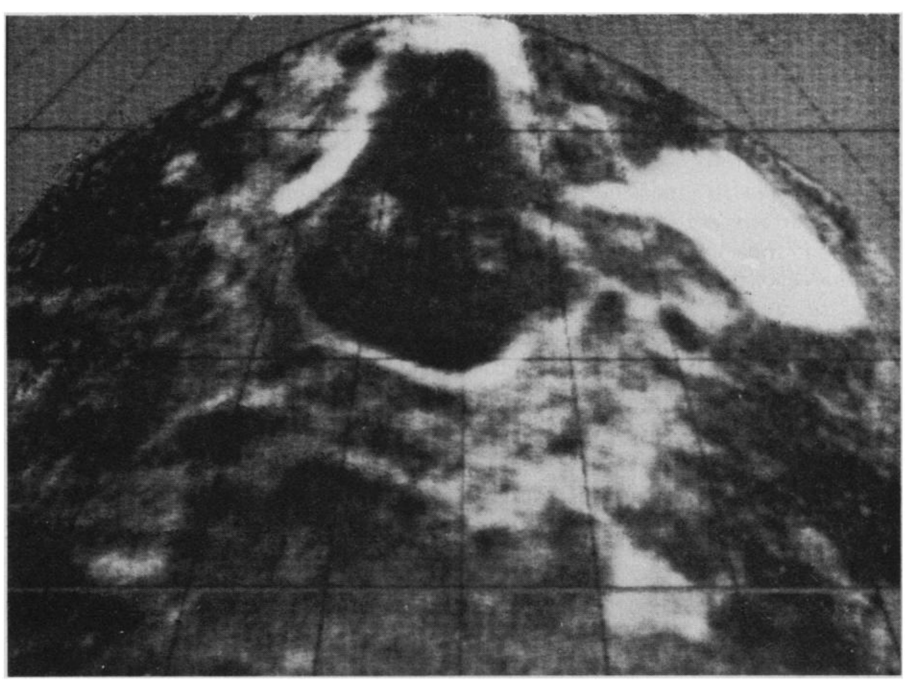

Fig. 1. Image of Venus showing the relative backscattered power between latitudes 46° and 75°. The meridians of longitude are spaced at 10° with the 0° meridian running through the center of the large high-contrast feature, Maxwell. The horizon at the top is determined by the longest processed time delay, relative to the subradar point.

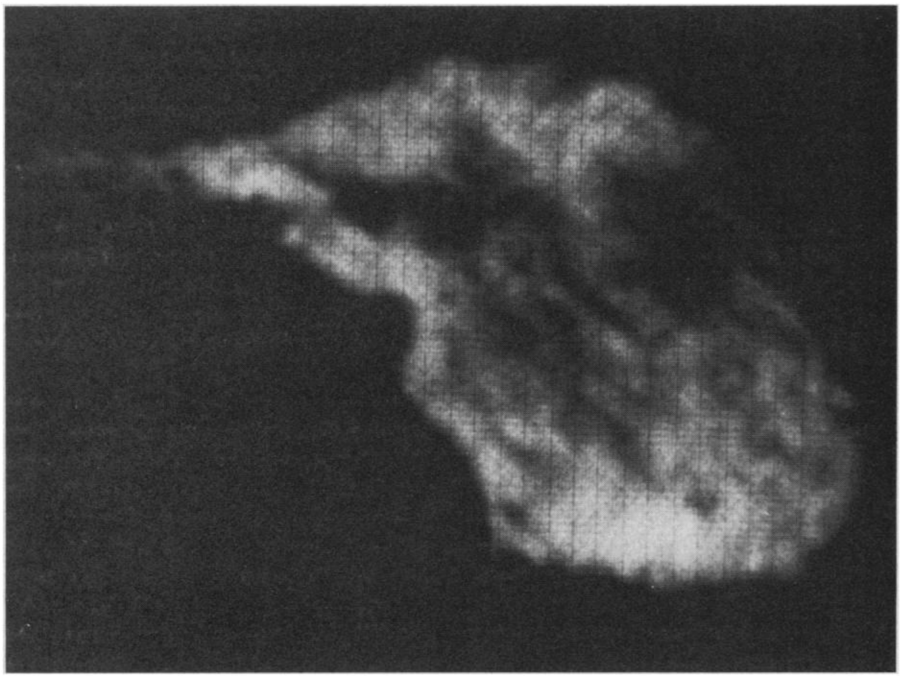

Fig. 2. Enhanced image of the feature Maxwell made by using monostatic data alone. A Mercator projection was used, as opposed to the equal-area projection of Fig. 1.

70-cm radar (*8, 9*) and was tentatively named Maxwell at that time. The power backscattered from the two small features is about ten times that from the floor of the basin, and at this resolution they do not exhibit much more detailed structure than is apparent in Fig. 1. Maxwell, on the other hand, backscatters about 25 times as much power as the floor of the basin and has considerable structure, which we discuss below. All three of these features have very sharply defined perimeters and give the impression of overlying an older surface. This is especially apparent where the "panhandle" of Maxwell appears to intersect a linear feature perpendicular to it. These high contrasts at large angles of incidence, about 50°, most likely indicate that the surfaces are extremely rough, at least on the scale of the 12.6-cm wavelength of the radar. This is supported by the previous observations of Maxwell at 70 cm, which showed that the incident circularly polarized wave was largely depolarized on reflection (*8*), indicating a very rough surface.

We find that the basin extends about 1500 km in the north-south direction and has an average width of about 1000 km. The floor appears to be of relatively uniform low contrast except for two small bright features about 200 km in size. The bright rim on the southern side backscatters two to three times as much power per unit area as the areas immediately adjacent to it to the south and close to ten times as much as the floor of the basin. It is not possible to say with certainty whether this enhancement in the backscattered power is due to a large change in average slope, indicating a raised rim, or whether it is due to an increase in the small-scale roughness, or both. If it is the former, then the high contrast and approximately 100-km width suggest a series of short but very steep slopes. The fact that the rim is bright only in the region where it is nearly perpendicular to the line of sight and the suggestion of shadowing in the center tend to support this alternative. The area of moderately high contrast approximately concentric with at least the southern half of the basin has the appearance of an ejecta blanket. It extends between 400 and 1000 km from the rim with the area of highest contrast to the southeast and a suggestion of ridges parallel to the rim in the southwest.

Figure 2 is an enhanced image of Maxwell. Except for the eastern side, the edges of the feature backscatter considerably more power than the central area. This consists of several large, relatively low contrast regions approximately 200 km in size, and there is again a suggestion of approximately linear ridges. Since these are nearly perpendicular to the line of sight of the radar they may be due to changes in the average slope and hence may actually be ridges.

In conclusion, Maxwell and the two other high-contrast features seem very indicative of tectonic activity. Their probable high degree of surface roughness, well-defined boundaries, and irregular shapes make an origin based on the impact history of the planet hard to conceive. There are no equivalent features on the moon. If this premise is correct, the degree of surface modification due to tectonic activity indicated by these three features raises some doubt as to whether the basin is the result of an ancient impact event. However, except for its somewhat irregular shape, which could be explained by a modification of the northern rim at some time, it has the characteristics of an impact crater. Coverage of this area at higher resolution or a study of other areas may answer this question.

D. B. CAMPBELL
R. B. DYCE
National Astronomy and Ionosphere Center, Arecibo Observatory, Arecibo, Puerto Rico 00612
G. H. PETTENGILL
Department of Earth and Planetary Sciences, Massachusetts Institute of Technology, Cambridge 02138

References and Notes

1. What is actually mapped is the power per unit surface area backscattered toward the radar. This is a function of the angle of incidence at the surface, the intrinsic reflectivity of the surface material at the frequency used, and the degree of small-scale surface roughness.
2. Resolution is obtained by simultaneously filtering the received echo in time and frequency. The outputs from these filters correspond to the signal backscattered from areas on the planet with a particular value of time delay and Doppler frequency shift with respect to the radar site. Unfortunately, there are, in general, two points on the surface of the planet which have the same time delay and Doppler shift, and it is impossible with a single observation from a single antenna to separate the echoes received from these two points.
3. A. E. E. Rogers and R. P. Ingalls, *Science* **165**, 797 (1969).

D. B. Campbell, R. F. Jurgens, R. B. Dyce, F. S. Harris, G. H. Pettengil, *ibid*. **170**, 1090 (1970); A. E. E. Rogers and R. P. Ingalls, *Radio Sci*. **5**, 425 (1970); A. E. E. Rogers, R. P. Ingalls, G. H. Pettengill, *Icarus* **21**, 237 (1974).

5. H. C. Rumsey, G. A. Morris, R. R. Green, R. M. Goldstein, *Icarus* **23**, 1 (1974); R. M. Goldstein, R. R. Green, H. C. Rumsey, *J. Geophys. Res*., in press.
6. For a continuous-wave transmitter the time resolution is obtained by reversing, or not reversing, the phase of the transmitted signal after each basic time interval (the baud length) according to a predetermined psuedorandom sequence. On reception the echo is converted to video by using a stable local oscillator, filtered, and then cross-correlated with a representation of the psuedorandom sequence. The resulting ambiguity function for the radar has a half-power width in time of approximately the baud length.
7. The longitudes given differ by about 3° from the system defined by the International Astronomical Union.
8. R. F. Jurgens, *Radio Sci*. **5**, 435 (1970).
9. D. B. Campbell, thesis, Cornell University (1971).
10. We acknowledge the tremendous effort of the staff of the Arecibo Observatory in preparing for and carrying out these observations. Special thanks are due T. Dickinson, V. Boriakoff, J. Liano, and R. Olver. We appreciate the assistance of R. Simpson and S. Ostro and discussions with S. Zisk. This work was carried out with support from the National Aeronautics and Space Administration and the National Science Foundation. G.H.P. also gratefully acknowledges support under NASA grant NGR 22-009-672. The National Astronomy and Ionosphere Center is operated by Cornell University under contract to the National Science Foundation.

2 July 1976