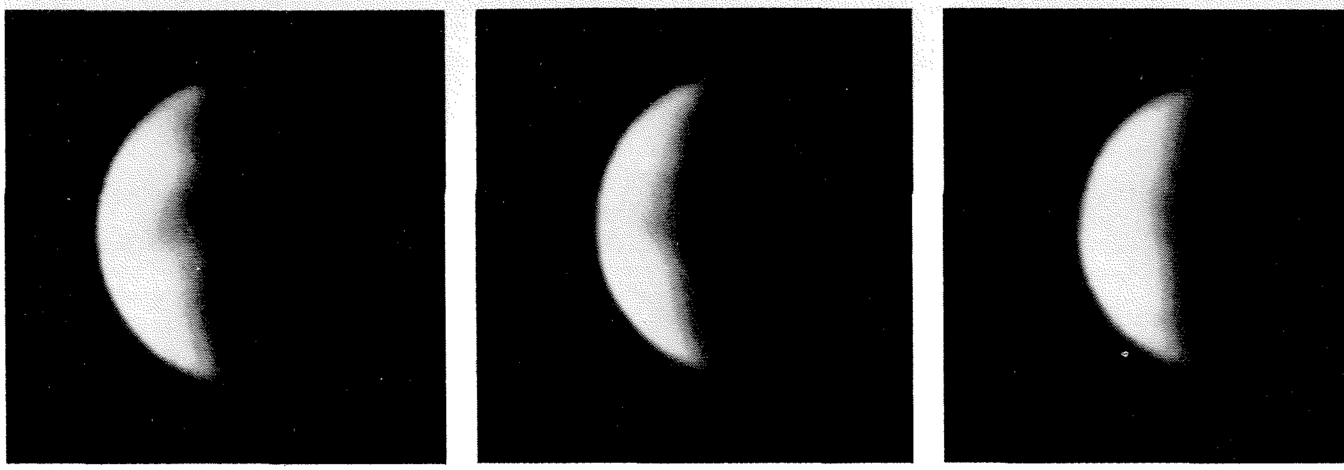


The Mountains of Venus

by Richard M. Goldstein

Venus well deserves its sobriquet of *mystery planet.* The dense clouds that perpetually cover Venus have prevented man from ever seeing the surface below. Of course, Earth's other planetary neighbors hold many secrets, and the accumulated observations of science and technology have yielded only the scantiest data. But compared to them, and despite Venus' occasional much nearer approach to Earth, the almost featureless clouds have successfully preserved Venus' enigmatic status.

Because of this one might think that Venus would not be a fertile field for geological investigations. However, some observations do exist, and they lead to rather bizarre and conflicting interpretations. The clouds themselves presented the earliest observations. They are very bright, reflecting almost all of the visible rays of the incident sunlight. By analogy with the clouds of Earth, astronomers at the turn of this century decided that the clouds must be made of water. And since no break in the clouds had ever been observed, they concluded that the clouds were very thick and that, consequently, the abundance of water on Venus was very great. The presence of so much water suggested that Venus was a steamy swamp, perhaps populated as are our own rain forests.

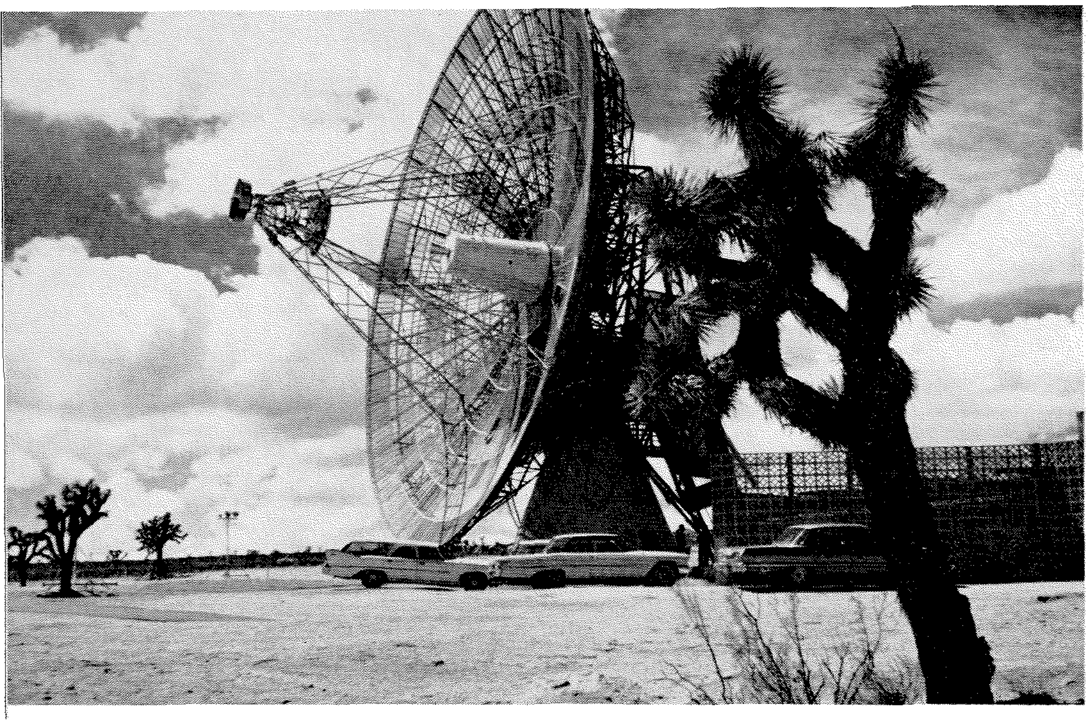
To test this argument spectroscopic studies were made to detect the characteristic signature of water vapor in the reflected sunlight. The early attempts failed to find any water vapor at all, and only the latest measurements show that, at least in the upper atmosphere, there is a very small amount of it.

But if the clouds are not water, what are they? An alternate idea arose that they are dust clouds, permanently stirred up from the surface by strong winds. Thus, Venus became a desert planet, dusty, windswept, and probably hot.

This theory gained support in later years from the spectroscopic discovery of large amounts of carbon dioxide in the Venus atmosphere. On our own planet there is an equilibrium maintained between carbon dioxide in the atmosphere and carbonate minerals on the surface. The large amount of carbon dioxide in the atmosphere of Venus was thus taken to indicate the absence of surface water.

A completely opposite point of view was possible and, in keeping with the divergent theories of Venus, was not overlooked. There is the possibility that no minerals are available to react with the carbon dioxide, because the surface is entirely covered by water. In this view Venus is a featureless planet of oceans.

Still another explanation of the large amount of carbon dioxide in the atmosphere makes use of a presumed chemical balance at the time when Venus was formed. In the case of Earth there was an excess of water over hydrocarbons, leading to our atmosphere and oceans. Venus, on the other hand,



At JPL's Goldstone Tracking Station in the Mojave desert, this 85-foot parabolic dish is used for investigations of the surface features of Venus.

may have had a primordial excess of hydrocarbons, which would lead to an atmosphere consisting of carbon dioxide and smog and to oceans of oil.

That four such diverse pictures of the surface conditions on Venus could seriously be entertained at the same time is an indication of the paucity of real data prior to 1956. At that time radio observations at the Naval Research Laboratory disclosed that Venus is very hot, about 600°F. As is usual in such cases this new datum raised more questions than it answered. Why was Venus so hot? The explanations offered agree that some mechanism allows solar energy to enter the atmosphere easily but prevents the resulting heat from radiating away as easily. They disagree markedly on what this mechanism might be.

One such "greenhouse effect" theory is that the carbon dioxide of the atmosphere is responsible. However, it would require very high atmospheric pressure before the temperature could rise to 600°. Another current theory is the so-called "aeolosphere theory." According to this view solar energy is captured in the form of the mechanical energy of great dust storms. These storms lash the surface continuously, generating the needed heat. This heat is retained, so the theory goes, by the insulating action of the dust clouds.

Radar is one of the most recent instruments to be used for planetary investigations, the first echo from Venus having been received in March 1961. The reason for this relatively late planetary fruition of radar lies in the extraordinary capability needed to do the job. Because of radar's inverse 4th power relationship, ten million times more power is required to probe Venus than is needed for the moon. Since 1961 radar capability has improved steadily, and Venus can now be observed at the far point of its orbit—another factor of one thousand in capability.

The radar studies to be discussed here were all performed at JPL's Goldstone Tracking Station in the Mojave high desert, 150 miles from Death Valley and 50 miles from Barstow. The equipment lends itself well to this service since there is a great similarity between a planetary radar system and a deep space command and telemetry system. The current radar parameters are, briefly:

Antenna	85-foot paraboloid
Power	100 kilowatts, continuous
Wavelength	12½ cm.
Noise Temperature	27°K.

Radio waves are beamed toward Venus in a tight cone of only 22′ of arc. Since the largest angle Venus ever subtends from Earth is less than 1′, Venus is almost uniformly illuminated by the beam. Certainly the beam has not enough resolution to discriminate between different areas of Venus, the "mountains" for example.

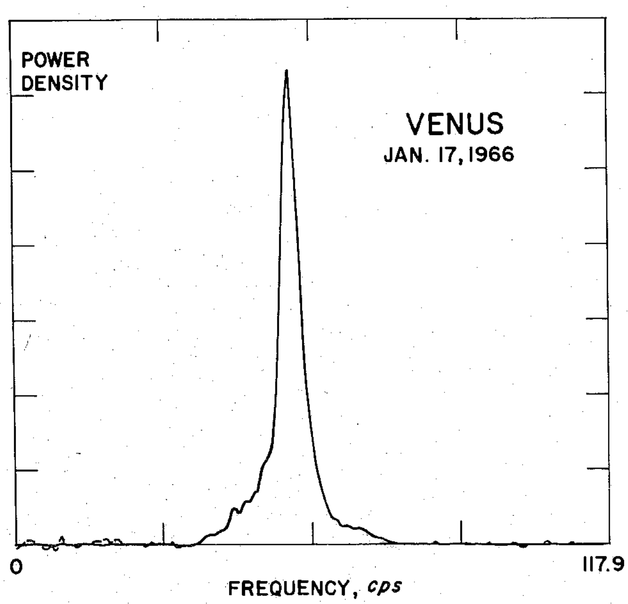
Two methods of obtaining such resolution are available to radar astronomers, however, and they have been used both singly and together. One is time delay. The echo from different areas may return to Earth at different times so that proper signal processing can separate them. Doppler shift is the other. Because Venus rotates, different areas may also have different line-of-sight velocities, hence the echoes will have different frequency shifts. Again, proper signal processing can separate them. In this case signal processing is simply spectral analysis, and the result of an observation is a spectrogram. It is, in effect, the result of scanning Venus with a slit which is parallel to the effective axis of rotation of the planet.

The limit of resolution is set by the oscillator stability of the radar system and by the available signal-to-noise ratio. To date the signal-to-noise ratio limit has always been reached first. Time delay precision of better than 10 microseconds has been achieved, which corresponds to resolution better than 1 mile on the surface of Venus. Frequency precision of 0.1 cycles per second has also been achieved, corresponding to 20-mile resolution on the surface.

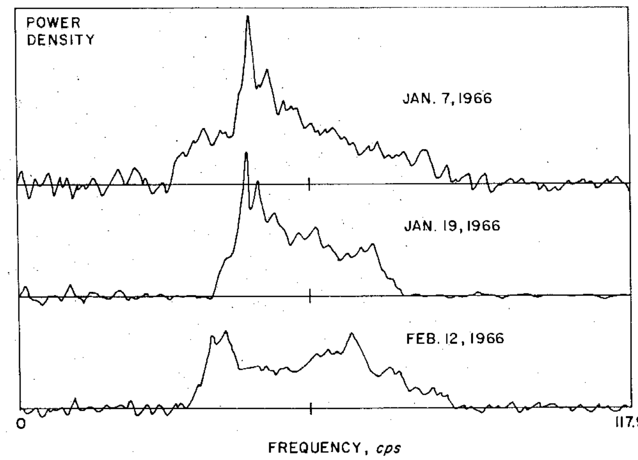
The study of the mountains of Venus is closely tied in with the study of Venus' rotation rate. Much like the early days of x-rays and crystallography, the two subjects developed together and each provided insight into the basic nature of the other.

Perhaps at this point the poetic license inherent in the title "mountains" should be mentioned. There is no proof that the objects observed are truly mountains, although mountains are quite consistent with the data. It may be, as the forests are in the Angeles National Forest, that the mountains of Venus are mountains in name only.

The first measurements of the rotation of Venus were made by R. S. Richardson at Mt. Wilson in 1956. He used a spectrographic technique which compared the doppler shifts in the reflected sunlight from the approaching limb of Venus with that from the receding limb. It was a difficult measurement because the solar spectral lines were not narrow enough, Earth's atmosphere severely modified the spectrum, and the rotation of Venus is quite



Radar spectrogram of Venus, made on January 17, 1966, shows that Venus is smooth to radio waves and would appear as a disk with a bright highlight at the center.



When a spectrogram is depolarized, topographic features can be seen clearly. In this series, peaks move from right to left, corresponding to Venus' rotation.

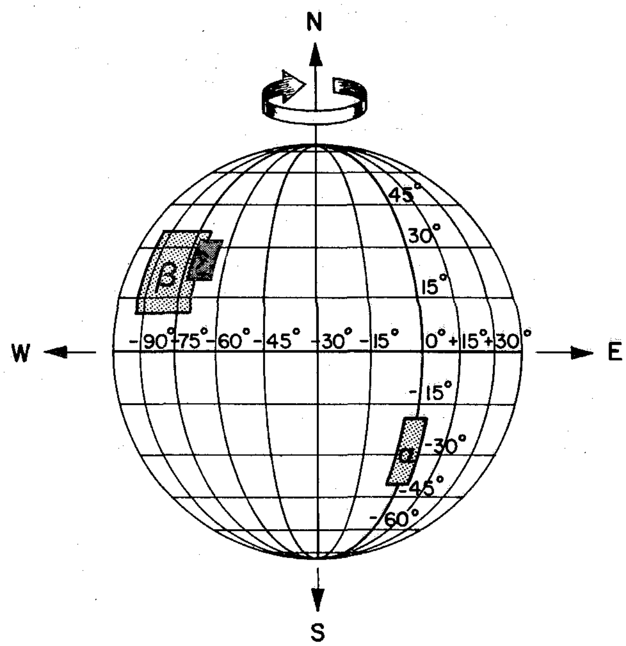
slow. Richardson was able to set an upper limit of 18 days to the period, however.

The early radar measurements of the rotation used the same technique, except microwaves were used instead of visible light. The extraordinarily pure monochromatic radiation available from Earth made the method very much more sensitive.

In 1962 the radar studies yielded the surprising period of 250 days, but in the retrograde direction. That is, all of the planets revolve around the sun in the same direction, and all the major planets spin in this same direction—except Venus.

Radar spectrograms show that Venus is very smooth, or shiny, to radio waves. Most of the power has no doppler shift; hence, it has reflected from the central region of the disk. To radar eyes Venus would appear as a disk with a bright highlight at the center and with darkly discernible limbs. Some of the eponymous mountains appear in the spectrogram as faint structures to the left and to the right of the central peak.

It is evident (left) that the presence of the large peak is similar to a glare that obscures the detail we wish to study. A polarization technique has been very effective in removing this glare. Normally, circularly polarized waves of, say, the right-hand sense are beamed towards Venus. Since a smooth, uniform reflector reverses circularly polarized waves, the receiver is set for the left-hand sense. However, double reflections may be expected to occur from regions that are rough or mountainous. To investigate this possibility the receiver is set for the same polarization as the transmitter. In the resulting spectrogram (above), the "glare" is eliminated, leaving the spectrogram rich in structure. Over successive days of observation the peaks appear on the right and move slowly across the spectrogram,



Schematic map of Venus shows locations of three major features (indicated by α, β, and δ). Two large prominences have also been definitely identified on the other side of the disk, and many smaller ones have been located with less accuracy.

being carried by Venus' rotation. Finally, after several weeks of observation, they disappear on the left.

These are the first data to show that the surface of Venus has relatively permanent features of any kind. If one subscribes to the ocean-covered model of Venus, the possibility of large-scale floating objects comes to mind. To holders of the super-dense atmosphere point of view comes the possibility of formations drifting about with the clouds.

Is it possible to locate these objects on the surface of Venus using the previously measured rotation vector and the motion of the spectral features? And will the deduced location and rotation accurately predict their reappearance at the next set of radar observations, a full 18 months later? The answer is yes. The location that provided a "best fit" to the data taken during the June 1964 inferior conjunction was also a good fit to the "mountains" when they returned to radar view in January 1966 and again in August 1967. Thus, the features are fixed to the solid surface of Venus and rotate with the planet.

The rotation vector gives information about the mountains of Venus. In return, the mountains give information about the rotation vector. Using two years of observations of the features, one can find both their location (above) and the rotation of Venus with surprising accuracy. Our calculations show that the period is 243.0 ± 0.2 days, and still retrograde. Concurrently, the longitudinal extent and location of several prominent features has been fairly accurately determined, the latitudinal extent less so.

Within the uncertainty of ± 0.2 of a day of Venus' rotation period lies a very special number, which we first postulated in 1964, corresponding to synchronism with the earth. Consider an observer on Venus who sees the earth at his zenith at midnight at the time of inferior conjunction. If synchronism holds, he would see the sun rise in the west and set in the east four times; exactly at the fourth midnight the earth would have returned to his zenith. The rotation period required of Venus for this synchronism is 243.16 days. We feel that this remarkable agreement can be no coincidence and that Venus' rotation is synchronized to the earth.

The radar observations have demonstrated that large topographic prominences exist on Venus and that they are fixed to the surface and rotate with the planet. The exact nature of these prominences is unknown. We call them mountains, but there is no assurance that they really are. They may be chains of craters, or features such as the Grand Canyon, or they may be only vast fields of rubble. They do have the ability to alter the polarization microwaves, so they must be rougher than the surrounding area. However, the roughness need only be greater in scale than the wavelength used, which is 12½ cm.

The radar observations also demonstrate that Venus rotates backwards with a period at, or extremely near, synchronism with the earth. It has been inferred from this that Venus must have a large gravity asymmetry (with concomitant internal stresses) and probably a liquid core.

We can now look forward to fairly accurate knowledge of the size and shape of these prominences. Radar data already taken are being processed to yield this information, and observations with the new 210-foot antenna at Goldstone are in the process of being taken.

Other information is in the offing. At the time of this writing Mariner V has just completed a flyby mission on a course to within 2,400 miles of Venus. The important data that we receive from Mariner V will greatly increase our knowledge. Venus is also under intense study from Earth-based optical, infrared, and radio observatories.

We feel that the time is especially ripe for the geological study of Venus and that we have come to the time where an exponential increase of information will soon provide many of the answers we seek. However, if the past is any guide, each new answer obtained will in turn engender more questions. Venus is likely to remain mysterious for much time to come.