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24 June 1963

Radar Observations of Mercury

Subsequent to the radar observations of Venus (*1*) and Mars (*2*), similar observations have now been made of Mercury during its recent conjunction in May. This latter series of measurements was made at the Jet Propulsion Laboratory's Goldstone tracking station, located in the Mojave desert of California. Mercury was illuminated with 100 kw of power at a wave length of 12.5 cm. An 85-ft parabolic antenna was used alternately for both transmission and reception.

The same techniques were used for the three different types of signal processing as were used for the data obtained for Venus (*1*), so that the two sets of data may be compared directly. In the simplest type of processing, the receiver was used in the configuration of a Dicke radiometer (except that the transmitter was keyed instead of the receiver), and the total power of the echo was measured. Typically, signals obtained over 4 hours were integrated. The measured value of the signal power was eleven times the root mean square of the fluctuations, which are caused by noise. This high-confidence measurement was made upon a signal of only 5×10^{-22} watt. The radar cross section of Mercury was measured as 5 percent of its geometric cross section. This compares with 10 percent for Venus and 3 percent for Mars.

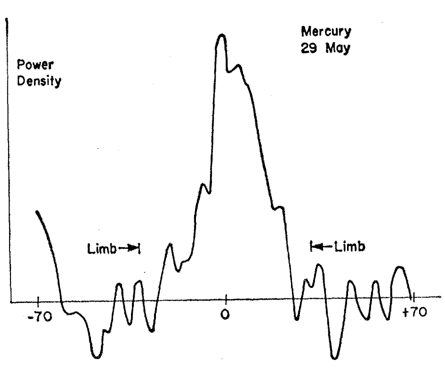

Fig. 1. A spectrogram showing data obtained for Mercury during 2 hours of signal integration.

In the second type of data processing, the power of the echo was analyzed into its frequency components by means of the autocorrelation function approach. A wave of high spectral purity was transmitted to Mercury, but the echo was both shifted and broadened in frequency by the Doppler effect. The shift was caused by the relative orbital velocity between Mercury and the radar station; the broadening was caused by the apparent rotation, which imparts differing velocities along the lines of sight to different parts of the surface.

In Fig. 1, the lines marked above the abscissa show the calculated position of echoes reflected from the limbs of Mercury; echoes are detected almost to the limbs. This corroborates our conclusions that Venus undergoes a slow retrograde rotation, for such a conclusion requires that Venus echoes (which are much stronger) be detectable near the limbs.

The width of the spectrograms, in relation to the size and rotation of Mercury, gives a measure of the roughness of its surface. In this sense Mercury is much rougher than Mars and perhaps twice as rough as Venus. The Doppler shift of the signal was removed by an ephemeris-tuned receiver, hence the frequency of the central part of the spectrograms gives directly the velocity errors of the ephemeris. Table 1 shows a list of these residuals.

In the third type of data processing a spectrometer was used to analyze the signal selected by a range-gate. The transmitter was modulated with a wideband waveform. The range-gate was set to accept echoes from a specified 178-km zone of Mercury, and to reject all others (Fig. 2). The selected signal was then analyzed for its frequency content.

Since these echoes originate from known areas on Mercury, its speed of rotation may be inferred. Of course, it has long been known that the period of Mercury's rotation is 88 days; but the measurement, which was in excellent agreement, serves as an effective check on one of the techniques we used to measure the rotation of Venus.

Table 1. Residuals calculated for Mercury.

Date	Velocity (cm/sec)	Range (meters)
5/15/63	−28	
5/16/63	−20	
5/21/63	−49	
5/23/63	−44	
5/24/63		+1.1 10^5
5/25/63	−38	
5/26/63	−25	
5/28/63	−22	+1.7 10^5
5/29/63	−22	

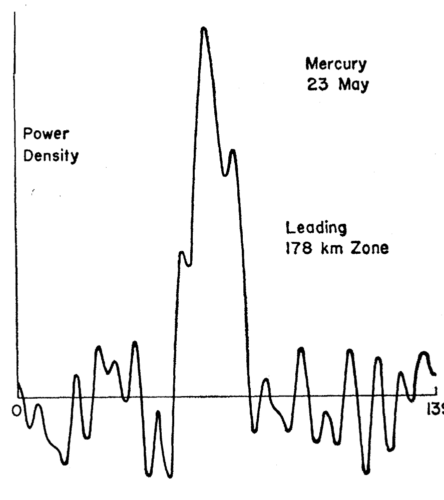

Fig. 2. A spectrogram showing data obtained for Mercury by means of a spectrometer in which the range was restricted with a range-gate set to accept echoes only from a specified 178-km zone.

From spectrograms of this type we also measured the time taken by a radar signal to get to Mercury and back, and hence the distance. The internal consistency of this method was good to within 15 km. Since the orbital velocity of Mercury carries it through one range zone in only a dozen seconds, it is necessary to control the range-gate with an ephemeris also. Thus the range-gated spectrograms give the range error of the ephemeris. These residuals are also presented in Table 1.

The trends seen in these data are essentially eliminated by adjusting the argument of the ephemeris by only 6 seconds, and the astronomical unit by only 10^5 meters. These data provide a striking confirmation of the astronomical unit reported by Muhleman (*3*) of this laboratory, which was based on radar observations of Venus during the conjunctions of 1961 and 1962.

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12 August 1963

Stress Differences and the Reference Ellipsoid

In a recent communication, Hulley (*1*) has connected gravity anomalies with other geophysical phenomena including faults and the pole positions. Unfortunately, the latter suggestion is not substantiated mathematically; for areas of any extent and for realistic rheology the *polfluchtkraft* can even be in the direction opposite that shown in Hulley's diagram (*2*). In this work, Hulley made use of diagrams of the contours of the geoid supplied by Kaula (*3*). The geoid contours to which Hulley refers do not give a clear picture of the distribution of the stress differences. This is because the reference ellipsoid is an approximation to the average ellipsoid. Stress differences, however, arise from the difference between the actual form of the earth and the theoretical one for fluid equilibrium. The flattening which corresponds to fluid equilibrium is approximately 1/300 as was pointed out by Henriksen (*4*) and later discussed by O'Keefe (*5*) and Munk and MacDonald (*6*). If we plot the values of the gravity anomalies referred to an ellipsoid with a flattening of 1/300, we get the result as shown in Fig. 1, which is based on Kaula's work. In comparison with Hulley's paper, Fig. 1 indicates that there may be a relation between the tectonic activity and gravity anomalies; at least the strong positive anomalies in the East Indian area appear to correspond with the maximum tectonic activity.

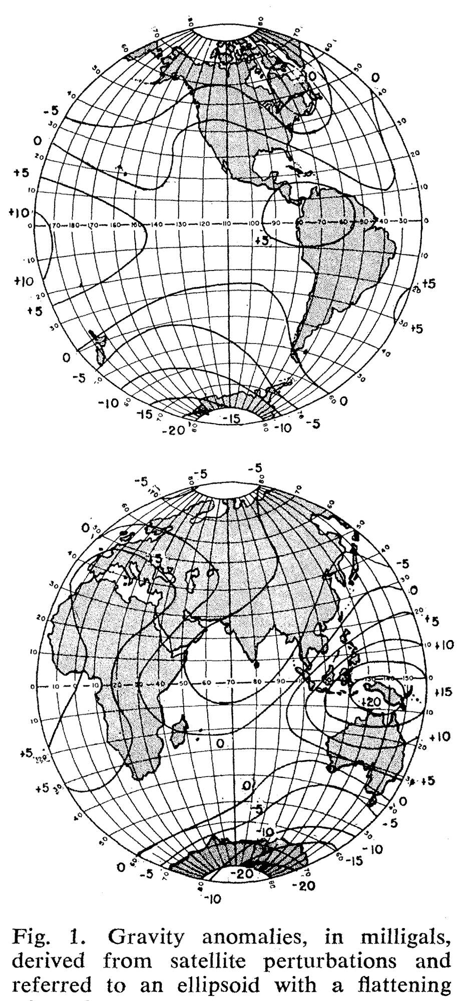

Fig. 1. Gravity anomalies, in milligals, derived from satellite perturbations and referred to an ellipsoid with a flattening of 1/299.8.

On the other hand, it should also be pointed out that there is a special explanation associated with the largest part of the discrepancy between the actual and equilibrium figures: the difference in oblateness can be considered as a lag of 10^7 years in adjustment to the slowing of the earth's rotation (*6*). So it is not entirely clear what the proper reference figure should be.

It is interesting to note that, regardless of the reference figure used, the shape of the geoid does not lend any particular support to the suggestion of Girdler (*7*) that the rift valleys and the mid-ocean ridges are the loci of up-currents in a convection system. It has been shown, by Licht (*8*) for example, that the top of a convection current should be in the area of positive gravity anomalies.

The positive anomaly areas near Central America, West Africa, and the East Indies are not associated with any ocean ridges. On the contrary, the ocean ridge system extending from the northwest Indian Ocean, around south of Australia, and up to the east Pacific is strongly correlated with a negative belt in the gravity field.

A similar negative correlation exists between heat flow and the gravity field, as shown by Lee and MacDonald (*9*), whose harmonic analysis of thermal measurements shows areas of maximum heat flow in central Asia and the eastern Pacific, and areas of minimum heat flow in the south Atlantic and western Pacific.

The various correlations shown are suggestive of what hypotheses to pursue, but they undoubtedly have a strong subjective element, and need both firmer mathematical models and more extensive data: in particular, more widespread gravimetry.

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9 September 1963

Geomagnetic Polarity Epochs: Sierra Nevada II

Abstract. *Ten new determinations on volcanic extrusions in the Sierra Nevada with potassium-argon ages of 3.1 million years or less indicate that the remanent magnetizations fall into two groups, a normal group in which the remanent magnetization is directed downward and to the north, and a reversed group magnetized up and to the south. Thermomagnetic experiments and mineralogic studies fail to provide an explanation of the opposing polarities in terms of mineralogic control, but rather suggest that the remanent magnetization reflects reversals of the main dipole field of the earth. All available radiometric ages are consistent with this field-reversal hypothesis and indicate that the present normal polarity epoch (N1) as well as the previous reversed epoch (R1) are 0.9 to 1.0 million years long, whereas the previous normal epoch (N2) was at least 25 percent longer.*

A recent paleomagnetic investigation (*1*) of six radiometrically dated igneous rocks of late Pliocene and Pleistocene age from the Sierra Nevada of California led to the conclusion that if the polarity epochs of the earth's magnetic field are equal or nearly equal in length, then they are either ½ or 1 million years long. Normal polarity epochs are defined in terms of the geomagnetic field-reversal hypothesis