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Mercury's mean radius and shape from radio occultations

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Abstract

To support studies of Mercury's internal structure, a MESSENGER mission goal is to measure the shape of Mercury. Radio-frequency occultation observations contribute to this objective. We describe here the techniques used to derive radius measurements from such observations. We report results from flyby and early-orbit observations and compare them with planet-shape measurements by the Mercury Laser Altimeter.

1. Introduction

Before the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission, Mercury's shape was poorly constrained by existing measurements, which consisted primarily of Earth-based radar observations at low Mercury latitudes. Mercury Laser Altimeter (MLA) observations during MESSENGER's flybys of Mercury improved our understanding of the degree-2 equatorial shape [1]. From orbit about Mercury, the MLA is acquiring an extensive data set on the topography of Mercury's northern hemisphere, but most of the southern hemisphere is beyond MLA range because of MESSENGER's highly-inclined, eccentric orbit with initial periapsis at 60°N. Along with limb measurements and global stereo mosaics, occultation-derived radius measurements are essential for understanding the shape of Mercury's southern hemisphere.

Every twelve hours, for most of its one-year primary mission, the MESSENGER spacecraft passes behind Mercury as viewed from the Earth. This geometry causes Mercury to occult the radio frequency (RF) transmissions, and we use an open-loop receiver to record RF power at the ingress and egress of each occultation. Incorporating the effects of diffraction, we extract the time of occultation and use it to define the RF path that grazes Mercury's surface. The point on that RF path that is tangent to the surface defines a latitude, longitude, and radius.

To relate the measured radius to the planet shape, we evaluate local topography using images to identify the high-elevation feature that controls the RF occultation or use altimeter data to quantify surface roughness. The resulting radii, adjusted for topography, provide information on Mercury's shape, which we compare to MLA measurements in the northern hemisphere.

2. Flyby and early orbital data

There are three occultation events from MESSENGER's flybys of Mercury: the ingress and egress during the first flyby (M1) and egress during the third flyby (M3). Mercury did not occult the spacecraft during the second flyby, and a spacecraft anomaly prevented observation of the ingress during the third flyby. There are 330 occultations during the first 4.5 months in orbit about Mercury. Fig. 1 shows the latitude and longitude of these occultations, which are all north of 30°S. These northern occultations are ideal for calibration by comparison with MLA data, but they provide little information on the otherwise-unmeasured shape of the southern hemisphere. Later occultation observations include extensive coverage of Mercury's southern hemisphere.

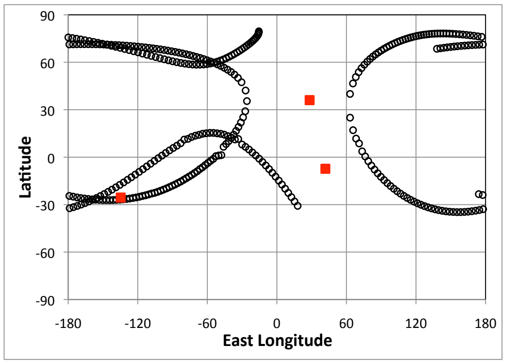

Figure 1. Location of the surface tangent point of flyby occultations (red squares) and early-orbit occultations (black circles).

Most occultation data have a low signal-to-noise ratio (SNR) because the spacecraft RF link is through MESSENGER's low-gain antennas. During the flybys, use of 70-m Deep Space Network (DSN) antennas produced signal levels of 24 to 36 dB-Hz. Because DSN's 34-m antennas are used for most communication from orbit, the signal level is lower for most orbital occultations.

3. Deriving measurements of radius

There are three parts to using RF occultations to derive knowledge of Mercury's shape [2]:

(1) Obtain the time of occultation ingress and egress by extracting power levels from the RF data, and then compare the levels to a calculated diffraction pattern. We assess several techniques for analyzing the RF data to produce power histories that have high time resolution and low noise. The technique that works best for low power levels is to track the frequency with a software phase-locked loop Subsequent fits of edge-diffraction patterns recover the time of occultation with a resolution between 0.03 s and 0.5 s, depending on the SNR.

(2) Use the known time-based position of MESSENGER relative to Mercury to convert the time of each occultation event to the radius, latitude and longitude at the point where the RF path grazes the surface. Reconstructed trajectory accuracy in the radial direction varies from 30 m for the flybys to as large as 600 m during the orbital mission phase. Timing uncertainty contributes less than 150 m for any of the flyby events but may contribute up to 750 m for low-SNR events during the orbital mission phase.

(3) Relate an occultation-derived radius measurement to the general shape of the planet at the point of measurement by adjusting for the relative height of topography where the grazing path contacts the surface. Data on local topographic features provide heights of those features relative to the value that we seek, the average radius of the surrounding terrain. We use the relative heights to adjust the absolute measurement derived from the occultation event. From images we identify the highest-elevation feature that defines the RF occultation point. Alternatively, we use altimeter data to quantify surface roughness [3]. For M3 egress, the grazing RF path appeared to intersect a crater, and we estimated the average height of surrounding terrain by subtracting the estimated height of the crater rim from the occultation measurement. For the M1 events, which showed no such intersecting feature in the images, we adjust the measured radius by 500 m, the average difference in MLA data between peak terrain and the height of surrounding terrain.

4. Results

Radius results from the flyby occultations, before and after adjusting for local topography, are shown in Figure 2. The uncertainty in the height of the surrounding terrain, after adjustments based on topography, is 350 m. Figure 2 also compares the radius measurements derived from RF occultations to Mercury's equatorial shape derived from MLA observations. The three independent estimates of radius from occultation events collectively yield a mean radius for Mercury of 2,439.2 ± 0.7 km.

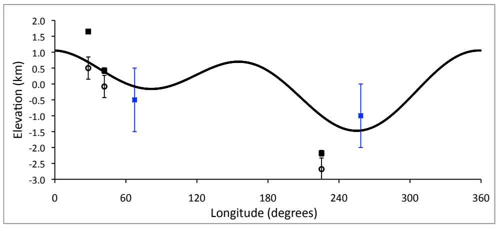

Figure 2. MESSENGER and Mariner 10 occultation measurements of radius compared to the spherical harmonic shape (degrees 1 and 2, black line) fit to MLA data obtained near Mercury's equatorial plane during MESSENGER's first and second flybys [1]. The square symbols show the elevation relative to a sphere of radius 2440 km. The circles and their associated error bars show the results after adjusting the MESSENGER measurements for local topography. Mariner 10 results are in blue [4].

We are currently using early orbital occultation results to verify agreement between occultation and MLA measurements. In the second half of the orbital mission phase, we will use the southern-hemisphere occultation measurements to map the low-degree shape of the southern hemisphere.

References

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