DOES MERCURY HAVE LUNAR-LIKE MASCONS?

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Introduction: In January and October 2008 the MESSENGER spacecraft conducted flybys of Mercury on its way to Mercury orbit insertion in March 2011. The closest approach on both flybys was 200 km above the surface [1], closer than any of the three flybys of Mercury in 1974-75 by the Mariner 10 spacecraft. The MESSENGER flyby trajectories were significantly perturbed by the anomalous gravity field of Mercury as well as by Mercury's mass. During both flybys the spacecraft approached Mercury at a relative velocity of 6 to 7 km/s, underwent a change in direction of 20° to 25°, and receded from the planet at a similar relative velocity. During the 30 minutes around the two closest approaches the spacecraft experienced greater perturbations in velocity [2] than was expected from Mariner 10 observations of the Mercury gravity field [3]. Further, it was impossible to represent these perturbations by adjustments to the planetary gravitational flattening and the equatorial gravitational ellipticity alone. Having ruled out errors in the tracking data, the effect of several-hundred-meter-level errors in the position of Mercury with respect to the Earth or Sun, other perturbing forces such as solar radiation and Mercury albedo pressure, we investigated the possibility of gravity anomalies associated with surface features, in particular large impact basins.

Flyby Perturbations: We analyzed approximately 14 days of Doppler tracking data centered on the time of closest approach on each of the flybys. The observed residual Doppler perturbations for 100 minutes around closest approach relative to the gravity field from Mariner 10 [3] are shown in Figure 1. On the first flyby the spacecraft was occulted from Earth for approximately 47 minutes, during which time tracking data were unobtainable. The velocity perturbation on flyby 2 was unexpectedly much larger than for flyby 1. Both ground tracks were slightly south of the equator and on opposite sides of the planet and should be equally sensitive to the equatorial ellipticity and equally insensitive to the polar flattening.

Estimating new values for GM (the product of the gravitational constant and mass of Mercury) and the low-degree gravity field in a combined two-MESSENGER-flyby solution reduced the residual Doppler near closest approach from 4.3 to 2.1 cm/s on flyby 1 and from 14.1 to 2.9 cm/s on flyby 2. For both flybys the largest reduction was a result of improving the value of GM over that estimated from Mariner 10.

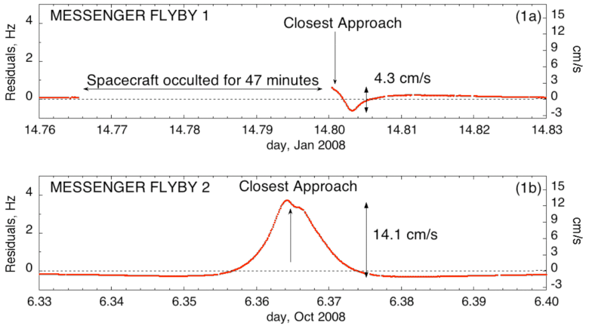

Figure 1. The residual perturbations after estimating the trajectory using gravity information from Mariner 10, which included the mass, flattening, and ellipticity of the equator.

Increasing the number of gravity coefficients reduced the magnitude of the residual patterns, but the value of the flattening became negative, implying a prolate mass distribution, which is implausible. In addition, solutions for several coefficients were highly correlated (correlation coefficient > 0.8).

We also estimated 10° x 10° block gravity anomalies along the ground tracks [2]. In individual flyby solutions, the addition of six gravity anomalies for flyby 1 decreased the residual pattern to 3 mm/s with acceptable values for GM and the degree 2 gravity coefficients. But for flyby 2, the addition of eight anomalies reduced the residual pattern to only 6 mm/s, the gravitational flattening went negative, and some of the correlations between the parameters exceeded 0.9. In a combined solution for flybys 1 and 2 with 12 gravity anomalies along the ground tracks, the residual pattern was reduced only to 18 mm/s and 31 mm/s, respectively, but with acceptable values for the second-degree gravity coefficients. In addition, the gravity anomalies in the combined solution suggested an increase of positive magnitude between 215 and 255°E for flyby 2. We decided to investigate the sensitivity to the locations of the gravity residual anomalies of the combined solution.

Localized Anomalies: In addition to the mass, flattening, and equatorial ellipticity we estimated values of eight anomalies at latitudes ±45° and longitudes 0, 90, 180, and 270°E. The choice of location was arbitrary and was an attempt to assess the sensitivity of the flybys to a global distribution of a small number of anomalies. Other distributions could have served the same purpose. *A priori* standard deviations of the gravity anomalies were 10 mGal. Results from this solution are shown in Figure 2.

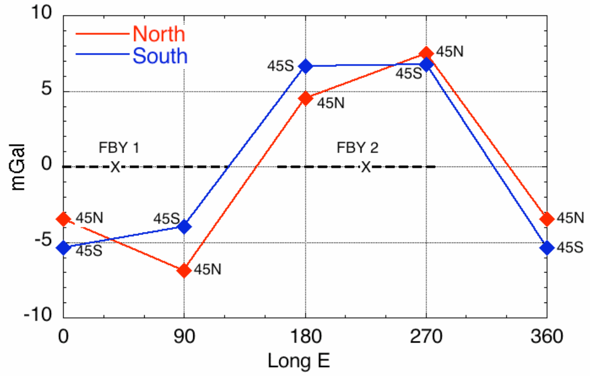

Figure 2. Gravity anomaly results for locations at latitudes 45°N and S. Black dashed lines show the longitudes of the ground tracks and the X indicates the approximate location of closest approach. Both ground tracks were a few degrees south of the equator. Gravity anomalies were estimated simultaneously with GM, the gravitational flattening, and gravitational equatorial ellipticity.

The results clearly show an increase in gravity anomaly magnitude between 180 and 270°E in both hemispheres, consistent with the individual result we saw for flyby 2. We then moved three of the eight gravity anomalies to locations of known basins [4]: Caloris, 30°N, 163°E; Tolstoj, 20°S, 195°E; and Matisse-Repin, 24°S, 285°E. These basins were chosen because they were close to the region of large anomalies and to the ground track of flyby 2. Figure 3 shows the results and the locations of the anomalies. All three basins show positive gravity anomalies.

The anomaly differences between the grid results of Figure 2 and the grid/basin results of Figure 3 are relatively small, but the solution with anomalies at three basins was a better fit to observations from both flybys. The grid solution (Figure 2) of anomalies had residual patterns for flybys 1 and 2 of 2 and 2.6 cm/s, respectively; the solution with the three basins (Figure 3) had respective residuals of 1.7 and 1.6 cm/s, a major improvement for flyby 2 and better than was obtainable with 12 anomalies along the two ground tracks.

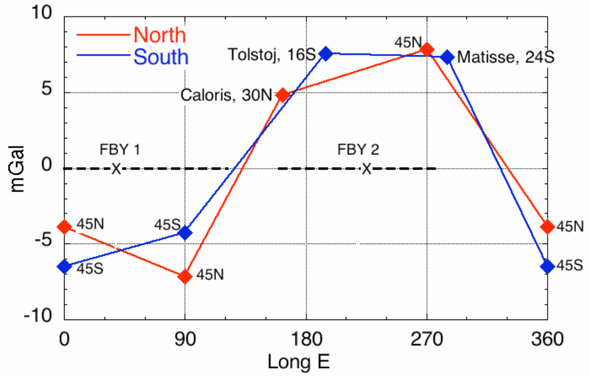

Figure 3. Mascon results. Latitudes are shown next to the value. Black dashed lines show the longitudes of the ground tracks and the X indicates the approximate location of closest approach. Gravity anomalies were estimated simultaneously with GM, the gravitational flattening, and gravitational equatorial ellipticity.

The three basins were chosen because of their size and location but with no prior reason to believe they would be a better choice for the location of a gravity anomaly than the locations in the regular grid. In addition, the standard deviations of the three basin anomalies were smaller than the other anomalies. The two basins that appear to have had the largest effect and also the smallest relative uncertainties are Tolstoj and Matisse in the southern hemisphere.

Summary: Our analysis of the two MESSENGER flybys suggests that Mercury has an increase in gravity between longitudes 180 and 270°E in both the northern and the southern hemispheres. Moreover, when we placed three mass anomalies at the locations of large impact basins, the resulting model fit the flyby Doppler data better than when these mass anomalies were positioned at arbitrary latitudes (±45°). We suspect that this result indicates that Mercury will be seen to have mass concentrations, or mascons, correlated with basins, much like the Moon [5], when MESSENGER enters Mercury orbit in 2011.

By using the approach described here to introduce other basin anomalies into our solution, it will be possible to assess which, if any, further improve our modeling of the Doppler tracking observations from the two MESSENGER flybys.

References: [1] Zuber M.T. et al. (2008) *Science, 321,* 77. [2] Smith D.E. et al. (2008) *Eos Trans. Am. Geophys. Un., 89,* Fall Meeting Suppl., U11C-03. [3] Anderson J.D. et al. (1987) *Icarus, 71,* 337. [4] Spudis P.D. and Guest J. D. (1988) *Mercury,* ed. F. Vilas, C.R. Chapman, and M.S. Matthews, Univ. Ariz. Press, Tucson, pp.118-164. [5] Muller P.M. and Sjogren W.L. (1968) *Science, 161,* 680.