MERCURY GRAVITY OBSERVATIONS DURING THE MESSENGER FLYBY OF JANUARY 2008.

David E. Smith[1], Maria T. Zuber[2], Roger J. Phillips[3], Sean C. Solomon[4], Stanton J. Peale[5], Jean-Luc Margot[6], Frank G. Lemoine[1], Gregory A. Neumann[1], Mark E. Perry[7], Dipak K. Srinivasan[7], Mark H. Torrence[8], Steven A. Hauck, II[8], [1]NASA Goddard Space Flight Center, Code 690, Greenbelt, Maryland 20771 (dsmith@tharsis.gsfc.nasa.gov; neumann@tharsis.gsfc.nasa.gov; Frank.Lemoine@gsfc.nasa.gov); [2]Massachusetts Institute of Technology, Cambridge, MA 02129 (zuber@mit.edu); [3]Southwest Research Institute, Boulder, CO 80302 (roger@boulder.swri.edu); [4]Carnegie Institution of Washington, Washington DC 20015 (scs@dtm.ciw.edu); [5]University of California, Santa Barbara, CA 93106 (peale@io.physics.ucsb.edu); [6]Dept. of Astronomy, Cornell University, Ithaca, NY 14853 (jlm@astro.cornell.edu); [7]Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723 (Mark.Perry@jhuapl.edu; Dipak.Srinivasan@jhuapl.edu); [8]SGT, Inc., 7701 Greenbelt Rd., Greenbelt, MD 20770 (Mark.H.Torrence.1@gsfc.nasa.gov); Case Western Reserve University, Cleveland, OH 44106 (hauck@case.edu).

Introduction: On January 14, 2008, the MESSENGER spacecraft will fly by the planet Mercury at a closest approach altitude of 193 km. The spacecraft will be tracked nearly continuously by the Deep Space Network (DSN) for about 2 days before and after the encounter and will provide Doppler tracking measurements whenever MESSENGER is visible from Earth. The tracking data will provide important information on the low-degree gravity field of Mercury, which was last measured by Mariner 10 in 1974-75 and which could provide critical data on the size of Mercury's core [1, 2].

Orbital Geometry of the Flyby: The important time period for estimating the coefficients of Mercury's gravity field is within about 5 hours on either side of closest approach. At the greater distances the orbit is almost unperturbed by Mercury except for its central mass term, but as MESSENGER approaches the planet the effect of the very-low-degree terms in the gravity field becomes detectable in the Doppler and range tracking signals. Figure 1 shows the altitude of MESSENGER above the surface of Mercury for 10 hours when within 10^5 km. The closest approach will occur around 1905 GMT on January 14, 2008, just south of the equator at longitude ~38°E.

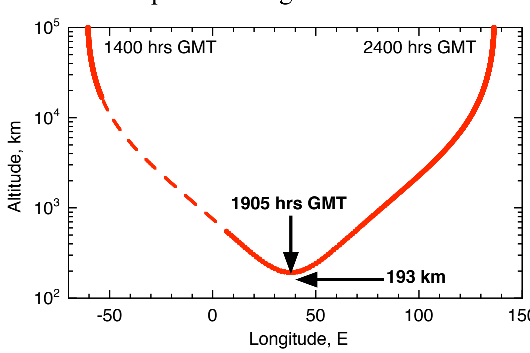

Figure 1. The predicted altitude of MESSENGER above Mercury during the 10-hour period centered on closest approach on January 14, 2008. The dashed line is when the spacecraft is behind Mercury and not observable from Earth.

Mercury's Gravity Field: Our present knowledge of Mercury's gravity field comes exclusively from three flybys of Mariner 10 in 1974 and 1975 [3, 4]. These flybys provided estimates of the C_{20} and C_{22} terms, which represent the latitudinal flattening (oblateness) and equatorial ellipticity of Mercury's gravity field. Their quoted uncertainties [4] are 30% for C_{20} and 50% for C_{22}. The geometry of the MESSENGER flyby is different from that of any of the Mariner 10 flybys because the longitude and latitude of closest approach will be different, and the lowest altitude will be less. Further, the geometry of the flyby is such that the spacecraft motion is almost in the line-of-sight direction from Earth after closest approach, enabling the maximum Doppler signal to be observed. Figure 2 shows the geometry of the MESSENGER flyby projected onto the equatorial plane of Mercury.

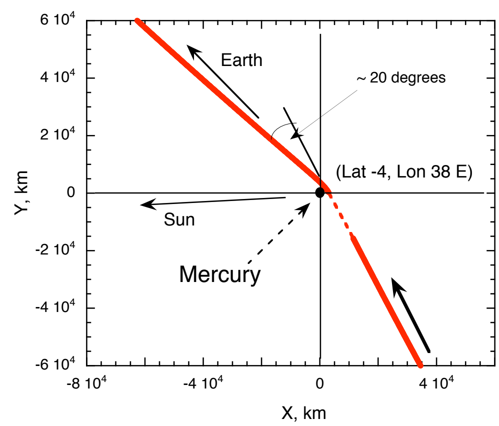

Figure 2. Trajectory of the MESSENGER flyby projected onto Mercury's equatorial plane (X,Y). The predicted closest approach by MESSENGER is 193 km altitude at 4°S, 38°E, and the MESSENGER trajectory is deflected approximately 20° by the flyby.

The flyby of MESSENGER has the possibility of significantly reducing the uncertainties in the C_{20} and C_{22} coefficients. A 1-σ error in either coefficient could produce a 1 cm/s change in spacecraft velocity, which would be observable in the X-band Doppler signal, which has an accuracy of ~0.1 mm/s [5].

Figure 3 shows the perturbations in spacecraft line-of-sight velocity as a result of propagating a 1-σ error in the gravity coefficients C_{20} and C_{22}. The effect of an error in either coefficient is to produce an initial rise or decline in velocity (not observable due to the occultation by the planet) followed by a fall (or rise) after closest approach. The Doppler-like curves in Figure 3 are not symmetric because the deviations shown are a propagation rather than a fit to the data.

Any deviation in range-rate signal from the predicted will be the result of the combined errors in the Mariner 10 gravity coefficients used to generate the prediction, and will have a signature similar in form to the red curve in Figure 3 but of unknown amplitude or sign.

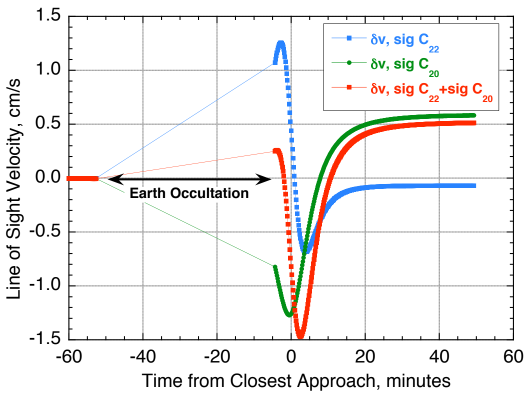

Figure 3. Changes in the velocity of the MESSENGER spacecraft resulting from the published 1-σ errors in the C_{20} and C_{22} gravity field coefficients.

The biggest challenge in interpreting the flyby gravity signal will likely be separating the C_{20} and C_{22} components, and possibly identifying contributions from other gravity coefficients presently ignored. But if the present values are in error by even 10% we expect to be able to deduce that information directly from the tracking data, and thereby hope to reduce the uncertainties in C_{20} and C_{22} significantly. More tightly constrained values of these coefficients will significantly reduce the uncertainties in the extent of the liquid core."

References: [1] Peale S. J. et al. (2002) *Meteoritics & Planet. Sci., 37*, 1269-1283. [2] Zuber M. T. et al. (2007) *Space Sci. Rev., 131*, 105-132. [3] Howard H. T. et al. (1974) *Science, 185*, 179-180. [4] Anderson J. D. et al. (1987) *Icarus, 71*, 337-349. [5] Srinivasan D. K. et al. (2007) *Space Sci. Rev., 131*, 557-571.