EPSC Abstracts
Vol. 6, EPSC-DPS2011-139, 2011
EPSC-DPS Joint Meeting 2011

Mercury's Gravity Field from MESSENGER after Six Months in Orbit

Frank G. Lemoine[1], David E. Smith[2], Stanton J. Peale[3], Roger J. Phillips[4], Sean C. Solomon[5], Maria T. Zuber[2], Jean-Luc Margot[6], Gregory A. Neumann[1], Mark H. Torrence[7], and Mark E. Perry[8]; [1]NASA Goddard Space Flight Center, Code 690, Greenbelt, MD 20771, USA (Frank.Lemoine@gsfc.nasa.gov; gregory.a.neumann@nasa.gov); [2]Massachusetts Institute of Technology, Cambridge, MA 02129, USA (David.E.Smith@nasa.gov; zuber@mit.edu); [3]Department of Physics, University of California, Santa Barbara, CA 93106, USA (peale@physics.ucsb.edu); [4]Planetary Science Directorate, Southwest Research Institute, Boulder, CO 80302, USA (roger@boulder.swri.edu); [5]Carnegie Institution of Washington, Washington, DC 20015, USA (scs@dtm.ciw.edu); [6]Department of Earth and Space Sciences, University of California, Los Angeles, CA 90095, USA (jeanlucmargot@gmail.com); [7]SGT, Inc., 7701 Greenbelt Rd., Greenbelt, MD 20770, USA (Mark.H.Torrence@nasa.gov), [8]Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA (Mark.Perry@jhuapl.edu)

Abstract

After an interplanetary cruise phase of nearly 7 years, including three flybys of the innermost planet, the MESSENGER spacecraft entered into orbit about Mercury on 18 March 2011. One of the major science measurement objectives of the orbital mission phase is the determination of Mercury's gravity field for improving our understanding of the planet's internal structure, the state of the core, the thickness of the crust, and the tectonic and thermal history of the planet.

1. Introduction

The orbit of the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft is eccentric, with a periapsis altitude that varies between approximately 200 km and 500 km, an apoapsis altitude of approximately 15,000 km, and an orbit inclination of 82.5°. The periapsis latitude was initially at 60°N and is moving slowly northwards with time. As a consequence, the ultimate resolution of the gravity field is of order a few hundred kilometers at northern latitudes and a few thousand kilometers over the southern hemisphere.

Tracking data from the first full 59-day rotation of Mercury show that the performance of the X-band microwave tracking system on the high-gain phased-array antenna is performing at the expected level of 0.1 mm/s averaged over 5 s intervals. Data are also being obtained regularly on the medium-gain antenna but with a lower signal strength and greater noise when MESSENGER is on the far side of the Sun from Earth.

2. Gravity Field Determination

To determine Mercury's gravity field from MESSENGER tracking data, we are using the NASA Goddard Space Flight Center's GEODYN precision orbit determination and geodetic parameter estimation program to process the data and develop normal equations in spherical harmonics. The orbit geometry provides direct Doppler coverage over the northern hemisphere to just south of the equator to 1500 km altitude. Preliminary solutions are being obtained for fields of spherical harmonic degree and order 20, which represents a block size on the surface of approximately 200 km in the vicinity of periapsis. After one rotation of the planet (59 days), the estimate for the mass of Mercury has confirmed the value obtained from the MESSENGER flybys [1] to be less than the value obtained from the three Mariner 10 flybys [2].

The primary perturbations of the MESSENGER orbit, in addition to the gravity field are, in order of magnitude, the forces of solar radiation pressure, the infrared radiation from Mercury, Mercury's albedo, and thermal radiation from the spacecraft. These non-conservative forces, which produce accelerations smaller than those induced by the low-degree coefficients in the gravity field, are still a major factor in the quality of the gravity signal that can be estimated from the tracking data because they require complex modeling of the spacecraft. We model these forces following Marshall and Luthcke [3] and Milani et al. [4] using a box-wing representation of the spacecraft and quaternions that specify the orientation of the spacecraft and the articulating solar arrays. The thermal radiation is modeled with an *a* *priori* surface thermal model of Mercury [5] adapted for use in GEODYN. In addition to modeling of these forces, the analysis of the tracking data follows conventional procedures and models other perturbations including, for example, the third-body perturbations and relativity effects in both the force and measurement modeling (cf. [6]). *The a priori* Mercury-based reference frame for this analysis is the Mercury orientation model of Margot [7].

The traditional representation in spherical harmonics of a gravity field for which the resolution varies markedly with latitude presents further issues for estimating the field. Alternative representations for gravity, particularly for local areas, are consequently being developed and tested.

3. Importance of the Second-degree Gravity Coefficients

Since Mercury is in a Cassini rotation state that fixes the spin axis in a frame precessing with the orbit [8], the accurate determination of the second-degree gravitational field coefficients C_{20} ($-J_2$) and C_{22}, together with the radar-measured obliquity [8], will determine the normalized moment of inertia C/MR^2 [9]. This moment of inertia combined with C_{22} and the radar-determined amplitude of the 88-day physical libration in longitude will determine C_m/C [9], the ratio of the moment of inertia of the mantle and crust to the total moment of inertia. A known moment of inertia will provide fundamental constraints on the interior distribution of mass and the radius and light-element content of the liquid core [10,11].

References

[1] Smith, D.E., et al., The equatorial shape and gravity field of Mercury from MESSENGER flybys 1 and 2, Icarus, 209, 88–100, doi: 10.1016/j.icarus.2010.02.026, 2010.

[2] Anderson, J.D., et al., The mass, gravity field and ephemeris of Mercury, Icarus, 71, 337–349, 1987.

[3] Marshall, J.A.M., and Luthcke, S.B., Radiative force model performance for TOPEX/Poseidon precision orbit determination, J. Astronaut. Sci., 45, 229–246, 1994.

[4] Milani, A., Nobili, A.M., and Farinella, P., Non-Gravitational Perturbations and Satellite Geodesy, Adam Hilger, Bristol, 1987.

[5] Paige, D.A., Wood, S.E., and Vasavada, A.R., The thermal stability of water ice at the poles of Mercury, Science, 258, 643–646, 1992.

[6] Mazarico, E., Lemoine, F.G., Han, S.C., and Smith, D.E., GLGM-3: A degree 150 lunar gravity model from the historical data of the NASA Moon orbiters, J. Geophys. Res., 115, E05001, 2010.

[7] Margot, J-L., A Mercury orientation model including non-zero obliquity and librations, Celest. Mech. Dyn. Astron., 105, 329–336, 2009.

[8] Margot, J.L., Peale, S.J., Jurgens, R.F., Slade, M.A., and Holin, I.V., Large longitude libration of Mercury reveals a molten core, Science, 316, 710–714, 2007.

[9] Peale, S.J., Phillips, R.J., Solomon, S.C., Smith, D.E., and Zuber, M.T., A procedure for determining the nature of Mercury's core, Meteorit. Planet. Sci., 37, 1269–1283, 2002.

[10] Hauck, S.A., Solomon, S.C., Peale, S.J., Margot, J.L., Phillips, R.J., Smith, D.E., and Zuber, M.T., Constraints on the internal structure of Mercury after three MESSENGER flybys, Lunar Planet. Sci., 41, 2107, 2010.

[11] Harder, H., and Schubert, G., Sulfur in Mercury's core? Icarus 151, 118–122, 2001.