EPSC Abstracts
Vol. 13, EPSC-DPS2019-1464-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

The Gravity Field of Mercury after the MESSENGER mission

Antonio Genova (1), Sander Goossens (2), Erwan Mazarico (3), David E. Smith (4), and Maria T. Zuber (4)
(1) Sapienza University of Rome, Italy, (2) Center for Research and Exploration in Space Science and Technology, University of Maryland, Baltimore County, MD, USA, (3) NASA Goddard Space Flight Center, MD, USA, (4) Massachusetts Institute of Technology, MA, USA, (antonio.genova@uniroma1.it)

Abstract

The MESSENGER spacecraft orbited Mercury for more than 4 years providing unprecedented gravity measurements of the planet. We analyzed the entire MESSENGER dataset including the three Mercury flybys in 2008 and 2009 to determine a high-resolution map of the gravity field. This latest solution, *HgM008*, was retrieved by using a novel technique of orbit determination that also enabled new estimates of the planet's pole coordinates and tides. These measured geophysical quantities allowed us to provide crucial information on Mercury's internal structure including evidence for the presence of a large solid inner core [1].

1. Introduction

The determination of Mercury's gravity field was one of the main science objectives of the MESSENGER radio science investigation. The radio science system aboard the MESSENGER spacecraft enabled highly accurate measurements of the relative distance (*range*) and velocity (*range-rate*) along the line-of-sight between the spacecraft and the Deep Space Network stations [2]. An accurate processing of these radio tracking data is fundamental to retrieve the gravity field of the planet.

The data acquired during MESSENGER's orbital mission are very sensitive to the gravitational anomalies in the northern hemisphere since its initial orbit was highly eccentric and nearly polar, with a periapsis at 200-km altitude and ~60ºN latitude. This orbit configuration was controlled by using orbit-correction maneuvers (OCMs). After one year of operations around Mercury, the mission was extended for another year allowing a natural drift of the spacecraft periapsis altitude and latitude due to the third-body perturbation of the Sun. A second extended mission (XM2) started in March 2013, and a low-altitude campaign was performed from 2014. This last year of operations until the spacecraft's impact onto Mercury's surface on 30 April 2015 led to the acquisition of radio tracking at periapsis altitudes as low as 15-25 km for several weeks.

We analyzed the full MESSENGER dataset to estimate a high-resolution model of the gravity field of Mercury in the northern hemisphere. Our solution includes the retrieval of the coordinates of the pole and the Love number k_2 that provide significant constraints on the interior of Mercury.

2. Method

Our processing of the MESSENGER radio tracking data is based on a novel technique that consists of the co-integration and co-estimation of both planet and spacecraft orbits. The NASA Goddard Space Flight Center (GSFC) orbit determination software GEODYN II [3] was modified to enable this approach for the analysis of the MESSENGER data. Previous works on the determination of Mercury's gravity field adopted the Jet Propulsion Laboratory (JPL) Development Ephemeris (DE) for the orbit of Mercury. In this study, we integrated the ephemeris of Mercury from the initial epoch of MESSENGER's first Mercury flyby (7 January 2008) by modeling the solar system with all the planets, the Moon, and 343 main belt asteroids. The combined integration of MESSENGER and Mercury orbits enabled the estimation of parameters related to geophysics (*e.g.*, Mercury's gravity field), and to other disciplines, such as fundamental physics (*i.e.*, General Relativity) and heliophysics [4].

To determine the geophysical parameters that affect the orbit of the MESSENGER spacecraft, we divided the orbital mission into 1499 1-day arcs from 2011 to 2015. Three additional ~10-day arcs were also added for the three Mercury flybys. However, because of the solar plasma noise in the radio tracking data during superior solar conjunctions and perturbative effects due to maneuvers, we excluded ~600 arcs in the final gravity solution *HgM008*. In each arc, we estimated the initial state of the spacecraft, sunshade and solar panel effective areas to mitigate mismodeling of solar radiation pressure or thermo-optical properties of the spacecraft panels. These arc-dependent parameters were then adjusted in a global iteration with Mercury's ephemeris, and heliophysical, General Relativity, and geophysical model parameters that consisted of the gravity field expanded in spherical harmonics to degree and order 100, the pole obliquity, longitudinal librations, and the Love number k_2.

3. *HgM008* Gravity Field

The resulting spherical harmonics coefficients of our gravity solution are archived on the NASA GSFC Planetary Geology, Geophysics and Geochemistry Laboratory at https://pgda.gsfc.nasa.gov/products/71. Figure 1 shows the free-air gravity anomaly of *HgM008* in the northern hemisphere over a shaded topographic relief in a stereographic projection. The correlation between gravity and topography is significantly improved in regions where the spacecraft was at low altitudes.

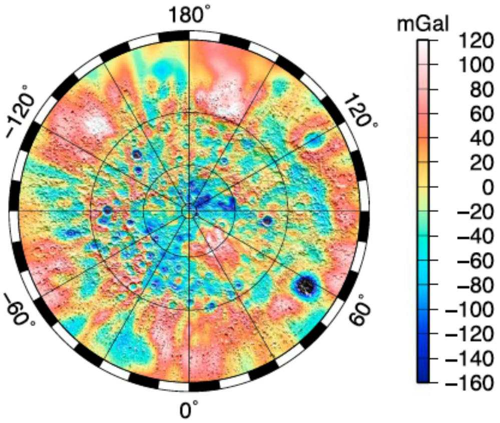

Figure 1: *HgM008* Free-air gravity anomaly map (mGal) in a polar stereographic projection between 30ºN-90ºN latitudes.

These improved free-air gravity anomaly map allows us to determine the thickness variations of Mercury's crust. By assuming a homogenous crustal density ρ_c = 2800 kg m^{-3}, we derived the Bouguer gravity anomaly as the difference between free-air gravity and the gravity predicted from topography. We included the effects of finite-amplitude corrections by raising the topographic relief to a power of 5 when computing the spherical harmonic coefficients of the gravity predicted by surface topographic relief [5]. To determine the crustal thickness variations from the Bouguer anomalies, we also assumed an average thickness for the crust of 35 km [6,7], and a mantle-crust density contrast of 400 kg m^{-3}. Figure 2 shows the resulting crustal thickness variations in the northern hemisphere.

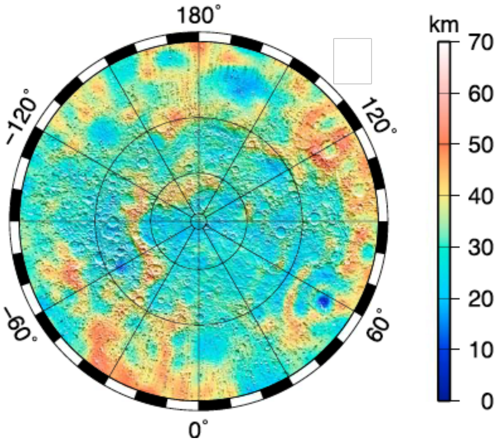

Figure 2: Crustal thickness map (km) in a polar stereographic projection between 30ºN-90ºN latitudes.

4. Summary

We will present the latest solution of Mercury's gravity field by showing its correlation with topography on local regions of the northern hemisphere. Our results also include the estimation of the Love number k_2 and the pole's obliquity that inform on Mercury's mantle and deep interior, respectively.

References

[1] Genova, A., et al., Geodetic evidence that Mercury has a solid inner core. *Geophys. Res. Let.*, 46, 3625– 3633.

[2] Srinivasan, D. K., et al. (2007). The radio frequency subsystem and radio science on the MESSENGER mission. *Space Sci. Rev.*, 131(1), 557–571.

[3] Pavlis, D. E.,Wimert, J., and McCarthy, J. J. (2013). GEODYN II System Description, vol. 1-5. Greenbelt, MD: SGT Inc.

[4] Genova, A., et al. (2018). Solar system expansion and strong equivalence principle as seen by the NASA MESSENGER mission. *Nature Comm.*, 9(1), 289.

[5] Wieczorek, M. A., & Phillips, R. J. (1998). Potential anomalies on a sphere: Applications to the thickness of the lunar crust. *J. Geophys. Res.*, 103(E1), 1715–1724.

[6] Padovan, et al. (2015). Thickness of the crust of Mercury from geoid-to-topography ratios. *Geophys. Res. Let.*, 42, 1029–1038.

[7] James, P. B., et al., S. C. (2015). Support of long-wavelength topography on Mercury inferred from MESSENGER measurements of gravity and topography. *J. Geophys. Res. Planets*, 120, 287–310.