Mercury's Rotation Rate from Three Years of Observations by the Mercury Laser Altimeter.
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Introduction: Mercury's rotation is tidally coupled to its orbit. The planet rotates three times for every two revolutions around the Sun. In addition to its mean rotation, longitudinal librations are expected because of Mercury's eccentric orbit and the aspherical distribution of mass within the planet. The annual libration has a period of about 89 days and an amplitude of 38.5 arc seconds [1]. Further, perturbations on Mercury's orbit by other planets can lead to long-period librations (with a dominant period of about 12 years [2,3]), which at short time scales would manifest themselves as an apparent small secular change to the mean rotation rate. Measurements of rotational parameters are of considerable interest because they are related to key internal structural parameters [1]. Furthermore, precise knowledge of the planet's rotation rate is essential for producing accurate maps and planning spacecraft observations.

The MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft, in orbit about Mercury for more than three years, enables precise measurements of rotational parameters. As of April 2014, MESSENGER's Mercury Laser Altimeter (MLA) had performed over 30,000,000 high-accuracy range measurements to Mercury's surface. Because of the spacecraft's eccentric orbit and high northern periapsis the ranging by the instrument is performed dominantly in Mercury's northern hemisphere (Fig. 1).

Method: From the MLA observations we determined simultaneously the spherical harmonic coefficients of the topography and the rotation rate of Mercury. This method has been described for simulated MLA data [4] and was recently applied to simulated data from the BepiColombo Laser Altimeter (BELA) [5]. The method benefits from the wide temporal and spatial distribution of the observations. From the laser range measurements at different epochs we applied a model with static and dynamic topography components. The static topography was expanded in spherical harmonics. The body-fixed coordinates of the laser altimeter measurements were computed from the rotation rate value and the dynamic component of the topography. Observations at the same coordinates but at different epochs allow us to separate dynamic and static topography. The observation equation for the inversion is

$$r_{\mathrm{LA}}^i = \sum_{l=0}^{l_{\max}} \sum_{m=-l}^{l} \begin{Bmatrix} C_{lm}, & m \geq 0 \\ S_{lm}, & m < 0 \end{Bmatrix} Y_l^m(\lambda^i, \phi(t^i)) + \epsilon_r^i \,, \quad (1)$$

where Y_l^m is the spherical harmonic function and C_{lm}, S_{lm} are the corresponding coefficients of degree l and order m. The expansion is performed up to a maximum degree $l_{\max}$ of 60. r_{LA}^i is the ith observation of the planet's radius, λ^i is the corresponding body-fixed latitude, and $\phi(t^i)$ the longitude. The mismatch between the observed radius and the model is denoted by the residual ϵ_r^i. The longitude of the observation is computed from the inertial longitude φ^i of the laser altimeter footprint and the time of observation t^i by

$$\phi(t^i) = \varphi^i + \omega_1 t^i \,, \quad (2)$$

where ω_1 is the apparent rotation rate during 2011-2014. Although the method in principle can also be used to determine the amplitude of the forced libration, the limited coverage with MLA profiles in equatorial regions makes the detection of the small librations challenging and is not treated in this work. Further, we neglected any variation in ω_1 and derived a mean value for the three years of observations.

We performed a least-squares inversion for the unknown parameters. We applied a weighting scheme to account for varying observing conditions (e.g., off-nadir pointing of the instrument). Because MLA observations are limited to the northern hemisphere of Mercury, the inversion for the (global) spherical harmonic coefficients cannot be performed without constraining the solution with a priori information. For that purpose, we applied a spherical harmonic solution for Mercury's topography (HTM02) to degree and order 120. This was obtained with the help of a regularization technique, based on Kaula's power law, and additional radio occultation data in the southern hemisphere [6]. With that solution as a priori information, we solved simultaneously for the topography coefficients and the rotation rate of the planet. We also performed our calculation with a priori information provided from limb images [7] and with a localized spherical harmonic approach [8].

To assess the uncertainty in the rotation rate value we performed simulations of laser altimeter measurements with an assumed rotation rate and characteristic uncertainties for spacecraft position and laser time-of-flight measurements. Then we inverted for the assumed rotation rate and derived the uncertainty from the variance of the simulation results.

References: [1] Margot J.-L. et al. (2012) *JGR, 117*, E00L09. [2] Peale S. J. et al. (2007) *Icarus, 187*, 365-373. [3] Yseboodt, M. et al. (2010) *Icarus, 207*, 536-544. [4] Zuber M. T. and Smith D. E. (1997) *LPS 28*, abstract 1637. [5] Koch C. et al. (2008) *Planet. Space Sci., 56*, 1226-1237. [6] Perry M. E. et al. (2013) MESSENGER Radio Science Reduced Data Record (MESS-H-RSS-5-SDP-V1.0). NASA Planetary Data System. http://pds.nasa.gov/ds-view/pds/viewDataset.jsp?dsid=MESS-H-RSS%2FMLA-5-SDP-V1.0. Data set released on 1 April 2014 (last accessed 02.01.15). [7] Elgner S. et al. (2014) *Planet. Space. Sci., 103*, 299-308. [8] Wieczorek M. A. and Simons F. J. (2005) *Geophys. J. Int., 162*, 655-675.

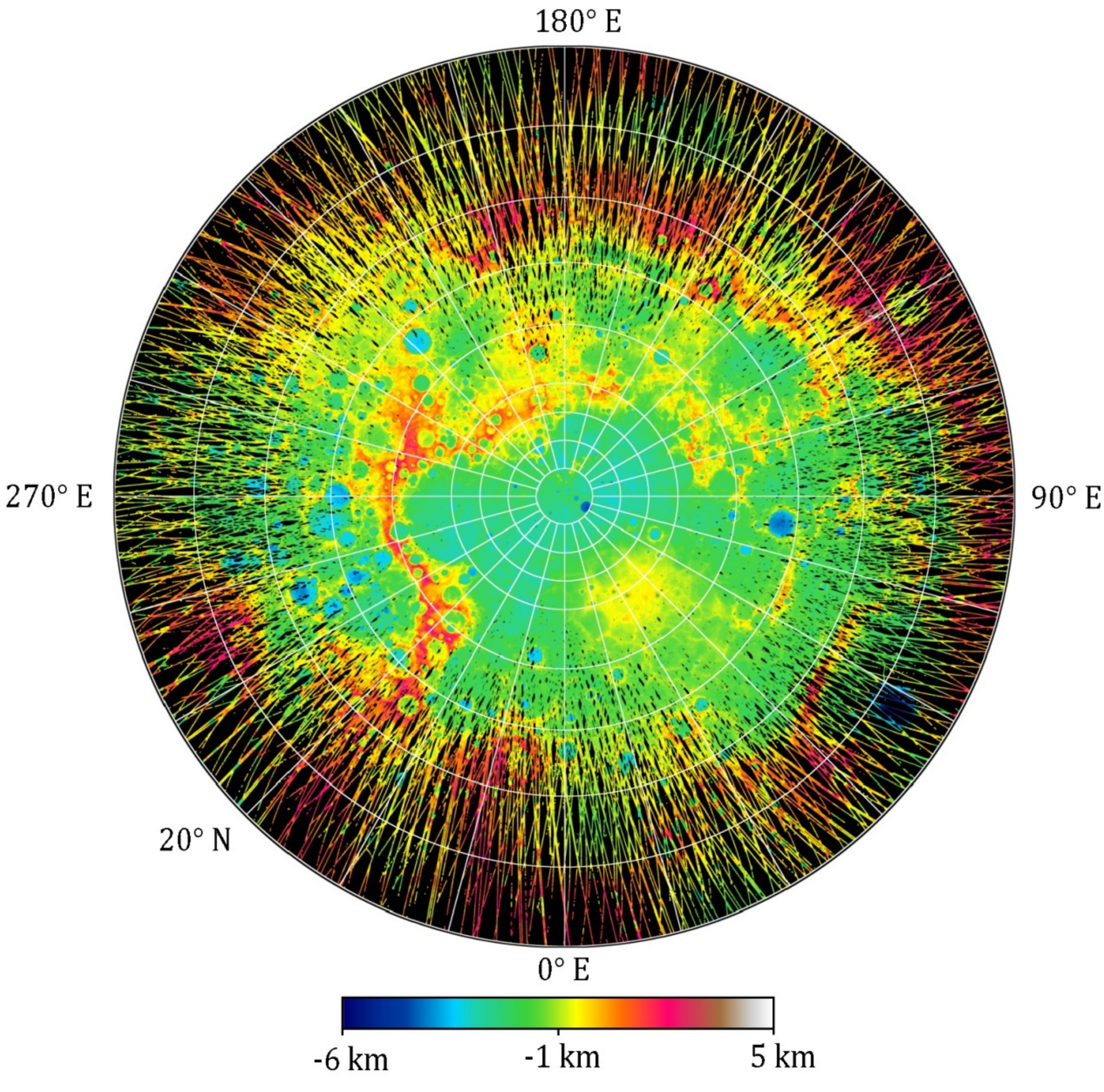

Figure 1. Mercury Laser Altimeter profiles as of April 2014 in a stereographic projection centered on the north pole and extending southward to 20°N.