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# Mercury's Rotational State from self-registration of Mercury Laser Altimeter profiles

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## Abstract

We use Mercury Laser Altimeter (MLA) data to measure Mercury's rotational state. In four years of orbital observations MLA onboard the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSNEGER) spacecraft provided 3226 topographic profiles of Mercury. Counting in total more than 22 million precise range measurements this dataset represents a valuable source for the measurement of Mercury's rotational state. Indeed, Mercury's obliquity and libration amplitude represent critical constraints for models of its interior.

## 1. Introduction

Mercury exhibits a unique rotation state. Its rotation is tidally coupled to its orbit in a 3:2 resonance. As Mercury's mantel is decoupled from the molten outer core forced longitudinal librations, i.e. small periodic changes in the rotation rate, are observed [1,2,3]. Furthermore, driven by tidal forces the rotation axis of Mercury occupies a Cassini state, i.e. an equilibrium configuration of rotation axis with the orbital plane normal and Laplace plane normal. Both the obliquity and libration amplitude comprise information about the moments of inertia of the planet. Combined with low degree and order spherical harmonics coefficients of Mercury's gravity field one can infer the depth of the core-mantle boundary and the densities of the mantel and core.

In a recent work Mercury's rotation was measured using co-registration of MLA profiles and digital terrain models (DTMs) derived from images using stereo photogrammetry [3]. Due to the limited coverage provided by the stereo DTMs the authors have used only 50% of the MLA measurements distributed over three years of MESSENGER orbital observations. Nonetheless, Mercury's mean rotation rate, obliquity, and the libration amplitude could be determined through precise co-registration of the two complementary topographic data sets.

## 2. Data

The MESSENGER spacecraft orbited Mercury from March 2011 to April 2015. On its eccentric near-polar orbit the range to the surface of Mercury typically varied from about 200 km up to 15,200 km. With the pericenter located at high northern latitudes the coverage with MLA profiles is limited to the northern hemisphere of Mercury. However, at the polar region where all profiles intersect the density of MLA footprints, usually separated by about 400 m, becomes very large and allows the compilation of an accurate DTM with resolutions of a few hundred meters.

## 3. Method

In this work we exploit the idea of the co-registration method and perform a "self-registration" of the MLA profiles. In contrast to the co-registration approach where two data sets originate from different instruments, the self-registration approach comprises the registration of one data set to itself. In order to measure Mercury's rotational state we construct a precise, internally consistent DTM of Mercury using the self-registration approach. This reference DTM subsequently serves for the measurement of Mercury's rotational state. We focus on the high northern latitudes where the density of MLA footprints allows the construction of a DTM with a pixel resolution of 222 m. To remove the MLA profiles from residual errors in spacecraft orbit and pointing, as well as Mercury rotation, we iteratively select a random subset of MLA profiles (typically 25%) and co-register them to a DTM constructed from the remaining profiles. Thereby, we allow maximal flexibility in the co-registration parameters in order to achieve maximal compensation of all lateral offsets between the profiles. After about 50 iterations all profiles are removed from false detections, i.e. noise considered as valid range measurements, and positioned consistently to other profiles. With the reference DTM we can now take the initial (uncorrected) laser profiles and explicitly solve for the rotational state of Mercury. In fact, as each profile was obtained within a relatively short time period (a few minutes) we can solve for the instantaneous orientation of Mercury at the observation time of the profile. By analysis of sets of profiles taken over longer time we may carry out a precise tracking of Mercury's rotation. Moreover, the procedure permits validation of the assumed rotational models, which typically is not feasible in a least-squares adjustment.

## 4. Discussion and Outlook

The self-registration technique is similar to the more common cross-over adjustment, where height differences of intersecting profiles are used as observables [4,5,6]. However, typical issues arising in the usage of the cross-overs are resolved in the self-registration approach. For instance, the interpolation errors due to large separation of laser footprints typically diminish the accuracy of the cross-over observables. Indeed, while the cross-over observables are determined by four footprints, in the self-registration approach all footprints of a profile are used to align it to footprints of all other profiles in its vicinity.

The self-registration method builds upon a high density of laser altimeter footprints. For spacecraft in polar orbits (as is the case for MESSENGER) laser altimeter profiles merge near the poles. Here, however, the angle of rotation about the axis causes the smallest lateral displacement. Consequently, the measurement of the rotation angle becomes challenging and is associated with a higher uncertainty. In contrast, the orientation of the rotational axis is typically very well constrained and allows precise measurement of the obliquity. The proposed method can also be used to measure tidal deformations, as the reference DTM comprises a static topography to which the periodic radial displacements caused by tides can be tracked over time. Such measurement, however, require precise sub-meter range measurements and accurate spacecraft orbit and pointing information, conditions possibly achievable with the BepiColombo Laser Altimeter (BELA) [5].

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## References

[1] Margot, J. L. et al., *Science*, 316, 710, doi: 10.1029/2012je004161, 2007.
[2] Margot, J. L., et al., *JGR-Planets*, 117, E00L09, doi: 10.1126/science.1140514, 2012.
[3] Stark, A., et al., *GRL*, 42, 7881, doi: 10.1002/2015gl065152, 2015.
[4] Neumann, G. A. et al., *JGR-Planets*, 106, 23753, doi: 10.1029/2000je001381, 2001.
[5] Mazarico E. et al, *47$^{th}$ Lunar and Planetary Science Conference*. The Woodlands, Texas, Abstract number 2062, 2016.
[6] Steinbrügge, G. et al., *PSS*, in press, doi:10.1016/j.pss.2018.04.017, 2018.