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Determination of Mercury's gravity and orientation through the BepiColombo's radio science experiment

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Abstract

The Mercury Orbiter Radio science Experiment (MORE) is one of the investigations of the ESA/JAXA BepiColombo mission to Mercury. MORE is designed to estimate the Mercury's gravity field, its rotational state, and to perform tests of relativistic gravity. The state-of-the-art onboard and ground instrumentations enables simultaneous two-way links in X/X, X/Ka, and Ka/Ka, providing a range rate accuracy of 3 micron/s (at 1000 s of integration time) and range accuracy of 20 cm. The non-gravitational acceleration will be provided by a dedicated accelerometer (Italian Spring Accelerometer, ISA). We present the results of the numerical simulations of the Mercury's gravity field and orientation recovery. They were carried out considering the latest mission scenario and including the ISA in-flight calibration in the orbit determination process to reduce measurement errors due to electronic noise, thermal drift, and ageing.

1. Introduction

The European Space Agency (ESA) and the Japanese Space Exploration Agency (JAXA) are developing the dual-spacecraft mission BepiColombo to survey and explore the planet Mercury. The mission is scheduled for launch in October 2018, with arrival in Mercury in December 2025. Due to gravitational perturbations the orbit will undergo significant changes, with an increase of the eccentricity and a latitudinal precession of the pericenter. One of the two spacecraft, the Mercury Planetary Orbiter (MPO), will be devoted to the study of the internal structure of Mercury and its surface geology. The MPO will have a near-polar orbit with pericenter at 480 km and apocenter at 1500 km and will host the Mercury Orbiter Radio science Experiment (MORE). MORE consists of a radio tracking system that supports multi-frequency radio links in X- and Ka-band between the spacecraft and ground stations. Range rate and range measurements, accurate respectively to 3 μm/s (at 1000 s time scale) and 20 cm at nearly all elongation angles, will be collected to reconstruct the spacecraft orbit and to estimate Mercury's gravity field, its pole orientation parameters (right ascension and declination of the pole), and the amplitude of librations in longitude [1]. Non-gravitational accelerations, quite large at Mercury (about 10^{-6} m/s^2), will be removed to a large extent using the accelerometer data provided by the Italian Spring Accelerometer (ISA).

2. End-to-End simulation of MORE experiment

We simulated the two-way Doppler and range data accounting for station visibility (we used two ground antennas, at Goldstone and Cebreros) and operational constraints due to the pointing of the moveable High Gain Antenna (HGA). These data were processed in in batches 24 h long using JPL MONTE code and software developed in house to integrate the trajectory and carry out the orbital fit. The mathematical formulation is based on [2]. We also modeled the reaction wheels' desaturation maneuvers twice a day that produce uncompensated ΔVs of about 70 mm/s and we simulated and included the ISA acceleration measurements to recover the MPO orbit. The accelerometer error is composed by a random noise, systematics, and biases. In the instrument measurement band, (3×10^{-5}-10^{-1} Hz), the intrinsic random noise decreases from 8×10^{-8} m/s^2/Hz$^{1/2}$ at 3×10^{-5} Hz to 7×10^{-8} m/s^2/Hz$^{1/2}$ at 7×10^{-4} Hz, then remains constant up to 10^{-1} Hz. The main systematic errors evolve periodically following MPO's orbital period and half of Mercury's orbital period. The amplitude of the 44-days error is 4.2×10^{-8} m/s^2. This error can be calibrated by means of a daily bias and bias-rate estimation. The amplitude of the orbital error is 7×10^{-9} m/s^2 for the ISA proof masses in radial and cross-track direction, and 3×10^{-9} m/s^2 in the along-track direction. The ISA scale factors error is due to the effect of the thermal hysteresis and can be assumed constant and equal to 10^{-2}. The a priori Mercury's gravity field and tidal Love number k_2 ware taken by the HgM005 solution derived from

MESSENGER radio data [3]. The assumed Mercury's orientation parameters are based on Margot's recommended model, including the librations in longitude [4]. The parameters of interest were estimated applying a multiarc method by means of square root information, weighted, least-squares filter. The global solve-for parameters are the gravity field in spherical harmonic to degree and order 30, the pole orientation, the amplitude of the libration in longitude, and the ISA scale factor. The local solve-for parameters are the spacecraft position, the velocity, the ISA bias, its drift, the amplitude of ISA error at orbital period and the ΔV of desaturation maneuvers. We simulated the 1-year of MORE operations in orbit about Mercury demonstrating that the scientific goals of the gravimetry experiment will be met. The attainable accuracies are in of about $1x10^{-11}$ for the degree 2 field and about 5×10^{-9} for the degree 30.

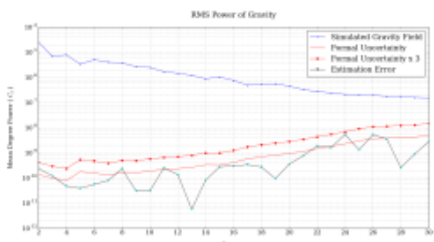

Figure 1: Power spectrum of Mercury's gravity field with estimation error and formal uncertainty.

Despite the introduction of dynamical perturbations and initial errors in the dynamical model, the results meet the science requirement of MORE. The k_2 Love number and the amplitude of 88-days longitudinal libration are determined with formal uncertainties of 3.2×10^{-4} and 0.2", respectively. The right ascension and the declination of Mercury's pole are estimated at the level of 0.32" and 0.11". The reconstructed trajectories provide uncertainty of < 30 cm in the radial direction that will allow a well referencing of the altimetry observations from the BELA laser altimeter. For all estimated parameters, the estimation error remains in the range between one and three formal uncertainty.

3. Summary and Conclusions

The results of the simulation of the gravity and rotation experiment using radio tracking observable and accelerometer data indicate that BepiColombo will provide a global determination of Mercury's gravity field meeting and exceeding the science requirements of the mission. These goals will be attained thanks to the state of the art radio tracking system in Ka-band and the ISA accelerometer. The MORE experiment will improve the knowledge of Mercury's gravity field in the equatorial region and in the southern hemisphere. The MPO spacecraft will cover Mercury's regions at low altitudes (200-500 km) where MESSENGER had poor sensitivity because of its highly eccentric orbit.

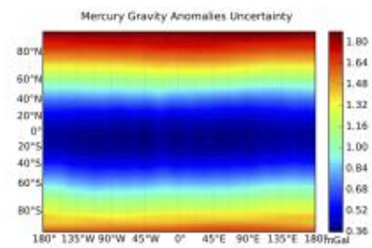

Figure 2: Gravity anomalies uncertainty obtained by the gravity field (30x30) covariance.

Acknowledgements

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