BEPICOLOMBO RADIO SCIENCE TO DETERMINE MERCURY'S GRAVITY AND ORIENTATION.

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Introduction: The European Space Agency (ESA) is developing the dual-spacecraft mission BepiColombo to survey and explore the planet Mercury from the magnetosphere to the interior.

The mission will be probably launched in April 2018 starting its 1-year mapping phase in December 2024. The injection orbit is near-polar with pericenter at 480 km and apocenter at 1500 km. 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 (MRO), will be devoted to the study of the internal structure of Mercury and its surface geology. The geophysics of the deep interior will rely on geodetic measurements of gravity field, orientation, tides, topography, and magnetic field enabled by the onboard Mercury Orbiter Radio science Experiment (MORE), BEpiColombo Laser Altimeter (BELA), high resolution camera (HRIC), and magnetometer (MERMAG).

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 spherical harmonic coefficients, pole's orientation parameters (right ascension and declination of the pole), and the amplitude of forced 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).

Data and method: We simulated the 2-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 dynamically in a time span of 24 h using a batch least-squares filter through the NASA JPL MONTE software, based on the mathematical formulation by Moyer [2].

We also simulated and included the ISA acceleration measurements to recover the MPO orbit in a pseudo drag-free environment. For this reason, we integrated MPO trajectories with respect to the accelerometer reference point instead of the spacecraft center of mass. This assumption significantly simplifies the orbital equations although it requires the accurate computation of the relative distance between ISA and the HGA phase center [3].

We also modeled the reaction wheels desaturation maneuvers twice a day that produce uncompensated ΔVs of about 70 mm/s.

The *a priori* Mercury's gravity field is the HgM005 solution derived from MESSENGER radio data [4]. Tidal effects have also been taken into account by means of a single, complex, Love number k_2. The assumed Mercury's orientation parameters are based on Margot's recommended model, including the librations in longitude [5].

The parameters of interest were estimated in two-step method. First, we applied a multiarc method by means of square root information weighted least-squares filter that results in the estimation of the global parameters, gravity field in spherical harmonic to degree and order 30, the planetary orientation, and the ISA calibration parameters. The ISA bias, its drift, amplitude of the orbital errors, and scale factors are local parameters. However, we time-constrained the latter two on a time span of 88 days. After the multi arc, a batch sequential method is used to estimate the state vector and the magnitude of the desaturation maneuvers [6].

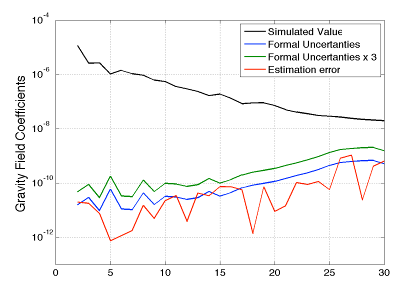

Figure 1. Power spectrum of Mercury's gravity field: associated formal uncertainty (blue 1-sigma, green 3-sigma) and estimation error (red).

For a precise orbit determination, ISA requires in-orbit calibration to reduce measurement errors due to electronic noise, thermal drift, and ageing. ISA error is composed by a random noise, systematics, and biases. In the instrument measurement band, which is 3×10^{-5} - 10^{-1} Hz, the intrinsic random noise decrease 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 remain constant up to 10^{-1} Hz. In order to reduce the effect of the random noise on the orbit determination process, the accelerometer measurements will be pre-processed by means of decimation filter.

The main systematic errors evolve periodically following MPO orbital period, sidereal period, and half of the Mercury orbital period. The amplitude of the sidereal 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 proof masses in radial and cross-track direction, and 3×10^{-9} m/s^2 in the along-track direction. The scale factors error is due to the effect of the thermal hysteresis and can be assumed constant in a time span of several days. The scale factors and the amplitude of error at MPO orbital period are assumed to be stable and calibrated on a time span of 88 days.

Results: 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 10^{-10} for the degree 2 field and 2×10^{-9} for the degree 30 (the corresponding ratio between the value and its uncertainty is about 10^5 for the degree 2, and 10 for the degree 30). Despite the introduction of dynamical perturbations and initial errors in the dynamical model, we obtained faithful results both for gravity and orbit reconstruction. The batch-sequential estimation [5] strategy leads to estimate an accurate spacecraft trajectory.

The Love number k_2 and the amplitude of 88-days longitudinal libration are also well determined, with formal uncertainties of 3.2×10^{-4} and 0.2 arcsec, respectively.

The right ascension and the declination of Mercury's pole are estimated at the level of 0.5 arcsec and 0.2 arcsec. The state vector uncertainties will allow an excellent referencing of the altimetric observations from the BELA laser altimeter. Indeed, the reconstructed trajectories provide uncertainty of < 30 cm in the radial direction. For all estimated parameters, the estimation error remains in the range between one and three formal uncertainty.

Conclusions. The results of the simulation of the gravity and rotation experiment in a pseudo drag-free environment 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 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 the MESSENGER spacecraft was not able to operate because of its highly eccentric orbit.

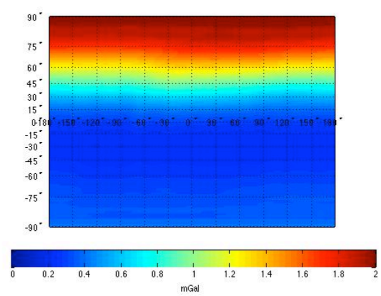

Figure 2. Gravity anomaly uncertainty obtained by the gravity field covariance (Miller projection).

References: [1] Iess L. et al. (2009) *Acta Astronautica 2009 666-675, 58 (2010) 300-308.* [2] Moyer T. D. (2000) JPL/Caltech, 00-7, Wiley. [3] Schulte H.-R. (2007) TN BC-ASD-TN-00090. [4] Mazarico E. et al. (2014), *J. Geophys. Res. Planets 119, 2417-2436*. [5] Margot J.L. (2009), *Celest. Mech. Dyn. Astrom. 105, 329-336*. [6] Genova A. et al., *22 ISSFD.*