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Orbit of the Mercury Planetary Orbiter (MPO) in the Gravity Field of Mercury: Implications for Surface Coverage with the BepiColombo Laser Altimeter (BELA)

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1. Introduction

The BepiColombo Laser Altimeter (BELA) is part of the payload of the Mercury Planetary Orbiter (MPO). The MPO is part of the ESA/JAXA mission BepiColombo. We investigate the orbital evolution of the Mercury Planetary Orbiter (MPO) in the gravity field of Mercury. For the gravity field we use the low-order coefficients determined from radio-tracking of the MESSENGER spacecraft during Mercury flybys [1]. Implications for the surface coverage with Laser tracks by the BepiColombo Laser Altimeter (BELA).

An important goal of BELA is the global coverage of Mercury's surface with laser tracks in order to derive the planet's global topography. The MPO orbit is elliptic with pericenter and apocenter at an altitude above Mercury's surface of 400 and 1500 km, respectively. Based on the current instrument specifications and estimates of Mercury's albedo at the laser wavelength of 1064 nm, the altitude up to which BELA can obtain range measurements is expected to be 1050 km. Therefore, only about 60% of the orbit can be used to obtain range measurements. However, because of deviations from spherical symmetry of the Hermean gravity field and the corresponding pericenter shift of the MPO orbit, global coverage can be obtained. The gravity field coefficients, especially the J2 coefficient, are crucial for the rate of shift of pericenter. In this work we investigate the orbital evolution of the MPO taking into account current knowledge of Mercury's gravity field obtained from the MESSENGER flybys [1].

2. Method

For the numerical integration of the MPO orbit we use a SPICE-based integrator. Positions of the Sun and the planets are obtained from ephemeris kernels for each time-step. The gravity field of Mercury is implemented by a harmonic expansion using Legendre polynomials. For the expansion coefficients we use the solutions described in [1], e.g., HgM001. The coefficients in [1] are given for a reference radius of 2440 km and a *GM*-value of 22031.80 km^3/s^2. The value of the normalized J_2 – coefficient is 0.857 x 10^{-5}. As additional perturbations we include the gravity of the Sun as well as other planets as Venus, the Earth-Moon system and Jupiter. Furthermore, we included the solar radiation pressure as a non-gravitational force. To compute the effect of the solar radiation pressure, the MPO is described by its solar panel (always oriented perpendicular to the direction to the Sun) and six surfaces with areas of a few m^2. We use reflectivities of 0.8 and 0.21 for the surfaces and the solar panel, respectively. We assume a constant mass of 1250 kg of the MPO spacecraft. The acceleration of the MPO due to the various perturbations is shown in Fig.1. It can be seen that Mercury's gravity field terms up to 4^{th} order and the gravitational perturbation by the Sun are the major perturbations acting on the MPO. Solar radiation pressure and gravitational perturbations by the other planets play a minor role. As initial conditions we assume the specifications given in [2] for the north and south polar approach.

3. Results

A comparison of the various perturbations acting on the MPO is shown in Fig.1. Spacecraft accelerations due to individual perturbations are plotted over a time-span of 10 days of the science orbit. It can be seen that accelerations due to the higher order gravity field of Mercury (here we used the HgM001 field [1]), the gravity of the Sun, and the solar radiation pressure are the major factors. Perturbations by other planets are negligible. The large fluctuations in the acceleration due to solar radiation pressure are

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different scale of the y-axis). This time Mercury's degree-4 field is taken into account.

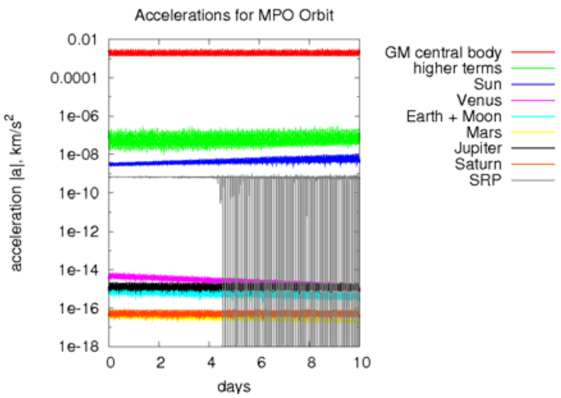

Fig1: Comparison of the various perturbations acting on the MPO.

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Figure 2 shows an example of the pericenter shift of the MPO under the influence of different J_2 terms assuming a mission-duration of two years (including an optional extended mission). The J_2 values were varied over a wide range for testing purposes. The result compares very well to the mission analysis done by ESA [2]. After having tested our numerical solutions we have calculated the evolution of the MPO orbit using the gravity field of Mercury (HgM001) as determined in [1].

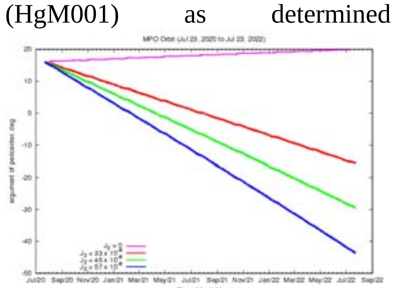

Fig.2: Evolution of the argument of pericenter for different J_2 values.

In Fig.3 we show the evolution of pericenter using the same initial conditions as for Fig.2 (note the different scale of the y-axis). This time Mercury's degree-4 field is taken into account.

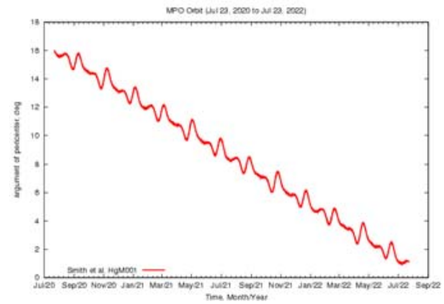

Fig.3: Evolution of the argument of pericenter taking into account the 4th-order gravity field (HgM001 solution of [1]).

We have evaluated the corresponding surface coverage of BELA for a one-year mission duration. The entire surface is covered by tracks. Best data including measurements of slopes and surface roughness by analyzing the shape of the return-pulse will be obtained in the mid-latitudes (-30° to +60° latitude) and in the north-polar region. However, in the studied scenario the south-polar region will be ranged only from greater distance (800 to 1055 km) with lower detection probability. Cross-over points are obtained in the northern latitudes. However, for some objectives of BELA (recovering Mercury's tidal signal and assisting in orbit determination) a high number of cross-over points is required. This can only be achieved by a highly inclined orbit (e.g., 85°) instead of an exact polar orbit. According to our analysis, the MPO orbit would still be stable in such an alternative mission scenario.

References

[1] Smith D. E. and 16 colleagues: The equatorial shape and gravity field of Mercury from MESSENGER flybys 1 and 2, Icarus 209, 88-100, 2010.

[2] Garcia, D., R. Jehn, J. Schoenmaekers, and P. de Pascale: BepiColombo Mercury Cornerstone, Current Report on Mission Analysis BC-ESC-RP-05500, Issue 3.1, 2009.