Geophysical Research Abstracts
Vol. 13, EGU2011-12152, 2011
EGU General Assembly 2011

BepiColombo radio science experiment: determination of Mercury's gravity field

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BepiColombo is an interdisciplinary dual spacecraft mission to Mercury jointly carried out by ESA (European Space Agency) and JAXA (Japan Aerospace Exploration Agency). The mission will address a comprehensive set of scientific questions in order to gain knowledge about the planet, its evolution and environment. The ESA's Mercury Planetary Orbiter (MPO) hosts several experiments and instrument suites devoted to the remote sensing of the planet. The MPO will focus on a global characterization of Mercury through the investigation of its surface and interior. In addition, it will carry out a number of tests of Einstein's theory of general relativity. The second spacecraft, the Mercury Magnetospheric Orbiter (MMO), led by JAXA, carries five instruments aimed at a comprehensive study of the planet's exosphere and magnetosphere, and their interaction processes with the solar wind and the planet itself.
One of the MPO eleven instruments suites is the Mercury Orbiter Radio Science Experiment (MORE), designed to provide an accurate estimation of Mercury's gravity field by means of highly stable, multi-frequency radio links in X and Ka band. In order to support this investigation, the MPO will be equipped with dedicated on-board instrumentation: high gain antenna of 1.2 m diameter, two deep space transponders (supporting radio links at X and Ka, band, coherent with an X band downlink) and full Ka-uplink/Ka-downlink transponder (KaT). The spacecraft hosts also a high sensitivity accelerometer ISA (Italian Spring Accelerometer) and laser-altimeter with FOV = 0.6 mrad. The sophisticated microwave equipment enables a two-way, multi-frequency radio link in X/X (7.2 GHz uplink/8.4 GHz downlink), X/Ka (7.2/32.5 GHz) and Ka/Ka band (34/32.5 GHz) that will provide range rate accuracies of 3 micron/s (at 1000 s integration time) at nearly all elongation angles. Range observables accurate to 20 cm (two-way) will be attained using a novel, wideband (12 MHz) ranging system, based upon a pseudo-noise modulation scheme. These measurement accuracies are possible using the plasma noise cancellation system, developed for the Cassini mission [2], [3]. Radio tracking from suitably equipped ground stations will therefore provide high quality Doppler and range observables for precise orbit determination and estimation of the gravity field up to degree 25. Dynamical noise from non-gravitational accelerations (mainly solar radiation pressure, planetary albedo and infrared emission) will be removed to a large extent by means of the on-board accelerometer.

A full numerical simulation of the Radio Science Experiment was carried out in the early phases of the BepiColombo project in order to test if the attainable accuracies in the gravity field estimation were compatible with the scientific goals of the mission [4]. This paper reports on a new set of numerical simulations, which take into account the development in the new spacecraft design, the mission profile and the tracking system. The recovery of gravity harmonic coefficients is necessary to constrain the internal structure of the planet and to compute Mercury's geoid. The coefficients of the second-degree harmonics of the gravity field, together with Mercury's obliquity and the amplitude of its 88-days physical librations in longitude will indicate whether or not Mercury has a molten core and allow calculating the radius of this core. The simulations reported in this work provide updated realistic estimate of the uncertainties in the determination of the polar moment of inertia of the core and the whole planet, Mercury's gravity field (with SNR from 104 for degree 2 to 10 for degree 20), geoid (2-3 cm over spatial scales of 300 km) and the tidal Love number k2 (1-2% of relative accuracy).

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