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Simulation of BepiColombo's Mercury Rotation Experiment

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Since the discovery of an intrinsic magnetic field of Mercury by the Mariner 10 flyby in 1974, the study of the rotational state of this planet has gained interest due to the possibility to gather information about its core. The rotational state of a celestial body is characterized by its obliquity and librations. The obliquity is the angular amplitude between the normal to the orbital plane of the planet and its spin axis direction. The physical librations are characterized, in the case of Mercury, by a longitudinal motion (which approximately takes the form of a sinusoidal wave) superimposed to the nominal planet spin motion. This behavior is due to the Sun gravity-gradient effect inducing a forced libration whose maximum amplitude is expected to be about 400 m at the equator.

On ESA's mission to Mercury, BepiColombo, the method used to estimate Mercury's rotational state makes use of a combination of optical images acquired by the High Resolution Imaging Channel (HRIC) of the SIMBIO-SYS instrument, radio tracking data provided by the Mercury Orbiter Radioscience Experiment (MORE) Ka-band transponder and the Italian Spring Accelerometer (ISA) readings, all part of the Mercury Planetary Orbiter (MPO) scientific payload.

The underlying idea is that by imaging the same surface area on Mercury at different times, and computing the relative displacement, one could form a certain number of observables that can be fed into an estimation algorithm where the unknowns are the planet's rotational state parameters.

The observables are computed by matching pairs of HRIC optical images of the planet surface, both looking over the same surface area at different times. The image matching algorithm requires knowledge of the spacecraft position and orientation in space (derived by an orbit determination process making use of the MORE and ISA data and by the spacecraft telemetry data, respectively).

A delicate aspect to assess the achievable accuracy of the method sketched above, is the setup of realistic error models for all measurements involved in the process. These include (but are not limited to): orbit determination errors, spacecraft attitude determination errors, HRIC focal axis misalignments with respect to the spacecraft reference frame, image time-tagging errors, image matching algorithm errors.

In order to characterize and quantify each error source in the most precise way, an end-to-end Mercury rotation experiment simulator is under development by a joint MORE/HRIC team, which includes, on the "simulation" side, a Mercury simulated digital elevation model, a HRIC optics and electronics simulator, an orbital propagator which accounts for all expected gravitational and non-gravitational perturbations experienced by MPO, and an attitude simulator; on the "estimation" side, image processing algorithms and a rotational state estimator have been included.

This talk focuses on the description of the full Mercury rotation experiment simulator, its preliminary results from a first set of images pairs, simulated under simplified assumptions, the future developments roadmap and the expected results, in particular concerning the achievable accuracy in the determination of the rotational state parameters. As a by-product, the simulator is designed to allow the optimization of the HRIC images acquisition scheduling, in particular those focused to the rotation experiment, a feature which may offer significant advantages for the limitation of MPO total data volume.