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Accuracy of Phobos gravity field determination from radio-tracking of spacecraft flybys

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Abstract

We study the impact of systematic errors (such as those in the ephemeris of Phobos or in its rotation model) on the estimates of the gravity field coefficients of a small celestial body obtained through the precise orbit determination of a flying-by spacecraft. The main focus will be on previous encounters, in particular those of Phobos by Mars Express (MEX), although the analysis will be expanded to future possible flybys of Phobos.

1. Introduction

Knowledge of the gravity field of Phobos can help constrain models of its interior structure [1]. Radio tracking data from spacecraft flying by Phobos is sensitive to its gravity field. The reconstruction of orbits described by the Viking, Phobos-2, and above all Mars Express (which experienced the closest Phobos encounter to date) orbiters allowed to determine the GM of the Martian moon and the C_{20} coefficient of its gravity field with formal uncertainties of up to 0.1% and 30%, respectively [2, 3]. The reliability of such estimates is however limited by the errors on the ephemeris of Phobos. This study aims at precisely characterizing the effect of such systematic errors on the gravity field solution.

2. Data and Methodology

Propagation of orbits reproducing those of MEX in its Phobos flybys is used to asses the sensitivity of the spacecraft trajectory to the low-degree gravity field of the moon. The integration of the orbits is performed assuming a realistic dynamical model for the spacecraft, parameterized by the values of the Phobos gravity field coefficients. As a result, the set of parameters relevant to the study is reduced to include only those appreciably affecting the trajectory of the spacecraft.

The main tracking observable considered in this study is the Doppler shift in the frequency of the radio link between the spacecraft and a station on Earth. This quantity is proportional to their relative velocity along the line-of-sight (LOS), hence large signatures on the MEX trajectory do not directly translate into equally large signatures on the radio science observables, as the latter depend also on the relative orientation of the Earth and the orbital plane. Therefore, in order to further restrict the set of parameters to take into account, two-way Doppler measurements are simulated to deduce the signature of the parameters of interest on the radio science observables. These synthetic data, including a realistic noise component, are then employed to retrieve the values and uncertainties of the parameters of interest through an iterative weighted batch least squares filter, taking as a priori values of the parameters to estimate small deviations from their true values (those used for the simulation of the measurements). This process yields the correlations between the adjusted parameters and the formal uncertainties, which can be compared to the actual deviations of the solution from the true values (true errors) to evaluate the reliability of the estimates.

Eventually, the robustness of the results is tested against variations in the other parameters of the dynamical model, especially the ephemerides and the rotation of Phobos, as well as the Martian gravity field and rotation model.

The orbit propagation, the simulations, and the analysis of the radio science data are performed using the GINS (*Geodésie par Intégrations Numériques Simultanées*) software package [4].

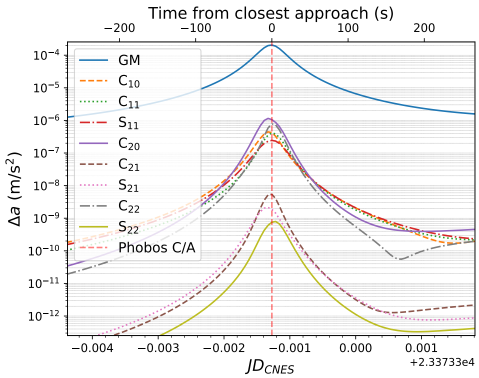

Figure 1: Signature of Phobos low degree gravity field on the acceleration of MEX during the 2013 flyby.

3. Discussion and Outlook

Most of the Phobos gravity field information in the radio tracking data from flybys is expected to come from the central terms and the degree one and two, zonal and sectorial harmonics (Fig. 1). The degree one coefficients, however, are known to be highly correlated to the error on the ephemerides of the moon, as both describe uncertainties in the position of the center of mass of Phobos [5]. Here, the separability of these two sets of parameters will be studied, taking into account the errors provided for the Phobos ephemerides [6]. Thus, it should be possible to conclude whether the first degree coefficients of the gravity field may be determined with sufficient accuracy from real tracking data, or if they shall be used to absorb the ephemeris error.

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