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Librational Motion of Phobos

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Abstract

Mars' satellite Phobos is the target of the Russian space mission Phobos-Grunt. One objective of this mission is to measure the rotational motion of Phobos by using Doppler and Star Tracker measurements. The purpose of this paper is to model the rotational motion of Phobos based on the recently determined ephemerides [1] and constraints on its interior [2,3].

1. Introduction

Phobos is in synchronous spin-orbit resonance, like our Moon. Its rotational motion is not uniform and presents oscillations, called physical librations. This motion results from the interaction of the non-spherical shape of the satellite with the gravitational field of Mars and from the variations in its orbital velocity. Here, we present a numerical model of rotation for Phobos, taking into account the different spin-orbit and geophysical couplings important for Phobos. In addition, we assess the prospect to determine these librations by Doppler measurements and star-tracker in preparation for the Phobos-Grunt mission [4].

2. Model of Rotation

The variations in Phobos' rotational motion are sensitive to the orbital motion of the satellite around Mars, the dynamical figures of Phobos and Mars, and solid-body deformation. Phobos' orbital motion is computed from numerical ephemerides [1]; the moments of inertia come from a recent study based on Mars Express images [2]; and the tidal bulge is estimated for both an ice-rich interior and a porosity-dominated model [3].

3. Librational Response

In a three-dimensional reference frame, the rotational motion may be decomposed as a function of the pole

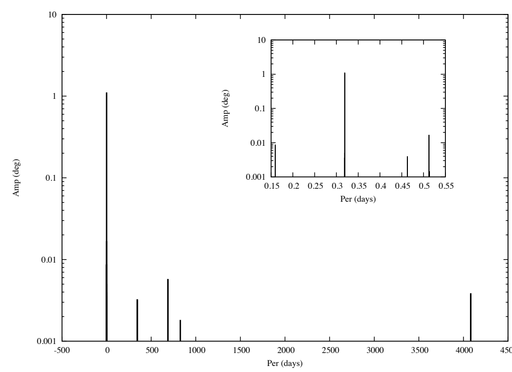

Figure 1: Physical libration in longitude spectrum of Phobos.

orientation variations, which are described by the librations in latitude, and the variations of the satellite's long-axis direction in its equatorial plane, called the libration in longitude. The amplitudes of the libration angles depend on the magnitude of the external torque, but also on the proximity of the forcing frequency to the proper frequencies (also called free libration frequencies) resulting from the spin-orbit resonance. For Phobos, the free frequencies are 12.27 rad/days, 7.57 rad/days, and 12.20 rad/days. It is interesting to note that Phobos' proper frequencies are close to the forced libration frequencies. This opens the door to a potentially significant increase of the amplitudes from resonant effects. The detection of free librations is a tantalizing source of information on the distribution of mass inside the body but also on its dissipative properties and dynamical history (cf. [6] for the Moon). Figure 1 shows the spectrum of forced librations affecting the satellite. It is composed of long periods (longer than 300 days) related to the motion of the nodes and the motion of Mars around the Sun. As shown in [5], the long-period librations are expected to show little dependence on geophysical properties. On the other hand, the short-period librations are particularly interesting because their amplitudes and phases are functions of interior structure and geophysical activity. We also identified short-period librations close to 0.5 days that are close to a resonance with the proper period in longitude of 0.512 days.

Through careful analysis of the spectrum of the librations amplitudes at different frequencies (in longitude as well as in latitude), it is possible to derive geophysical parameters, such as the moments of inertia, higher harmonic (gravitational) coefficients, the impact of Mars' J_2, and dissipative properties of both Mars and Phobos (complex tidal Love numbers k_2, h_2, l_2), with high precision.

4. Observational simulations

Based on the capability and mission plan for the Phobos-Grunt mission, first numerical simulations of the precision of the Phobos libration angle determination have been performed using both star-tracker and direct-to-Earth Doppler measurements. It seems that the main librational amplitudes have been retrieved with a precision better than a percent after a few days of observations (see details of the simulations in [4]). Thus that geodetic technique is likely to prove a powerful method for sounding the geophysical properties of the satellite, and thus offers the prospect to constrain its origin and the evolution of the Martian system.

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