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Mass distribution inside Phobos: A key observational constraint for the origin of Phobos.

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Abstract

In this study, we construct models of the mass distribution inside Phobos. We explore the possible internal mass distributions, considering three kinds of material inside Phobos: rock, porous-rock and water-ice. We compute the principal moments of inertia, related to the second-order gravity field coefficients, C_{20} and C_{22}, and libration amplitude of Phobos, for each of these possible internal mass distribution. Then, we select the distributions that fit the measured libration of amplitude and the density of Phobos within their error bars. For those distributions, we find values of the gravity field coefficients which departs from the expected value of a homogeneous mass distribution for a large amount of porosity and a low amount of water-ice. In turn, precise measurements of both gravity field coefficients and rotation variations of Phobos may provide new constraints on the origin of this small moon of Mars.

1. Introduction

The origin of the Martian moons, Phobos and Deimos, is still an open issue. It has been proposed that they formed away from Mars and then captured by Mars gravitational attraction [1] or that they formed *in-situ* from a disk of debris in Mars' orbit [2]. The capture scenario has, however, major difficulties to account for the current near-circular and near-equatorial orbit of Phobos [1]. Previous works of tidal orbital evolution have shown the critical role of the tidal dissipation inside a satellite to make the capture possible, i.e. Phobos' interior might have high dissipative properties [3], which would be closer to those of icy material than to those of rocky material [4]. Among the recent observations made by the Mars Express spacecraft, those concerning the internal structure of Phobos are particularly pertinent for assessing the scenario of origin [4]. Indeed, the density of Phobos, 1.87 +/- 0.02 g/cm^3 [4,5], is lower than the density of presumed material analogs, suggesting that the interior of this small moon can contain light elements like porosity or water-ice. The former supports *in-situ* formation while the latter favorizes an asteroid capture scenario [4]. Therefore, the assessement of the porosity/water-ice content inside Phobos is a key measurement relevant to the open question about its origin.
In this study, we develop models of mass distribution inside Phobos, and use the measured libration of amplitude and density of Phobos to constrain the mass distribution within.

2. Models of mass distribution inside Phobos

The proportion and repartition of water ice and rock porosity cannot be determined from the average density alone. Another datum, like the libration amplitude (-1.24 +/- 0.15 degrees [6]), which depends on the principal moments of inertia of Phobos (thus on its internal mass distribution), is likely to provide further constraints. In order to constrain Phobos' interior structure, we have discretized its volume by a set of cubes (2626), each having an identical volume of 1300mx1300mx1300m. The cubes are made of one of three different materials: water ice (940 kg/m^3), porous-rock and non-porous rock. For a given porosity and non-porous rock density the number of cubes of each material is determined from the bulk density of Phobos. Our model contains a parameter that controls the size of clusters of identical material within the volume of Phobos. We have calculated the probability density functions for the three principal moments of inertia and for the libration amplitude taking various degrees of porosity, fractions of water ice and rocky material density into account.

3. Results

Our results show that the most likely models with a homogeneous matter distribution have libration amplitudes that deviate from the estimated libration amplitude, suggesting a Phobos interior mass distribution that deviates from homogeneous distribution. In order for the models to fit the observed libration amplitude the smoothing parameter values have to be chosen such that clusters of material of intermediate size are obtained. Models with rocky material density lower than about 2.1 g/cm^3 do not fit the libration amplitude whatever the porosity/water ice content and the smoothing parameter values. However, the precision on the observed libration does not allow for a tight constraint on the porosity/water ice content inside Phobos. From our models we have also computed the C_{20} gravity field coefficient. The predicted C_{20} values depart more and more from the value expected for a homogeneous mass distribution when more and more porosity (up to 40%), and equivalently less and less water-ice content (down to a few percent of the mass of Phobos), are considered. In turn, it shows that a precise measurement of Phobos' gravity field could provide additional constraints on its interior and origin.

4. Summary and perspectives

A precision of a few percent on the gravity field and the rotation measurements of Phobos is needed to tightly constrain its interior structure. Such precise measurements are challenging but might be obtained from the Mars Express very close flybys of Phobos [7] and from the Phobos-Grunt spacecraft [8], due to launch in November 2011 (arrival date to Phobos in early 2013). The Phobos-Grunt spacecraft will indeed orbit Mars at close distance to Phobos (45-55 km), offering the opportunity to measure the gravity field of Phobos and then will stay at Phobos' surface, offering the opportunity to measure the fine variations of the spin rate and orientation of the rotation axis of Phobos. Our models of Phobos' interior will be useful for interpreting these future data. For instance, they can be used for modeling of the rotation of Phobos [9] which will be constrained by the Phobos-Grunt observations [10].

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