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Dissipative Behavior of Phobos as a Key Constraint on its Composition and Origin

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Abstract

We compare and contrast the dissipative properties expected for two models of Phobos, the mysterious irregular satellite of Mars, target of the upcoming Phobos-GRUNT mission. These models are based on different scenarios for the origin of the satellite implying distinctive internal structures. We show that the presence of hydrated minerals and water ice can significantly increase tidal dissipation. In contrast dissipation in a rubble-pile subject to low tidal stress appears to be limited. Hence, it should be possible to constrain Phobos' interior and composition from accurate measurements of its dynamical properties.

1. Problem

The mechanisms driving attenuation in primitive bodies, such as irregular satellites (e.g., Phobos, Janus) and binary asteroids and Kuiper-Belt objects, are poorly constrained. The state of the art generally suggests that the dissipation factor is about 100 if these objects are monoliths and 10 if these are rubble-piles [e.g., 1]. However, the theoretical framework behind these numbers is unclear, and these values actually appear inconsistent with experimental data obtained on solid or granular materials [see 2 for a review]. Experimental simulation of tidal dissipation in conditions relevant to these objects is challenging, e.g., low tidal stress, temperature, and gravity, high porosity, etc. These objects are also covered by a thick regolith, which may be mechanically decoupled from the deep interior, thus limiting the transmission of external stress to the more coherent bulk part of the object.We evaluate the amplitude of dissipation in these objects based on our current understanding of shear heating in granular layer and in hydrated and water-rich materials.

2. Case Study – Phobos

Phobos is a particularly interesting case study. First, to the best of our knowledge, its dissipative properties have not been studied in details; that satellite is generally assigned a dissipation factor Q=100 [e.g., 3]. Also, the different internal structures suggested for Phobos [4, 5] imply very different dissipation mechanisms. Measuring the dissipation of the object thus offers the prospect to constrain its origin. Such a measurement could be obtained from, e.g., a detailed measurement of Phobos' rotation [6].

We consider as a first step two very different endmember models for Phobos. The first model assumes that Phobos is a rubble-pile or, at least, that its regolith is so thick that it is mechanically decoupled from the interior. This situation is possible if Phobos is the product of reaccretion in a disk of ejecta from Mars' surface [7], a model suggested by the recent detection of Martian-looking material at the surface of the satellite [8]. The alternative model assumes that Phobos is globally coherent, water-rich, and that its regolith is only a few hundred meters [e.g., 5, 9]. This is expected if it is a capture asteroid, for example.

3. Key Results

We find that the amount of dissipation achieved in the solid model is primarily a function of the fraction of volatiles present in the rock, and possibly free ice filling in the pores. In the thermal environment offered by Phobos' interior, water could be close to its melting point, especially if soluble material and hydrated salts are also present [10]. This situation is expected to lead to a dissipation factor as low as 1, if the fraction of water ice is significant.

In the case of the rubble-pile model, dissipation is driven by friction between fragments and is limited to the few outer hundred meters of the satellite, i.e., where the tidal stress amplitude is greater than the lithostatic pressure. The amount of dissipation is thus a function of the shear stress, sliding velocity (i.e., strain rate) and fragment size. Although the latter parameter is poorly constrained, experimental measurements on granular material extrapolated to Phobos' conditions indicate that the corresponding dissipation factor is of the order of 1000. While the tidal deformation of the weak rubble-pile may be enhanced by one order of magnitude with respect to that undergone by a coherent object [11], the total dissipation appears to be still greater than 100.

4. Discussion

This result opens the door to new orbital evolution models that can help assess the origin of Phobos, whether it accreted in a disk in Mars equatorial plane or is a captured planetesimal. Then, an accurate characterization of Phobos' dynamical state could help detect the present of water ice in the satellite. The accuracy expected on the characterization of Phobos' rotation with Phobos-GRUNT (Star Tracker and Doppler tracking), offers such a prospect [12].

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