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The martian moons as the remnants of a giant impact

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Abstract

The origin of Phobos and Deimos is still an open question. Currently, none of the three proposed scenarios for their origin (intact capture of two distinct outer solar system small bodies, co-accretion with Mars, and accretion within an impact-generated disk) is able to reconcile their orbital and physical properties. Here we show that gas-to-solid condensation of the building blocks in the outer part of an extended impact-generated disk could reproduce the spectral and physical properties of the moons.

1. Introduction

The present low eccentricity, low inclinations and prograde orbits of Phobos and Deimos are very unlikely to have been produced following capture [1] (see panel a in Fig. 1), thus favoring a formation of the moons around Mars (i.e., co-accretion with the planet or accretion in an impact-generated disk) [3, 5]. Despite such early robust evidence against a capture scenario, the fact that the moons share similar physical properties (low albedo, red and featureless VNIR reflectance, low density) with outer main belt D-type asteroids has maintained the capture scenario alive [4, 6]. Co-accretion with Mars appears unlikely because Phobos and Deimos would consist of the same building block materials from which Mars once accreted which are spectrally incompatible with the martian moons (see panel b in Fig. 1). Recently, a detailed study demonstrated how Phobos, whose distance to Mars is decaying due to tidal forces, could have survived since its formation within an impact-generated disk, asserting the strength of the scenario [7]. Although the impact scenario has become really attractive, it has not yet been demonstrated that it can explain the physical properties and spectral characteristics of the martian moons. We therefore investigated the mineralogical composition and texture of the dust that would have crystallized in an impact-generated accretion disk. We show that under specific disk's pressure and temperature conditions, Phobos and Deimos' physical and orbital properties can be finally reconciled.

2. Methods and Results

We considered various impact-generated disk chemical compositions as both the nature of the object that would have impacted Mars and the relative proportions of the impactor's mantle and Mars' mantle that would end up in the debris disk are unknown. More precisely we considered disks with a Bulk Silcate Mars, Bulk Silicate Moon and Interplanetary Dust Particle chemical compositions. We used a normative calculation (CIPW norm calculation) to infer the mineralogical composition of the solids that would cristallize from such disks. The cooling timescales of the disk and the clumps that would form from the magma layer in the midplane were estimated to determine the size range (i.e., texture) of the grains that would crystallize. We find that olivine and pyroxene are likely to be the major crystallized minerals for each composition considered. The grains that would crystallize from the molten midplane layer would typically fall into the 0.1–1 mm size range. Such minerals have well defined absorption bands that would be clearly identifiable in the spectra of Phobos and Deimos. These findings disagree with the observed featureless spectra of both moons (Fig. 1 panel c-left).

3. Discussion

Our study preclude the formation of Phobos and Deimos from a molten disk that would spread and form clumps while crossing the Roche limit ($\sim$4 R_{Mars}), similarly to the processes that gave birth to the Moon [2]. However, the temperature and pressure conditions in the extended disk (in the vicinity of the synchronous orbit at $\sim$6 R_{Mars}) are likely to allow the direct condensation of the vapor into solid grains. Laboratory experiments show that the condensation

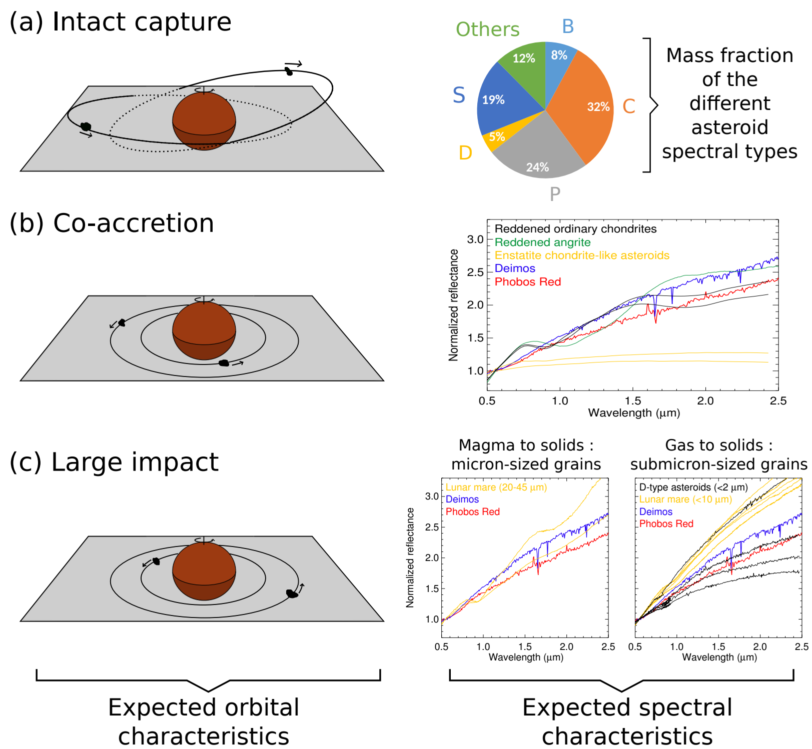

Figure 1: Schematic representation of the expected orbital (left) and spectral (right) characteristics of the martian moons for each of the three different scenarios currently invoked for their origin.

of a silicate vapor results in very fine dust grains, with typical sizes of 0.1 microns [8]. Recent studies have shown that a space weathered mixture of sub-micron sized olivine and pyroxene grains would possess spectral properties similar to those of P- and D-type asteroids [9]. The formation of Phobos and Deimos in a low-pressure extended disk would therefore naturally results in objects whith spectral properties very close to those of these primitive asteroids (panel c-right of Fig. 1). This conclusion is in agreement with a recent dynamical study demonstrating that the formation of Phobos and Deimos should have occured in the extended debris disk to account for their current orbits [7].

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