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# What can we really say about the origin of Phobos?

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## Abstract

There has been a renewed interest in the scientific investigation of Phobos and Deimos in recent years, in particular with the new observations of the former by ESA's Mars Express mission [1]. The origin of Phobos remains an especially vexing mystery [2]. This has reinforced interest worldwide, at ESA, ROSCOSMOS, NASA, and JAXA, to include Phobos as a potential target for future missions. Here, we review recent observations of the surface and interior of Phobos, as well as modeling efforts, to see where we stand on the formation of both Phobos and Deimos.

## 1. Introduction

The origin of the two small Martian moons is one of the most mysterious in our solar system in spite of the numerous spacecraft mission sent to the Martian system. They could be either primitive objects captured by Mars or formed in Mars' orbit. The numerous data collected by at least 6 Martian spacecraft have not allowed deciphering between those two distinct scenarios of origin. Although variant of these scenarios have been proposed, all of them are flawed and data to fix that issue have not all been acquired yet. Phobos and Deimos are two small bodies easy to access and appear now as privileged targets for space agencies aiming to study the small celestial bodies too. The study of the Martian moons concern also the formation and the early dynamics of the solar system, and even the formation of the moons in the exo-planetary systems.

## 2. The capture scenario

The science community has accepted this scenario since the NASA Viking missions. Nevertheless, this scenario suffers weakness and disagreement between the observations and modeling. The main observational argument supporting the capture scenario is the reflectance spectra of the surface in the visible and near infrared (Vis-NiR) domain. These spectra look like those of primitive asteroid [3 and references therein]. However, no prominent absorption features, which are the diagnostic of the composition, have been identified in these spectra so far [4]. The Phobos and Deimos spectra are indeed flat and reddened as for highly space-weathered surfaces. Recently, emissivity spectra in the thermal infrared (IR) domain have been performed. Clear signatures are visible unlike Vis/NiR spectra. But these signatures have been interpreted either as silicate material [5] or as carbonaceous primitive material [6]. On the other hand, the capture scenario has serious issues to account for the capture in Mars' orbit and for the current near-equatorial and near-circular orbits of the moons. The first step of capture would be feasible, although assuming a "kick-off" through a collisional event in or close to Mars' orbit between two former bodies [7]. However, the post-capture orbital changes by tidal dissipation of orbital energy inside Mars and Phobos would need too high dissipation rate in Phobos (closer to icy material than to rocky material) in order to reach the current orbit (e.g. [8]). The required orbital changes for Deimos even require orbital evolution over more than the age of the solar system. Although several alternatives have been proposed to help the orbital changes after capture, not all have been thoroughly studied and none of them have been shown to work properly [2].

## 3. The *in-situ* formation

Several authors have proposed alternative scenarios of formation of both moons in Mars' orbit. One of them has recently retained the attention of scientific community. This scenario largely relies on the formation of the Earth's moon, i.e. re-accretion of debris blasted into Mars' orbit after a giant collision [9]. The formation of the circum-Mars disk after a giant collision has been modeled, and has shown that most of the material of the disk is concentrated close to Mars below the Roche limit (at about 2.5 Mars Radii) [10]. Nevertheless, the moonlets formed from such a disk could not reach the synchronous limit (at 6 Mars radius) before the disk be emptied primarily from its inner edge and then the moonlet orbit recede back to Mars [11]. Such an accretion disk and associated moonlet system is thus expected to last not more than about 200 millions of years that is in strong contradiction with the surface age of Phobos estimated as old as 4.0 +/- 0.4 billions of years [12] and also with the current position of Deimos beyond the synchronous distance to Mars.

## 2. The interior of Phobos

The Mars Express (MEX) mission has allowed probing the interior of Phobos with unprecedented accuracy. The mass and the volume have been dramatically improved and the density very accurately determined. The low density of Phobos (less than 1.9 $g.cm^3$) strongly argues in favor of a compositionally and even structurally heterogeneous interior [2]. The libration amplitude has also been measured by MEX. Its value is close to the one expected for homogeneous Phobos (either monolithic Phobos interior or well-mixed compositionally heterogeneous Phobos interior) [13]. Nevertheless, the error bar is still as large as 14% and recovers the expected values for heterogeneous mass distribution obtained with interior models of Phobos containing, rocks, ice and voids [14]. The gravity field coefficients of Phobos, related to its internal mass distribution (along with the libration amplitude) have also been measured by MEX, but with an error bar close to 100% [15], thus precluding to identify the nature of possible heterogeneous mass distribution inside Phobos.

## 4. How to say more?

The most obvious lacking observation that will decisively help to decipher along scenarios of the origin of Phobos is its composition: What Phobos is made of? A return sample mission is certainly the best way to remove any ambiguity from remote sensing data. Nevertheless, one single sampling area would not necessarily represent both surface variability as suggested by the so-called red and blue spectral units [4] and bulk interior. The knowledge of interior homogeneity is useful test of our ability to extrapolate surface composition derived from returned sampling to the bulk body. Probing the interior of the bulk Phobos is therefore mandatory as well as a precise and complete characterization of the sampling area using former, but more precise, observations as well as new ones not performed at Phobos so far. For instance, determining whether Phobos interior contains water ice is a key element as to decipher its origin. Such ambitious new data could be acquired on orbit and on landing phases in one single mission or on two folds missions, depending on allowed cost and programmatic of space agencies.

## 5. Summary and Conclusions

Several missions to Phobos have been recently proposed to ESA and NASA exploration programs (e.g. [16]) and others are currently studied at ESA and Roscosmos. Beyond the Martian system origin, deciphering the origin of Phobos and Deimos will put additional constraints to the planetary formation and the early stage of solar system history. Indeed, if Phobos contains significant amount of water-ice, it might be a relieve of bodies spread from the outer to the inner solar system by dynamical instabilities in the first hundreds of millions of years of solar system history [17]. A better understanding of the formation of both Martian moons would bring clearer views in the processing of formation of moons around terrestrial planets that will have to be assessed with future observations of moons around extra-solar planets (i.e. exo-moons). Eventually, Phobos and Deimos offers accessible targets for sample return of the Martian system before the most challenging sample return of Mars surface.

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