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Search for the putative dust belts of Mars: The late 2007 opportunity

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Abstract

The putative dust belts of Mars, a thin equatorial Phobos ring and a thick tilted Deimos torus, whose existence was predicted several decades ago, remain undiscovered. The previous attempt of direct observational detection, undertaken with the Hubble Space Telescope (HST) during the Mars equatorial plane crossing in May 2001, set an upper limit on the normal optical depth to $\sim 3 \times 10^{-8}$ for the Phobos ring and $\sim 10^{-7}$ for the Deimos torus. This paper analyzes possible reasons for non-detection of the belts and focuses on the next, and the last for three decades to come, natural opportunity to search for the dust belts during the Mars ring plane crossing in December 2007. We have extended our dynamical models to predict the appearance of both dust belts and to estimate the distribution of their optical depth and brightness. Our new calculations show that at least the Deimos dust torus may have escaped HST detection in 2001 only marginally. A thoroughly prepared observational attempt in 2007 with HST, Keck or another comparable telescope will have good chances to discover the Deimos torus, if a detector has a sensitivity by about one order of magnitude better than the one used in 2001. Photometric detection of the Phobos ring appears to be more difficult.

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1. Introduction

Soter (1971) first suggested that two tiny martian moons, Phobos and Deimos, should act as sources of dust for the circummartian space. The proposed mechanism of dust ejection from the satellite surfaces is their continuous hypervelocity bombardment by interplanetary micrometeoroids. Soter has shown that, owing to low escape speeds from the surfaces and high ejecta yields, a copious amount of dust should get injected in aerocentric orbits, forming tenuous tori around the orbits of the moons. In course of the subsequent theoretical studies by many authors, substantial improvements have been made to the models of the martian tori (see, e.g. Krivov and Hamilton, 1997, and references therein).

So far, only two dedicated photometric attempts have been undertaken to discover the dust belts observationally. The first one was made by the Viking Orbiter 1 spacecraft in 1980 (Duxbury and Ocampo, 1988) and brought a negative result, setting the upper limit of the normal optical depth of the putative tori to $\tau \lesssim 3 \times 10^{-5}$. The second one was made in May 2001, when the Hubble Space Telescope (HST) was used to search for the martian belts and unknown moonlets of Mars (Showalter et al., 2006). This attempt, also unsuccessful, reduced the upper limit to the normal optical depth to $\tau_{\perp} \lesssim 3 \times 10^{-8}$ for the Phobos torus and, more tentatively, $\tau_{\perp} \lesssim \times 10^{-7}$ for the Deimos torus (Showalter et al., 2006). Strictly speaking, constraints were put rather on the edge-on brightness of the hypothesized tori which, assuming geometric albedo of 0.07, translate to the limits on the edge-on optical depth: $\tau_{\parallel} \lesssim 2 \times 10^{-6}$ (Phobos) and $\tau_{\parallel} \lesssim 10^{-6}$ (Deimos). Assuming a certain geometry of the dust belts, these values were then converted to the limits on the normal optical depth $\tau_{\perp}$ quoted above. On any account, the new observational limits are already close to the upper limit suggested by the theory (Krivov and Hamilton, 1997).

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There is some indication for the presence of dust from in situ measurements by the Phobos-2 spacecraft in the 1980s. During a Phobos orbit crossing, the magnetometer of Phobos-2 registered short-lasting fluctuations of the magnetic field and plasma parameters, called "Phobos events" (Dubinin et al., 1990). The Phobos events may indirectly evidence the presence of a dust torus around the Phobos orbit, although can be alternatively attributed to the presence of a gaseous rather than dusty torus (Dubinin, 1993; Baumgärtel et al., 1996). Magnetic field fluctuations were registered just before and right after the crossing of the Sun–Deimos line by the Phobos spacecraft as well ("Deimos event"). The Deimos event possibly indicates the existence of a dust or macromolecular cloud around Deimos itself (Sauer et al., 1995). Such a cloud acts as an obstacle to the solar wind and produces the Mach cone (a "plasma wake" in the solar wind downstream direction), during the crossing of which by the spacecraft the Deimos event was observed. However, these scarce facts cannot substitute direct in situ or remote sensing of the predicted dust belts.

In this paper, we focus on the observability of the putative martian dust belts from Earth during Mars plane crossings at opposition. We argue that at least the Deimos dust torus may have escaped HST detection in May 2001 only marginally. Given the observational conditions during the forthcoming Mars equatorial plane crossing at Mars opposition in the end of 2007 which are only slightly worse than in May 2001, and rapid improvement of detectors, another attempt with Keck or HST in 2007 would have good chances for success.

In Section 2, we outline essential properties of the martian dust belts, as expected from previous models. Our new model is described in Section 3. The updated model is used in Section 4 to estimate the expected mean optical depth of the dust belts and in Section 5 to calculate the distribution of optical depth and brightness of the dust belts during the upcoming Mars ring plane crossing in December 2007. Conclusions are made in Section 6.

2. Earlier predictions

Previous studies have shown that the dynamics, sinks, and lifetimes of dust debris lost by the martian moons strongly depend on the grain sizes. Accordingly, the whole dust complex formed by the Phobos and Deimos ejecta has been classified into four populations with distinctively different properties (Krivov, 1994; Krivov and Hamilton, 1997). Population 0 consists of the largest grains with radii $\gtrsim 1$ mm. Since these are subject to gravitational perturbations only, they stay within confined tori along the moons' orbits, the size of which is determined by the initial ejection velocity distribution (Kholshevnikov et al., 1993). As these particles rapidly re-accrete on the parent moon, their lifetimes and related number densities are very low. Population I contains smaller particles with radii from hundreds down to tens of microns. The dynamics in this size regime arise from the interplay between two perturbations, solar radiation pressure and planetary oblateness, resulting in extended asymmetric tori. The main loss mechanism of these grains is their occasional impacts with Phobos (for Phobos grains) and both martian moons (for Deimos ones), see Makuch et al. (2005). The lifetimes vary from tens of years (Phobos ejecta) to tens of thousands of years (Deimos debris). Below a certain critical radius, roughly ten microns, the particles collide with Mars at the pericenter of their orbits in less than 1 year, so they are present with low number densities. These grains are classified as Population II. Tiniest, submicron-sized fragments (Population III) are strongly influenced by electromagnetic forces and solar wind, are swept out from the vicinity of Mars in 10–100 days and form an extended, highly variable halo enveloping the martian system (Horányi et al., 1991). The properties of all four populations are summarized in Table 1.

As seen from the Table, the number densities, and therefore possible impact rates onto a dust detector aboard spacecraft near Mars, would be determined by Population II Phobos grains, Population I Deimos grains, as well as submicron particles of Population III from both satellites. For remote sensing, the picture is simpler. The cross section

Table 1
Populations of circummartian dust (Krivov, 1994; Krivov and Hamilton, 1997)

Pop.	Radii (μm)[a]	Perturbing forces[b]	Sinks	Lifetimes (years)	Shape	Number density[c]
0	$\gtrsim 1000$	J2	Parent moon	~ 1	Narrow tori	Low
I	10–1000 (P)	RP + J2	Parent moon	$\sim 10^2$ (P)	Equat. ring (P)	Med (P)
I	5–1000 (D)	RP + J2	Parent moon	$\sim 10^4$ (D)	Tilted torus (D)	High (D)
II	0.3–10 (P)	RP + J2	Mars	$\lesssim 1$	Asymm. ring	High (P)
II	0.3–5 (D)	RP + J2	Mars	$\lesssim 1$	Asymm. ring	Low (D)
III	$\lesssim 0.3$	EM + RP	IP space	~ 0.1?	Extended halo	High?

[a]For the dielectric material used in Makuch et al. (2005). The bulk density is 2.37 g cm^{-3}, the radiation pressure efficiency factor $Q_{\rm pr} \approx 0.4$ for $\sim 10\,\mu$m grains.
[b]J2 = Mars' oblateness, RP = radiation pressure, EM = electromagnetic (Lorentz) force.
[c]High: 10^4–10^5 km^{-3}, medium: $\sim 10^3$ km^{-3}, low: $\lesssim 10^2$ km^{-3}.