PHOBOS AND DEIMOS AS SOURCES OF MARTIAN DUST RING/TORUS

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Summary: Orbits of circumplanetary dust particles are largely controlled by solar radiation pressure and planetary oblateness. Around Mars, orbital eccentricity of particles from Phobos and Deimos is enhanced greatly and smaller dust particles (< 20μm) are quickly captured by Mars. Collisions of ring particles onto the satellites are the most important dust source, and the erosion of Phobos should set the upper limit on the dust production efficiency controlling this self-sustaining mechanism.

Several works have been done on Martian dust ring/torus whose particles are supplied from Phobos and Deimos by micrometeoroid impacts [1-11], although there have been no direct measurements of dust around Mars. Only plasma measurement by PHOBOS-2 ASPERA showed indirect evidence of a gas torus with submicron dust particles at the Phobos' orbit [12]. Between 1999 and 2001, Mars Dust Counter on board PLANET-B will investigate mass and velocity distribution of dust particles around Mars [13].

Impacts on satellites produce various size of dust particles. Around Mars, submicron particles are charged, scattered by solar wind magnetic field, and trapped by Mars quickly. Orbits of dust particles larger than micron are modified by solar radiation pressure and Martian oblateness. Their orbital eccentricity around Mars is greatly enhanced with periodic oscillation. At the Phobos' orbit, when dust size \( r < 200\mu m \), resonance between phase shifts from radiation pressure and oblateness increases eccentricity amplitude \( e_{max} \) greatly [9-11]. Larger dust of small \( e_{max} \) is trapped by Phobos with small relative velocity. The critical size over which dust can survive from collisions with Mars is 22μm. Orbital inclination \( i \) of particles from Phobos is kept as small as 0.01; they form a relatively thin “ring” whose dust size is between 22 and 200μm. At the Deimos' orbit, the planetary oblateness as well as the radiation pressure should enhance the orbital inclination \( i \) of particles to be as high as 0.2; dust distribution becomes "torus" [10-11]. Lifetime of Deimos particles (10^4 - 10^5 yr) is longer than that (10yr) of Phobos particles (Fig. 1).

Collision of dust particles onto satellites is not always a dust loss mechanism: some of ejecta may escape from the satellite and the Martian dust ring/torus becomes self-sustained [8]. Let us define dust production efficiency \( \eta \) as the total mass of escaping ejecta to the mass of a colliding particle. Analytically estimated \( \eta \) is larger than the unity when a particle hits Phobos or Deimos at velocity as low as 1km/s [8]. In the self-sustained dust ring, change of size by dust-dust collision is the dominant dust loss mechanism. When dust size \( r_d \) becomes smaller by collisional disruption, stronger radiation pressure would enhance \( e \) so that the dust would collide with Mars. Under the balance between the production from the satellite and the loss by the dust-dust collisions we have number density of the torus dust: \( n_d \sim (\eta - 1) V^{-1} (r_{sat}/r_d)^2 \) where \( V \) is the torus volume and \( r_{sat} \) is the satellite radius. Then we have the total dust number \( n_d V / (\eta - 1) \sim 1.6\times10^{17} \) (Phobos) and \( 0.5\times10^{17} \) (Deimos). Since the total particle number is independent of the volume, dust number density of the Phobos ring with smaller \( V \) is higher than that of the Deimos torus.

As for Phobos and Deimos, dust ejection is a mass loss mechanism. Intense bombardments supplying ring particles would erode the satellite surface. From the dust number density and the volume of a ring/torus, we obtained the surface erosion rate at \( \eta = 1 = 1 \) (Fig. 2). When dust size is larger than 40μm, Phobos' dust ring should erode the surface of Phobos by 10m in 10^5 yr. Here we take this short time scale, because Phobos' orbit is now approaching Mars due to tidal dissipation and the residence time of Phobos in the eccentricity enhancement zone (3.5 to 2.8R_M, [10]) is 10^7 to 10^8yr [14]. However, pictures taken by Viking shows that the present Phobos with morphologies smaller than 10m has no evidence of significant surface erosion. Then we should set the upper limit for the dust ejection efficiency: \( \eta = 1 \leq 0.1 \). Or the self-sustain mechanism would have not always operated. Because of the larger volume of the Deimos torus.
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than Phobos ring, dust collision rate onto Deimos is much smaller than that onto Deimos (Fig. 2). The surface erosion rate of Deimos is much smaller: even at $\eta - 1 = 1$ it is smaller than $10^3$ m/s when $r_A > 30 \mu m$.

In 1998, PLANET-B will be launched and between 1999 and 2001 it will observe the Martian environment with highly elliptic orbits intersecting Phobos and Deimos orbits. An impact ionization-type dust detector MDC with aperture 140 cm$^2$ will be on board PLANET-B and it will directly detect dust particles around Mars [13]. MDC can detect a few particles with size several tens micron at each crossing of dust ring/torus when the self-sustaining mechanism enhances the dust number density. Optical thickness of self-sustained dust ring/torus is insensitive to dust size, and edge-on optical thickness of the Phobos ring and the Deimos torus at $\eta - 1 = 0.1$ are $6 \times 10^{-6}$ ($i/0.01)^4$ and $1 \times 10^{-8}$ ($i/0.2)^4$, respectively. Although these are smaller than the upper limit by Viking Orbiter $3 \times 10^{-5}$ [15], future optical observation may detect at least Phobos ring using light scattering.

Figure 1. Life times of Phobos' ring particles (left) and Deimos' torus particles (right). The horizontal axis is optical parameter $\beta$ the ratio of solar radiation force to the solar gravity or dust size.

Figure 2. Erosion rates of Phobs (left) and Deimos (right) by the bombardment of dust particles of the self-sustained ring/torus.