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Estimation of micrometeorites and satellite dust flux surrounding Mars in the light of MAVEN results

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ABSTRACT

Recently, MAVEN observed dust around Mars from ~150 km to ~1000 km and it is a puzzling question to the space scientists about the presence of dust at orbital altitudes and about its source.

A continuous supply of dust from various sources could cause existence of dust around Mars and it is expected that the dust could mainly be from either the interplanetary source or the Phobos/Deimos. We have studied incident projectiles or micrometeorites at Mars using the existing model, in this article. Comparison of results with the MAVEN results gives a new value of the population index *S*, which is reported here. The index *S* has been referred in a power law model used to describe the number of impacting particles on Mars.

In addition, the secondary ejecta from natural satellites of Mars can cause a dust ring or torus around Mars and remain present for its lifetime. The dust particles whose paths are altered by the solar wind over its lifetime, could present a second plausible source of dust around Mars. We have investigated escaping particles from natural satellites of Mars and compared with the interplanetary dust flux estimation. It has been found that flux rate at Mars is dominated (~2 orders of magnitude higher) by interplanetary particles in comparison with the satellite originated dust. It is inferred that the dust at high altitudes of Mars could be interplanetary in nature and our expectation is in agreement with the MAVEN observation. As a corollary, the mass loss from Martian natural satellites is computed based on the surface erosion by incident projectiles.

1. Introduction and motivation

There is a continuous shower of micrometeorites in a planetary system and Mars, being a member of it, is not the exception. Because of continuous bombardment of micrometeorites on Mars and its natural satellites, viz., Phobos and Deimos, the secondary ejecta comes out from the surface and leave dust particles in the environment. It is difficult to explain the escape of secondary ejecta from Mars because of its larger escape velocity (~5 km/s). However, the secondary ejecta from Phobos and Deimos can easily escape the satellite and reach the outer space around Mars. In addition, levitation of charged dust grain occurs on the Phobos and Deimos, similar to the Earth's Moon (Pabari and Banerjee, 2016). Farrell et al. (2007) have reported that the grain velocity can be several meters per second on the Moon. This velocity can be much greater than escape velocity of the Phobos and Deimos (~10 m/s and ~6 m/s, respectively) and, the levitating dust particles may be able to escape into the outer space. Such dust particles, whose velocity is more than the escape velocity and less than the orbital speed (i.e., 2.1 km/s and 1.35 km/s for the Phobos and Deimos respectively) of the satellites are predicted to form thin dust rings around the satellites and therefore, also around Mars. However, no such rings have been detected to the present day (Oberst et al., 2014). As predicted by Krivov and Hamilton (1997), the width and height of Martian dust torus could be ~5 Mars radii (~16,950 km) in both planes. In other words, the distribution of dust could be in horizontal as well as vertical directions, with Mars taken as the centre (Krivov and Hamilton, 1997).

In addition to the Phobos/Deimos dust, other plausible source of the high altitude dust at Mars could be interplanetary in nature and it is due to continuous shower of the micrometeorites. A Mars Dust Counter (MDC) on Nozomi mission aimed to study the high altitude dust at Mars. The MDC detected ~100 particles during its cruise phase, several of them interplanetary (Igenbergs et al., 1998) in nature. Lee et al. (2014) have proposed a PADME mission for similar investigation. Recently, Andersson et al. (2015) have reported observations of dust at altitudes from ~150 to 1000 km by a Langmuir Probe and Wave (LPW) instrument on MAVEN. They

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predicted the dust particles to be interplanetary (Andersson et al., 2015) in nature. As such, the Langmuir probe is primarily used to study plasma parameters and it cannot explain the source of such particles, unambiguously. It is therefore, a puzzling question to the space scientists about the presence of dust at orbital altitudes and about its source. In the absence of detailed in-situ measurements of dust at Mars, one has to rely on limited measurements made available by various missions and also on the existing models used to describe the micrometeorites/dust parameters. Due to availability of MAVEN dust observations at Mars, there remains a possibility to improve the existing model towards more realistic outcomes. This is a motivating factor to relook into the existing model and possibly fine tune the parameters. A Mars Orbit Dust Experiment (MODEX) has been proposed (Pabari et al., 2016) for future Mars orbiter to study the origin, abundance, distribution, flux and seasonal variation of dust around Mars. The present work can help provide the predictions, which may be useful to design dust detector for future missions.

The rest of the paper is organized as follows. Section 2 presents incident micrometeorites in the Mars system, compares results with the MAVEN observations and provides a new value of the population index S used to compute the number of impacting particles on Mars. Section 3 investigates possible dust contribution from Martian natural satellites, a comparison of satellite dust with the interplanetary dust flux and computes the lifetime of satellites based on the surface erosion, as a corollary and, the paper ends with conclusion.

2. Incident micrometeorites and population index from MAVEN observations

There is a continuous bombardment of meteorites and micrometeorites in any planetary system. A big object hitting the planetary body may be observable from the ground based system or from the space and it causes a bigger event, while the smaller particles cause continuous erosion of a planetary body. The incident micrometeorites at Mars based on extension of a power law size distribution and its comparison with the MAVEN observations yields an interesting outcome in the form of a population index, for which no single value could be derived earlier in the absence of in-situ observations. This new value of the index has been reported in this section.

2.1. Population index of incident micrometeorites

The asteroids having a common range of heliocentric distances with Mars may be called as the Mars asteroids, which are the major source of debris impacting Mars (Opik 1966). The number of asteroids eliminated in time Δt by actual impact with Mars is given by Soter (1971)

$$\Delta N = 0.789 \left(\frac{N}{T}\right) \Delta t \tag{1}$$

where N is the present number of Mars asteroids and T is the characteristic survival time. Eq. (1) remains valid whether ΔN and N refer to the totality of Mars asteroids or to any given size range subset (Soter, 1971). To find out the number of impacting particles of any size from the sizes of the visible Mars asteroids, a power law size distribution has been suggested by Soter (1971) for the total number of objects with radius greater than or equal to R and it is given as

$$N_s = \zeta \left(\frac{Z}{R}\right)^S \tag{2}$$

where ζ and Z are the constants of the fitting curve and S is the population index. It can be noticed that the power law size distribution is based on the number of observed (big) events and fitting of the curve using some parameters. The fitted curve is extendable to the smaller size of particles, i.e., micrometeorites (which may not be observable).In other words, the observed cumulative numbers of the Mars asteroids are first plotted logarithmically and a range of slopes are suggested for extension of the law, to determine the number of objects of various sizes, which impact on Mars (Soter, 1971).

Table 1
Total number of particles and expected flux rate for different values of the slope.

Population Index or Slope S	N_S for 1–25 µm size (8.4×10^{-12} g to 1.3×10^{-7} g mass range) particles during T	Average Flux Rate for 1–25 µm size (8.4×10^{-12} g to 1.3×10^{-7} g mass range) particles during T in #/s
1.6	1.16×10^{17}	0.8
2.0	1.44×10^{21}	9.95×10^{3}
2.4	1.79×10^{25}	1.23×10^{8}

The population index $S = 1.6$ was suggested by Opik (1966) as the most probable for the Mars asteroids with the upper limit of S as 2. However, extensive grinding raises the index and Dohnanyi (1969) derived the value of S as 2.4 for the smaller size debris or micrometeorites. Such slope lines are extended to find out the number of micrometeorites hitting Mars and its natural satellites. Soter (1971) had suggested the value as $\zeta = 5$ and $Z = 17$ km for Eq. (2). Also, Opik (1963) had used 34 Mars asteroids to calculate an average value of T as 6×10^9 years which may be comparable to the age of the solar system. However, we use the value of T as 4.6×10^9 years as the age of solar system and find the average flux rate using the power law size distribution. Recent MAVEN observations suggest dust particles in the range from 1–25 µm (corresponding to the mass range of ~8.4×10^{-12} g to 1.3×10^{-7} g), based on the assumption of particle velocities.

Results obtained from Eq. (2) are given in Table 1 for different values of the slope S for the particle size from 1–25 µm which are expected around Mars due to interplanetary dust flux (Andersson et al., 2015). One can observe from Table 1 that the smallest value of particle rate is 0.8 #/s in the third column. Andersson et al. (2015) have reported the flux rate of about 0.001 hits per second based on the LPW instrument on MAVEN spacecraft, which is almost two orders less than the smallest value of the rate in Table 1 and it is for the slope of 1.6 in Eq. (2). MAVEN observation implies that the value of slope in the power law size distribution needs to be reduced for computation of incoming flux on Mars. If we back calculate the value of S from MAVEN results, we get the slope as 1.32 for 0.001 hits per second particle rate and it is somewhat less than 1.6, the smallest value of the slope in Table 1. Thus, the most applicable value of the slope may be taken as 1.32 based on the MAVEN observations.

3. Investigation of possible dust contribution from Martian natural satellites

The MAVEN observations specify that the source of high altitude dust could be interplanetary in nature (Andersson et al., 2015), based on the assumption of particle velocity. As such, the MAVEN results do not favour the dust from the Phobos/Deimos (or the dust torus) based on the shape of detection for a given period of time (7 months) around Mars (Andersson et al., 2015). Further, it is understood that the dust from Martian satellites should be confined to the satellite orbits. However, Krivov and Hamilton (1997) indicated that the dust can be confined in both the planes. Over a time period, the smaller particles (typically <0.5 µm) are swept away by the solar wind, while the bigger particles travel towards the Sun for any type of dust distribution generated by the