Detection of dust around Mars and its implications

J. P. Pabari

Recent observations of MAVEN find dust to be present at altitudes from ~150 to 1000 km from the Mars surface. It is expected that it could be interplanetary in nature, based on assumption of particle velocity. Existence of dust at orbital altitudes on Mars could be mainly due to two plausible sources, viz. interplanetary dust and Phobos/Deimos-originated dust. Dust devils prevailing near the surface can lift the dust to a few tens of kilometres and at present, no physical process can explain dust transport to high altitudes (>50 km) from the dust devils. Another possible source of dust around Mars could be interstellar in nature; however, its possibility is rare. Dust originating from Phobos/Deimos could be either due to secondary ejecta created by continuous bombardment of micrometeorites or due to grain levitation. Though dust levitation on the Moon is yet to be confirmed by in-situ measurements, it is expected that it should occur on the airless bodies. The velocity of secondary ejecta and that of levitated dust can exceed the escape velocity of Phobos/Deimos and cause the dust to escape into outer space. Such escaping particles can form dust ring/torus around Phobos/Deimos and therefore also around Mars. The dust ring/torus is yet to be studied and fully understood. Observations of dust, whether originating from Phobos/Demos or interplanetary dust particles, are necessary for finding its origin, abundance and distribution around Mars. This article discusses the existence of high-altitude (>100 km) dust around Mars, and techniques for the detection of these dust particles using an impact ionization detector in a future Mars orbiter mission.

Keywords: Dust devils, Mars, natural satellites, torus.

RECENT missions to Mars have confirmed the presence of dust in the Mars environment, suggesting that dust devils prevail near the Martian surface and occur mostly during the southern hemisphere summer, around areocentric longitude of 255°. Dust-laden vortices known as dust devils are common in semiarid and arid regions on the Earth[1]. On Mars, active dust devils were first observed in satellite imagery[2] and in lander images[3] and they occur frequently[4–7]. Dust devils are considered to be important in maintaining and replenishing the background dust opacity in the Martian atmosphere[8–10]. An improved understanding of physical parameters associated with models describing dust devils is necessary to understand their influence on the Martian atmosphere, climate and surface changes[11]. Dust devils prevailing near the surface can lift the dust to a few tens of kilometres, and at present, no physical process can explain dust transport to high altitudes (>50 km) from the dust devils.

The other possibility of dust at high altitudes on Mars is from Phobos and Deimos, the natural satellites of Mars. The Phobos/Deimos-originated dust could be either due to secondary ejecta created by continuous bombardment of micrometeorites or due to grain levitation. There is continuous shower of micrometeorites or Interplanetary Dust Particles (IDPs) around Mars. The velocity of secondary ejecta on Phobos/Deimos can easily exceed its escape velocity (~10 and ~6 m/s respectively), due to large impact velocity (a few km/s to few tens of km/s) of the incident micrometeorites. With regard to dust levitation, it is known that there is no atmosphere on Phobos and Deimos, and they are immersed in space plasma as dielectric bodies. Further, the moons are obstacles to solar wind and illuminated by UV rays. All these factors govern a variety of processes on the surfaces of the moons and lead to the formation of a complex plasma sheath as well as electric field above the surfaces. Surfaces of Phobos and Deimos are covered by a layer of loose small grains of regolith[12,13]. The electrostatic charging can levitate dust particles in the environment[14], similar to the case of Earth's Moon, where the Lunar Horizon Glow (LHG) was observed by a camera on the Surveyor

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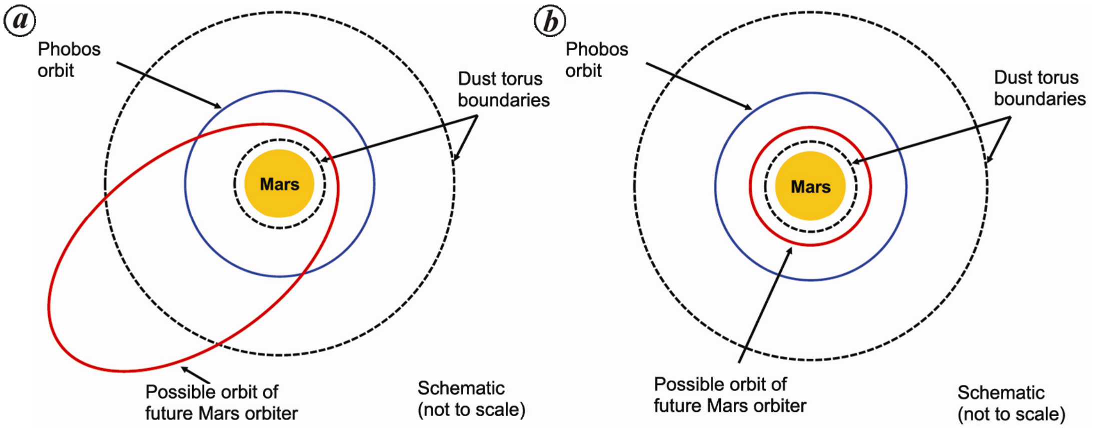

Figure 1. Dust ring structure in the Mars system and opportunity for measurement in case of (***a***) elliptical orbit and (***b***) circular orbit.

7 mission in 1968. However, the LDEX instrument on the LADEE mission provided no indication of 0.1 µm-sized particles near the terminator[15], in contrast to Apollo observations. Though dust levitation on the Earth's Moon is yet to be confirmed by *in-situ* measurements, it is expected that it should occur on the airless bodies like the Phobos and Deimos. The grain velocity of several metres per second has been reported for levitated dust particles on the Moon[16]. As such, the initial grain velocity of levitated particles is very less, however, at the plasma sheath boundary, the grain experiences a large velocity and then moves in a parabolic manner. The velocity of grain at the plasma sheath boundary can be larger than the escape velocity of Phobos/Deimos and hence, it can leave the parent body. Some heavy particles may not have large velocity at the plasma sheath boundary and after following parabolic trajectory beyond the boundary, they may return to the surface. Hence, the velocity of many dust particles can be larger than the escape velocity and they can escape into the outer space[16].

Thus, the levitated dust particles and the secondary ejecta may escape Phobos/Deimos. Such dust particles, whose velocity is more than the escape velocity and less than the orbital speed (i.e. 2.1 and 1.35 km/s for Phobos and Deimos respectively) of the satellites are predicted to form thin dust rings around the satellites[17] and therefore, also around Mars. However, no such rings have been detected till date[18]. Such a dust ring/torus is yet to be studied and fully understood by *in-situ* experiments. Krivov and Hamilton[19] have modelled the width and height of Martian dust ring/torus to be ~5 Mars radii in the horizontal and vertical planes. In other words, the dust ring distribution could be present in the horizontal and vertical directions with respect to Mars[19].

Other possible source of dust at high altitudes is the shower of micrometeorites or interplanetary in nature. Another possibility of dust at orbital altitudes on Mars could be interstellar in nature, however, its probability is rare and is likely to be negligible. The source of high-altitude dust around Mars requires further confirmation after Mars Atmosphere and Volatile EvolutioN (MAVEN)'s discovery of dust beyond 150 km above the surface. Further, it is important to know whether it is interplanetary in origin or Phobos/Deimos-originated to improve the current understanding of high-altitude dust around Mars.

Dust detection at high altitudes on Mars

Recently, MAVEN[20] observed dust around Mars from ~150 to ~1000 km, and it is a puzzling question to the space scientists about the presence of dust at orbital altitudes and its source. A Mars Dust Counter (MDC) was used during the Nozomi mission to study the dust around Mars and it had detected ~100 particles during its cruise phase, several of them interplanetary in nature[21]. A PADME mission has been proposed for similar investigation[22]. Andersson *et al.*[20] have reported observations of dust at about 150–1000 km altitude from the Martian surface using a Langmuir Probe and Wave (LPW) instrument during the MAVEN mission. It is predicted that the dust is interplanetary in nature, based on the assumption of particle velocity[20]. A Langmuir probe is used for determination of electron density and temperature, and cannot provide the source of such particles, unambiguously. A Mars Orbit Dust Experiment (MODEX) is proposed for future Mars orbiter missions to study the origin, abundance, flux, distribution and seasonal variation of dust around Mars[23]. If successful, it may provide an improved understanding of dust at orbital altitudes on Mars.

Figure 1 *a* shows dust tori around Mars and possibility of measuring dust in the Mars system by a future Mars orbiter having elliptical orbit, while Figure 1 *b* depicts the scenario for circular orbit of future Mars orbiter. The observation of dust ring around the Moons of Mars may be accomplished by planned or unplanned flybys (Figure 2). Moreover, the dust torus is expected to be around Mars as far as five Mars radii[19], which is about 17,000 km. A band of about 17,000 km wide in the *XZ* plane and a ring of about 17,000 km in the *XY* plane centred at Mars provide an excellent opportunity for measurement of dust by a dust detector in the future Mars orbiter missions, with or without any flybys near the Moons of Mars. If the final orbit of the satellite is expected to be 200 × 600 km, its initial orbits would be highly elliptical and subsequently, it would achieve the final orbit. The initial highly elliptical orbits could be utilized to study the possible ring/torus at about 17,000 km. Along with the dust ring particles, the dust instrument can measure IDPs (expected by MAVEN)[20] as well around Mars.

Dust detector configuration

Dust in the Mars system could be detected by impact ionization dust detectors. Whenever a hypervelocity (>1 km/s) dust particle makes an impact on a metal target dust detector, an impact plasma is generated. The electrons and ions are separated using the positively biased collector and negatively biased collector respectively. The charge produced by the electrons/ions is converted into voltage signal using a charge-sensitive preamplifier in the electron/ion channel. The pulse is then shaped using a semi-Gaussian pulse-shaping amplifier and its baseline is restored using a baseline restorer. The peak of the pulse and its rise time are measured using a peak detector and a timing discriminator respectively. Further processing is done in an Field-Programmable Gate Array (FPGA)/ microprocessor-based backend electronics and the data are stored in memory, which can be transmitted to the ground station. Typically, the impact charge generated by the detector due to incoming dust particles is given by[24]

$$Q = 0.5\, m\, v^{3.5}, \tag{1}$$

where Q is the charge (C), m the mass of the particle (kg) and v is the velocity of the particle (km/s). Figure 3 shows a plot of charge-to-mass ratio of the dust particles based on eq. (1). The charge pulses generated by the dust impact are processed and analysed by the electronics to arrive at the velocity (v) and mass (m) of the particles respectively, from the measured rise time (t) and peak charge (Q) using[21]

$$t = c_g\, v^{\eta}, \tag{2}$$

and

$$\pm\, Q/m = c_r\, v^{\beta}, \tag{3}$$

where c_g, c_r, η and β are constants which are determined by calibration experiments. The velocity is first determined from eq. (2) using the rise time and the mass is then derived from eq. (3) using the peak charge. Ground calibration is usually employed in impact ionization dust detectors to determine the calibration constants. The calibration process involves use of known mass (or size) particles, which are accelerated at known velocities. The rise time of the pulse generated is measured and plotted against velocity. A curve is fitted and constants are found for the eq. (2). Similarly, peak charge is measured during the calibration and charge-by-mass is plotted against velocity. The constants of eq. (3) are found using another fitted curve. Now, the rise time of the pulse is dependent on detector response and input capacitance of the charge sensitive preamplifier. The detector response time is basically dependent on the plasma travel time in vacuum, in case of metal target impact ionization dust detector. During calibration, the detector is tested inside a vacuum chamber with the condition similar to that in the outer space and therefore, the detector response remains the same. Also, input capacitance of the charge-sensitive preamplifier remains the same as that used during the ground calibration. Therefore, calibration constants of eq. (2) remain unchanged for the space experiment. Similarly,

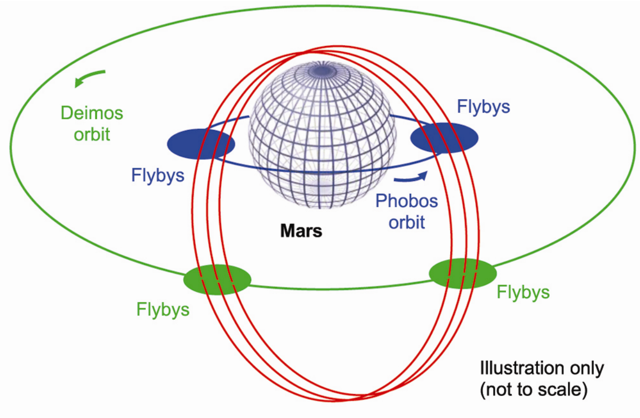

Figure 2. Planned or unplanned flybys of future missions and possibility of observing dust.

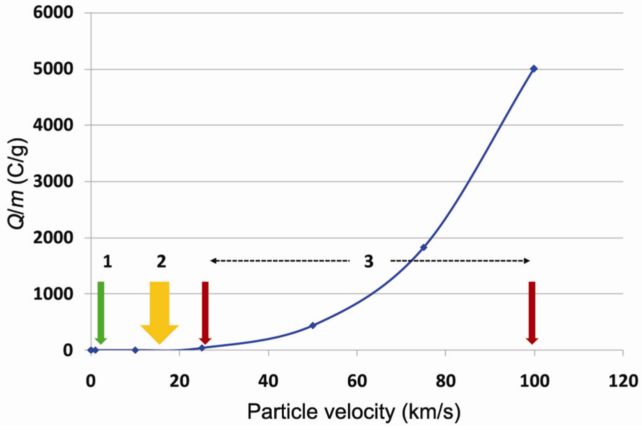

Figure 3. Charge-to-mass (Q/m) ratio of dust particles for detection by impact dust detector and the range of velocity for (1) ring dust, (2) interplanetary dust and (3) interstellar dust.

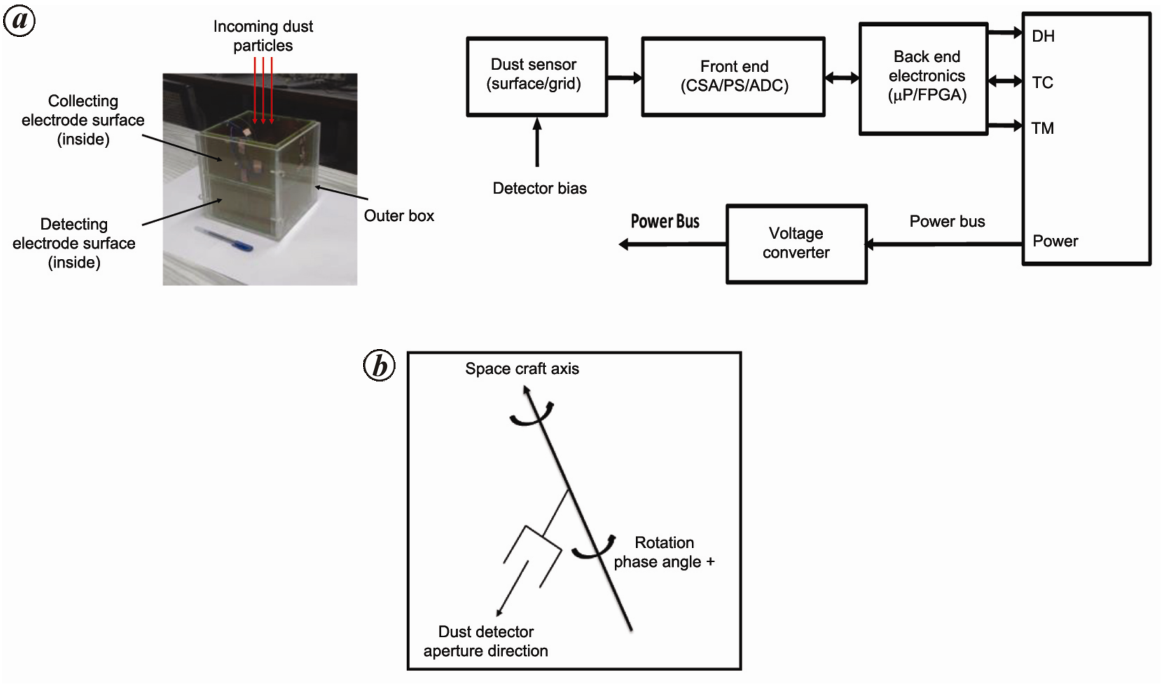

Figure 4. ***a***, A snapshot of dust detector and its block diagram. ***b***, Possible mounting on a spacecraft.

measured peak charge during calibration is dependent on the electronics, which remains the same in space. Hence, constants of eq. (3) also remain unchanged in the space experiment. In summary, the ground calibration remains valid for the space experiment. Similar calibration procedure is customarily followed for such dust detectors which are designed for various missions. The number density (n) of dust particles is proportional to the impact rate $\Delta N/\Delta t$ recorded by the dust instrument, and is given by[25]

$$n = \frac{\Delta N}{\Delta t}\frac{1}{v A_s(\psi)}, \tag{4}$$

where $A_S(\psi)$ is the sensor area as a function of the angle ψ with respect to the spacecraft spin axis, and v is the grain impact speed. In Figure 3, the range of particle velocity for dust ring, interplanetary dust and interstellar dust are marked on the plot[21]. Based on detected velocity of the dust particles, one may be able to differentiate among the particles coming from the planetary surface, those coming from interplanetary space and those from the interstellar region. There could not be ambiguity in differentiation of particles for surficial, interplanetary or interstellar regions, because the range of velocities for various cases is far apart (Figure 3). For instance, the interstellar particles could have an extremely large velocity (>22 km/s), while the surface particles would have (comparatively) less velocity (between 1–3 km/s). In case of interplanetary particles, which are most likely expected at high altitudes around Mars, there have been some measurements by previous missions. The MDC has detected some interplanetary dust particles during its cruise phase to Mars, whose velocity is between 3 and 20 km/s (ref. 26). Similarly, the Galileo dust detector to Jupiter has provided measurement of the interplanetary dust particles whose velocities are between 3 and 20 km/s (ref. 27). The interstellar dust particles are also measured by MDC[26]. Hence, the model of Figure 3 has validity for IDPs as well as interstellar dust particles, based on the measurements. There is additional opportunity for measurement of IDPs during the cruise phase of the Mars orbiter, i.e. in the region from Earth to Mars.

A prototype of the impact ionization dust detector, MODEX, is under development at the Physical Research Laboratory, Ahmedabad. Figure 4 *a* shows a snapshot of the detector under development and its block diagram, while Figure 4 *b* depicts its possible mounting on a spacecraft. From the measured parameters, one can obtain the dust particle parameters like mass, velocity, size, energy and density distribution to characterize dust transport at high altitudes. The instrument will also provide the abundance of dust particles around Mars. The counter electronics of the detector can provide the dust flux around Mars, as the satellite moves in orbit. Further, vertical profile in the form of the number of particles versus altitude, and dust size distribution for the measured events could be obtained from the dust experiment. Results obtained from the dust experiment on an orbiter could help enhance our understanding about the dust environment around Mars. A similar dust detector could be used for any planetary or asteroidal or cometary mission.

Implications of dust in the Martian atmosphere

The results obtained from the dust experiment could help enhance our understanding about upper atmospheric conditions on Mars. In particular, it would help in answering the long standing question of whether and where dust occurs in the circum-Martian system, and will quantify the dust production functions. It could provide confirmation whether dust exists in the form of a ring/torus. The seasonal variations of dust, if any, could also be understood in the circum-Mars region. The presence of dust could affect the atmospheric chemistry due to its associated electric fields. Also, radiations from both sides (surface and outer space) of fine dust particles could be blocked. The IDPs are composed of silicate minerals and glassy nodules, but sometimes include sulphides, metals, other minerals and carbonaceous material in orbit around the Sun. The study opens further possibility of analysis by future missions. Measurement during the cruise phase could help improve our understanding of the dynamical evolution of IDPs. Also, the circum-planetary dust particles probe the magnetospheric plasma and may affect the nature of plasma fields.

Conclusion

The presence of dust is expected at high altitudes around Mars, and it could be Phobos/Deimos-originated or interplanetary. The predicted dust ring/torus is yet to be studied and fully understood by future *in-situ* experiments. May it be of any origin, it is essential to further investigate dust (of any origin) at orbital altitudes on Mars, the dust may be observable from a future orbiter to Mars using an impact ionization dust detector. A MODEX is proposed to study the dust at orbital altitudes and also during the journey of the spacecraft; this can open a new direction of study.

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