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The role of electrostatic dust transport on the surface evolution of moons

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Abstract

Many of moons (e.g., Earth's moon, Martian moons - Phobos and Deimos) are covered with a layer of fine dust particles which are directly exposed to solar wind or magnetospheric plasmas as well as solar radiation. As a result, these dust particles are charged and may be transported or levitated. Such electrostatic process has been related to a number of space observations. Here we report the recent advancement in understanding the charging process and characteristics of lofted dust particles by laboratory studies. These laboratory results will help us determine the effects of electrostatic dust transport on surface processes on these moons. Especially, these results would be helpful for the upcoming JAXA's MMX mission.

1. Introduction

Due to meteoroid bombardment and thermal fragmentation, many of moons in the Solar System are covered with a layer of fine dust particles, called regolith. Most of them directly interact with solar wind or magnetospheric plasmas due to lack of atmosphere and global magnetic field. As a result, these dust particles are charged and may become mobilized, levitated or transported. This electrostatic process has been suggested to explain observations on the surface of Earth's moon, asteroids, Saturn's rings and icy moon Atlas as well as distant comets [1]. However, the fundamental charging mechanism remained poorly understood for decades until a milestone achieved by recent laboratory studies. A new patched charge model was developed and validated by laboratory experiments [1]. Basic characteristics of lofted dust particles, including their charge, size, velocity and lofting rate, were measured in simulated space conditions [1-3]. These results are important for understanding the effects of electrostatic dust transport on the surface evolution of these moons and for explaining the existing space observations.

2. Patched charge model

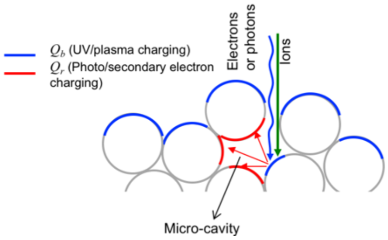

Figure 1. Schematic diagram of the patched charge model.

As shown in Fig. 1, the patched charge model [1] suggests that emitted photo- and/or secondary electrons can be re-absorbed inside microcavities formed between dust particles, resulting in large negative charges on the surrounding particles. These negatively charged dust particles repel each other to become lofted or mobilized.

This negative charge on a dust particle can be estimated using the following equation [1]

$$Q \approx -0.5C(\eta T_{ee}/e) \qquad (1)$$

where $C = 4\pi\varepsilon_0 a$ is the capacitance of a dust particle with radius a, η is an empirical factor between 4 and 8 based on laboratory measurements, T_{ee} is the emitted electron temperature in eV. $\eta T_{ee}/e$ shows the surface potential of the dust particle with respect to the ambient plasma.

3. Characteristics of lofted dust

Several laboratory experiments have been performed to characterize initial conditions of lofted dust in simulated space conditions [1-3]. Dust particles (including both lunar and Mars simulant with a size range between 10 and 50 μm in diameter) were exposed to UV (7.2 eV) or electron beams (120 eV).

1) Charge. All lofted dust particles are charged negatively, even under UV radiation [2]. The result is contrary to generally expected positive charge due to photoemission but in agreement with the patched charge model. The magnitude of the measured charge is ~ 10^{-14} C for 40 μm diameter particles [2].

2) Size. Lofted dust particles show wide size distributions [1]. In addition to single-sized particles, large aggregates (clumps with the size up to 140 μm held by the cohesive force between particles) are lofted. The high-porosity of aggregates enhances the total charge.

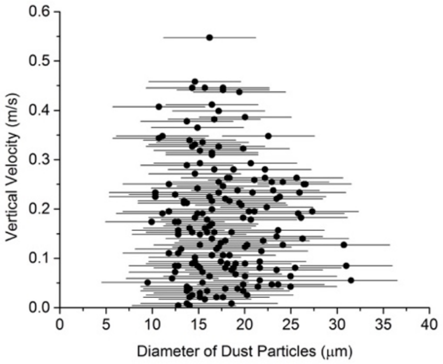

Figure 2 Vertical initial launch speed as a function of dust size.

3) Velocity. For dust particles of ~10 μm in diameter, their vertical launch speed is on the order of 1 m/s. Preliminary results from a new experiment show that smaller particles are lofted with a higher speed (Fig. 2). It also shows that the speed spreads over a wide range for same sized particles, which is likely attributed to large variations in the cohesive force between irregular shaped dust particles.

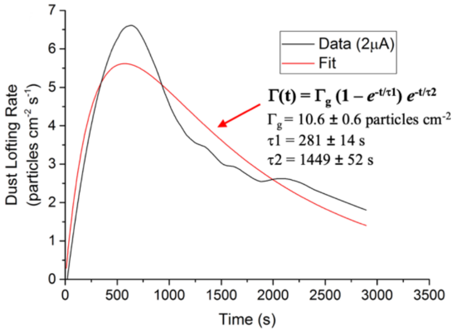

Figure 3. Dust lofting rate over time with simulated charging conditions at 1AU.

4) Rate. Our recent experiment [3] shows that the lofting process is time-dependent, which begins relatively fast and then slows down as time progresses (Fig. 3). The slow-down is likely due to the refilling or removal of microcavities as a result of dust movement, reducing the microcavity charging effects. Figure 3 shows that the transient rate may reach ~ 5 particles cm^{-2} s^{-1} that is fast enough to supply the lunar horizon glow event. The slow-down indicates that the average rate over the geological timescale remains low.

4. Summary and Conclusions

Recent laboratory experiments greatly advanced our understanding of electrostatic dust transport on airless bodies including most moons. A patched charge model was developed to explain the fundamental charging mechanism. Initial conditions, including the charge, size, velocity and rate of lofted dust particles, were characterized. These laboratory results are important for future studies and flight missions (e.g., JAXA's MMX mission) to advance our understanding of charged dust dynamics on the regolith of moons and subsequent effects on their surface evolution.

Acknowledgements

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