Electrostatic Dust Transport Effects on Lunar Regolith Evolution and Dust Hazards

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1. Introduction

Electrostatic dust charging and subsequent transport on the lunar surface due to direct exposure to the solar wind plasma and solar radiation is a long-standing problem. The first observed evidence for these processes was the lunar horizon glow (LHG) observed by several Surveyor lunar landers in late 1960s [Criswell, 1973]. Since then, more observations have been connected to this electrostatic dust phenomenon, including the Apollo observations of the high-altitude horizon glow and streamers [McCoy and Criswell, 1974; Zook and McCoy, 1991], the low-speed dust detections by the Lunar Ejecta and Meteorite Experiment (LEAM) [Berg et al., 1976], the formation of swirl-shaped, high-albedo markings on the lunar surface [Garrick-Bethell et al., 2011], and a recent observation of dust deposits on lunar rocks by the Chang'E-3 mission [Yan et al., 2019]. Beyond the Moon, related observations on other airless bodies, for example dust ponding on asteroid Eros [Robinson et al., 2001], radial 'spokes' in Saturn's rings [Smith et al., 1981], and the lack of fine-grained regolith on asteroid Ryugu [Jaumann et al., 2019], all indicated that electrostatic dust transport as a universal phenomenon across the solar system.

While electrostatic dust transport has been studied experimentally, and with analytical and numerical models, these provided contradictory results, and the fundamental mechanisms of dust charging and lofting remained unsolved. Recently, however, a series of advanced lab experiments [e.g., Wang et al., 2016; Schwan et al., 2017; Hood et al., 2018; Carroll et al., 2020] have made important breakthroughs in understanding the fundamentals of charging and lofting. The experiments and the resulting new "patched charge model" [Wang et al., 2016] demonstrate that the emission and re-absorption of photoelectrons and/or secondary electrons inside microcavities between dust particles can create a substantial charge buildup on the surrounding particles, such that the subsequent strong repulsive forces between these particles cause their lofting or mobilization.

In addition to naturally lofting, dust can be stirred up by human or robotic activities, which are expected to be significant during the upcoming Artemis missions, including the Artemis III crewed mission to the lunar south pole. Fine dust particles are likely to stick to every surface, and the fact that they have excess electrical charge due to natural plasma and/or triboelectric effects makes them to be even stickier and harder to be removed. Hazards posed by charged dust particles have been already recognized during the Apollo missions [Afshar-Mohajer et al., 2015] and more recently by the Lunar Surface Innovation Consortium (LSIC). Dust hazards include damage to spacesuits due to jagged lunar dust shards, degradation of radiators causing problems with thermal control systems, reduction of return efficiencies of the retroreflectors, interference with hatch seals and Extravehicular Activity (EVA) systems, and the health risks of inhalation by astronauts.

2. Outstanding Science Questions and their Significance

Here we highlight two outstanding science questions for the Artemis missions:

- What is the charging state and behavior of dust particles lofted naturally or by human activity in the near-surface plasma environments on the Moon?

Although much progress has been made in understanding the fundamentals of dust charging and behavior, lab experiments are not able to fully reproduce conditions on the lunar surface and dedicated in situ measurements are needed to determine the ground truth and to quantify the electrostatic dust phenomenon on the surface of the Moon. The role of electrostatic dust transport is yet to be fully assessed in shaping the surface properties of other airless bodies. As indicated by existing observations and recent laboratory studies, electrostatic processes may efficiently alter the surface morphology and porosity, lead to dust size sorting, and drive dust migration. The behavior of charged dust on the Moon needs to be well characterized in order to define the appropriate operations, design, testing, and mitigation strategies to reduce dust hazard.

- How does electrostatic dust transport play a role in shaping the physical and spectral properties on the surfaces of the Moon and airless bodies across the solar system?

Because charged dust motion is predicted to create surface redistribution, both the thermal properties (e.g., thermal emissivity and thermal inertia) and the spectral properties, which are sensitive to the upper most layer of the regolith [Delbo et al., 2015; Pieters et al., 1993] are expected to be significantly altered due to these changes in the regolith physical properties. Electrostatic processes potentially add a new dimension, in addition to impacts and space weathering, to understand the surface evolution of the Moon and other airless bodies.

Studies of electrostatic dust transport address outstanding science questions identified in the 2012-2023 Planetary Science Decadal Survey and the SMD Planetary Science Goal regarding *the evolution of objects in the solar system*. They address the Science Goal 8b in the Lunar SCEM 2007, and LEAG's ASM-SAT on *electrostatically transported dust grains and their effects on lunar exploration and lunar-based astronomy*. Additionally, these studies address HEOMD Lunar SKG-III-D-2, Strategic Objective 2.2 in the NASA 2018 Strategic Plan and Global Exploration Roadmap regarding *dust effects on human exploration on the Moon*.

3. Artemis III Measurement Objectives

To answer the outstanding science questions related to electrostatic effects on the regolith, the science experiments performed during the Artemis III mission in the lunar south pole should:

- Characterize surface lofted dust particles in response to local plasma and electric fields with deployed dust detector instruments in combination with plasma/electric field measurements.
- Characterize the effect of surface disturbances due to meteoroid impacts and/or human activity on electrostatic dust processes with deployed dust detectors, dedicated camera observations of lofted dust motion, and "witness" plate measurements to show changes with time.
- Characterize the charge state and behavior of human-caused dust lofting and identify its potential hazards to future lunar surface exploration with deployed dust detectors and witness plates, and careful characterization of dust behavior on contact (i.e. bringing back material samples).

For Artemis III astronauts to meet these science objectives, we envision a coordinated campaign involving the deployment of dedicated dust instruments on the lunar surface by the crew. The crew can also help set up the surface dust disturbance experiments to be coordinated with simultaneous the dust measurements. Dedicated charged dust sensors could be set up at any location, and should operate at all landing sites to determine local and global properties of dust behavior.

References

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