In-situ measurements of electrostatically lofted dust on the lunar surface

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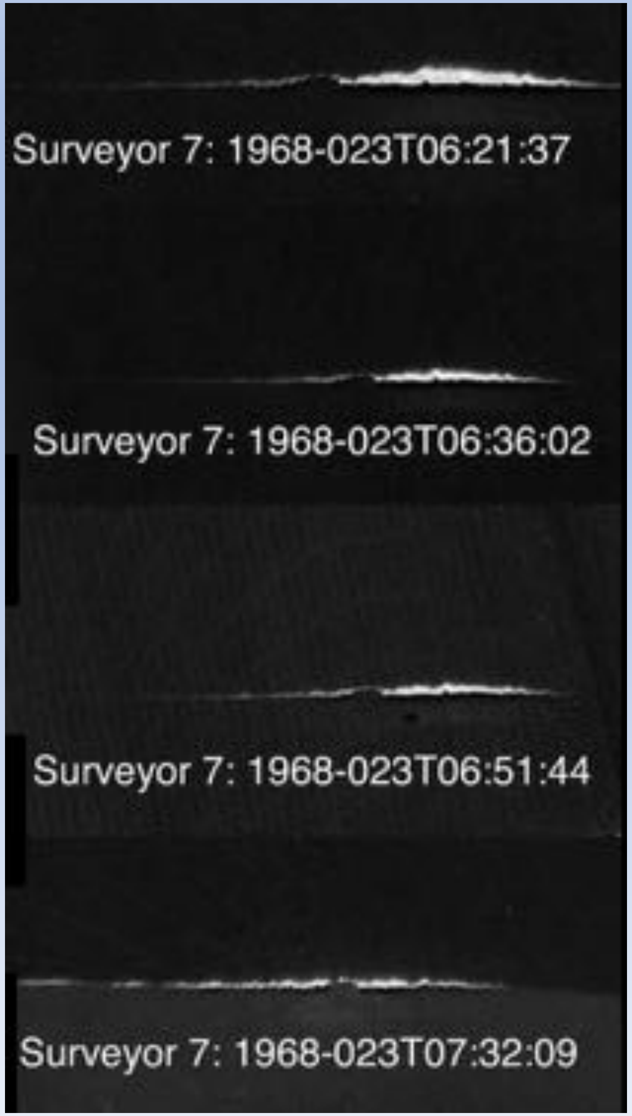
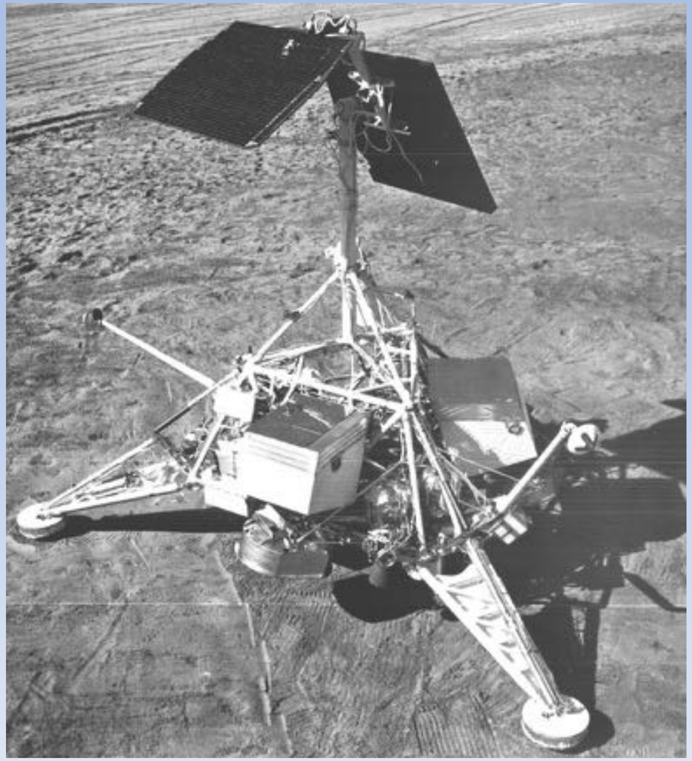
Apollo Observations Related to Electrostatic Dust Transport



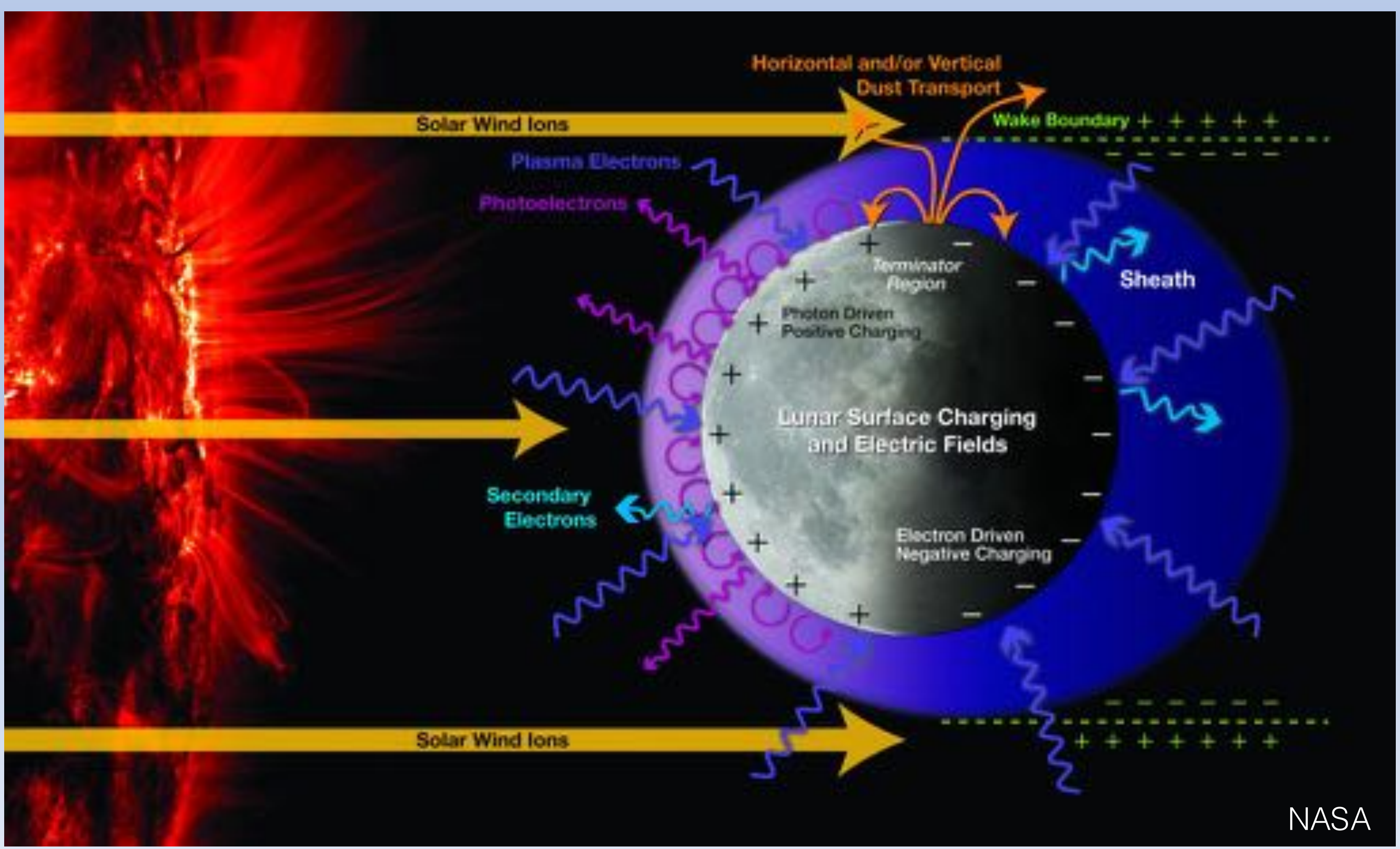
NASA



Surveyor 7 lander model

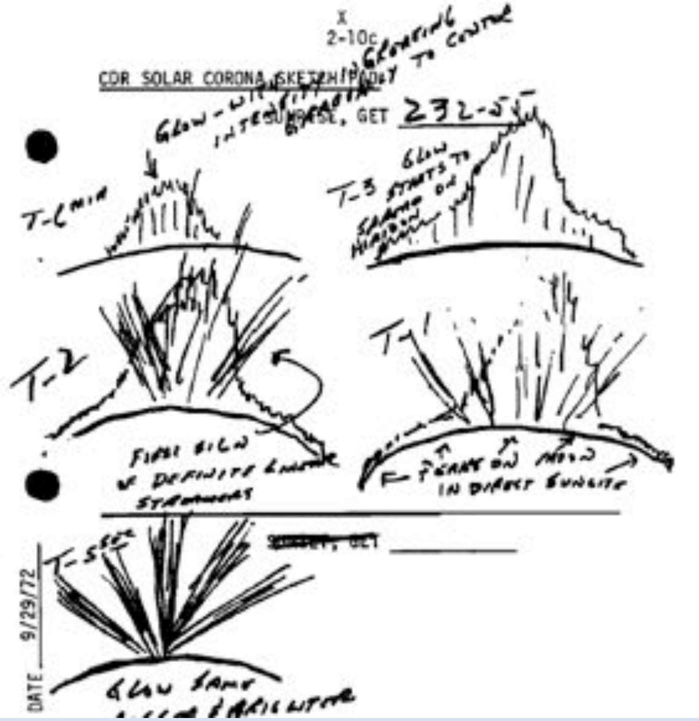
Lunar Horizon Glow (Rennilson and Criswell, 1974; Colwell et al., 2007)

Lunar Plasma Environment



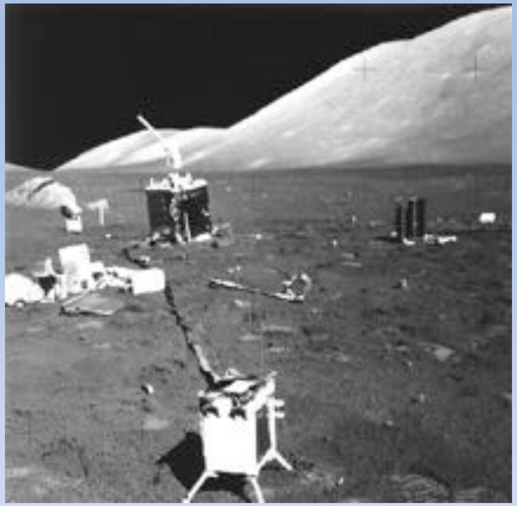
Dust particles on the surfaces of the Moon and other airless bodies are charged and may be transported due to electrostatic forces.

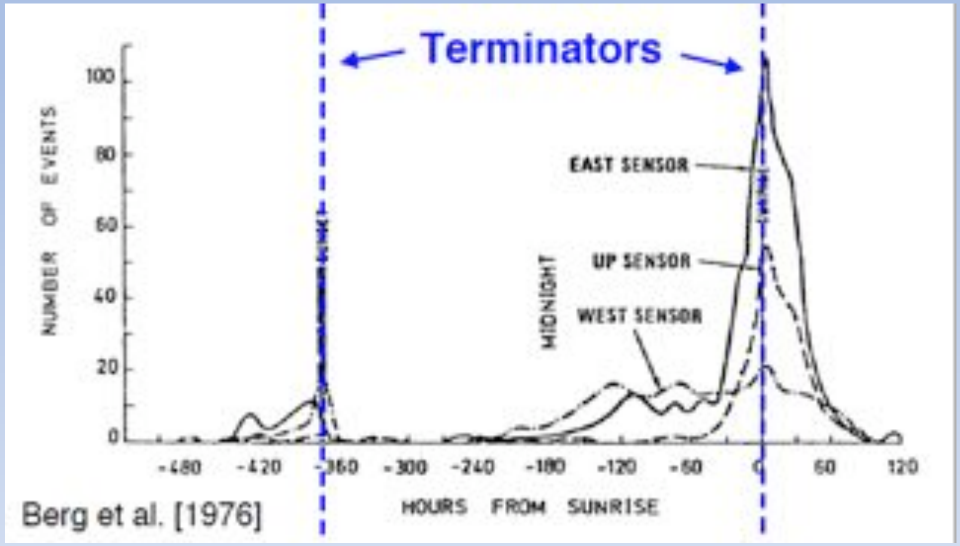
Apollo Observations Related to Electrostatic Dust Transport



Sketches drawn by Apollo 17 astronauts as as viewed from lunar orbit (Zook and McCoy, 1991)

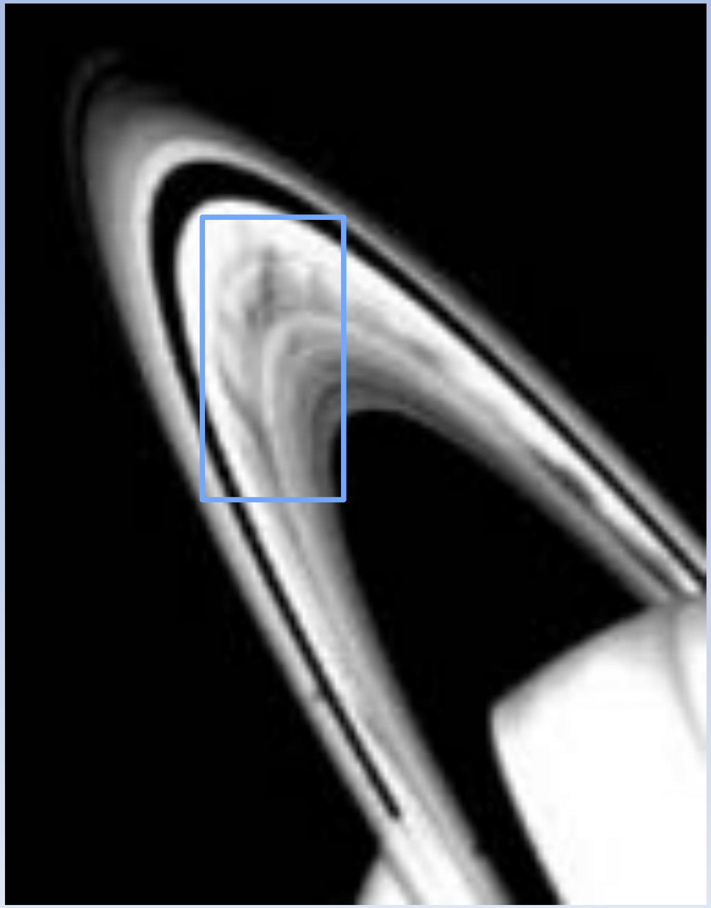
Lunar Ejecta and Meteorites (LEAM) Experiment



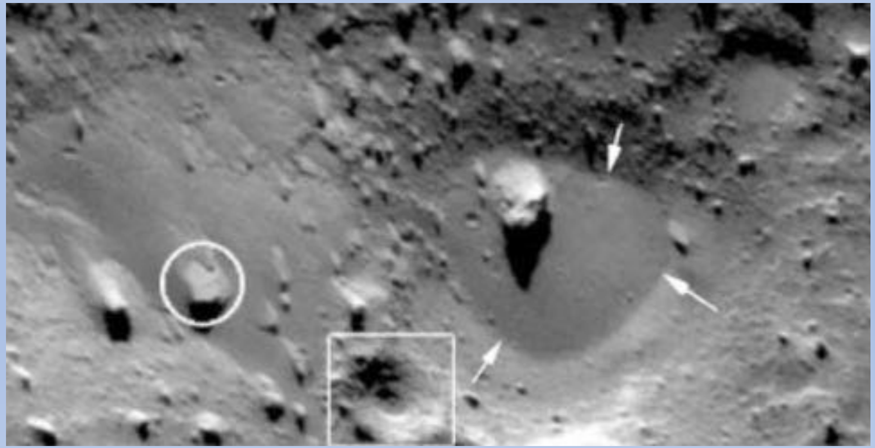


Lower velocity impacts instead of hypervelocity impacts were detected near terminators (Berg et al., 1976).

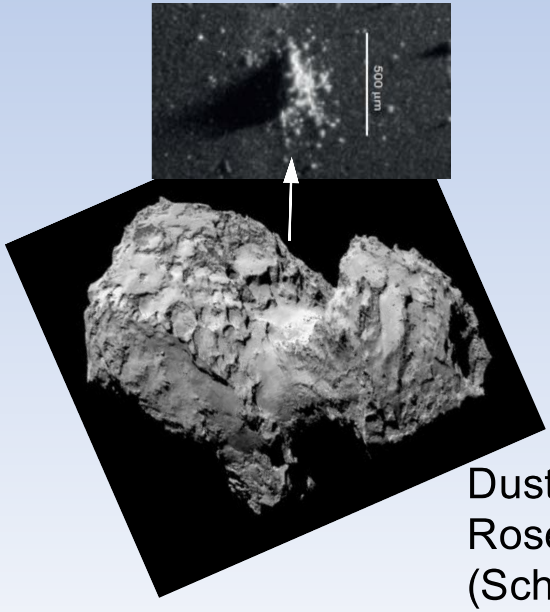
Possible Electrostatic Dust Transport Phenomena on Other Airless Bodies



The radial spokes in Saturn's rings (Smith et al., 1981, 1982)



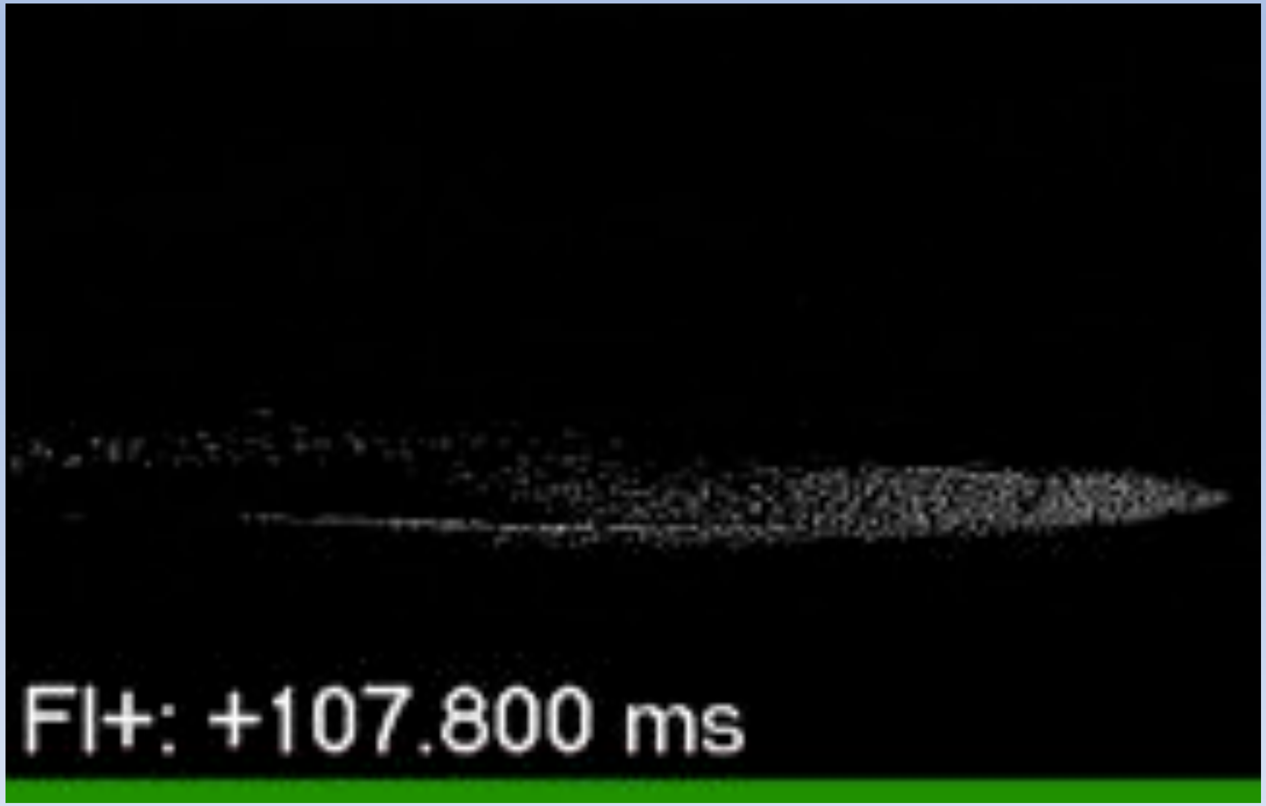
Dust ponds on asteroid Eros (Robinson et al., 2001)



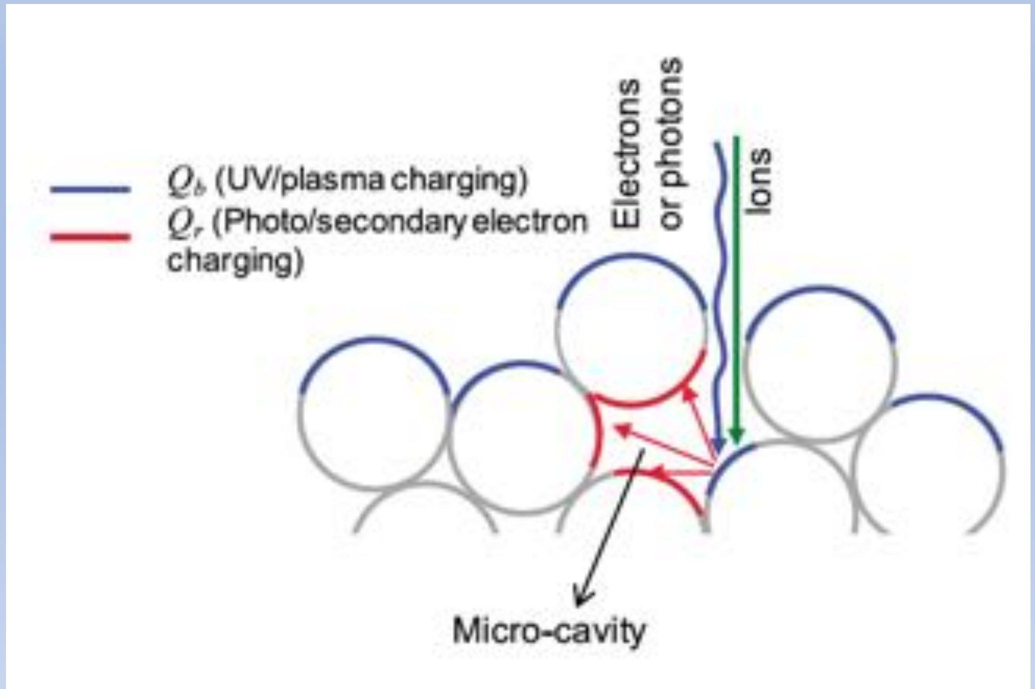
Dust particles collected by Rosetta from comet 67P (Schulz et al., 2015)

However, the charging and transport mechanisms remained unsolved for decades.

New "Patched Charge Model"



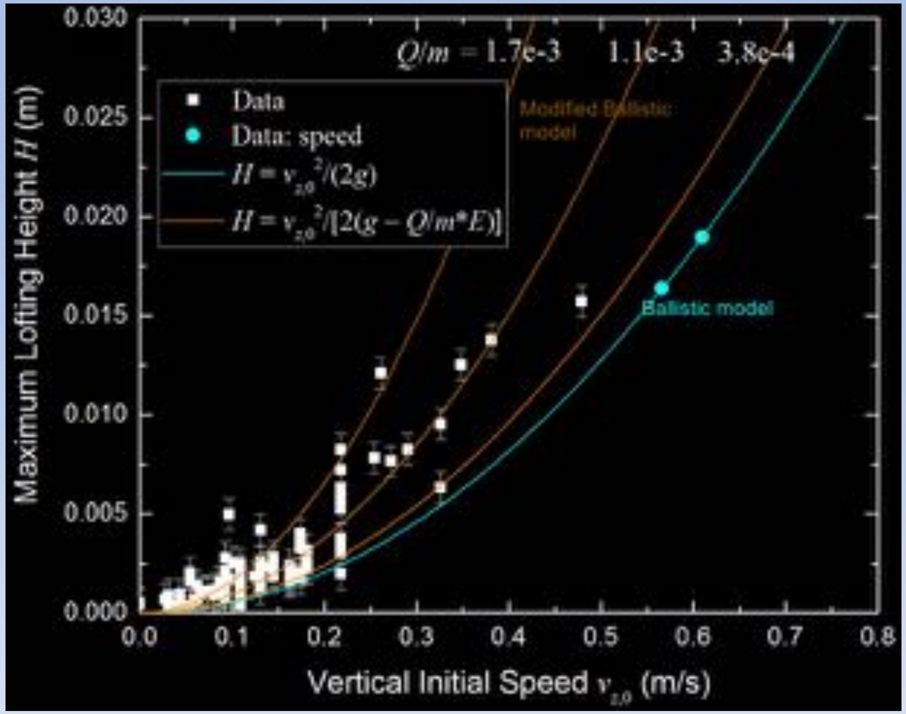
Laboratory observations of lofted micron-sized dust particles by exposure to UV radiation or plasmas



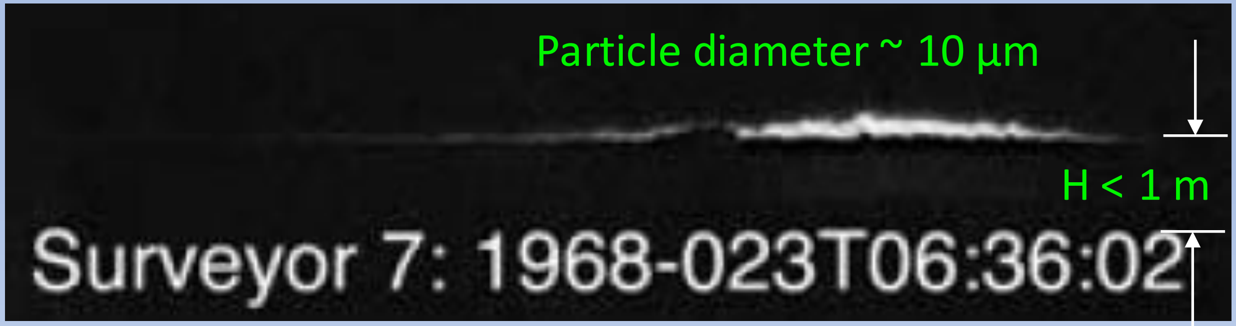
Wang et al., 2016; Schwan et al., 2017

- Dust particles that form microcavities in a regolith surface can attain large negative charges due to the cavity's absorption of photo- or secondary electrons emitted from their neighboring particles.
- The repulsive force between two adjacent negatively charged dust particles ejects them off the surface.

Dust Lofting Heights and Speeds



Wang et al., 2016



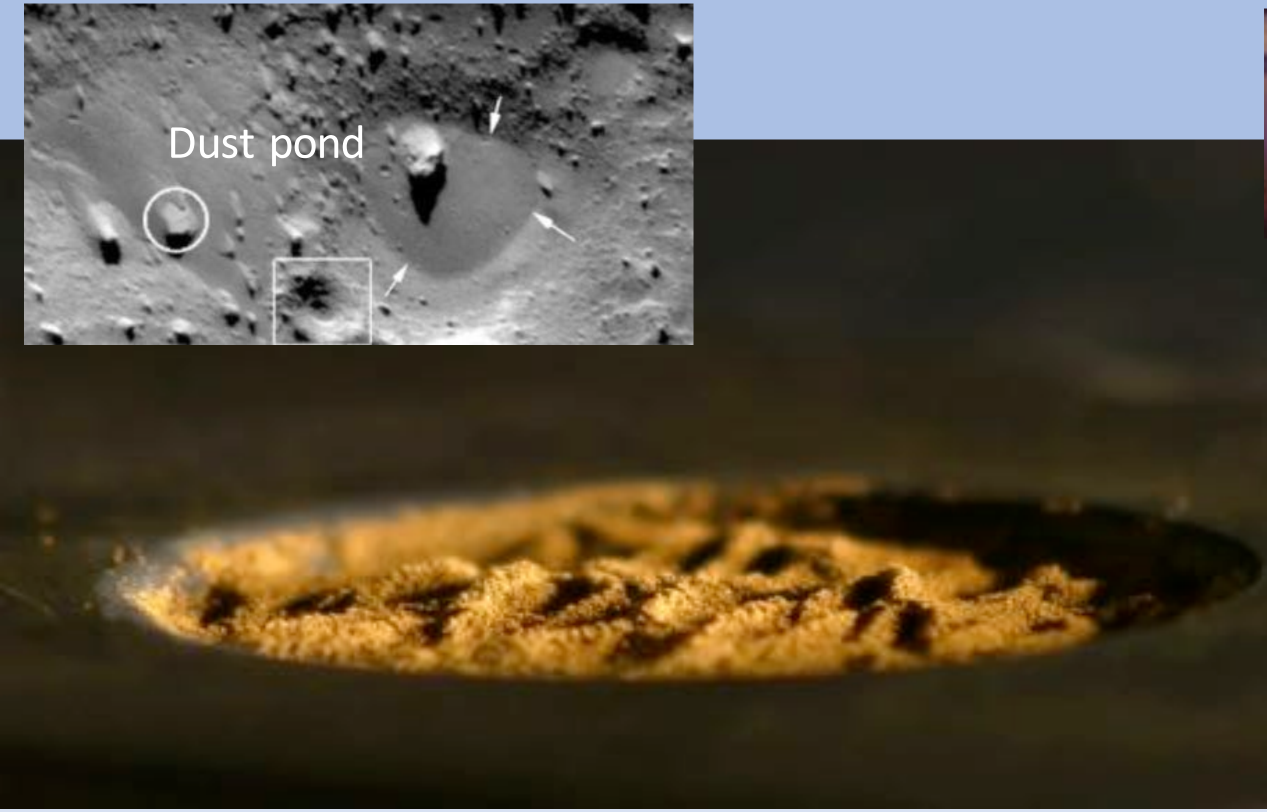
Lunar horizon glow

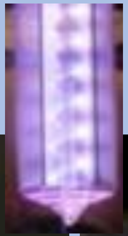
H_{earth} > 0.02 m (Particle diameter < 44 µm)

H_{moon} > 0.12 m (g_{moon}=1/6 g_{earth})

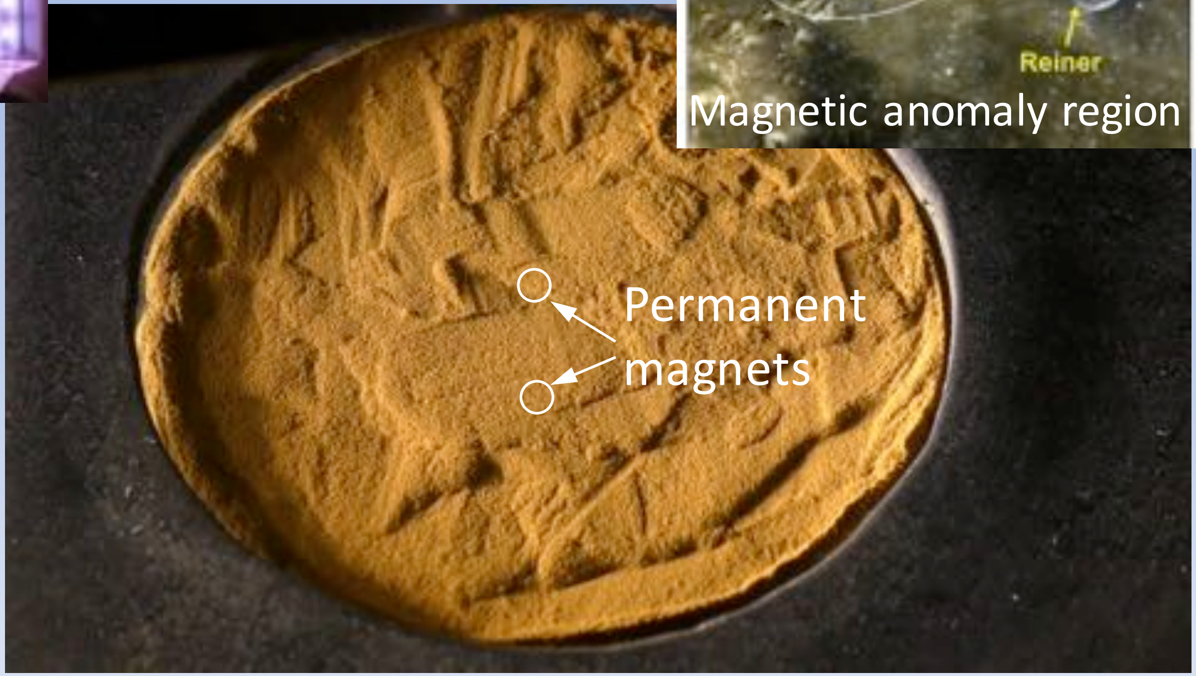
Surface Mobilization

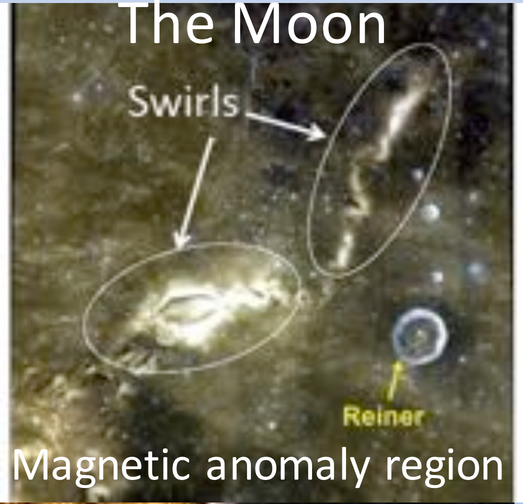
Asteroid Eros





UV light (172 nm)





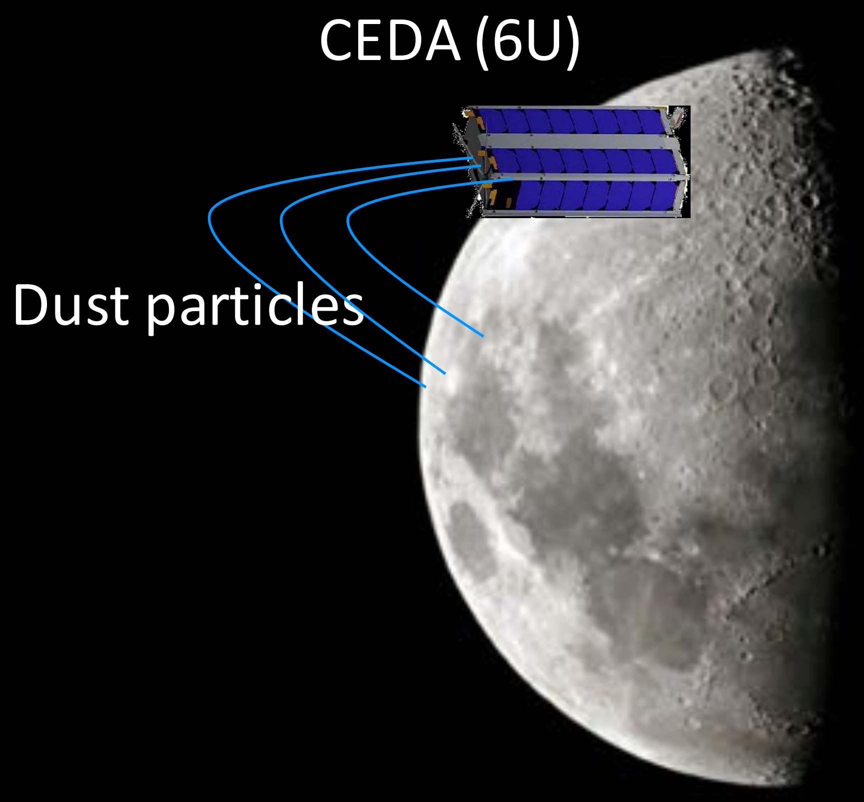
Dust lofting, transport and mobilization can eliminate existing surface features or create new surface features.

Recent laboratory experiments have shown

1) Dust can be lofted, even escape from smaller bodies, creating a near-surface dust environment;
2) Dust transport/mobilization can reshape the surfaces of airless bodies, such as surface morphology and porosity and therefore thermal inertia, redistribution of surface materials, alteration of the space weathering effects.

It is time to go there to find ground truth

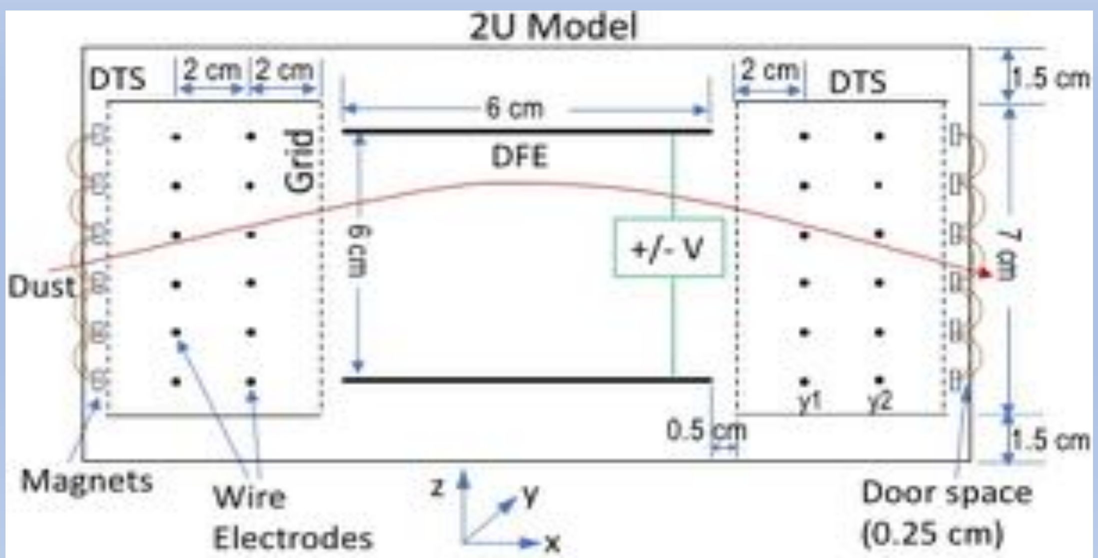
CubeSat Electrostatic Dust Analyzer (CEDA)

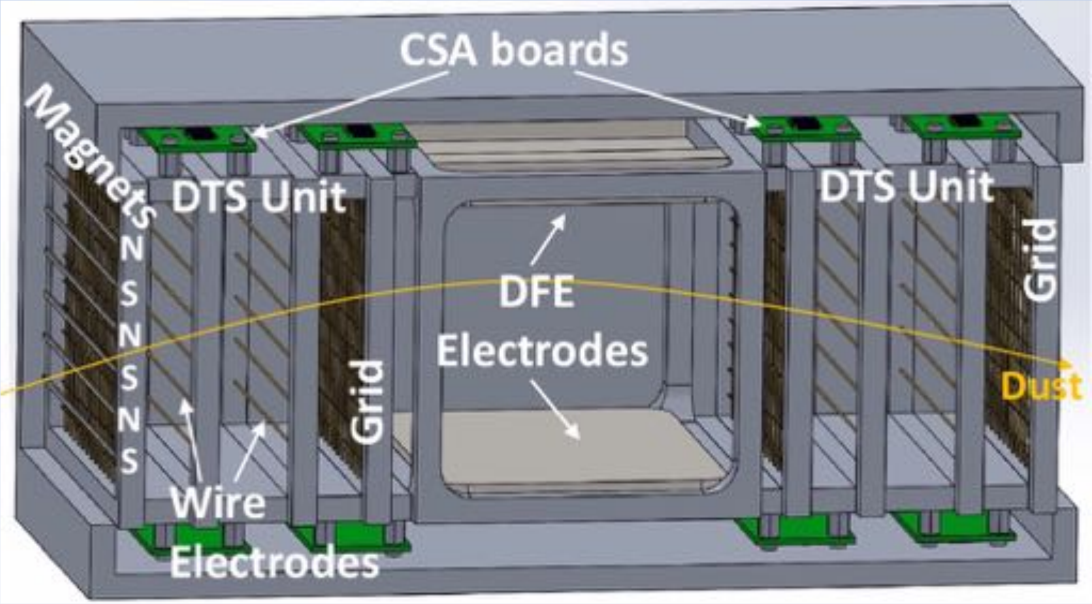


Mission concept

CEDA, a 6U CubeSat integrated with a 2U dust sensor, to be deployed on the lunar surface to explore electrostatic dust transport in order to understand its role in the surface evolution of airless bodies.

Dust Sensor





Goal: measure the charge, velocity, mass, and flux of electrostatically lofted dust on airless bodies.

Measurement Specifications

- Charge sensitivity: 10^4 electrons
- Velocity range: 0.1 – 100 m/s
- Q/M range: 2 – 20 x 10^{-4} C/kg

The dust sensor consists of two Dust Trajectory Sensors (DTS) and one Deflection Field Electrodes (DFE) unit.

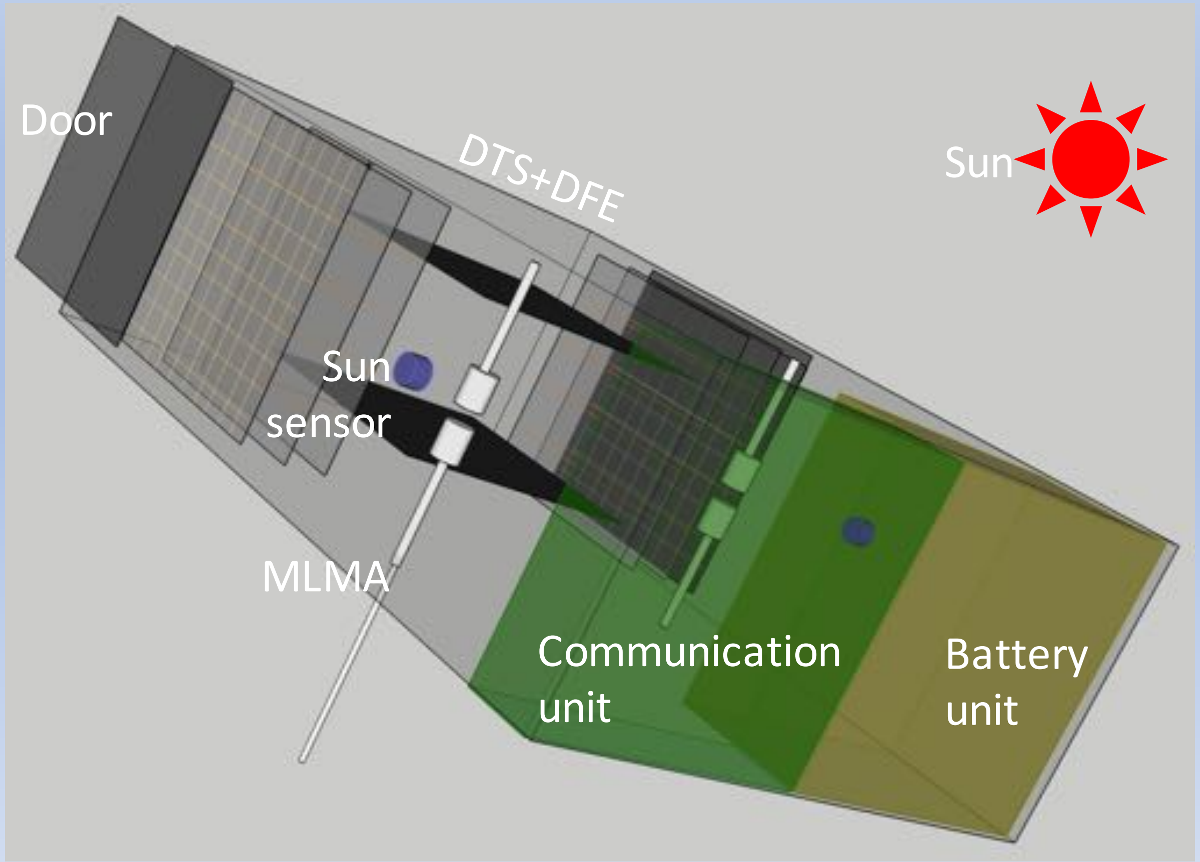
DTS components:
Wire Electrodes: Measure the ***charge*** and ***velocity*** of dust particles. The isolated wires measure the image charge of a dust particle passing by. The dust trajectory will then be tracked to get its velocity.

DFE components:
Two electrodes with a voltage across them to deflect a charged dust particle. By tracking the full trajectory from entering and exiting the analyzer, the charge-to-mass ratio (Q/M) is derived and therefore its ***mass*** is determined, given the measured charge.

CEDA with Integrated Dust Sensor

Specifications

- 6U (10 cm x 20 cm x 30 cm) Mass Estimate: <12kg Power Estimate: <12W
- Sun sensors (2-4 units): to determine the sun position.
- Miniature Linear Motion Actuators (MLMA, 4 units): to raise the analyzer on one side for larger dust collecting FOV. The raised side will be the shadowed side to minimize the UV and solar wind interferences.
- Doors (2 units): to prevent stirred-up dust during landing from entering the analyzer, and also to prevent UV and solar wind from entering the sunlit side of the analyzer.
- Solar panels: to be folded to avoid being covered by stirred-up dust during landing and then opened afterward.



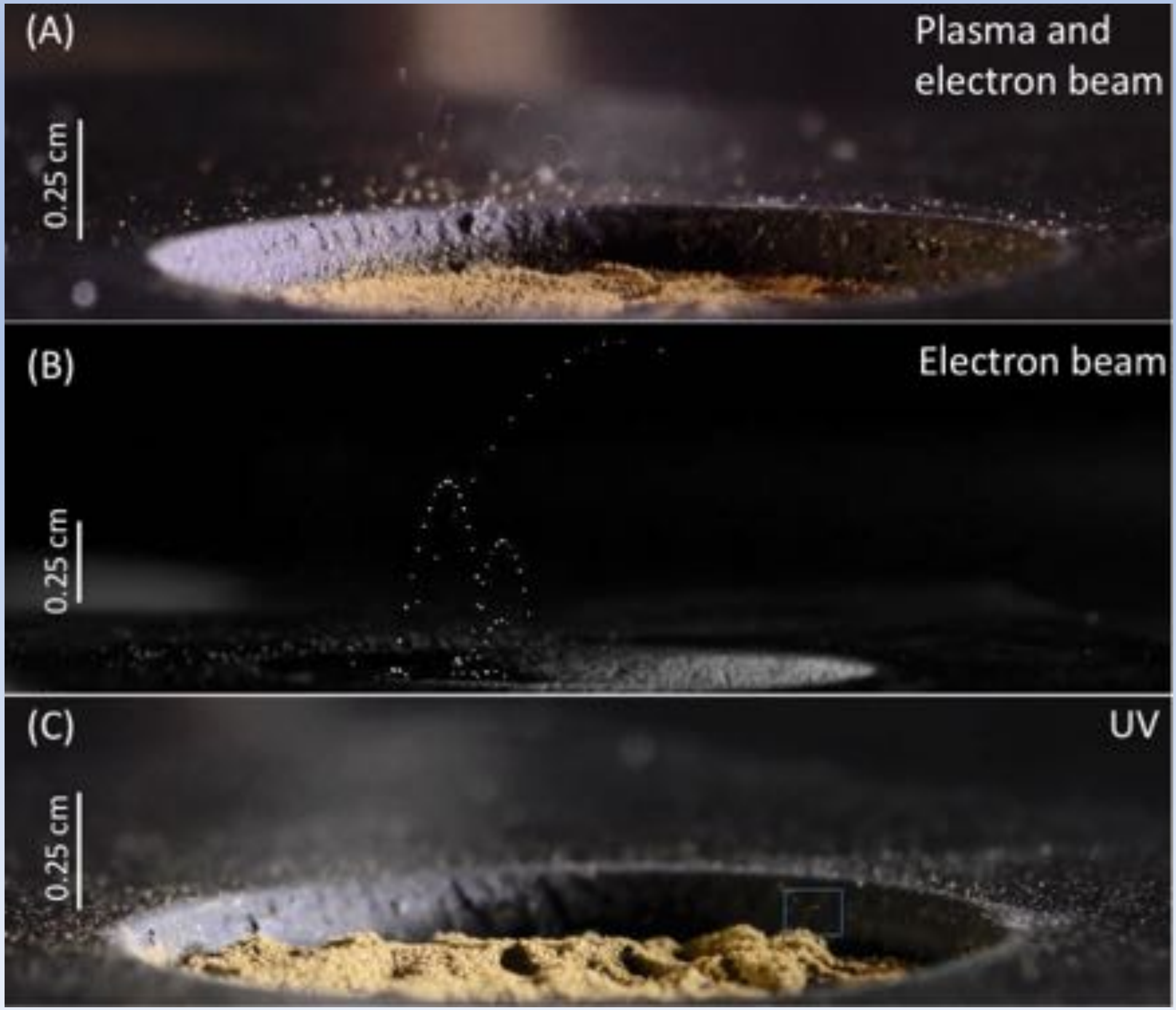
The design considers the orientation independence, large FOV, prevention from the solar wind and solar UV radiation interferences, and minimizing stirred-up dust covering the solar panels during landing.

Landing Site Selection

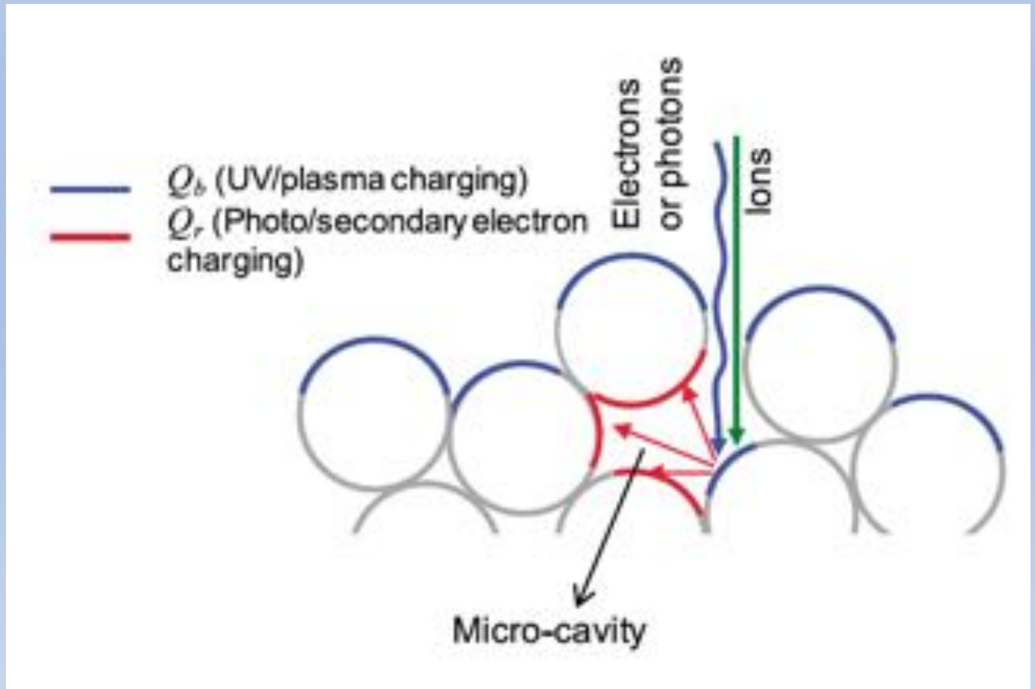
- The preferred landing site would be the areas exposed to sunlight (lower latitudes) because photoemission is expected to be an efficient charging process for dust lofting on the lunar surface (Wang et al., 2016).
- Multiple sites, such as Flat regions, Craters, Lunar Magnetic Anomalies (LMAs).
- Deployed from a lander or rover, or by astronauts.
- Mobility and sample return are NOT needed for these measurements.

Thank You

New "Patched Charge Model"



Laboratory observations of lofting dust



Wang et al., GRL, 2016

- Dust particles that form microcavities in a dusty surface can attain large negative charges due to the cavity's absorption of photo- or secondary electrons emitted from their neighboring particles.
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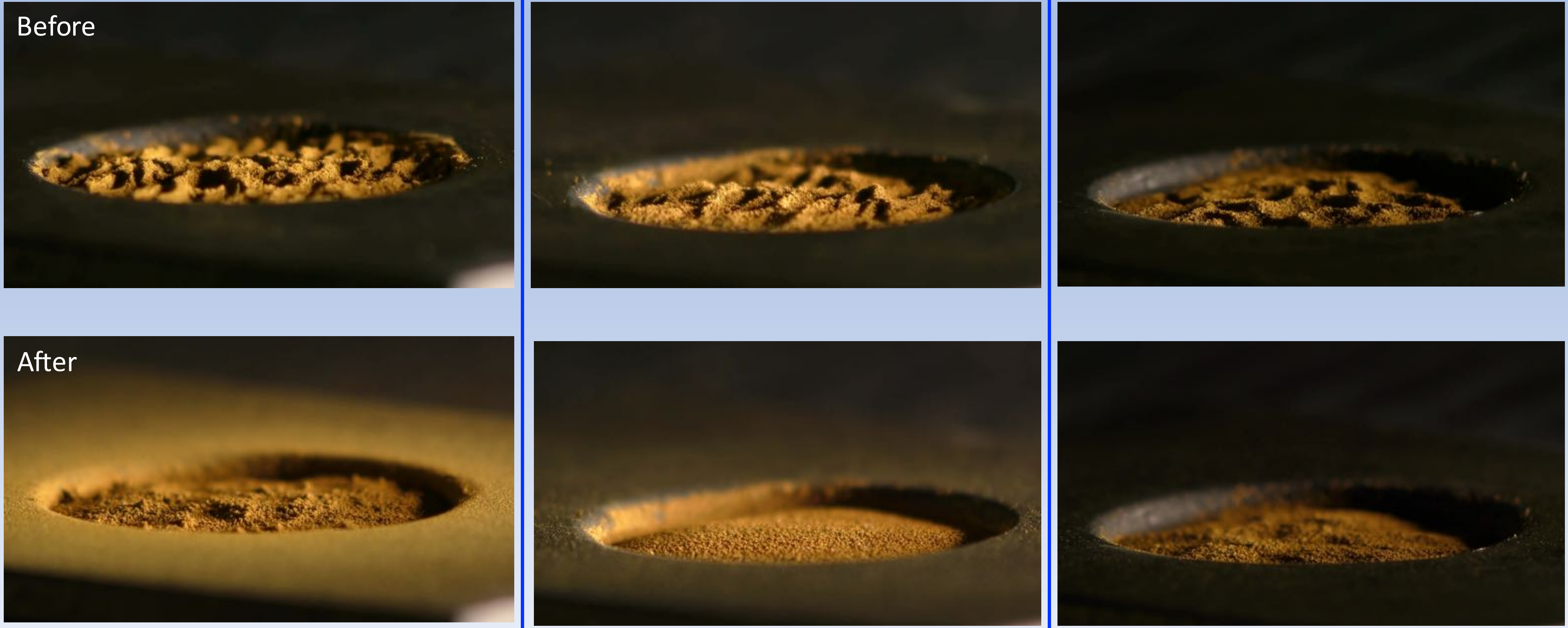
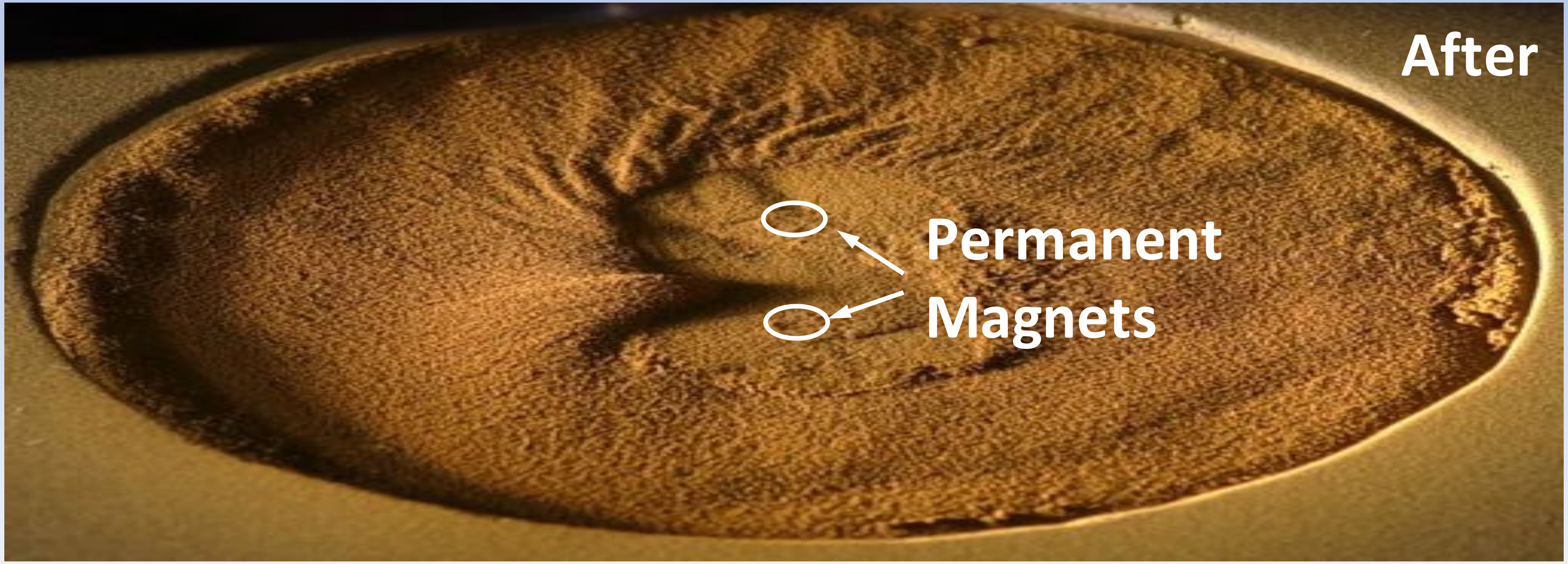
Surface Mobilization

< 38 µm | 38 - 45 µm | 53 - 63 µm




Before

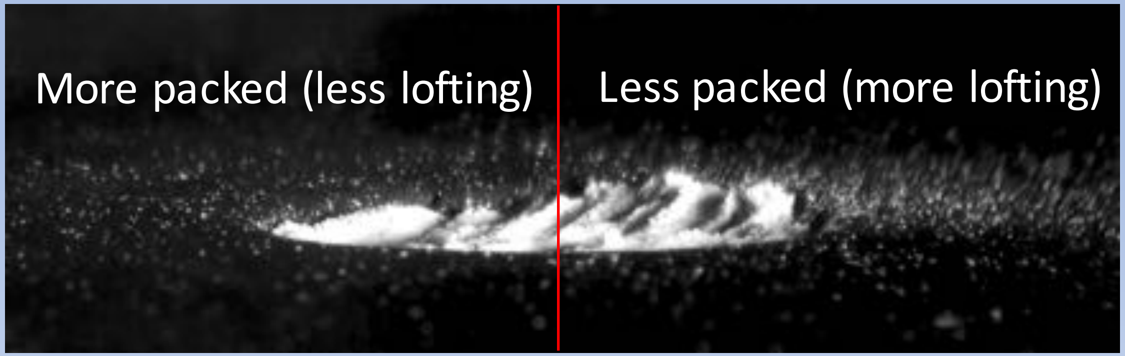

After
Permanent
Magnets

How fast can this process be on the Moon or other airless bodies?

Estimated rate in space (1 AU): **20 $\#p\ cm^{-2}\ s^{-1}$**

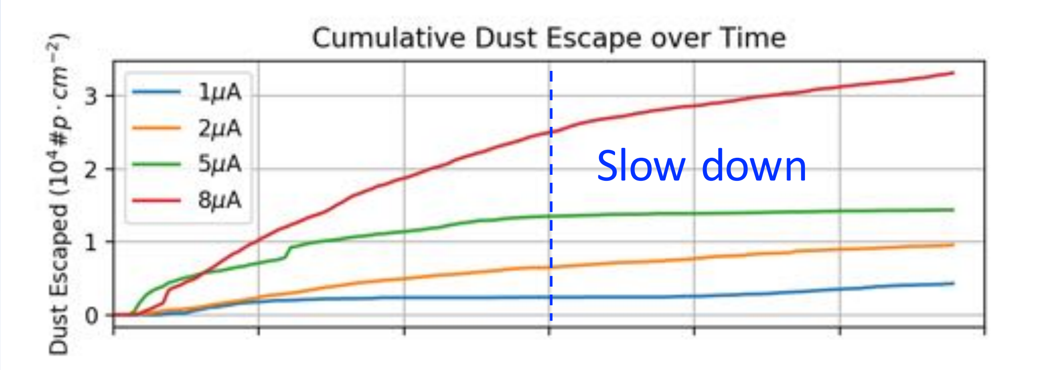
(Photoelectron flux: 2.5 x 10^{10} #e $cm^{-2}\ s^{-1}$; Particle > 10 μm in diameter and avg. diameter 20 μm)

Compactness



Dust size distribution: Intermediate sized particles are the easiest to move (Cohesion plays a critical role, Hartzell et al., 2013).

Slow-down process
(Porosity variation with the regolith depth?)



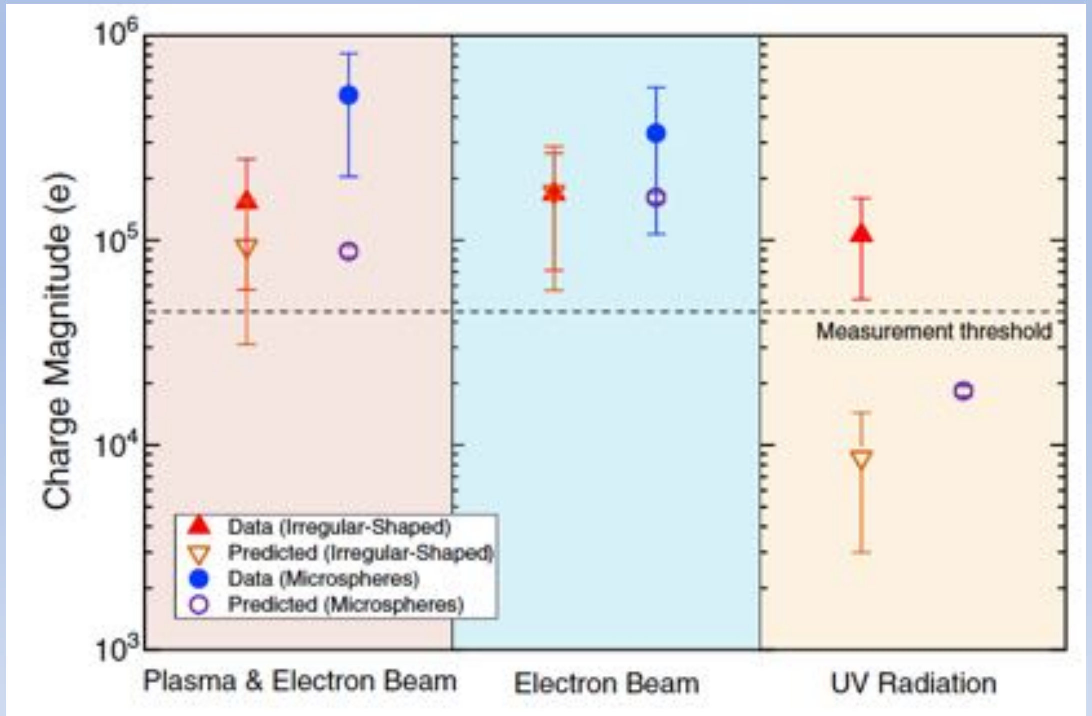
Charge State of Lofted Dust Particles

Polarity measurement

Negative voltage grid
(-3 kV)

Positive voltage grid
(+0.5 kV)

Magnitude measurement



Schwan et al., GRL, 2017

- All lofted dust particles after exposure to UV, electron beam or plasma & electron beam are charged negatively. This result is contrary to the generally expected positive charge due to photoemission but is in agreement with the “patched charge model”.
- Measured magnitudes are also in agreement with the “patched charge model”.