Regolith Cohesion Measurement via Induced Electrostatic Lofting

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Abstract:

Electrostatic dust lofting has been hypothesized to occur on airless bodies such as the Moon and asteroids, but in-situ evidence of this phenomenon has yet to be observed. Nonetheless, experiments and numerical models have provided ample insight into the fundamental physics of electrostatic dust mobilization. Prior to lofting, grains are bound tightly to the surface by cohesion, the dominant force for sub-mm particles. However, the magnitude of cohesion in regolith remains poorly constrained. We are developing a technology that will exploit our understanding of electrostatic dust lofting in order to measure cohesion. The same technology may also be useful to induce electrostatic lofting to clear dust from spacecraft surfaces. We introduce the design of the **E**lectrostatic **Sa**mple **C**ollection and **C**ohesion **Q**uantification (**E-SACCQ**) system, a technology that induces electrostatic dust lofting to measure regolith cohesion.

Instrument Description:

E-SACCQ induces electrostatic lofting of charged regolith grains via a biased attractor plate and simultaneously images their size and trajectory. Since the local gravity is known and the electrostatic force on the regolith grains is controlled by the attractor plate potential, it is possible to solve for the cohesive force on the grains. In this work, we assess the near-surface lunar plasma environment and a technique for grain characterization and position tracking in order to detail the preliminary design of the instrument.

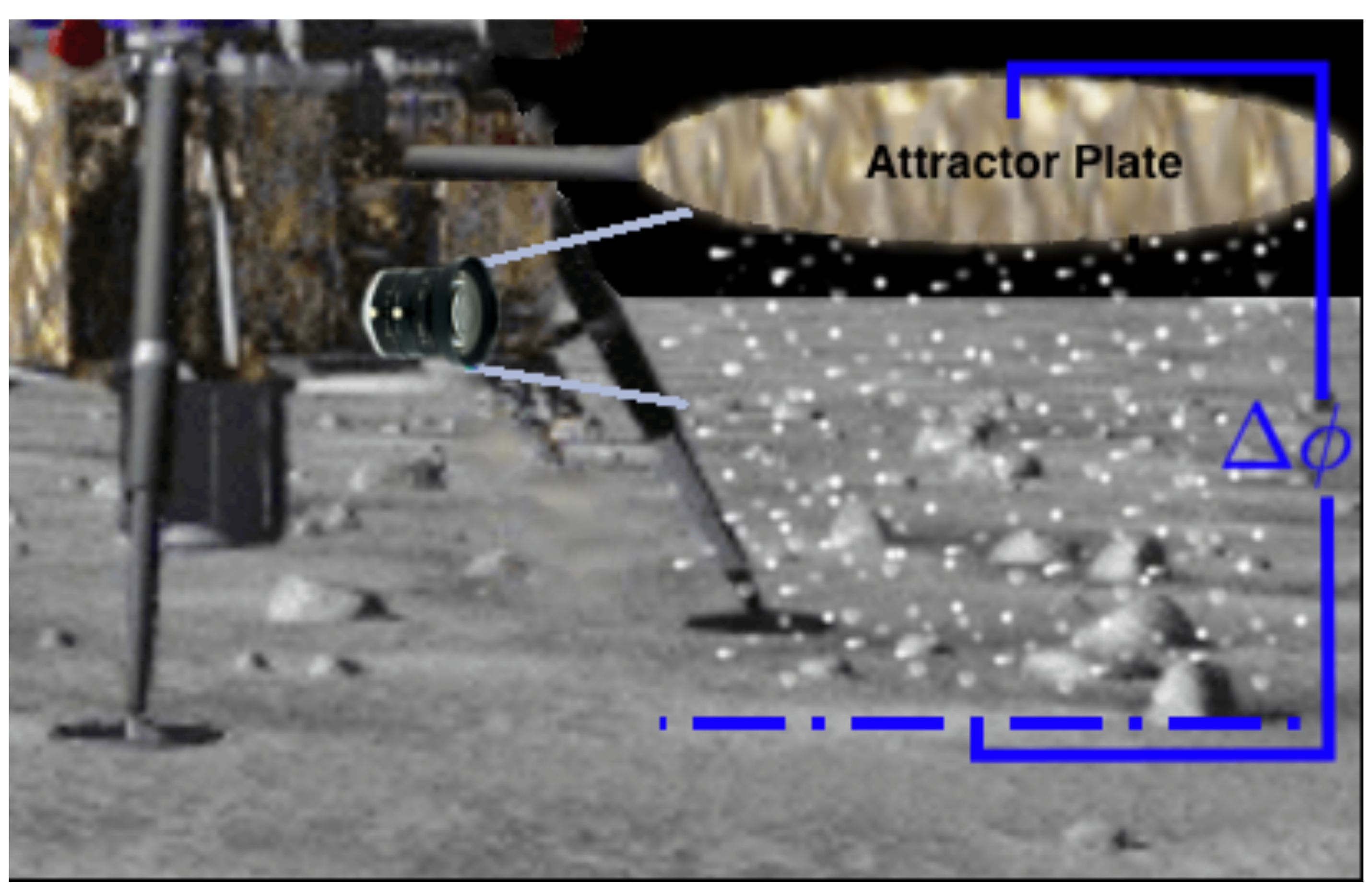

Fig1. E-SACCQ produces a voltage difference (Δφ) with the surface via a biased attractor plate, which induces electrostatic lofting of charged regolith grains. A camera simultaneously images the size and trajectory of the regolith grains. Since the local gravity is known and the electrostatic force on the regolith grains is controlled by the attractor plate potential, it is possible to solve for the cohesive force on the grains. The height of both the attractor plate and the camera is variable. The electric potential of the plate can also be adjusted.

Grain Detection and Tracking:

To calculate the electrostatic force required to break the cohesive force, we need to be able to measure the size and acceleration of grains when they loft from the surface. This depends on precise data on the position of grains between the electrode and the asteroid surface. We can then constrain the quantity AS^2 from the vertical component of the acceleration [1]:

$$AS^2 = \frac{48F_{co}\Omega^2}{r} = \frac{48\left(\ddot{y}\rho\frac{4}{3}\pi r^3\right)\Omega^2}{r}$$

Using stereo vision, we are able to meet minimum requirements of tracking, with order of 100-micron particle height uncertainty, and millimeter grain resolution against the black background of space.

Photoelectron Sheath Structure:

We model the undisturbed plasma sheath (i.e., without the attractor plate) as shown in Fig. 2. The equilibrium surface potential occurs when there is no net current to the surface (i.e. the plasma electron, plasma ion, and photoelectron currents sum to zero). Fig. 2 also represents the floating potential of the E-SACCQ attractor plate before activation. Once activated, the E-SACCQ electric field will modify the undisturbed plasma sheath. Thus, the plasma electron, plasma ion, and photoelectron currents will equilibrate at a new steady-state potential. Future work will model the plasma environment between the attractor plate and surface.

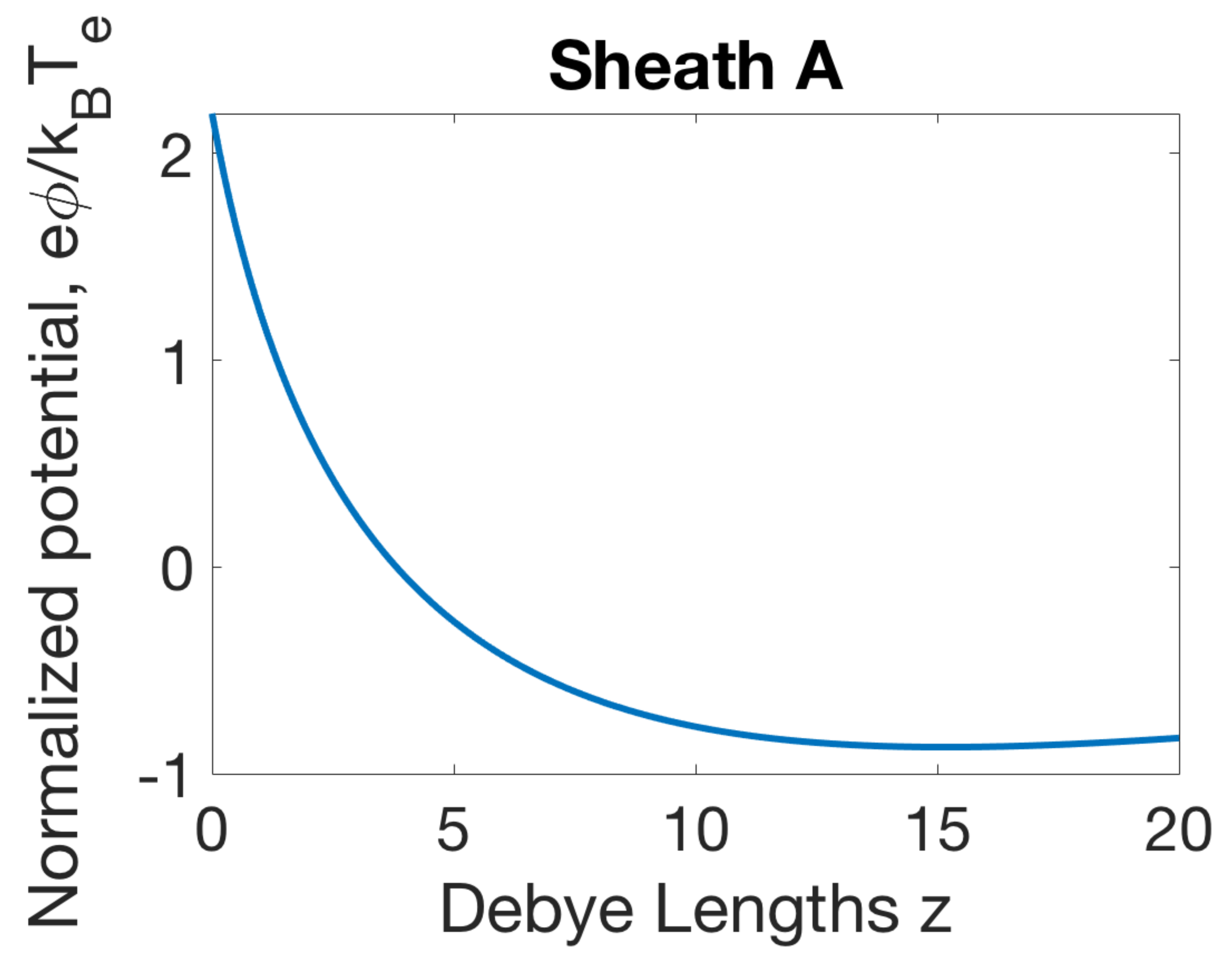

Fig2. Potential as a function of Debye lengths for a photoelectron sheath (as given in [2]). The asteroid surface, positioned at z=0, acquires a steady-state equilibrium potential of 3.22 V. The potential on the vertical axis is normalized by charge of an electron (e), Boltzmann's constant (k_B), and the plasma electron temperature (T_e).

E-SACCQ Electric Field:

The goal is to operate E-SACCQ such that there is a column between the attractor plate and the surface where there is effectively no plasma. The E-SACCQ electric field will naturally accelerate electrons toward the attractor plate and repel plasma ions. But selecting the appropriate combination of attractor plate potential, height, and length forces the electrons to impact the plate close to the edges, creating a central columnar region with effectively no plasma. The width of this region of constant and uniform electric field at the center of the plate is defined as the *Gap Width, G,* and is calculated as follows:

$$G = 2\left\{L - \left[x_0 + \left(\sqrt{\frac{2qT_e}{m_e}}\right)\frac{\sqrt{v_{y_0}^2 - 2\frac{q\Delta\varphi}{m_e H}(y_0 - H)} - v_{y_0}}{\frac{q\Delta\varphi}{m_e H}}\right]\right\}$$

Fig. 4-6 show the effects of attractor plate height, length, and potential on the achievable width of the region of constant electric field.

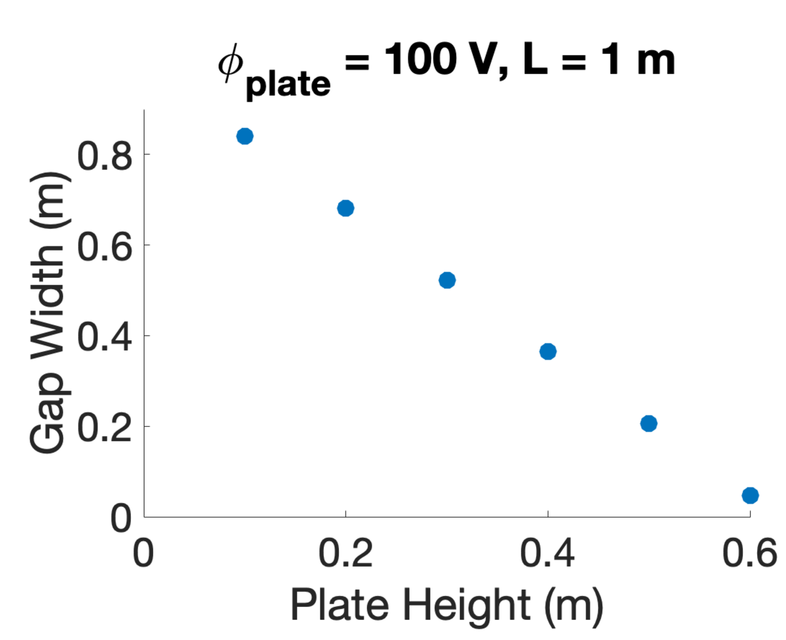

Fig4. For a fixed attractor plate potential and length, gap width increases as the plate height decreases. An increased electric field strength accelerates electrons to the plate, allowing less lateral motion towards the plate's center.

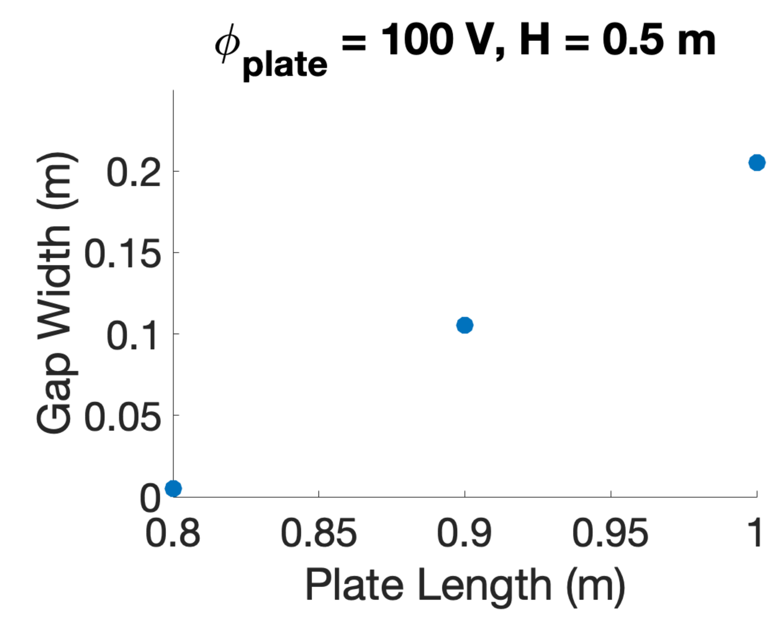

Fig5. Gap width for varying plate lengths with a fixed plate height and potential. Fixing the plate potential and height fixes the lateral distance electrons can travel from the edge before impacting the plate.

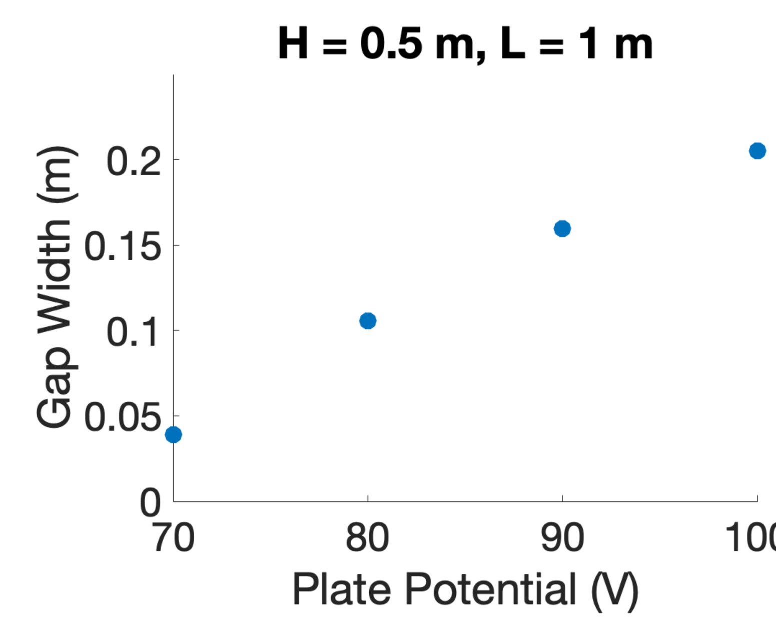

Fig6. As the attractor plate potential increases over a constant operating height, so does the magnitude of the electric field. A stronger electric field imparts a larger upward acceleration on the electrons such that they will impact the plate a shorter distance from the edge. Thus, the gap width increases as the plate potential increases.

Example E-SACCQ Configuration: The table below presents a possible operating configuration for the E-SACCQ attractor plate. A 0.7 m attractor plate biased to 100 V relative to the surface and deployed 0.3 m above the surface can achieve a 0.23 m wide gap where no external plasma will interfere with the E-SACCQ electric field. Once the attractor plate is activated, plasma within the gap volume will be cleared away almost instantaneously. Residual currents are too low to perturb the E-SACCQ electric field during operation.

Operating Parameters	Test-Section Plasma Fluxes	Exterior Plasma Currents
ϕ_{plate} = 100 V	F_e to plate = 44.5 electrons/cm^2	I_e to plate (C/s) = 2.26E-8
H = 0.3 m	F_i to surface = 149.7 ions/cm^2	I_i to plate (C/s) = 5.67E-12
L = 0.7 m	F_p to surface = 3.46E3 photos/cm^2	
A_{plate}=0.49 m^2	$t_{p,e}$ to plate = 1.03E-7 s	
G = 0.23 m	t_{ion} to surface = 4.41E-6 s	

Conclusions:

E-SACCQ is a technology that induces electrostatic dust lofting to measure regolith cohesion.

- Our models predict that the achievable gap width is too small to be practical. Thus, future work will model the plasma environment between the attractor plate and surface.
- With respect to grain characterization and position tracking, stereo vision is selected as the preferred solution.
- Additional plasma simulation modeling and experimental demonstration will be conducted in order to mature this technology.

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References:

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[2] T. Nitter, F. M., O. Havnes, "Levitation and Dynamics of Charged Dust in the Photoelectron Sheath Above Surfaces in Space,"Journal of Geophysical Research, Vol. 103, No. A4, 1998, pp. 6605–6620.