Laboratory Studies of Lunar Dust Transport

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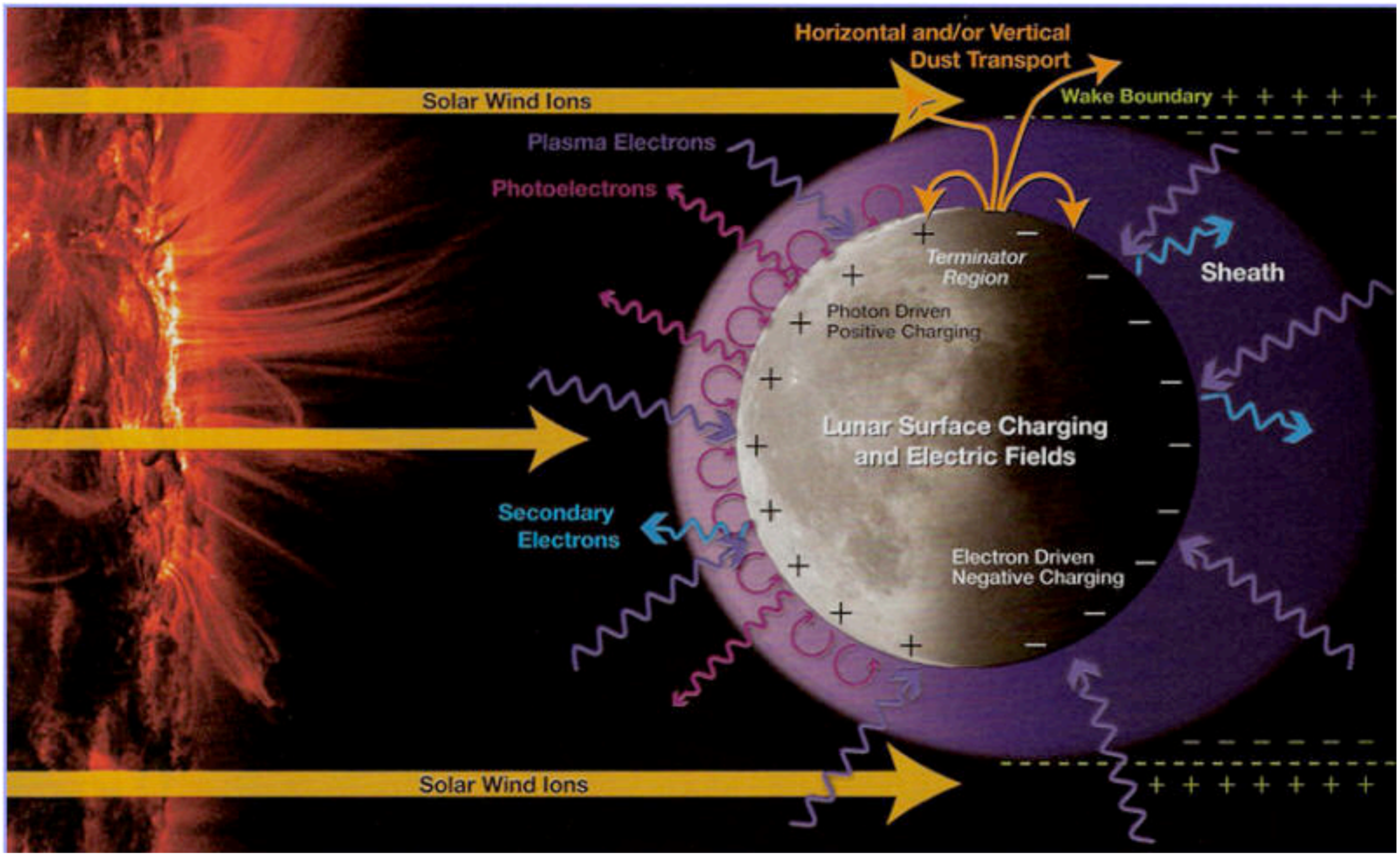
Lunar plasma Environment



Evidence of electrostatic dust transport on the lunar surface

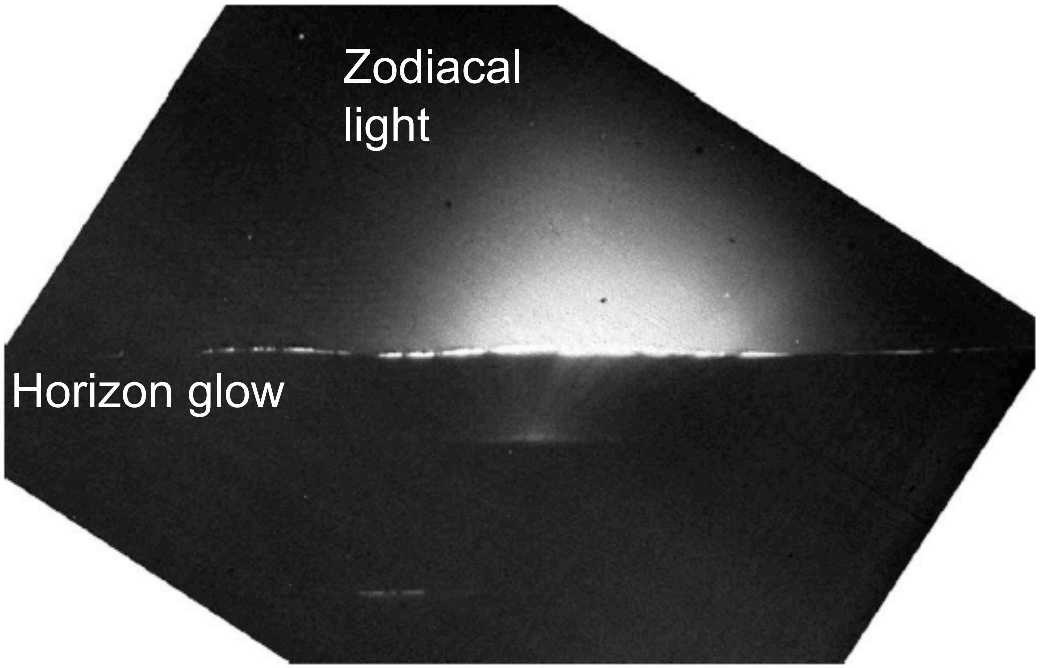


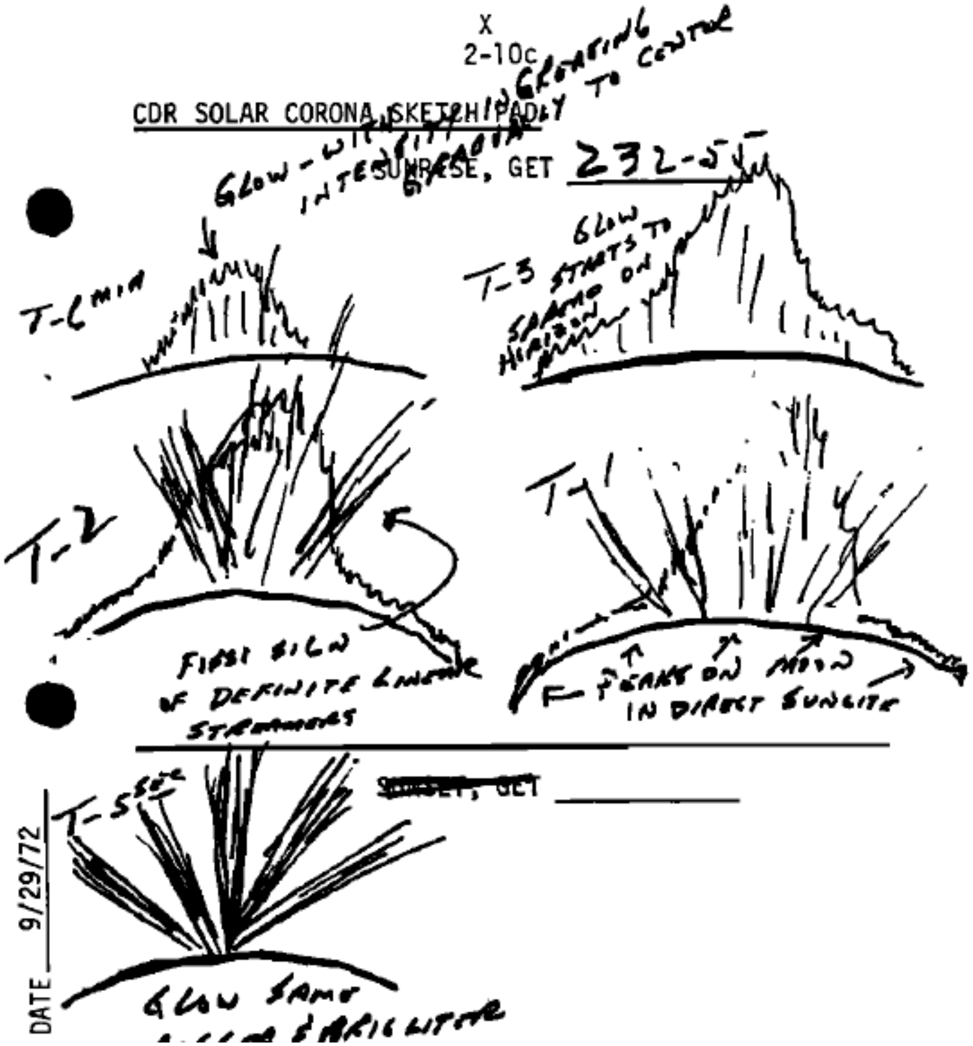
Image of Surveyor 6 lunar lander showing a glow on the western lunar horizon after sunset.

The "Horizon Glow" is due to light scattered from dust particles near the lunar surface.

Dust grains with radius of 5-6 μm at about 10-30cm from the surface.

Horizon glow ~10^7 too bright to be explained by micro-meteoroid generated ejecta.

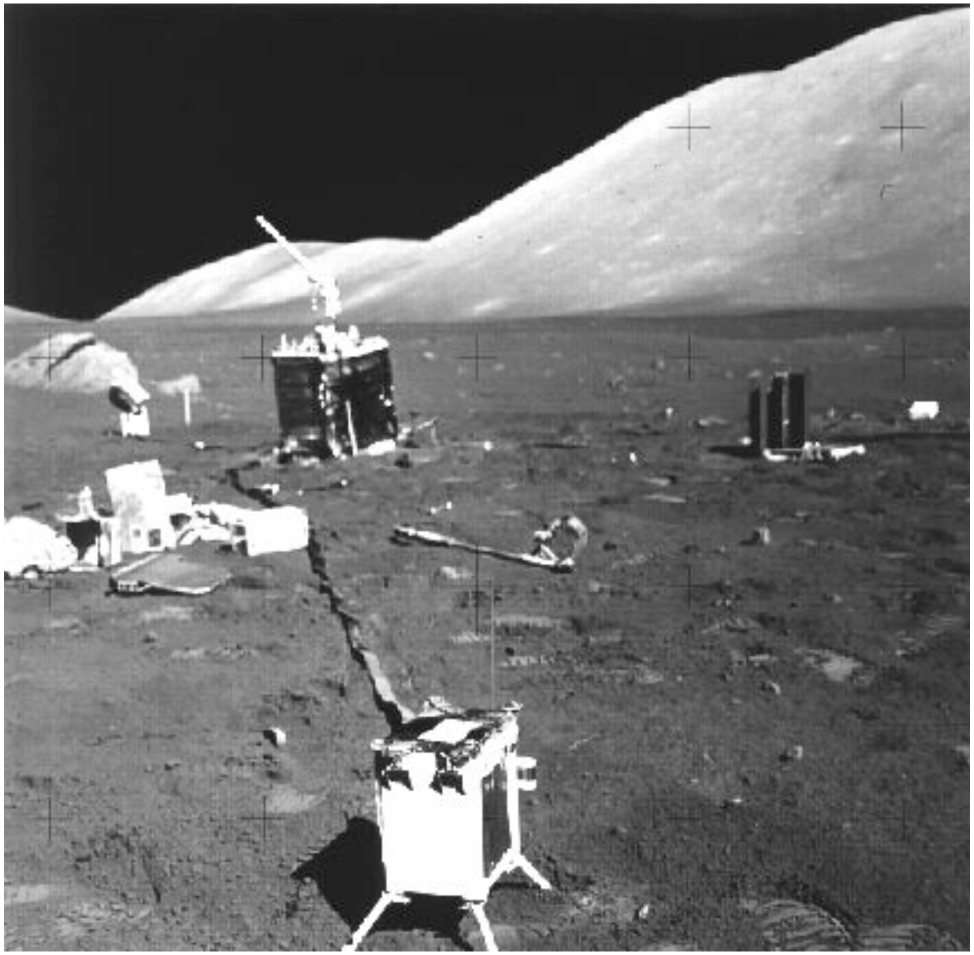
Dust release from the lunar surface



Sketches drawn by Apollo 17 astronauts of sunrise as viewed from lunar orbit

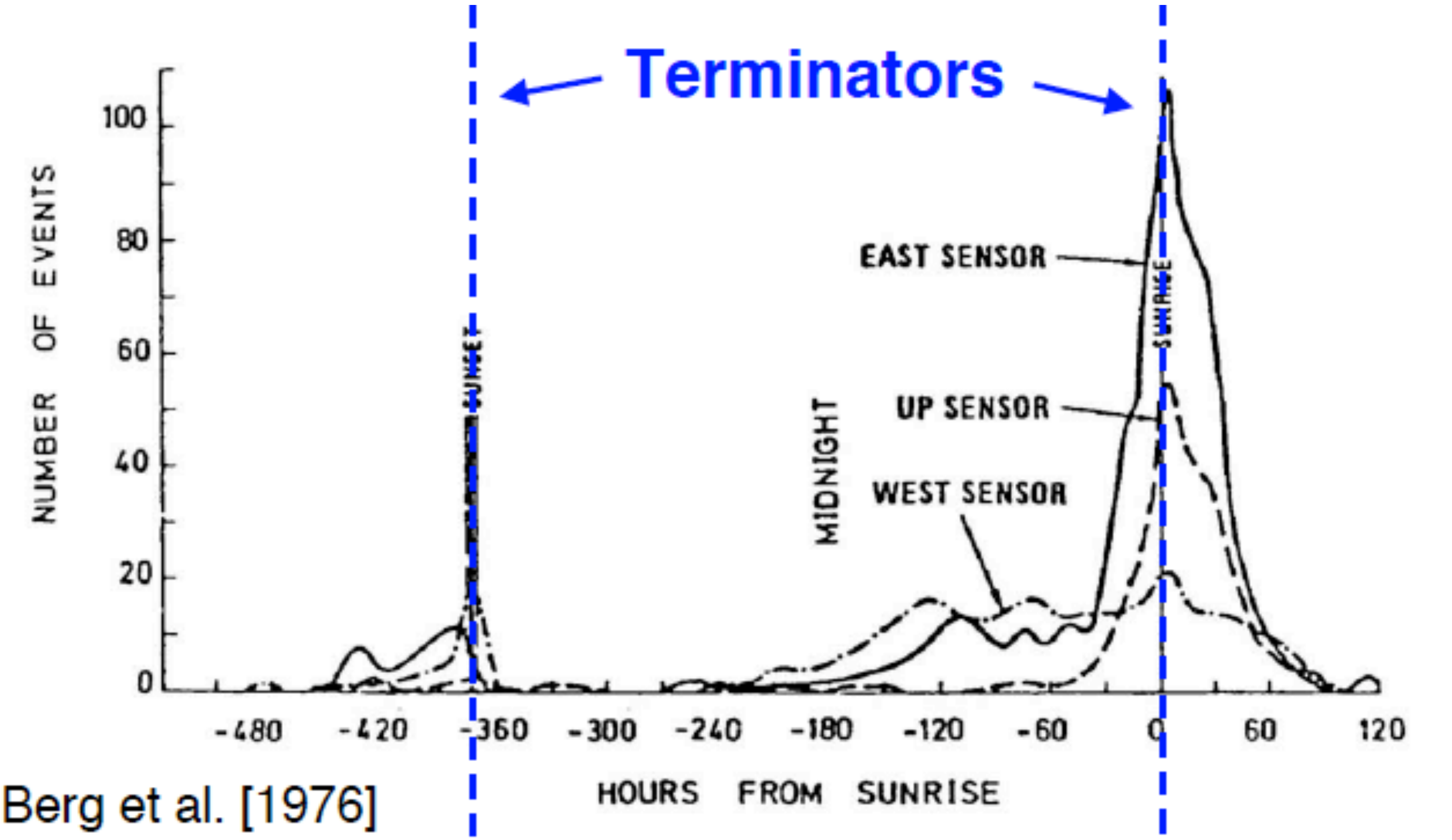
The linear streamers are attributed to dust particles (0.1μm scale) leaving the lunar surface.

Lunar Ejecta and Meteorites (LEAM) Experiment



The LEAM was deployed during the Apollo 17 mission

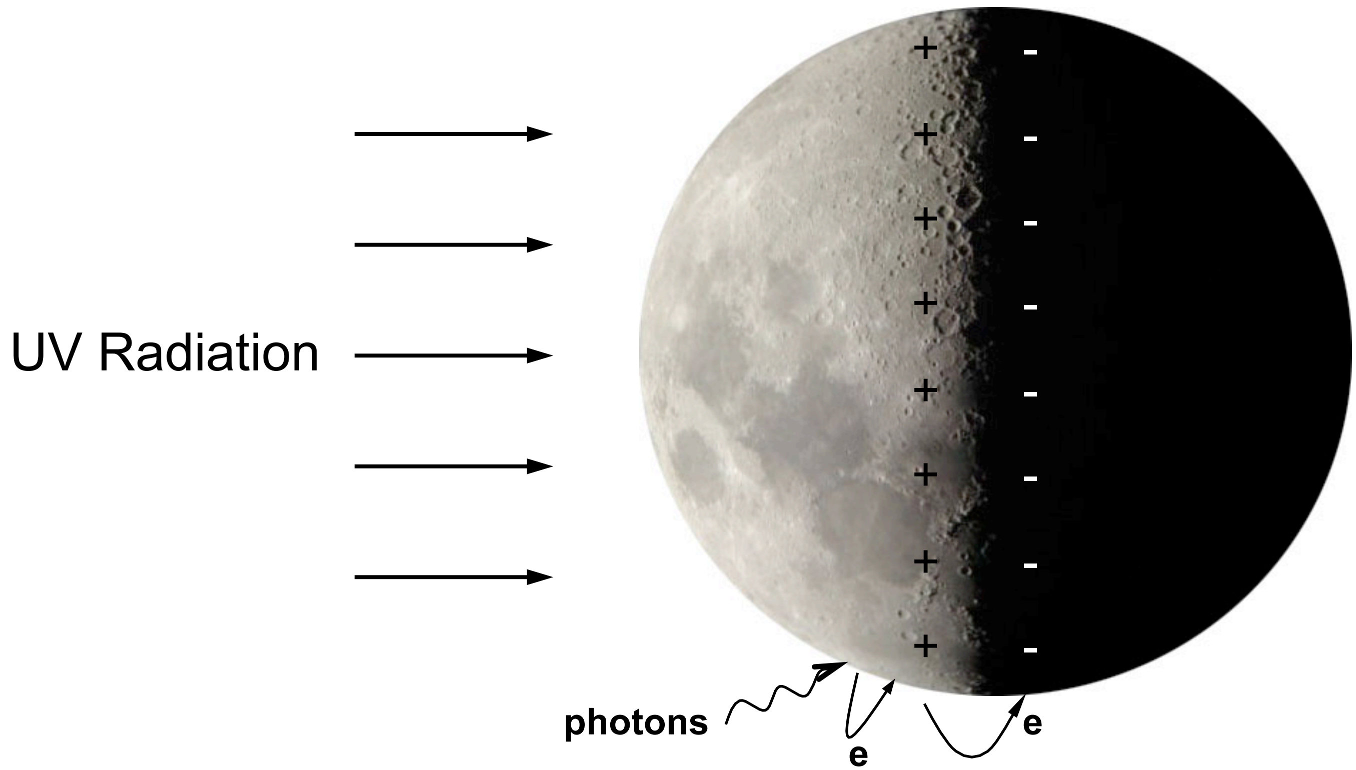
Dust detections from the LEAM experiment



Berg et al. [1976]

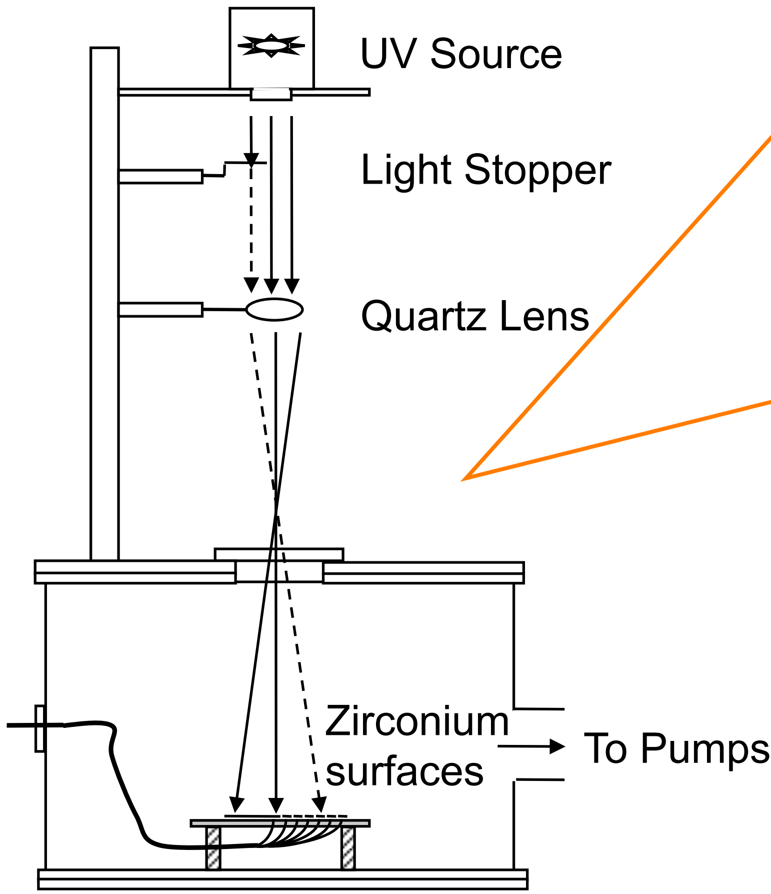
Lower velocity impacts instead of hypervelocity impacts were detected near terminators, which are attributed to electrostatic dust transport.

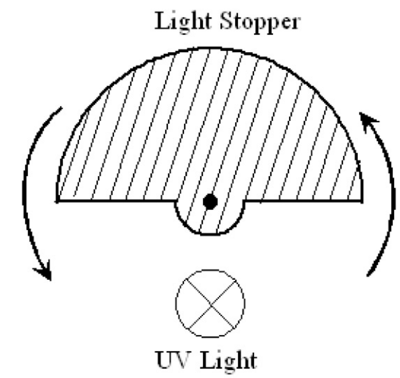
Photoelectric Charging on the Lunar Surface



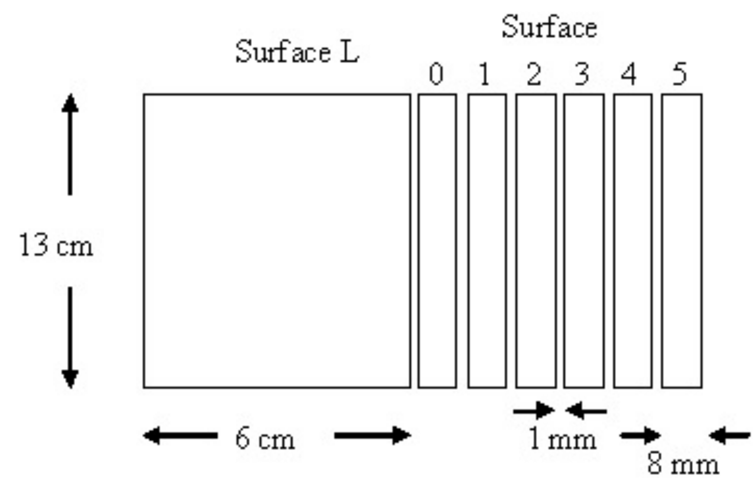
- Differential photoelectric charging near the boundary between lit and shadowed region.
- It has been suggested that time dependent charging at the terminator region may lead to ‘super-charging’, and the lift-off of lunar fines [Criswell and De, 1977].

Laboratory Setup



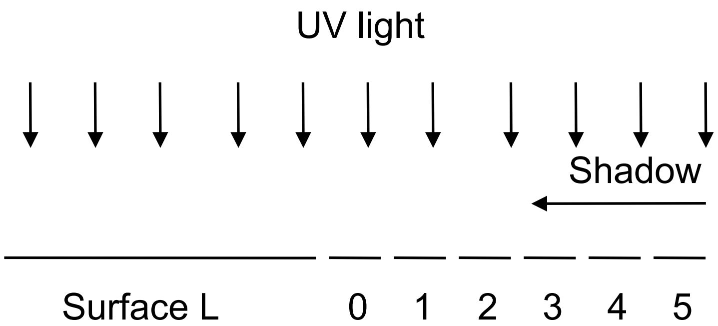


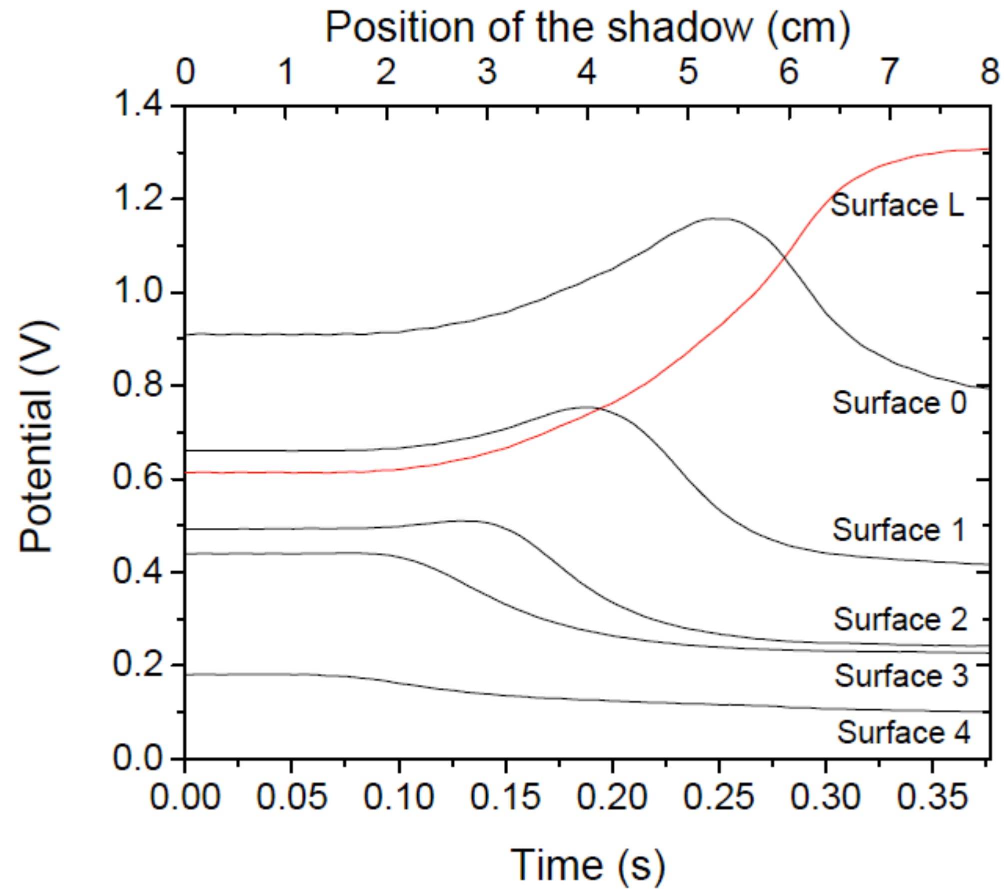
Top view of light stopper



Zirconium surface arrangement

Surpercharging near ***Moving*** Lit-Dark Boundaries

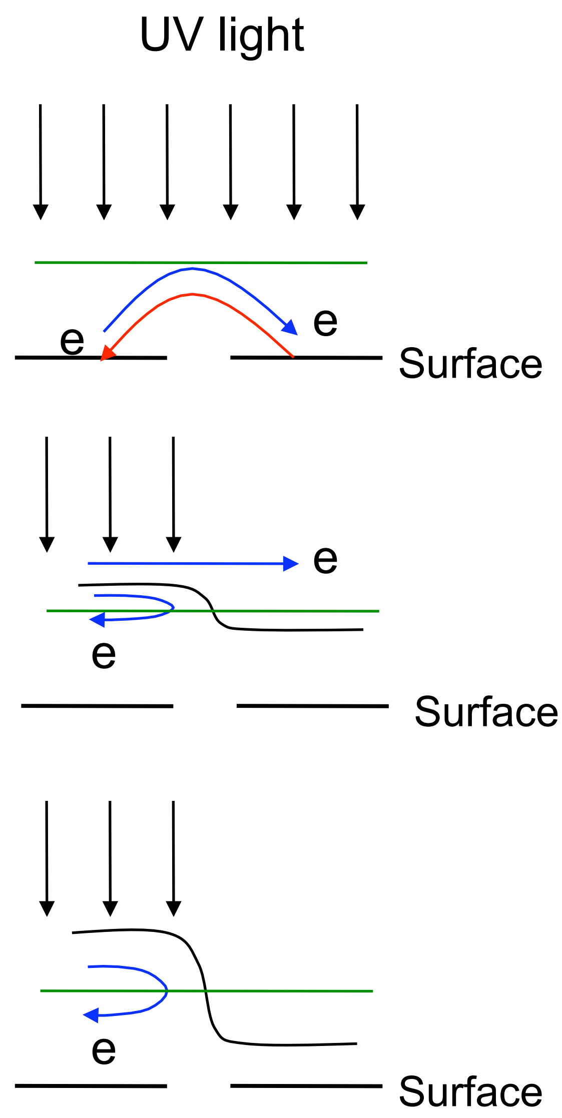




Surface L is 'supercharged' when the shadow approaches it (i.e. the progression of sunset).

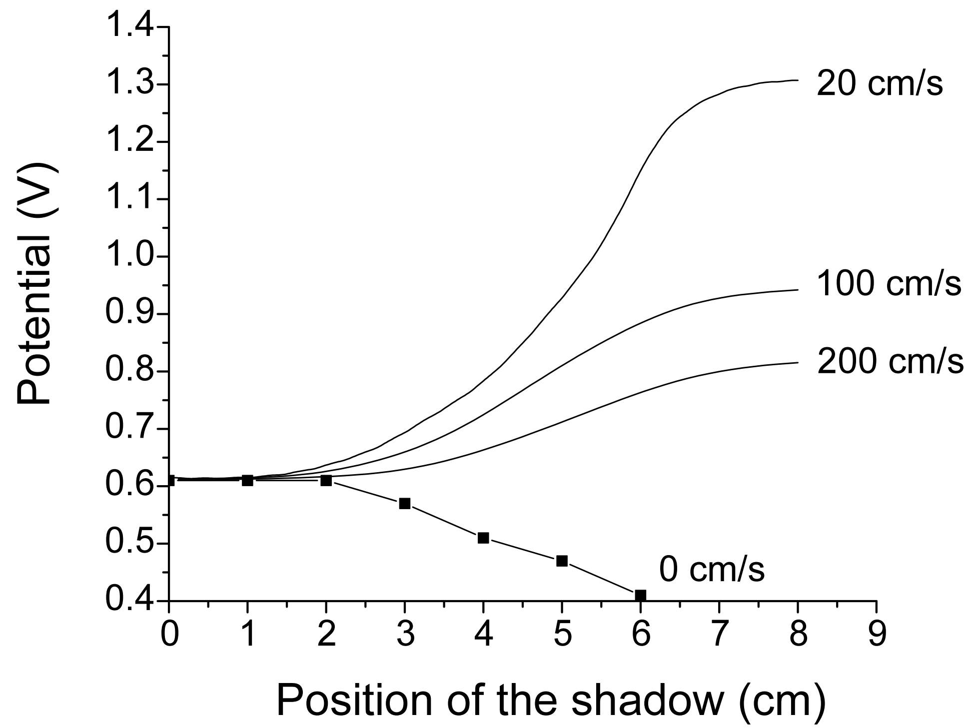
* X. Wang, M. Horanyi, Z. Sternovsky, S. Robertson and G. E. Morfill, *GRL*., 34, L16104 (2007).

This is because the newly darken surface attracts more electrons from still lit surfaces but without emitting its own.



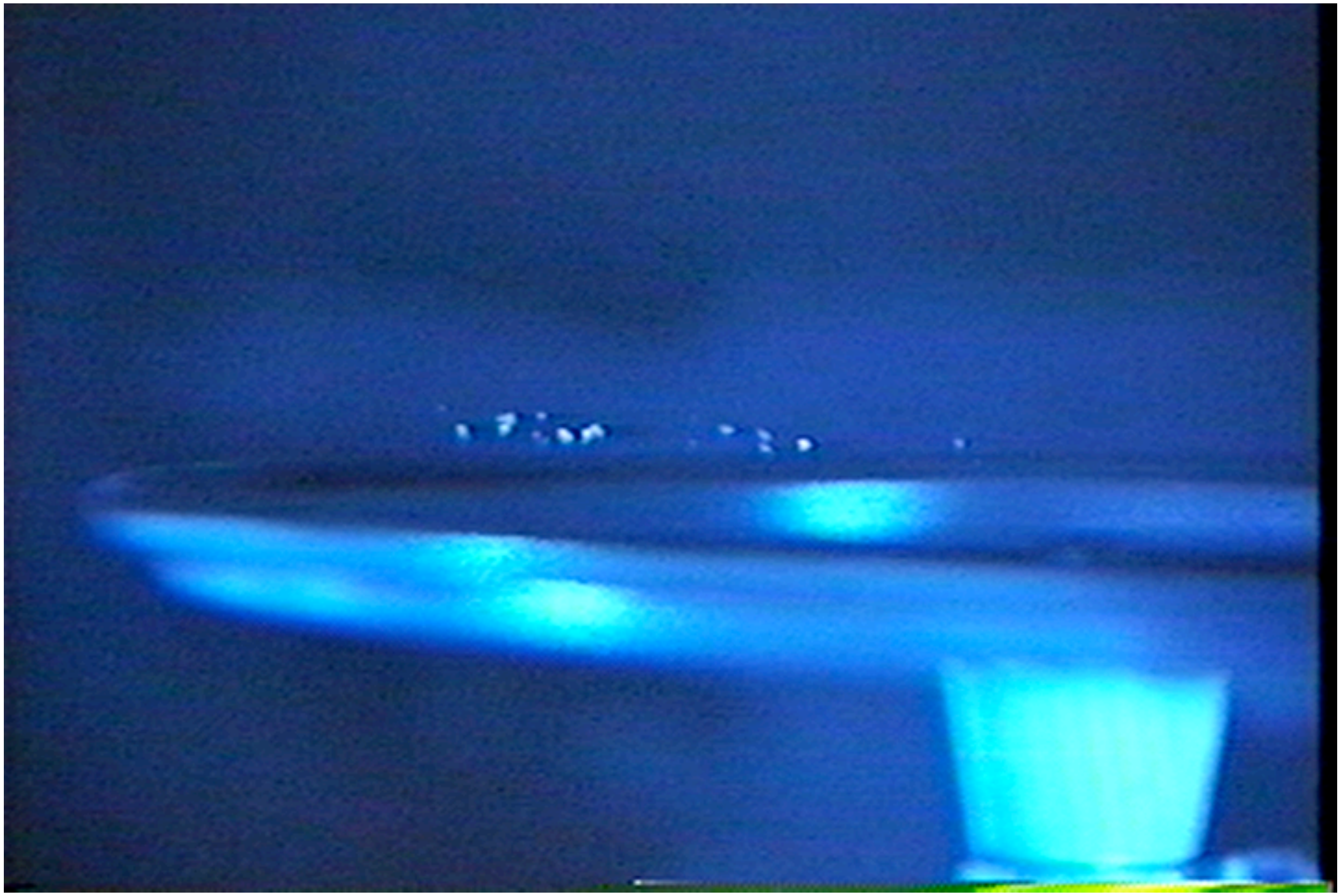
Supercharging near ***Moving*** Lit-Dark Boundaries

Potential on surface L when the shadow moves at various speeds



We expect the largest increase in the potential due to 'supercharging' when the charging time of a surface is similar to the transition time of the shadow.

Dust Levitation in Plasma Sheath



JSC-1 lunar simulants (< 25 μm) levitate at 1.1 cm above the surface (Sickafoose et al., 2002a).

Dust Levitation in Plasma Sheath

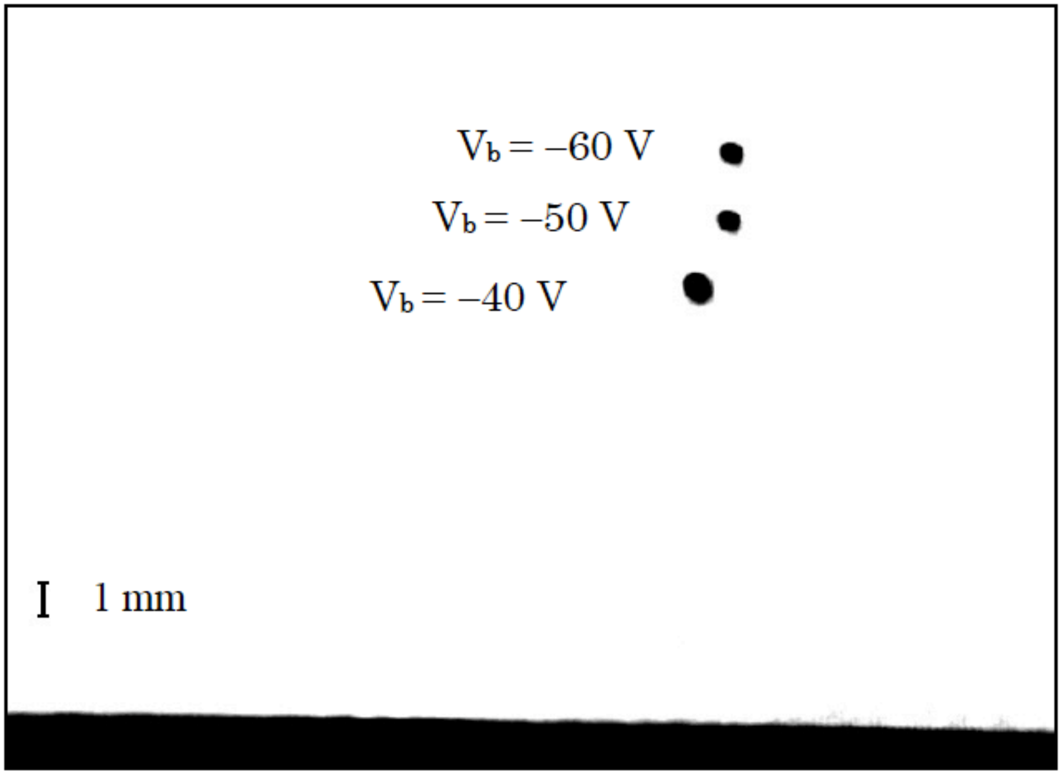
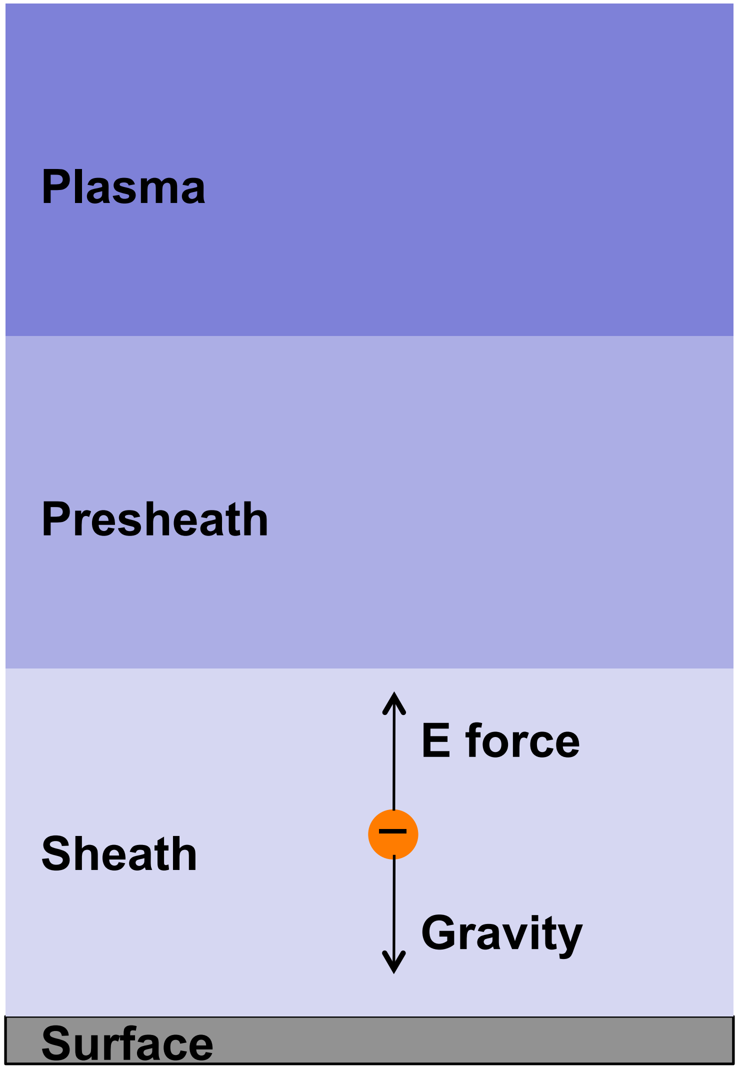
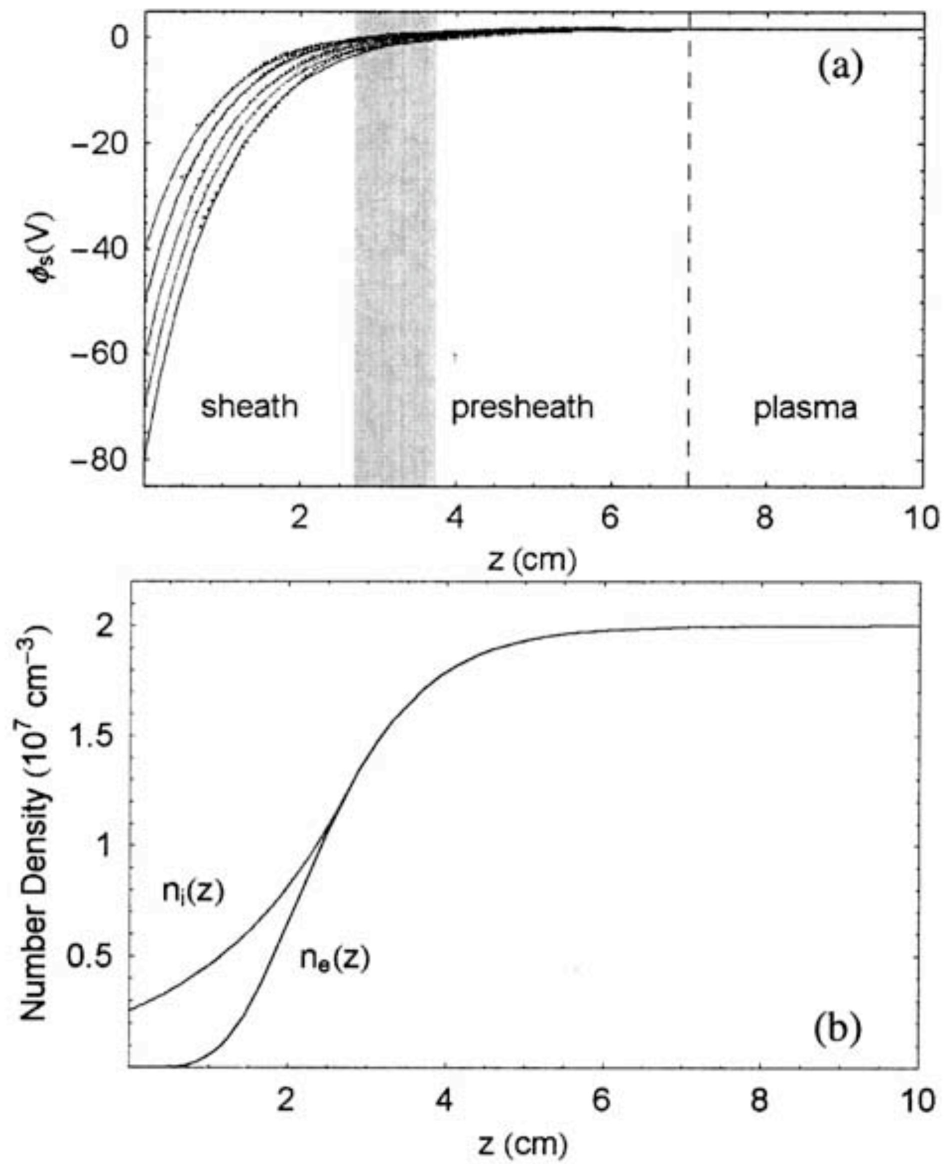


Figure III.4. Negative of three superimposed digital photographs showing a stable, levitated polystyrene DVB grain (10.0 μm in diameter) for the surface at three different biases : –40V, –50 V, and –60 V. As expected, the grain is at the highest position away from the surface when the surface bias is most negative. [*Sickafoose et al.*, 2002a]

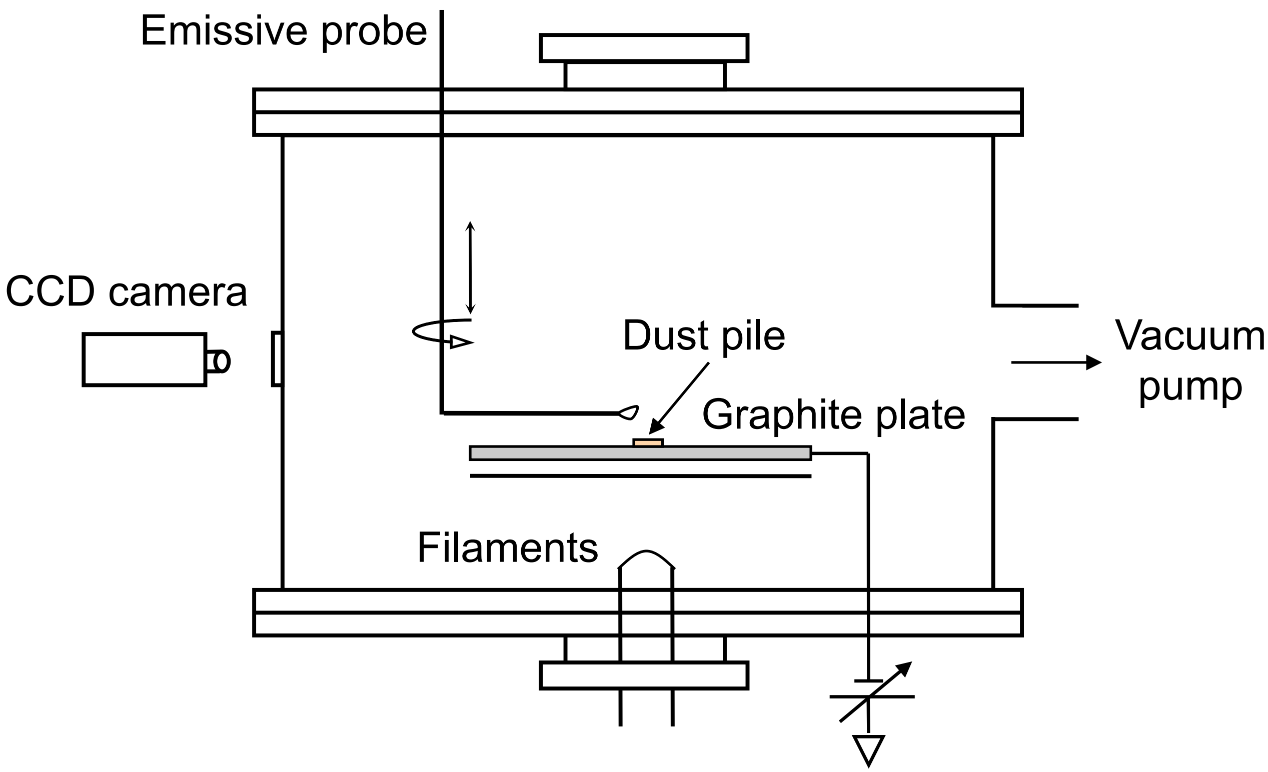
Dust Levitation in Plasma Sheath



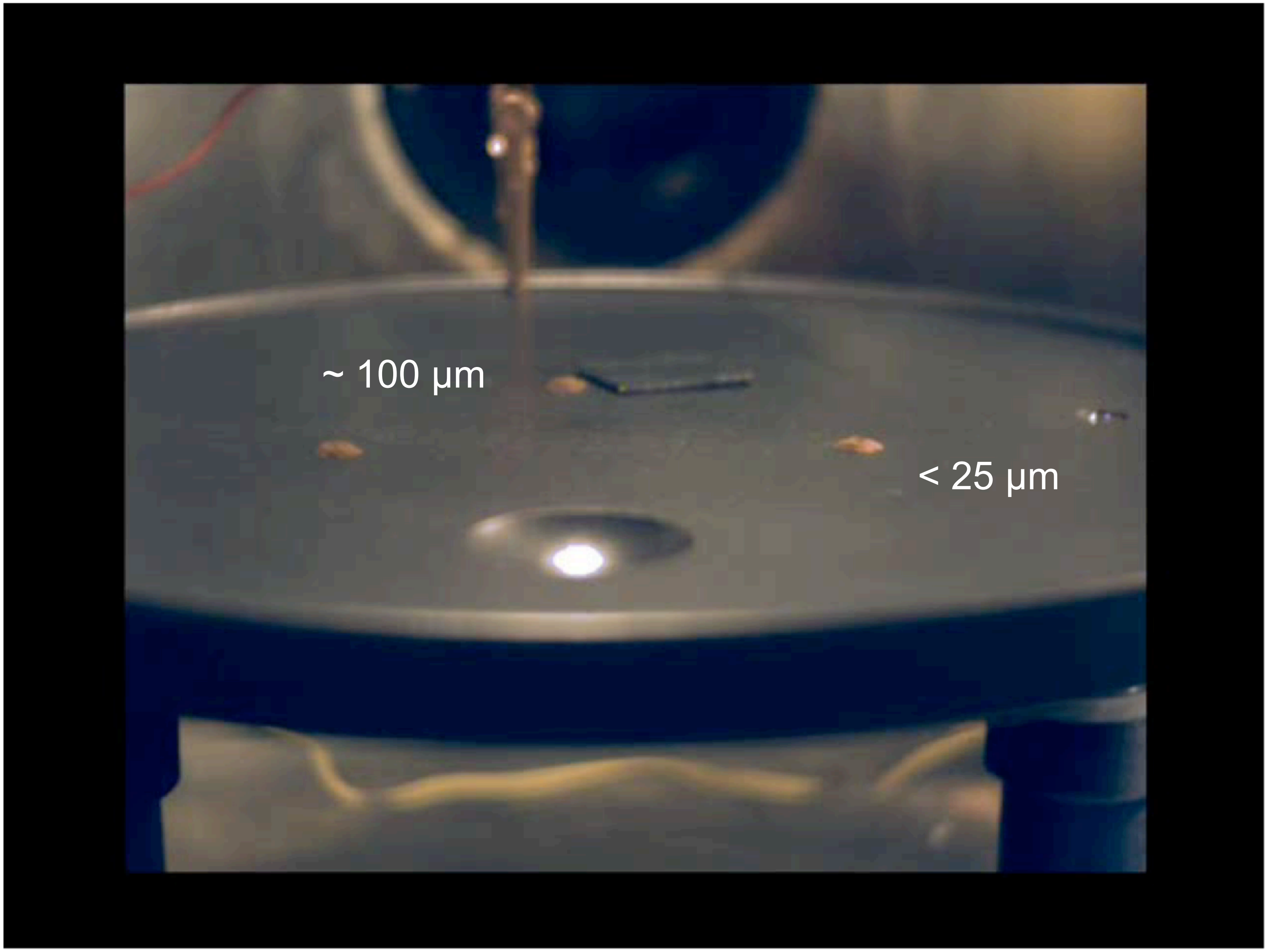
Dust levitates when $F_e - F_g = 0$



Dust transport experiments



Dust transport movie (JSC Mars simulant)



Dust Transport Still Images

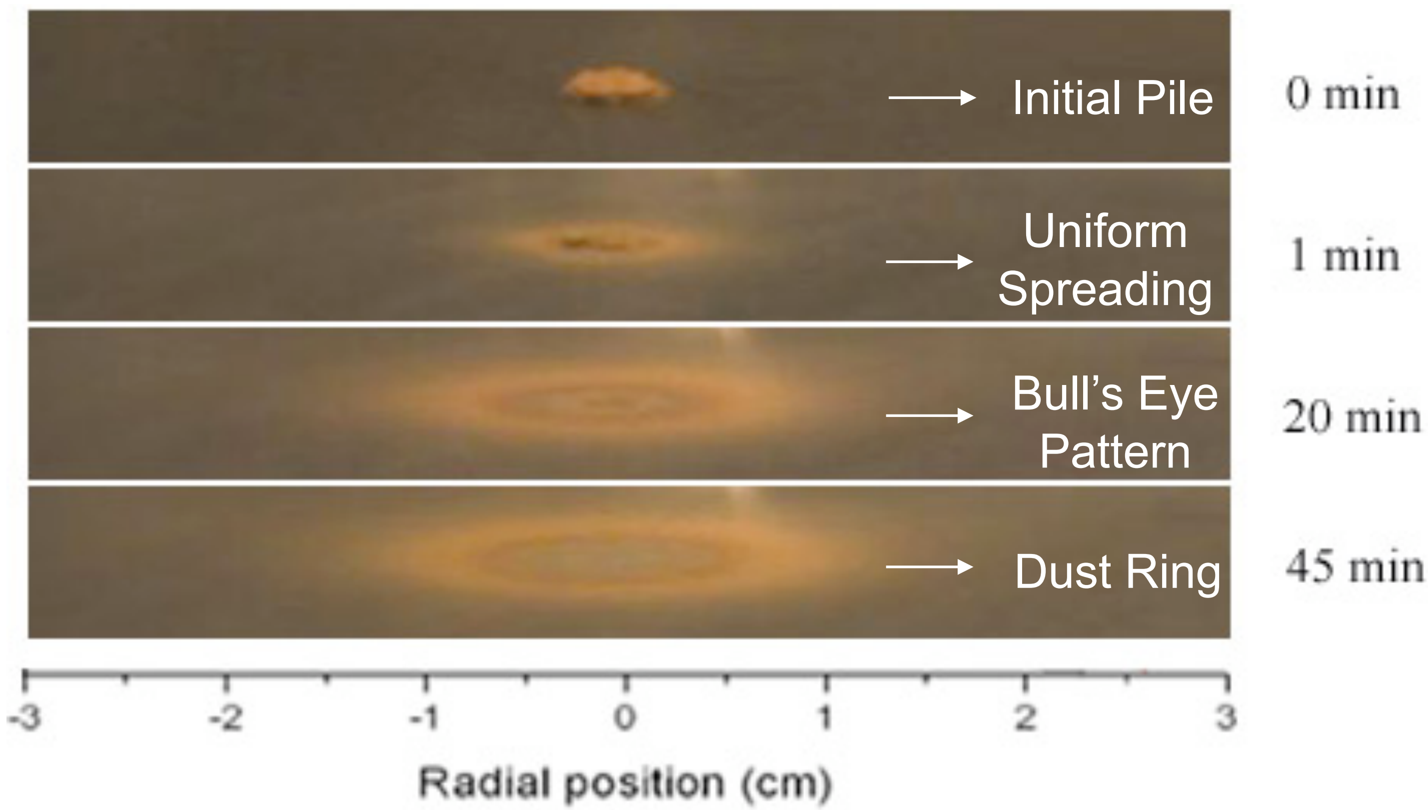
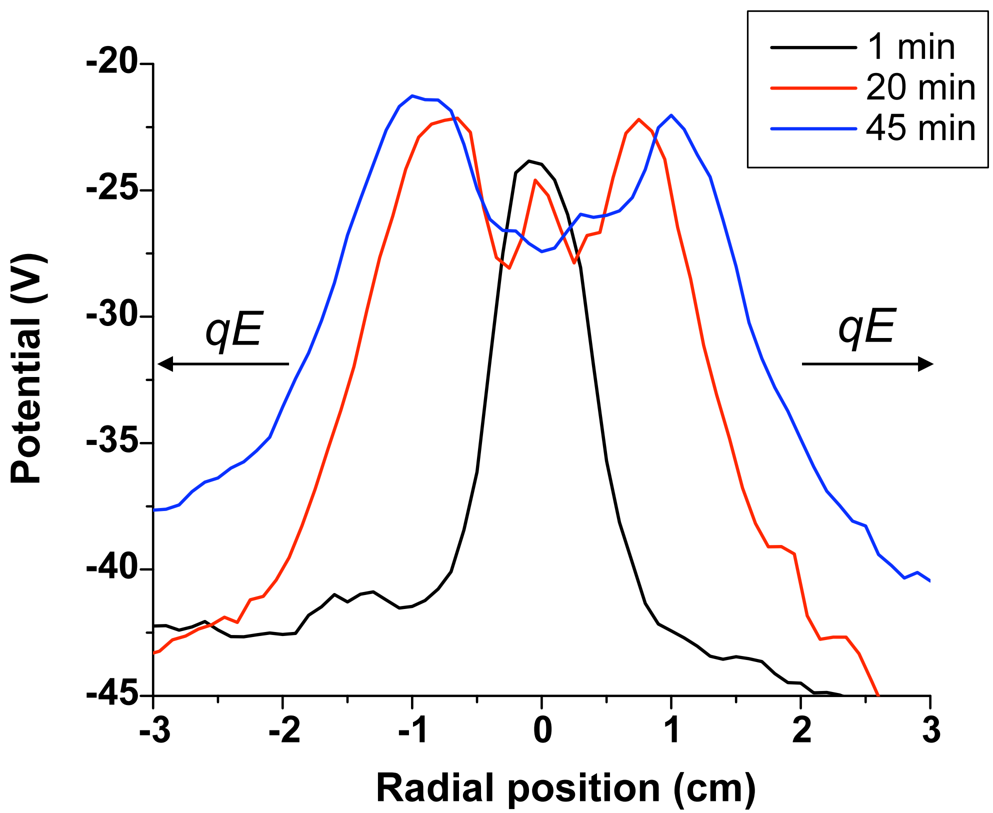


Image of initial dust pile on the surface (0 min) and images of dust spreading on the surface at 1 min, 20 min and 45 min after exposure to the plasma.

* X. Wang, M. Horányi and S. Robertson, *JGR*, 114, A05103 (2009).

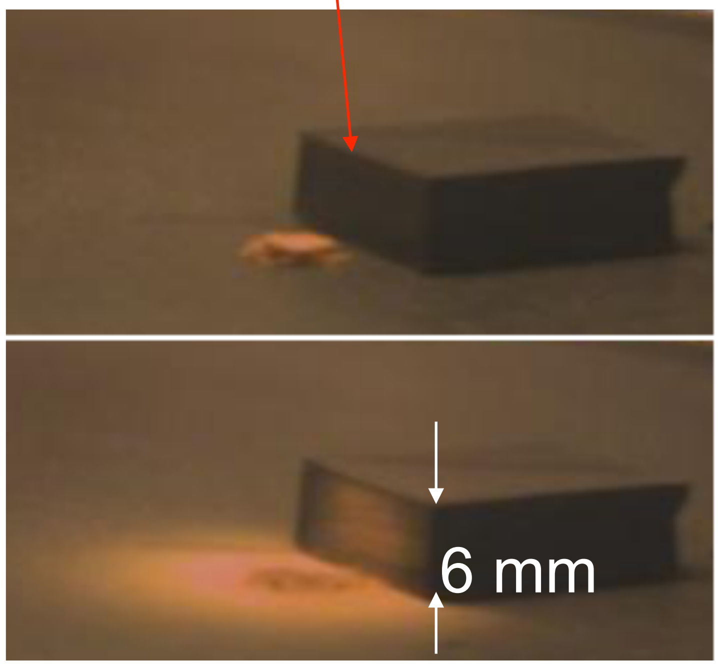
Horizontal Electrostatic Force



Radial potential scans 2 mm above the dust pile sitting on the graphite surface

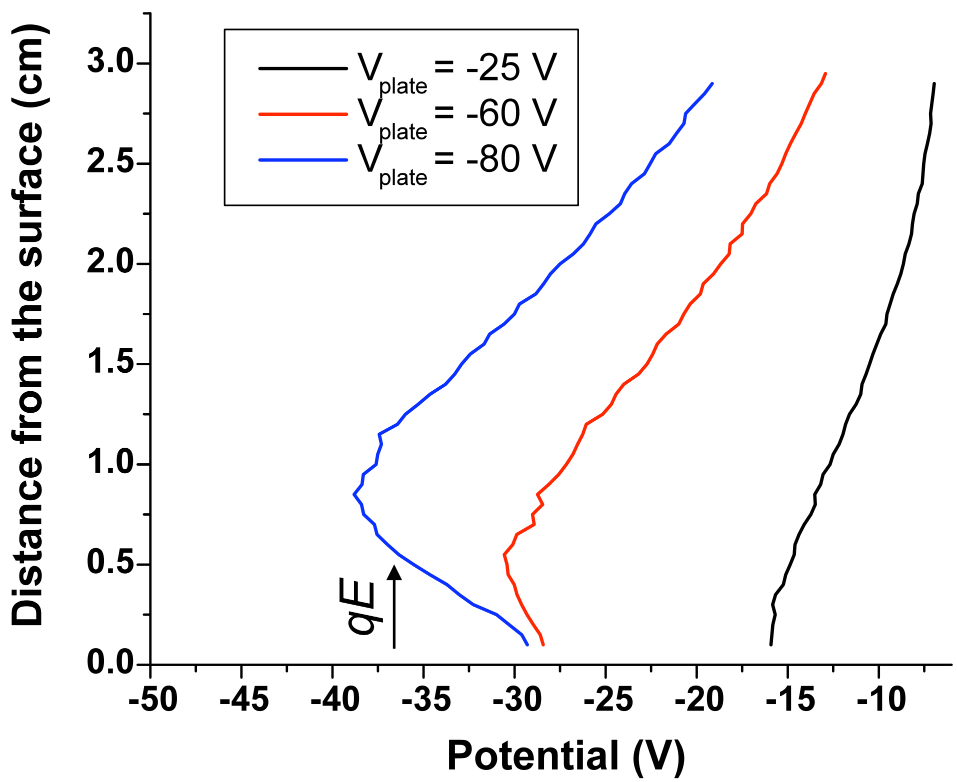
- Dust particles charge positively because negative bias on the plate collects ions.
- Electric field points outward to push dust spread on the surface.
- The potential profiles also indicate 'bull's eye' and 'ring' patterns.

Dust Lift-off Observations



Dust deposits on the side wall and top of an adjacent insulating block, which indicates a dust hopping motion.

Vertical electrostatic force

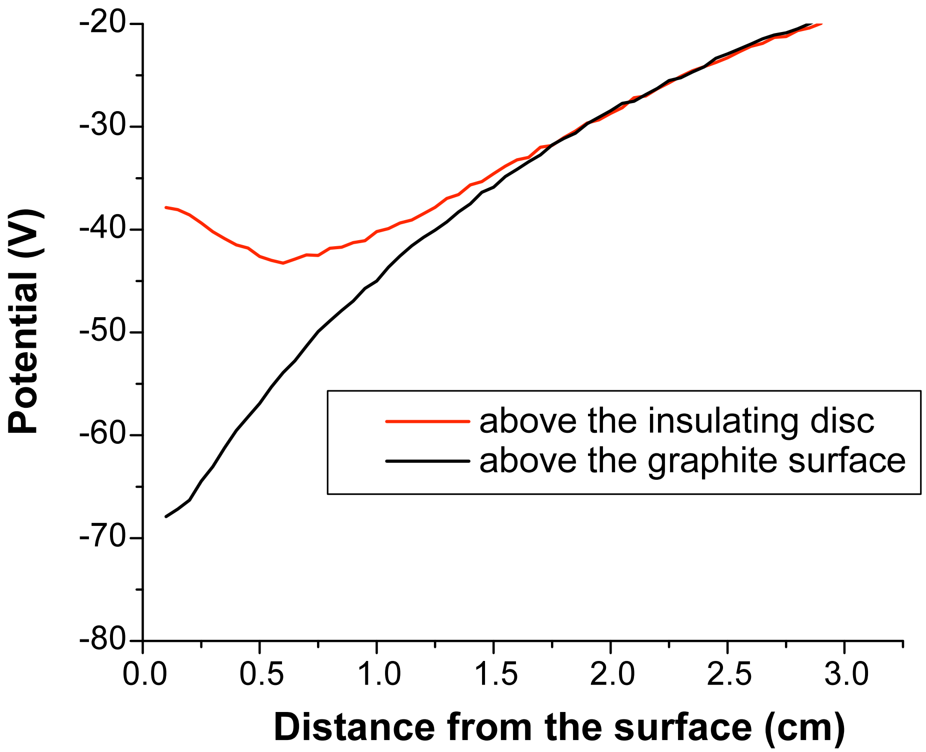


Vertical potential scans above an insulating disc (d = 1.1cm) sitting on the graphite surface

- A non-monotonic potential structure, a potential dip, is found above an insulating disc when the sheath thickness (~3cm) is larger than the radius of the disc.

- Electric field near the insulating disc points upward and increases with the plate bias voltage, which causes the dust lift-off.

Potential built-up above the dust pile



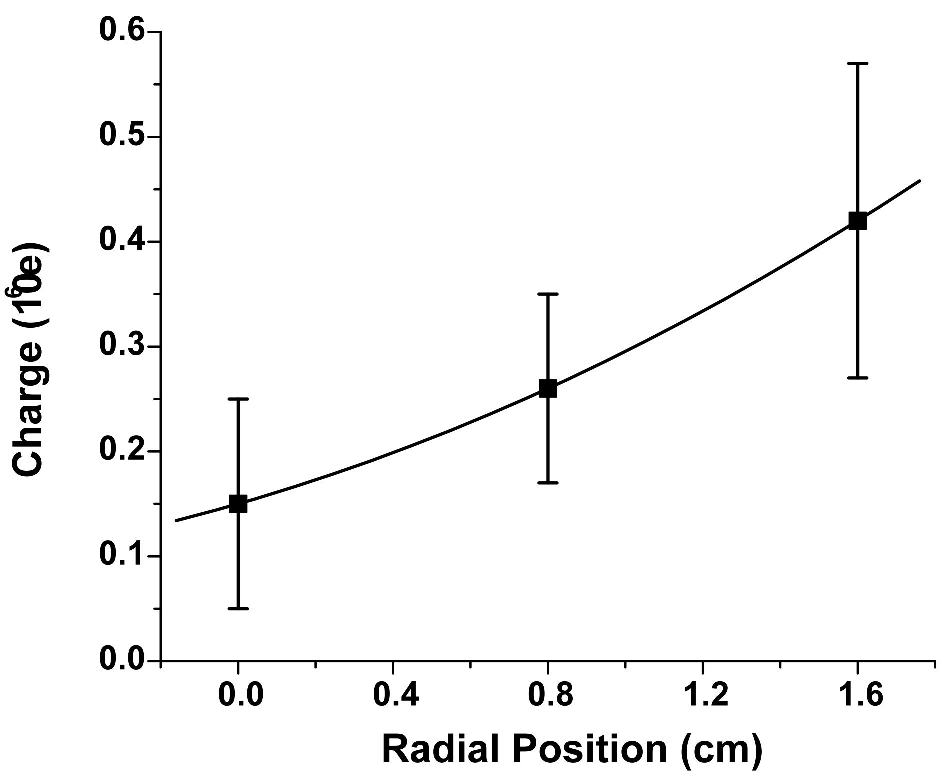
The graphite surface is biased at -80V and diameter of the disc is 0.7cm.

- The sheath thickness is larger than the radius of the disc.

- A negative potential barrier in the sheath returns most electrons and accelerate ions toward the dust pile.

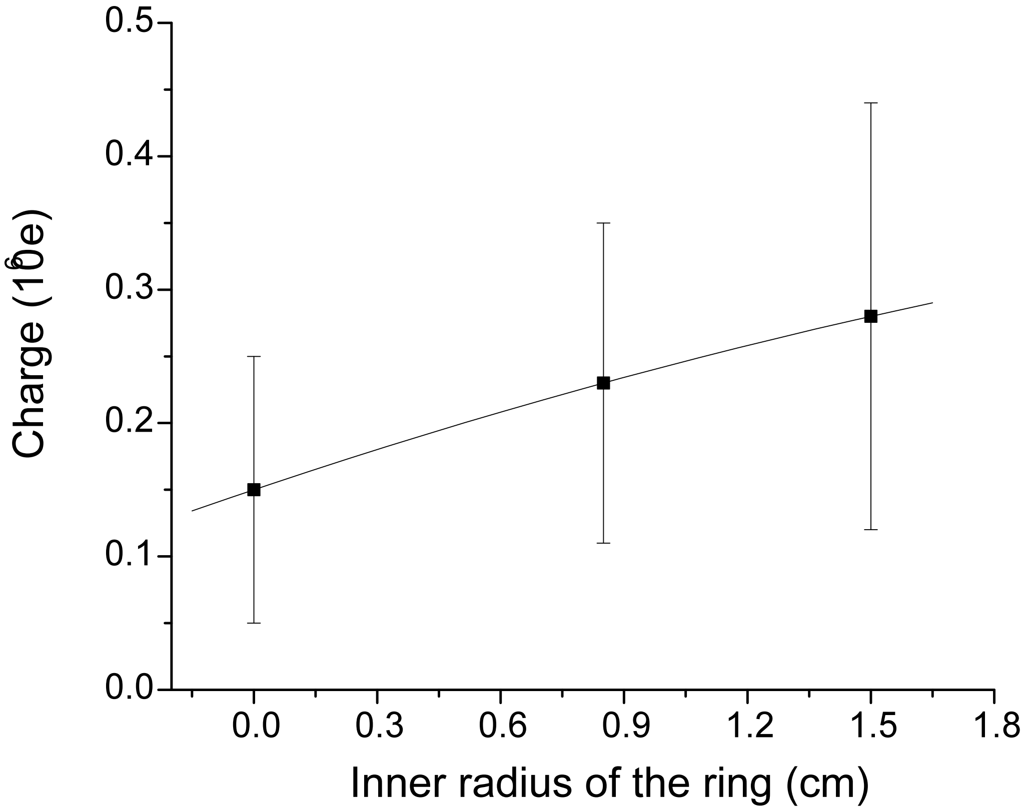
- Dust particles collect more ions to charge positively and build a positive potential barrier that tends to equalize the electron and ion fluxes.

Radial charge distribution during the spread



- D_{sheath} = 2.6 cm and R_{disc}= 2.2cm.
- $Q_{edge} \approx 3Q_{center}$.
- Combined with electric field distributions, a threshold could be created at a position where QE moves outer dust particles but not the central dust particles, which results in a 'bull's eye' formation.

Charge on central dust vs. ring expansion

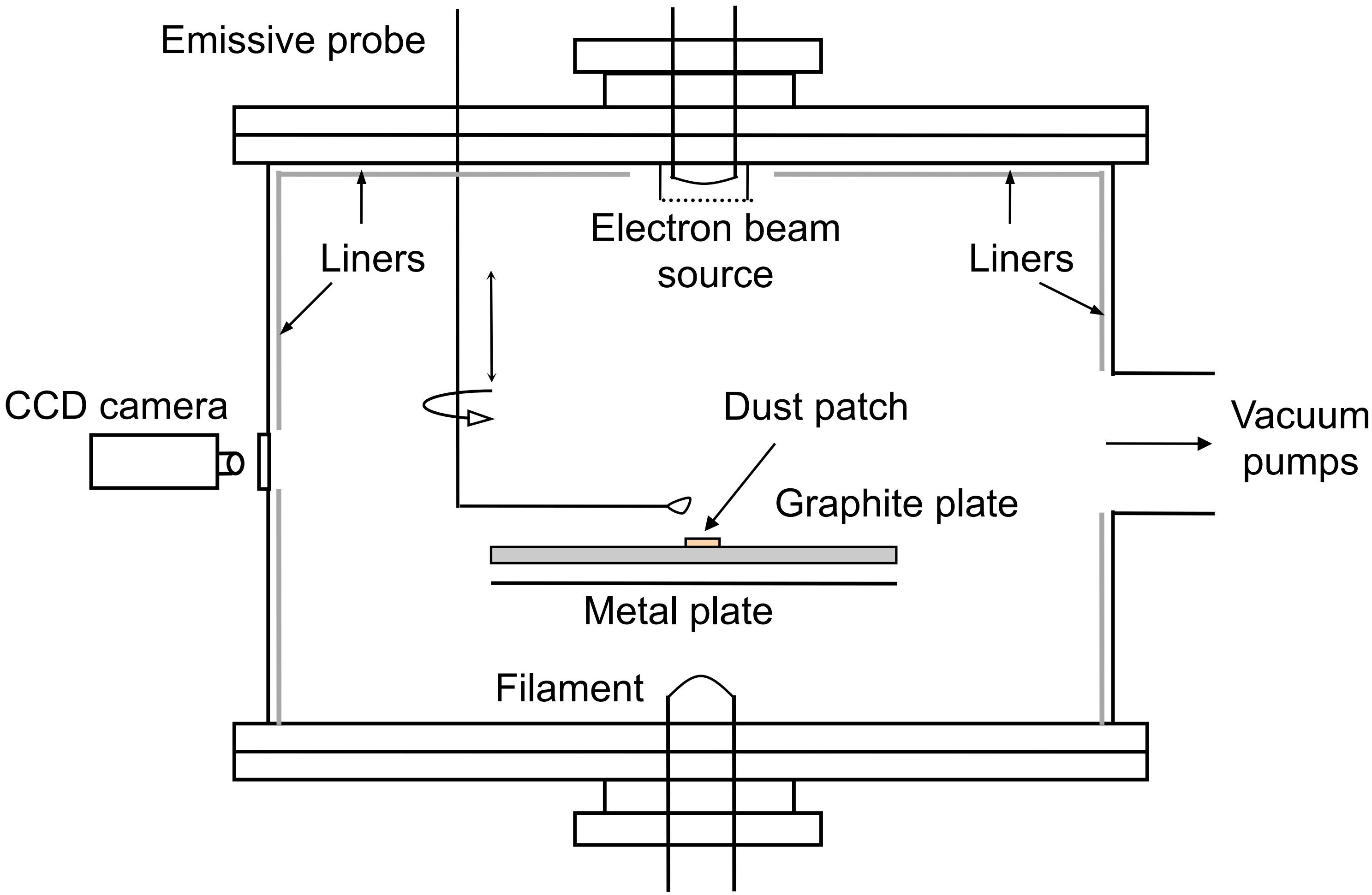


- Charge on dust on the central disc increases when the surrounding ring expands

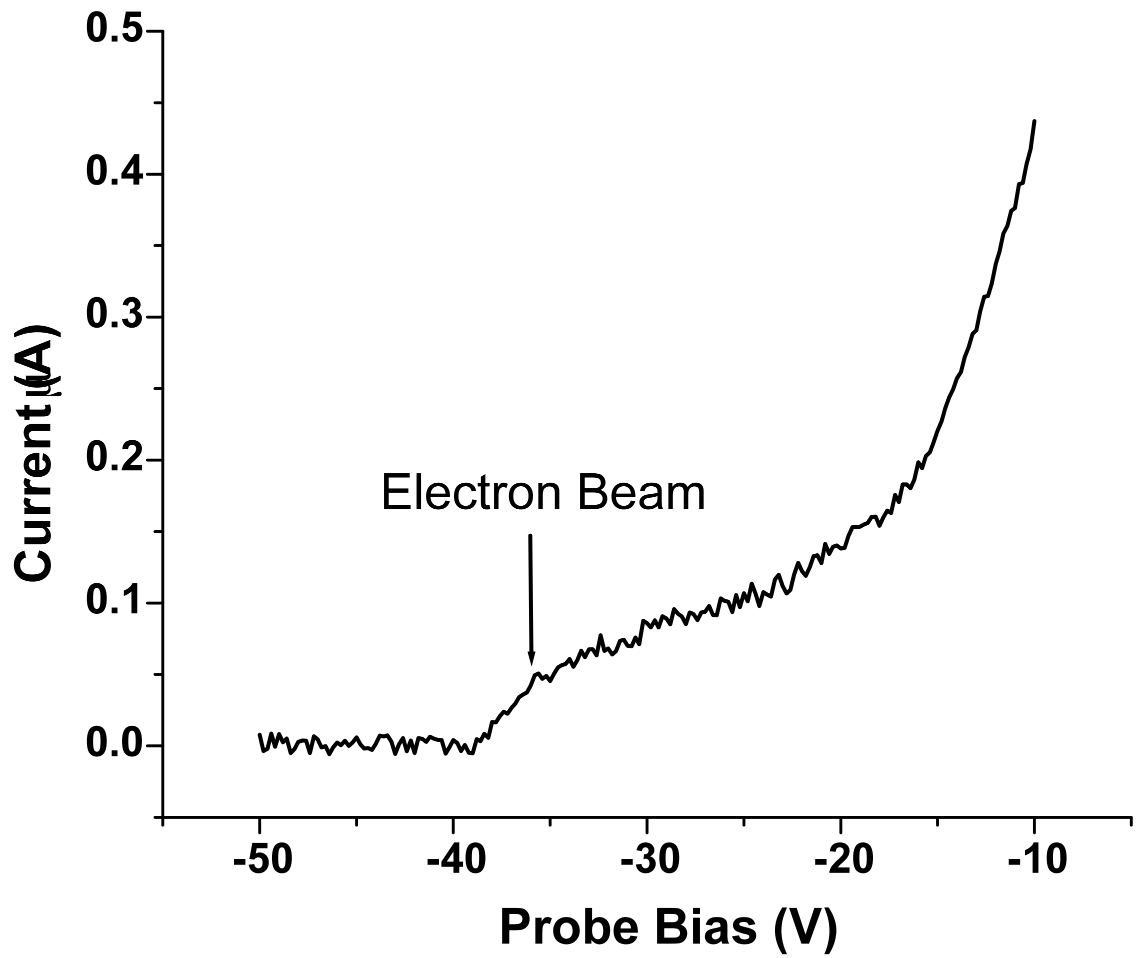
- Electric field is re-established when the graphite surface is exposed to the plasma again.

- Thus, central particles restart to spread and form a single ‘ring’ at the end.

Dust transport in plasma with an electron beam

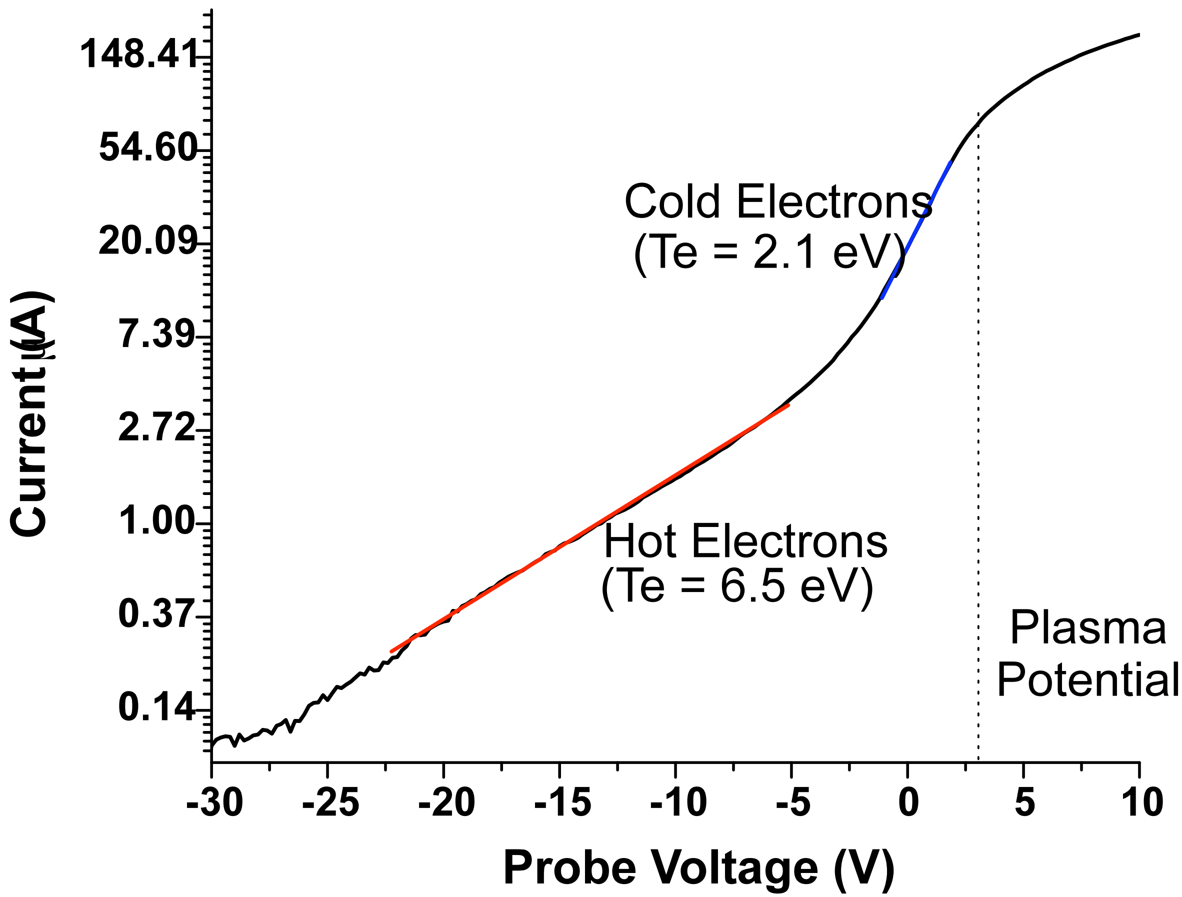


Electron beam at 35eV



Langmuir probe I-V trace shows an electron beam at 35 eV.

Bi-Maxwellian electrons



Currents to the dust and graphite surfaces

$$J_b + J_e^c(\Phi) + J_e^h(\Phi) = J_i + J_{se}$$

J_b is electron beam current density.

J_e^c is cold electron current density.

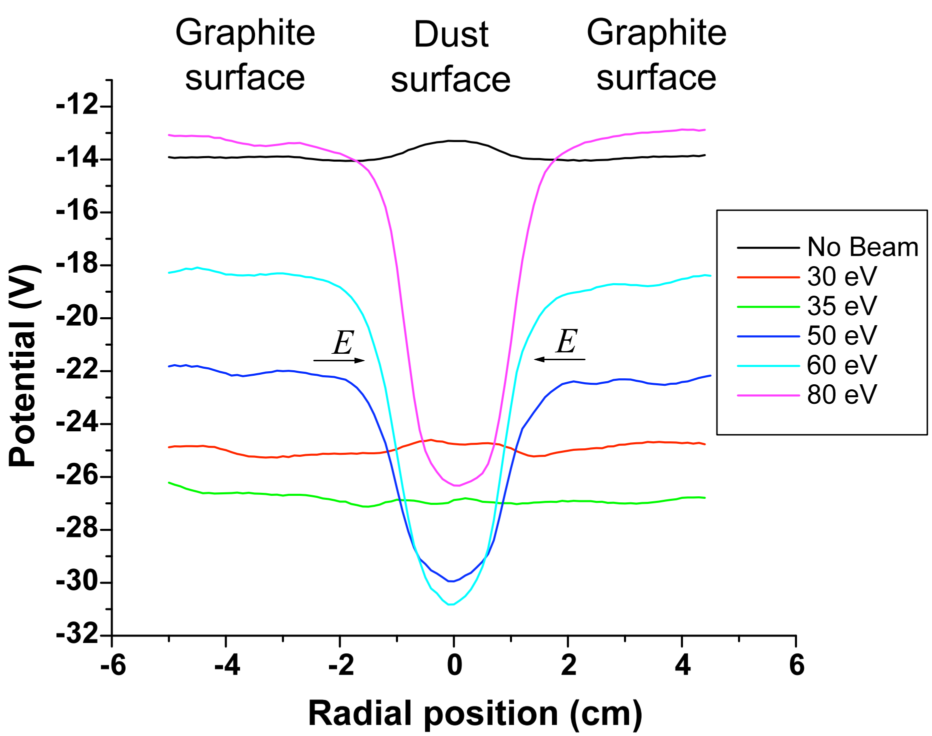
J_e^h is hot electron current density.

J_i is ion current density and equals $J_i \cong 0.6ne\sqrt{\frac{T_e}{m_i}}$

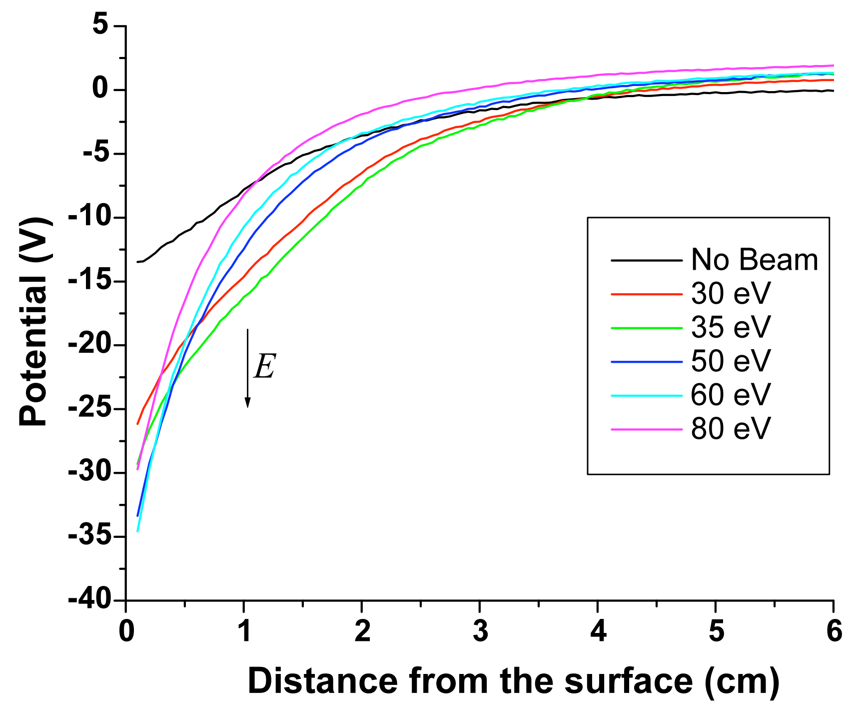
J_{se} is secondary electron current density and $J_{se} = kJ_b$.

Potential distributions above the dust surface

Matching beam: $J_b \approx J_i$

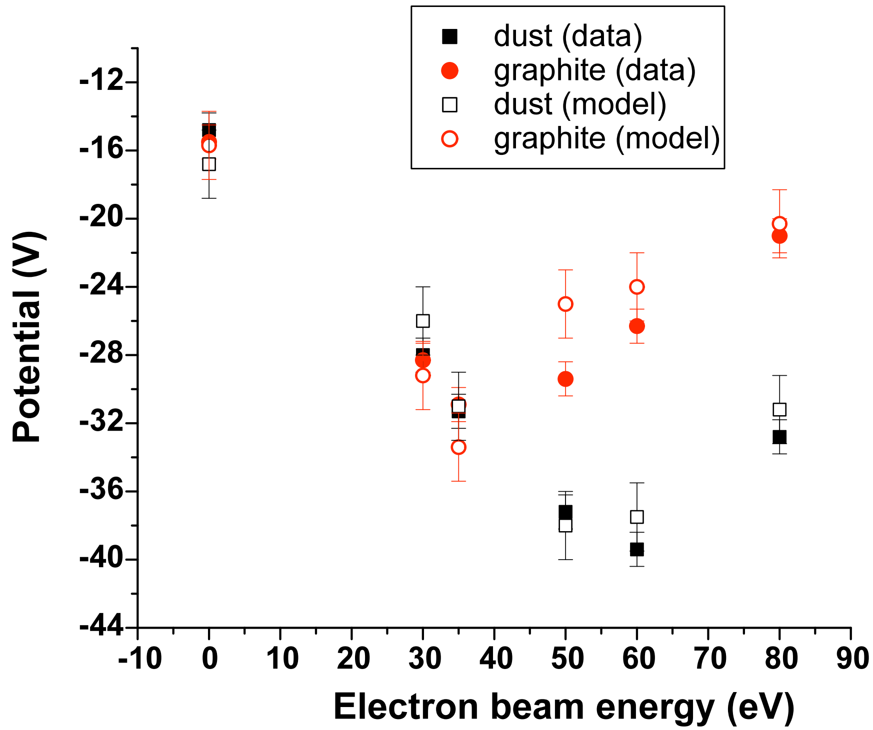


Horizontal potential profiles

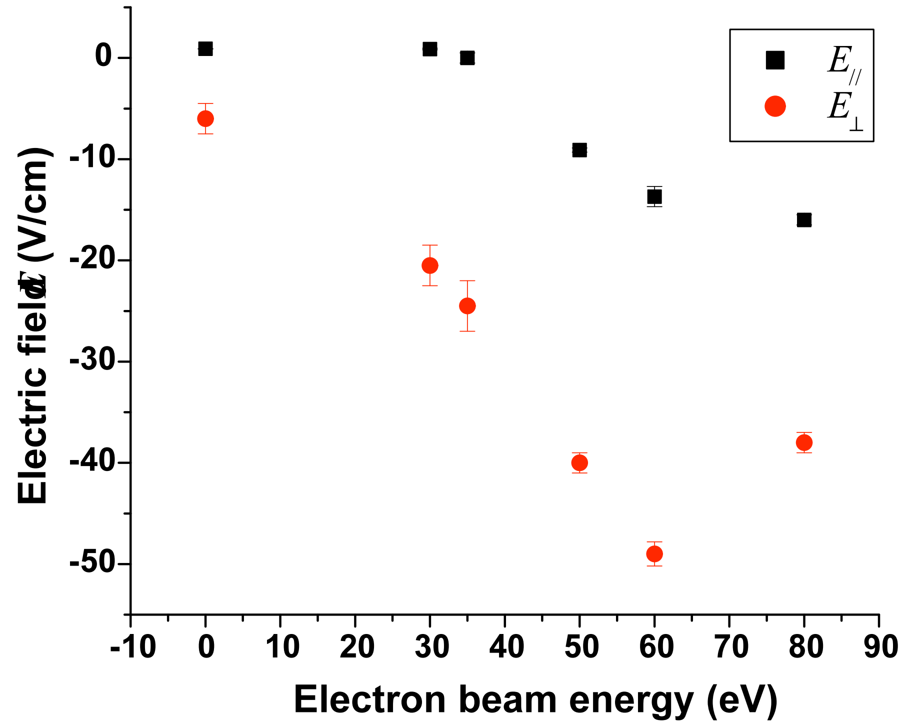


Vertical potential profiles

Potential distributions above the dust surface



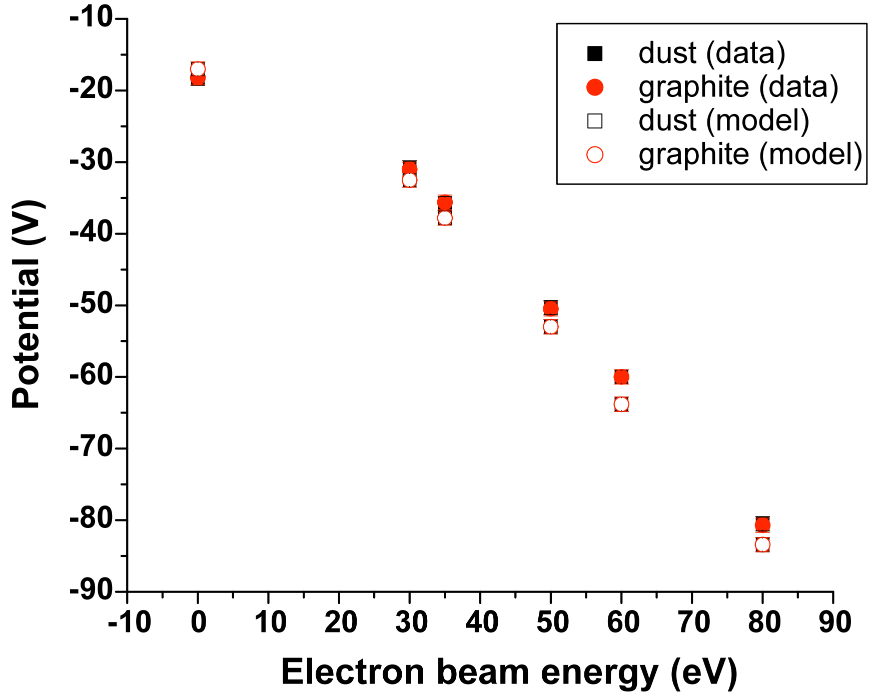
Surface potential vs. Beam energy

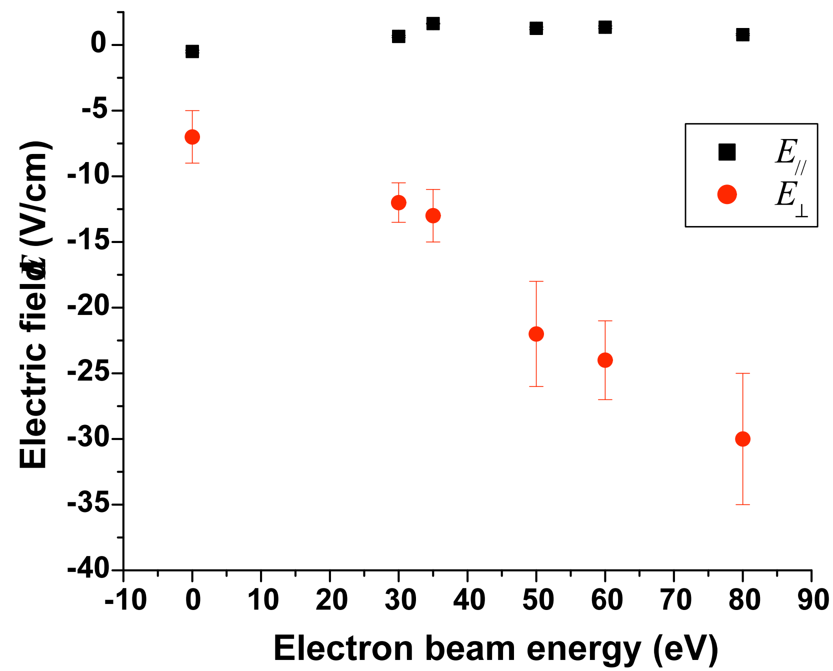


Electric field vs. Beam energy

- Secondary electrons are not negligible when beam energy is greater than 50eV.
- Potentials on the dust surface are more negative than on the graphite surface, indicating $\gamma_{SE\_dust} < \gamma_{SE\_graphite}$.
- $E_{\perp}$ is increased in an order of magnitude that significantly increases the dust release rate.

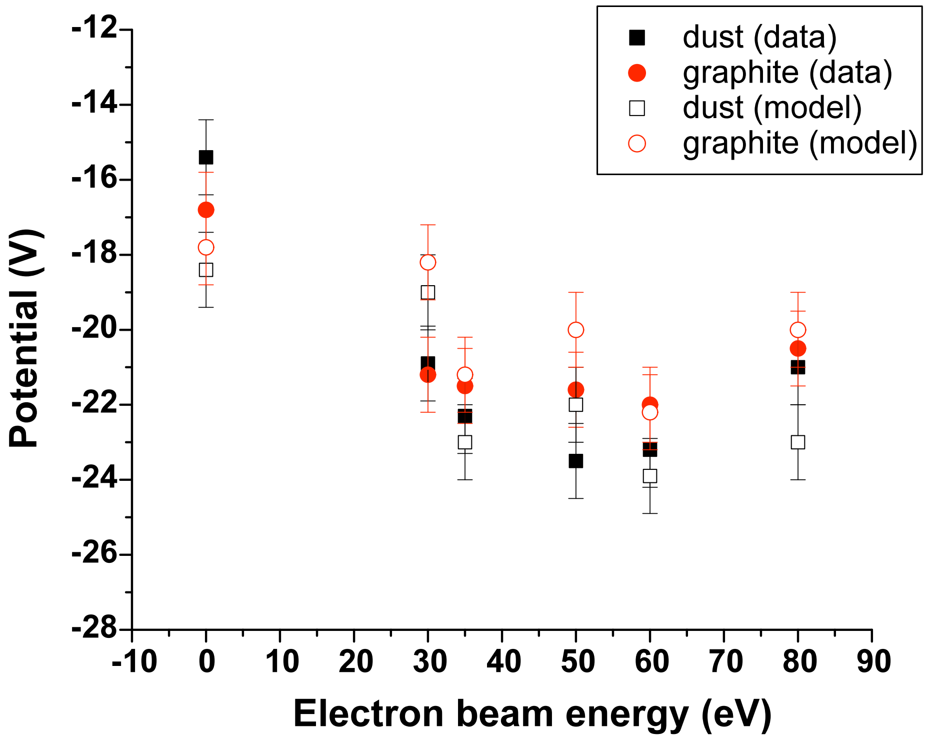
Strong beam: $J_b > J_i$

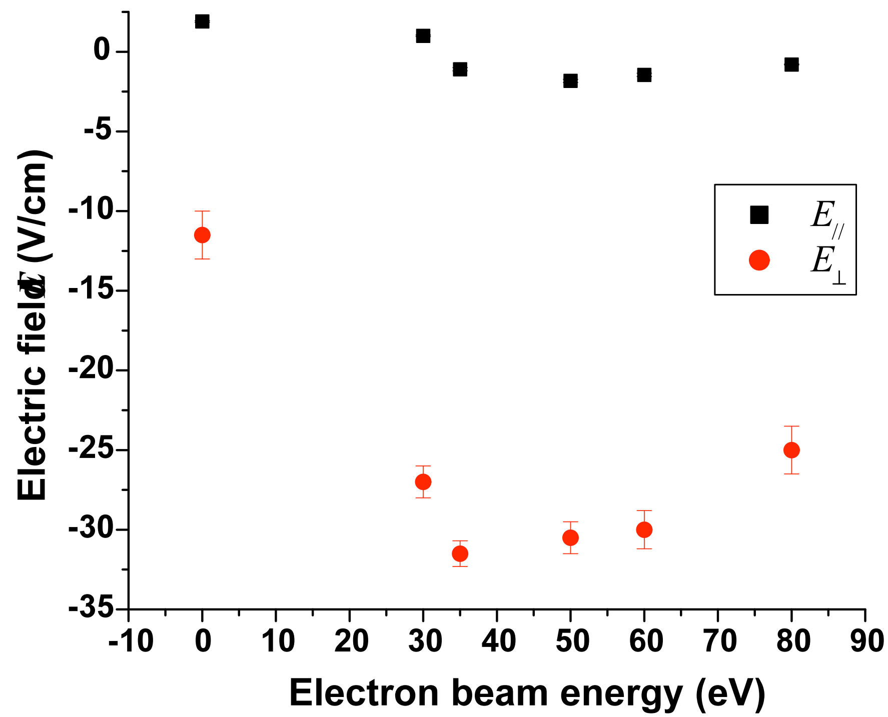




- Potential on both dust and graphite surface follows the beam energy.
- $E_{//}$ is near zero.
- $E_{\perp}$ has no significant increasement.

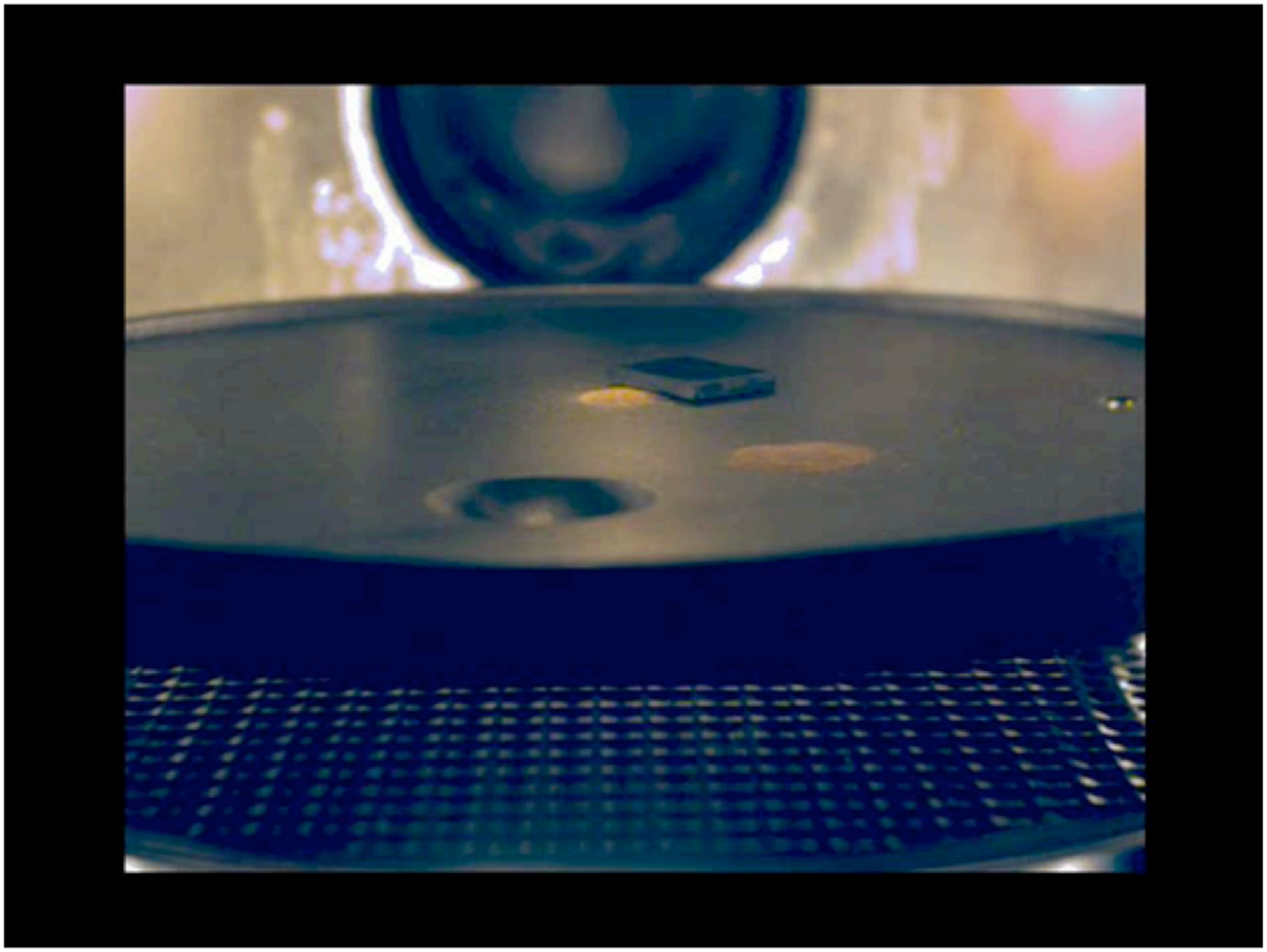
Weak beam: $J_b < J_i$





- Potentials on both dust and graphite surfaces are independent of the beam energy.
- $E_{//}$ is near zero.
- $E_\perp$ is near constant.

Dust transport observation ($J_b \approx J_i$, E_b=70 eV)



This is more likely to happen on the night-side lunar surface when the Moon enters Earth's magnetotail and the high energy electron fluxes create the secondary electrons.

Dust Transport in Craters

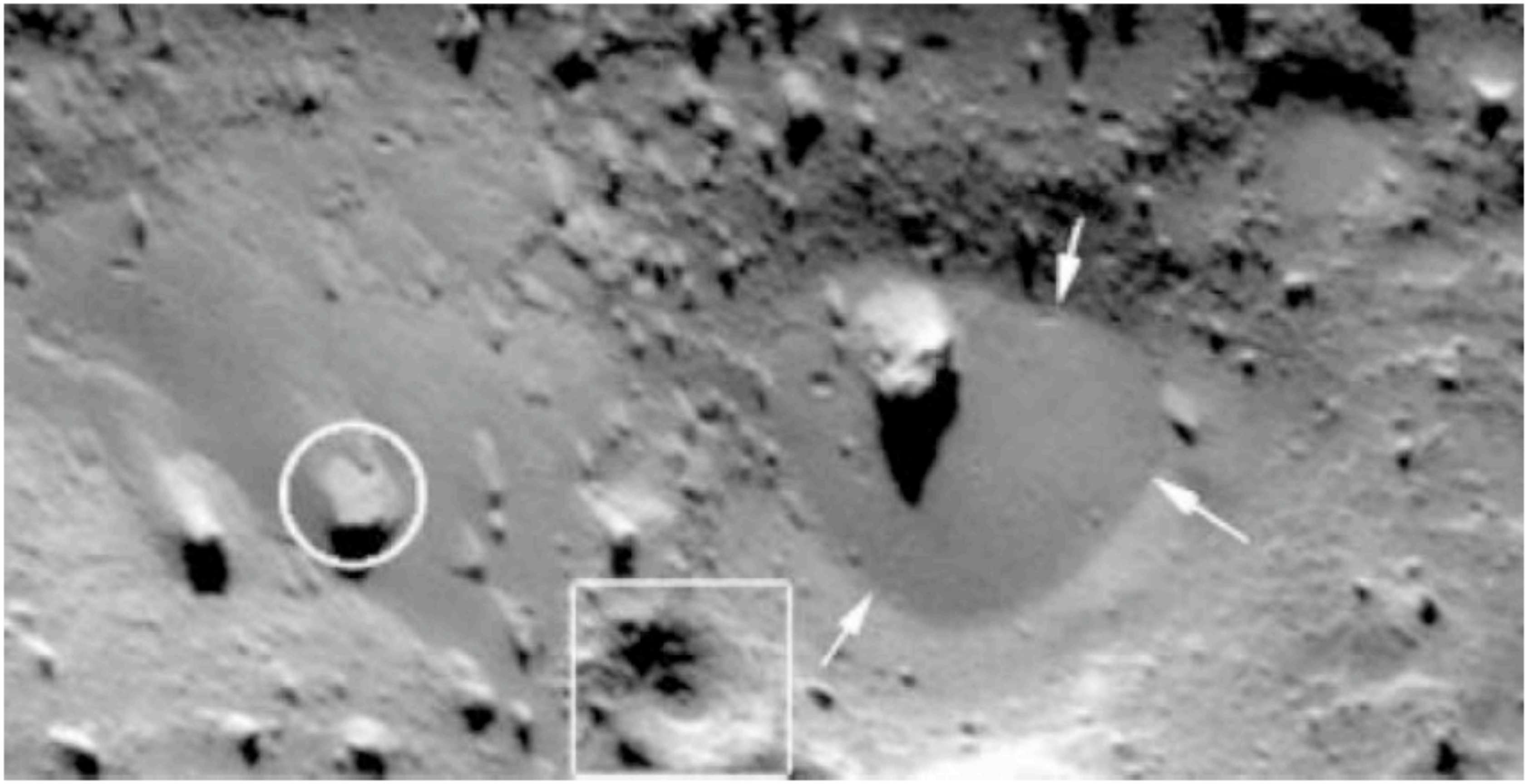
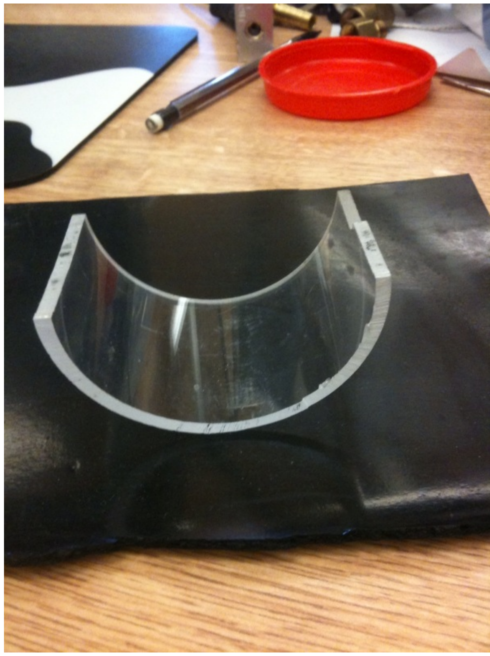
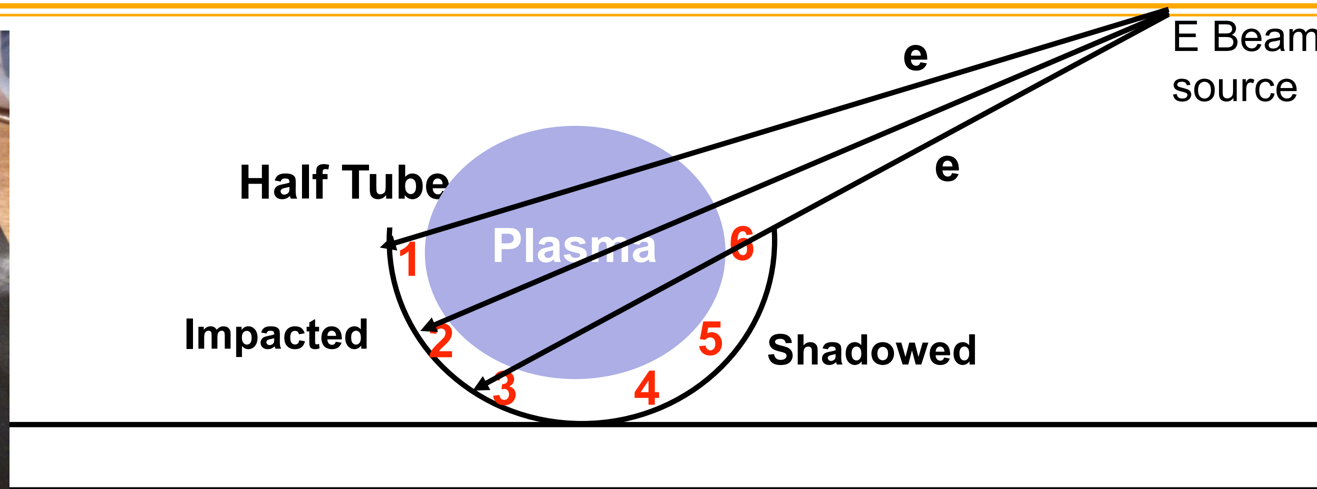


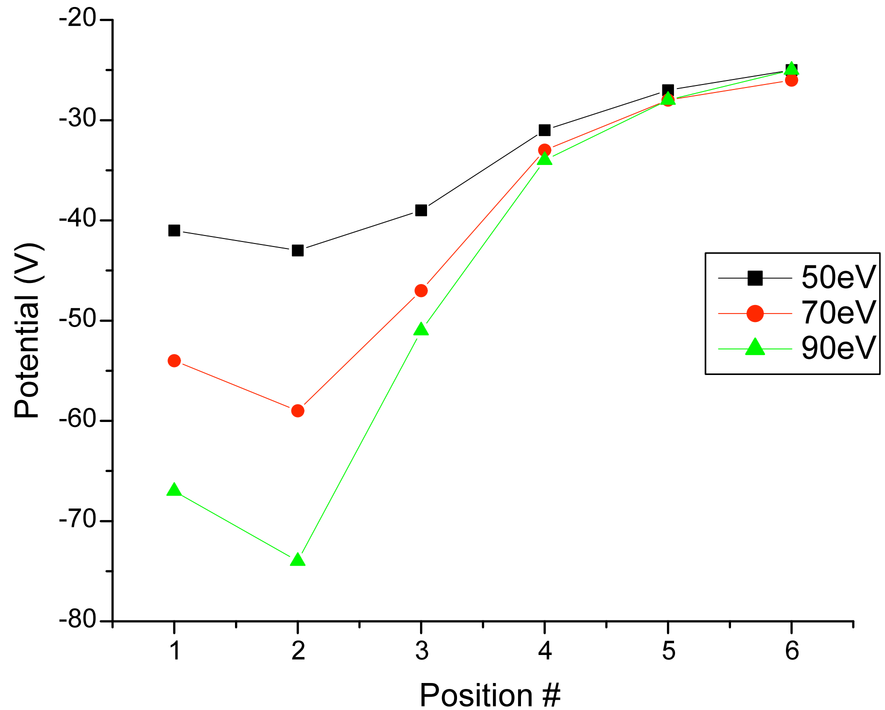
Fig. 6 Image of the surface of asteroid Eros showing evidence of dust particles moving downhill, filling craters and accumulating upslope of rocks **(Renno, 2008)**

The dust pond is most likely formed due to electrostatic dust transport to the bottom of the crater from outside and the upper slope.

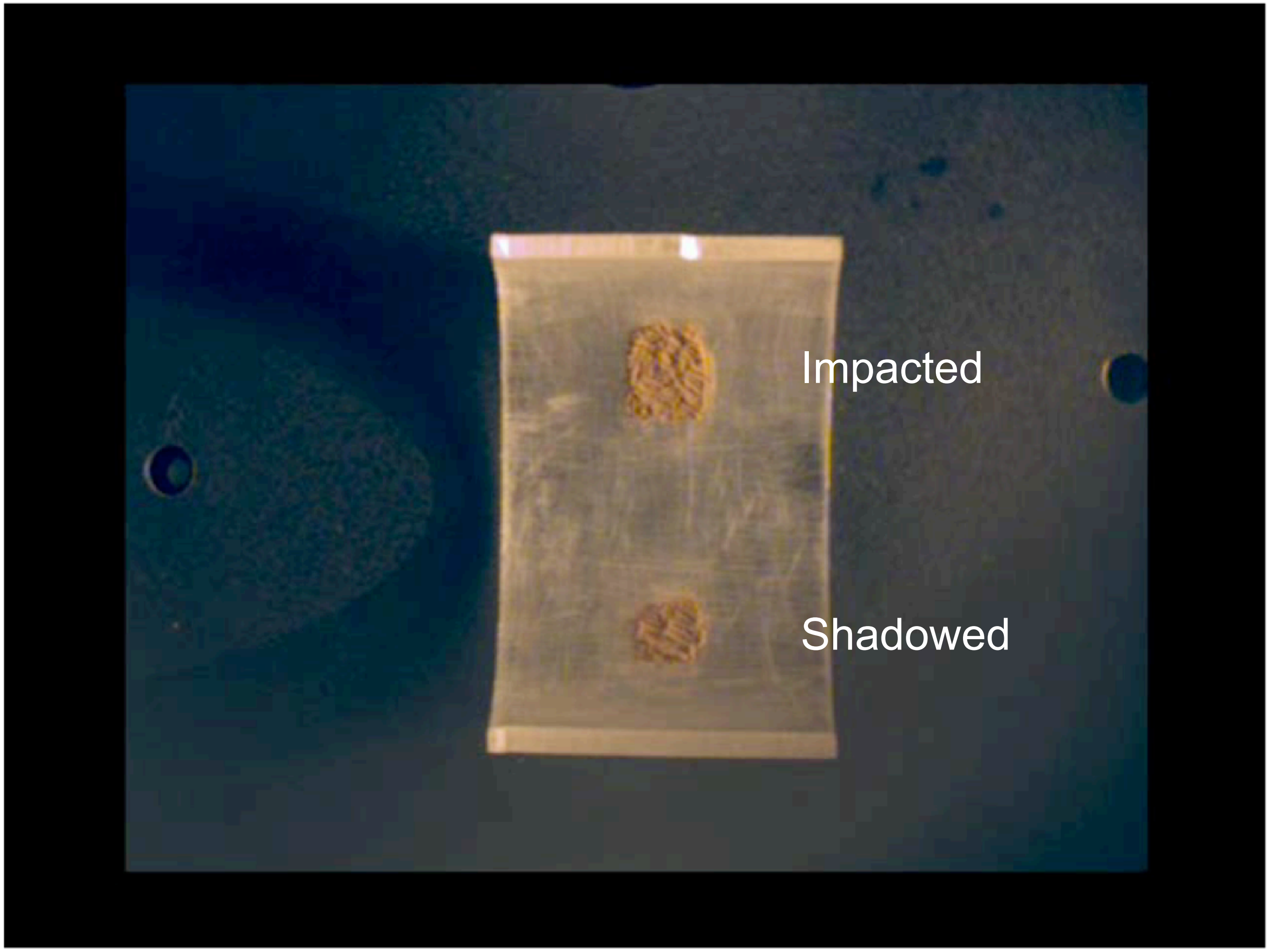
Electron Beam Induced Potential Differences





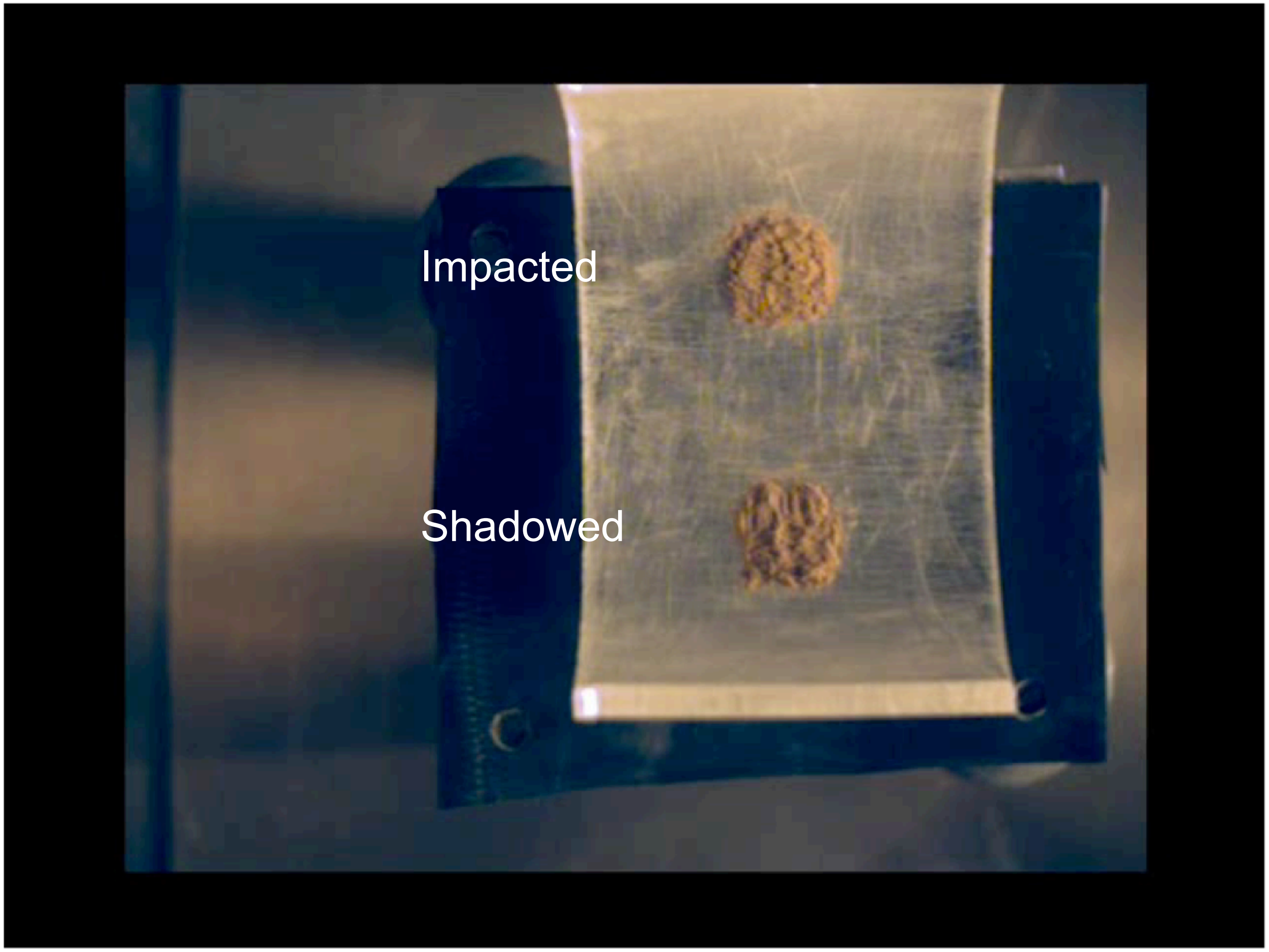


Beam Source Far from The Tube



Dust particles on the impacted slope move downhill.
Dust particles on the shadowed slope have no transport.

Beam Source near The Tube



Dust hopping process goes faster than surface transport.

Summary

- 'Supercharging' effect has been shown with moving lit/dark boundaries, which increases possibilities of dust lift-off near lunar terminators.

- Dust levitation in plasma sheath has been shown.

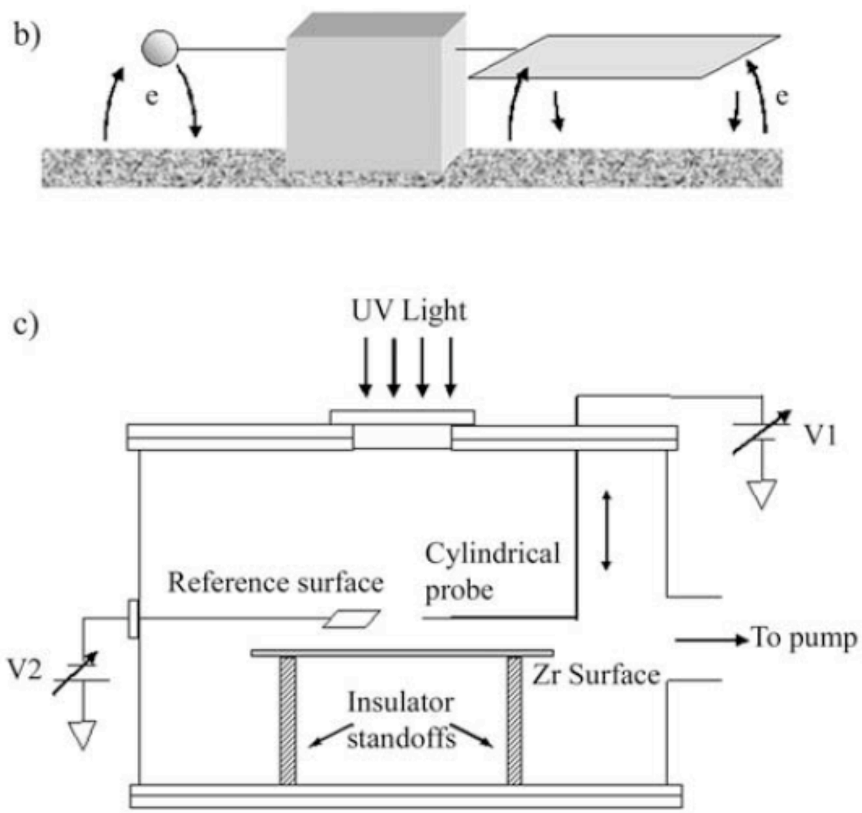
- Dust has been observed to transport on a surface that repels most of electrons and collects ions in plasma.

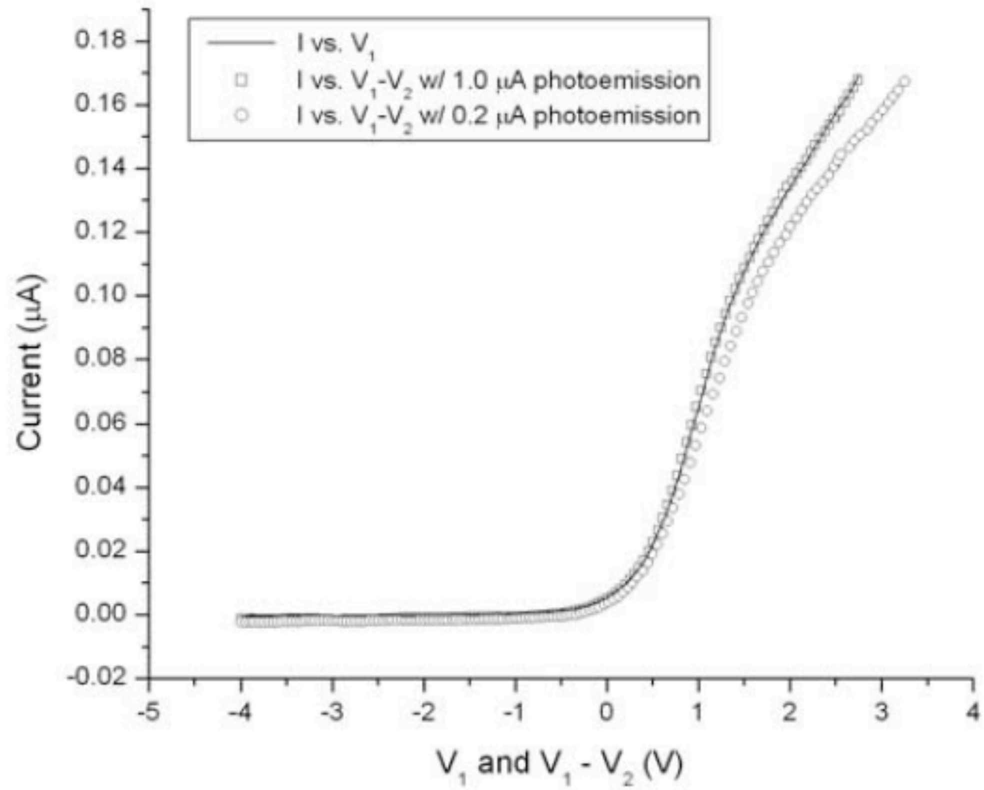
- Also, dust transports on a surface in plasma with an electron beam due to the secondary electrons emitting from surfaces. This is more likely to happen on the night-side lunar surface.

- Dust transport in craters is under investigation in laboratory.

Potential *in situ* measurements on lunar surface

Double probe for characterizing photoelectrons





* X. Wang, M. Horányi and S. Robertson, *JGR*, 113, A08108 (2008).

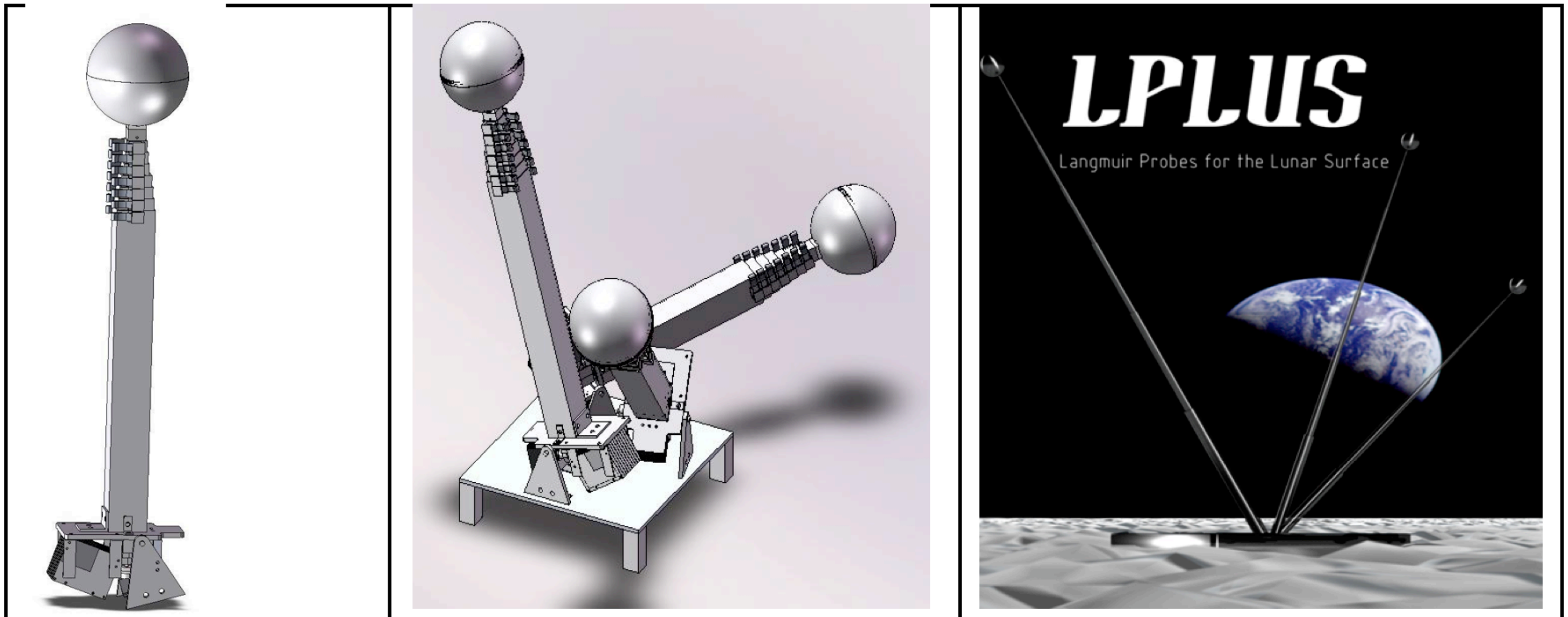


Figure 1. The design details of one of the booms (*left*), the configuration of LPLUS before deployment (*middle*), and LPLUS deployed on the lunar surface (*right*)

Langmuir Probes for the Lunar Surface (LPLUS)

Credit for the work is given to group of seven students: A. Berg, K. Hahn, T. Hanson, L. Martinez, R. Mayerle, M. Siegers, S. Valdez.

Thank You