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Investigations of electrostatic dust lofting and its mechanisms

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Charging of Airless Bodies

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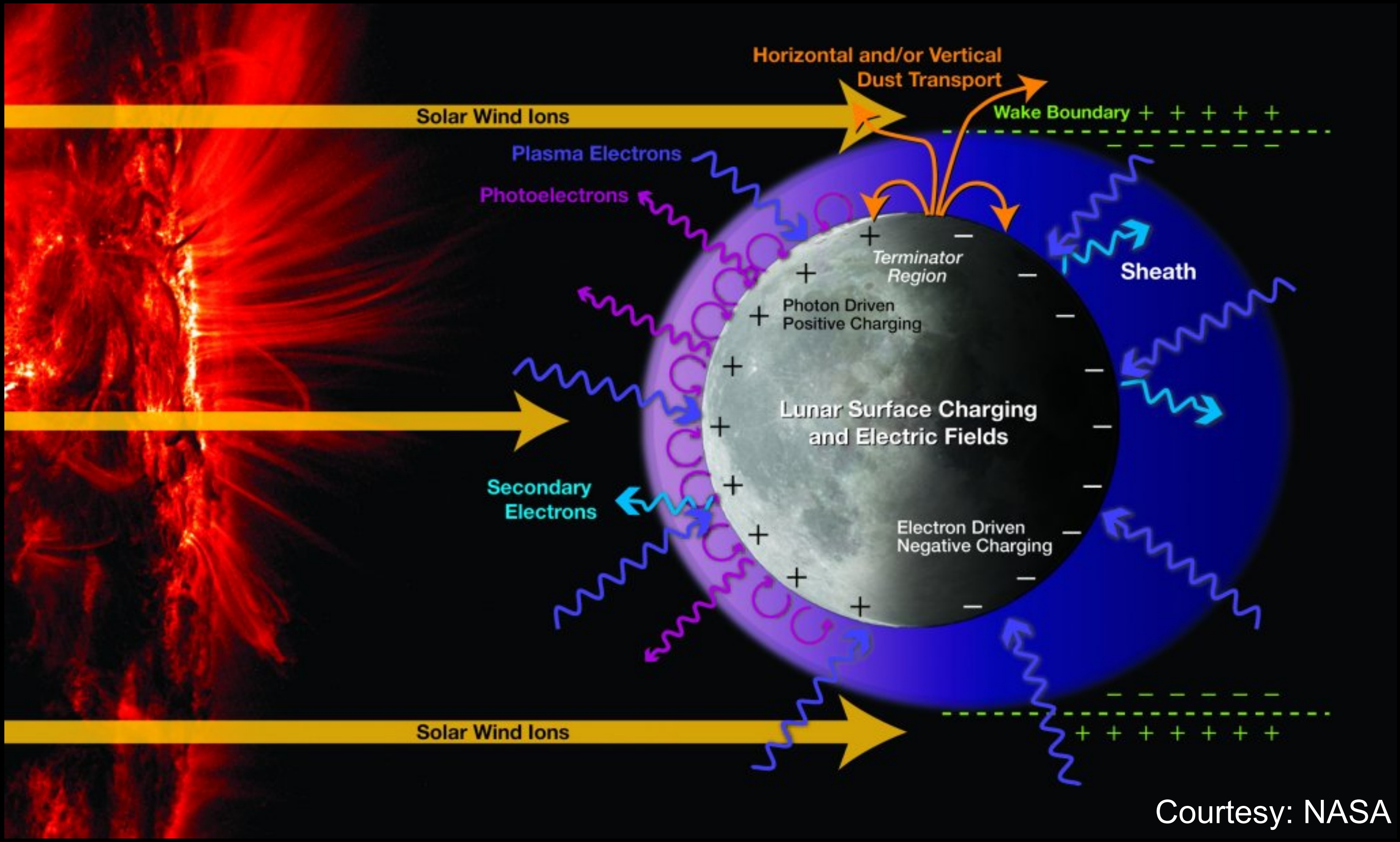

Courtesy: NASA

Dust particles on the regolith of airless bodies are charged and may be transported and lofted due to electrostatic forces.

In-situ Observations

(Electrostatic dust transport could play a role)

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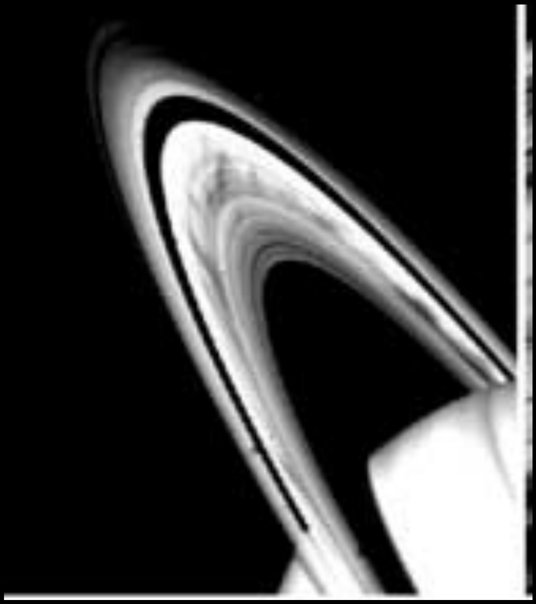
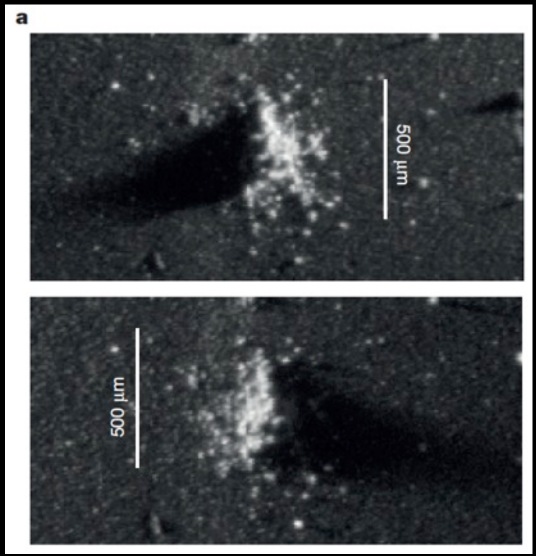
Lunar horizon glow (Rennilson and Criswell, 1974)



The Spokes in Saturn's B ring (Mitchell et al., Science, 2006)

Dust pond on asteroid Eros (Renno and Kok, 2008)

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



Previous Laboratory Experiments

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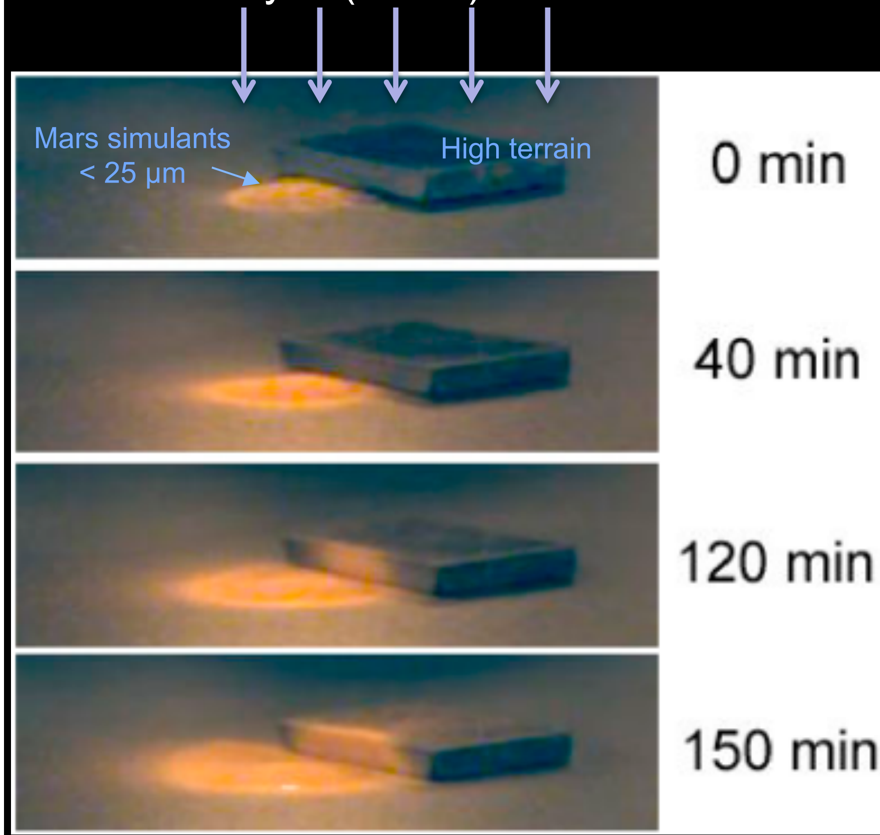
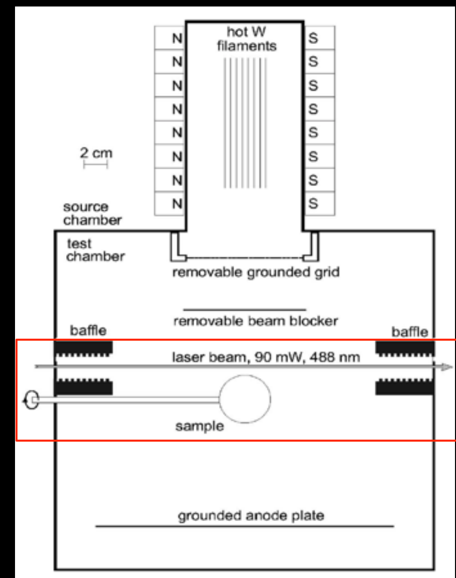
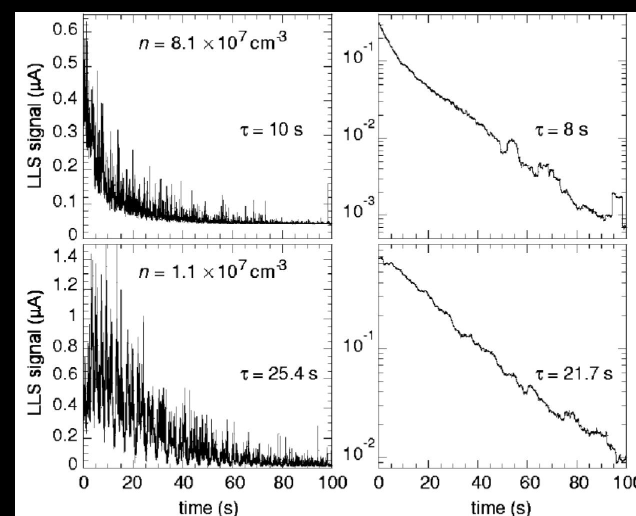
Primary e^- (75 eV) and Plasma



Wang et al., 2010



Laser Light Scatter (LLS)



Flanagana and Goree, 2006

Examination of Current Charge Models

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- Shared charge model
  (uniform surface charge density)

$Q = \varepsilon_0 E A = 4\pi\varepsilon_0 r^2 E$

$F_e = QE$

$F_c = 1/4\pi\varepsilon_0 \, (Q/2r)^2$

$F_g = mg$

*Cohesion force is not yet considered

Case I
(Wang et al., 2010)

$E = 100$ V/cm

$r = 12.5$ μm

$F_e = 1.7\text{e-}12$ N
$F_c = 4.3\text{e-}13$ N
$F_g = 1.5\text{e-}10$ N

$F_e + F_c \approx 10^{-2} \cdot F_g$

Case II (?)
(Lunar surface)

$E = 10$ V/m

$r = 5$ μm

$F_e = 2.8\text{e-}19$ N
$F_c = 6.9\text{e-}20$ N
$F_g = 2.5\text{e-}12$ N

$F_e + F_c \approx 10^{-7} \cdot F_g$

- Charge fluctuation theory (due to discrete electron and ion fluxes to the surface)

$$\frac{\delta Q_{\mathrm{rms}}}{e} = \sqrt{\frac{C T_e}{e}},$$

(Sheridan and Hayes, 2011)

Case I

$dQ_{rms} / Q = 807 / 1085 = 0.74$

$Q_{max} \approx 2Q$, small enhancement.

Charge induced by plasma is too small for dust particles to be lifted off.

New Dust Experiments

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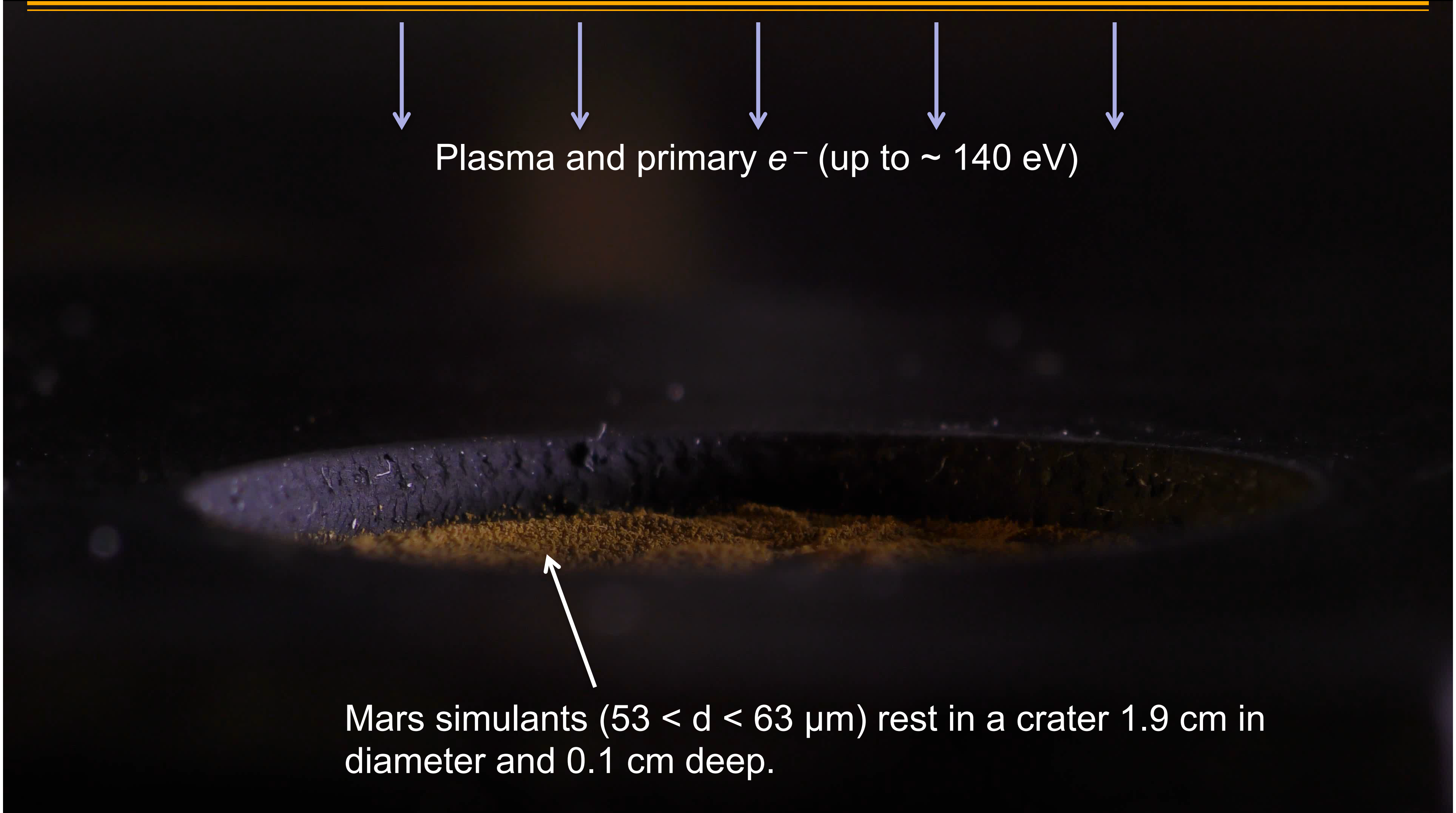
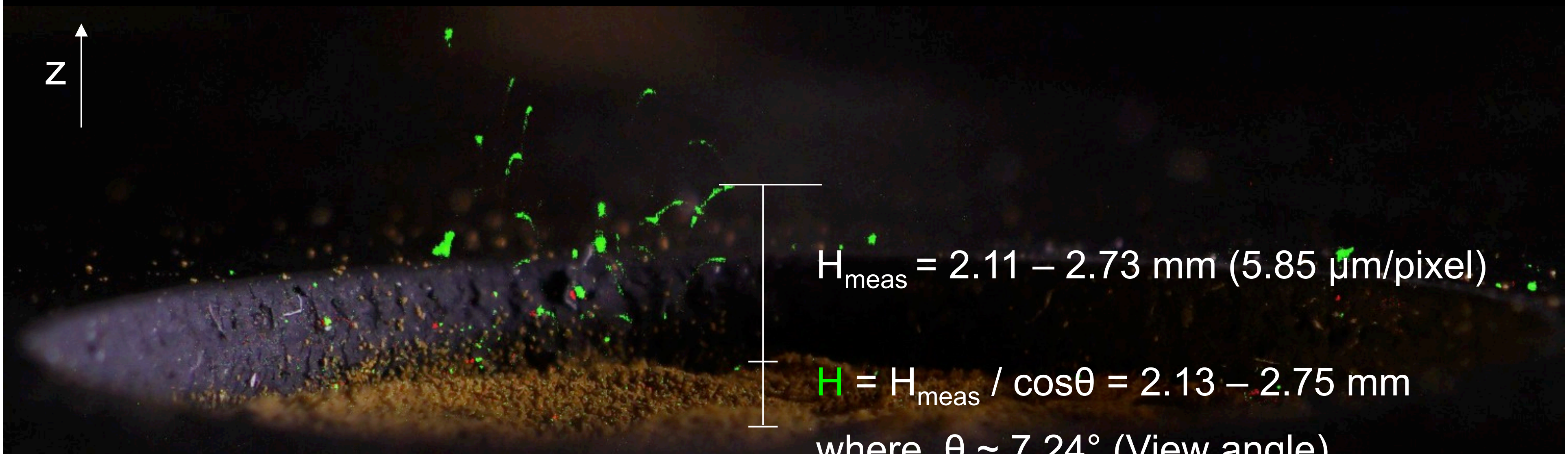


Trajectories of Dust Particles



H_{meas} = 2.11 – 2.73 mm (5.85 μm/pixel)

$H = H_{meas} / \cos\theta$ = 2.13 – 2.75 mm

where, θ ~ 7.24° (View angle)

$v_{z,0} = (2gH)^{1/2}$ = 20.3 – 23.2 cm/s

Trajectory Statistics

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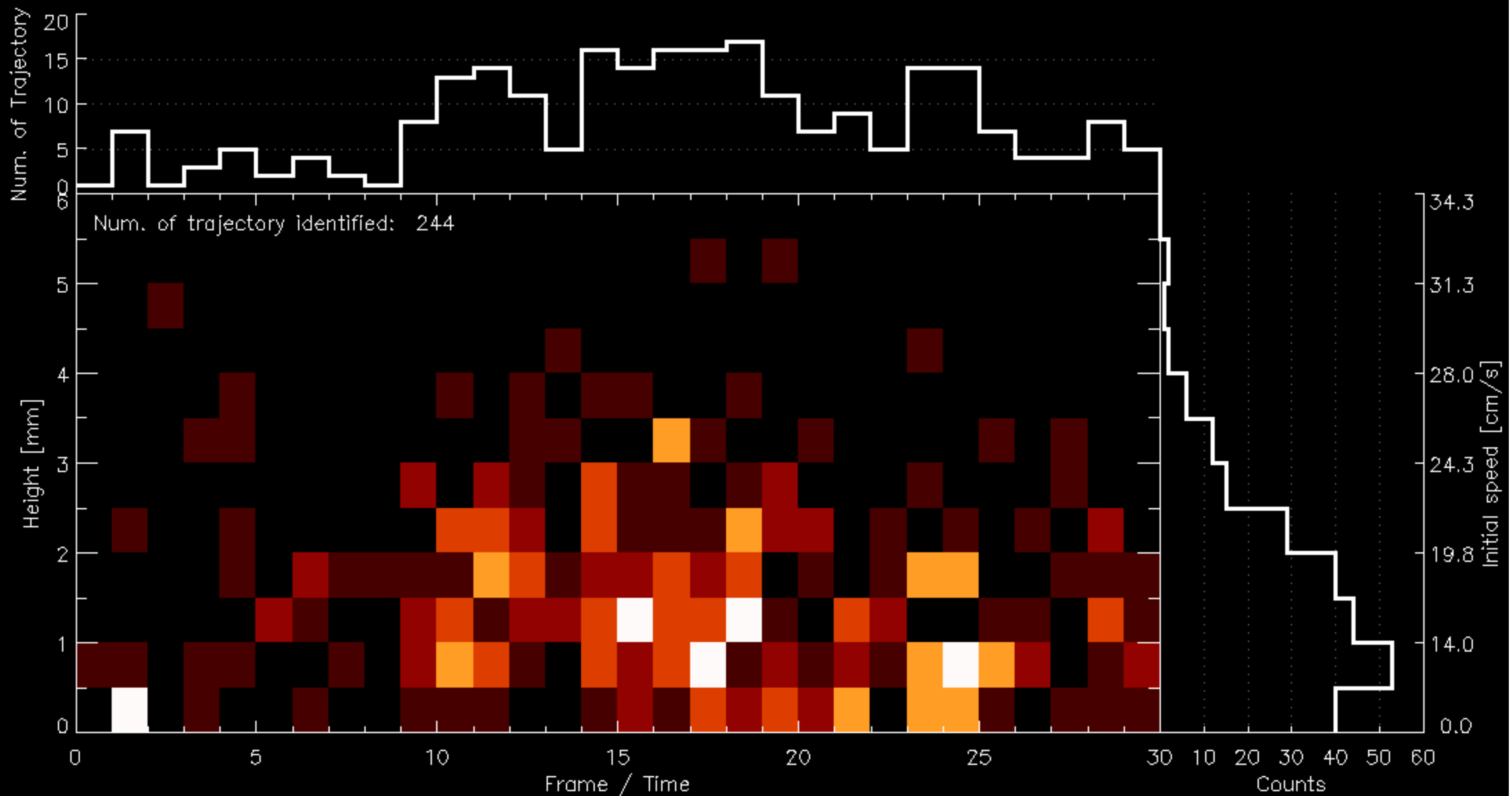

Average height: 1.5 mm and launch speed : 15 cm/s

Size Distributions of Lofting Dust

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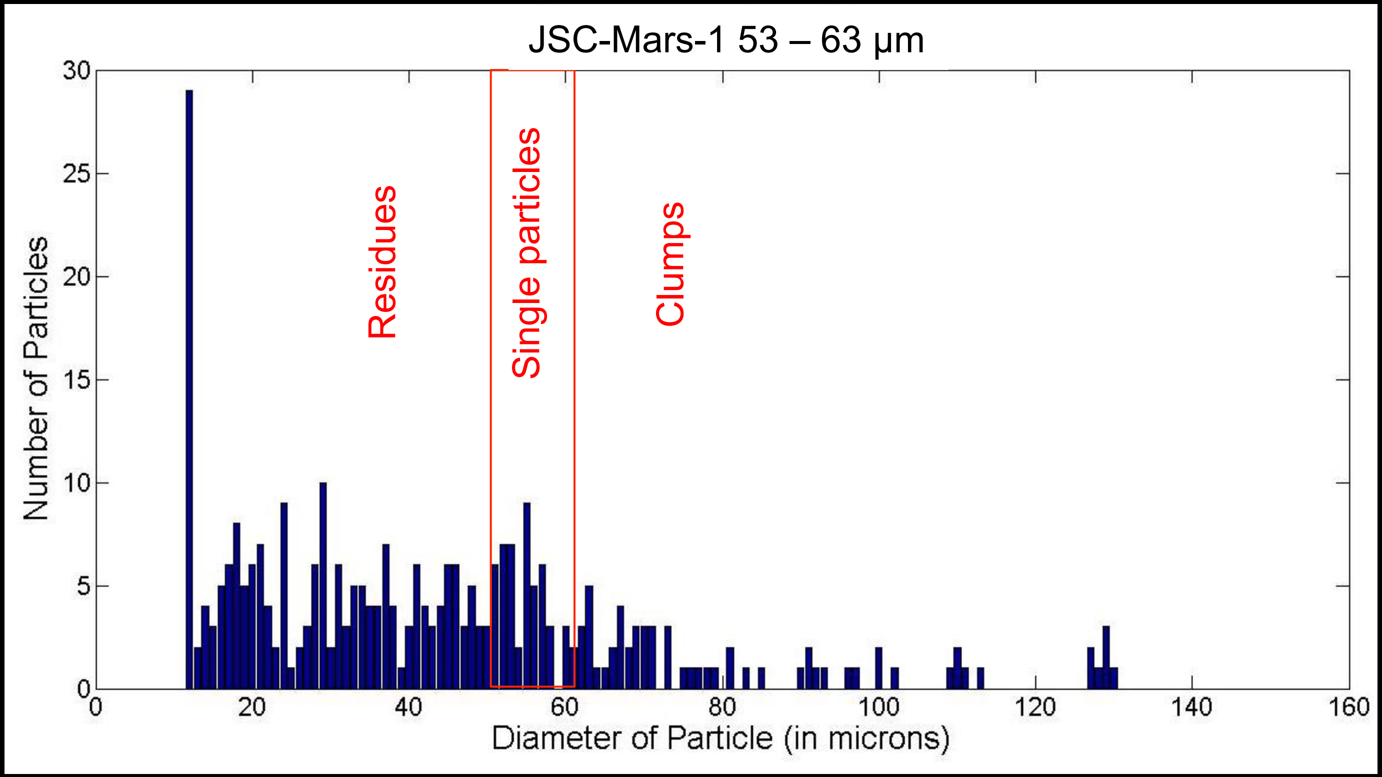
Filtered image of dust particles resting on the solid surface



Size composition

- Small residues on single particles;
- Single particles;
- Clumps due to the cohesion between particles.

Size Distributions of Lofting Dust

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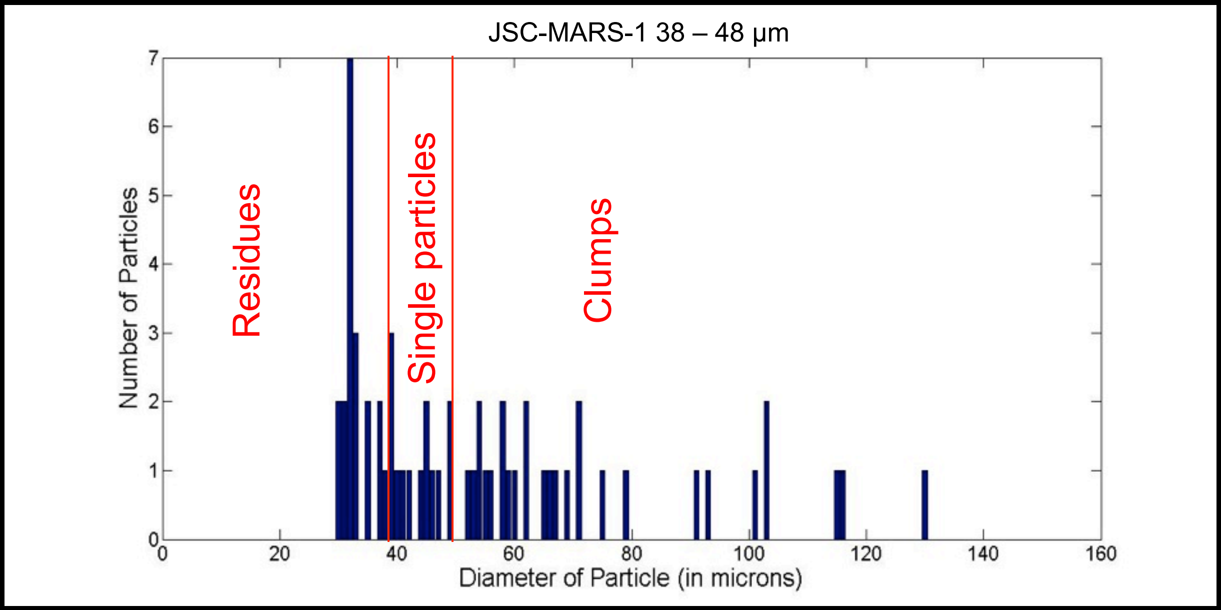

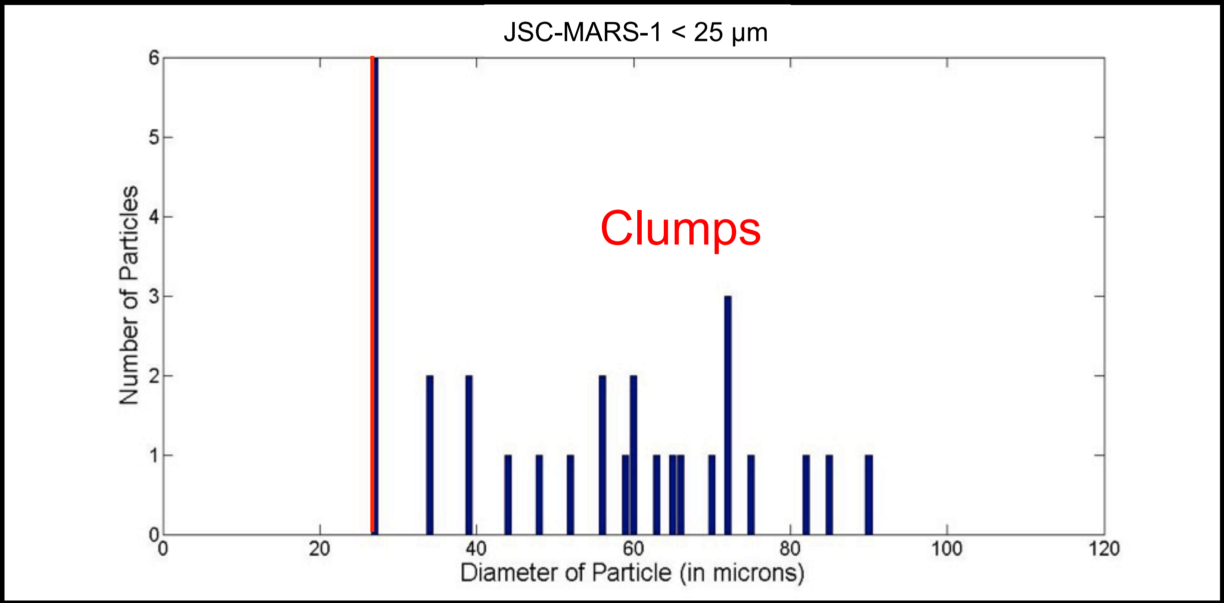

As the size becomes smaller, more clumps are lofted than single particles due to stronger cohesive force between smaller particles.

Charging Mechanisms (Micro-cavities)

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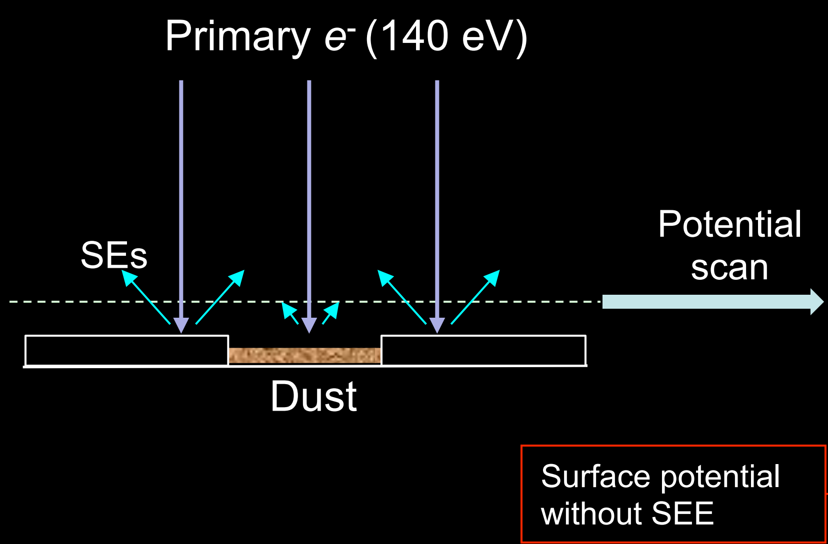

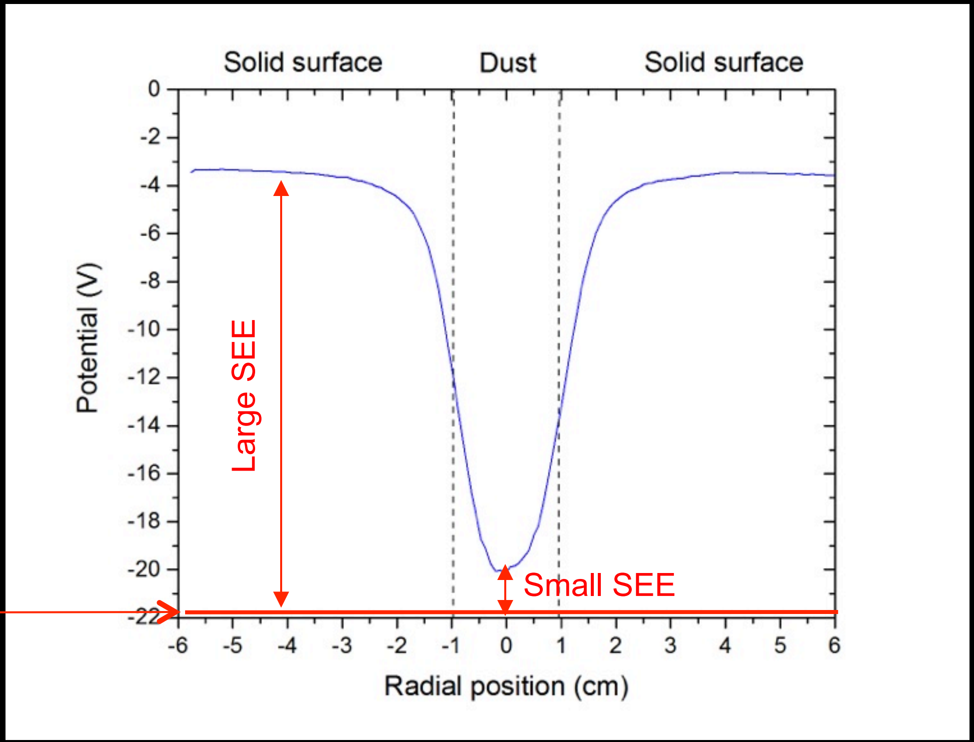

- Secondary electrons (SEs) are emitted from the surface.
- Secondary electron emission (SEE) from solid surface is larger than from the dust surface (Also tested with silica dust vs. silica solid surfaces).
- Emitted SEs are absorbed in the micro-cavities created by neighbor dust particles, reducing the emission from the dust surface.

Patched Charge Model (PCM)

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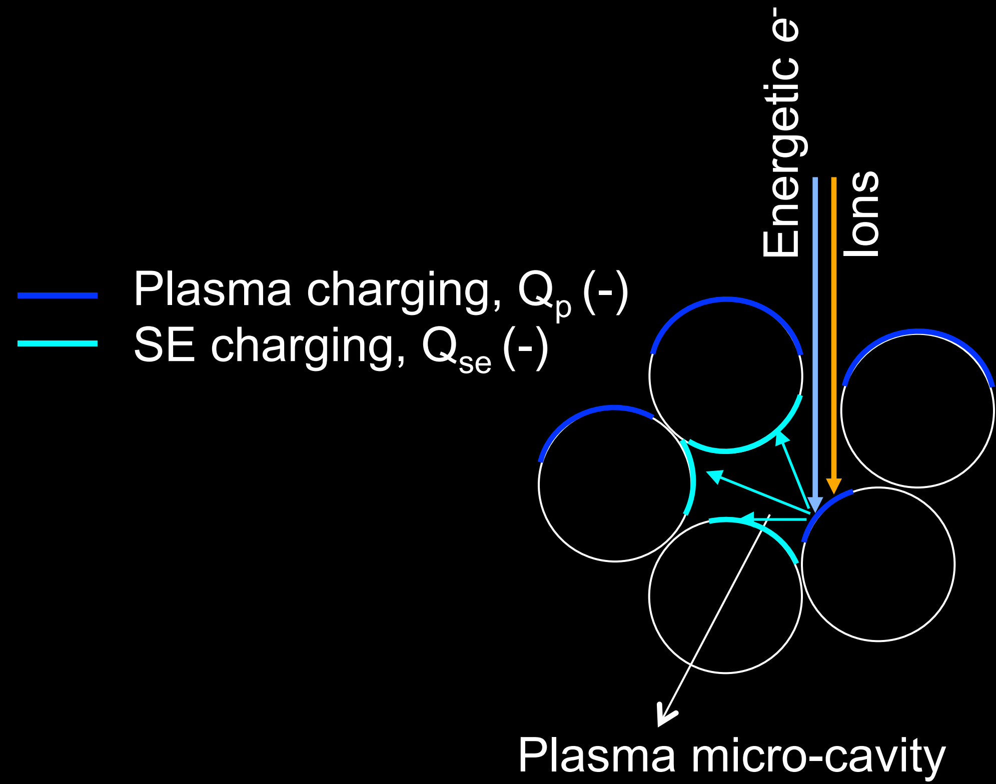

- The charge on single dust particles is patched due to different charging processes.
- Inside the plasma micro-cavity, the patches (light blue) are mainly charged by SEs and can go to a very negative potential, where high-energy tail SEs (Maxwellian distribution) are stopped from reaching the surfaces.

Experimental Verification of the PCM

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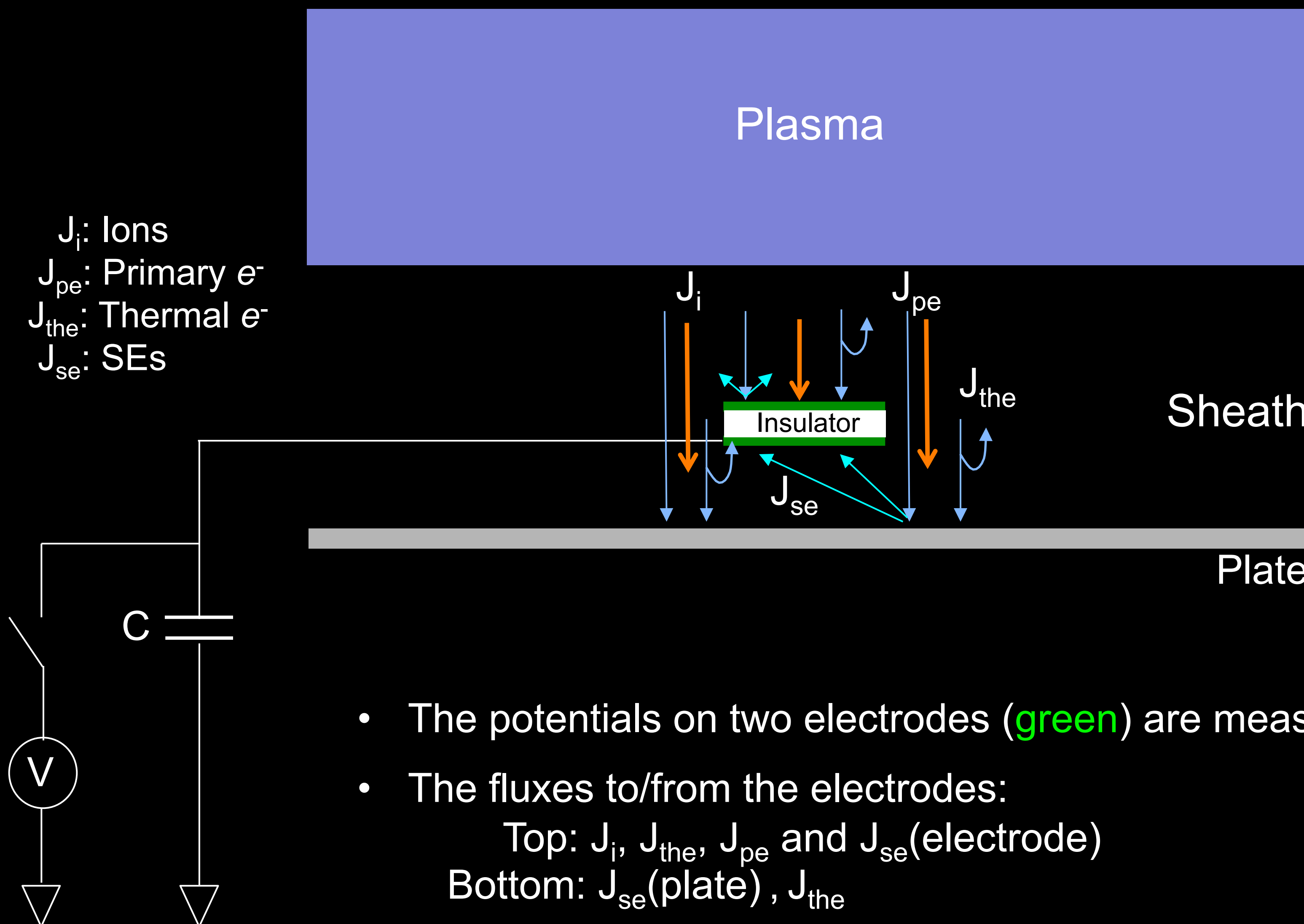

- The potentials on two electrodes (green) are measured.
- The fluxes to/from the electrodes:

  Top: J_i, J_{the}, J_{pe} and J_{se}(electrode)

  Bottom: J_{se}(plate) , J_{the}

Potentials on The Electrodes

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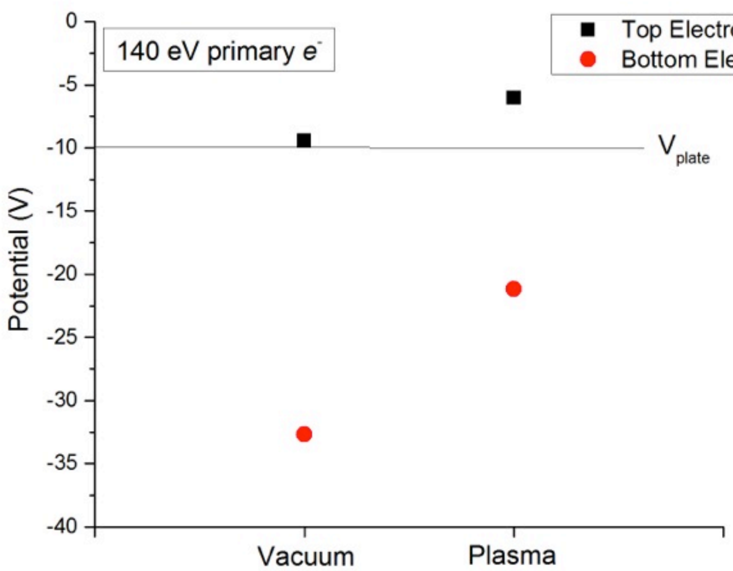
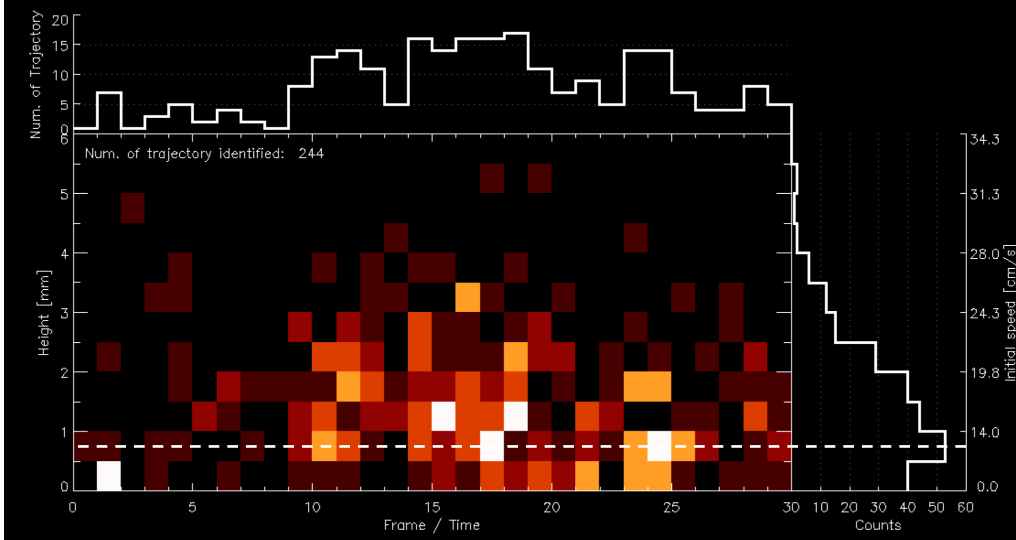


Trajectory Statistics (JSC-Mars-1, 53 < d < 63 μm)



- Top electrode potential is slightly more positive than V_{plate}.
- Bottom electrode potential is as negative as -22 V relative to V_{plate}.

60 μm particles

- Q_{se} ~ 7.3e-14 C >> Q_p ~ 1e-16 C
- F_c >> F_e ~ 7.3e-11 N
- F_c ~ 1.3e-8 N > F_g = 2e-9 N
- V_z ~ 10 cm/s (dashed line above).

- SE charge on the patches inside the micro-cavity is significantly large.
- Coulomb force (repulsion) is a dominant electrostatic force to lift dust off.
- Cohesive force could be the most ‘negative’ force to be overcome.

Summary and Future Works

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- Trajectories of dust particles were captured and analyzed.
- A new “patched charge model” with secondary or photo- electrons inside micro-cavities created between dust particles was proposed, which may explain the large charge on individual dust particles.
- Coulomb force (repulsion) between dust particles is likely a dominant electrostatic force to lift dust off the surface.
- Future works include
  - Tests with more dust properties, including surface morphology, shape, size etc.;
  - Improvement on experimental verifications of the “patched charge model” with an enclosed cavity;
  - Investigations of cohesion effects;
  - Photoemission;
  - Final destination is to apply the lab findings to explain electrostatic dust charging and transport on airless planetary surfaces.

Backup slides

Patched Charge Model for Lunar Dust

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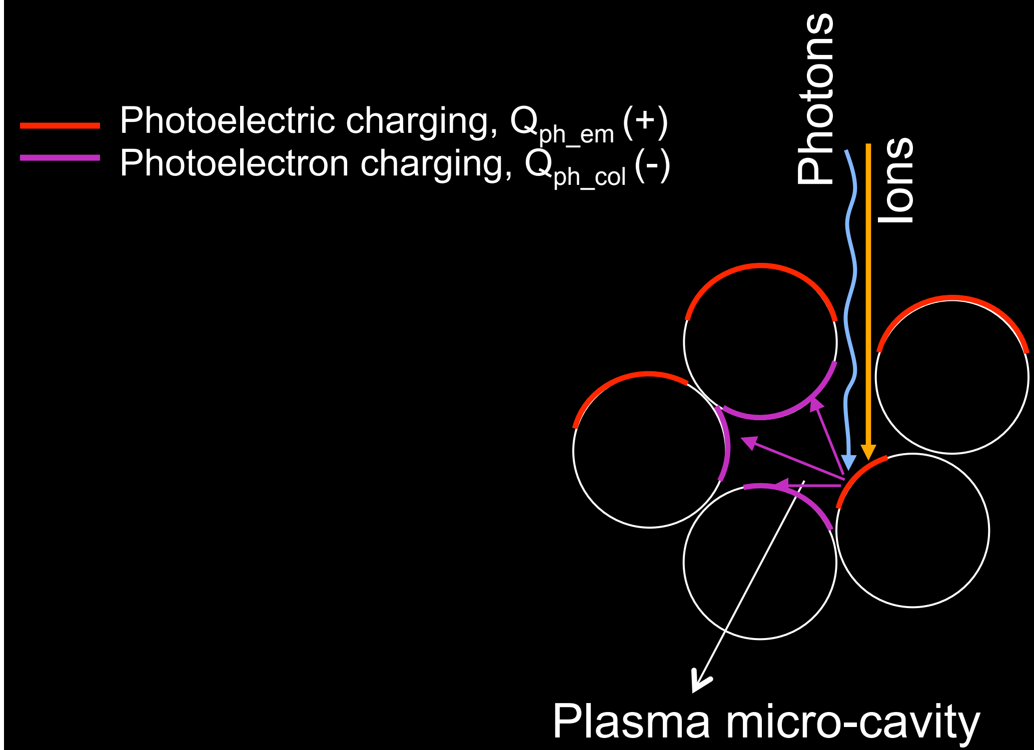

$E = 10$ V/m

$r = 5$ μm

$F_e = 3.1e\text{-}13$ N
$F_c = 8.4e\text{-}8$ N (Vd~55V)
$F_g = 2.5e\text{-}12$ N

$F_{co} = CS^2r = 8.4e\text{-}8$ N

Q_{ph_col} (-) >> Q_{ph_em} (+)

Charging Mechanisms (Micro-cavities)

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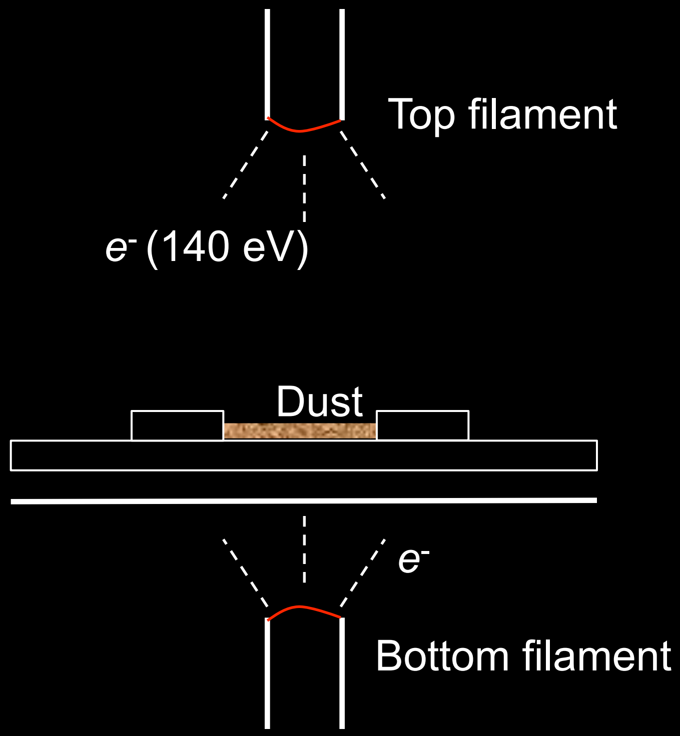
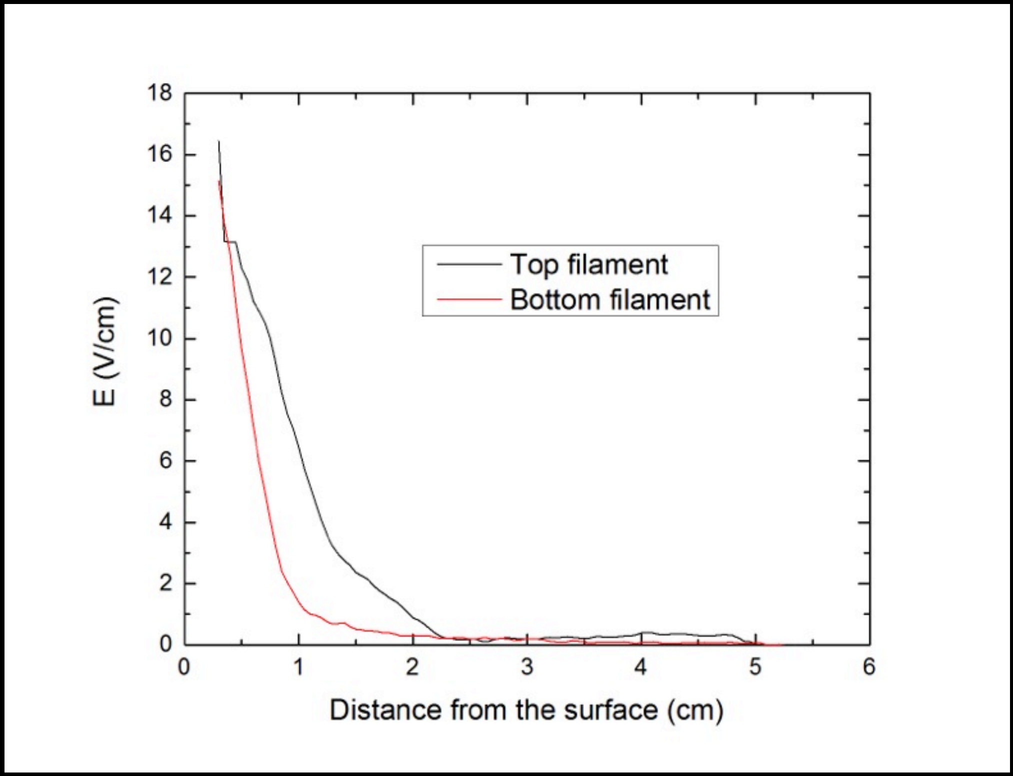
II. Comparison of dust movements between the filament (plasma source) on top and bottom





- E at the surface was set to be similar ~ 20 V/cm for two setups, resulting in a similar $F_e = \varepsilon_0 E^2 A$.
- However, dust particles only moved and lofted with the top filament setup, which created SEE from the surfaces.

Charging Mechanisms (Micro-cavities)

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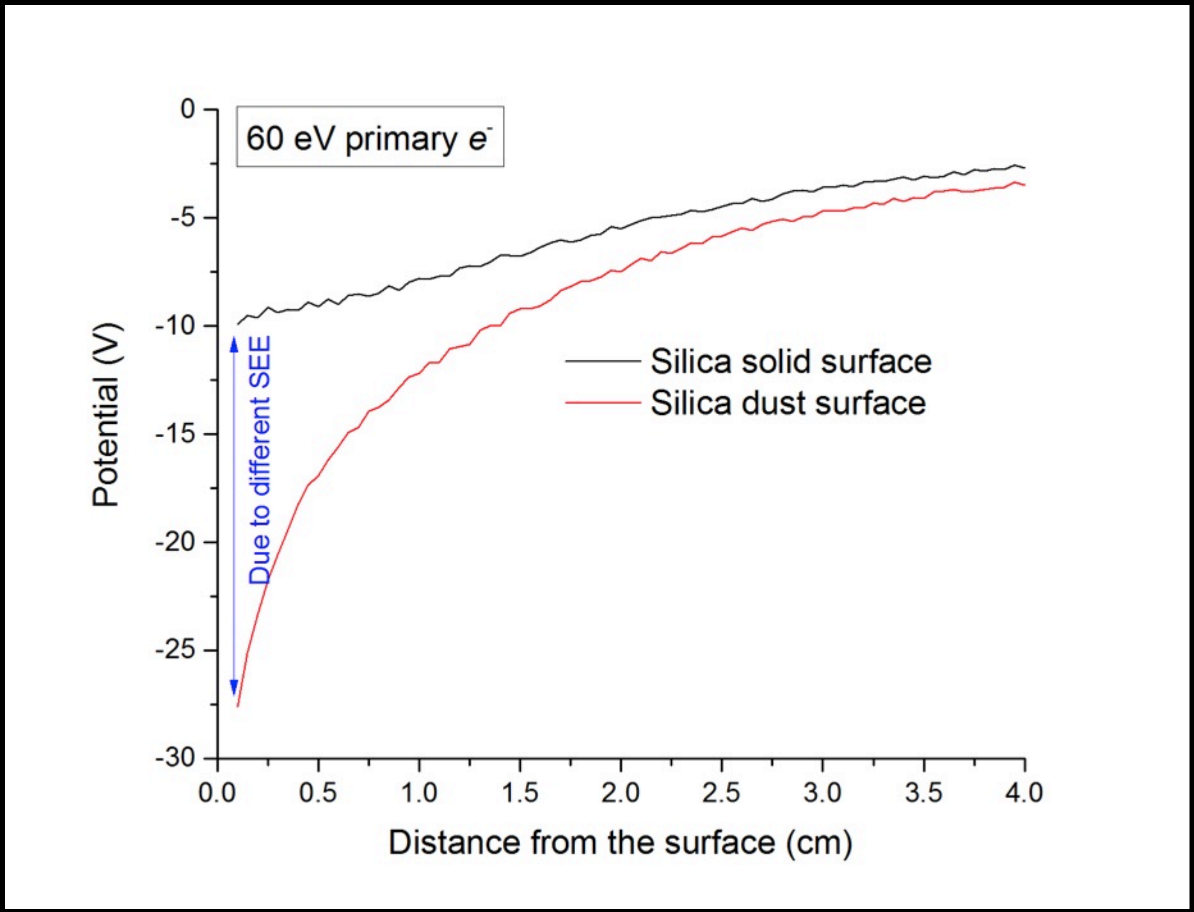
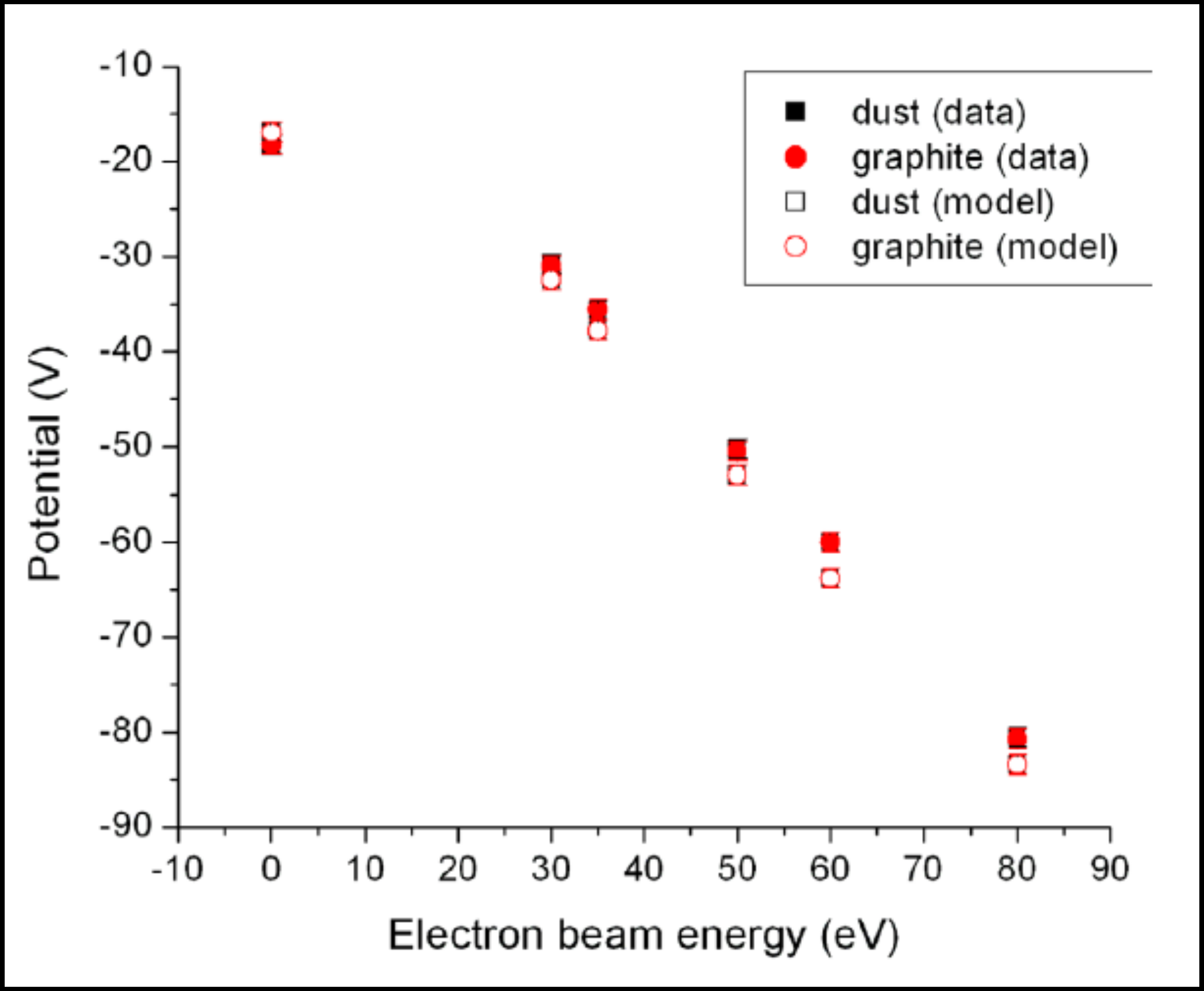
II. Surface potential of silica (SiO_2) dust vs. silica solid surfaces



Potential on dust surface is more negative than on solid surface due to the absorption of emitted SEs by the micro-cavities.



Potential on dust surface as a function of the energy of primary e^- when $J_{pe} >> J_i$.