Electrostatic Dust Transport On Airless Planetary Bodies

Joseph Schwan

Xu Wang, Hsiang-Wen Hsu, Eberhard Grün, Mihály Horányi

Laboratory for Atmospheric and Space Physics (LASP),

NASA/SSERVI's Institute for Modeling Plasma, Atmospheres and Cosmic Dust (IMPACT)

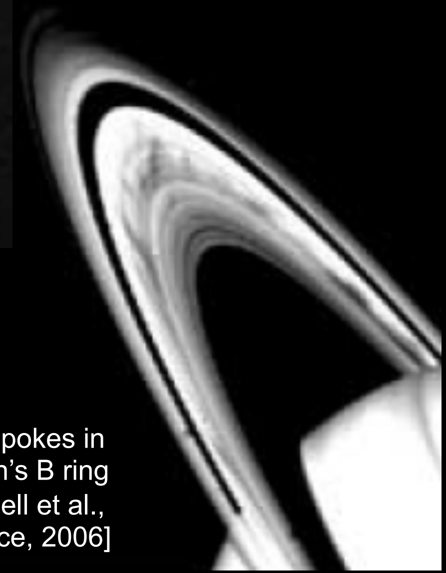
University of Colorado – Boulder

Dust, Atmospheres, and Plasma 2017
January 12, 2017

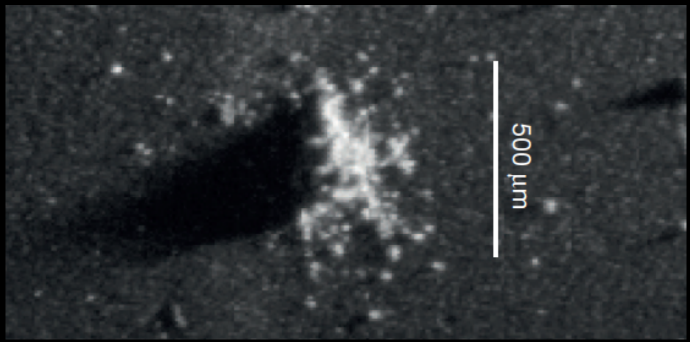
LASP

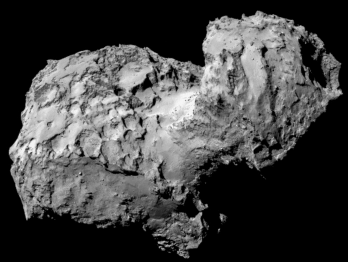
IMPACT

Examples of Spacecraft Observations of Electrostatic Dust Transport

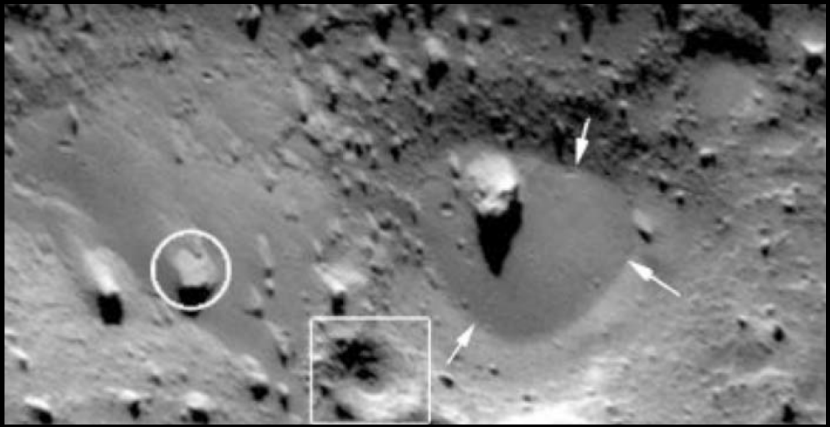


The Spokes in Saturn's B ring [Mitchell et al., Science, 2006]





Dust particles collected by COSIMA from Comet 67P at its relative low activity level [Schulz et al., Nature, 2015]



Dust pond on asteroid Eros [Robinson et al., Nature, 2001]

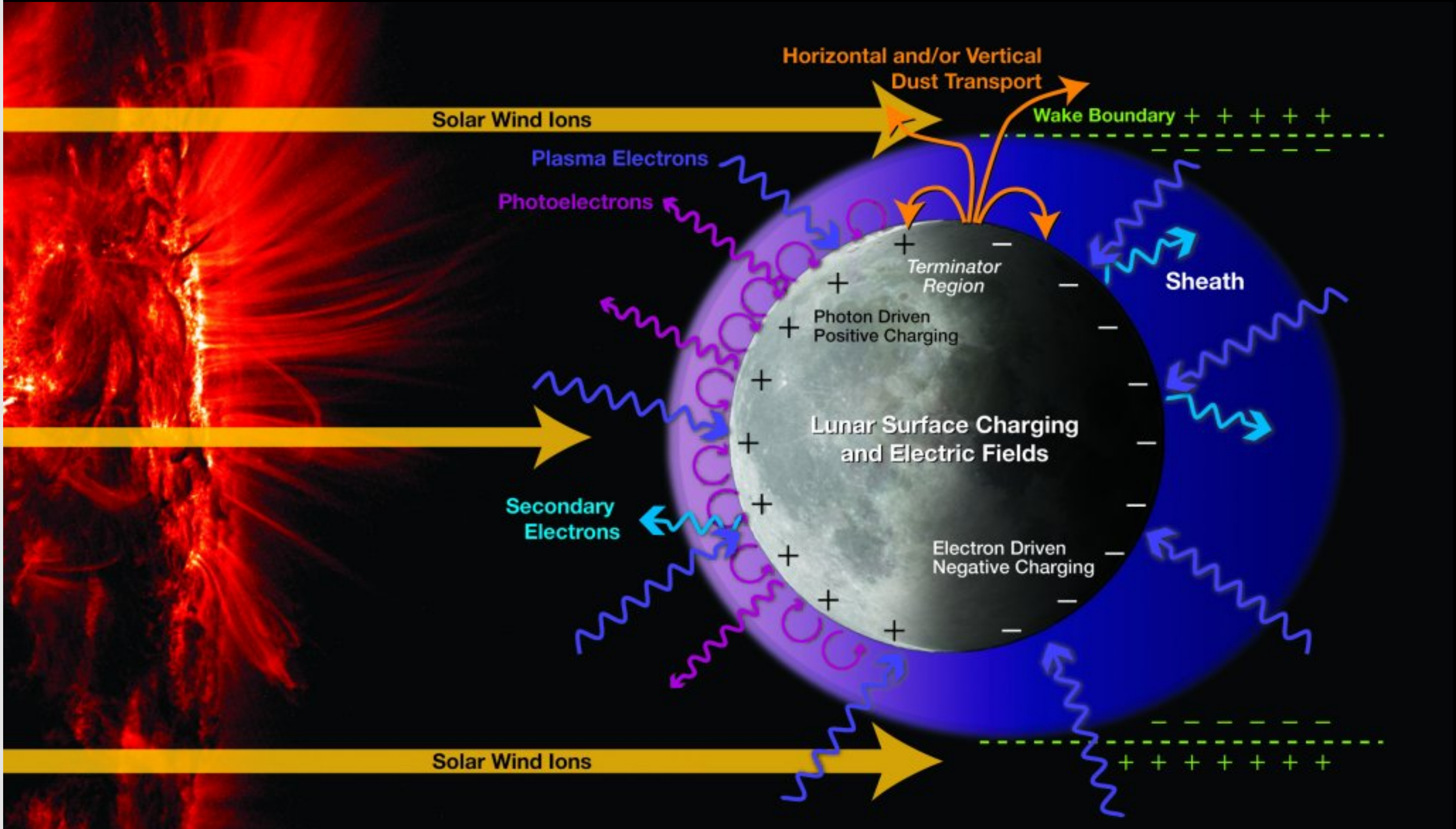
Significance of Electrostatic Dust Transport

Potential to explain:
- Surface morphology
- Surface porosity (thus, thermal inertia)
- Surface materials redistribution
- Space weathering

Uses in human and robotic exploration

Courtesy: Quora

Solar Charging of Airless Bodies



Courtesy: NASA

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

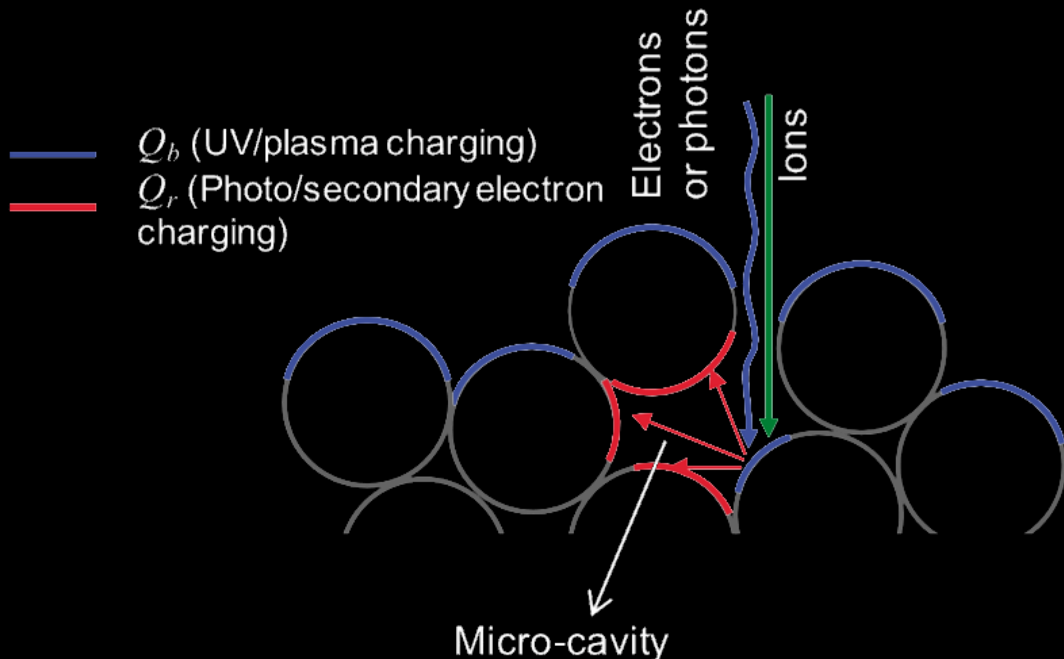
Trajectories of Lofted Dust Particles

[Wang et al., GRL, 2016.]

Exposure to 120 eV electron beam

Dust particles are lofted off the surface under UV, electron beam, or plasma & electron beam conditions, in which photo- or secondary electrons are emitted.

A New “Patched Charge Model”



[Wang et al., GRL, 2016.]

According to Gauss’s law

$Q_b \propto (\square_b - \square_p) / \square_{De}$

$Q_r \propto (\square_r - \square_b) / r$

$Q_r >> Q_b$ due to $r << \square_{De}$

$Q \ \square \ Q_r \ \square \ 0.5C(\square T_{ee}/e)$,

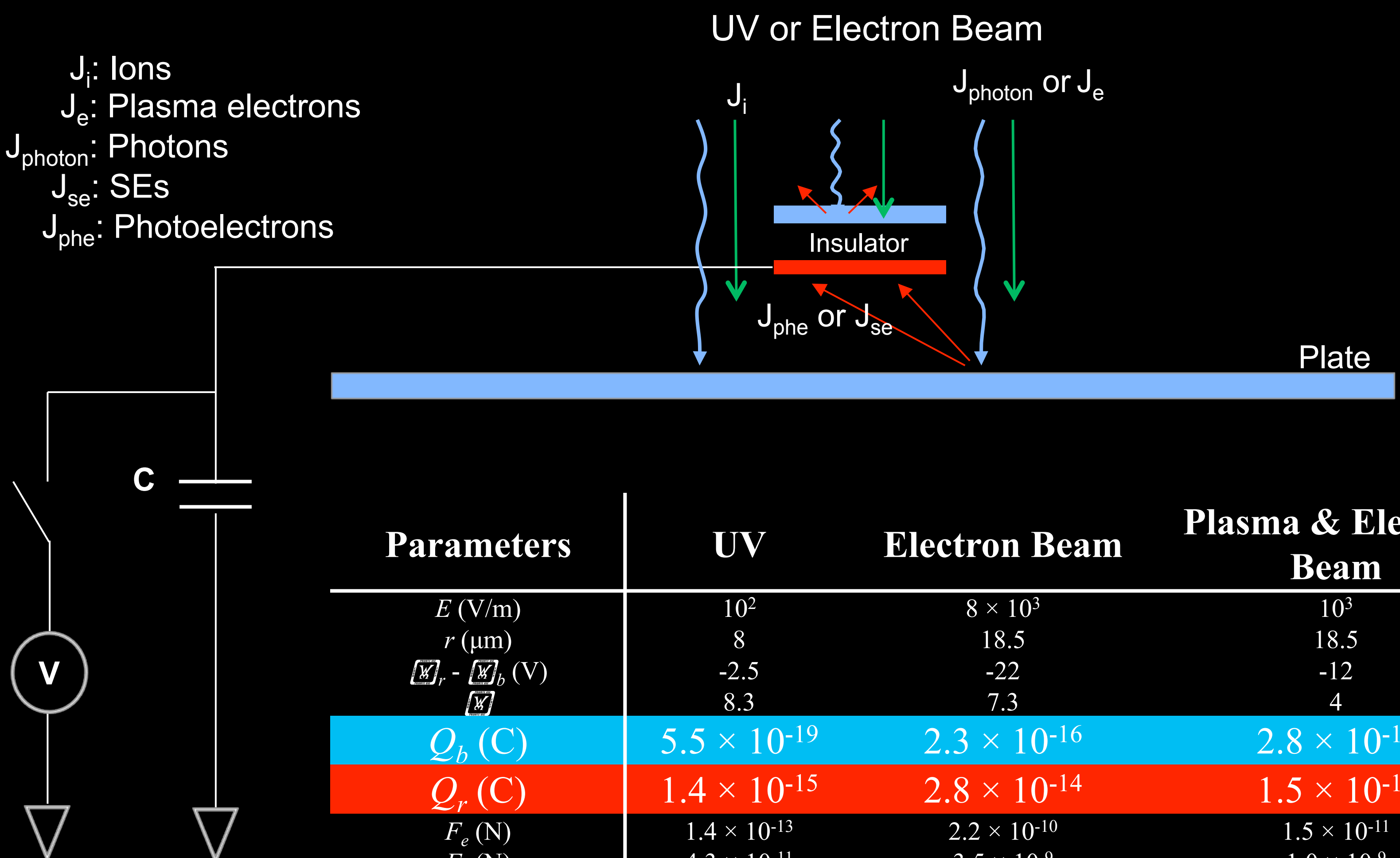
where T_{ee} is the emitted electron temperature;

$C = 4\pi \varepsilon_0 r$;

$\square > 1$ (empirical constant 4 ~ 10).

- Photo- or secondary electrons are absorbed by red surface patches in micro-cavities that are shielded from incoming photons or electrons/ions.
- These red patches have a very negative potential and their closeness ejects them.

Measurements of Surface Patch Potentials

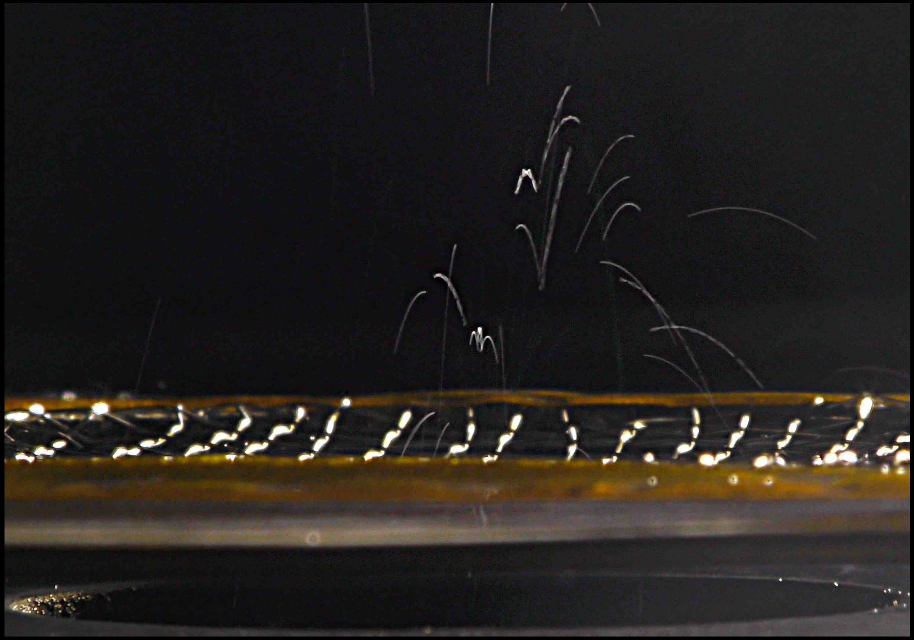


Parameters	UV	Electron Beam	Plasma & Electron Beam
E (V/m)	10^2	8×10^3	10^3
r (μm)	8	18.5	18.5
[illegible]$_r$ - [illegible]$_b$ (V)	-2.5	-22	-12
[illegible]	8.3	7.3	4
Q_b (C)	5.5×10^{-19}	2.3×10^{-16}	2.8×10^{-17}
Q_r (C)	1.4×10^{-15}	2.8×10^{-14}	1.5×10^{-14}
F_e (N)	1.4×10^{-13}	2.2×10^{-10}	1.5×10^{-11}
F_c (N)	4.3×10^{-11}	3.5×10^{-9}	1.0×10^{-9}
F_g (N)	4×10^{-11}	4.9×10^{-10}	4.9×10^{-10}
F_{co} (N)	4.4×10^{-9}	9.9×10^{-9}	9.9×10^{-9}
F_{es} / F_g	**1.1**	**7.5**	**2**

V_{top} (blue patch) is similar to V_{plate}. V_{bottom} (red patch) is negative relative to V_{plate}.

Charge Measurements (Polarity)

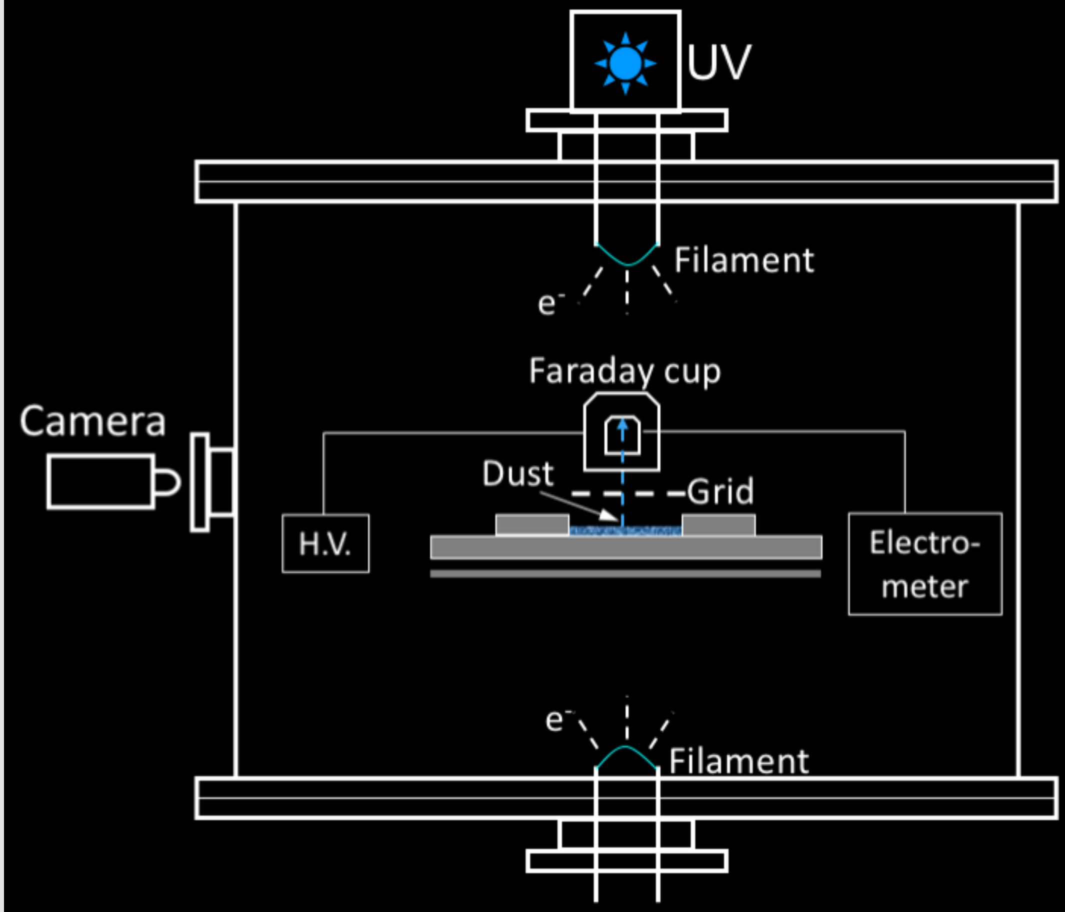
Negative voltage (-3 kV) grid



Positive voltage (+0.5 kV) grid

- Only negatively charged particles are accelerated under UV, electron beam, and plasma & electron beam conditions.
- This result is contrary to the generally expected positive charge due to photoemission but in agreement with our “patched charge model”.

Direct Charge Measurements



Procedure

1. Expose dust particles to UV, electron beam, or plasma & electron beam.

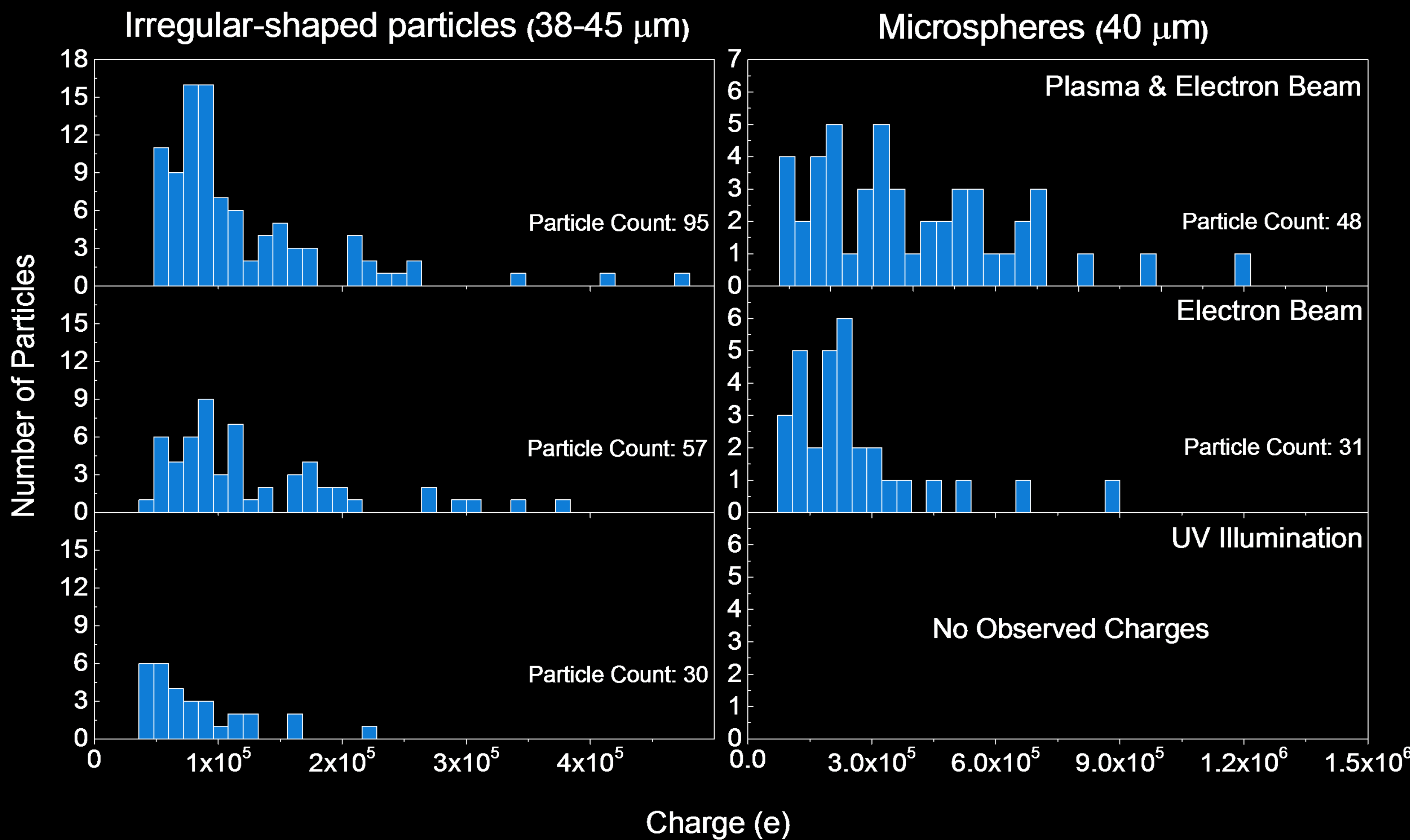
2. Turn off the charging source.

3. Move the Faraday cup above the surface to accelerate charged particles to the cup where their image charges are measured.

* The grid is used as a gate to control when charged dust will be accelerated, and also used for charge polarity measurements.

Both irregular-shaped (Mars simulants) and microspheres (silica) are used in the measurements.

Charge Measurements (Magnitude)

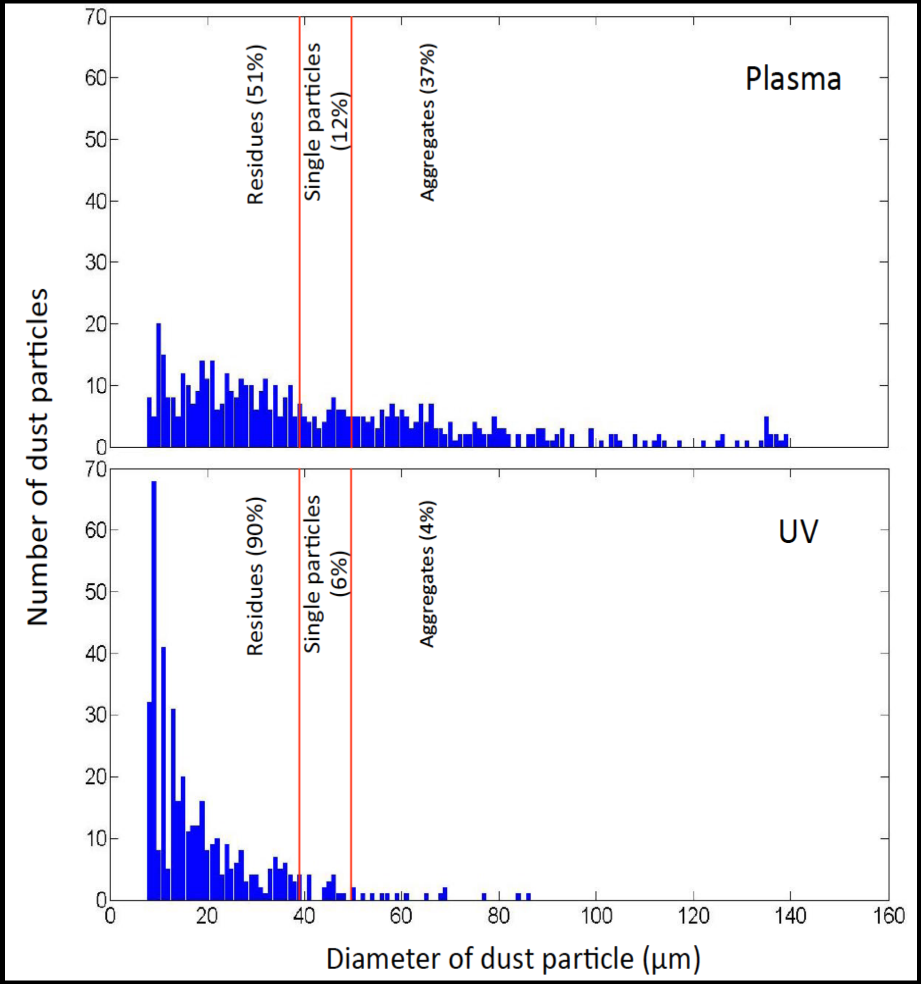


- Broad charge distributions due to broad size distributions of lofted dust [Wang et al., 2016].
- More irregular-shaped particles than microspheres are registered in the Faraday cup.

LASP

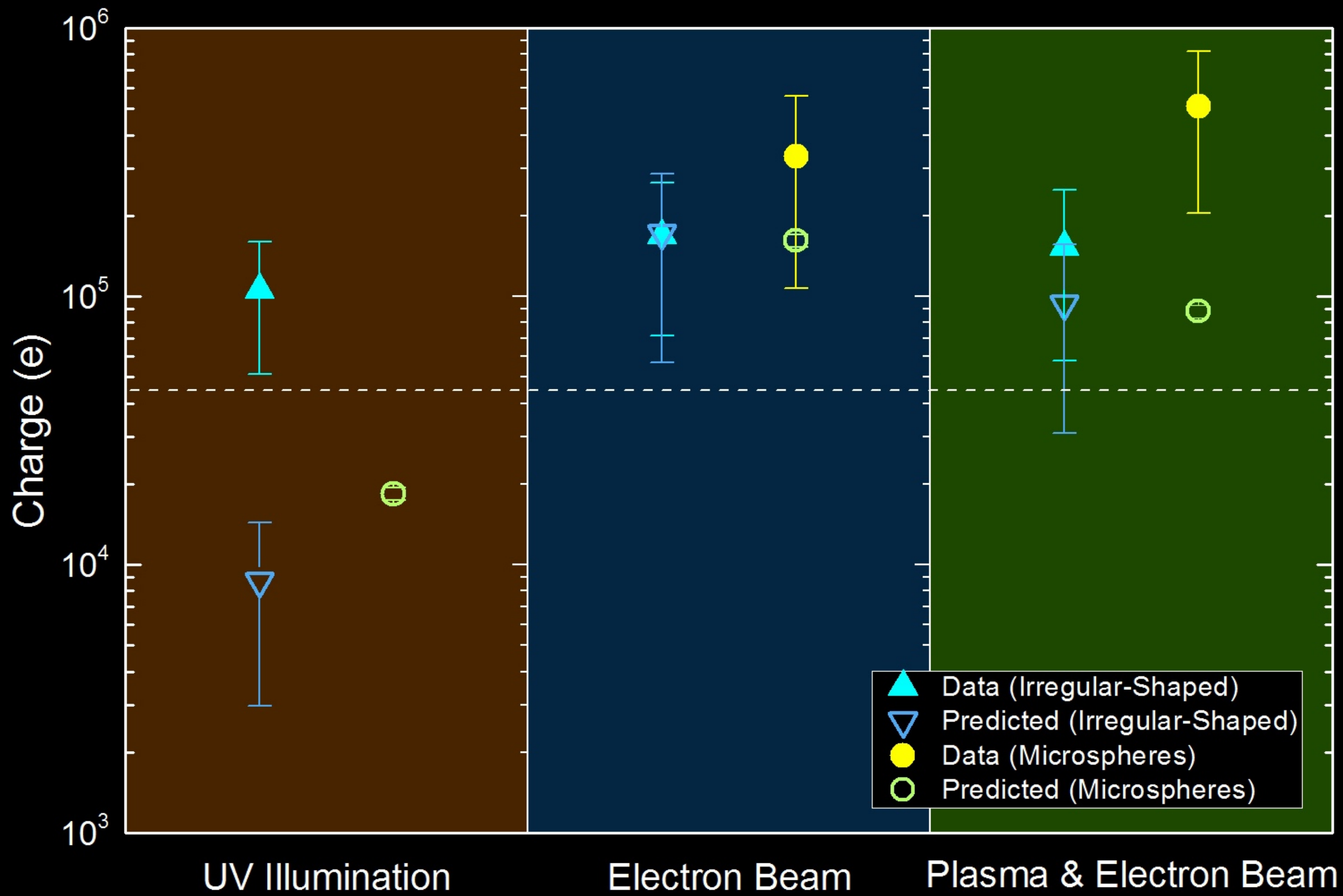
IMPACT

Charge Measurements (Magnitude)



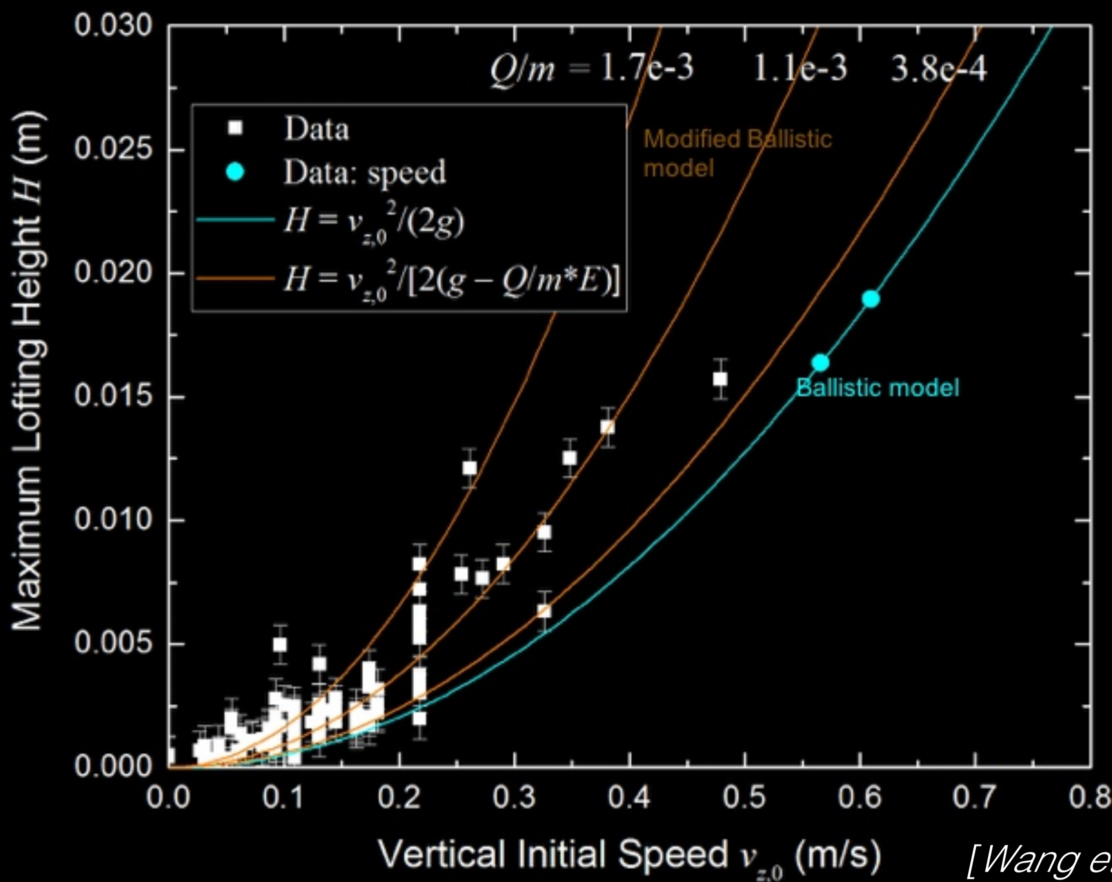
- Broad charge distributions due to broad size distributions of lofted dust [Wang et al., 2016].
- More irregular-shaped particles than microspheres are registered in the Faraday cup.

Charge Measurements (Magnitude)



- Charges estimated from the "patched charge model" are in a same order of magnitude with the measurements.

Lofted Particles Heights and Speeds



- Lofted dust particles with negative charges jump higher than the predicated heights for ballistic trajectories.
- The sheath electric field changes the dust dynamics.

[Wang et al., GRL, 2016.]

Size: < 44 μm in diameter

<u>On Earth:</u> Initial vertical speed: 0.6 m/s, Maximum height: 1.9 cm

<u>On Comet 67P:</u> Maximum height: 1,121 m

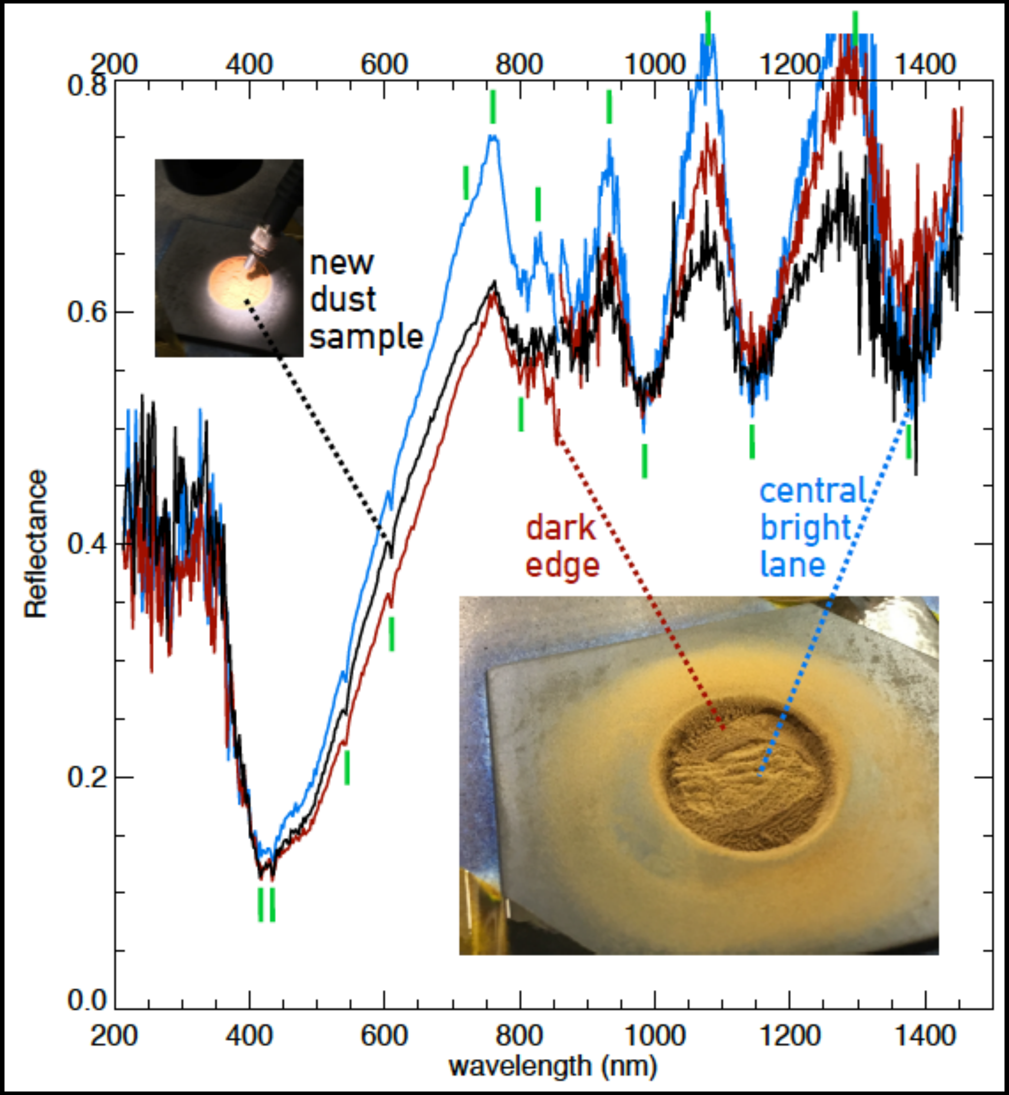
Surface Mobilization of Dust Particles

Mars simulant (38-45 μm) under plasma & electron beam
(1 hour long time lapse)

LASP

IMPACT

Dust Spectra



To understand the effect of surface morphology, porosity and dust size due to electrostatic dust transport on the spectra measurements

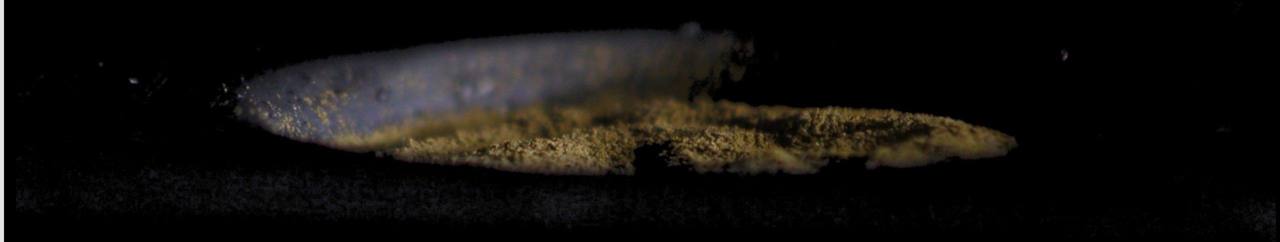
LASP

IMPACT

LASP

Summary and Conclusions

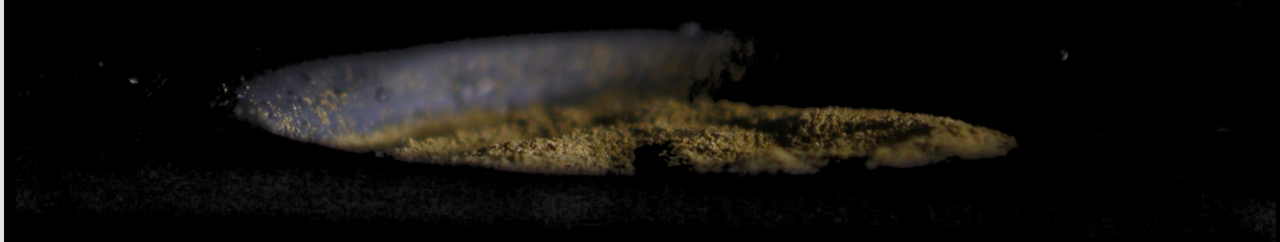
- Direct charge measurements confirmed the predications of our new “patched charge model”.
- Dust particles in part of a dusty surface that emits photo- or secondary electrons can attain net large negative charges, contrary to the generally expected positive charge polarity due to photoemission.
- Initial charging and launch conditions provided from our measurements are critical for dust dynamics studies and have not been well defined in the past.



IMPACT

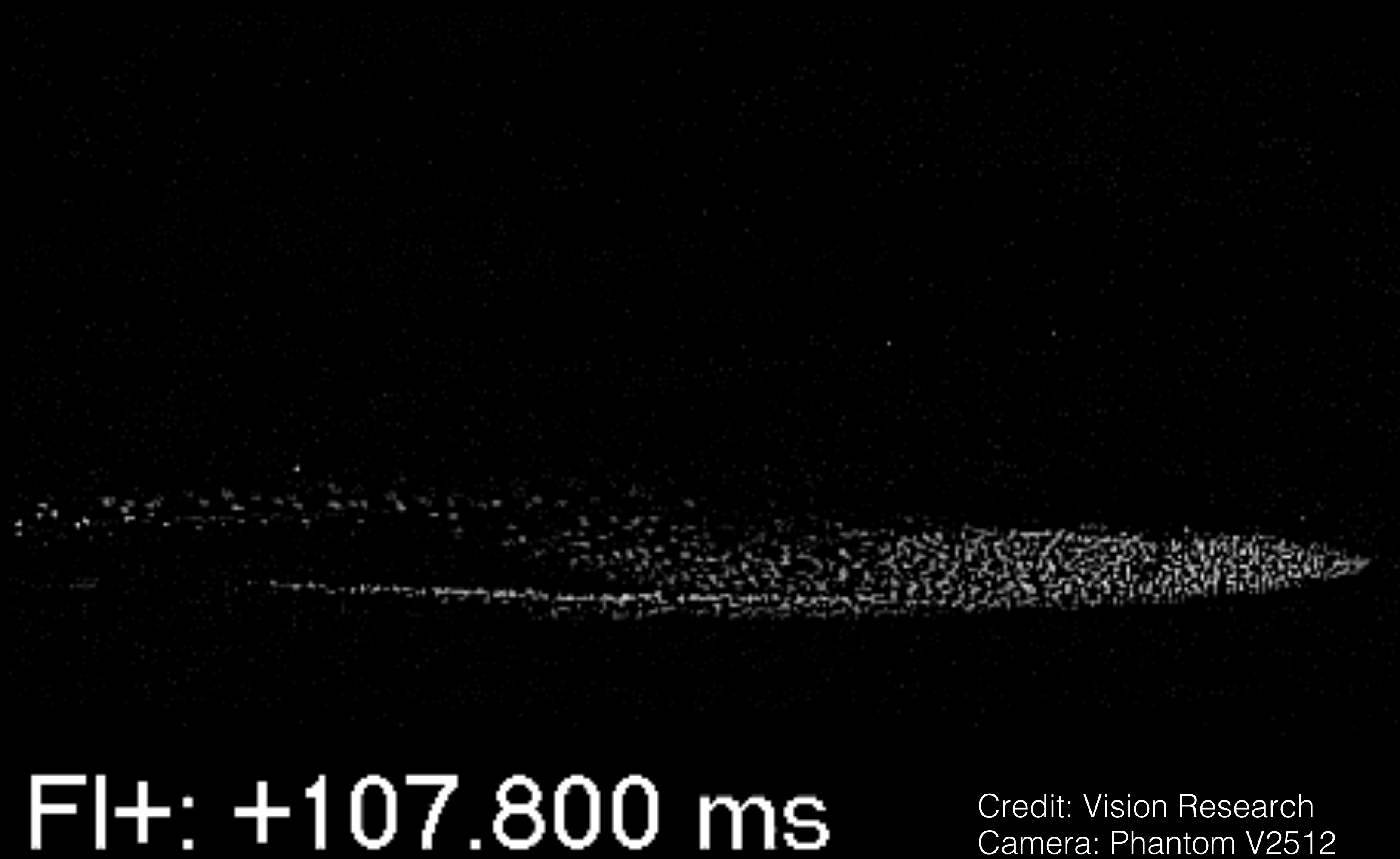
LASP

Questions?



IMPACT

Dust Transport in Electron Beam (120 eV)



Credit: Vision Research
Camera: Phantom V2512

Shooting stars
<u>Size</u>: < 44 μm in diameter; <u>Max. height</u>: 1.5 cm; <u>Vertical launch speed</u>: 0.5 m/s

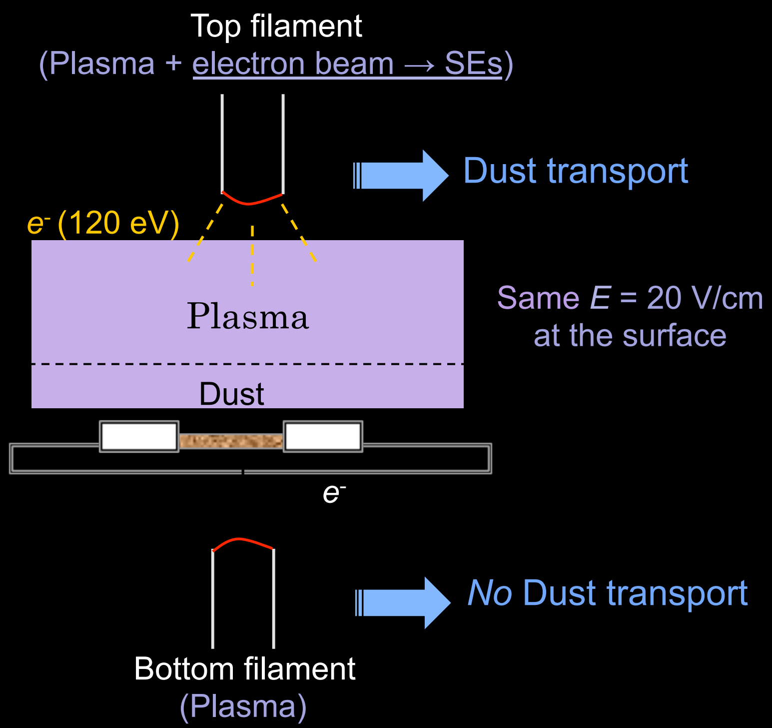
LASP
IMPACT

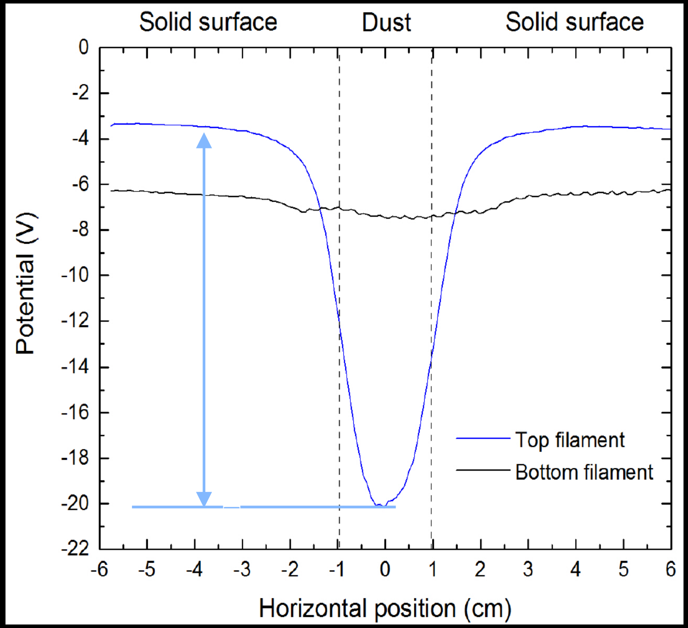
LASP

Backup slides

IMPACT

Charging Mechanisms
(Comparative experiments)

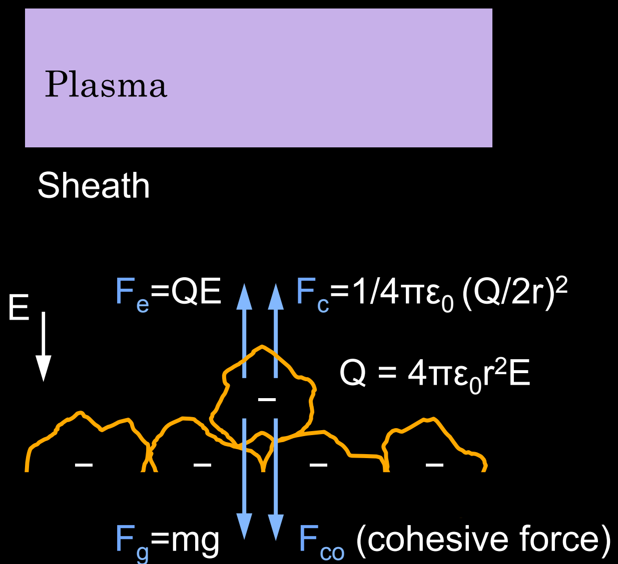




- Sheath electric field force is not a predominant force for dust transport. Secondary electrons (SEs) play a role in dust charging and transport.
- SE emission (SEE) from the dusty surface is smaller than from the solid surface, attributed to the absorption of emitted SEs by neighboring particles.

Examination of Current Charge Models

- Shared charge model (uniform surface charge density)



Case I (Wang et al., 2010)	Case II (Lunar case)
E = 100 V/cm	E = 10 V/m
r = 12.5 μm	r = 5 μm
F_e= 1.7e-12 N	F_e= 2.8e-19 N
F_c = 4.3e-13 N	F_c= 6.9e-20 N
F_g= 1.5e-10 N	F_g= 2.5e-12 N
$F_e+F_c \approx 10^{-2} \cdot F_g$	$F_e+F_c \approx 10^{-7} \cdot F_g$

*Cohesion force is not yet considered

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

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

(Sheridan and Hayes, 2011)

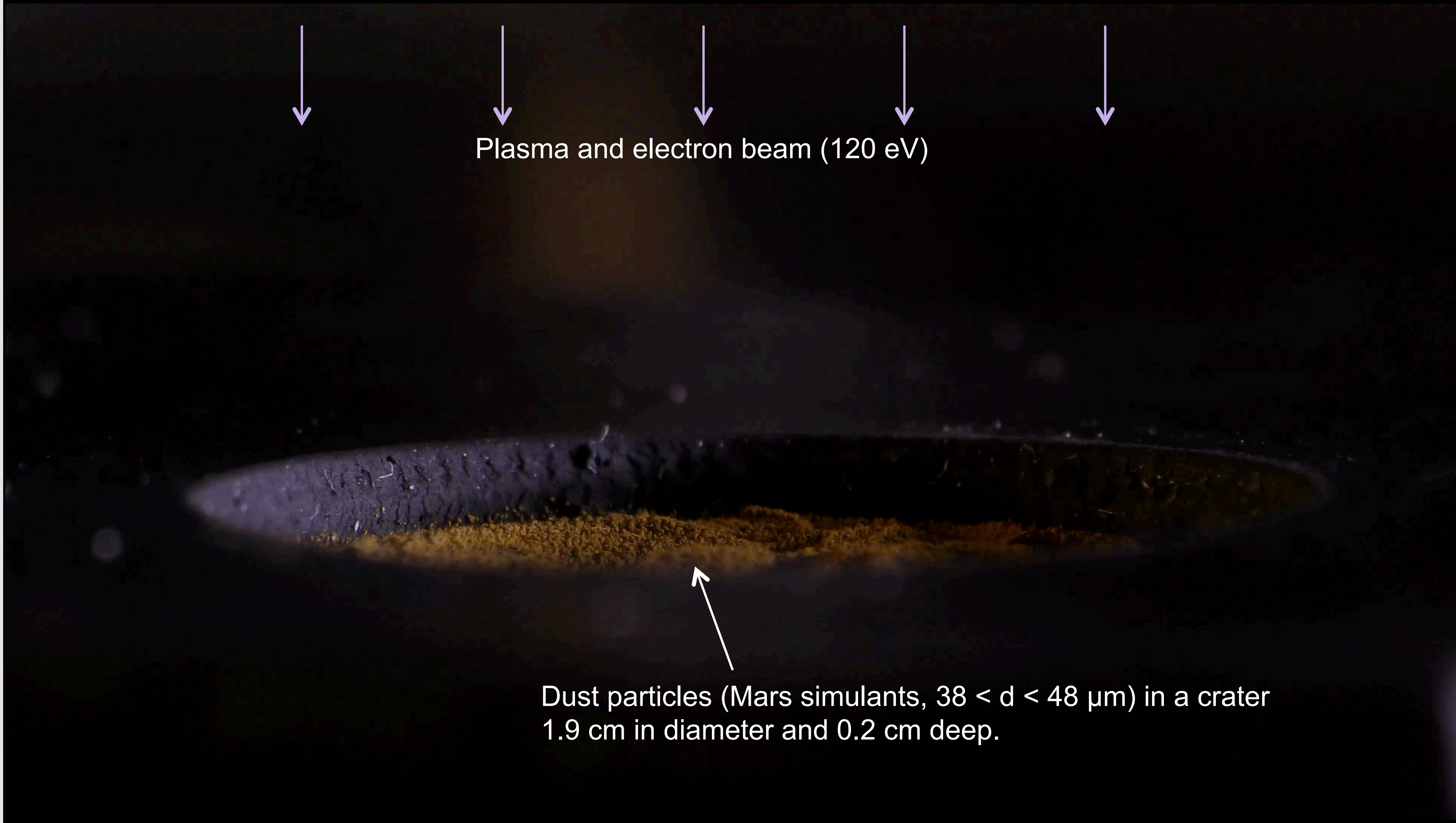
Case I

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.

More Plasma and Electron Beam Dust Experiments

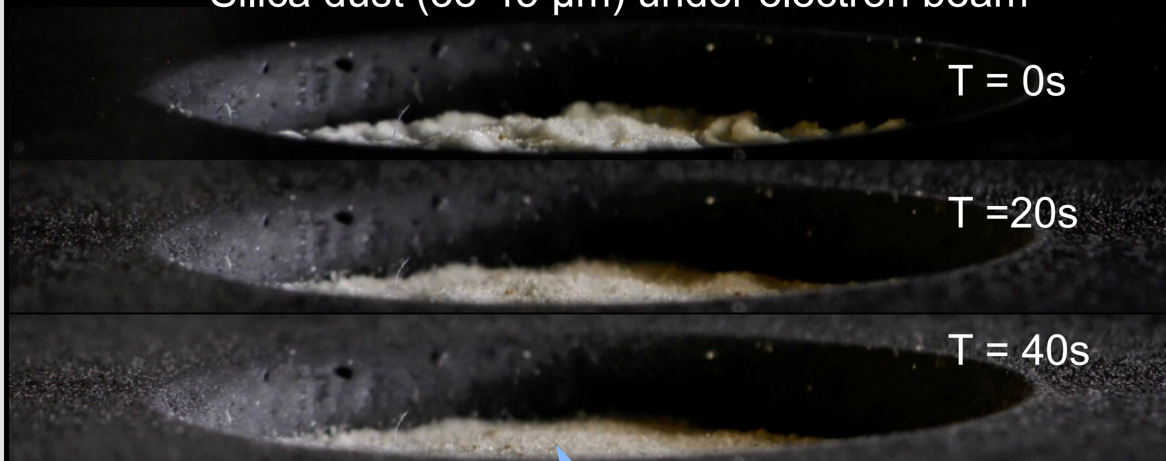


LASP

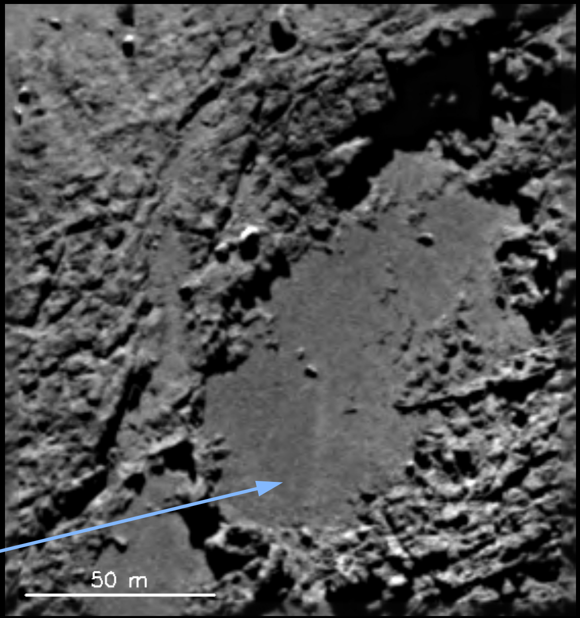
IMPACT

Surface Mobilization of Dust Particles

Silica dust (38-45 µm) under electron beam



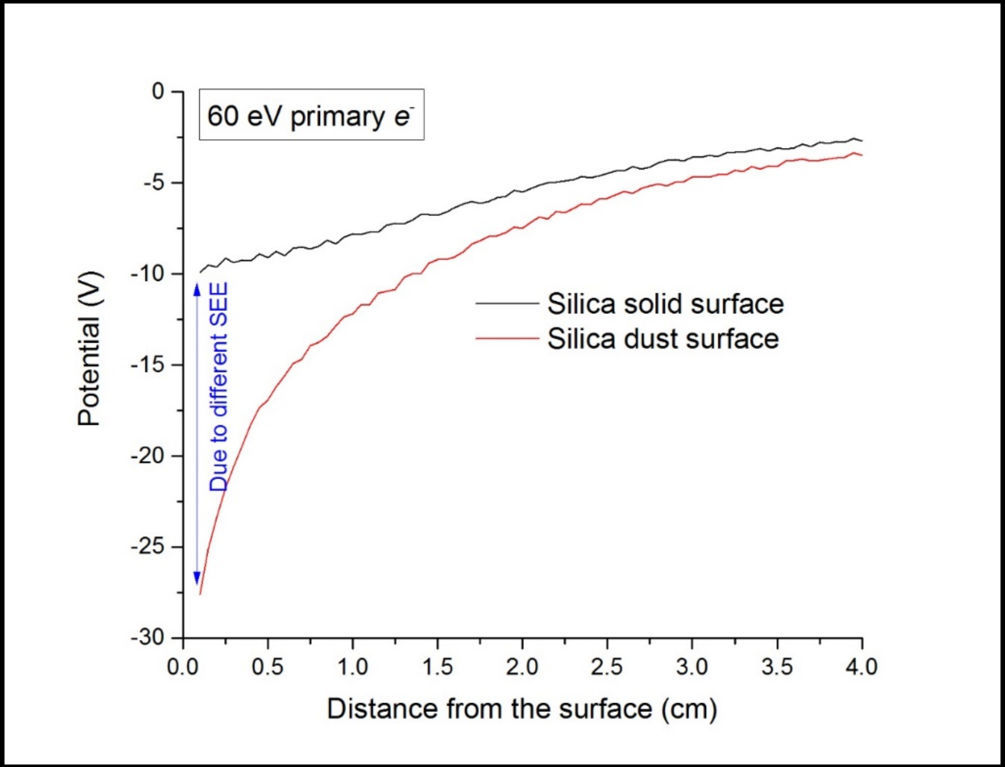
Smoothed surfaces



Ponded dust deposits in Khepry on Comet 67P (Thomas et al., 2015)

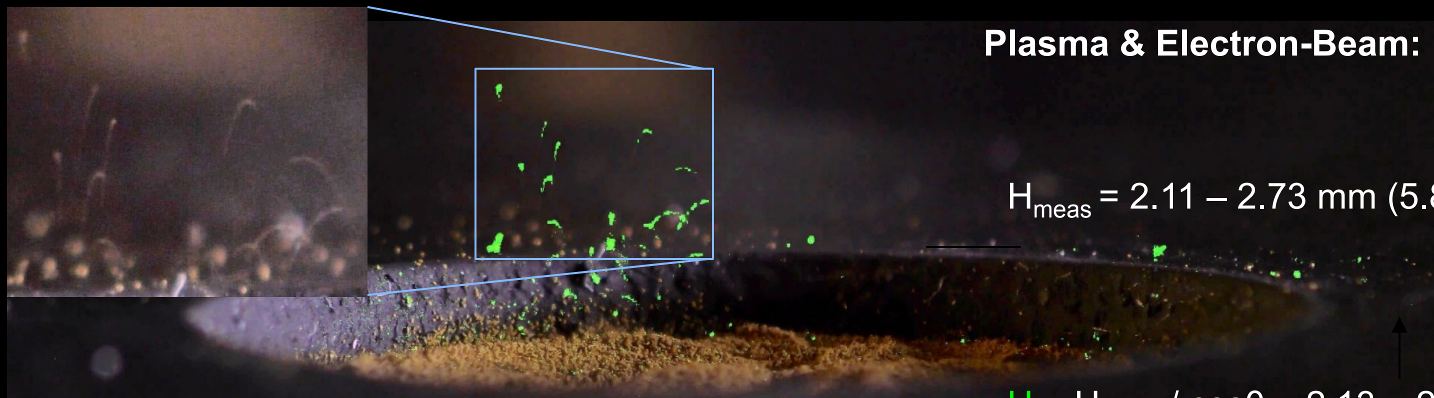
Charging Mechanisms (Micro-cavities)

Potential of silica dust vs. solid surfaces



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

Trajectories of Dust Particles



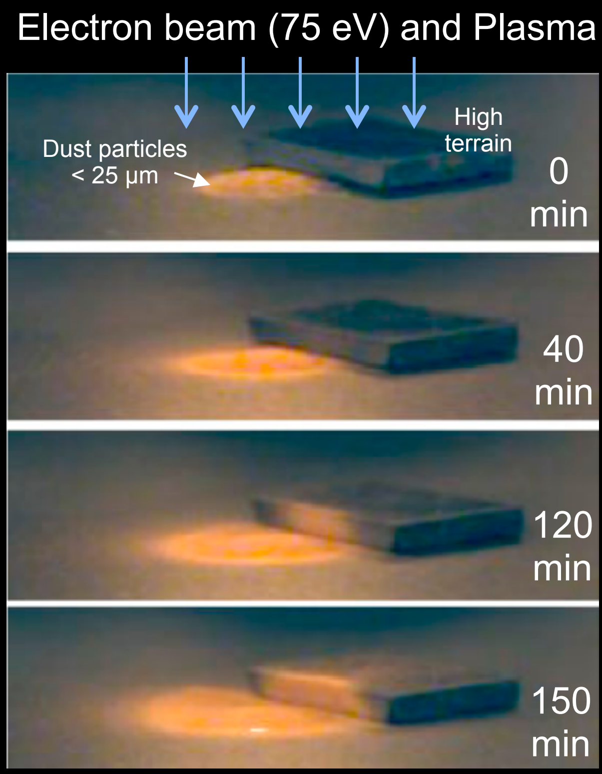
H_{meas} = 2.11 – 2.73 mm (5.85 μm/pixel)

$H = H_{meas} / \cos\theta$ = 2.13 – 2.75 mm
where, $\theta \sim 7.24°$ (View angle)
$v_{z,0} = (2gH)^{1/2}$ = 20.3 – 23.2 cm/s

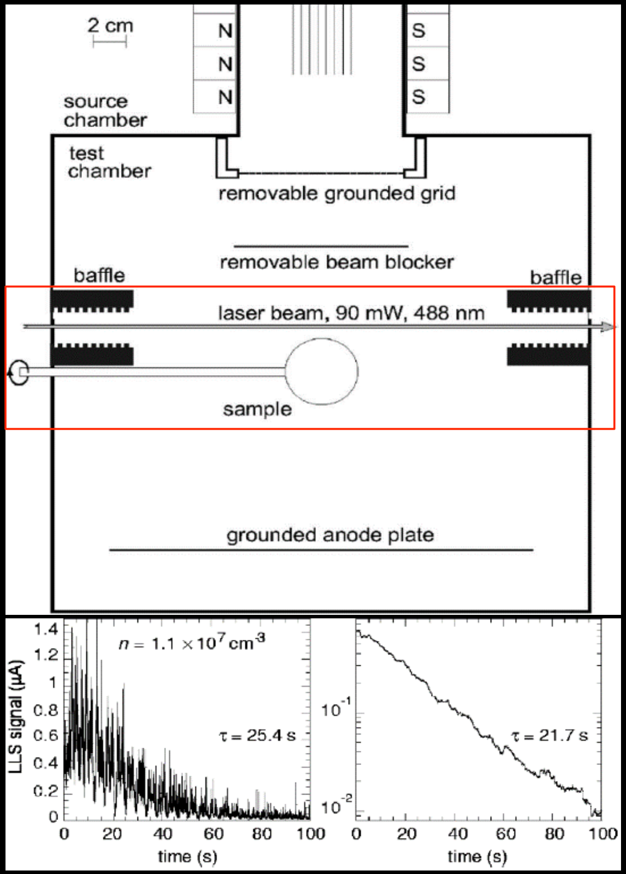
Lunar horizon glow (Rennilson and Criswell, 1974; Colwell et al., 2007)

Our measurements on the Earth
Particle diameter < 44 μm
H ≥ 0.025 m
$v_{z,0} = (2gH)^{1/2}$ and $g_{moon} = 1/6\ g_{earth}$
$H_{moon} \geq 0.15$ m

Previous Laboratory Dust Transport Experiments
(Two Examples)



Wang et al., 2010



Flanagan and Goree, 2006

What are the charging mechanisms?
How big are the electrostatic forces?

Comments & Implications

- Micron-sized insulating dust particles are recorded to jump to several centimeters high with an initial speed ~ 0.5 m/s under ultraviolet (UV) illumination or exposure to plasmas in laboratory.
- The interactions of the insulating dusty surface with UV radiation and/or plasmas are a **volume effect**, contrary to current charge models that only consider the interacting surface as a plane boundary.
- The emission and re-absorption of **photo- and/or secondary electrons** at the walls of **micro-cavities** formed between neighboring dust particles below the surface are responsible for generating unexpectedly large charges.
- **Repulsive (Coulomb) force** between dust particles, rather than sheath electric field force, is a dominant force to mobilize and lift dust off the surface.

- On the dayside surface, photoelectrons play the role. Due to much shorter UV wavelengths (i.e., higher photon energy) in space than in our laboratory, high-energy photoelectrons (> 10 eV) are expected, leading to even more negative charge on dust particles that form micro-cavities.
- On the nightside surface, secondary electrons play the role. Secondary electron emission from the nightside lunar surface [Halekas et al., 2009] was observed ~ 3 times smaller than that measured from a single lunar dust particle in laboratory [Horányi et al., 1998], indicating the absorption by micro-cavities.