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Plasma Physics of the Lunar Surface

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Symposium: “Prof. P.K. Shukla 60th Birthday

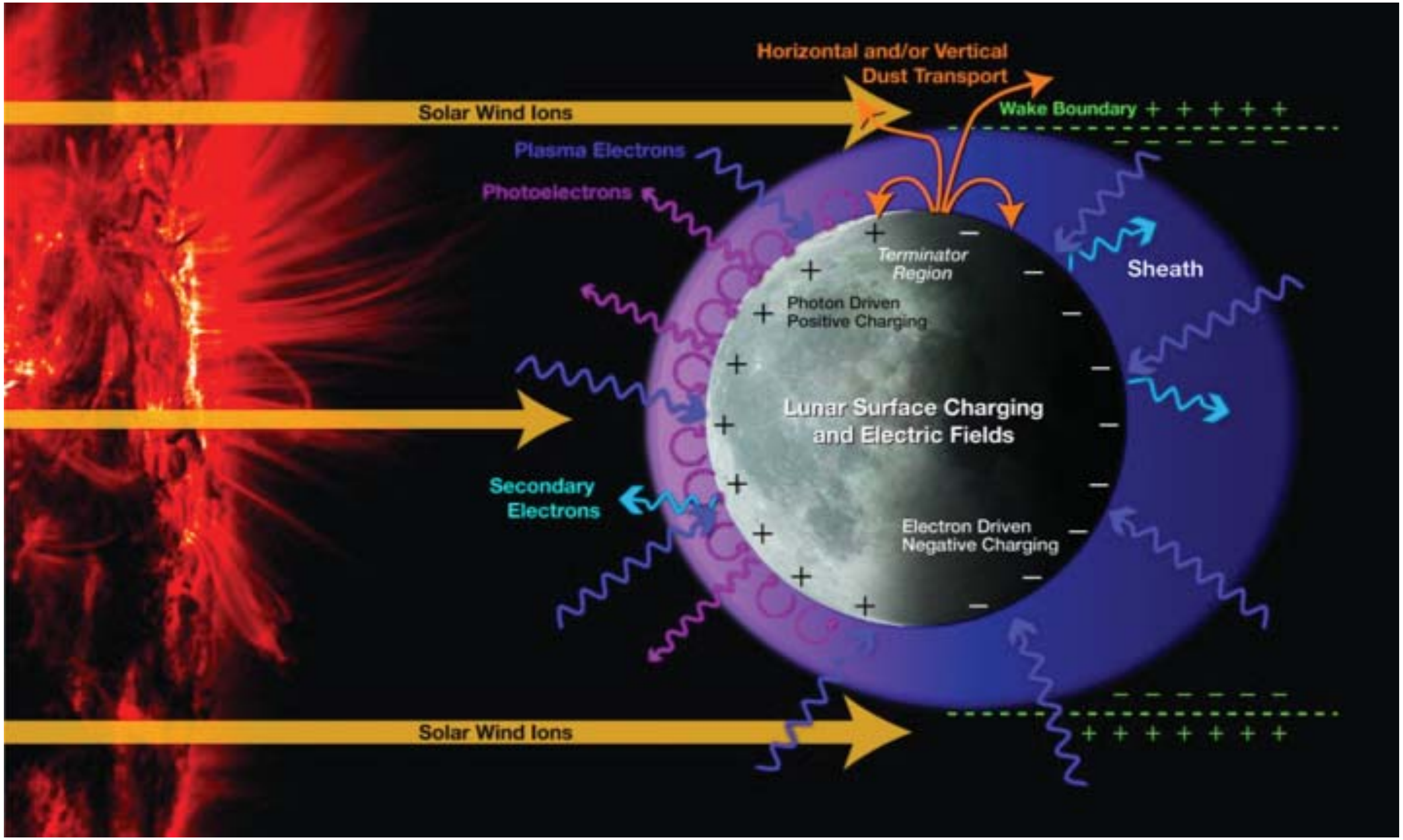
Outline

- Plasma Environment at the Moon

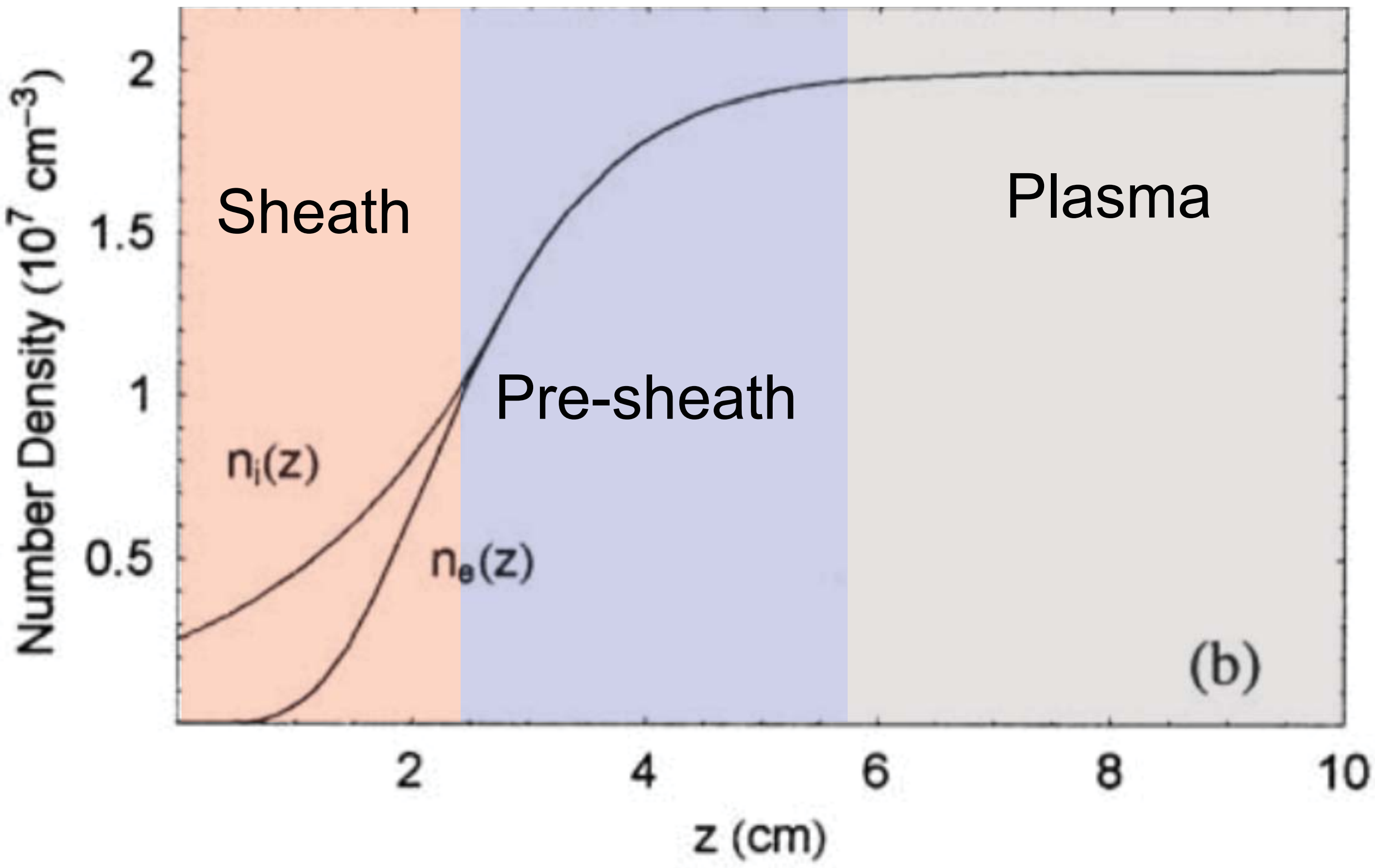
- Sheaths
  - *In-situ* Observations
  - Theory and Modeling
  - Laboratory Experiments

- Future Measurements

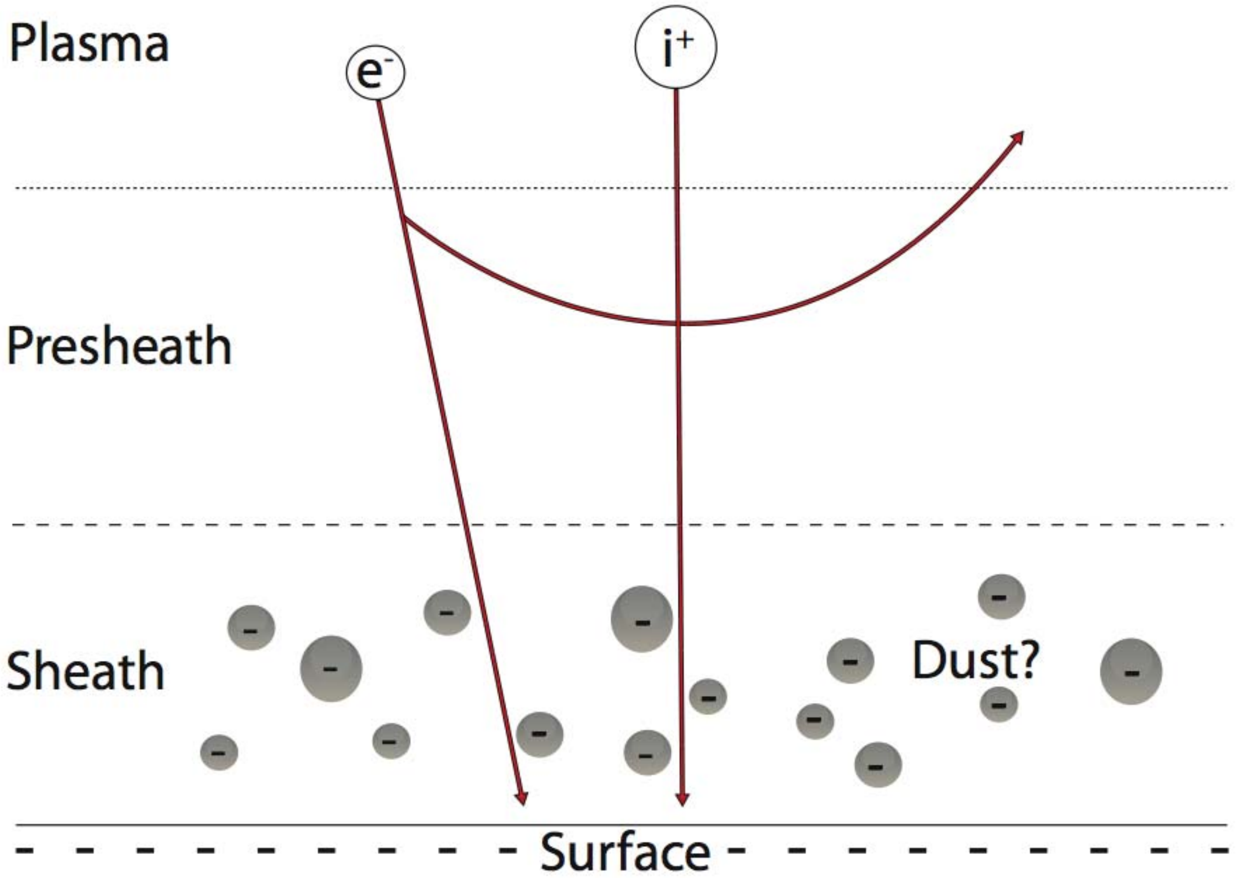
Lunar Plasma Environment



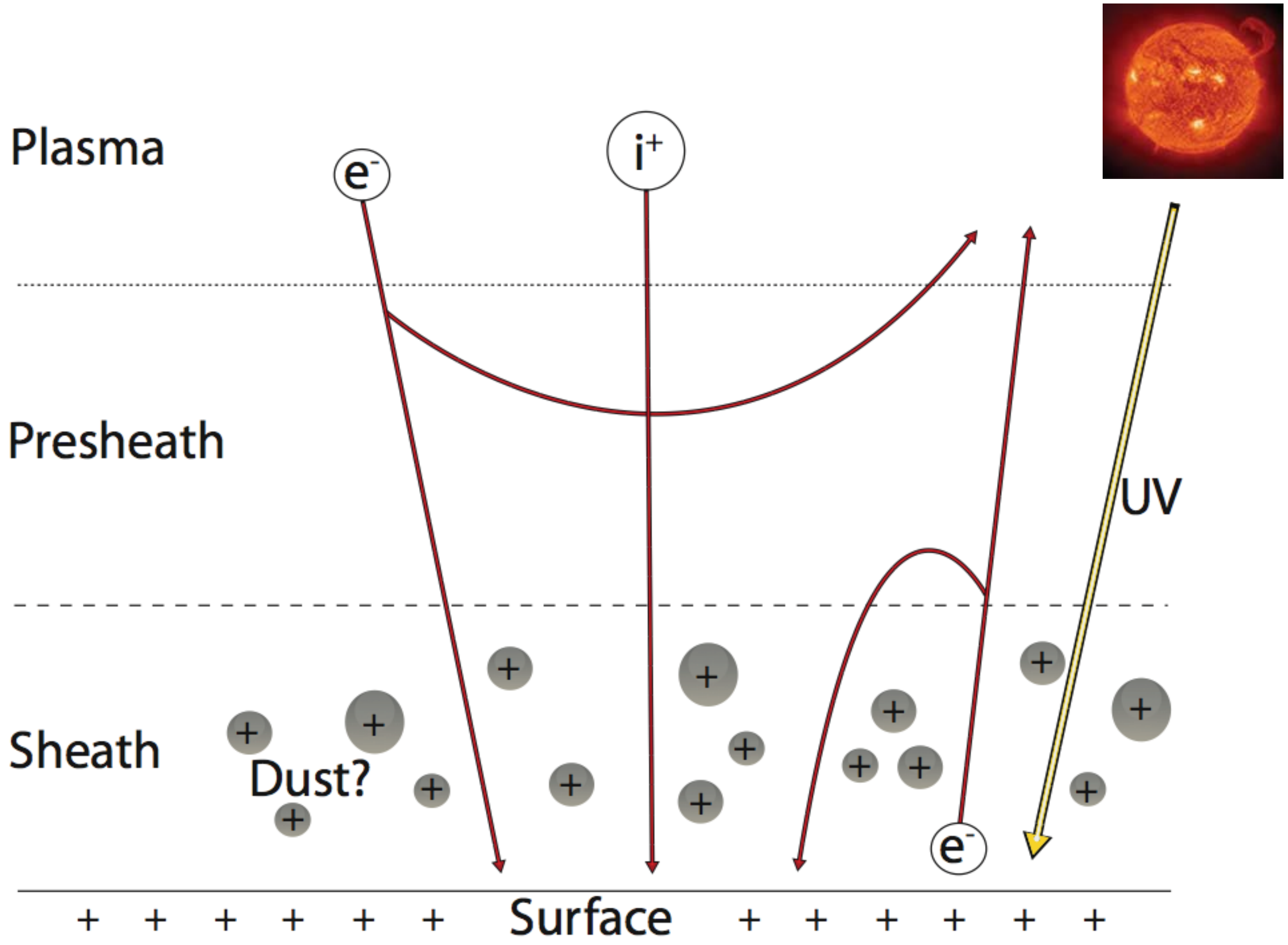
Plasma Sheaths



Plasma Sheaths - Nightside



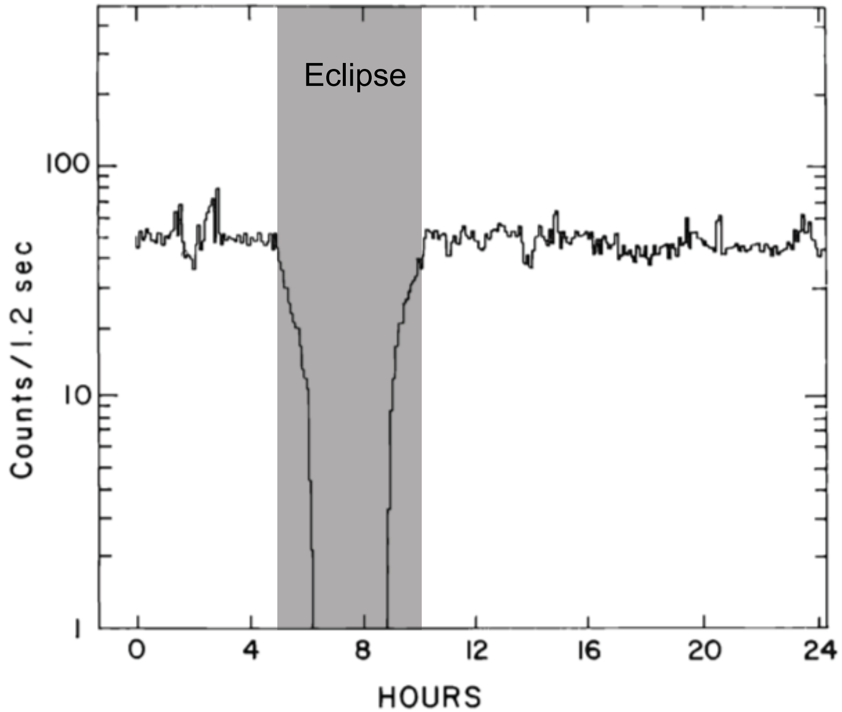
Photoelectron Sheaths - Dayside



Observations

In-situ Observations

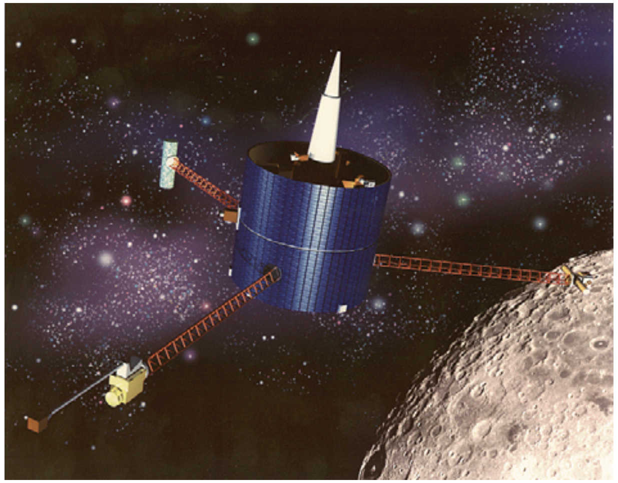
- Measurement of the photoelectron sheath



Reasoner and Burke, 1972

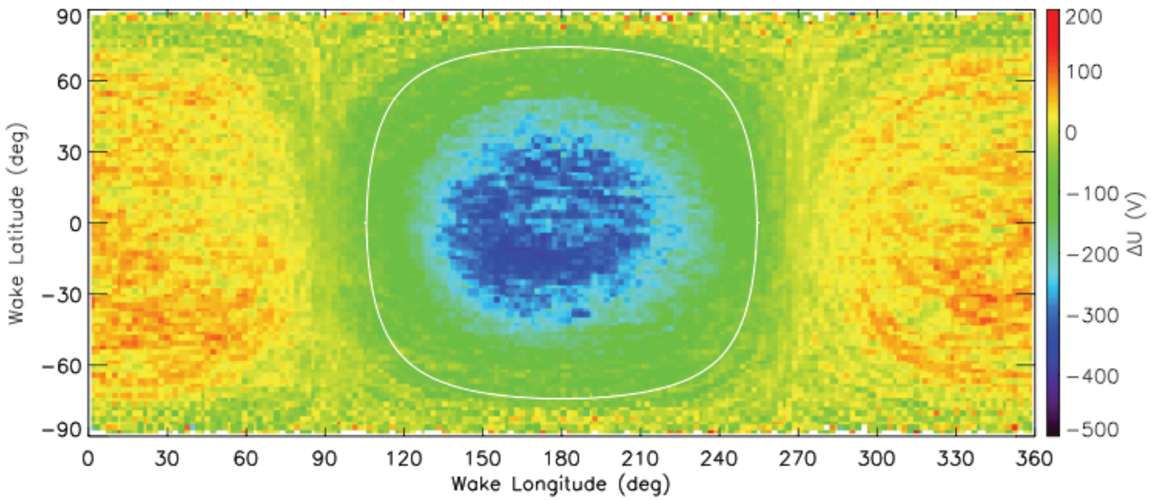
- Charged Particle Lunar Environment Experiment (CPLEE)
  - Deployed by the Apollo 14 astronauts
  - Only able to measure electrons, 40 eV to 50 keV
  - Some evidence of a photoelectron layer but can't measure the low-energy electrons

Lunar Plasma Observations



- Lunar Prospector - Electron Reflectometer
  - ER measured electrons reflected from the lunar surface
  - Able to extrapolate surface potential values

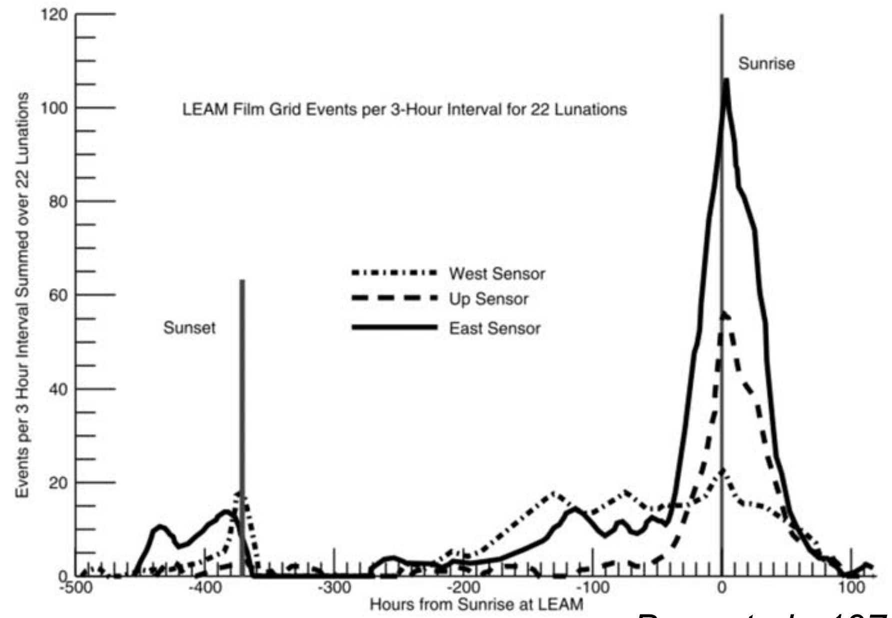
- Lunar Surface potential decreases dramatically behind the wake
  - More mobile electrons reach the surface more easily than the ions
  - Leads to negative charging on the lunar nightside



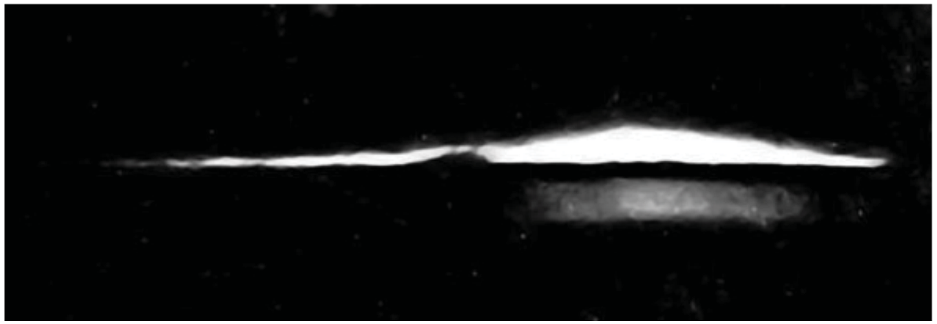
Halekas et al., 2005

Lunar Dust Observations

- Lunar Ejecta and Meteorites Expt. (LEAM)
  - Large number of counts near sunrise interpreted as slow-moving, horizontally transported dust particles
  - Charging and transport due to horizontal electric fields?



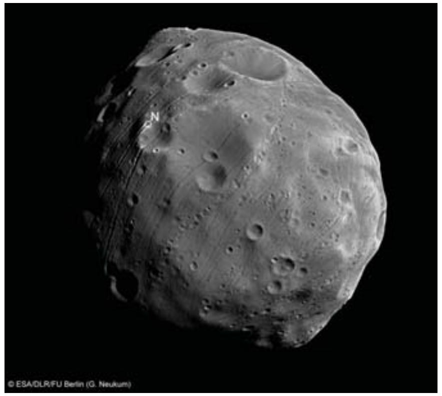
Berg et al., 1976



Colwell et al., 2005

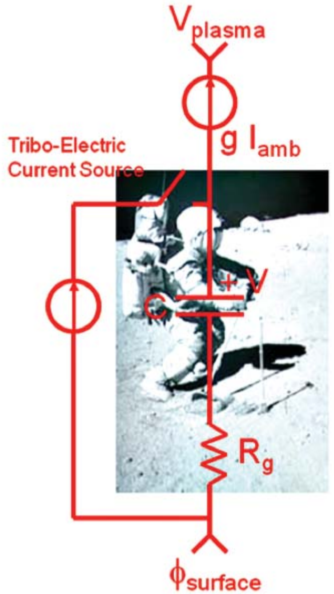
- Horizon Glow
  - Forward scattering of solar light detected by *Surveyor* spacecraft
  - Possibly levitated dust particles
    - ~ 6 μm in radius [*Rennilson & Criswell, 1973*]

Why should we study this?



- Fundamental physics and applications to other bodies
  - Plasma interaction with an unmagnetized body
    - Surface-bounded exospheres
  - Mercury, Phobos, Deimos, asteroids

- Human exploration of the Moon
  - Need to understand object (ie. astronaut!) charging

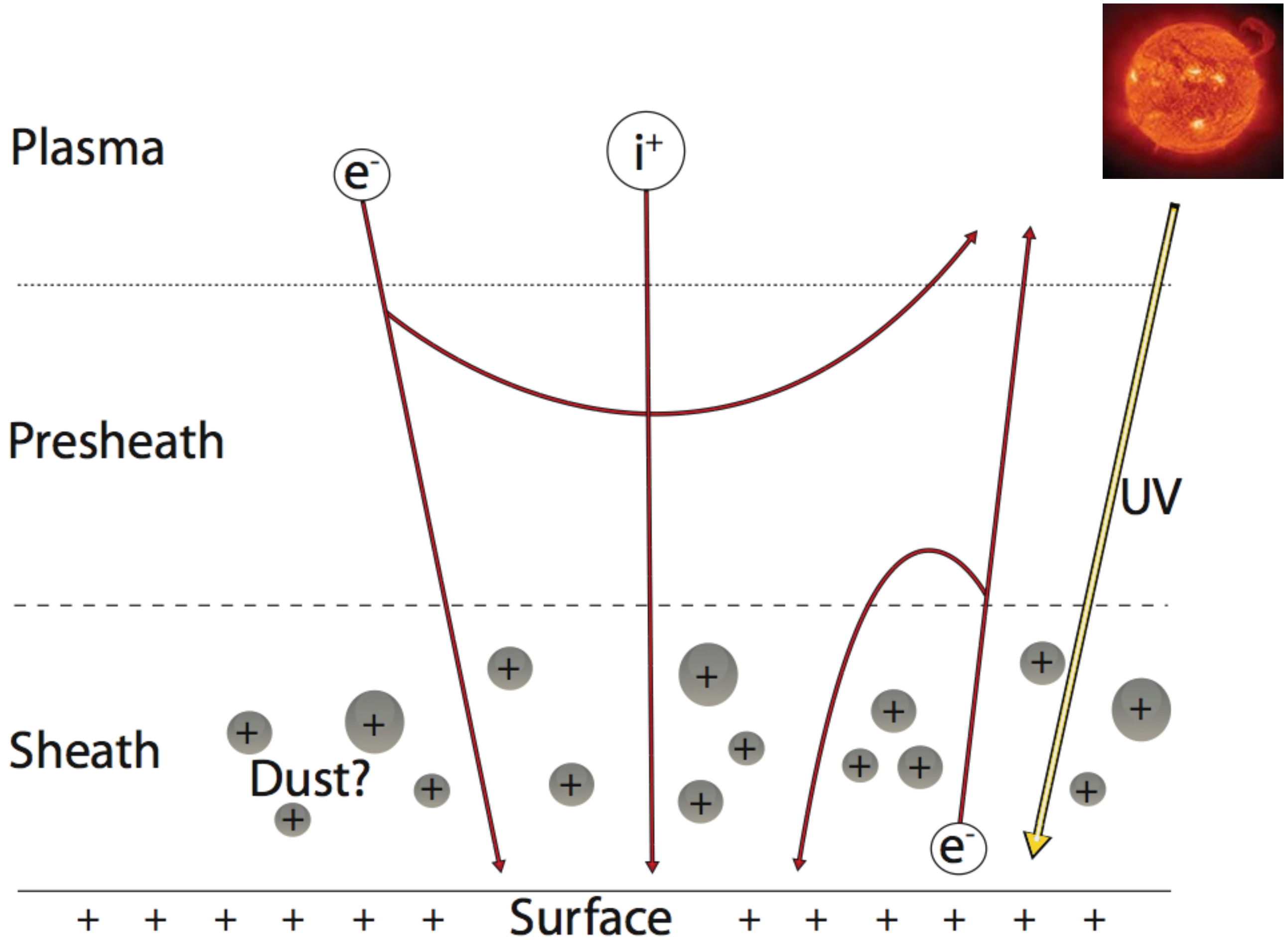


Farrell et al., 2008

- "*Dust - I think probably one of the most aggravating, restricting facts of lunar exploration is dust and its adherence to everything, no matter what kind of material…*" - E. Cernan, Apollo 17

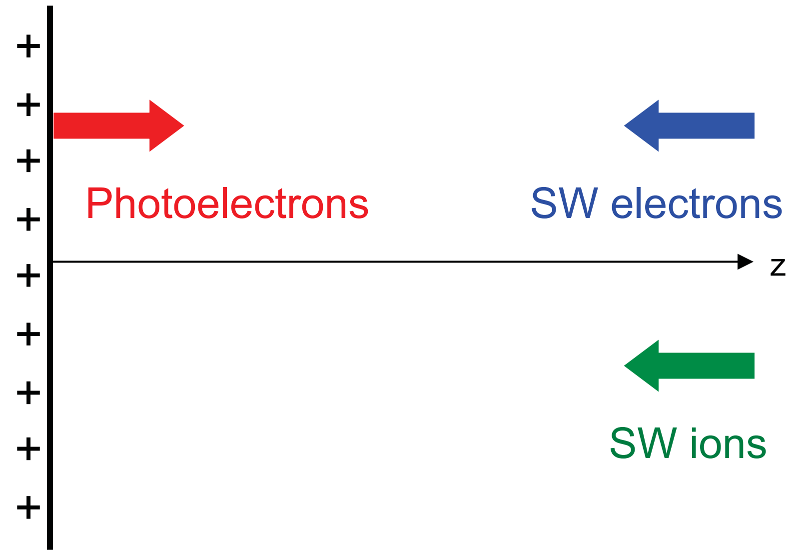
Theory and Modeling

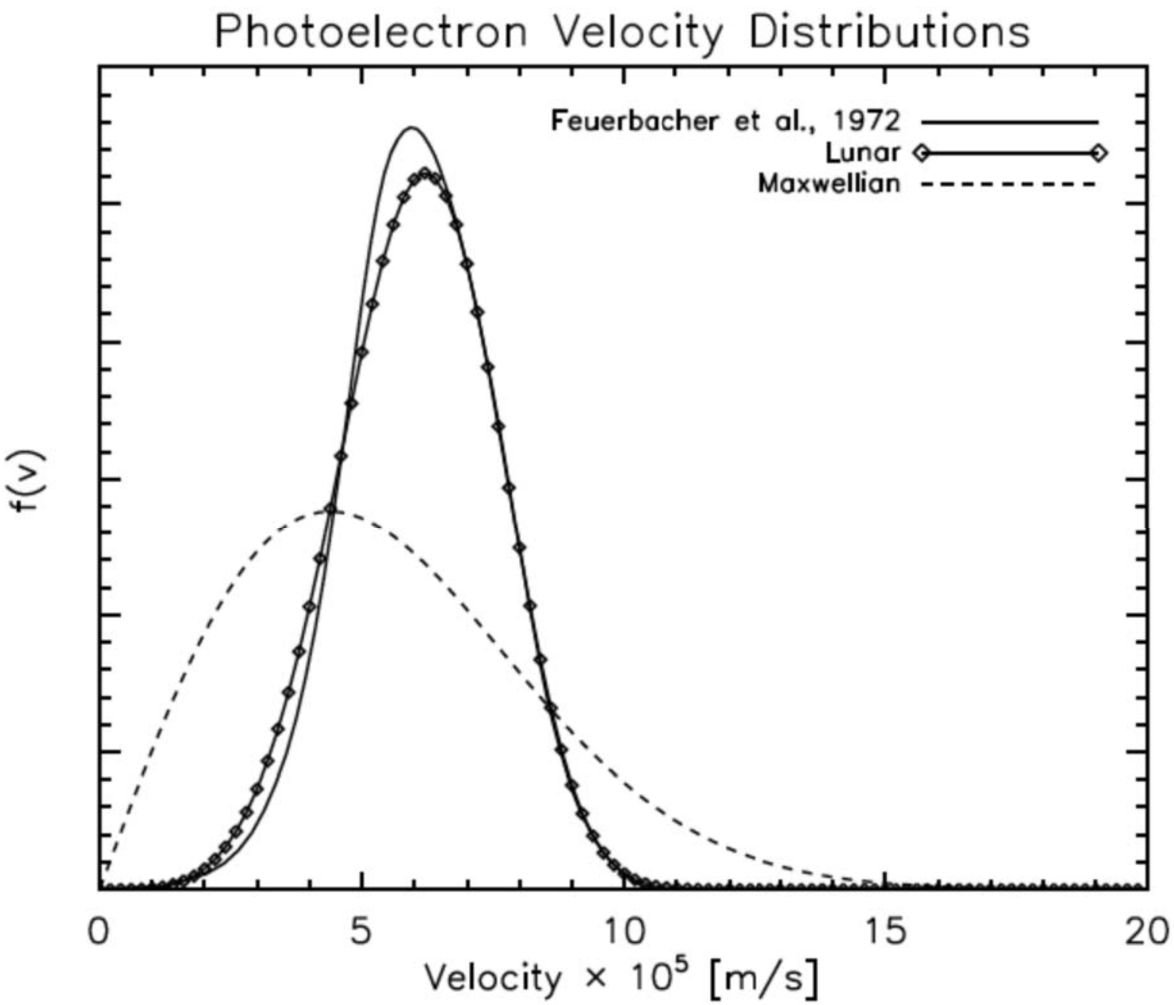
Photoelectron Sheaths - Dayside



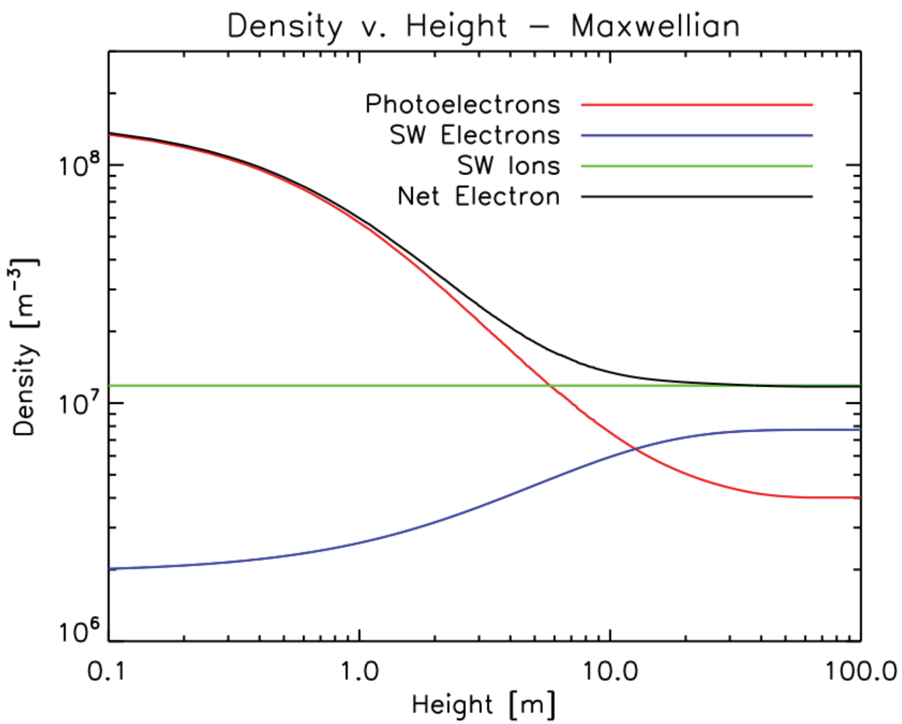
Particle-in-Cell Model

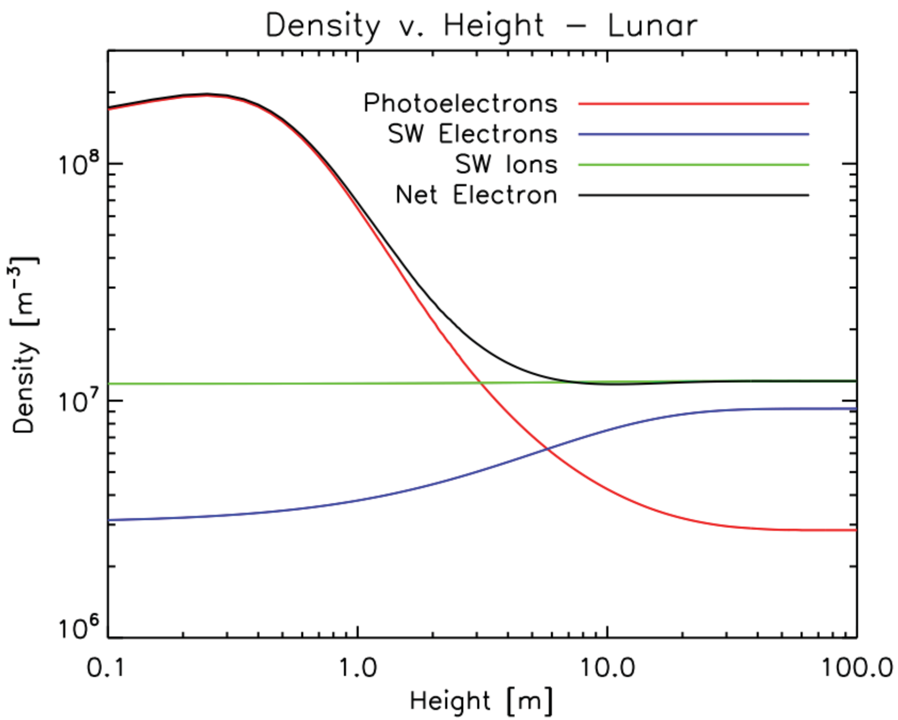
- Electrostatic 1D PIC
  - Photoelectrons emitted from left boundary
    - Two distributions:
      - » Lunar [*Feuerbacher et al., 1972*]
      - » 2.2 eV Maxwellian
  - Solar wind electrons/ion enter at right boundary
    - 10 eV, 400 km/s drift
  - Lunar surface charge density continuously calculated




Photoelectron Velocity Distributions
Feuerbacher et al., 1972
Lunar
Maxwellian
f(v)
0
5
10
15
20
Velocity × 10^5 [m/s]

Particle Distributions

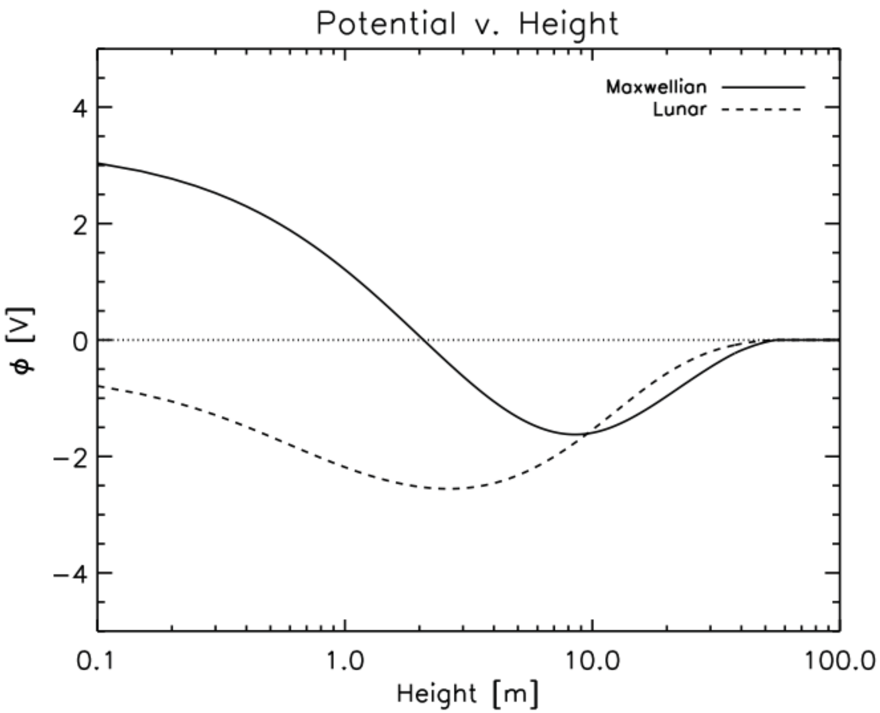


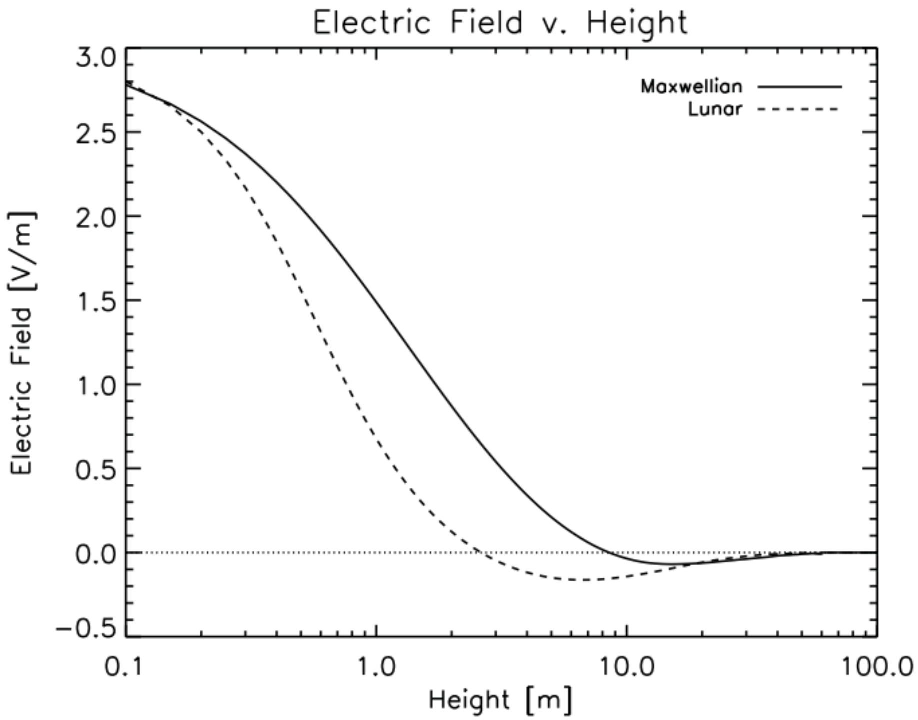


Poppe and Horányi, 2010, in press

- Photoelectrons dominate near the surface
- SW electrons accelerated into the surface
- Solar wind ion are supersonic - remain constant

Potential and Electric Field Dists.

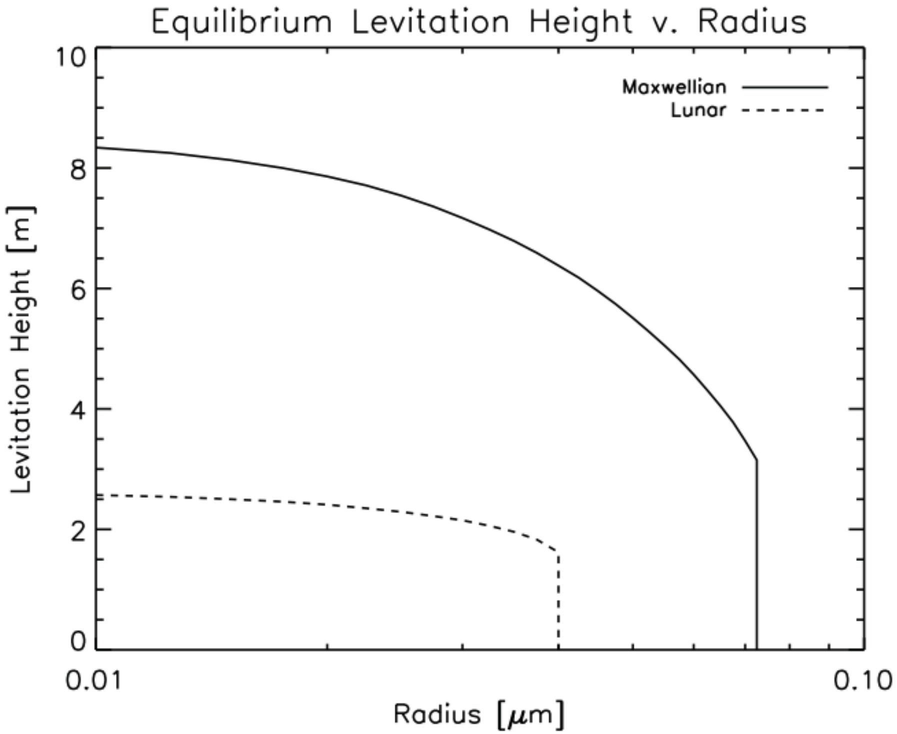




- Potentials both show non-monotonicity [*Guernsey and Fu, 1970; Nitter et al. 1998*]
- Electric fields similar, but lunar field consistently weaker
  - At sufficient heights, electric field becomes negative

Poppe and Horányi, 2010, in press

Grain Levitation



Small grains!

a < 0.1 μm

Poppe and Horányi, 2010, in press

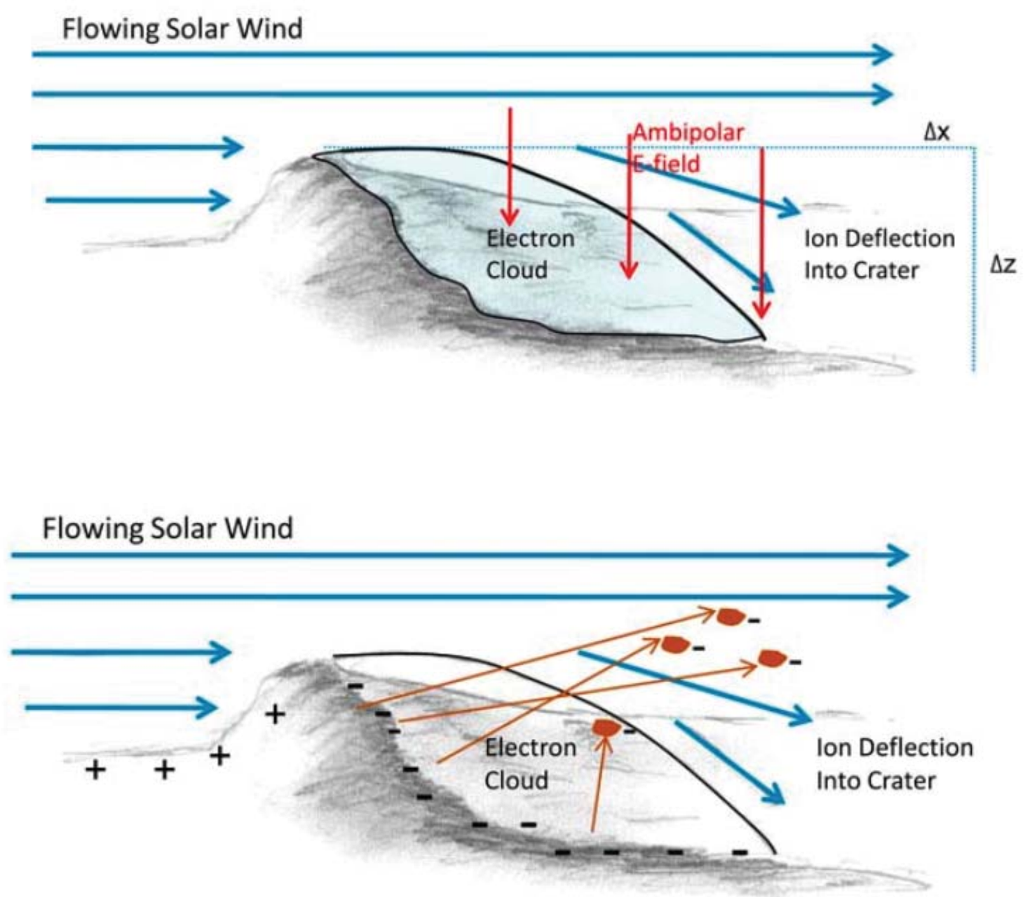
With modeled electric fields, very hard to levitate micron-sized dust grains

Crater Shadowing Effects

- The topography on the surface of the Moon yields lots of sunlit / shadowed boundaries
  - Sunlit portions photoemit electrons
  - Shadowed portions do not photoemit, but collect electrons!

Crater Shadowing Effects

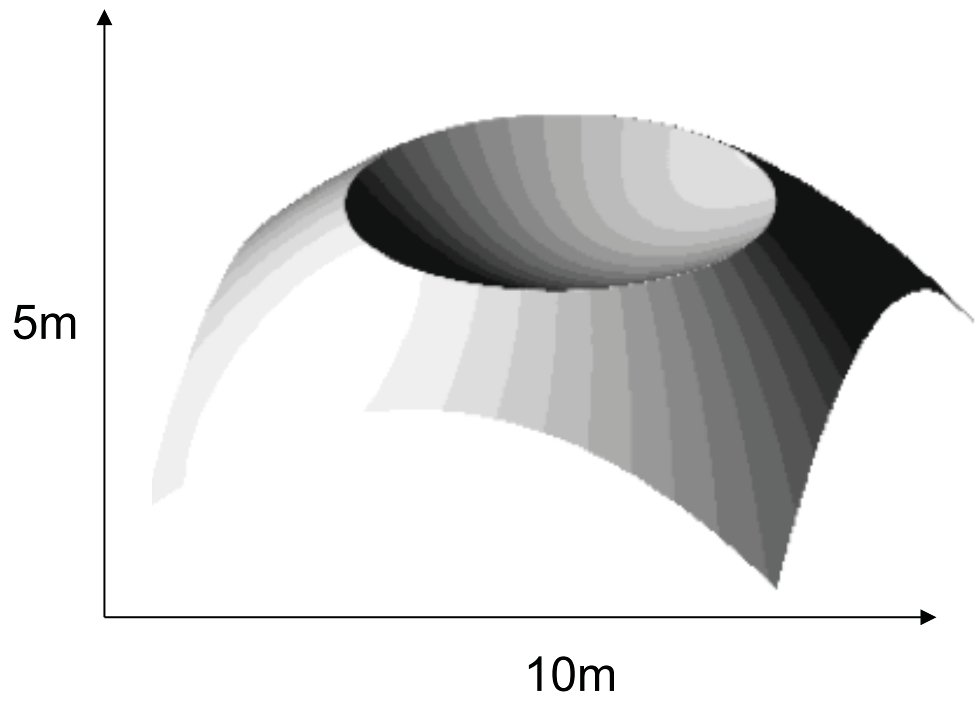
- Craters can give rise to “mini-wakes” in addition to complex shadowing
- Increased electric fields could yield greater dust mobility on the lunar surface



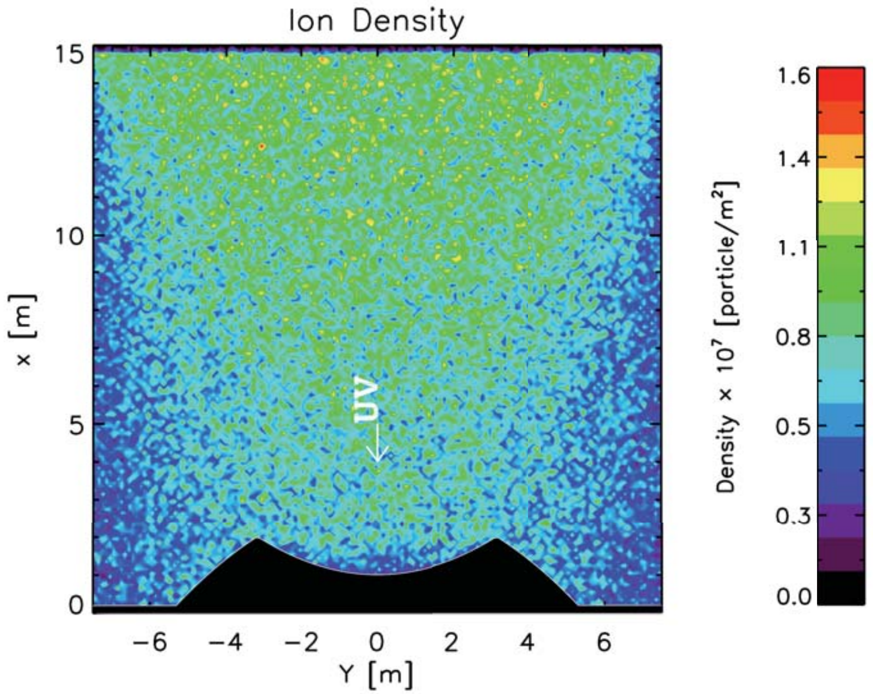
Farrell et al., 2010

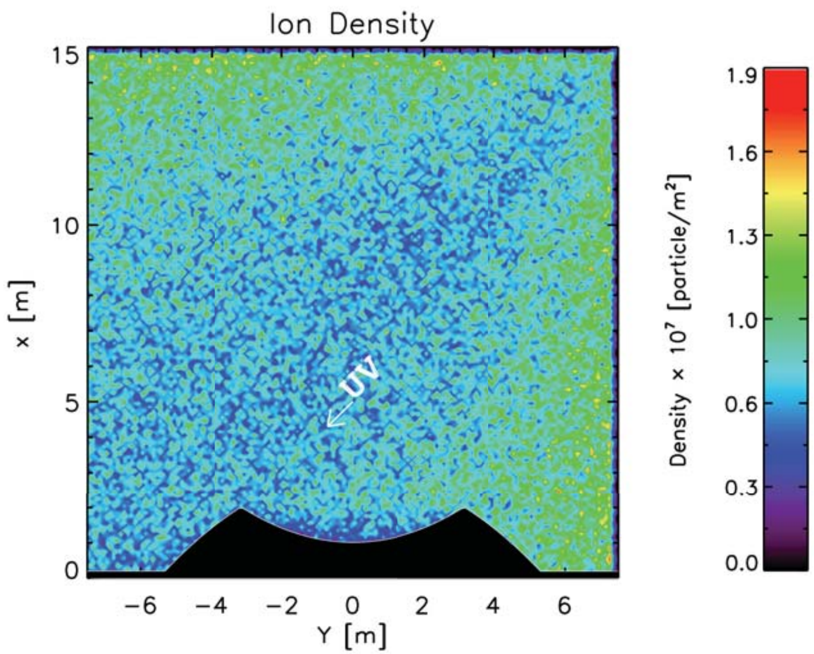
3-d Crater Simulations

- To understand the plasma conditions at the lunar terminator, CCLDAS has developed a 3-d plasma model of a sample crater
  - Illuminated at 45° - both UV radiation and solar wind flow

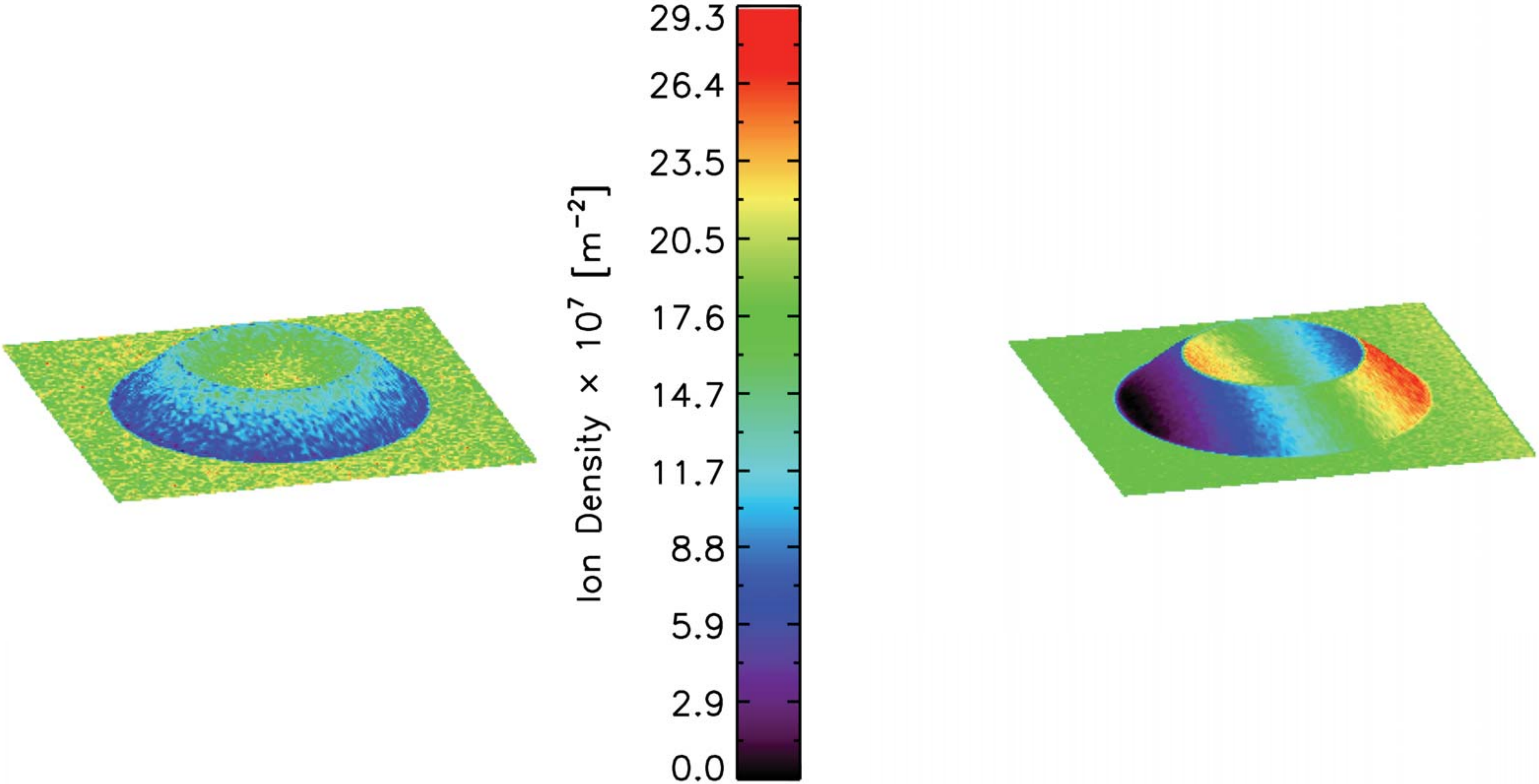


Ion density

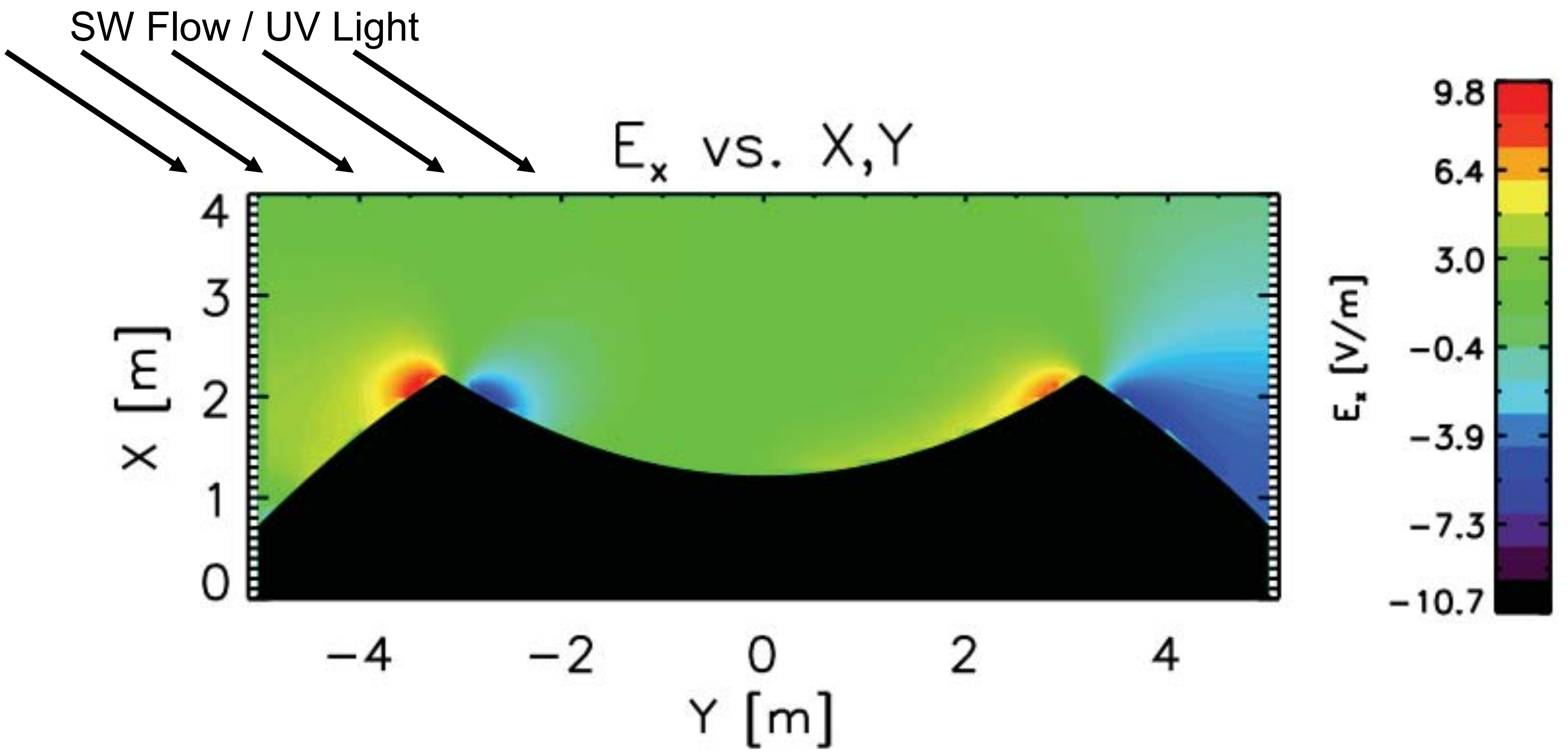

Ion Density
15
10
5
0
x [m]
−6 −4 −2 0 2 4 6
Y [m]
UV
Density × 10⁷ [particle/m²]
1.6
1.4
1.1
0.8
0.5
0.3
0.0


Ion Density
15
10
5
0
x [m]
−6 −4 −2 0 2 4 6
Y [m]
UV
Density × 10⁷ [particle/m²]
1.9
1.6
1.3
1.0
0.6
0.3
0.0

Surface charge density



3-d Crater Simulations



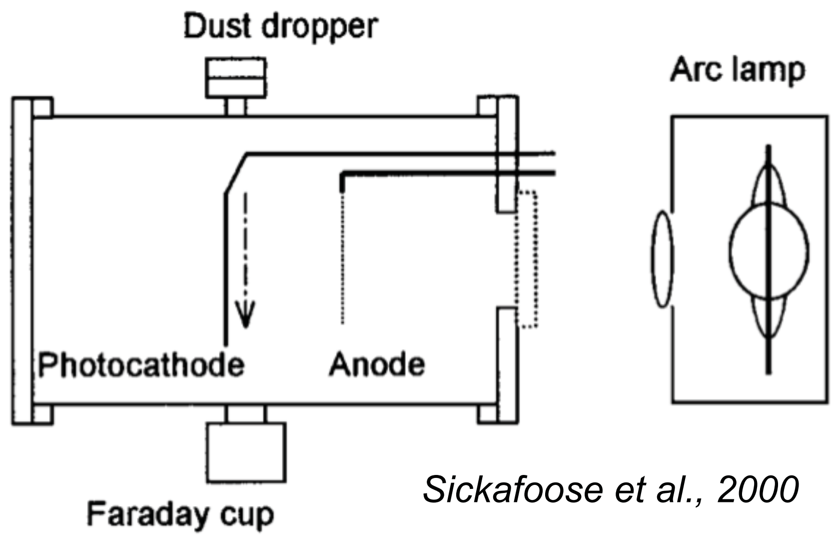
- Electric fields ~3 times the normal strength are seen at the crater rim
- These electric fields could give rise to dust launching and transport more readily than during the sub-solar case

Laboratory Experiments

Experimental Setup #1

Dust grains charge in a plasma when exposed to:

- solar UV radiation?
- ambient background plasma

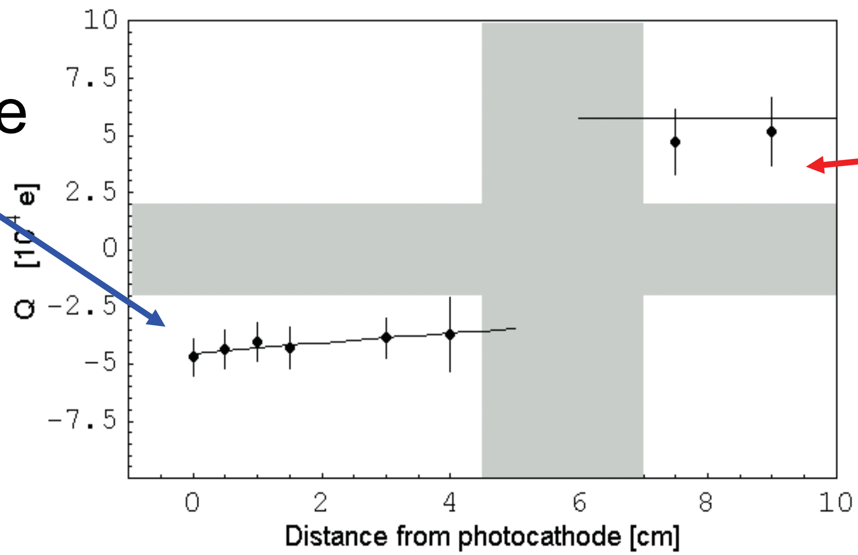


Sickafoose et al., 2000

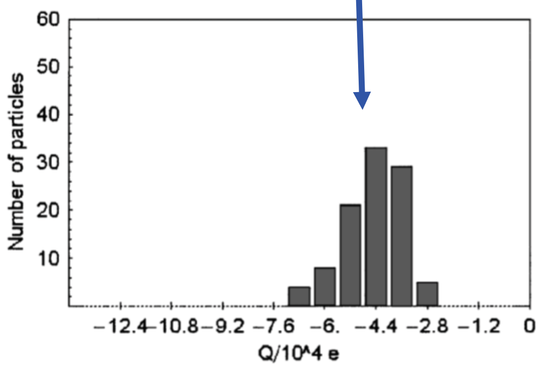
Results

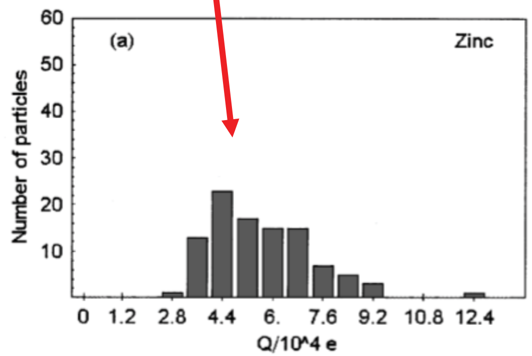
Dust grains charge negative close to the plate

Dust grains charge positive far from the plate



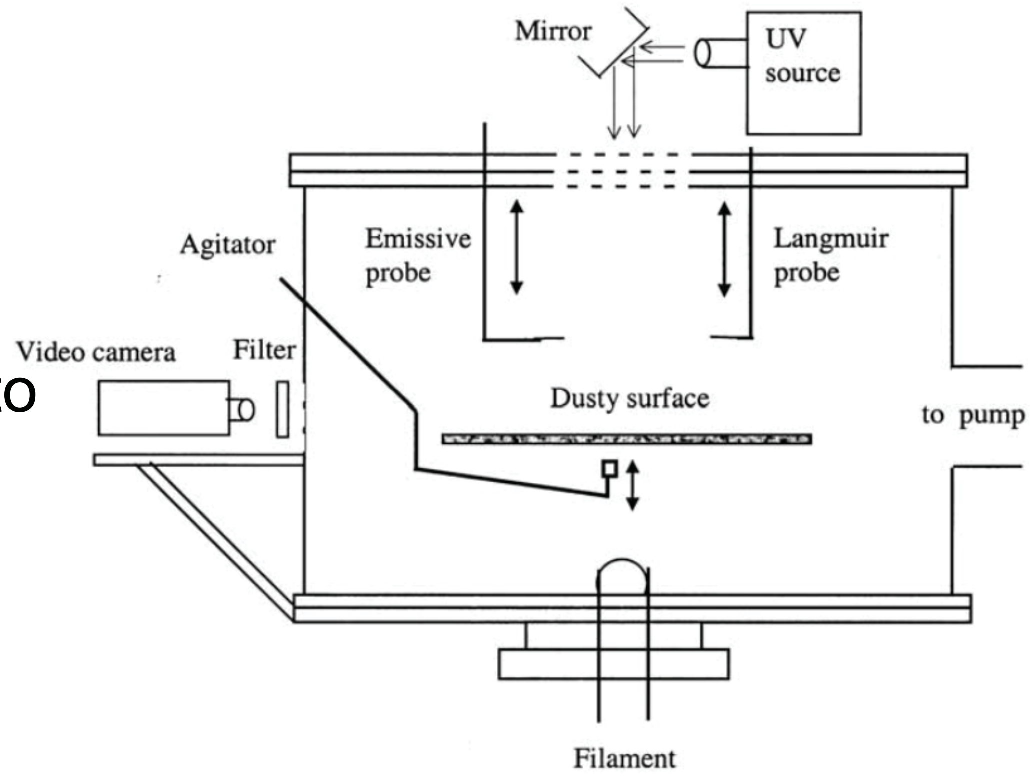
Sickafoose et al., 2000





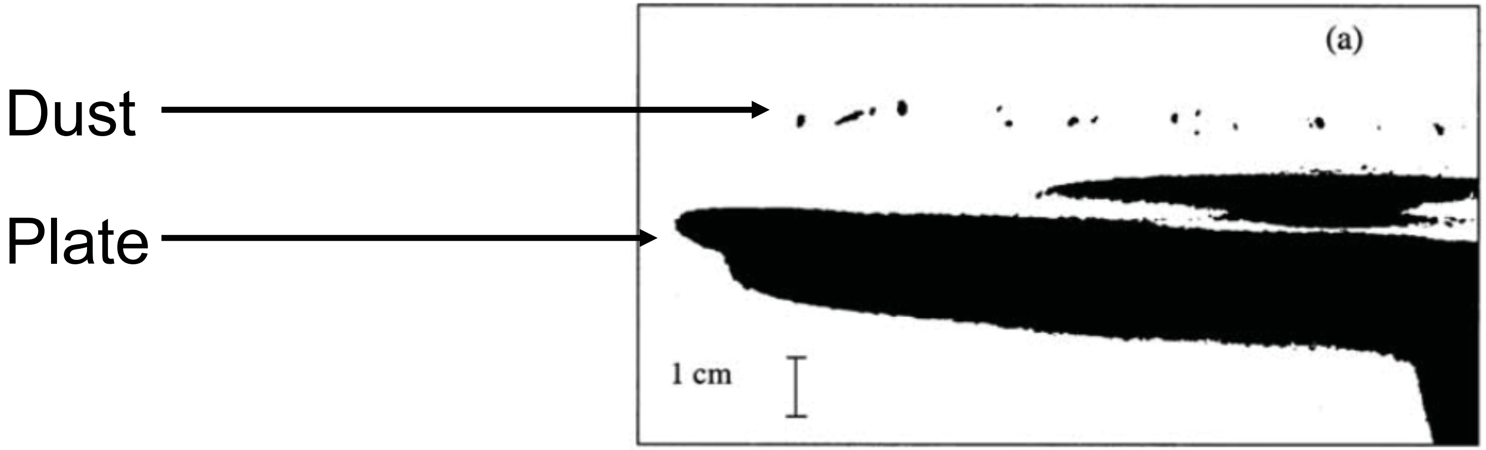
Experimental Setup #2

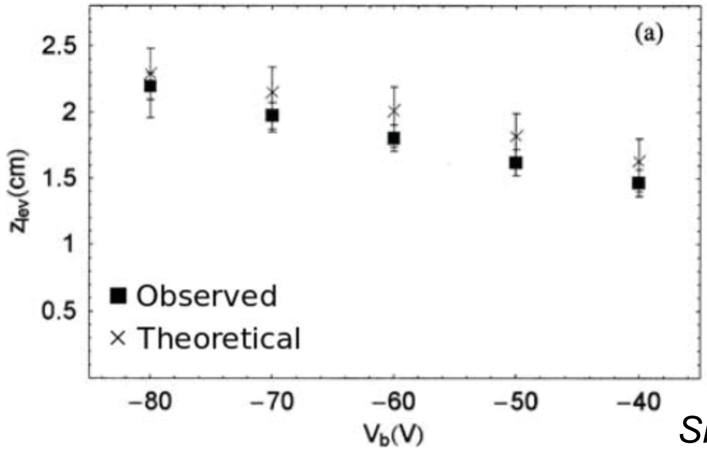
Dust be levitated above a charged surface exposed to a plasma



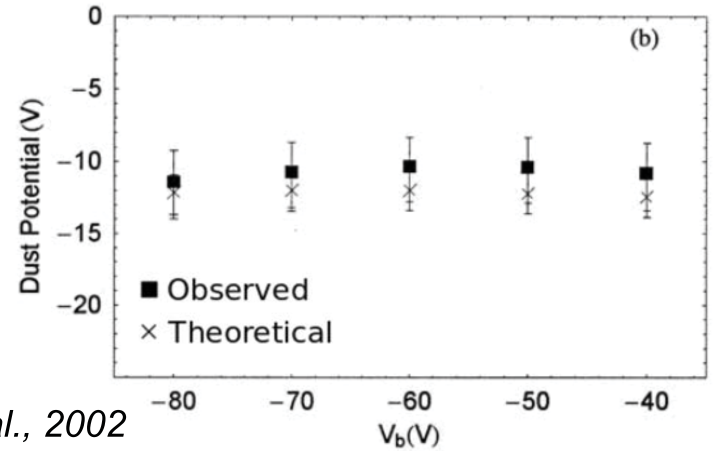
Sickafoose et al., 2002

Results



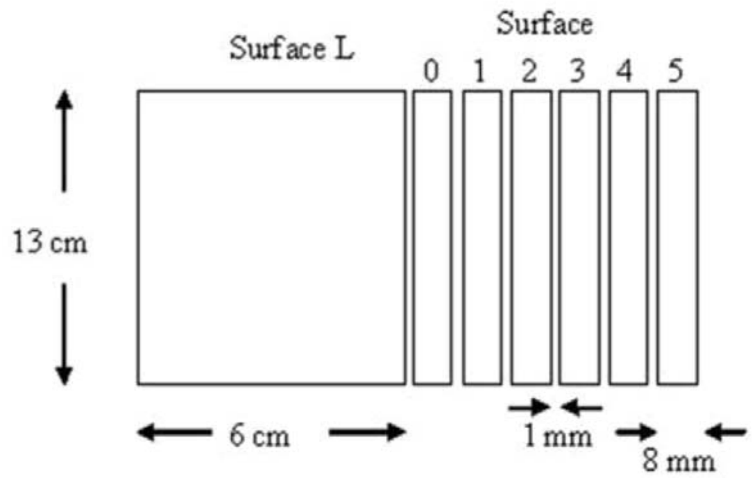


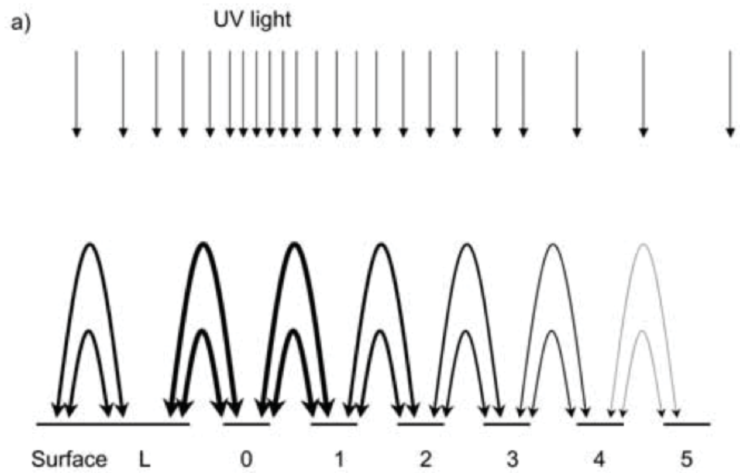
Sickafoose et al., 2002



Experimental Setup #3

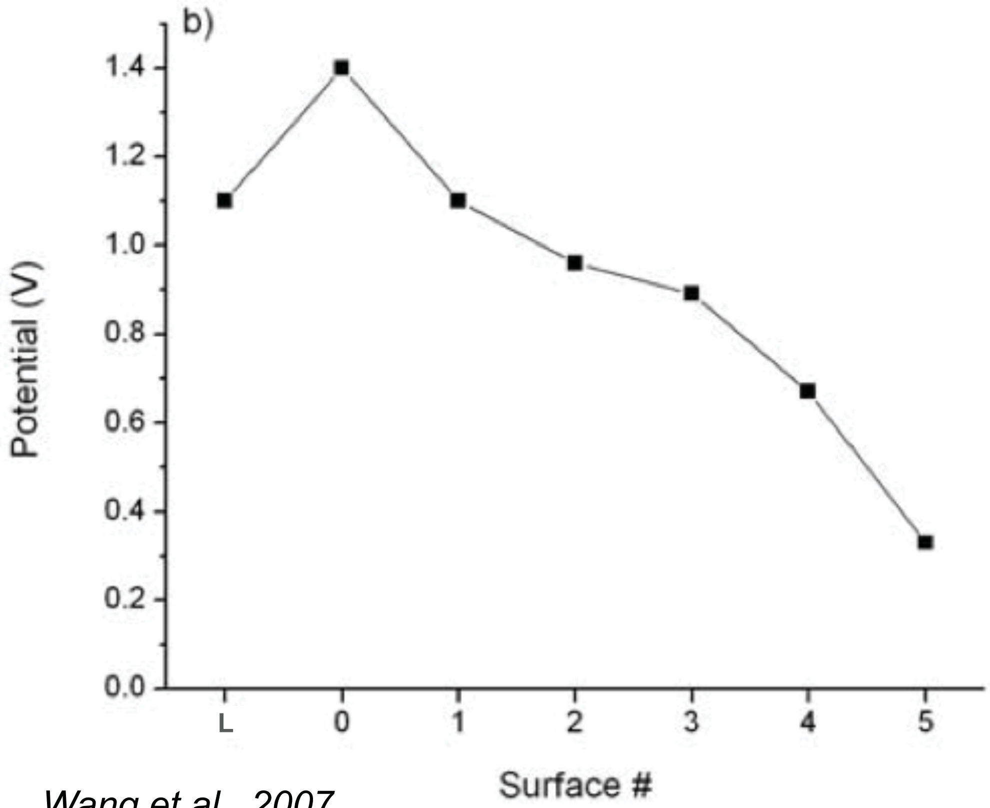
Differential illumination leads to differential charging





Wang et al., 2007

Results



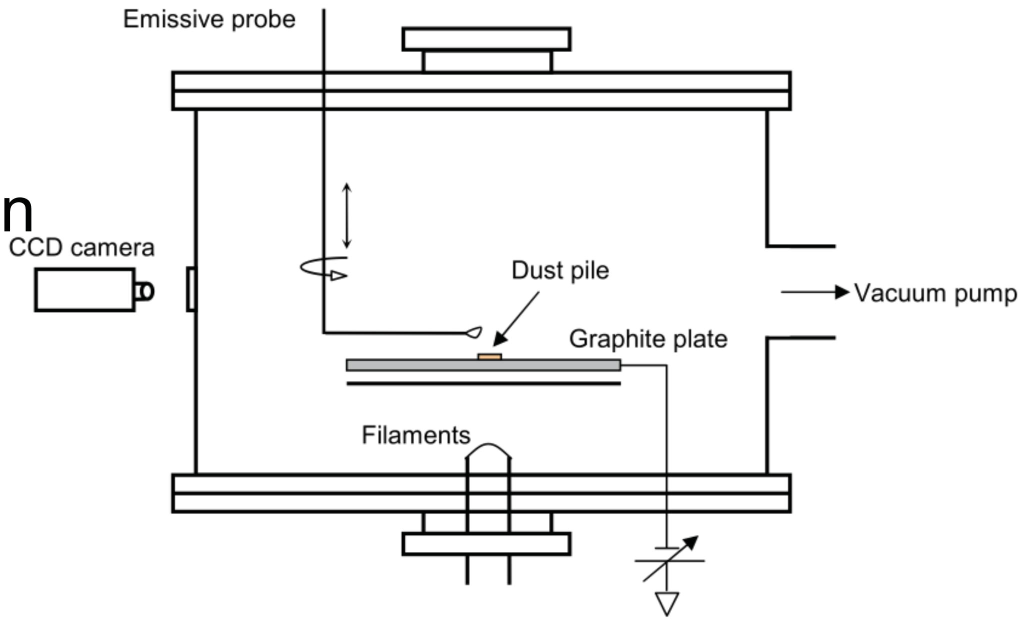
Wang et al., 2007

Surfaces with less illumination reach a lower potential

Horizontal charge gradients lead to horizontal electric fields!

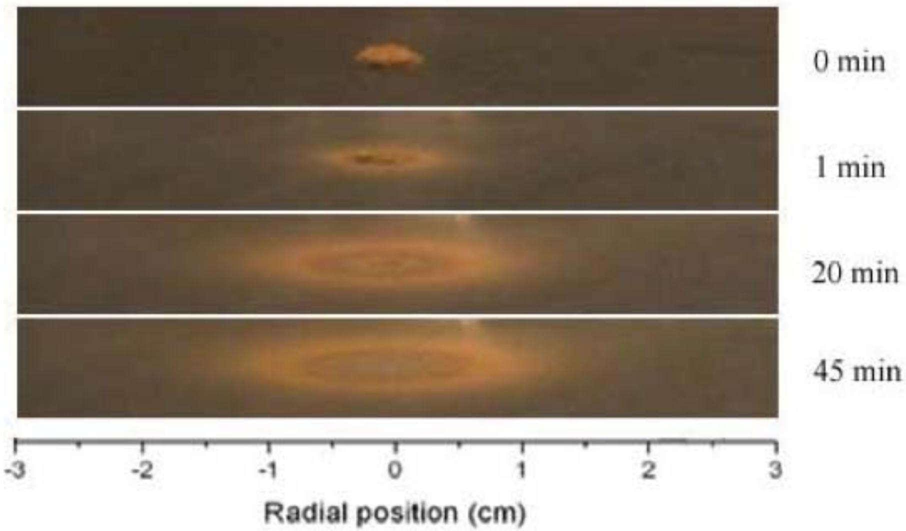
Experimental Setup #4

Dust transport is observed in a laboratory setting



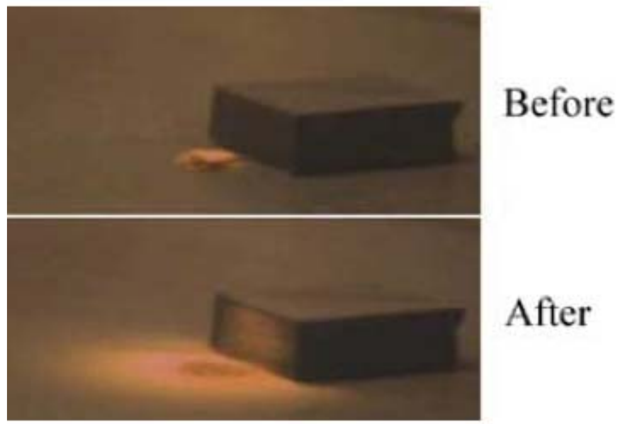
Wang et al., 2009

Results



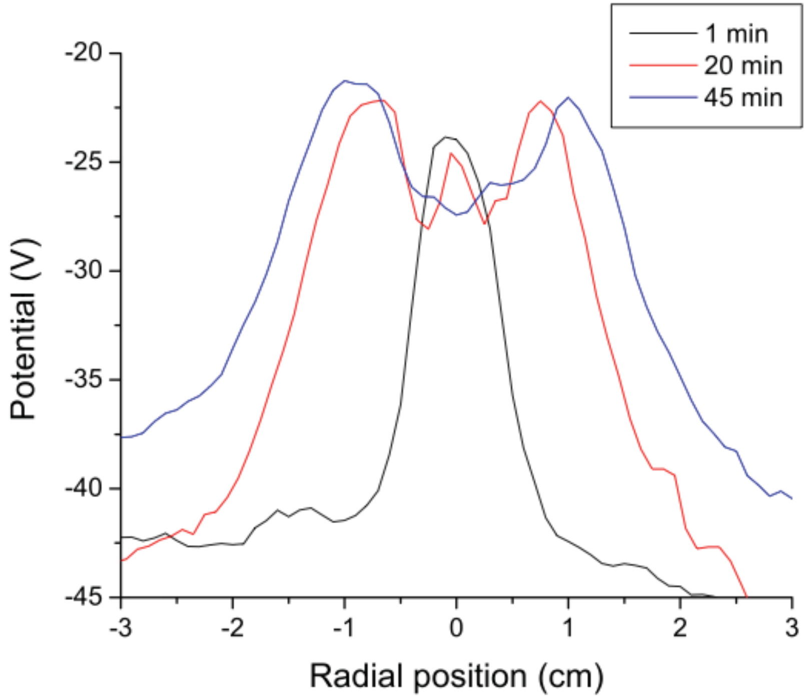
Dust is seen spreading symmetrically away from the center of the pile over time

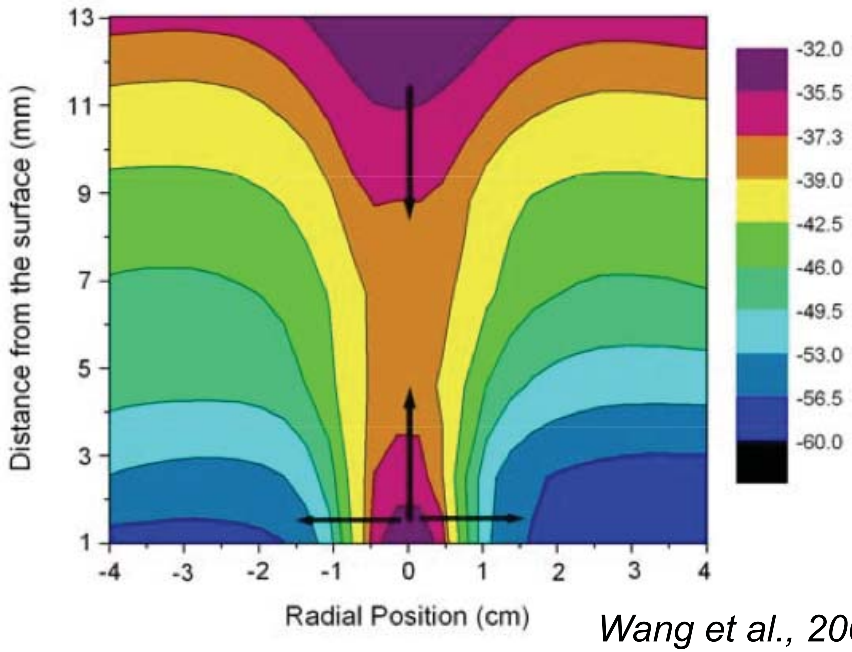
Additionally, the presence of a block shows that the dust has vertical motion as well - *hopping*?



Wang et al., 2009

Results



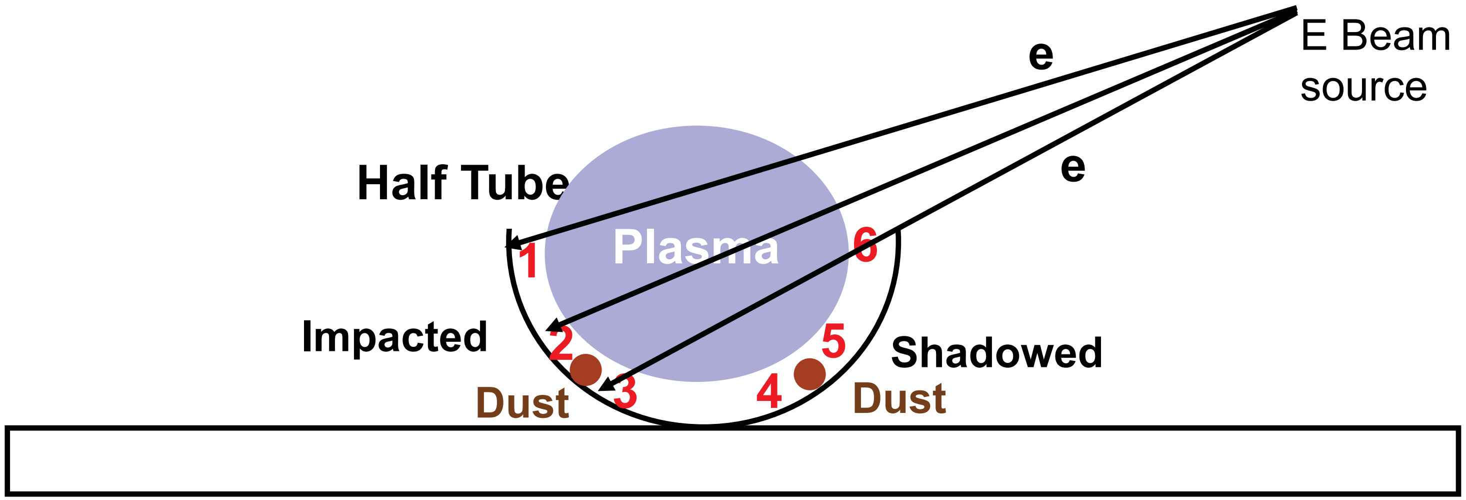


Wang et al., 2009

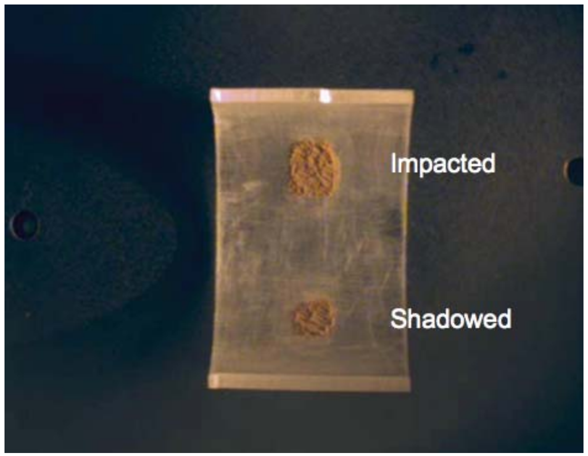
Complex potential structures exist above the dust and change as a function of time

- Horizontal electric fields exist

Experimental Setup #5



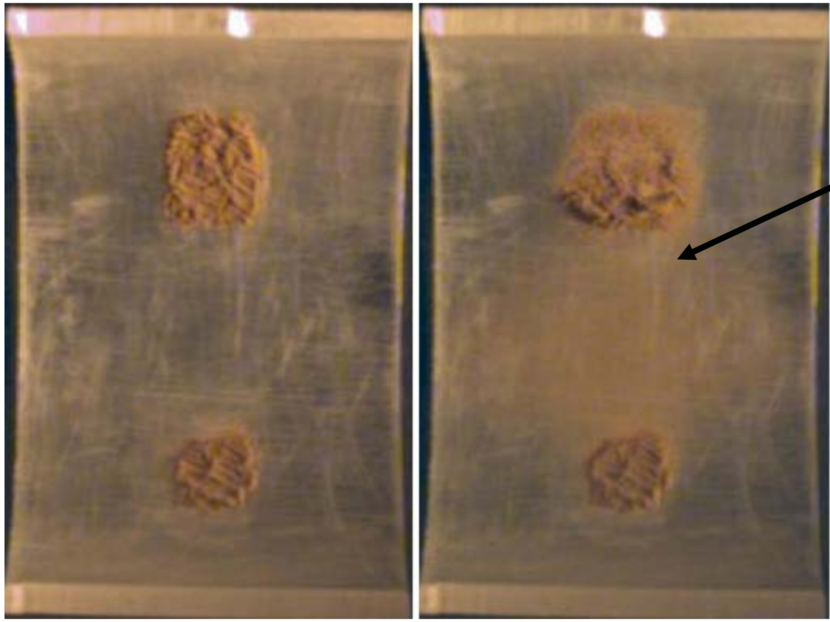
Dust transport is enhanced with differential charging



Results

Exposed dust

Shadowed dust



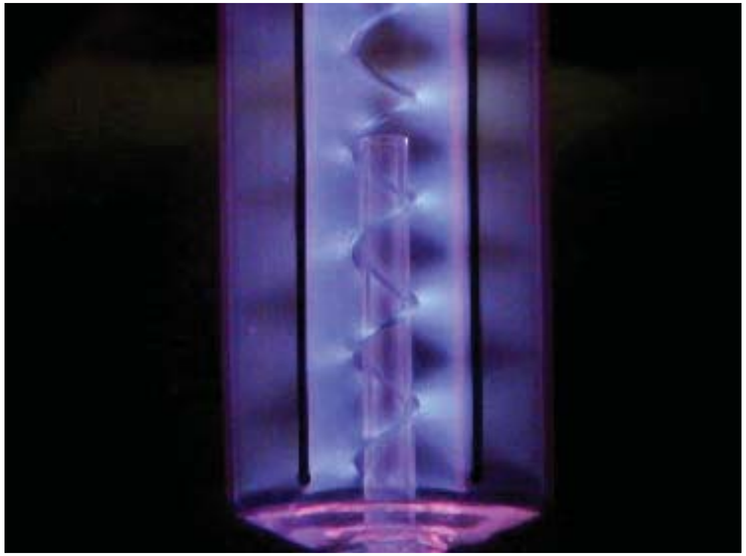
Dust transport

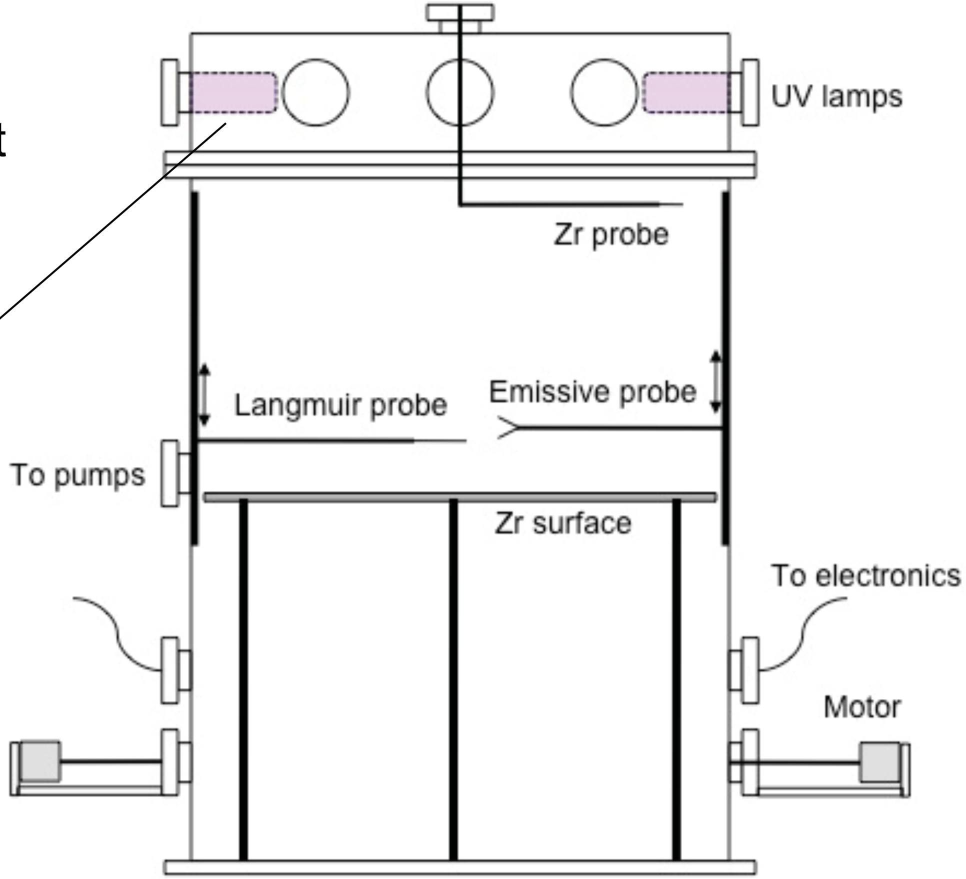
Before After

Movement seen in the exposed dust, but not in the shadowed dust

Future/Ongoing Experiments

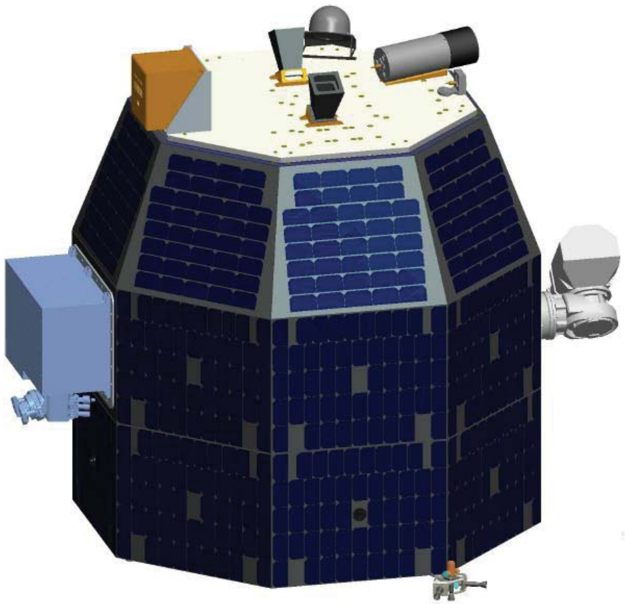
- Recreate photoemission in the lab with fancy UV lamps
- Series of planned experiments with dust in the chamber

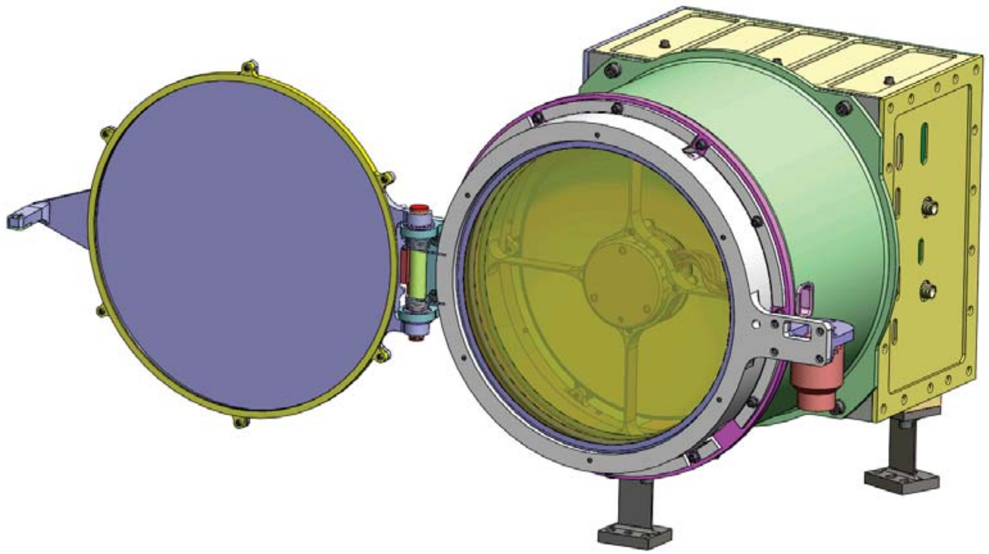




Upcoming Lunar Mission

Lunar Dust Experiment (LDEX) for the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission in 2013.

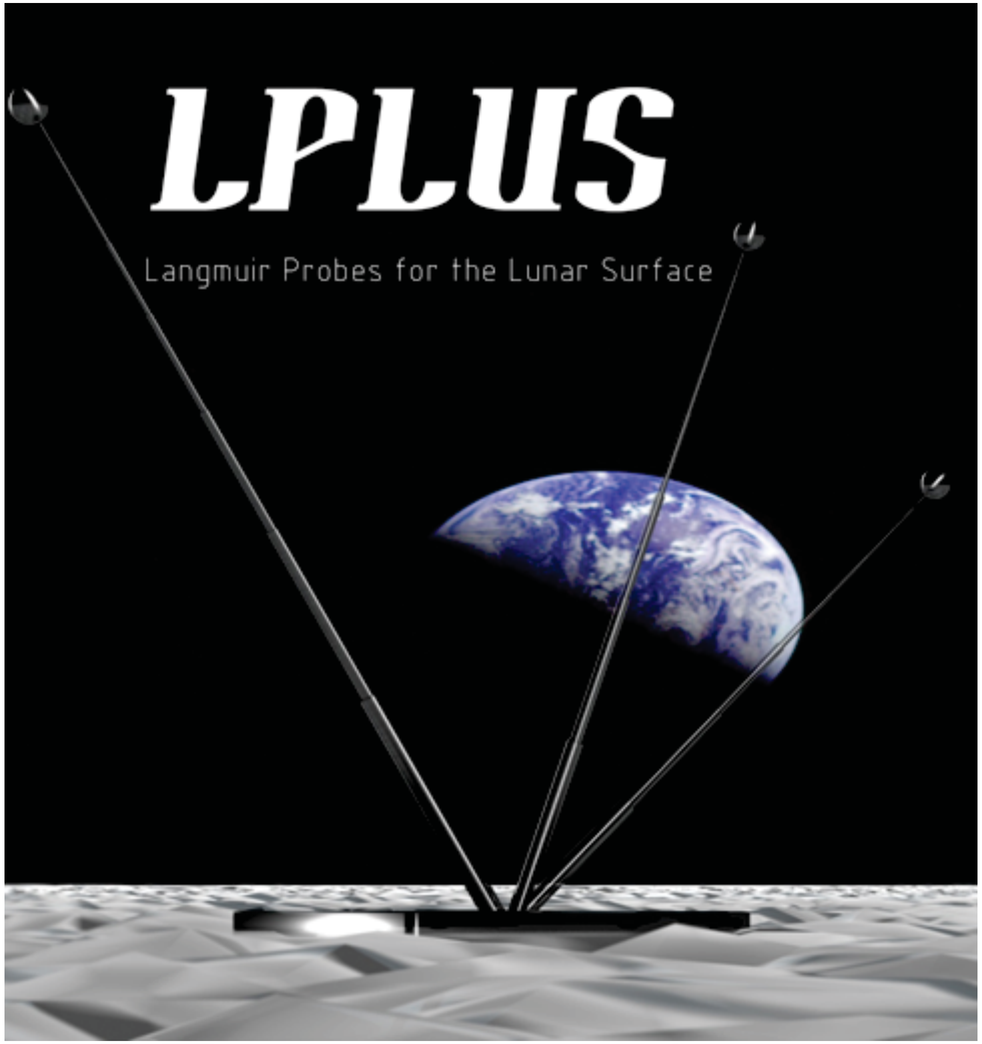




Future Measurements?

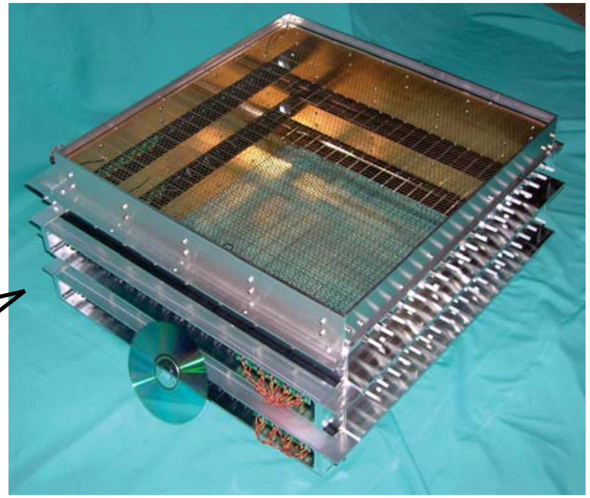
- Ground-truth measurements are needed to constrain the models and laboratory experiments

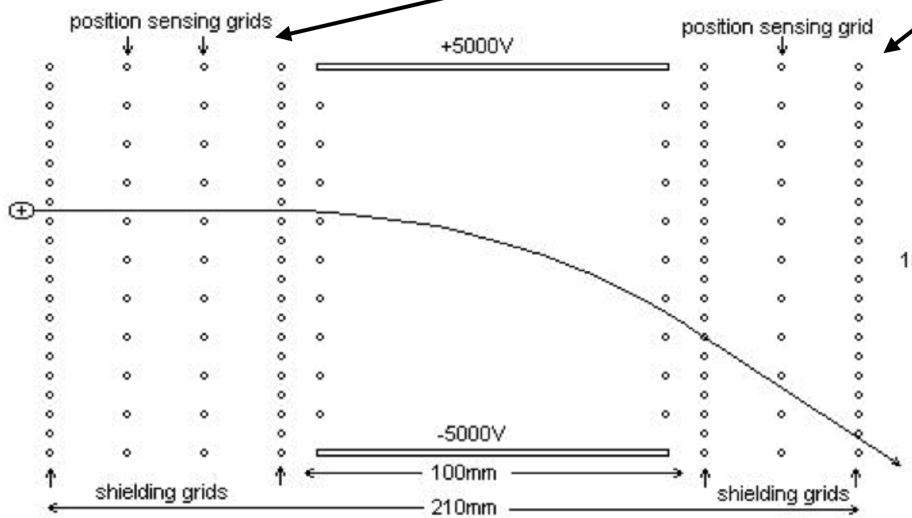
- Langmuir Probes for the Lunar Surface (LPLUS)
    - Concept in development at CCLDAS by CU students

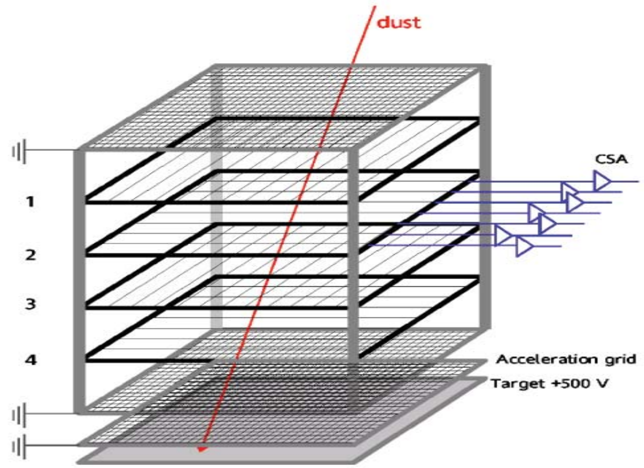


Future Measurements

- Electrostatic Lunar Dust Analyzer
  - Capable of measuring slow, highly-charged dust grains
  - Will measure the charge, velocity and mass of the grain

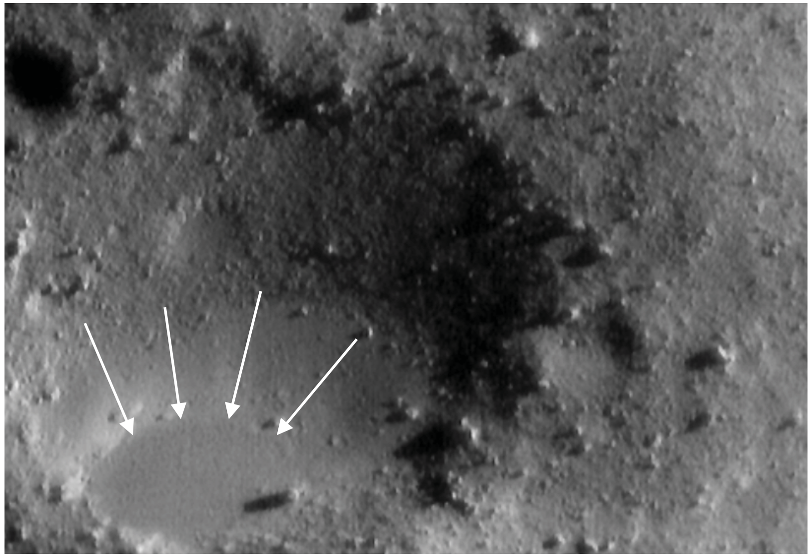


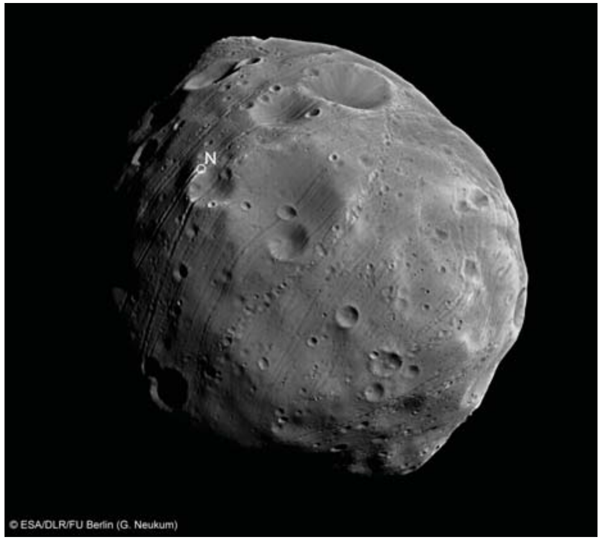




Applications to Other Bodies

- Evidence of dust transport seen on other bodies
  - Eros 433
  - Phobos / Deimos?





- No matter where humans explore, there'll be dust…

Conclusion

- Theory and modeling can predict the plasma environment, but laboratory and *modern* in-situ measurements are sorely needed

- Studying dust and plasma at the Moon is relevant for airless planetary bodies throughout the solar system

The Moon is an excellent dusty plasma laboratory!