ASTEROID SURFACE HAZARDS
DUST, TOXIC MATERIALS*, CHARGING

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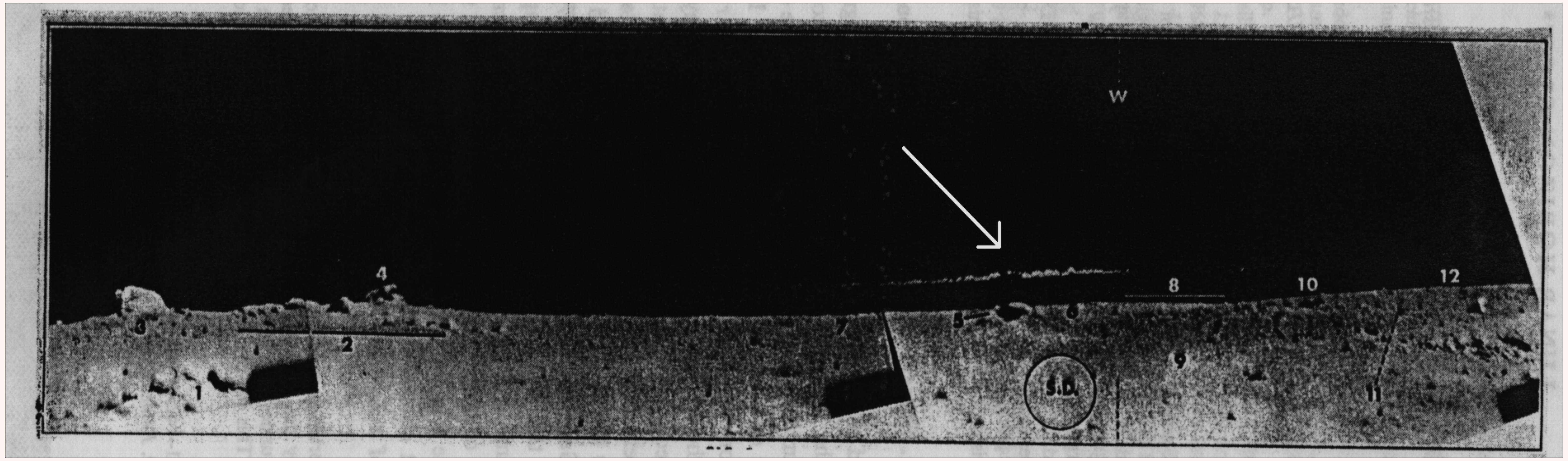
*** Except not the toxic materials.**

OUTLINE

- Observations relevant to dust near planetary surfaces;
- Numerical and analytic models of dust levitation and transport;
- Some experimental results;
- Future experiments, modeling and observations.

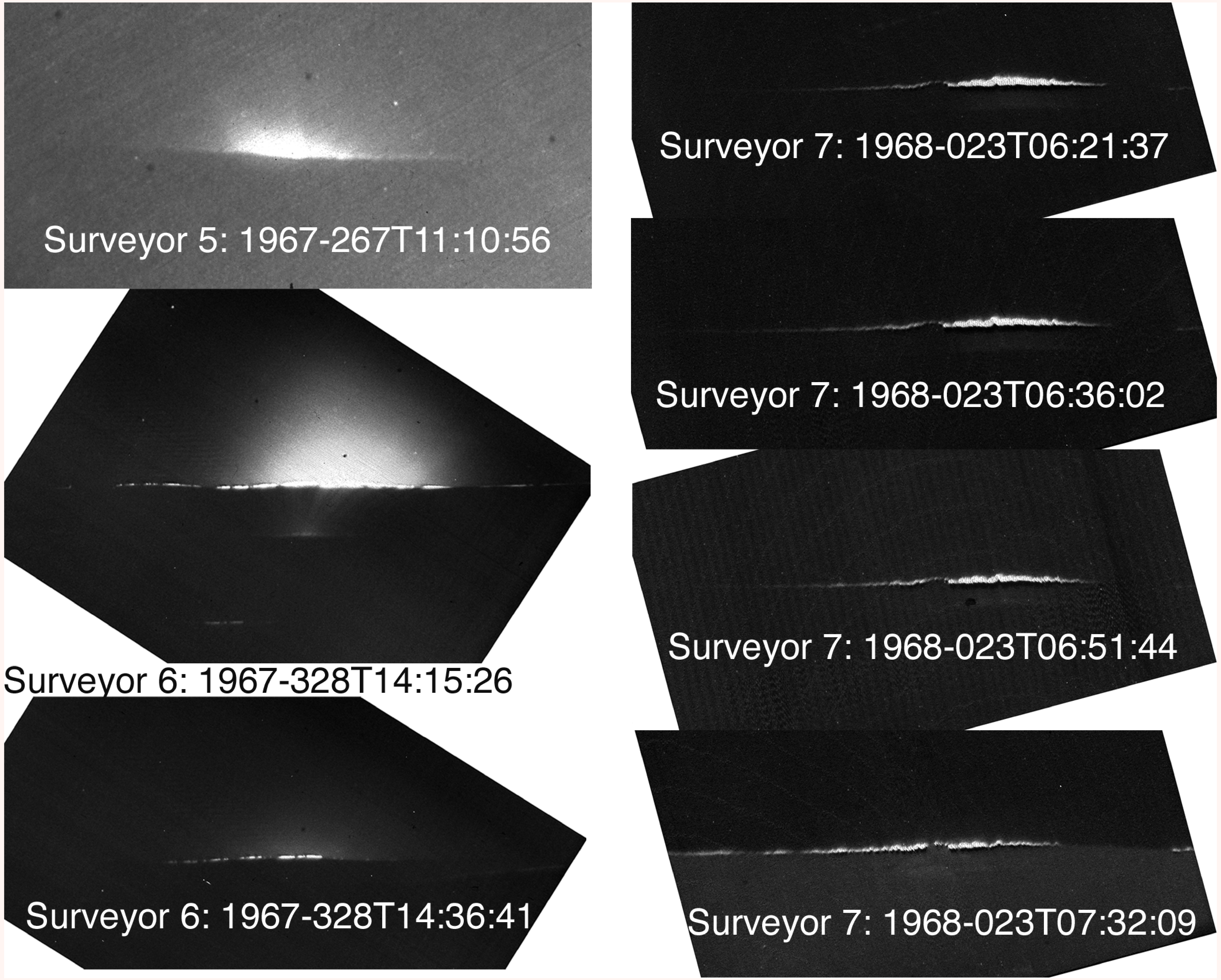
LUNAR HORIZON GLOW - 1



Rennilson and Criswell (1974): Analysis of Surveyor lander images of horizon glow after sunset.

- **Image is a composite;**
- **dust cloud has been repositioned;**
- **distance to horizon ~ 150 m suggests h~0.3 m;**
- **angular extent suggests particle radii ~6μm.**

LUNAR HORIZON GLOW - 2

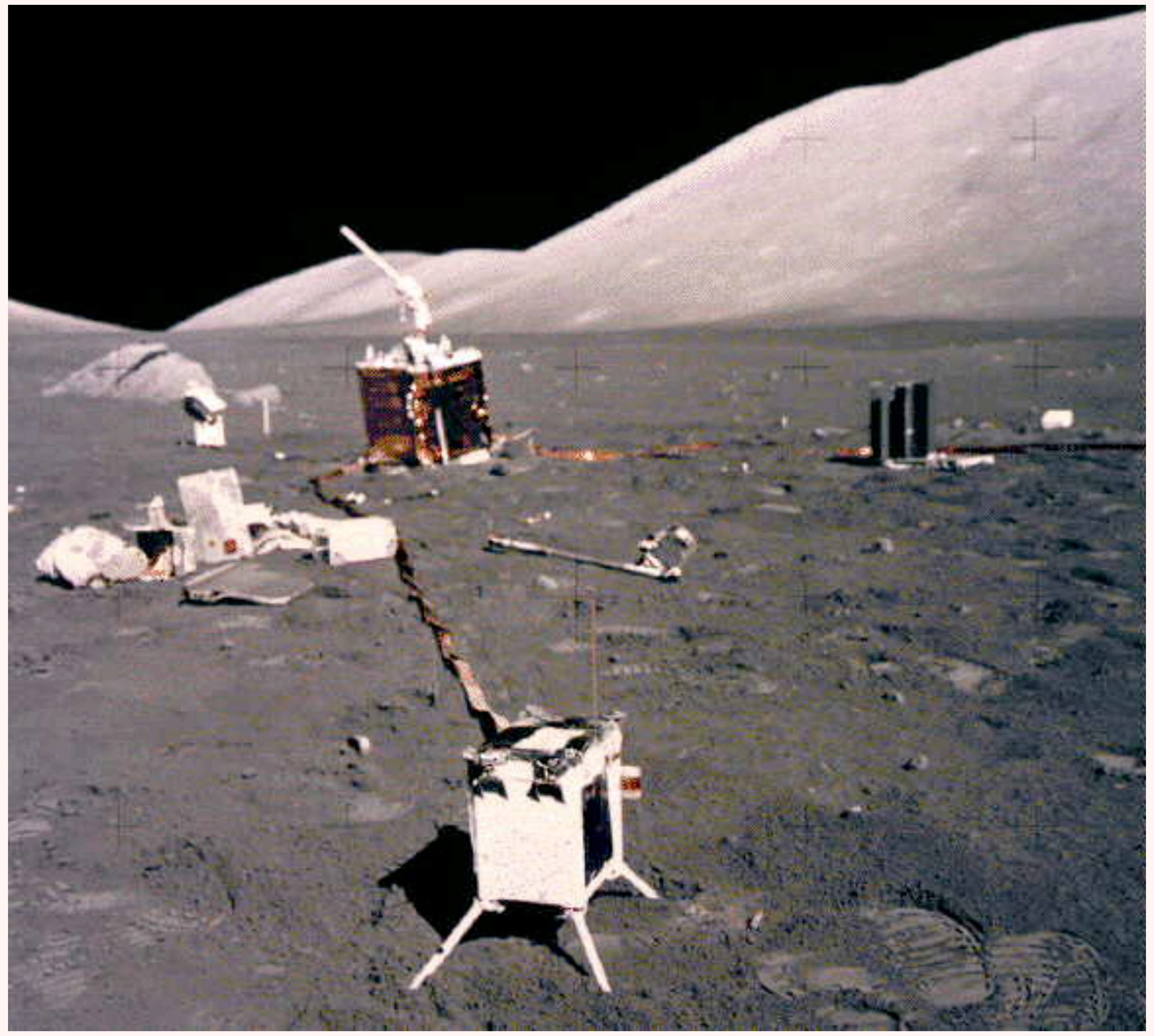


EARLY THEORETICAL STUDIES

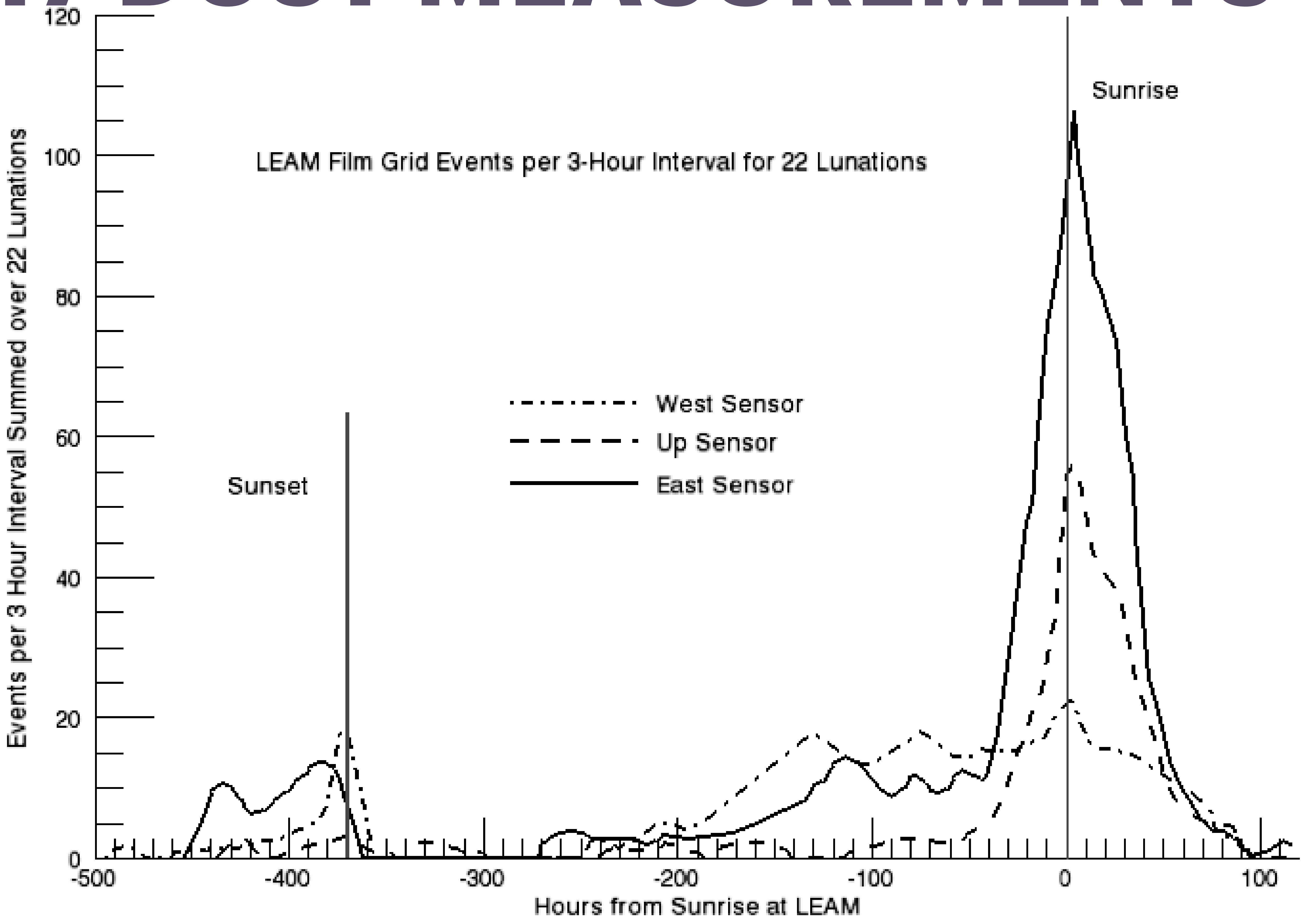
- Motivated by Surveyor observations and later Apollo astronaut sketches
- Focused on lunar environment:
  - lunar surface potential
  - lunar regolith photoelectron yield
  - near-surface electric field strengths

[Singer and Walker (1962), Grard and Tunaley (1971), Manka (1973), Criswell (1972, 1973, 1974), Walbridge (1973), Rennilson and Criswell (1974), Freeman and Ibrahim (1975), De and Criswell (1977), Criswell and De (1977), Reasoner and Burke (1973), Willis et al. (1973), Tunaley and Jones (1973), Whipple (1981)]

LEAM APOLLO 17 DUST MEASUREMENTS



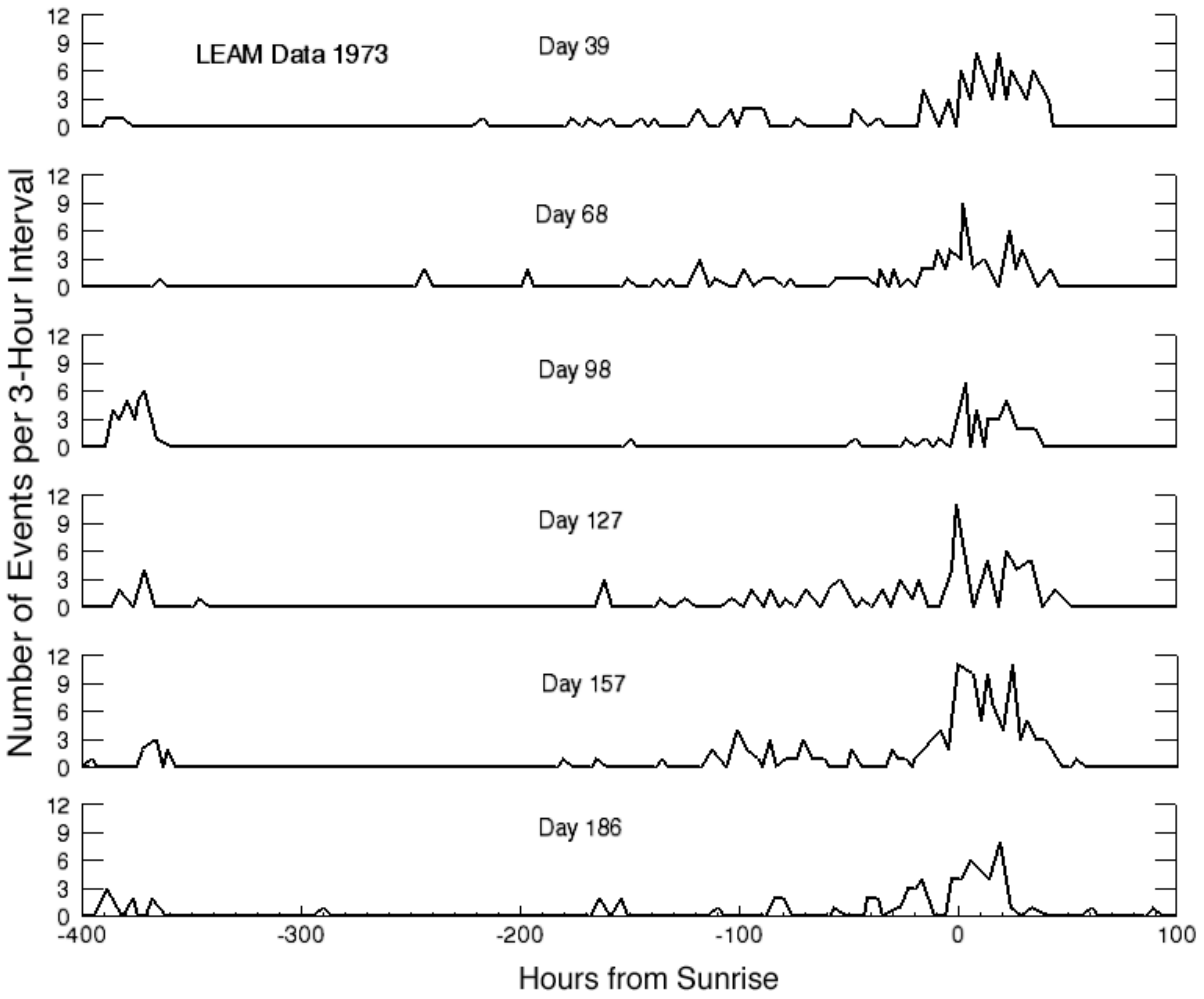
Berg et al. (1976)



Designed to detect meteoroids and ejecta. Showed anomalous readings indicating large, slow-moving particles.

7

LEAM Data by Lunar Day

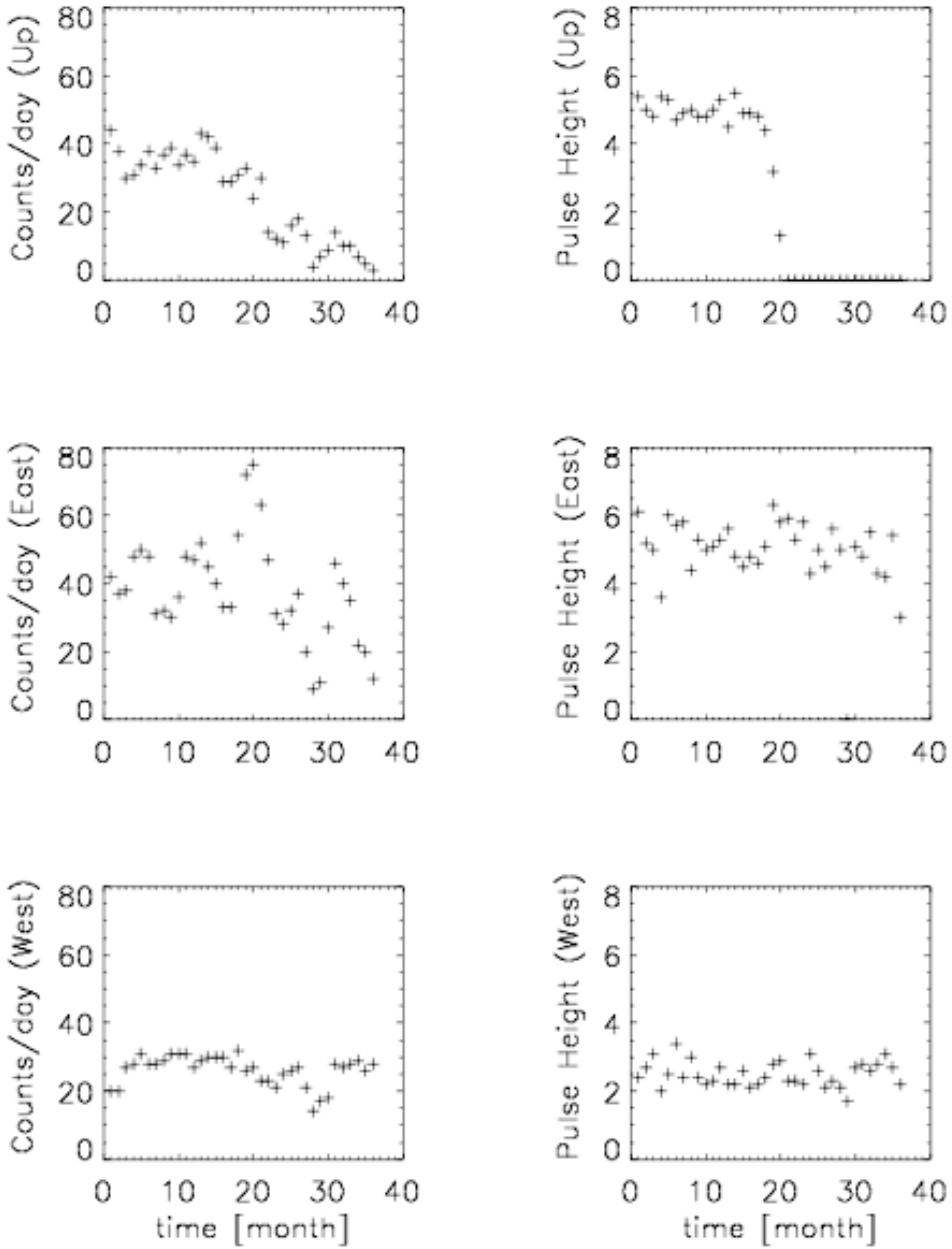


Lunar Ejecta And Meteorite Experiment

Berg et al. (1976)

LEAM count-rate changes consistent with dust accumulation on upper sensor.

Colwell et al. (2007).

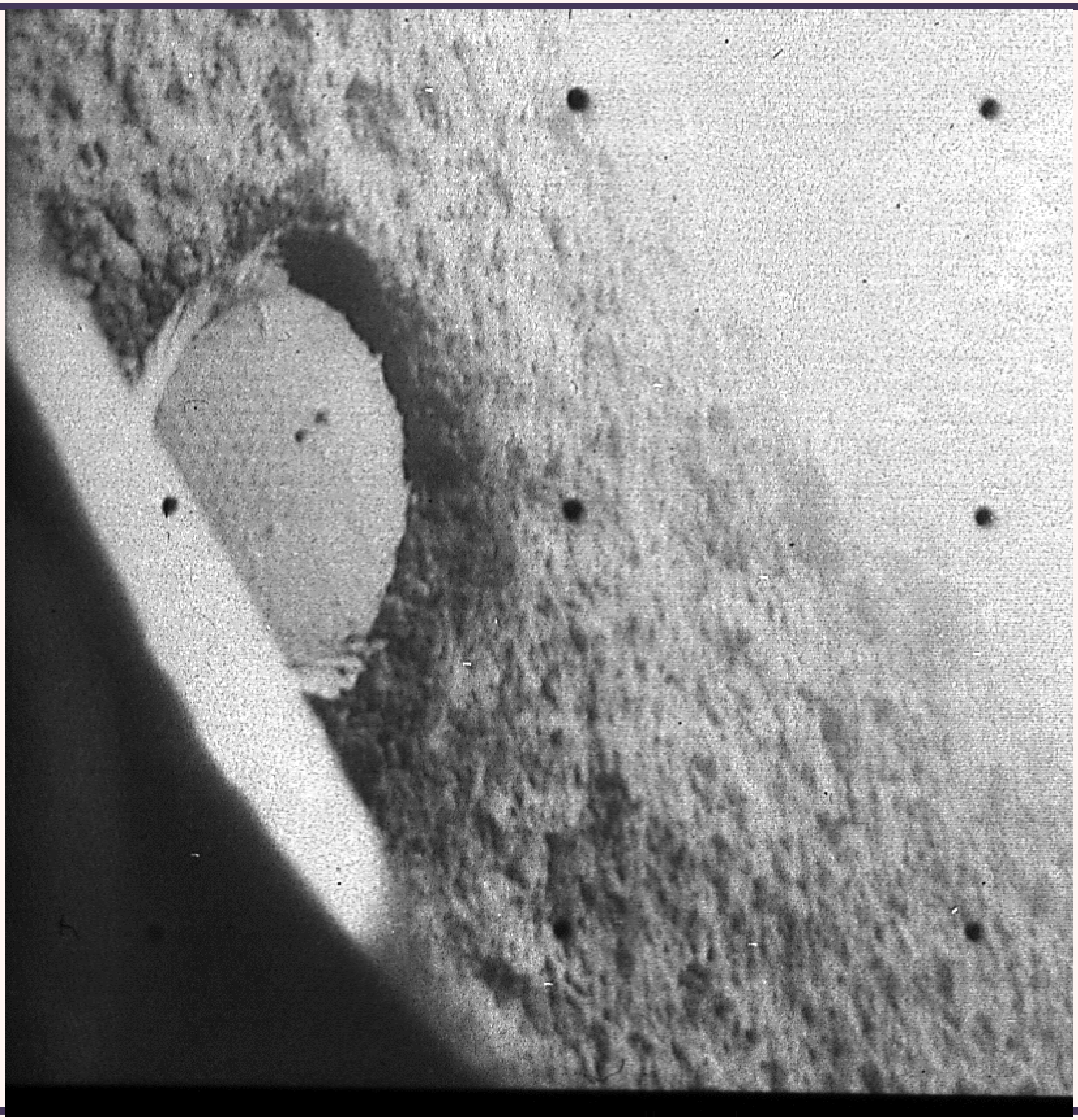


However...

Surveyor 3 Footprint

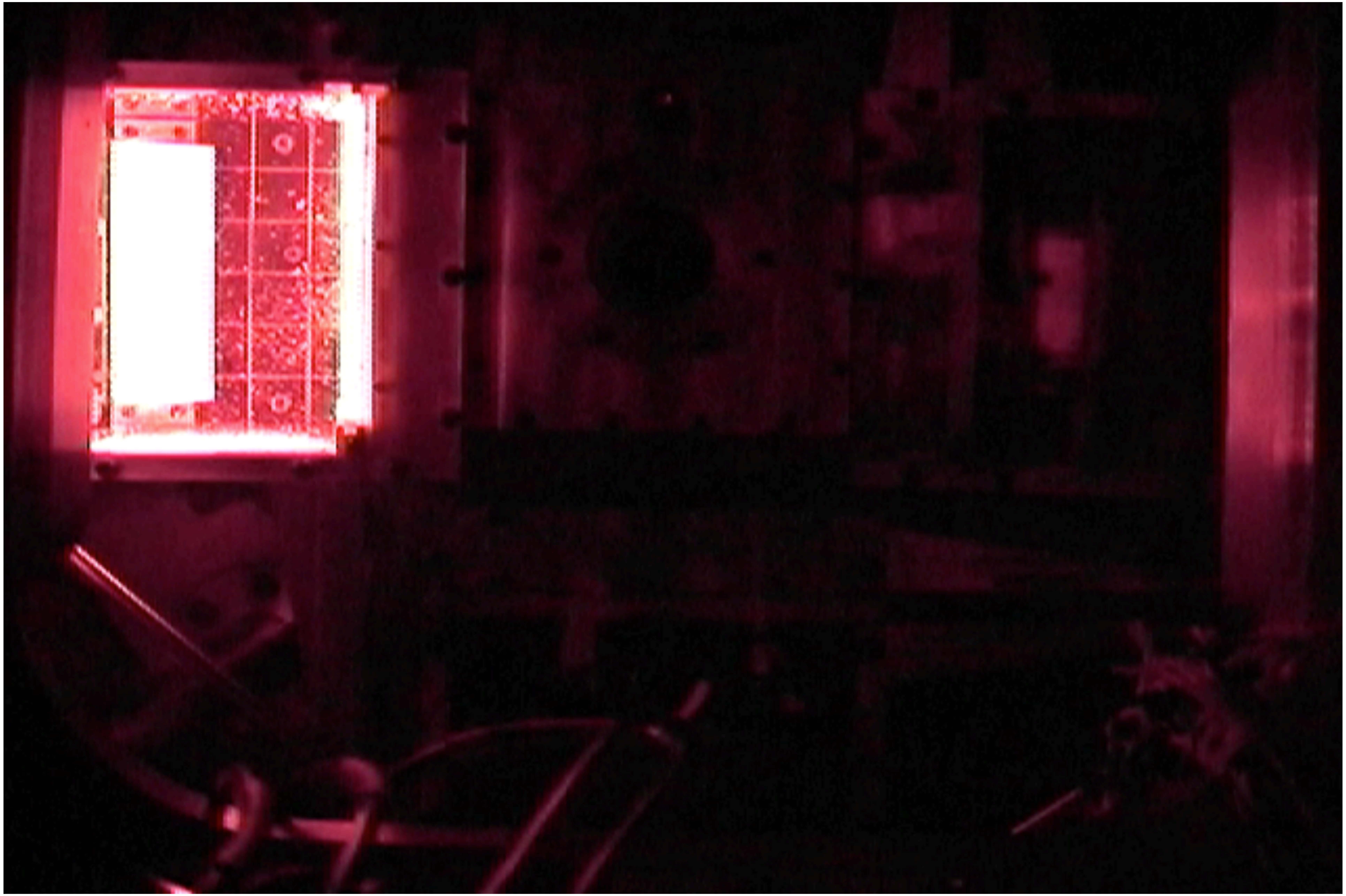
Surveyor image, April 1967.

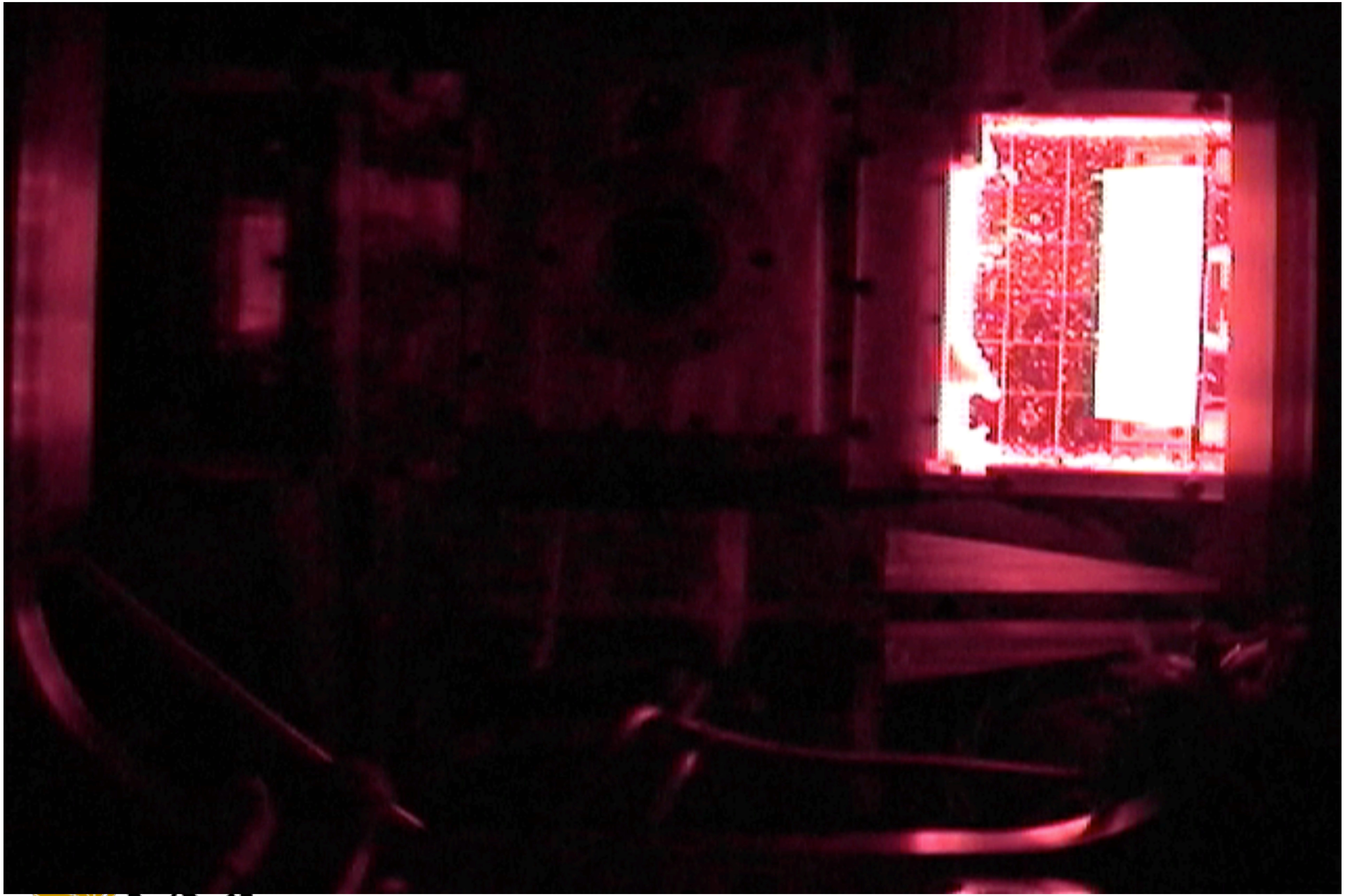
Note pattern in regolith left by lander foot after it bounced.

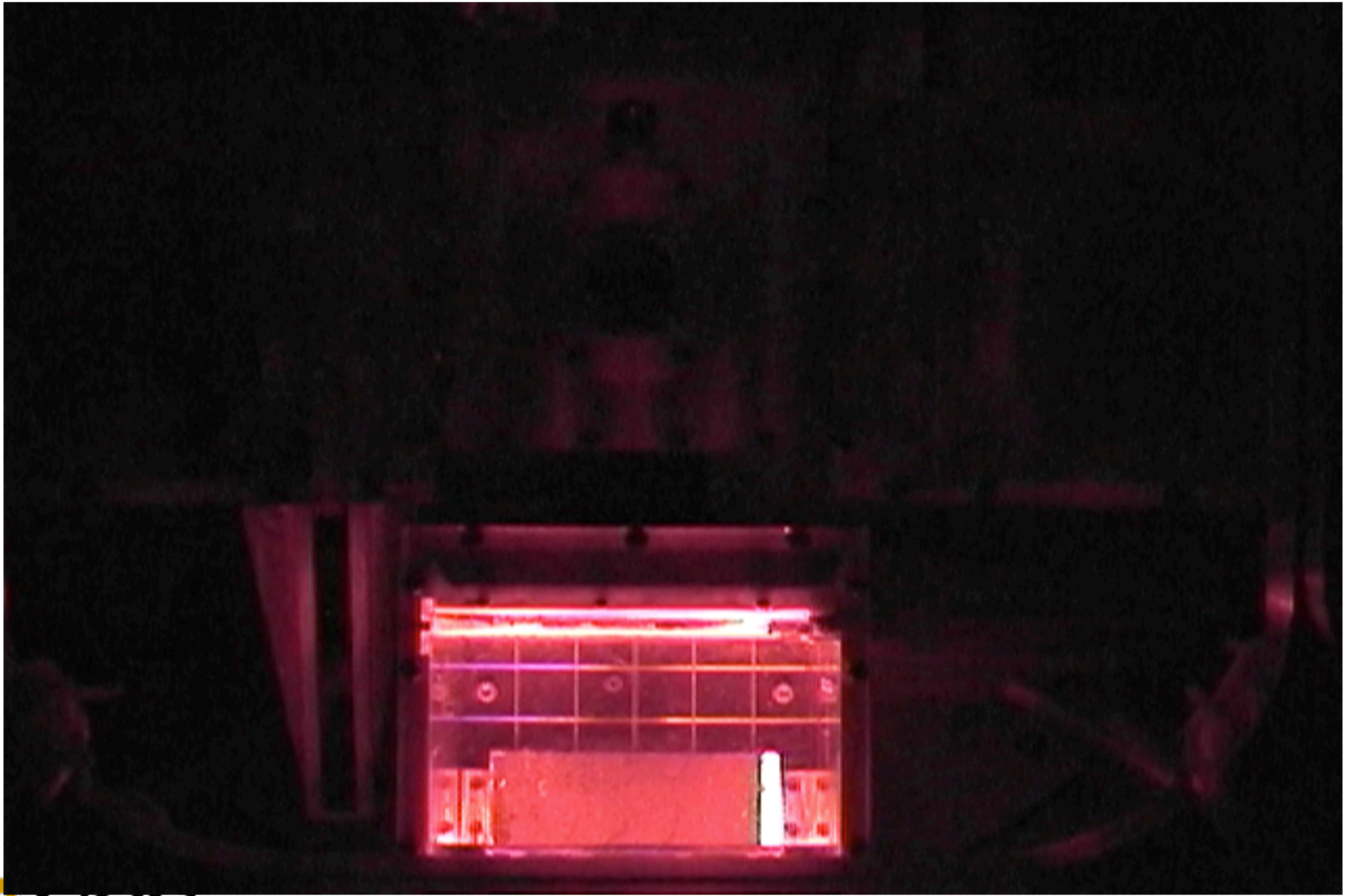


Apollo 12 astronaut image of Surveyor footprint. Image taken November 1969

The lunar surface is not a roiling dust popper.





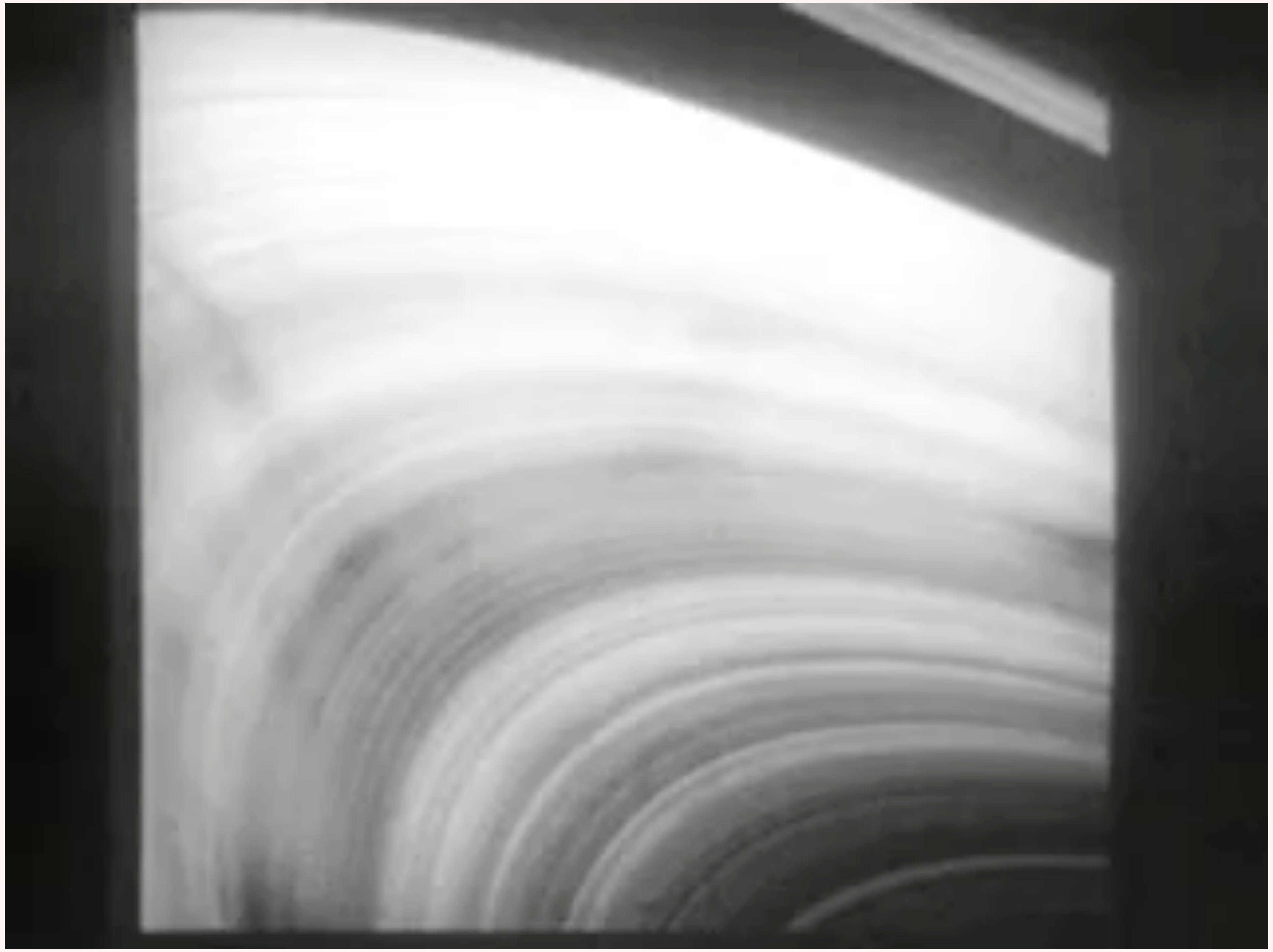


UCF

SPOKES IN SATURN'S RINGS SUGGESTED A NEW PLANETARY ENVIRONMENT FOR CHARGED DUST TRANSPORT

Voyager 2 Images ca. 1981

Image: NASA/JPL/U. of Arizona



Spokes discovered by Voyager. Light-scattering properties indicate particles are micron-sized. Morphology suggests charged dust dynamics. Details are still being researched.

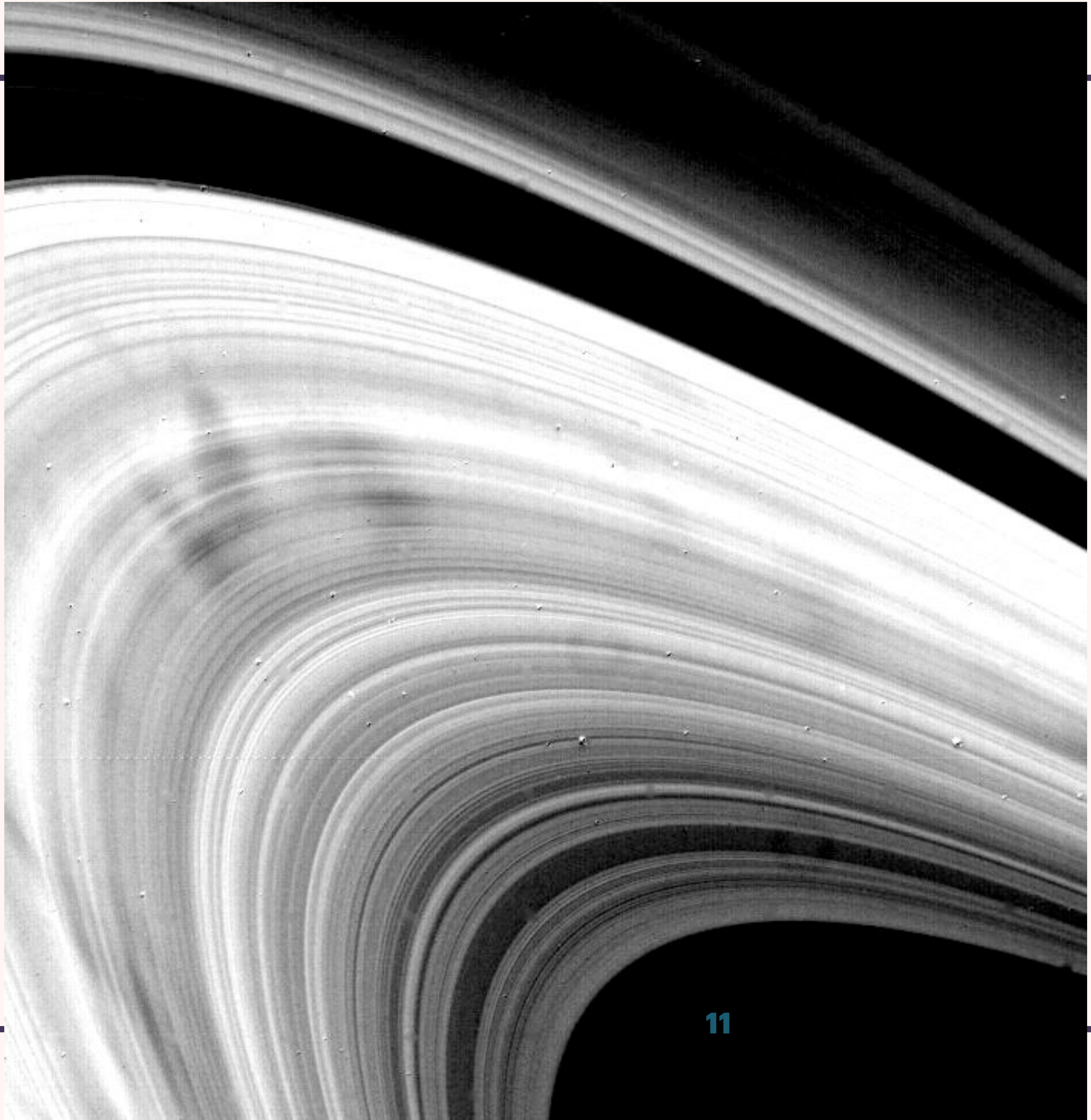


Image: NASA/JPL/U. of Arizona

Spokes absent in initial Cassini observations. Why?

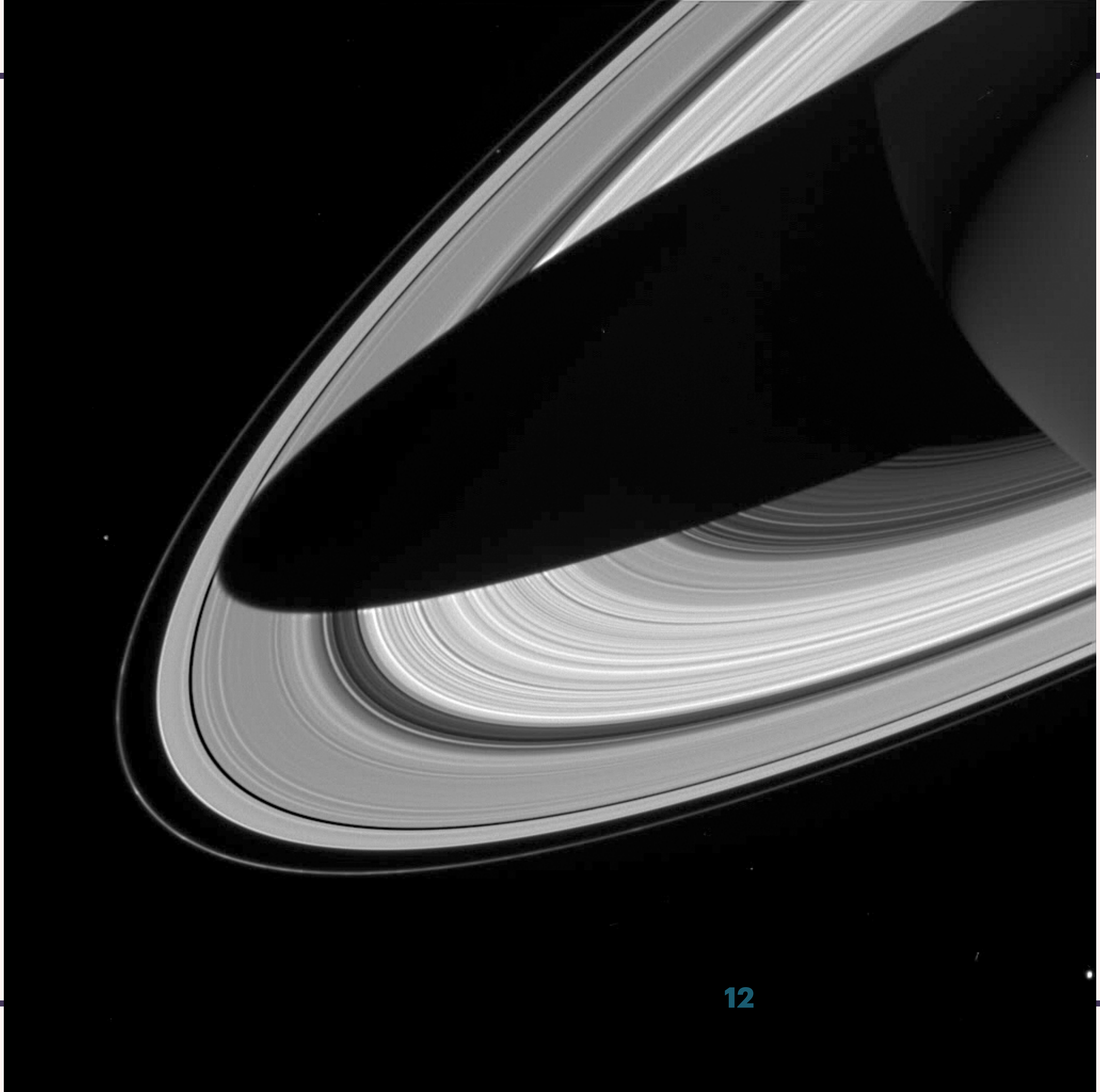
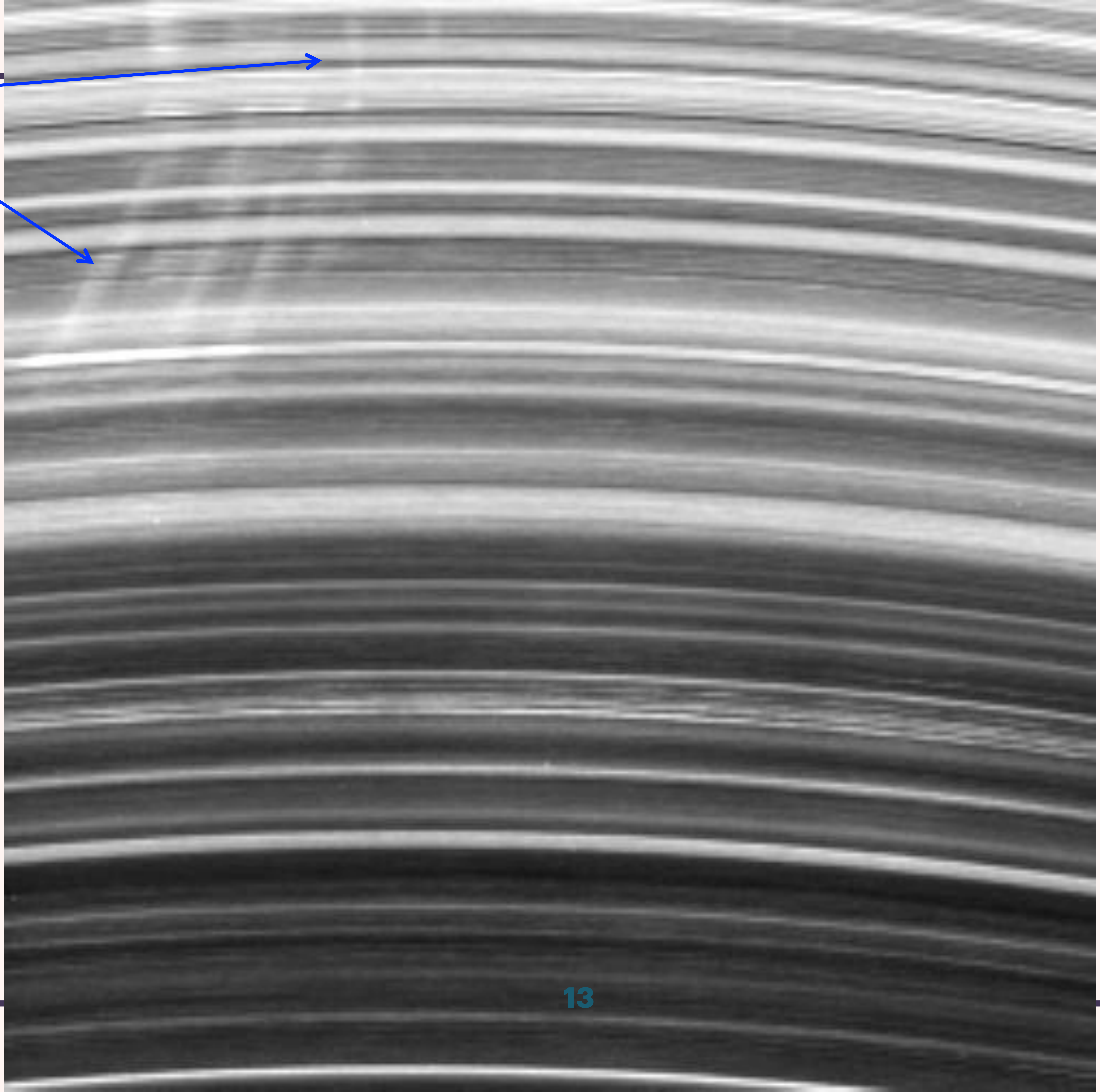


Image: NASA/JPL/U. of Arizona

Spokes

Cassini arrived closer to summer, Voyager closer to equinox. Reappearance of spokes as solar elevation angle closed down shows the Sun plays a major role in modulating chaged dust activity (Mitchell et al. (2006)).

Image: NASA/JPL/U. of Arizona



SECOND ROUND OF THEORETICAL STUDIES

- **Detailed models of dust levitation and dynamics in a variety of planetary enviroments**

  [Nitter and Havnes (1992), Nitter et al. (1994, 1998), Ip (1986)]

- **Discussion of regolith removal from asteroids [Lee (1996)]**

EQUATIONS OF CHARGE AND MOTION

$$dQ_d/dt = I_{pe} - I_e - I_{sw} \qquad \frac{d^2z}{dt^2} = \frac{Q_d}{m_d}E - g \qquad E = 2\sqrt{2}\Phi_s\lambda_D\left(1+\frac{z}{\sqrt{2}\lambda_D}\right)^{-1}$$

$\Phi_d<0$

$$I_{sw} = \pi r_d^2 e n_{sw}\sqrt{\frac{8k_BT_{sw}}{\pi m_e}}\exp\left(\frac{e\phi_d}{k_BT_{sw}}\right)$$

$$I_e = \pi r_d^2 e n_{pe}\sqrt{\frac{8k_BT_{pe}}{\pi m_e}}\exp\left(\frac{e\phi_d}{k_BT_{pe}}\right)$$

$$I_{pe} = \pi r_d^2 e I_{ph0}\exp\left(\frac{-e\phi_d}{k_BT_{pe}}\right)$$

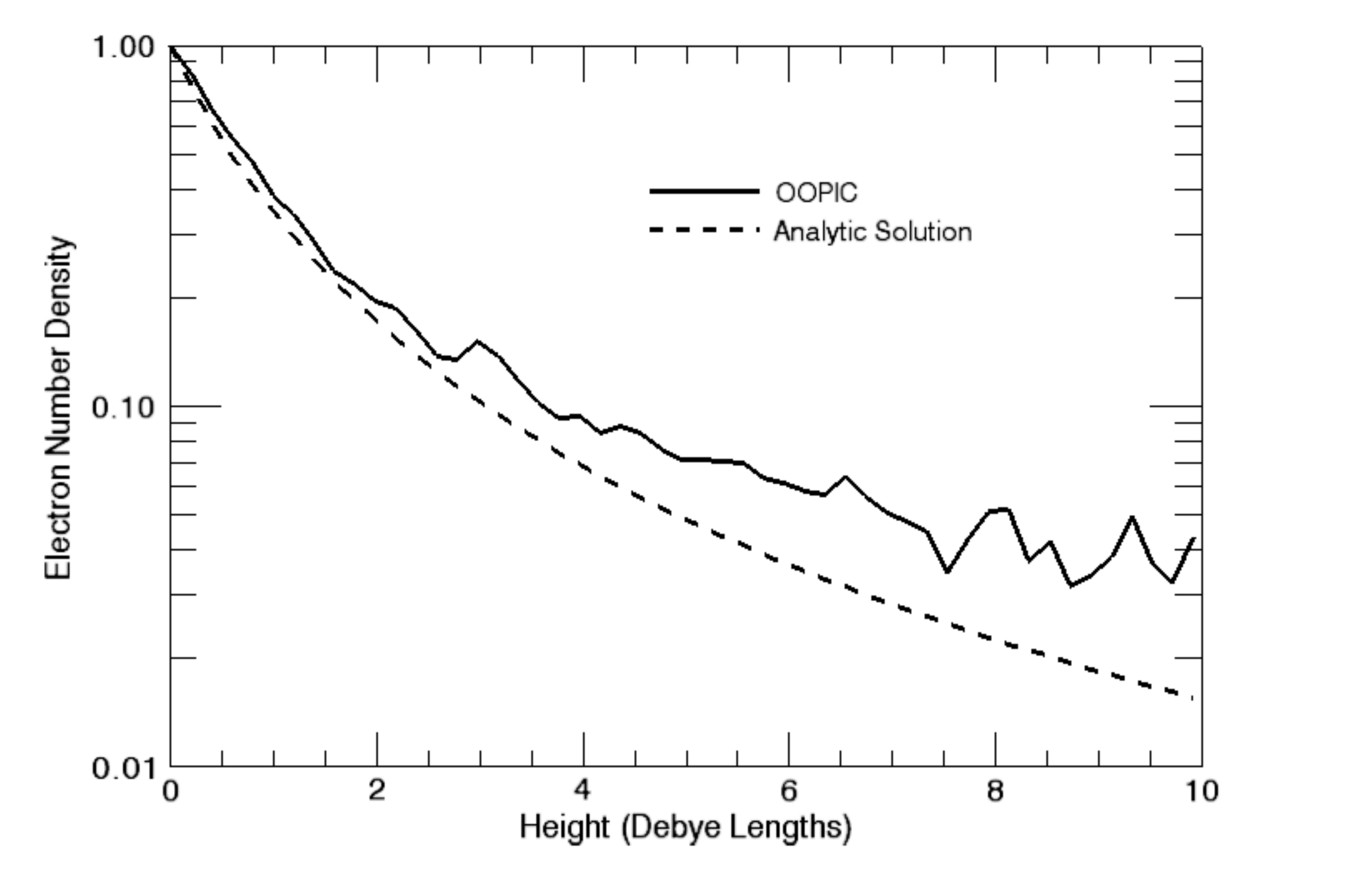
$\Phi_d>0$

$$I_{sw} = \pi r_d^2 e n_{sw}\sqrt{\frac{8k_BT_{sw}}{\pi m_e}}\left(1+\frac{e\phi_d}{k_BT_{sw}}\right)$$

$$I_e = \pi r_d^2 e n_{pe}\sqrt{\frac{8k_BT_{pe}}{\pi m_e}}\left(1+\frac{e\phi_d}{k_BT_{pe}}\right)$$

$$I_{pe} = \pi r_d^2 e I_{ph0}$$

OOPIC SIMULATION OF SHEATH



Colwell et al. 2009 (J. Aero. Eng.)

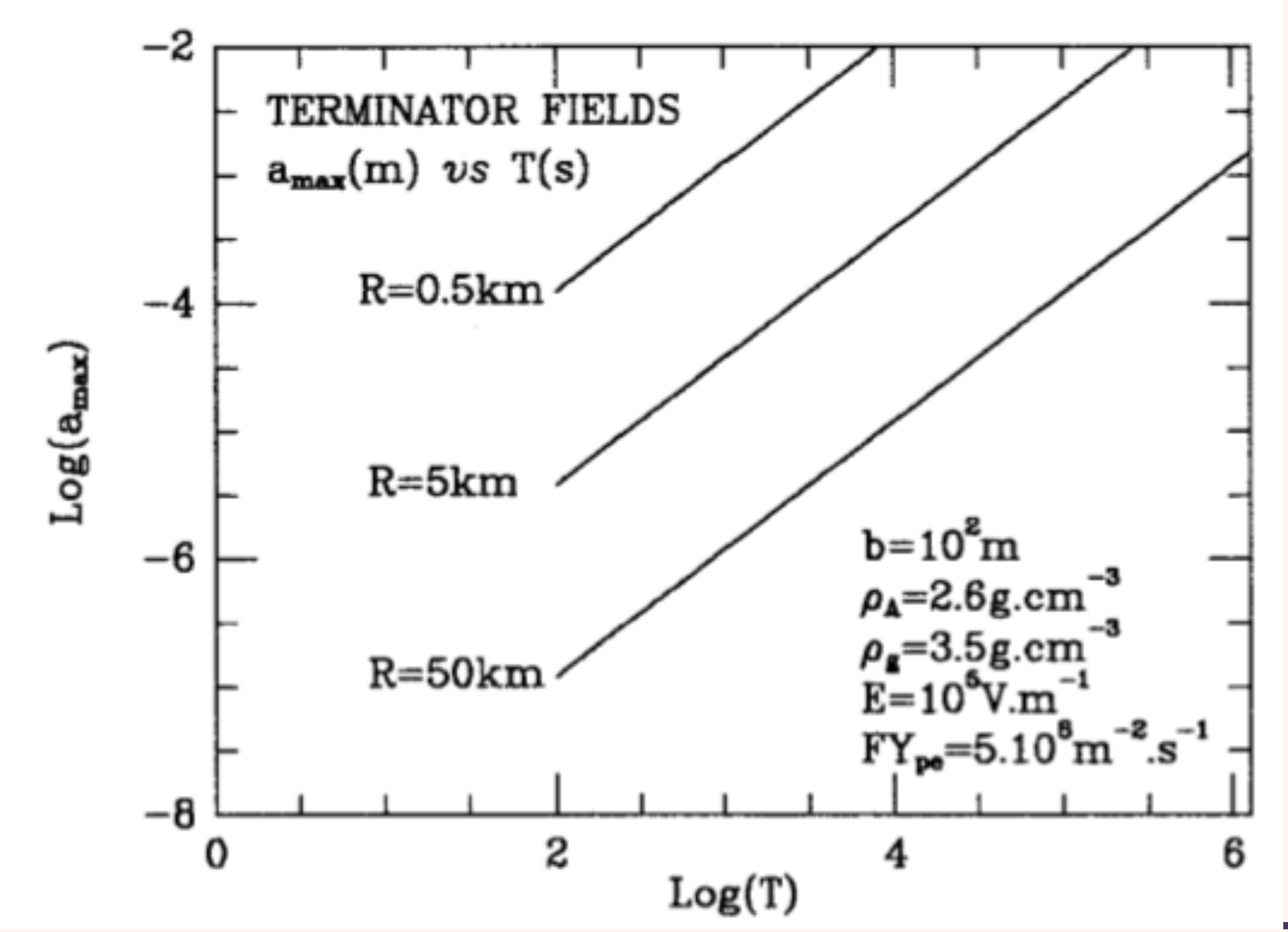
SURFACE POTENTIALS AND ELECTRIC FIELDS

- On the dayside the dominant current is photoelectron emission, leading to a positive potential of a few Volts.
- On the nightside the dominant current is collection of solar wind electrons leading to a negative potential of tens to ~100 Volts.
- Passage through Earth's magnetotail can enhance the potential on both dayside and nightside to 100s of V.
- Vertical electric fields are on the order of V/m, while small-scale surface fields may be ~100-1000 x larger, perhaps especially near the terminator.

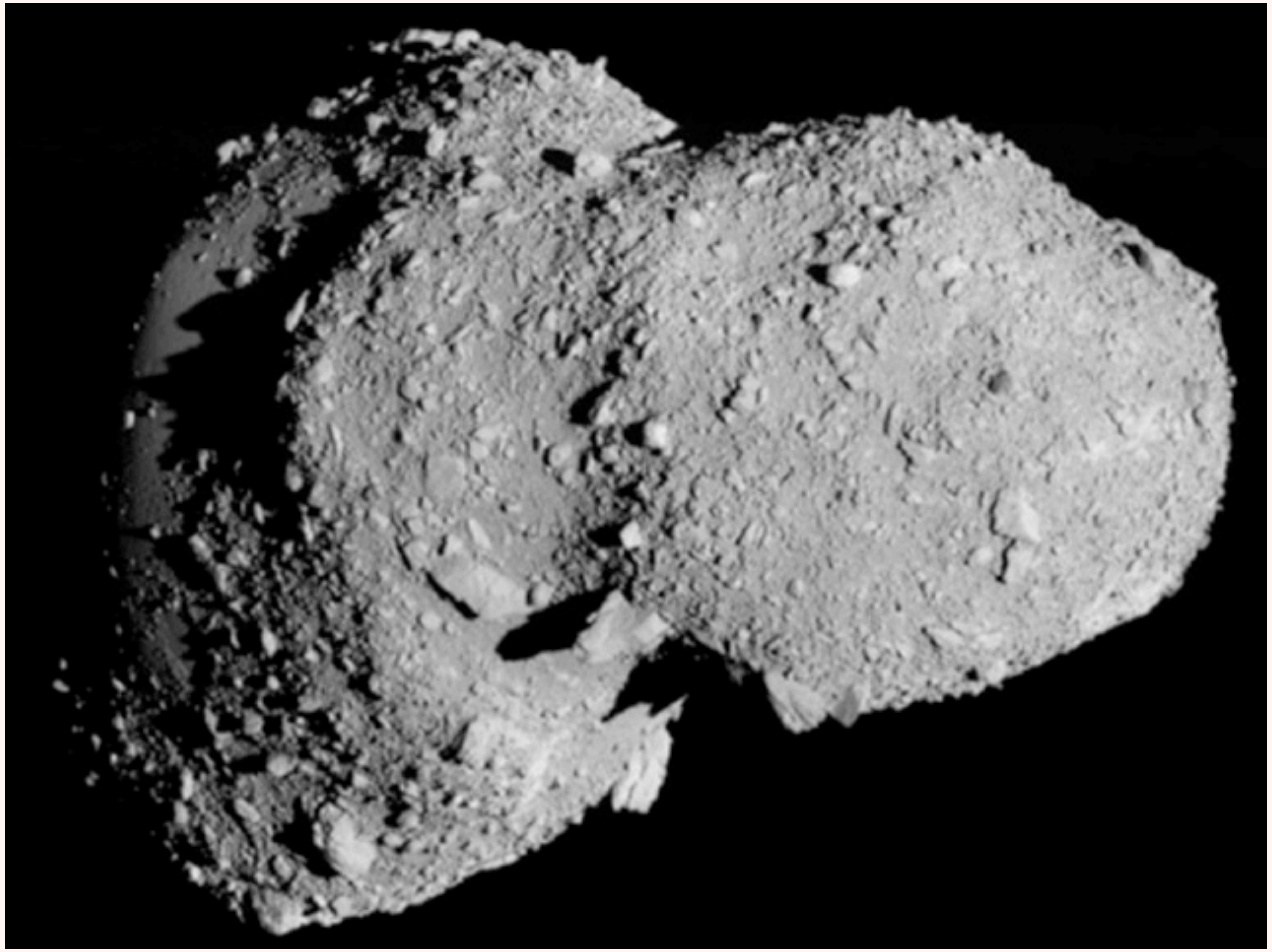
SIZE OF LAUNCHABLE PARTICLES

Launchable: can be lifted off the surface by electrostatic force.

Levitatable: can be stably levitated above the surface by a balance between gravity and electrostatic force.

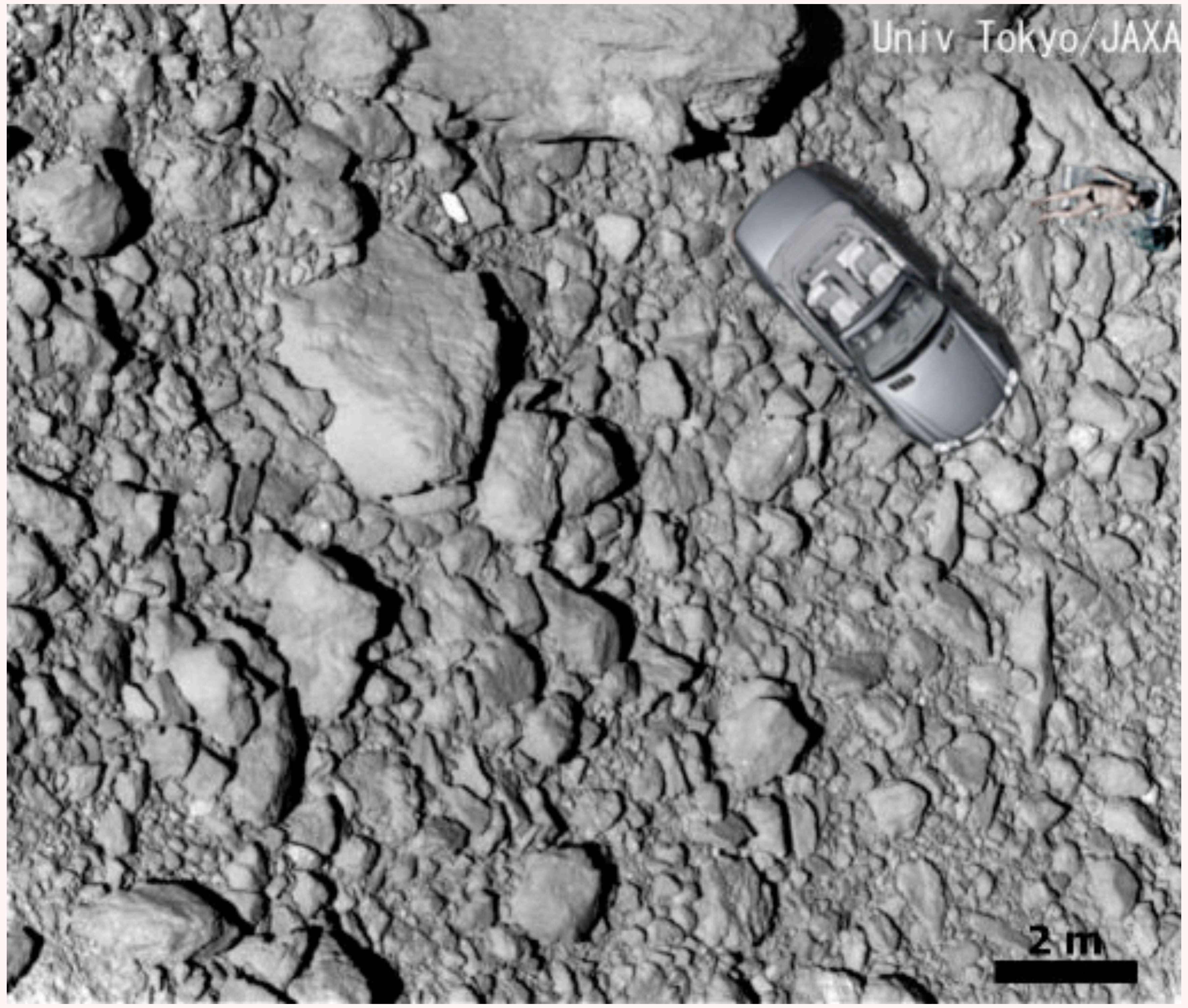


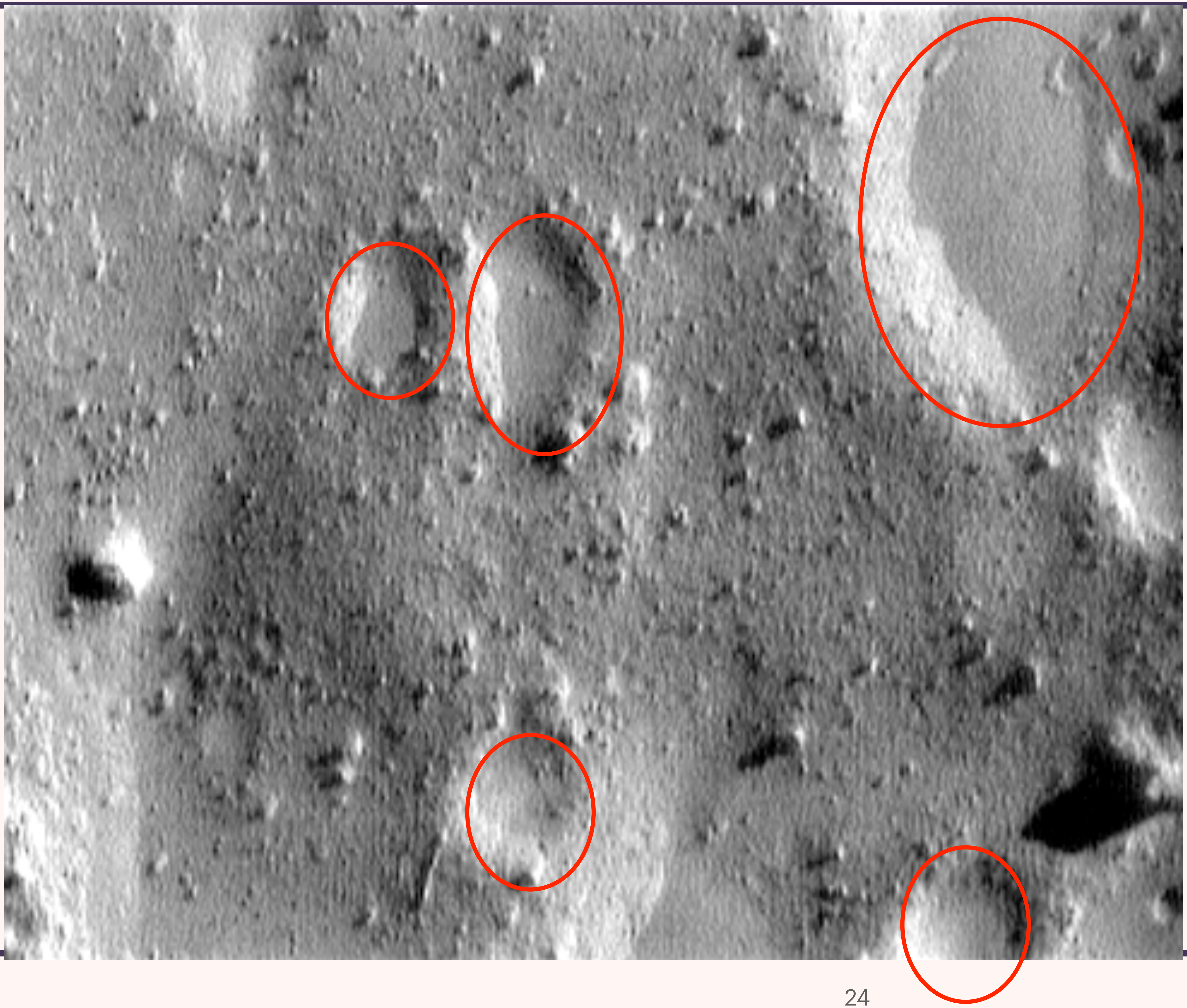
Lee (1996)



Itokawa, length~500 m, shows regions free of dust and other smooth regions.

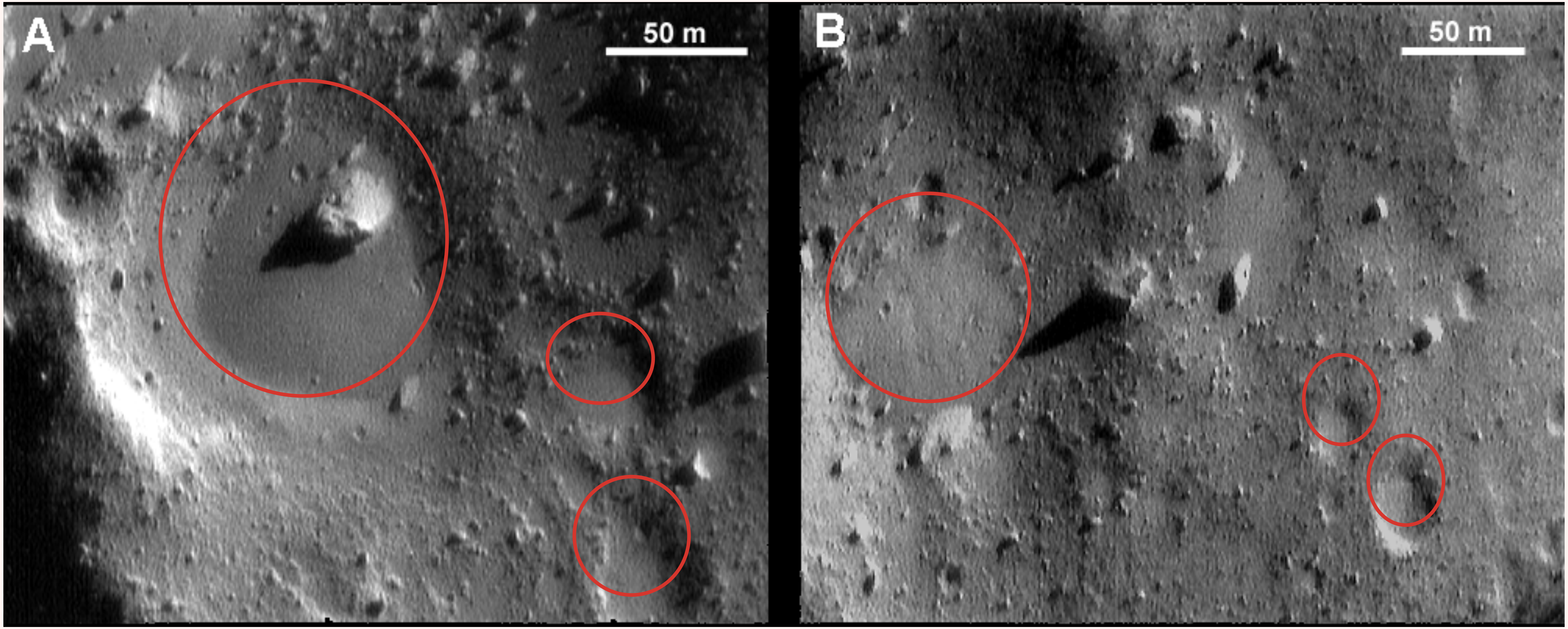
Smooth areas at gravitational lows. Downslope movement plays a role.





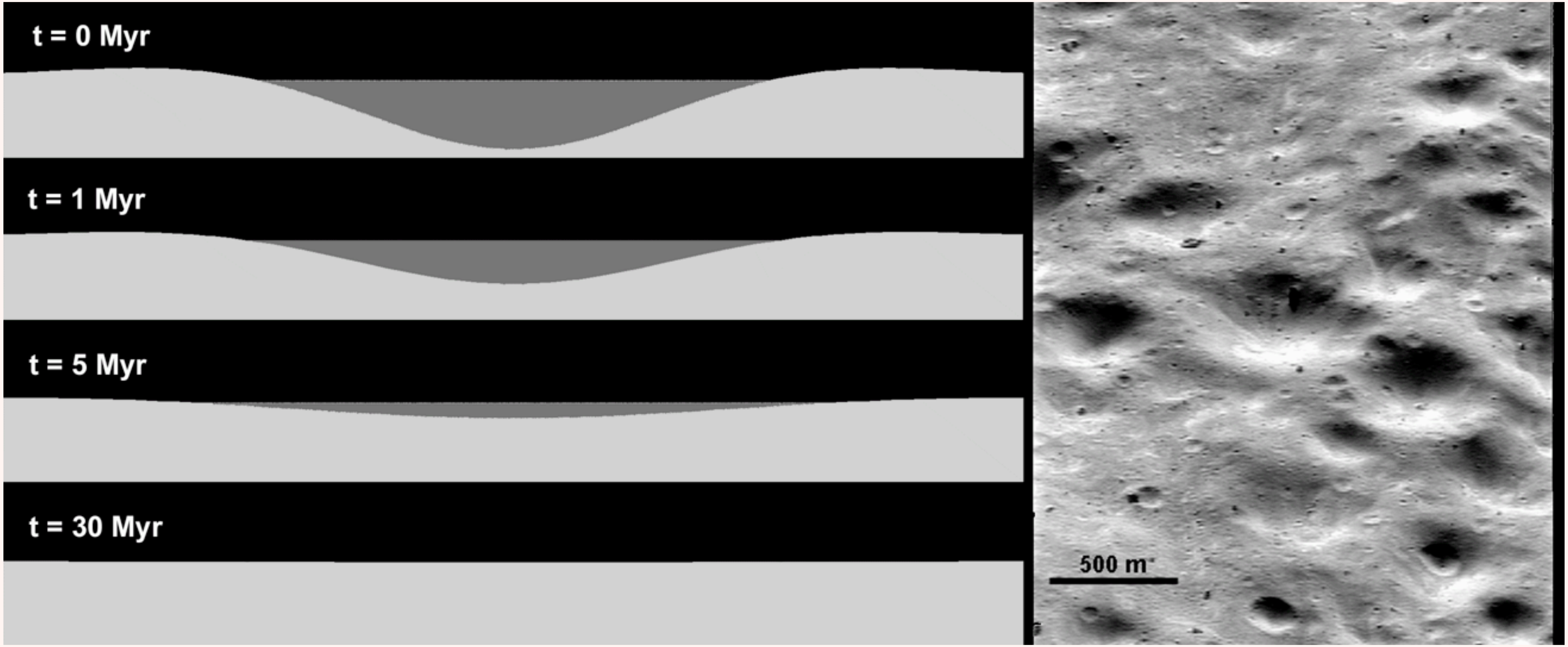
DUST "PONDS" ON EROS

PONDS ARE CLUSTERED AT THE ENDS OF EROS WHERE G IS SMALL, CONTRARY TO ITOKAWA



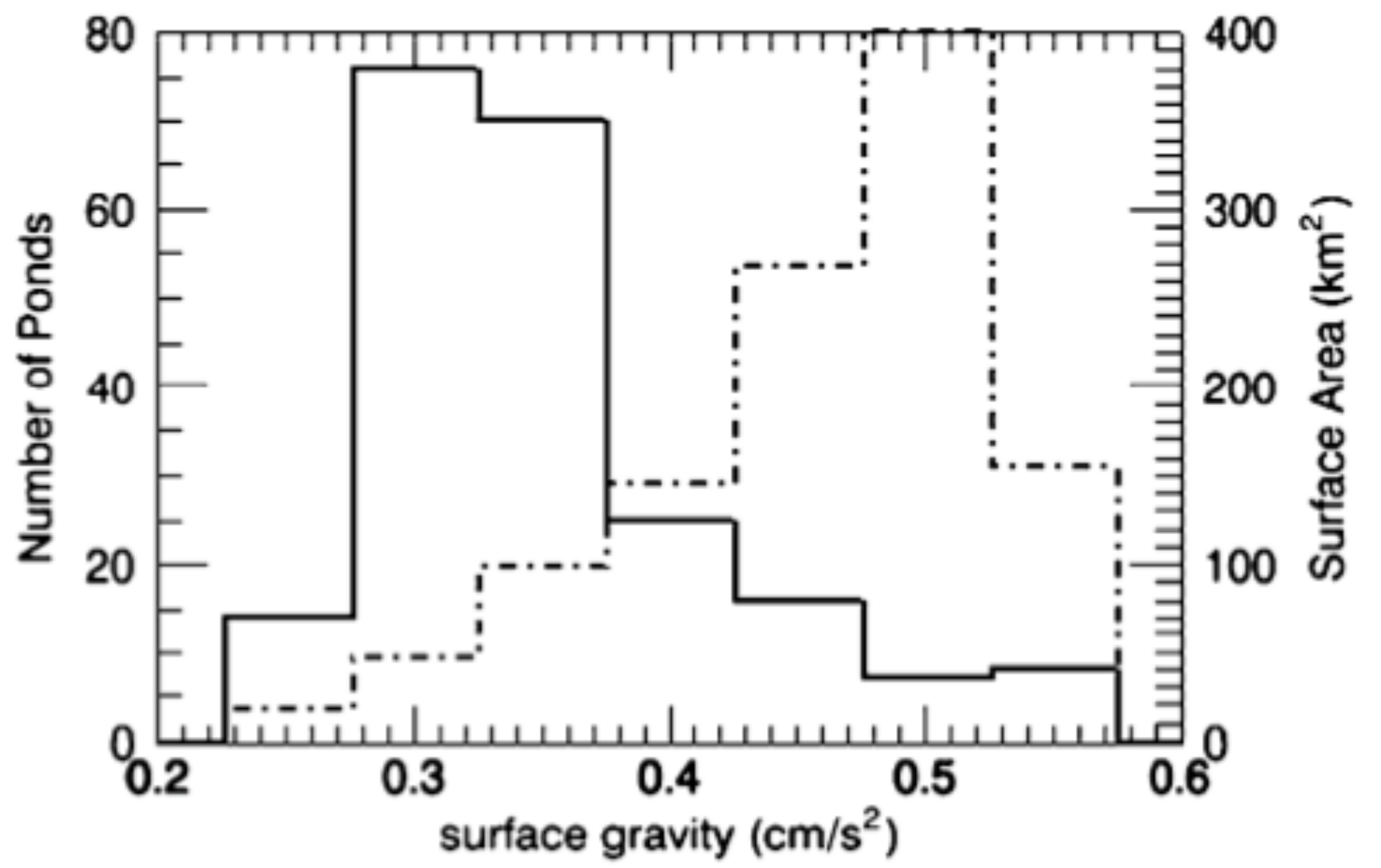
(but g is larger everywhere on Eros than anywhere on Itokawa)

SEISMIC SHAKING PRODUCES MORE ROUNDED CRATER FLOOR PROFILES THAN WHAT IS OBSERVED IN PONDS.



PROPERTIES OF EROS PONDS

- 255 ponds > 30 m diameter.
- ~90% near Eros's equator.
- Eros has obliquity near 90 degrees, suggesting solar illumination may play role in pond formation.



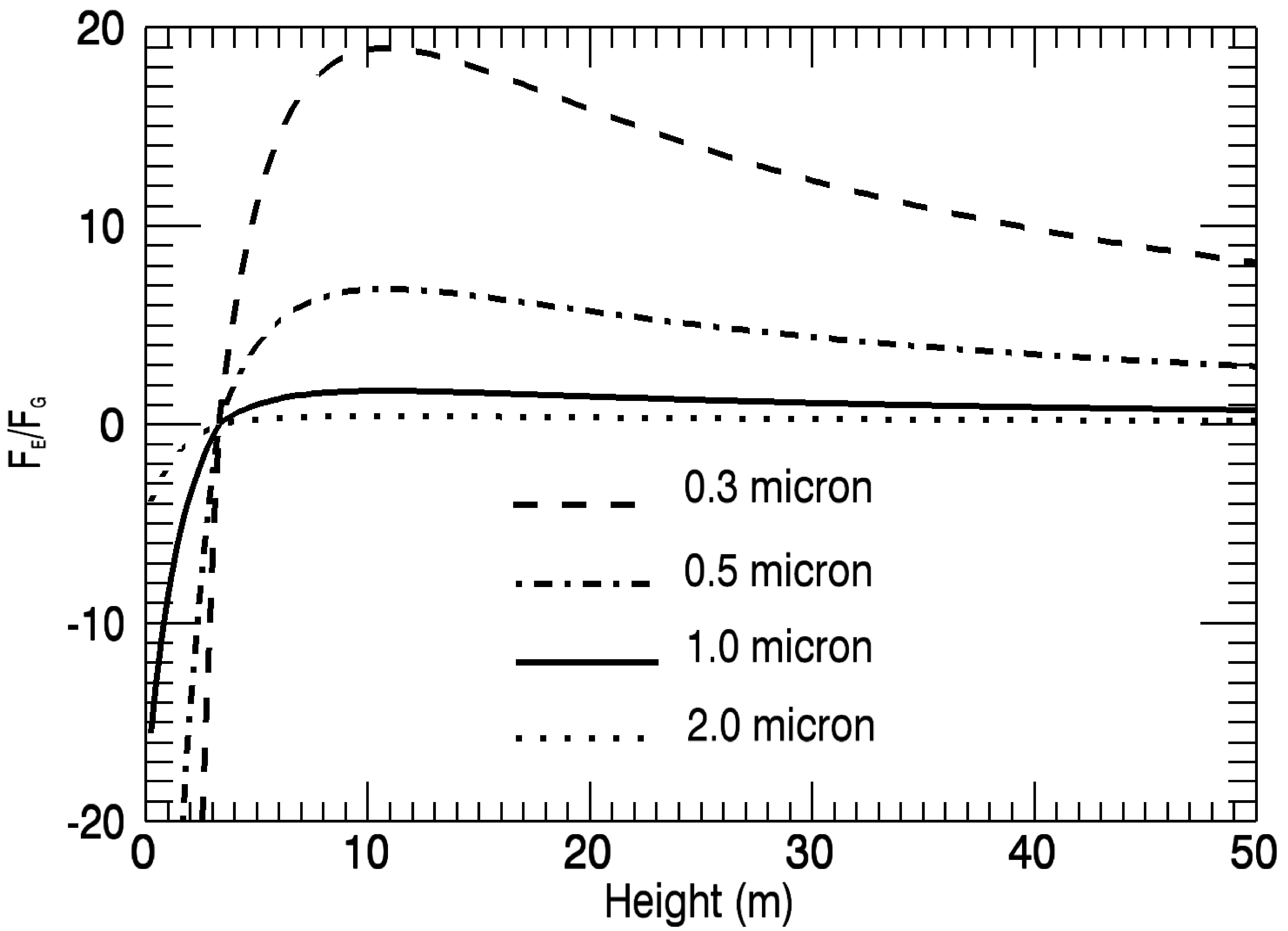
Shape of Eros places ponds mostly at areas of low surface gravity.

(Robinson et al. 2002, Hughes et al. 2008)

NUMERICAL SIMULATIONS

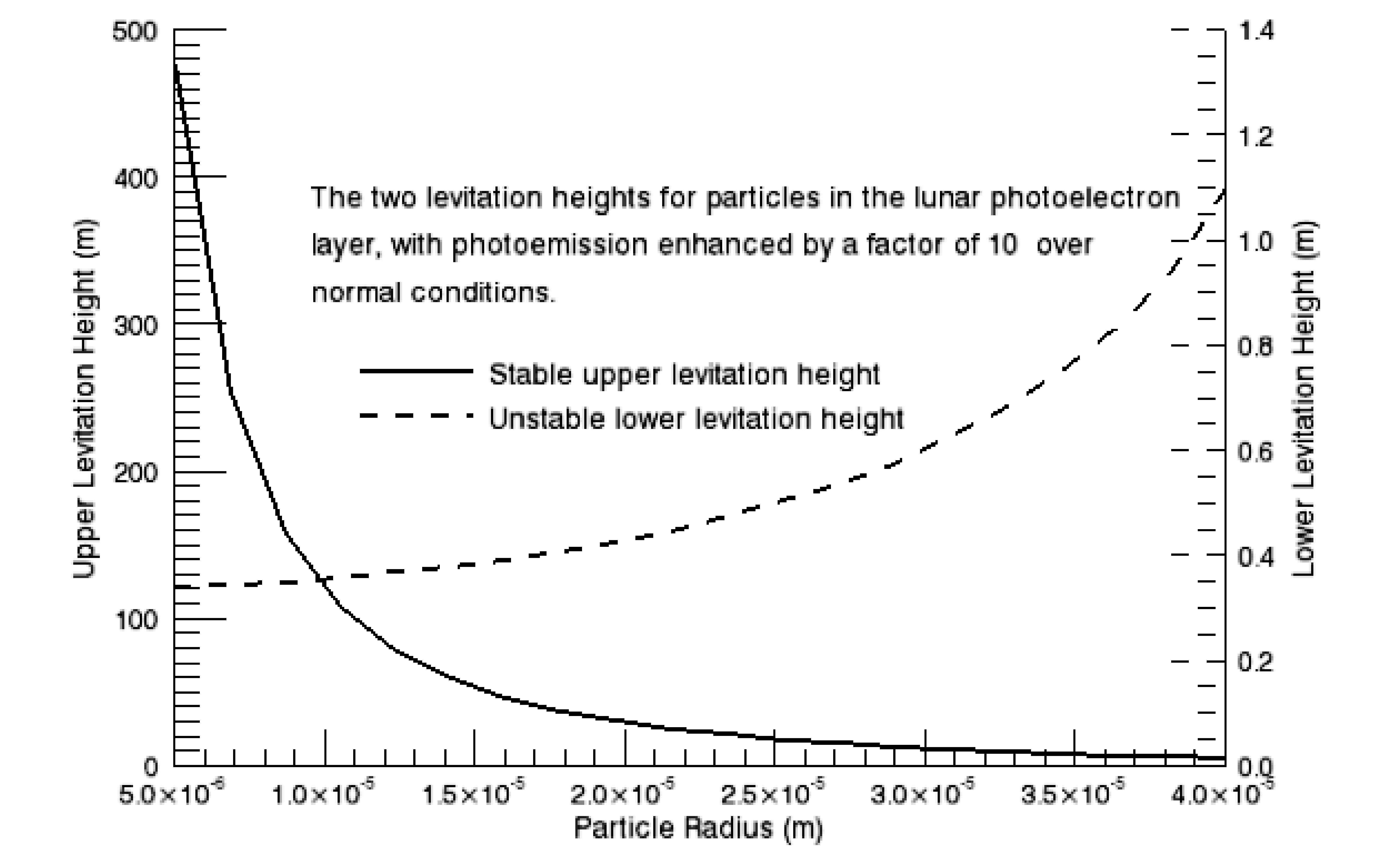
- Dayside photoelectron sheath.
- Calculate surface potential.
- Calculate currents to dust particle.
- Integrate equation of motion under force of gravity and electric force.
- Include effects of topography on shadowing (surface potential) and trajectories.

FORCE BALANCE

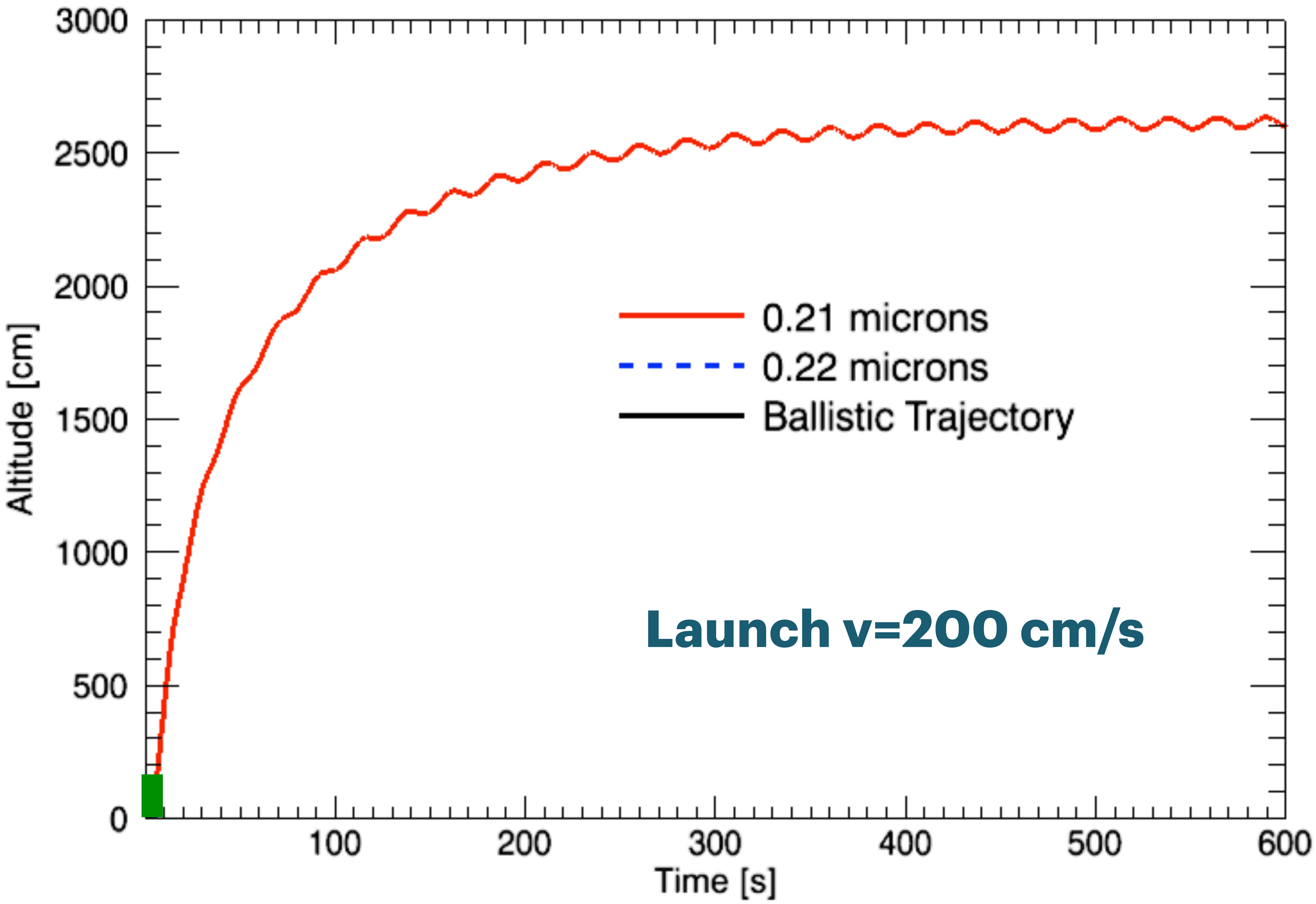


Example for Moon

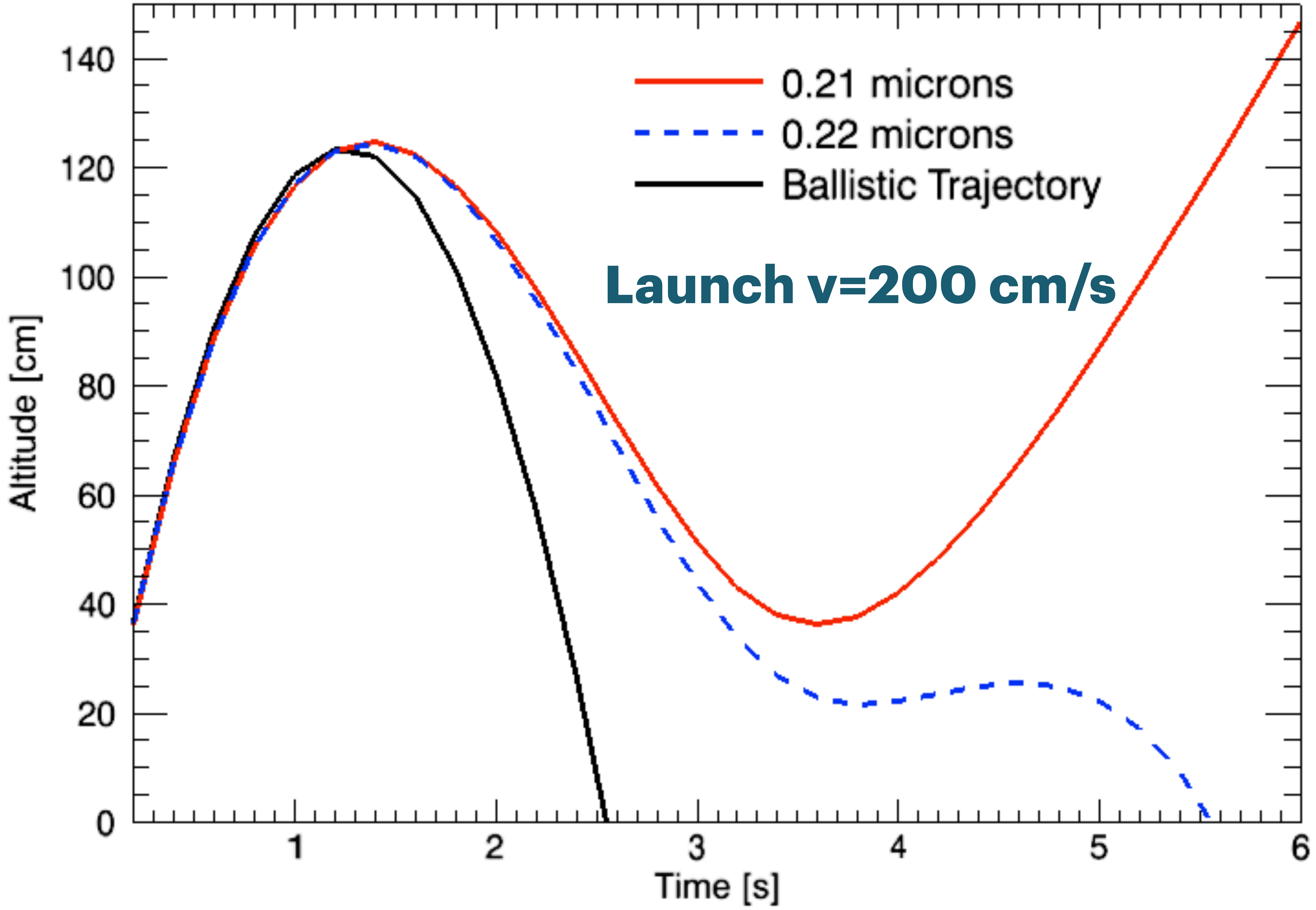
LUNAR LEVITATION HEIGHTS



TRAJECTORIES OF LUNAR DUST



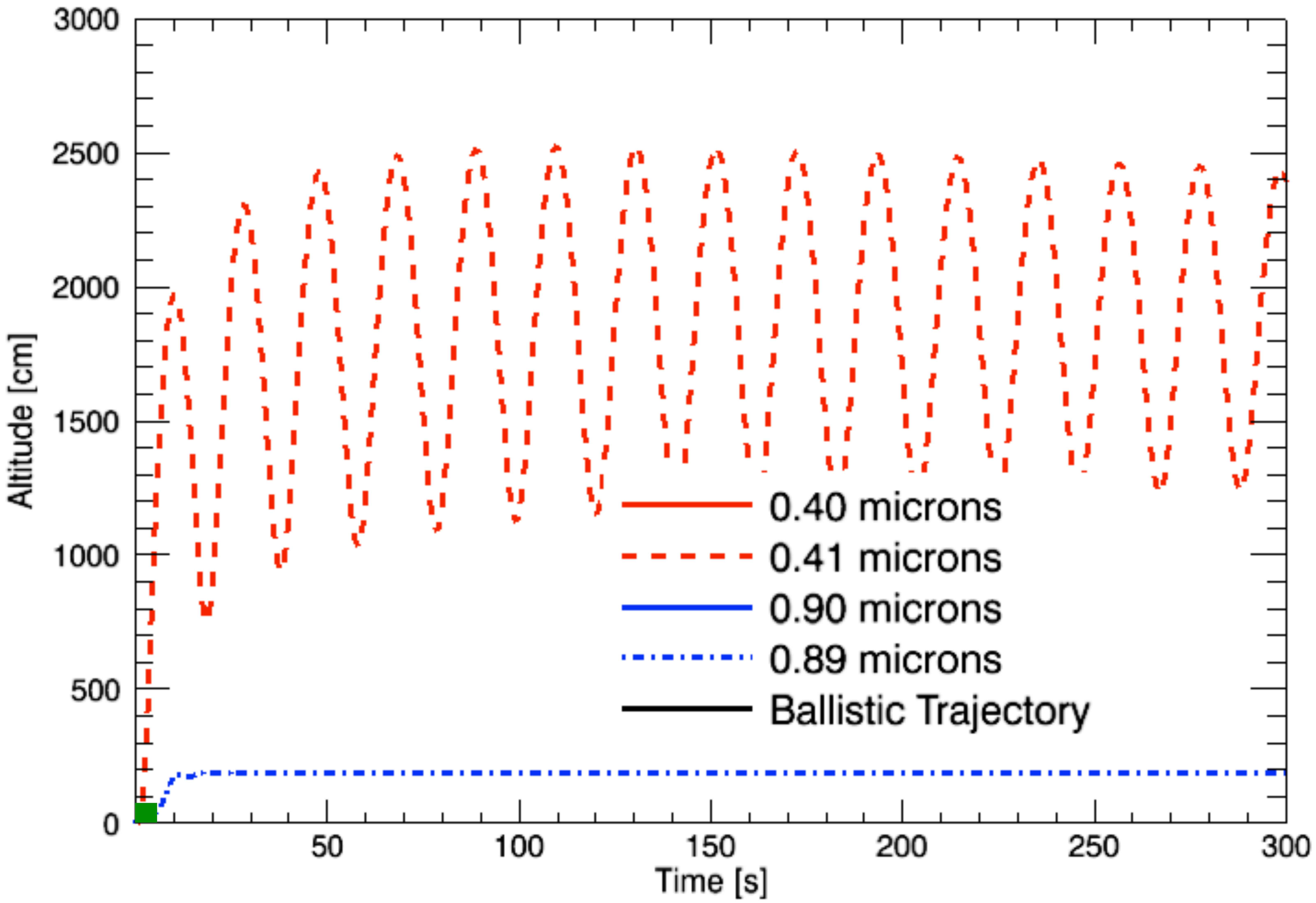
TRAJECTORIES OF LUNAR DUST



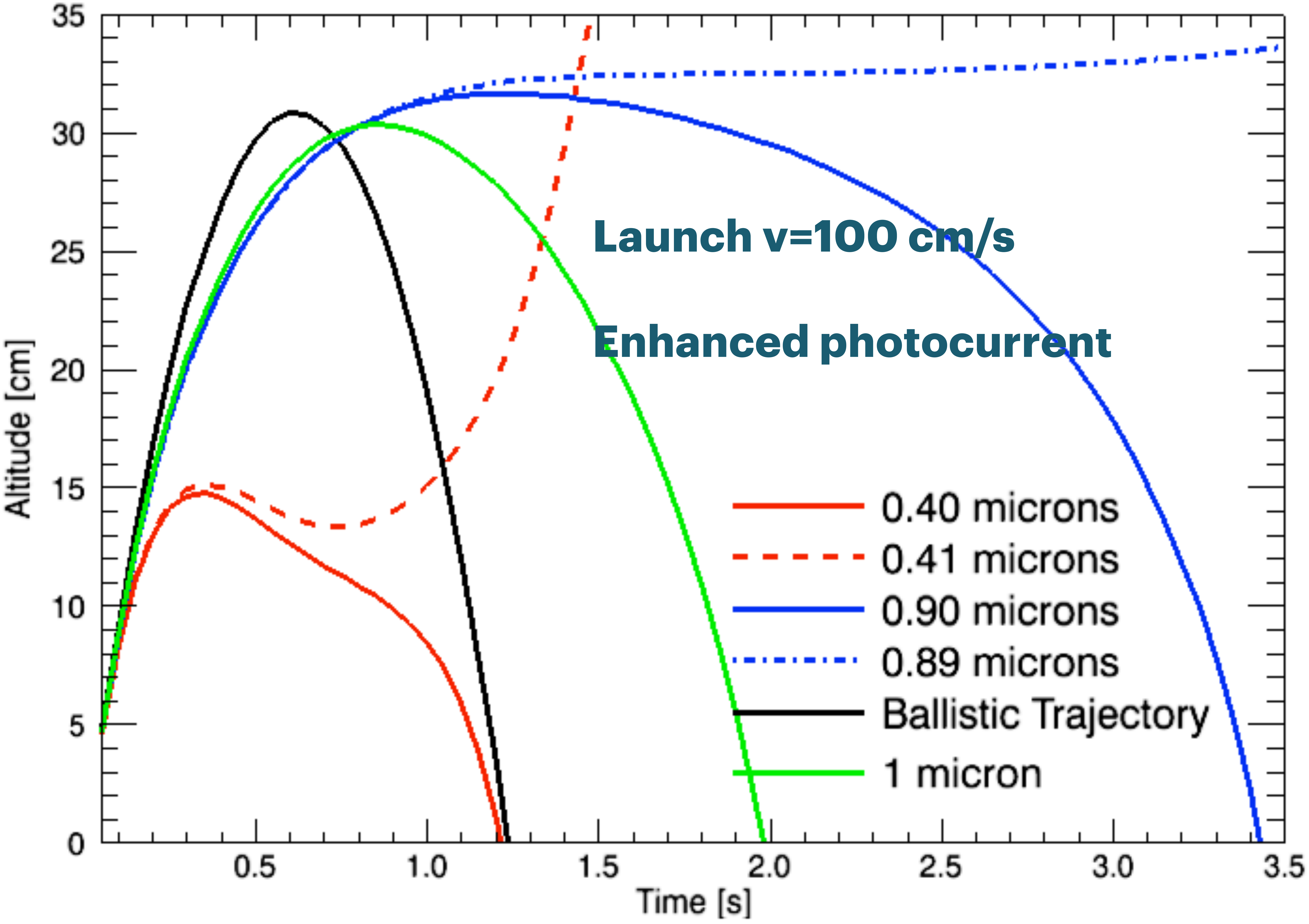
TRAJECTORIES OF LUNAR DUST

Launch v=100 cm/s

Enhanced photocurrent



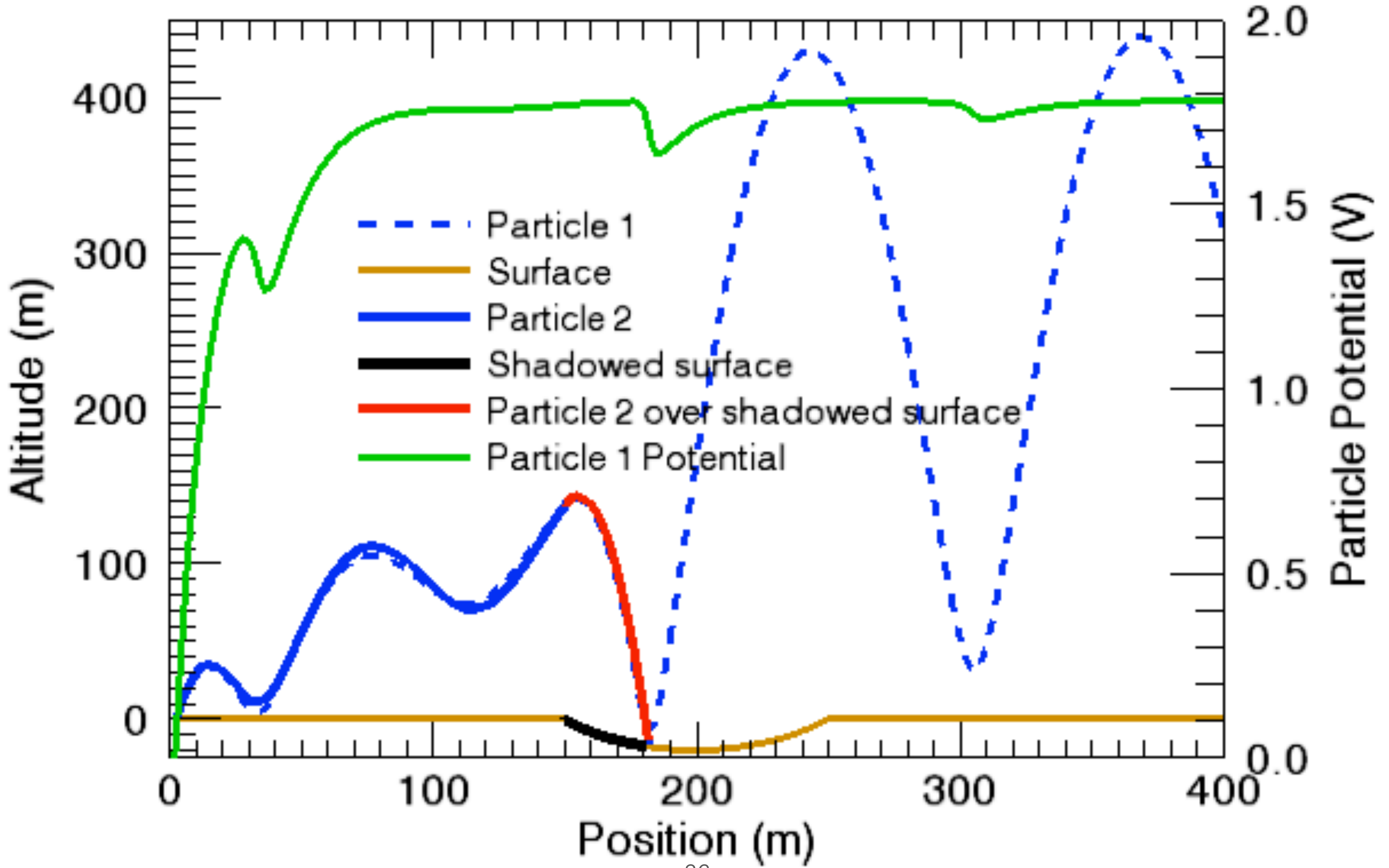
TRAJECTORIES OF LUNAR DUST



LUNAR SIMULATIONS: WHAT DO THEY MEAN?

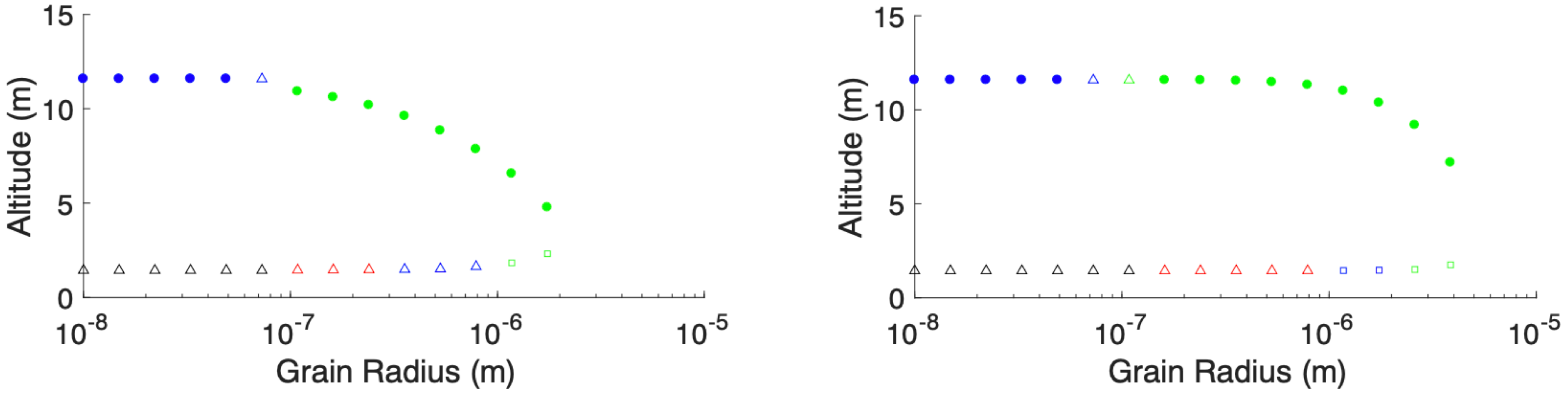
- Surveyor Horizon Glow particles are not levitating (would be much higher, extended cloud), but are on ballistic trajectories (launched somehow).
- Height of HG cloud and size of LEAM (~30 cm) constrain electrostatic launch velocity at 1 m/s.

EFFECTS OF TOPOGRAPHY



EFFECTS OF RADIATION PRESSURE

- **Suppresses vertical oscillations.**
- **Lowers altitude of levitation.**
- **Global 2D simulations shows levitation can still occur with global transport.**



(a) With Solar Radiation Pressure (b) Without Solar Radiation Pressure

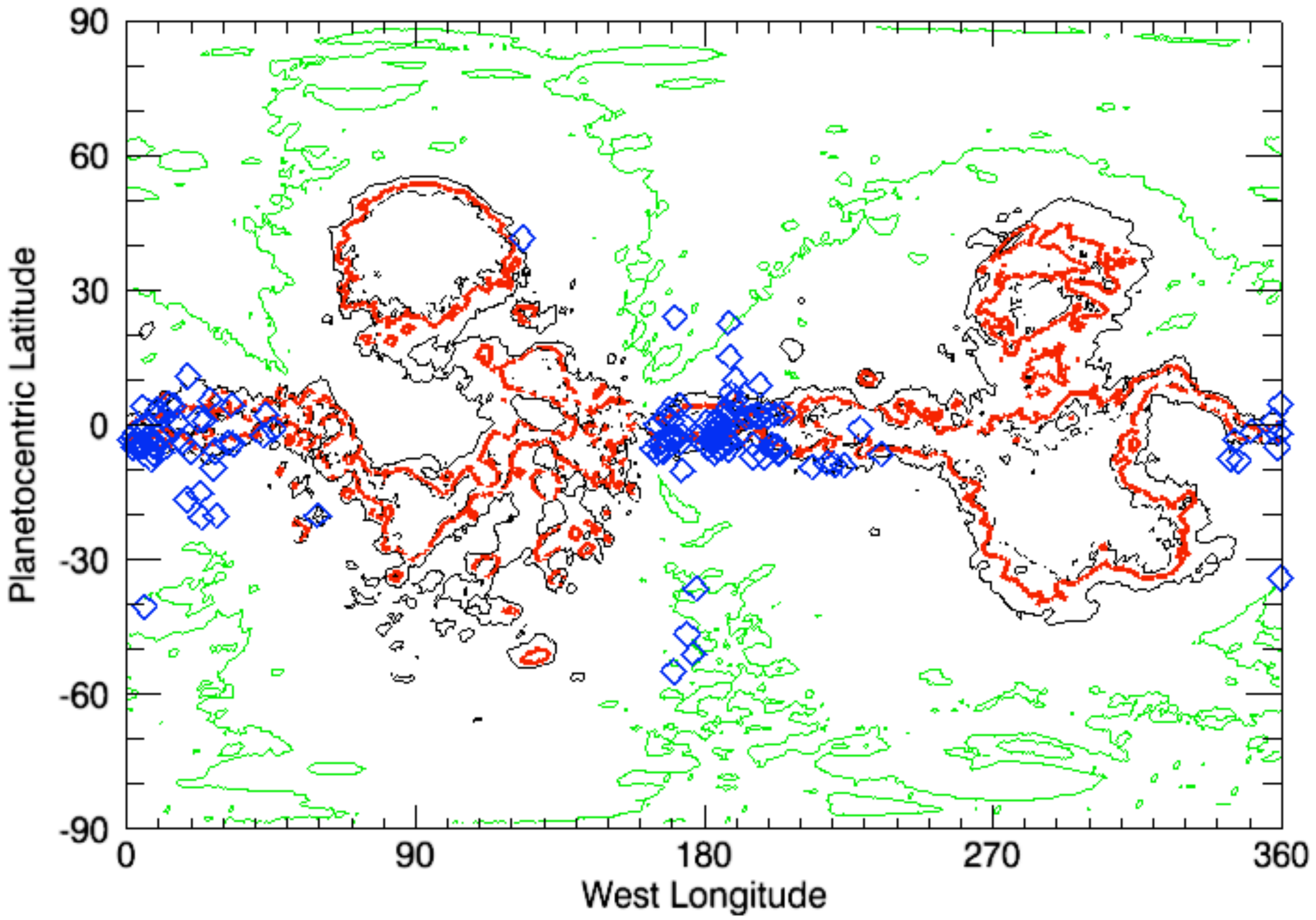
Fig. 2. Equilibria as a function of grain size for a non-spinning, 250 m radius asteroid with and without solar radiation pressure (SRP). Note that the equilibrium state includes an altitude and charge. The equilibrium charge is indicated by the color of the points (Black: 0–1 electron, Red: 1–10 electrons, Blue: 10–100 electrons, Green: > 100 electrons). The solid points are stable equilibria and the hollow points are unstable equilibria. The hollow triangle equilibria have one positive real pole and two negative complex poles. The hollow square equilibria have three real poles, one of which is positive. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Hartzell 2019

CAN CHARGED DUST EXPLAIN EROS PONDS?

- Use two numerical models to model diurnal and seasonal dust transport with topography.
- Tabulate probabilities of dust deposition in craters.

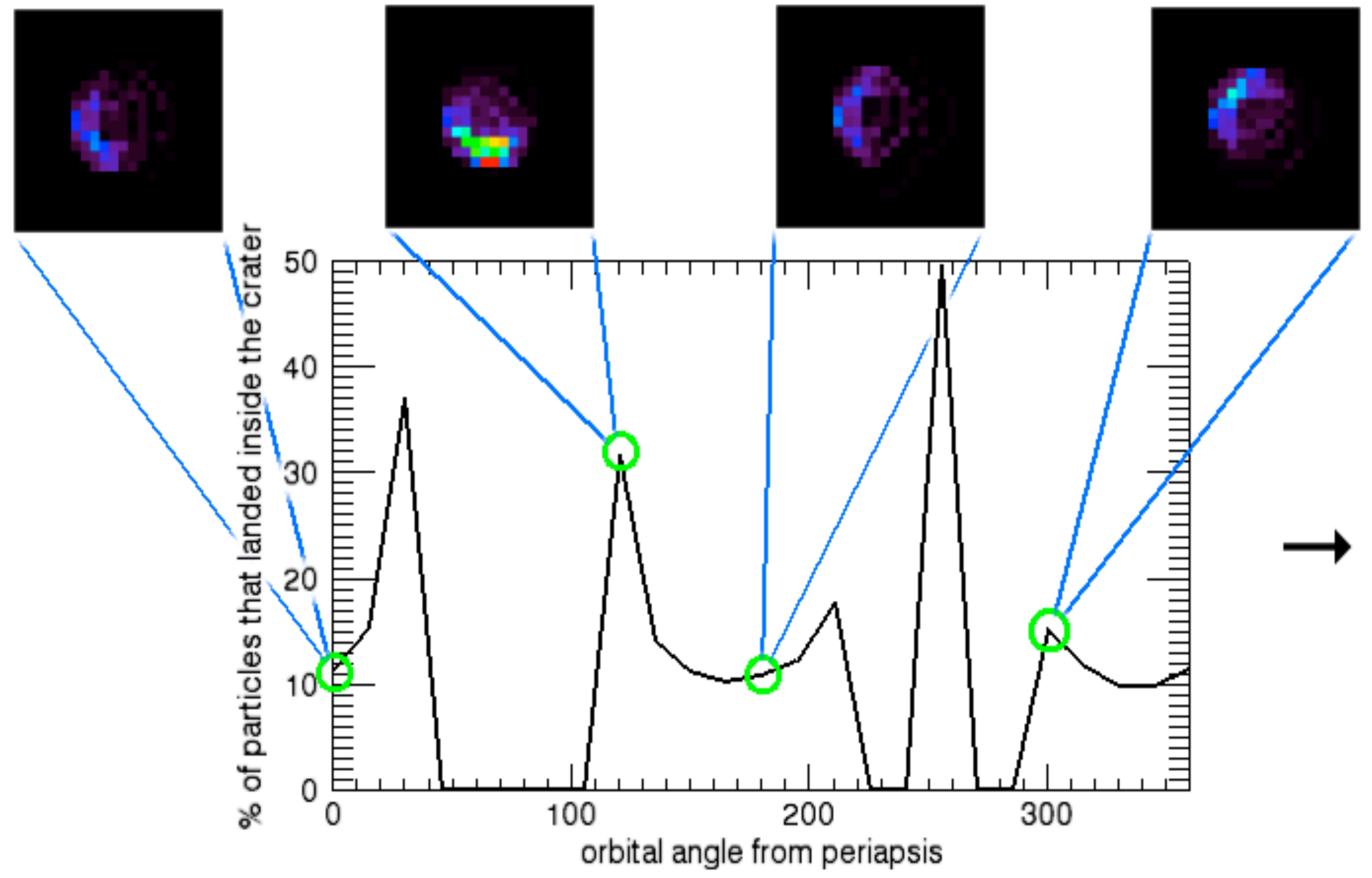
DISTRIBUTION OF PONDS ON EROS

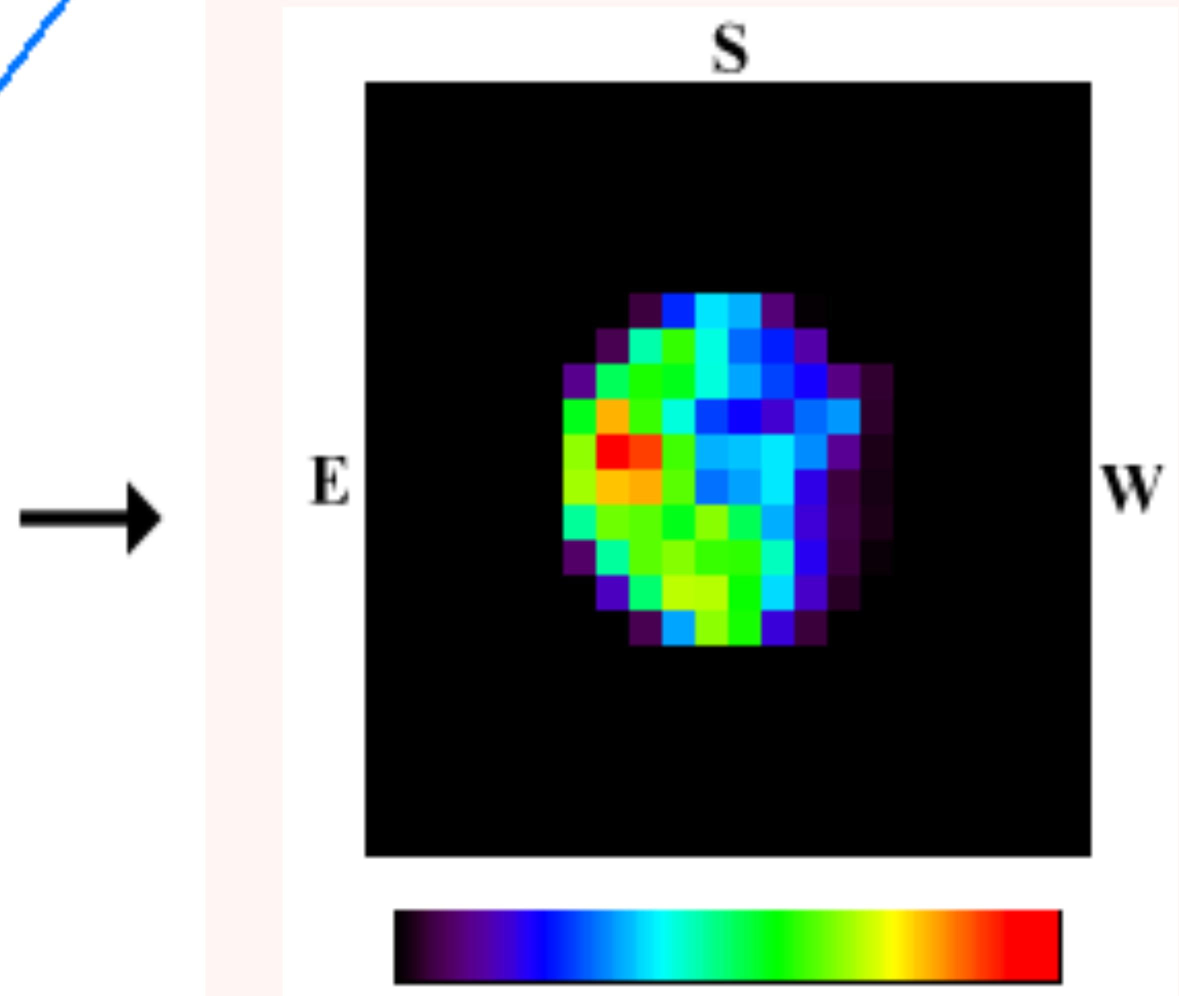


Contours are areas that spend large fraction of time with Sun near the horizon.

Hughes et al. 2008

"FLOATING" DUST SIMULATION OF PONDS

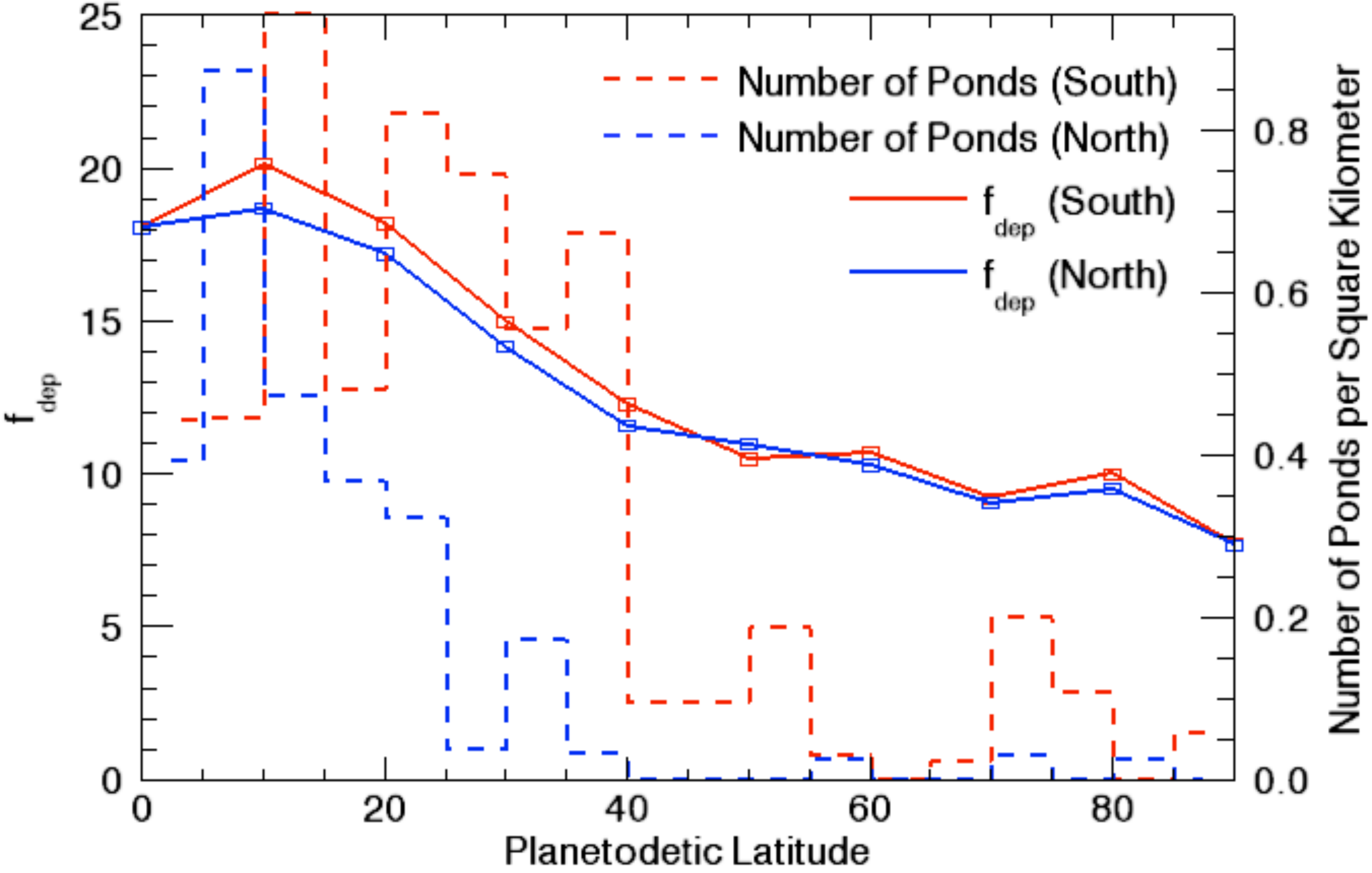




Seasonal variations in dust deposition

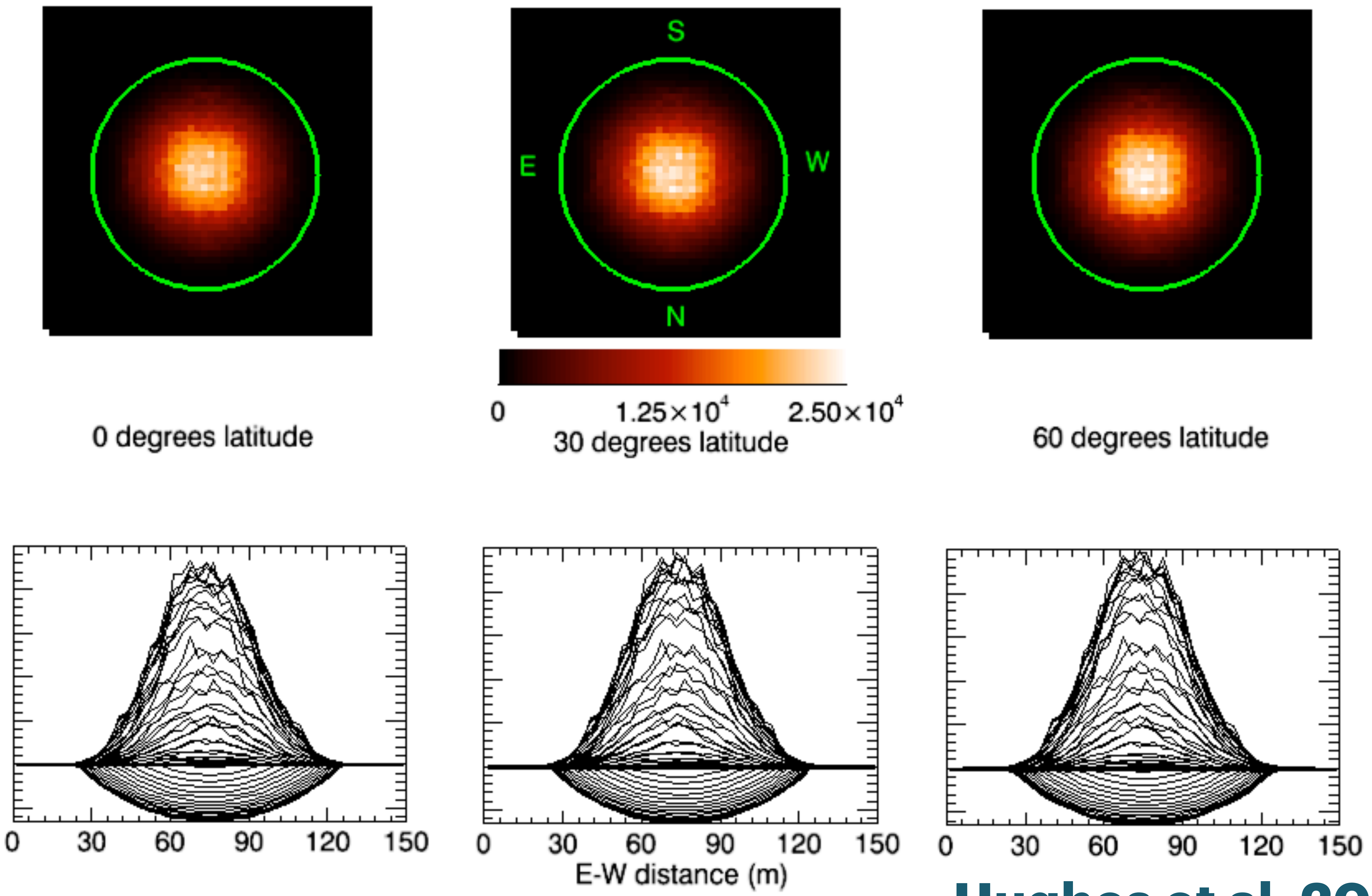
Hughes et al. 2008

Efficiency of dust deposition in craters on Eros

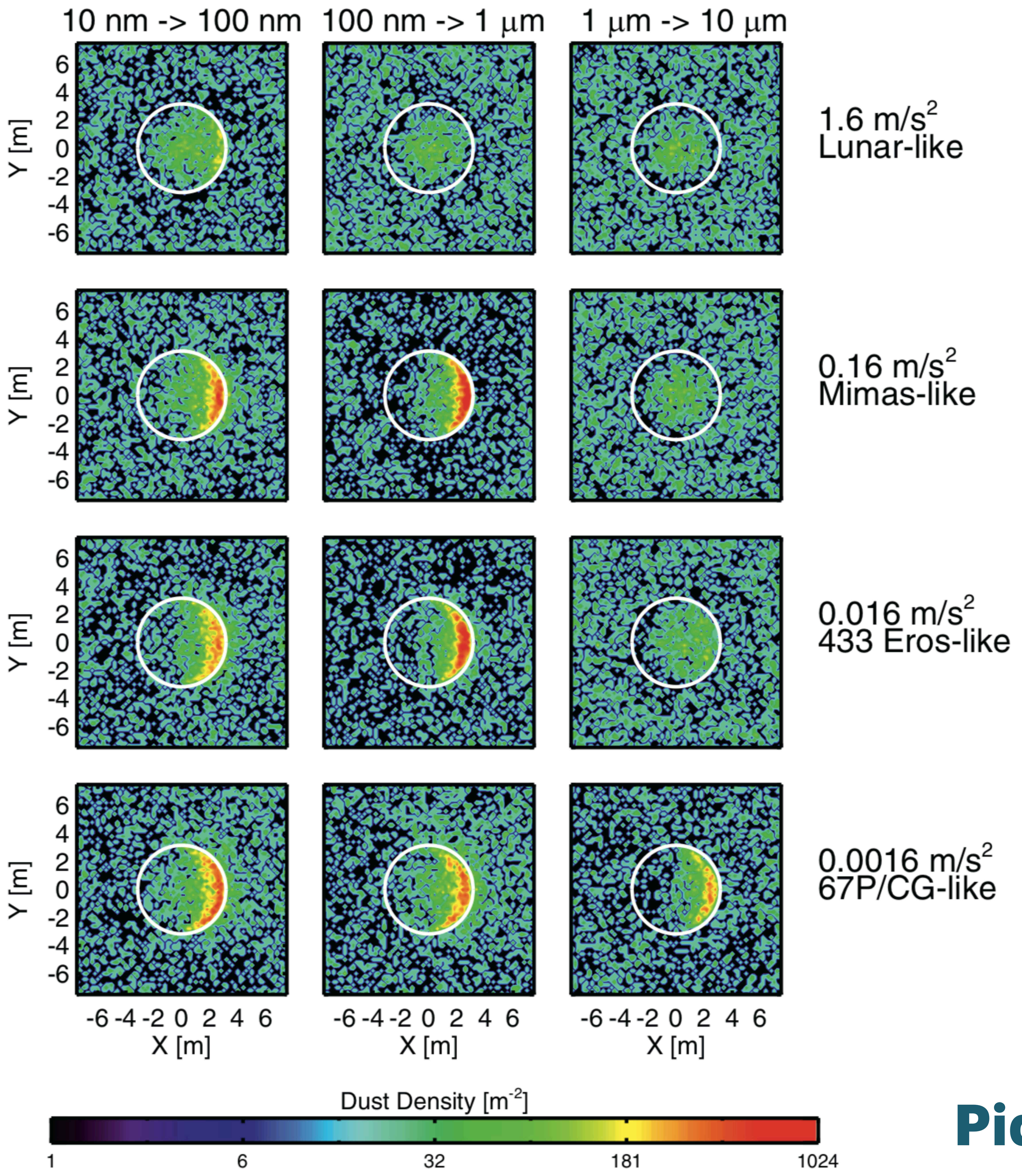


Hughes et al. 2008

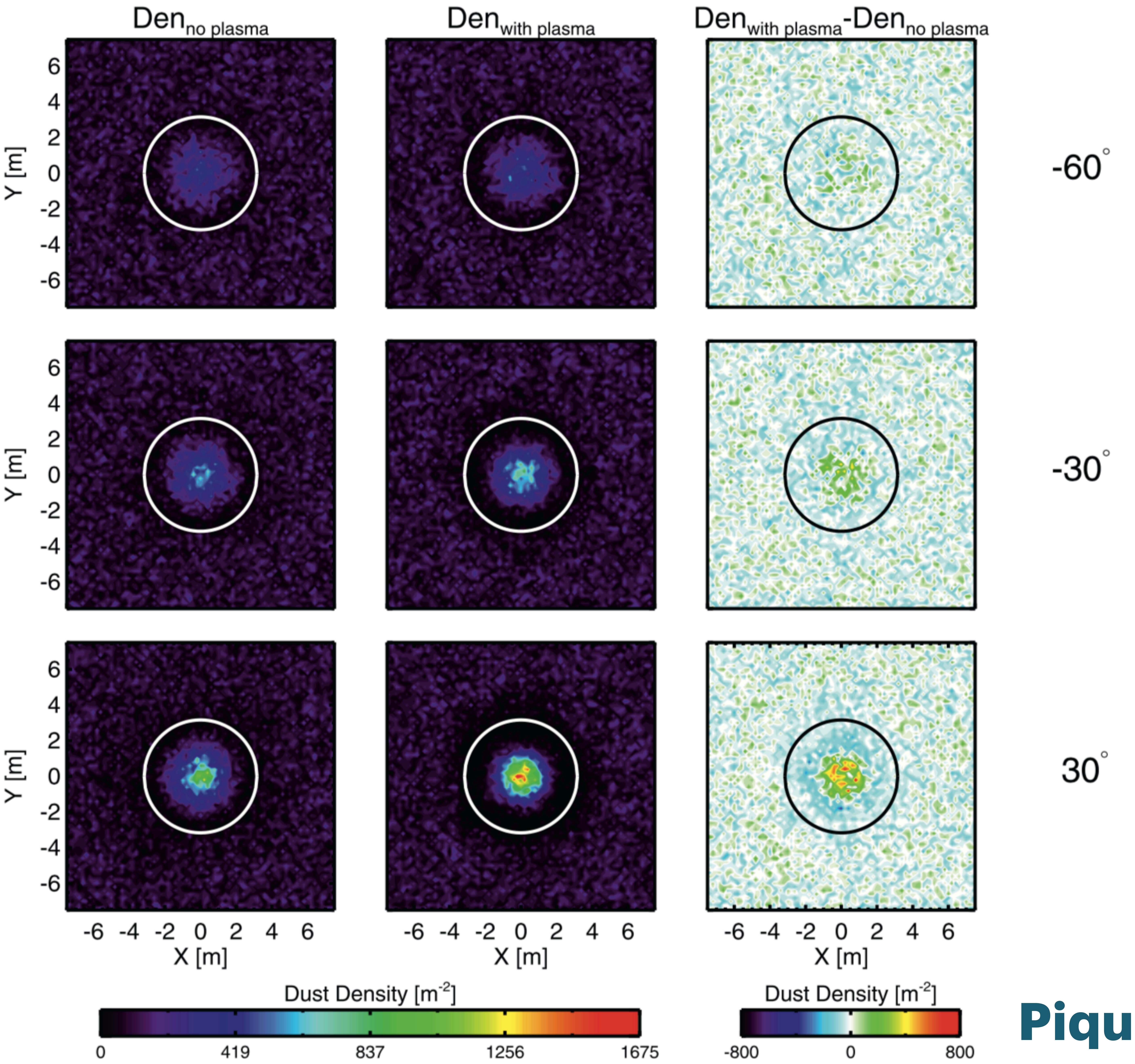
ALTERNATE MODEL: "HOPPING" DUST



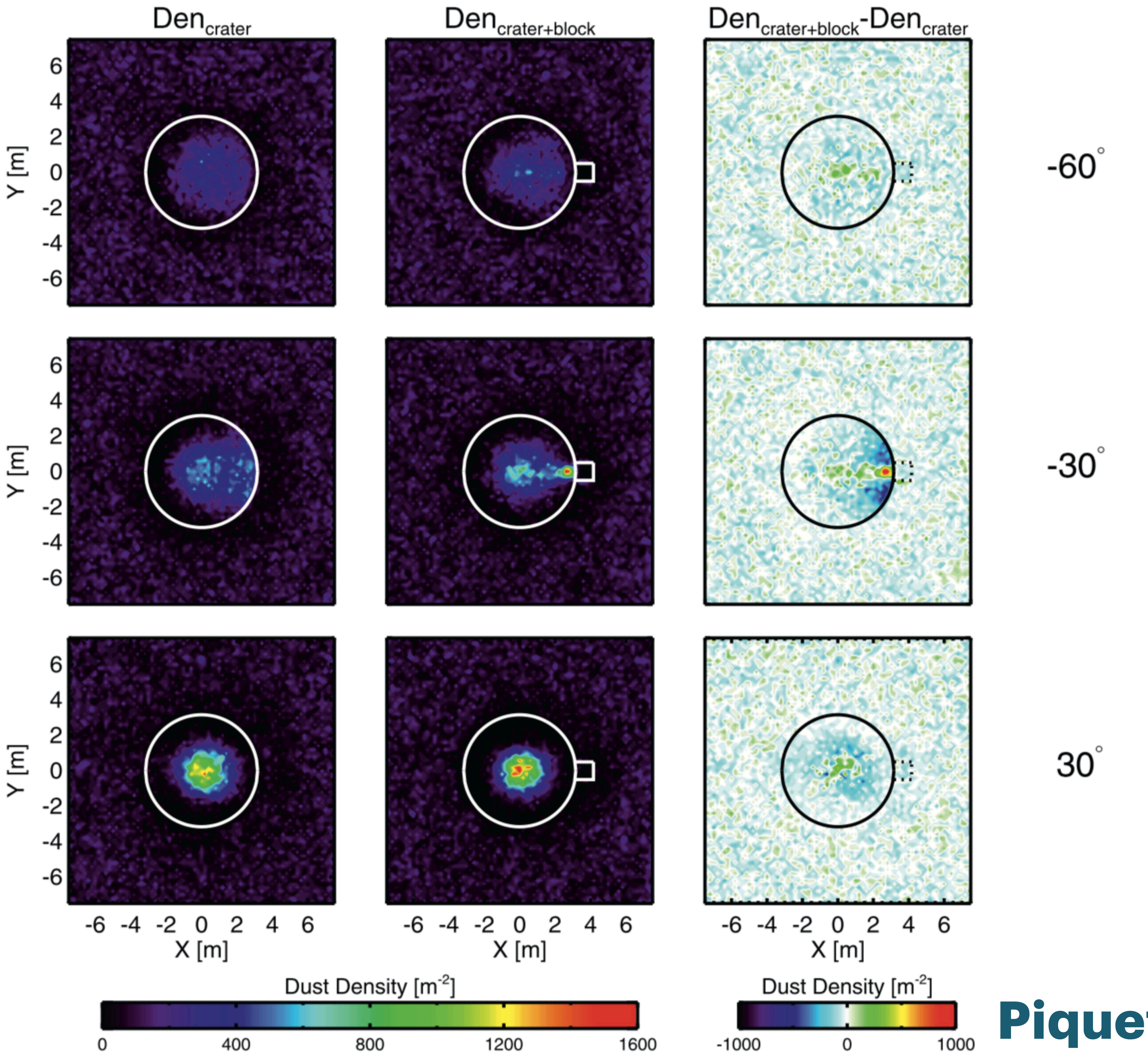
Hughes et al. 2008



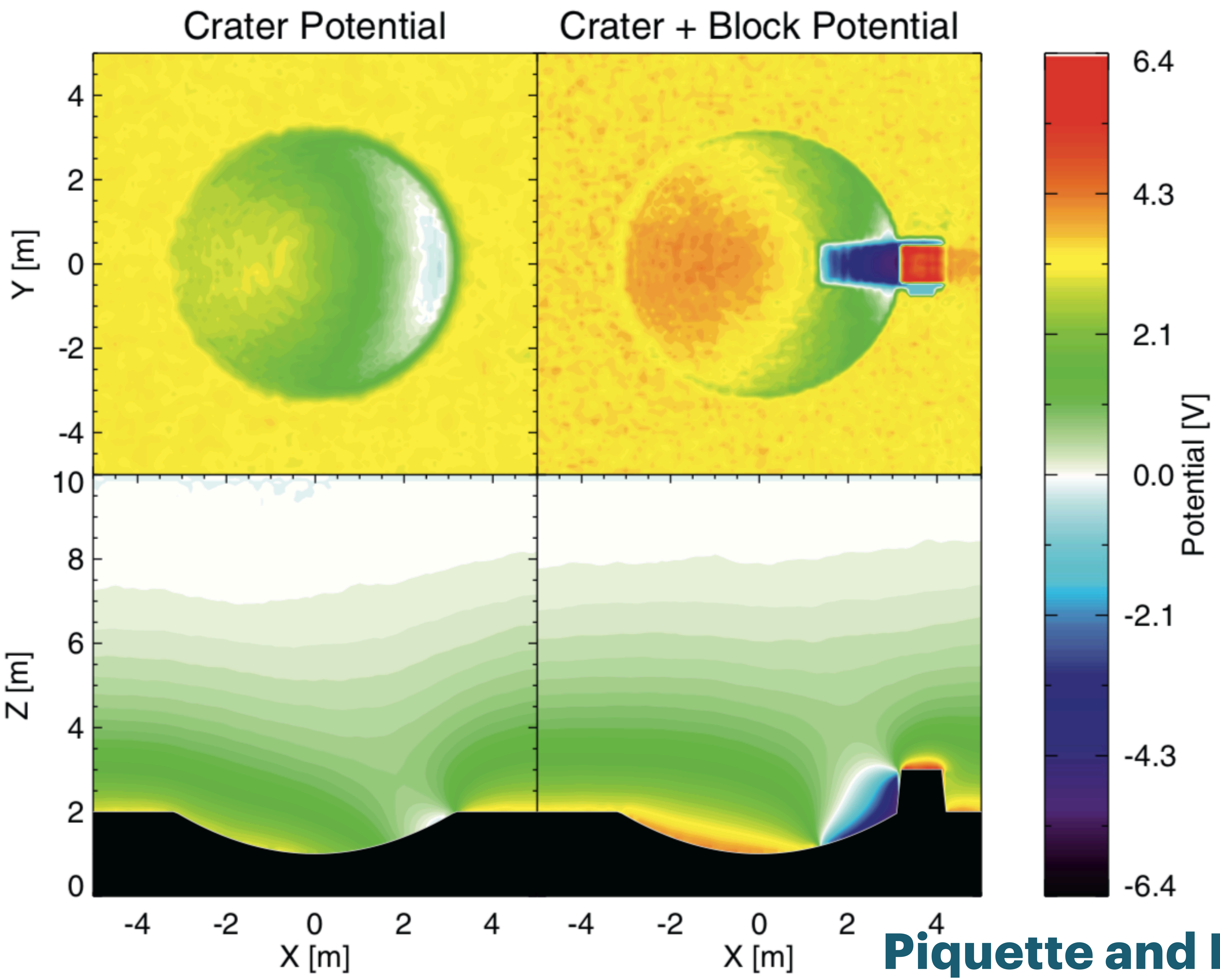
Piquette and Horanyi 2017



Piquette and Horanyi 2017

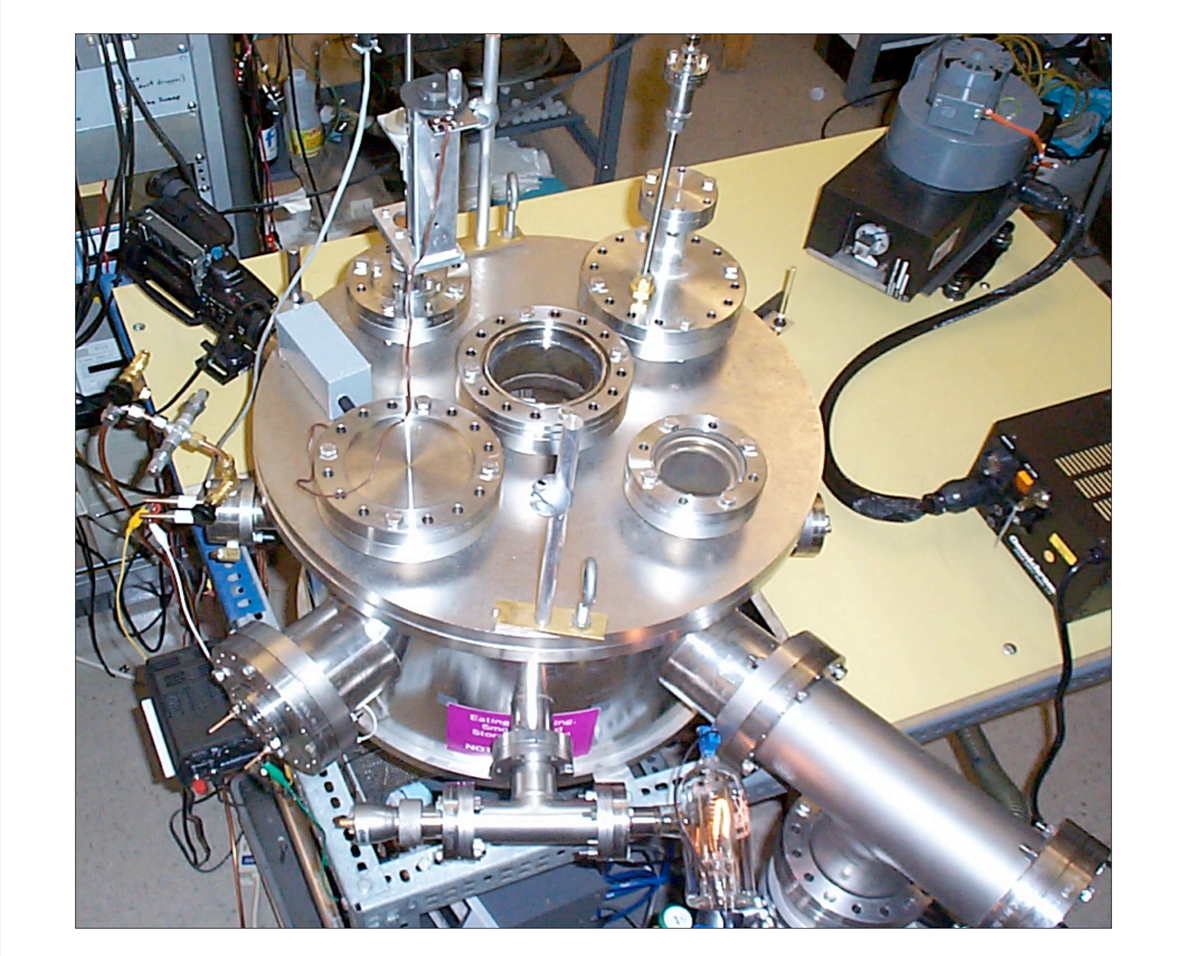


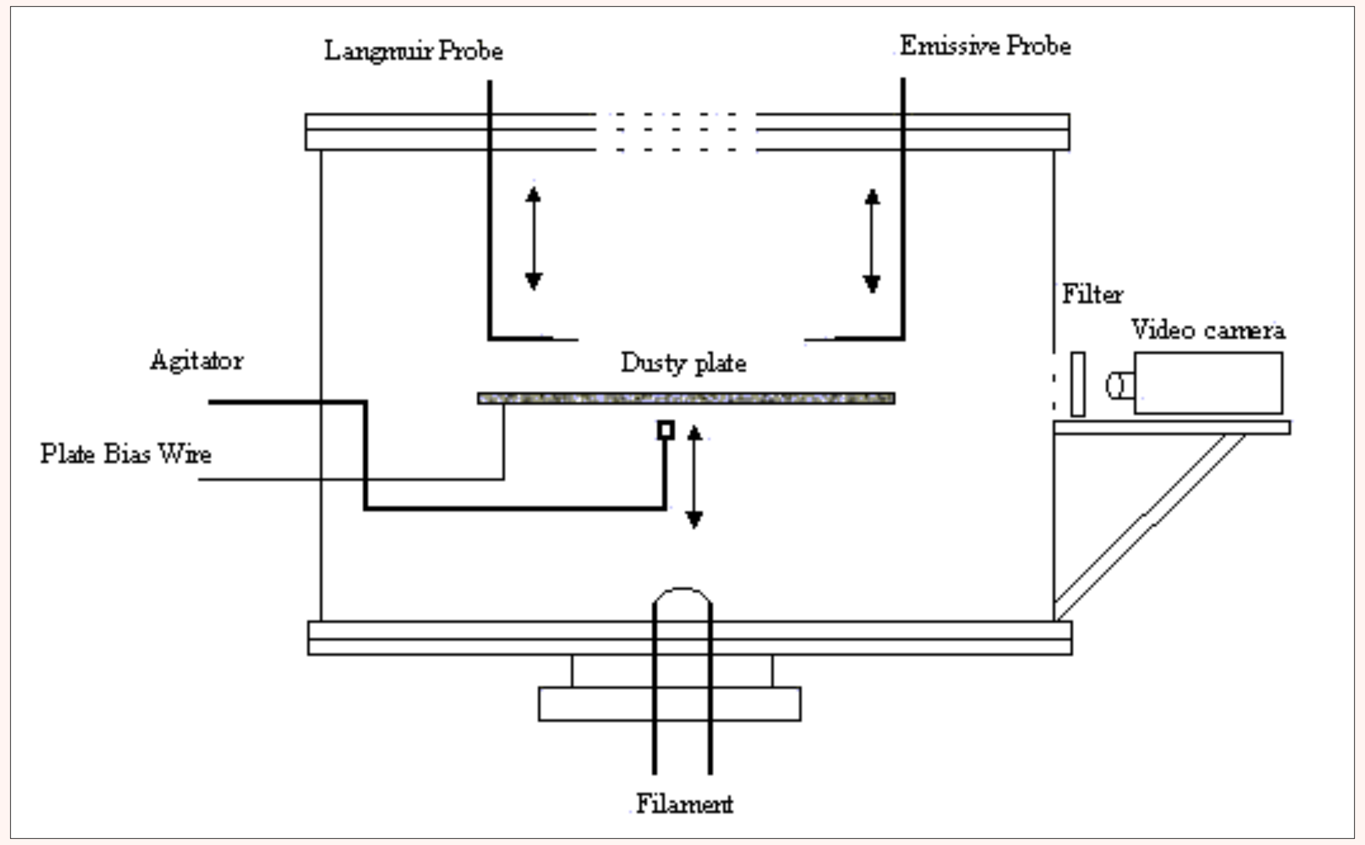
Piquette and Horanyi 2017

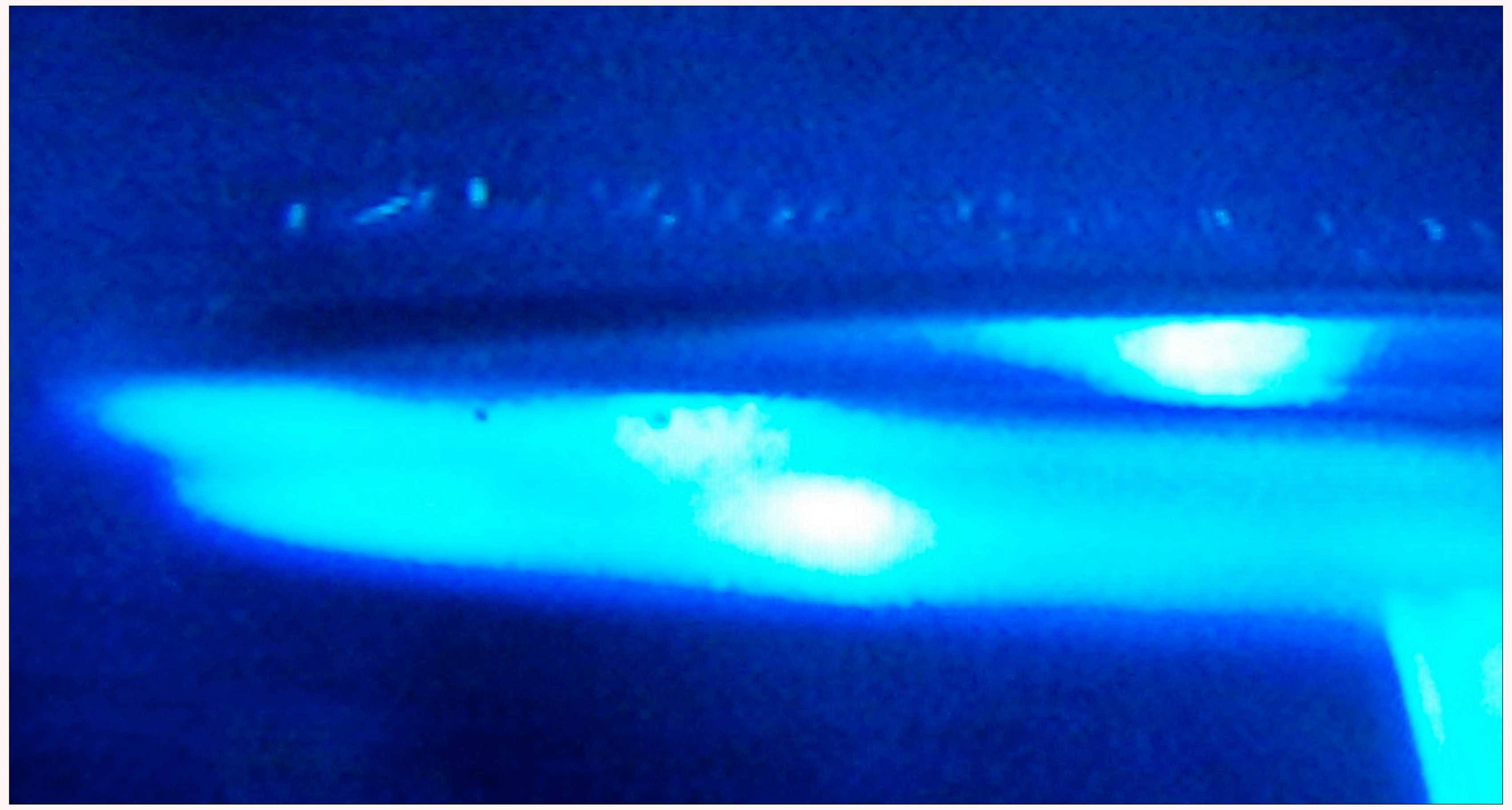


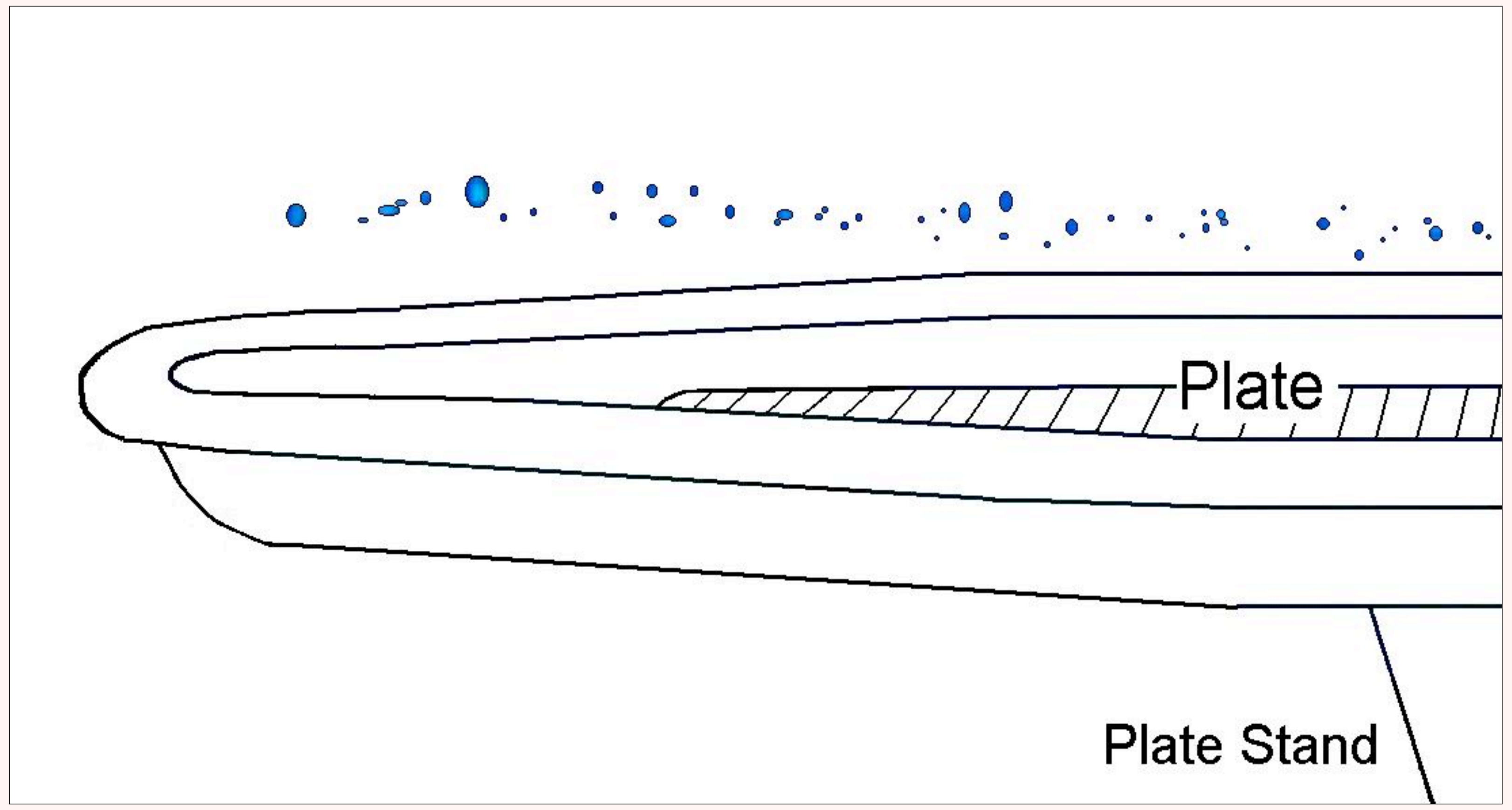
Piquette and Horanyi 2017

DOES IT REALLY HAPPEN?
LEVITATION EXPERIMENTS

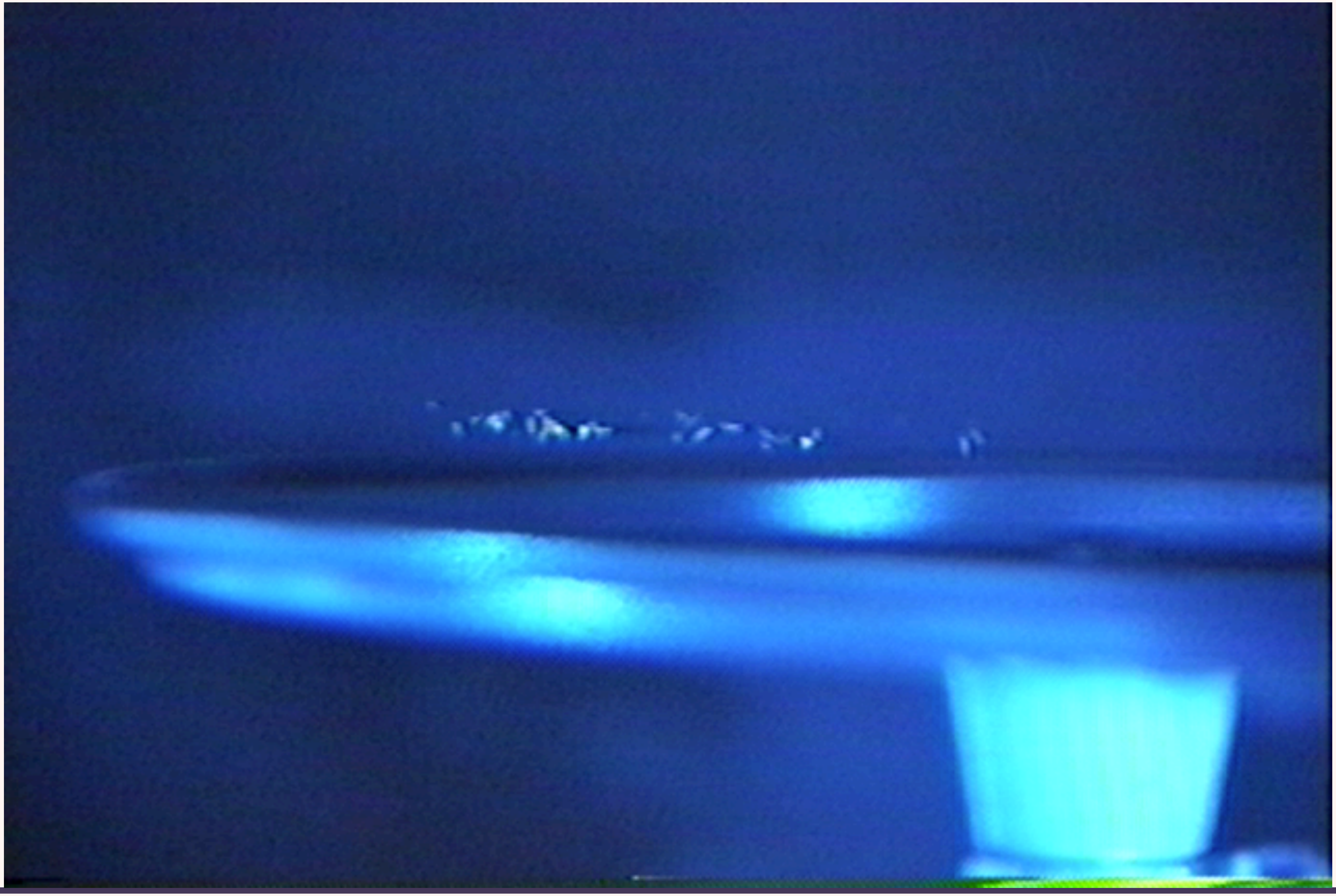






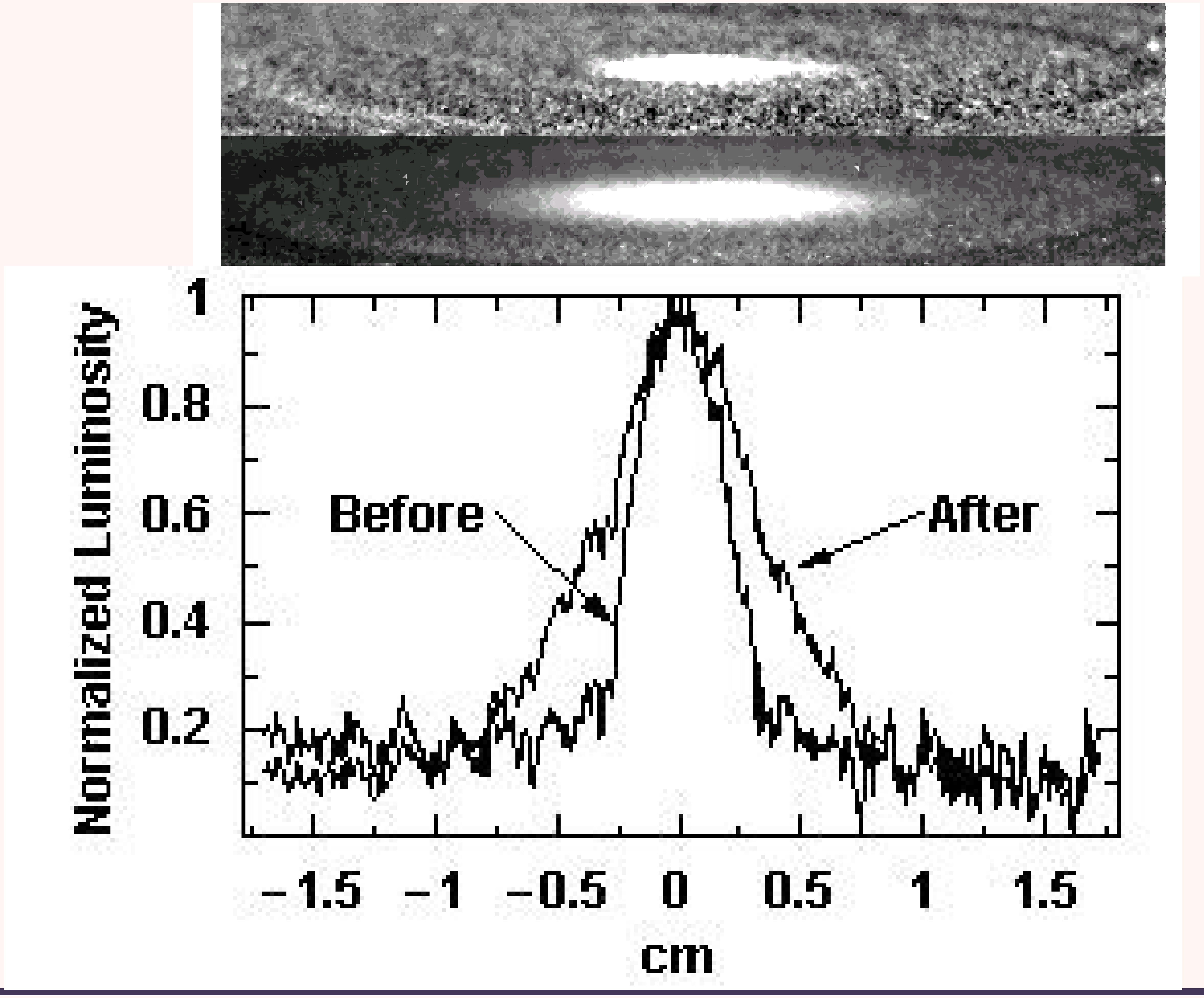


LEVITATION EXPERIMENTS



Sickafoose et al. (2001, 2002)

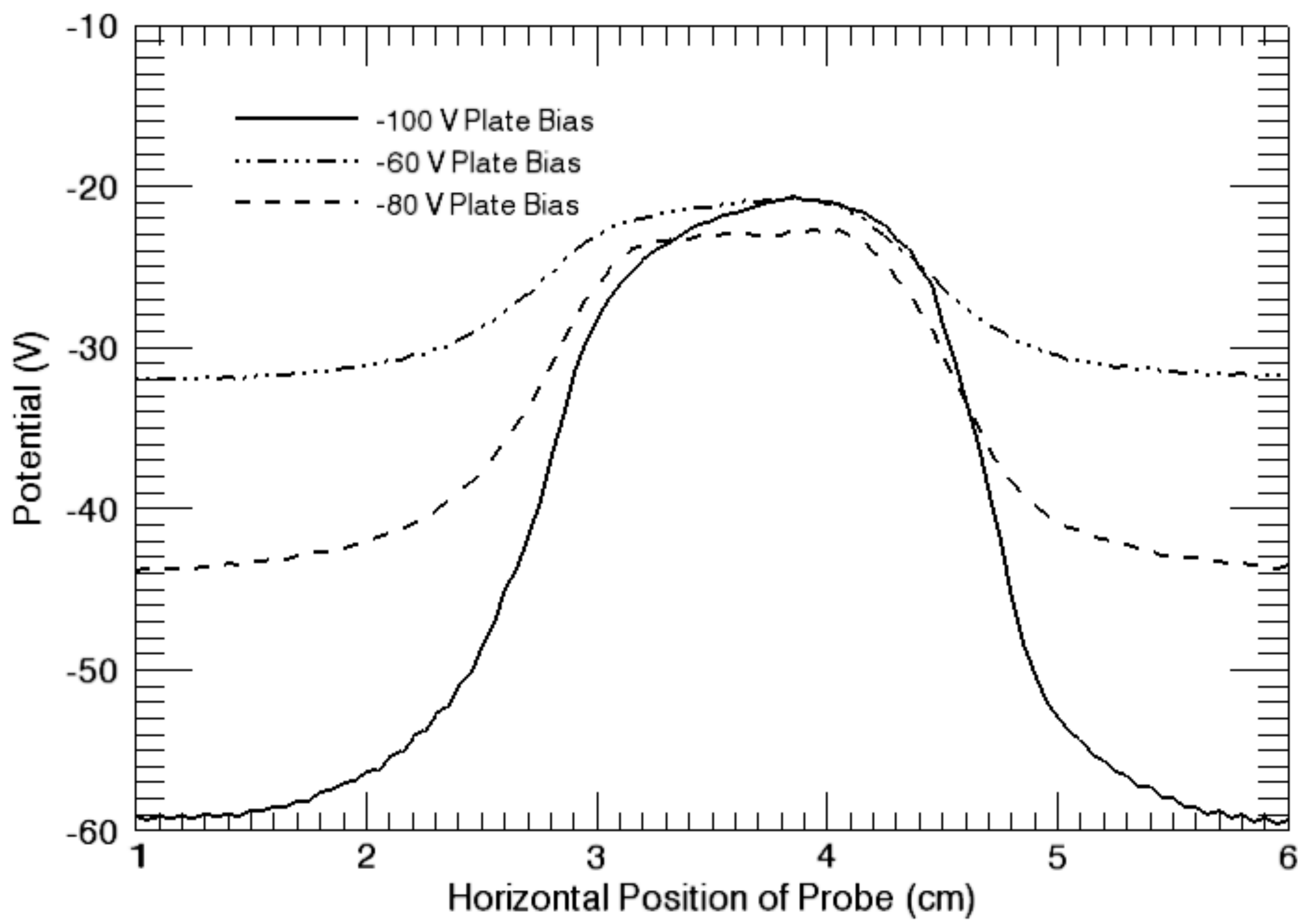
HORIZONTAL TRANSPORT EXPERIMENT

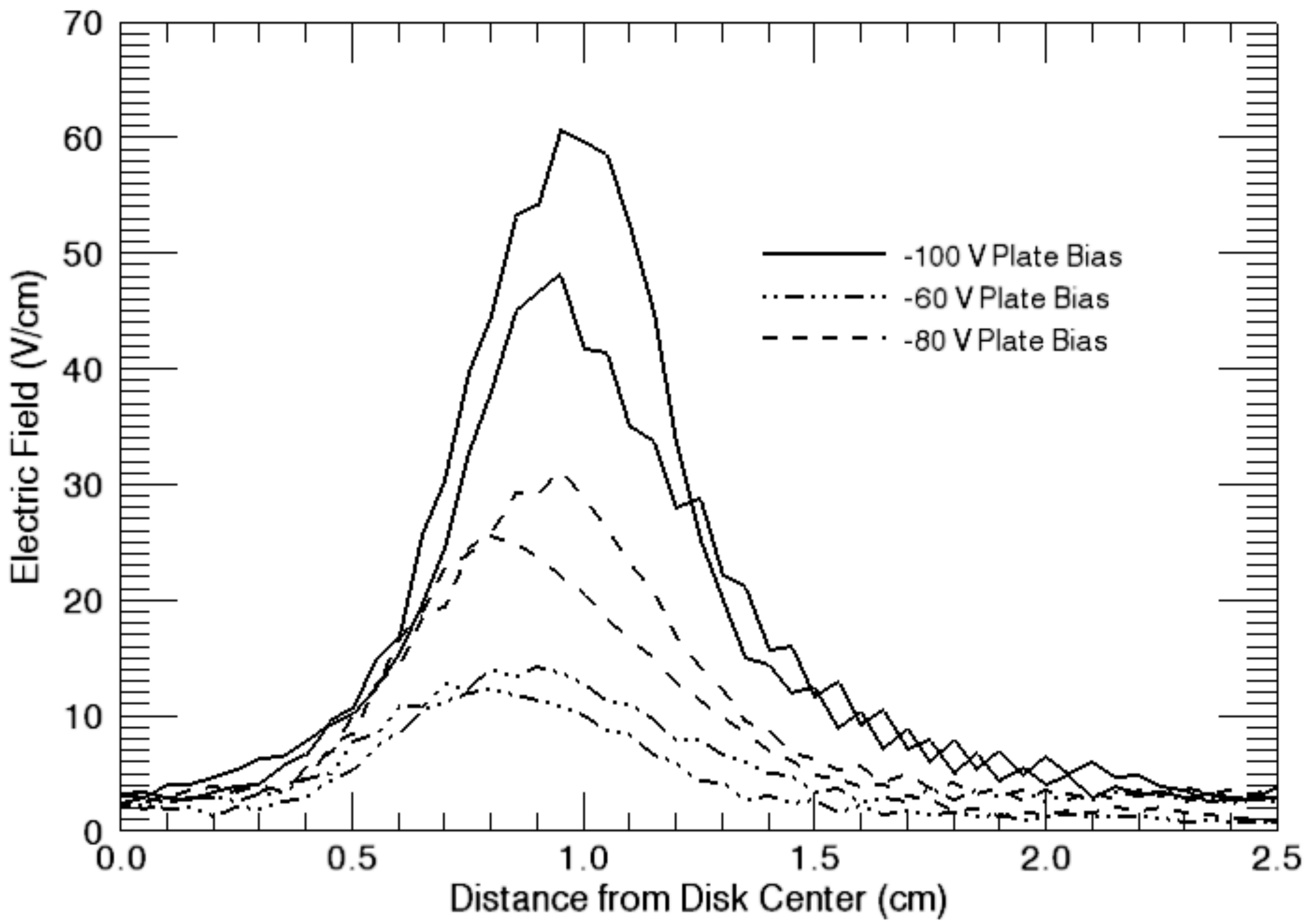


Dust on a conducting surface charges to a different potential and produces horizontal transport.

Colwell et al. 2009

HORIZONTAL ELECTRIC FIELDS





Insulating disk on graphite plate.

Heterogeneity in the surface charge produces horizontal electric fields which transport dust across the boundary.

Colwell et al. 2009

EXPERIMENTS MIMICKING TERMINATOR REGION

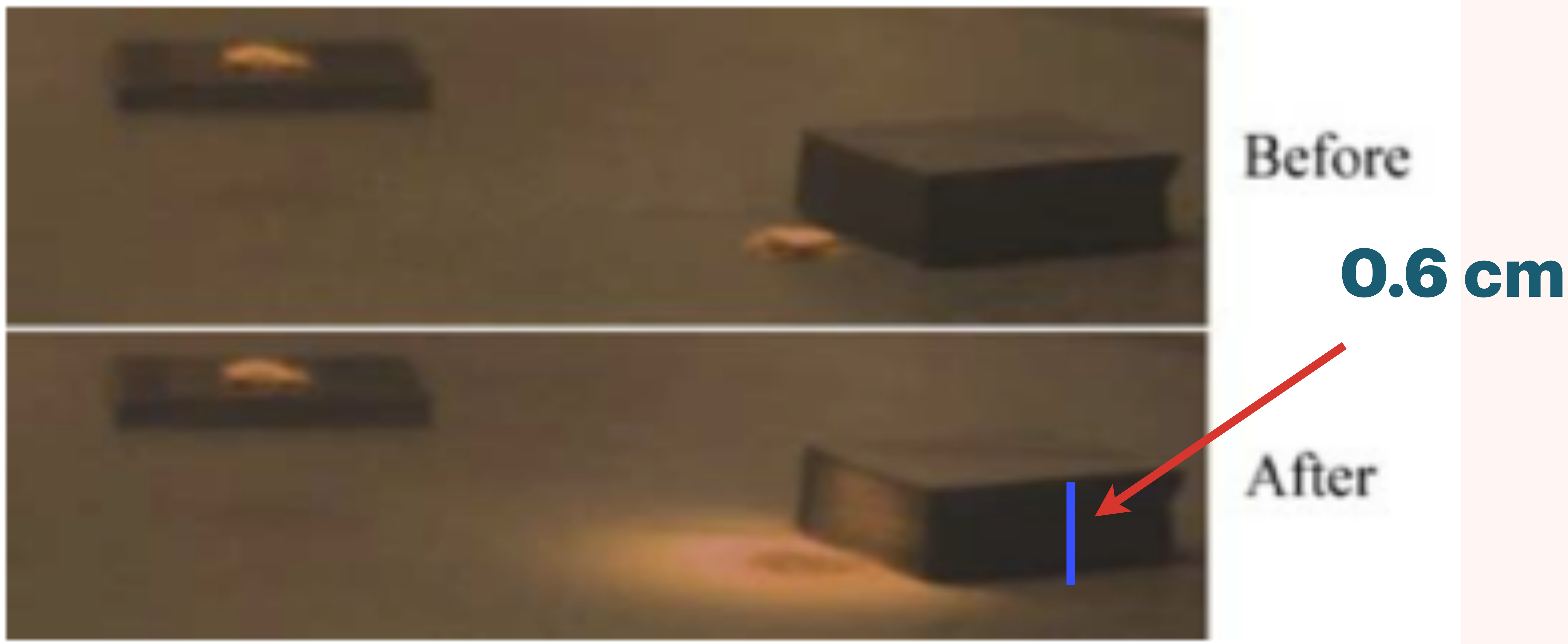
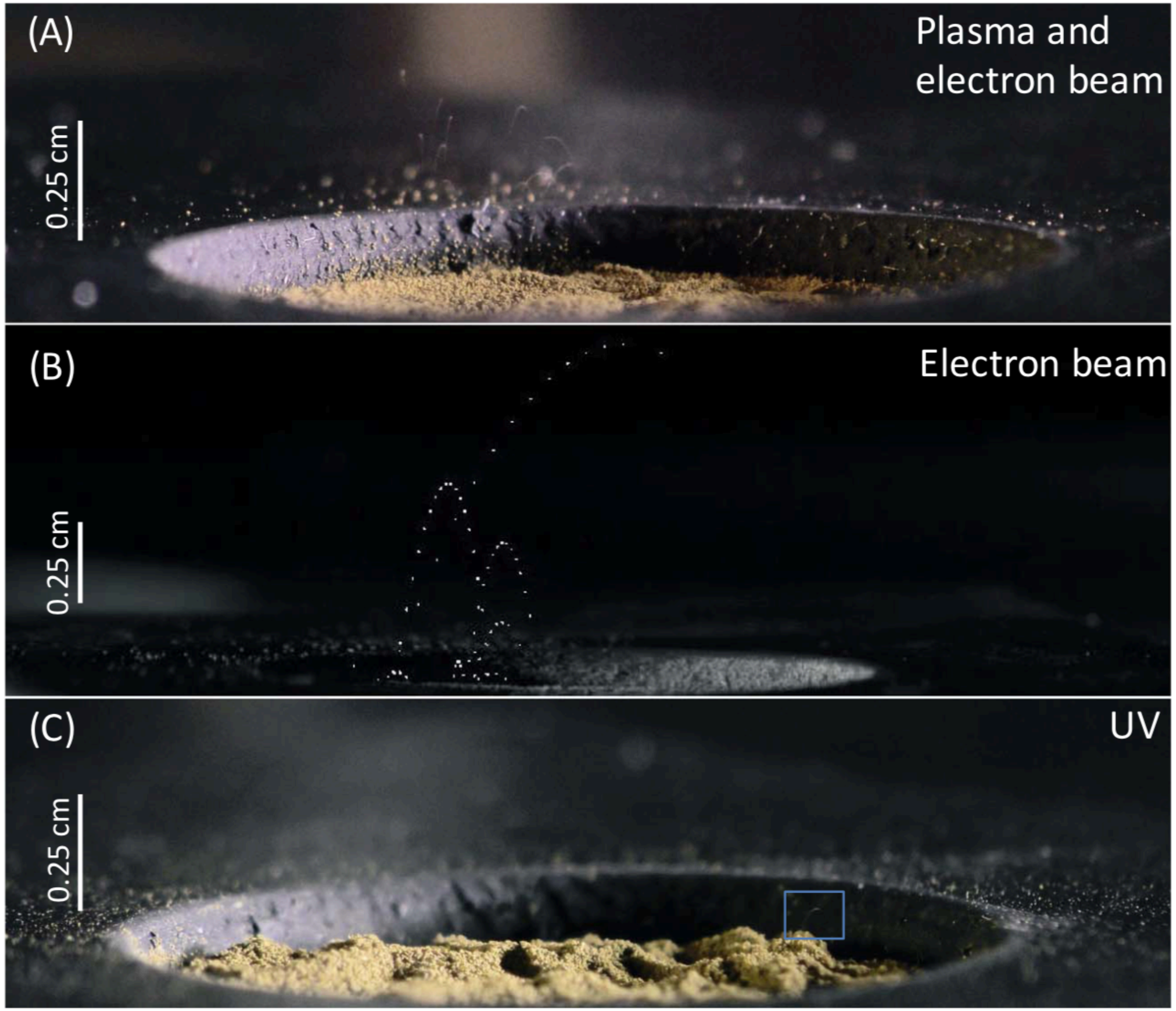


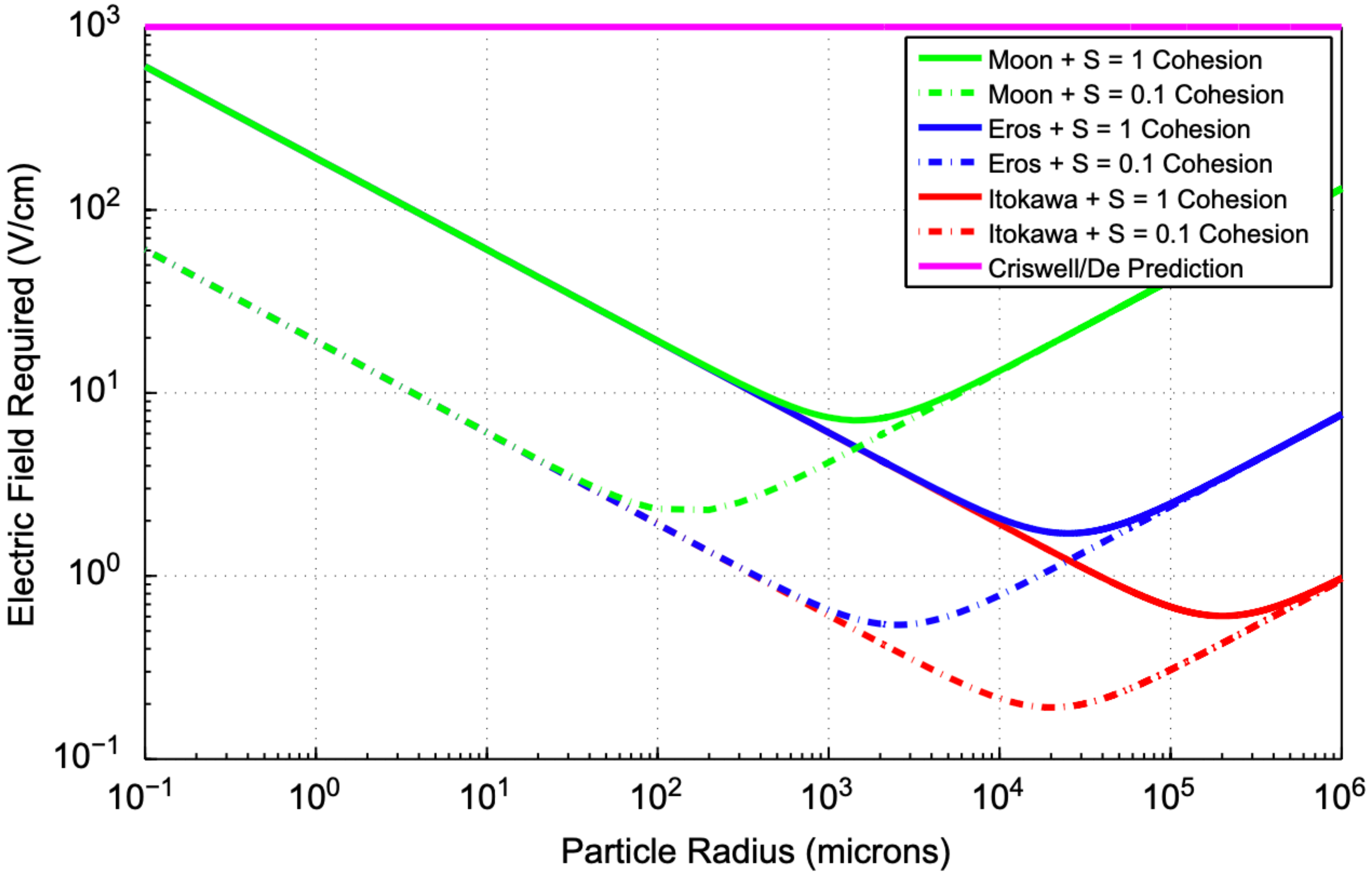
Figure 3. A dust pile resting on the graphite surface 3 mm away from a 6-mm high insulating block and another on an insulating sheet at $t = 0$ and $t = 45$ minutes after plasma is turned on.

Dust Hopping in Different Plasma Environments



Adhesion and Launching of Particles

C.M. Hartzell, D.J. Scheeres / Planetary and Space Science 59 (2011) 1758–1768



Easiest to loft particles that are not so massive as to be heavy and not so small as to have an overwhelming particle-particle electrostatic adhesion to neighboring regolith. Minimum in the competition is in the 100 micron - 1 cm size range.

Hartzell and Scheeres 2011

SUMMARY

- Electrostatic levitation seems to be restricted to very small grains (< 10 microns). Launching may occur for much larger grains (~100 -1000 microns?).
- Dynamics influenced by season and perhaps solar cycle.
- Global redistribution of dust possible.
- Electrostatic launching and long-term levitation are two possible modes of charged dust transport.
- Natural electric fields will not lead to dangerous amounts of dust flying around, but fields introduced by human activity could lead to collection of dust on sensitive equipment.
- Surface potentials can be many tens of Volts on the nightside and terminator region, or 100s of Volts if the asteroid is passing through the Earth's magnetotail.

SOME OPEN QUESTIONS

- What are the small-scale surface potentials asteroids and moons as a function of local time and latitude, particularly near the terminator and poles?
- What are the near-surface plasma properties and electric field strengths, and how do they vary with time and latitude?
- What are the initial velocity and size distributions of electrostatically mobilized dust?
- What are the interparticle forces that must be overcome to launch dust?