Plasma, Planetary Surfaces, and Cosmic Dust Experiments at the University of Colorado

Tobin Munsat
University of Colorado

Bringing Space Down to Earth Workshop, UCLA
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Outline: Three Laboratory Experiments

- **Colorado Solar Wind Experiment**
- **Dust Charging and Transport**
- **Micrometeoroid (Dust) Accelerator**

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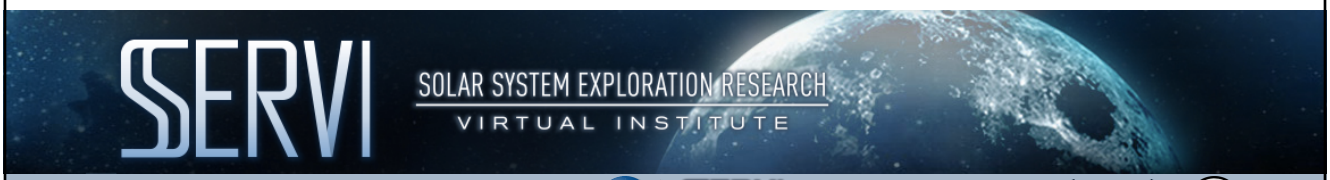
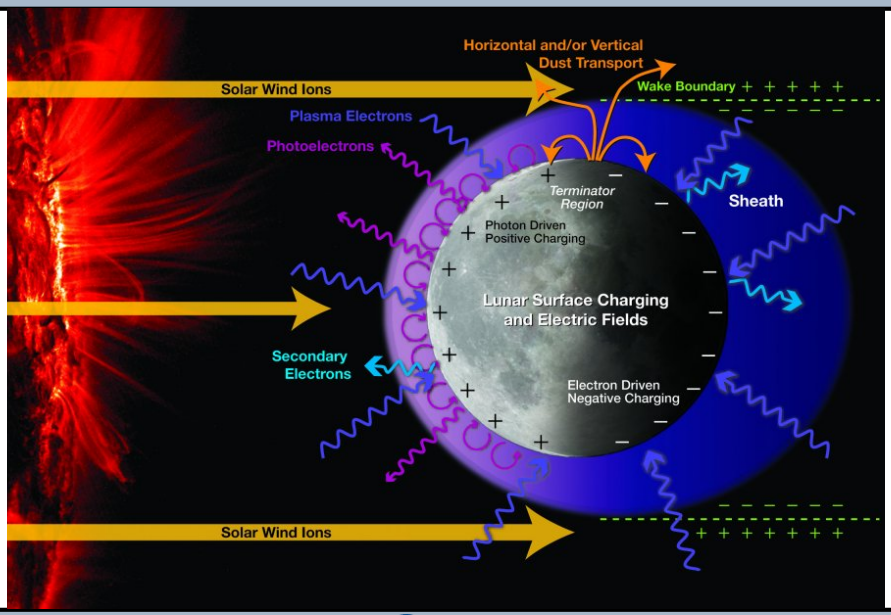


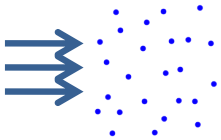
Solar Wind Interaction with Lunar surface



Experimental Objectives

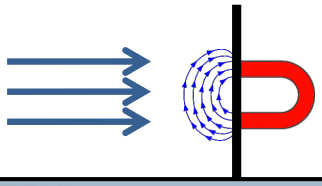
Plasma Wakes: SW Interaction with Large Bodies

Charging and Transportation of Dust

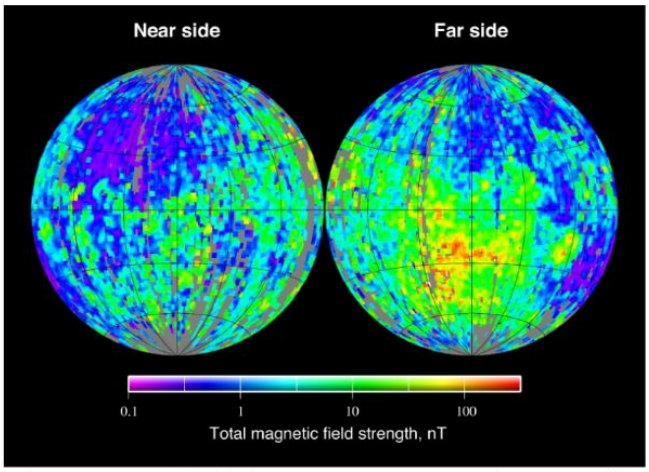


SW Interaction with Surface Features

SW Interaction with Lunar Magnetic Anomalies



Lunar Magnetic Anomalies



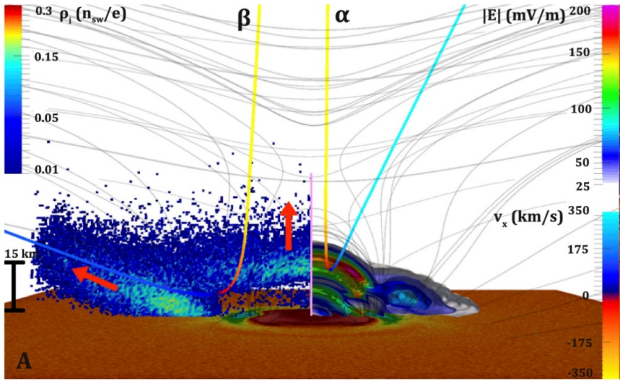
Surface magnetic fields by Lunar Prospector Electron Reflectometer

- The Moon has no global magnetic field
- Crustal magnetic fields (Lunar magnetic anomalies) are all over the surface
- B-field strength varies from 0.1 to hundreds of nanoTesla
- Anomaly size range from < 1 km to > 100 km

Solar Wind Interaction with Magnetic Anomalies

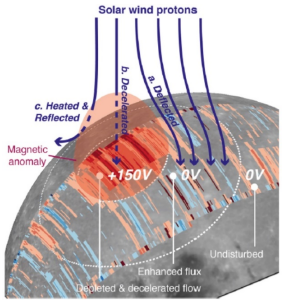
Solar wind **ions** are mainly reflected/deflected by electric fields created due to charge separation while **electrons** are magnetically reflected/deflected.

Simulation



Deca and Divin, 2016

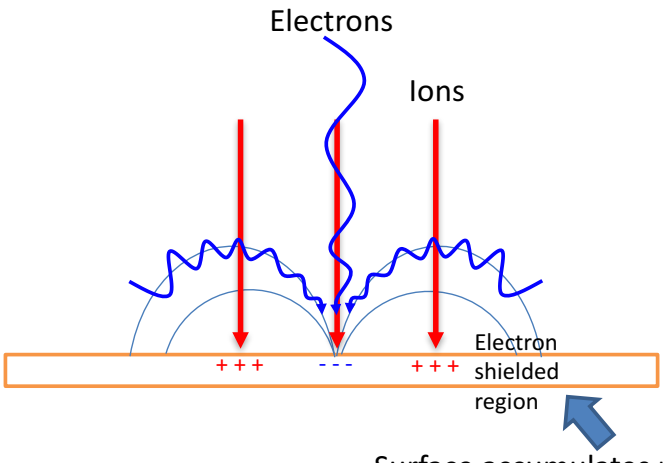
Observation



Gerasimovich magnetic anomaly

Futaana et al., 2013

Basic Physical Picture of Electron Shielding



- Electrons are reflected/deflected by magnetic field.
- Ions are weakly magnetized or unmagnetized, build up on the surface.

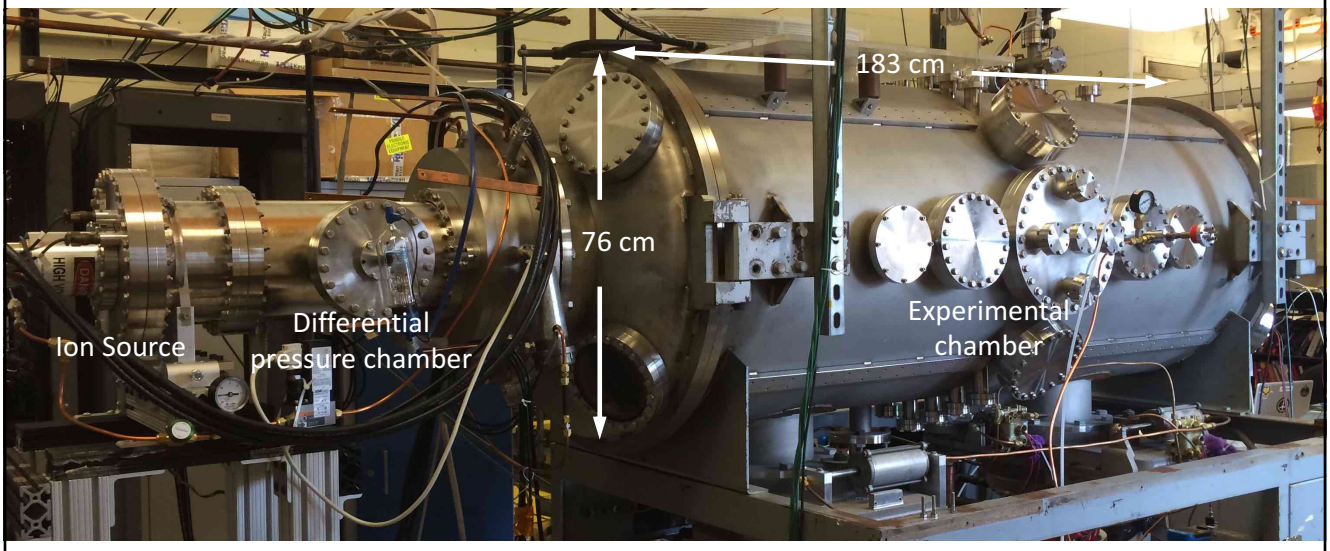
Surface accumulates positive charge until potential reaches ion flow energy

Surface electric environment in magnetic anomaly regions

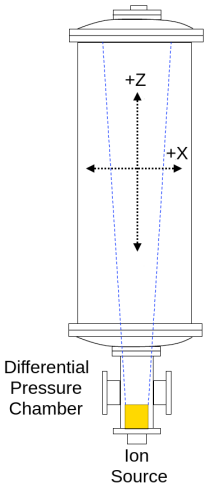
Significance

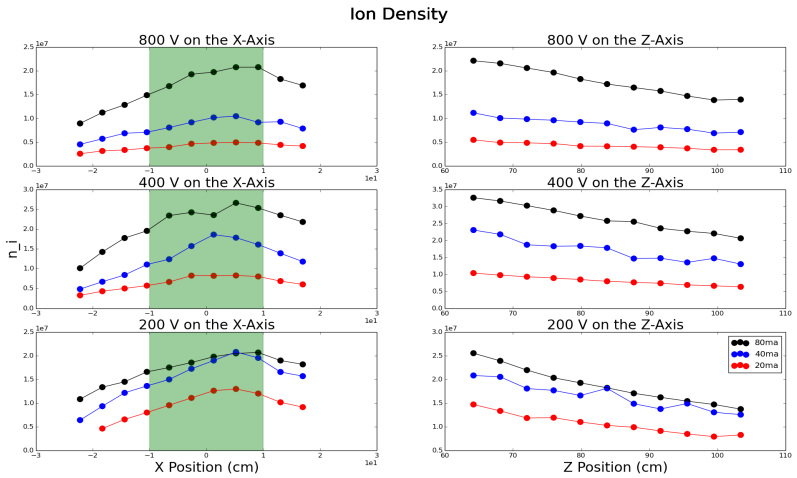
- Space weathering: How large are the energies of ions that bombard the surface in these regions?
- Electrostatic dust transport: How does dust get redistributed by the electric fields created in these regions?

The Colorado Solar Wind Experiment (CSWE)



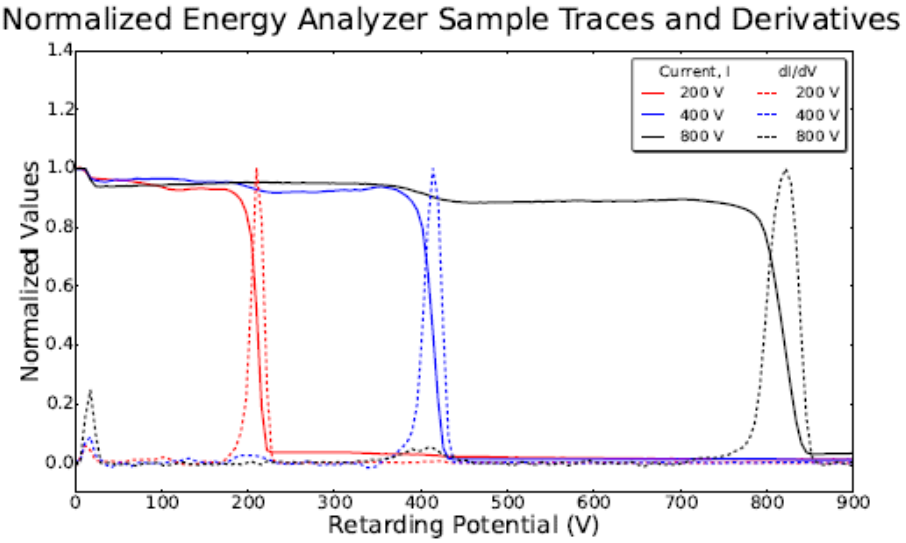
CSWE Facility Parameters



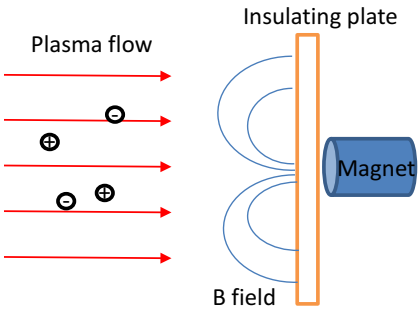


Current density up to 1 mA/cm^2

Beam Energy Distribution



Experimental setup and parameters

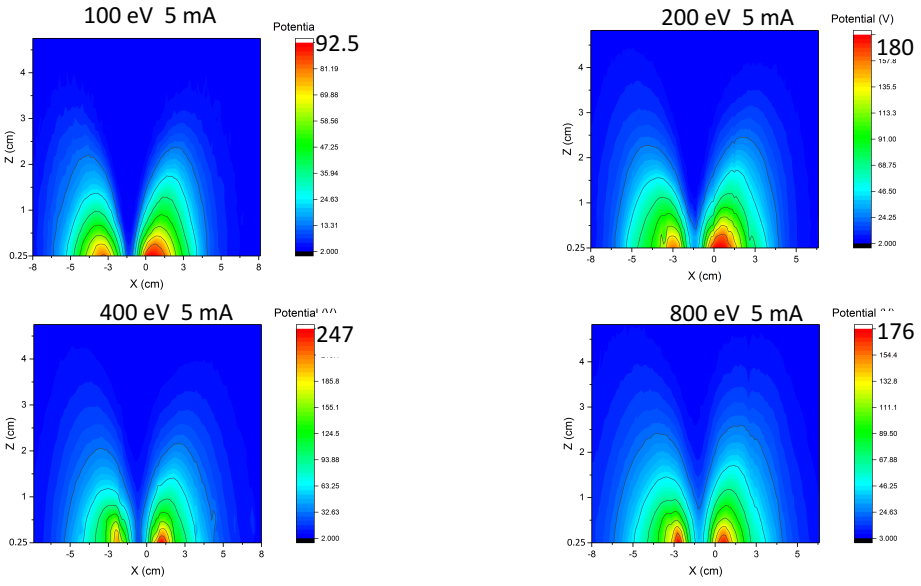


B field strength ~580G maximum

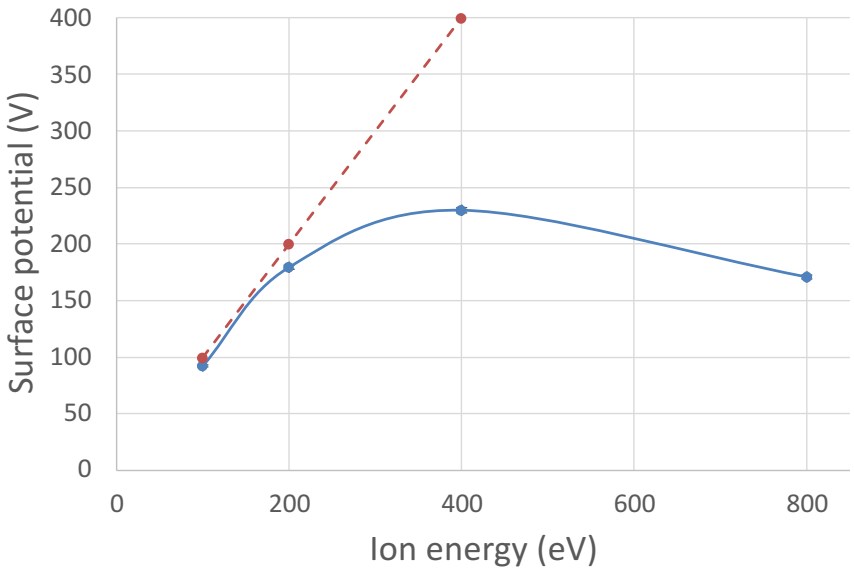
Parameter	Laboratory	Lunar case (Strong |B| region)
Ion species	N_2^+	H^+
Ion flow energy E_b (eV)	100 – 800	1000
Electron Temperature T_e (eV)	0.5 (cold), 10 (hot)	10
Ion Temperature T_i (eV)	14	10
Ion Mach number M	11	9
Electron gyro ratio (r_e / L)	< 1 (0.3 cm / 2 cm)	<< 1 (0.35 km / 30 km)
Ion gyro ratio (r_i / L)	>> 1 (250 – 720 cm / 2 cm)	> 1 (150 km / 30 km)
Electron Debye ratio (λ_{De} / L)	< 1 (0.2 cm / 2 cm)	<< 1 (0.01 km / 30 km)
Ion Debye ratio (λ_{Di} / L)	< 1 to > 1 (1.4 – 6.5 cm / 2 cm)	<< 1 (0.1 km / 30 km)

* The magnetic field strength 30 nT at 30 km altitude is used for the lunar case with strong magnetic anomalies [*Hood et al.*, 2001].

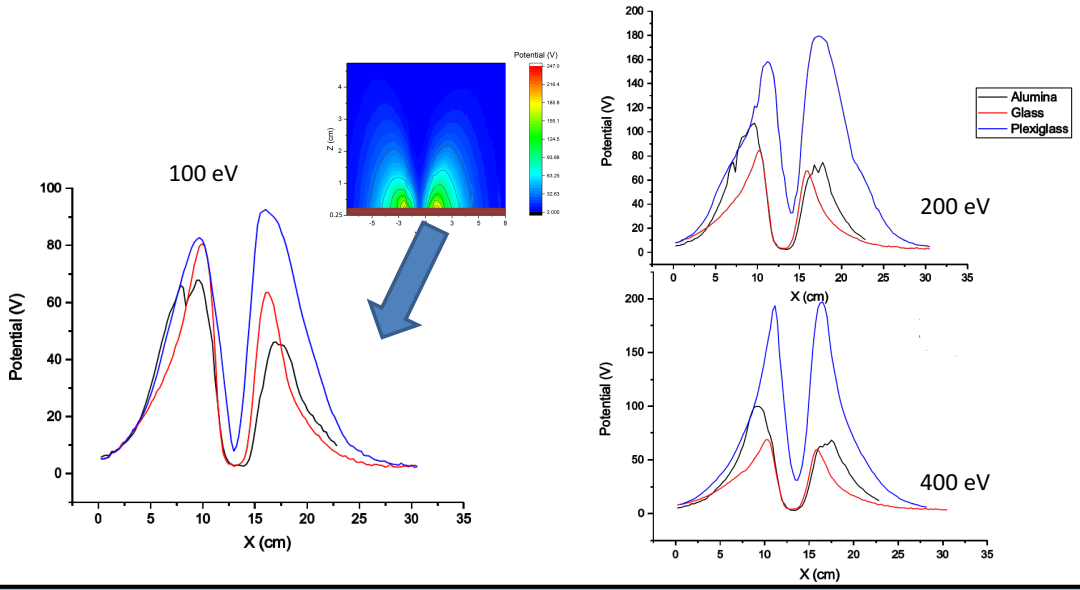
2D Potential Contours



Surface potential falls off at high ion energy



Surface Material Effects



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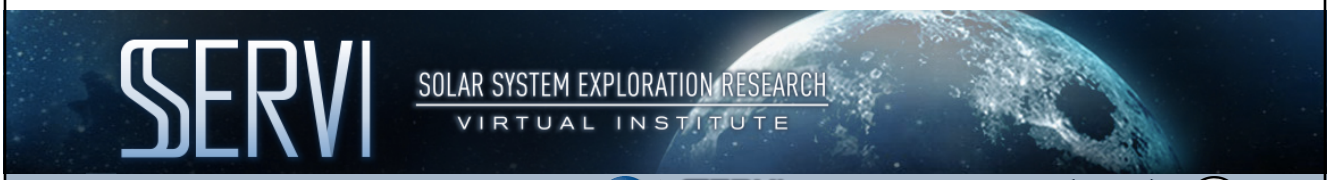
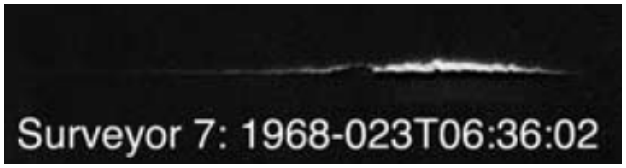
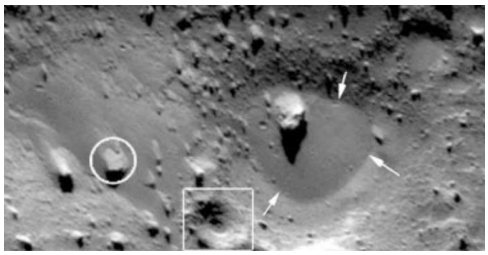


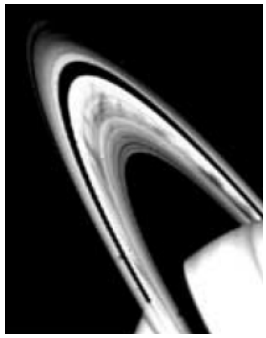
Examples of Spacecraft Observations of Electrostatic Dust Transport



Lunar horizon glow (Colwell et al., 2007)

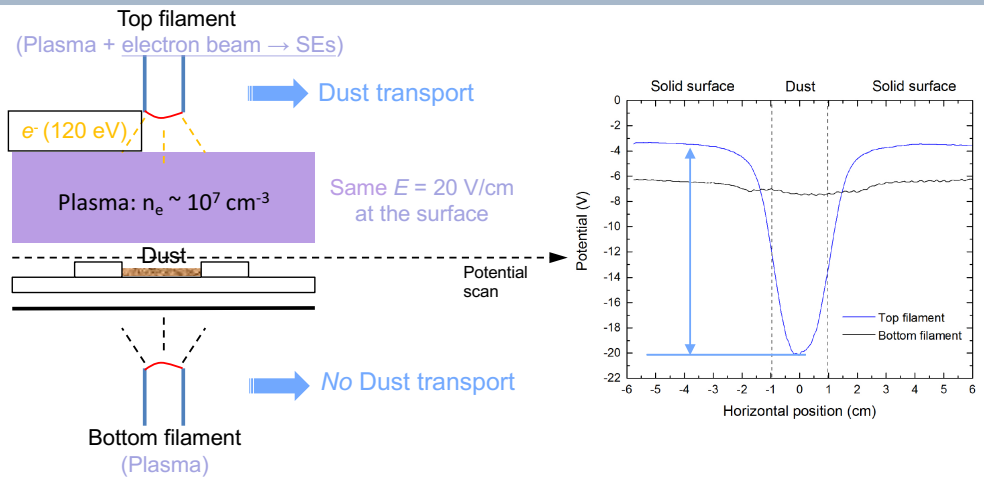


Dust pond on asteroid Eros (Robinson et al., Nature, 2001)



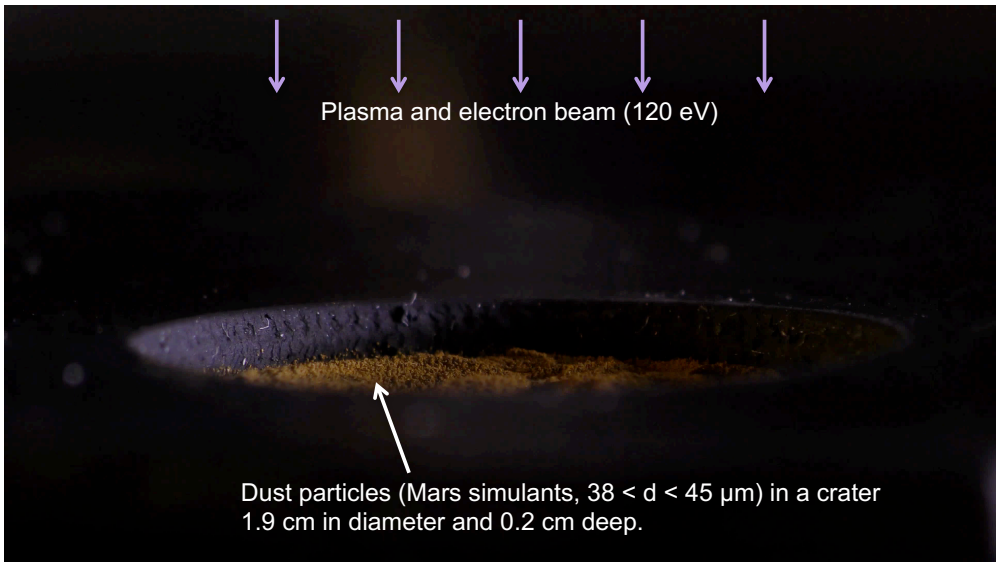
The Spokes in Saturn's B ring (Mitchell et al., Science, 2006)

Dust Charging Measurements

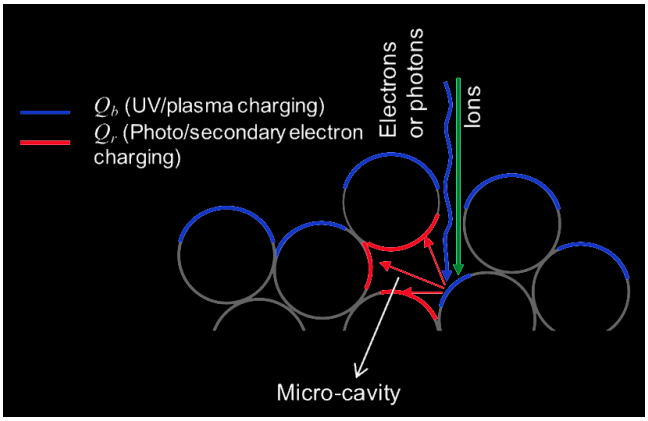


- Sheath electric field force is not a predominant force for dust transport.
- Secondary electrons (SEs) play a role in dust charging and transport.
- SE emission (SEE) from the dusty surface is smaller than from the solid surface, attributed to the absorption of emitted SEs by neighboring particles.

Dust Lofting from Plasma and UV



"Patched Charge Model"



[Wang et al., GRL, 2016.]

From Gauss's law

$Q_b \propto (\phi_b - \phi_p) / \lambda_{De}$

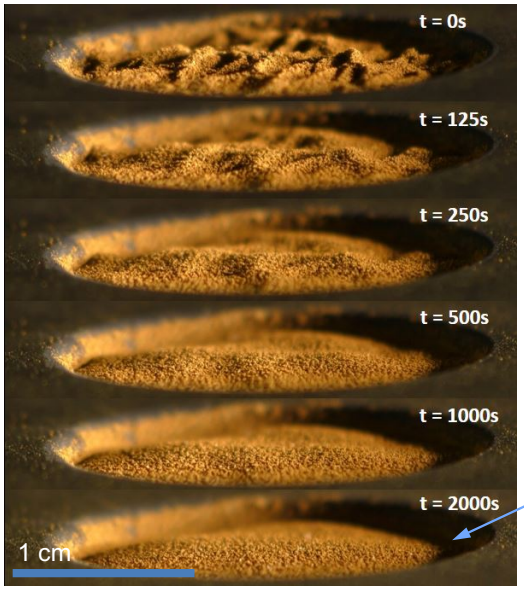
$Q_r \propto (\phi_r - \phi_b) / r$

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

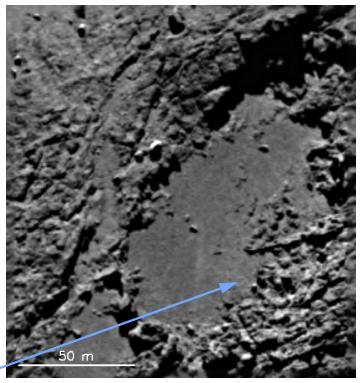
$Q \approx Q_r \approx 0.5C(\eta T_{ee}/e)$,
where T_{ee} is the emitted electron temperature;
$C = 4\pi\varepsilon_0 r$;
$\eta > 1$ (empirical constant 4 ~ 10).

- 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 negative potential (ϕ_r) w.r.t the blue patch (ϕ_b).
- At equilibrium, $-e(\phi_r - \phi_b)$ can be a few T_{ee}.

Dust Mobilization/Ponding from Plasma and UV

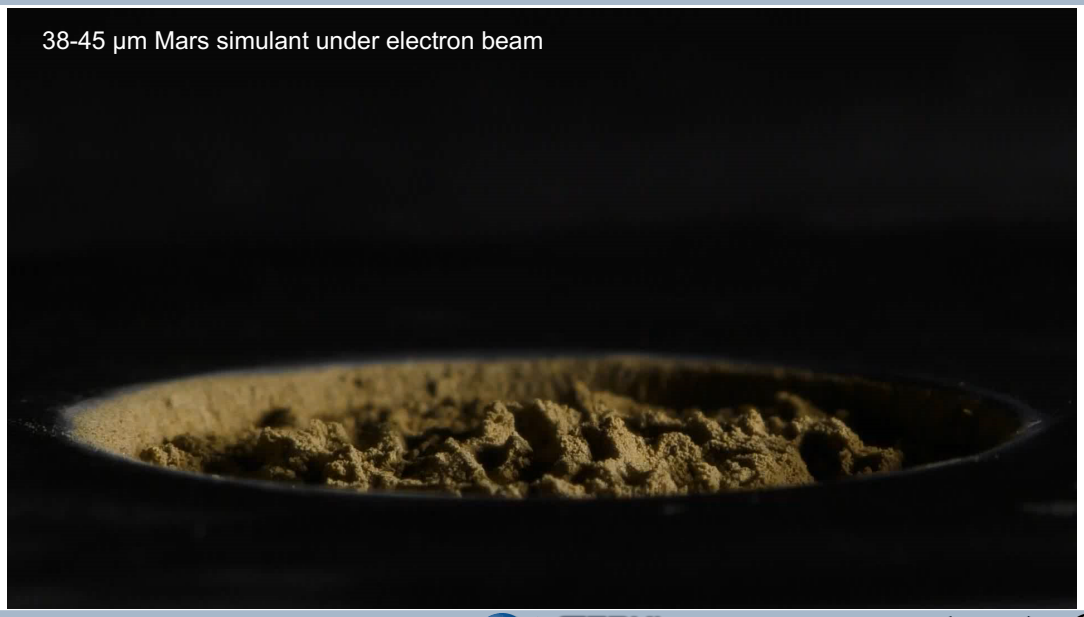


Smoothened surfaces



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

Dust Mobilization/Ponding from Plasma and UV



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SERVI SOLAR SYSTEM EXPLORATION RESEARCH VIRTUAL INSTITUTE

Dust is Ubiquitous in the Universe

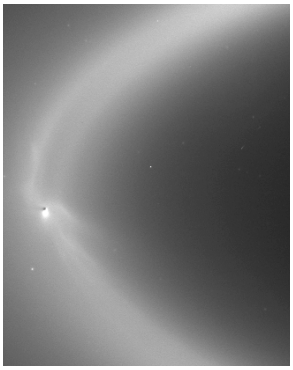
Interstellar

Nova Remnants of V838 Monoceros

Interplanetary

Zodiacal Light

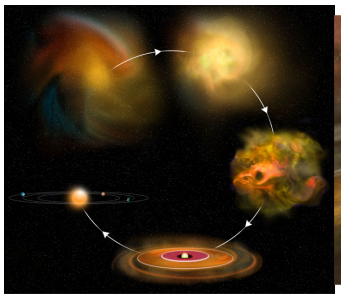
Planetary



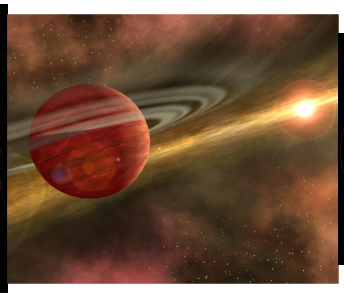
Saturn's E Ring

Dust is Ubiquitous in the Universe

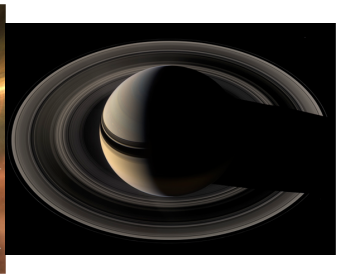
Star Formation



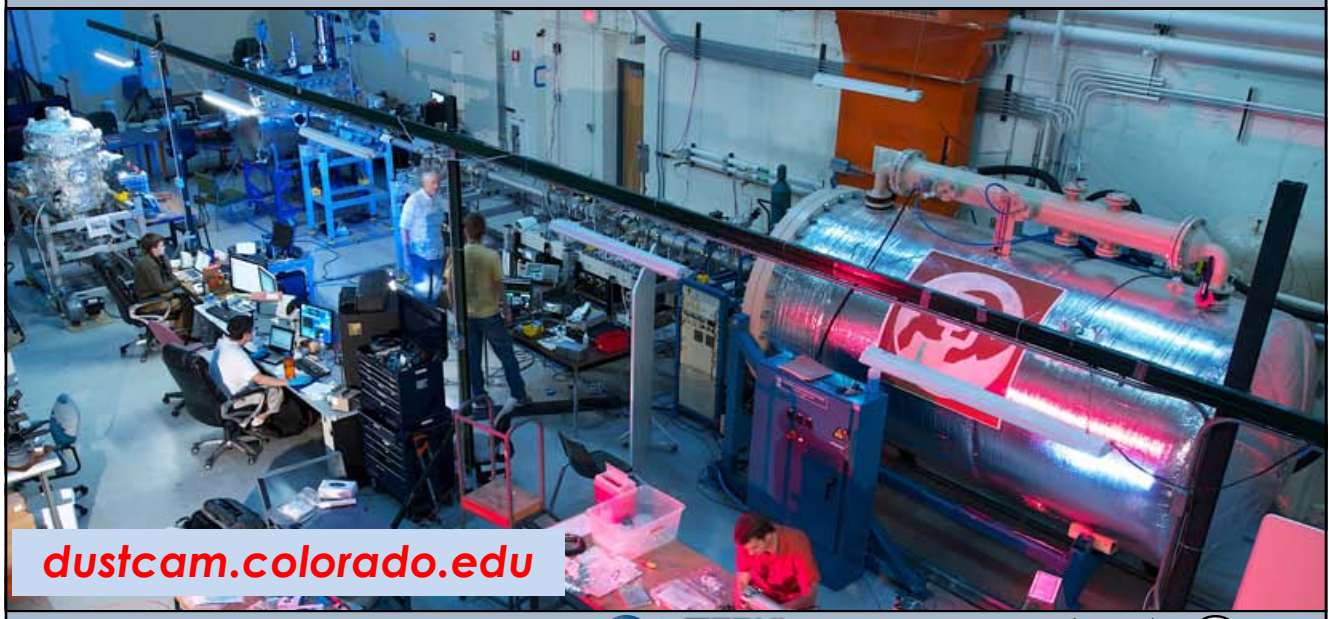
Planet Formation



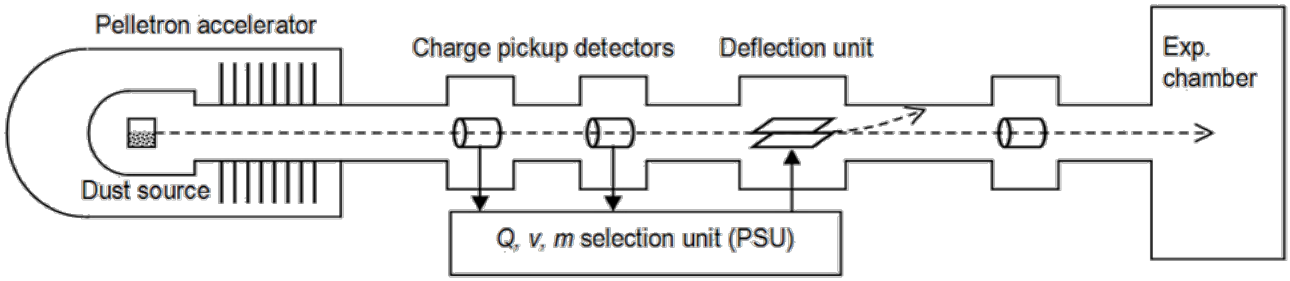
Solar System Evolution



The Colorado Dust Accelerator

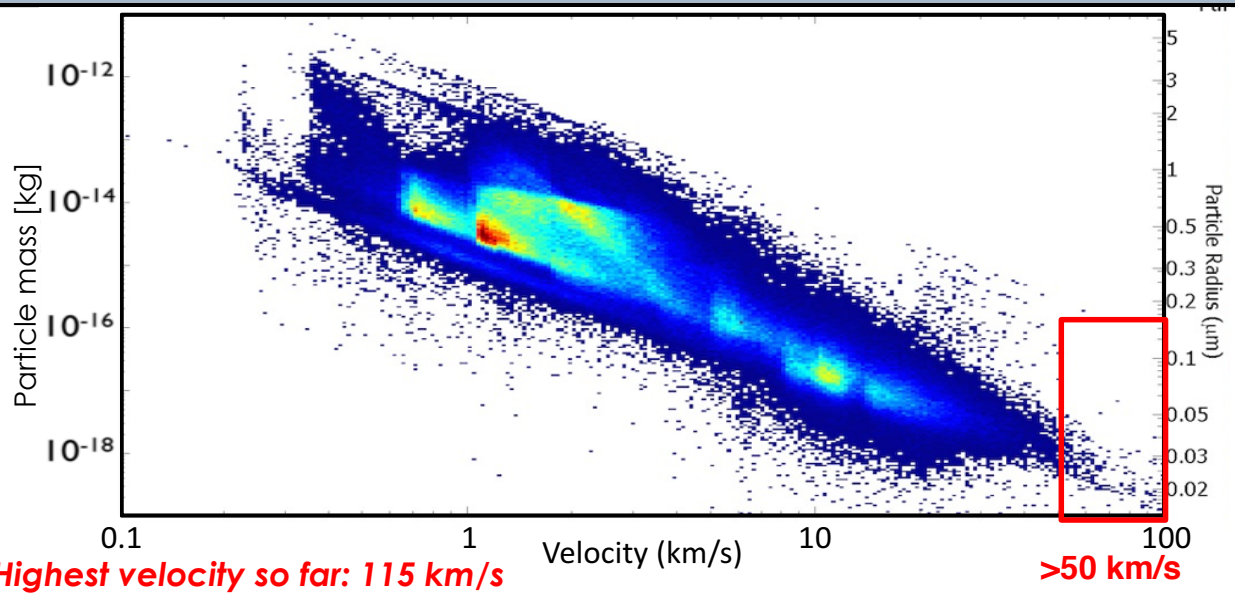


Technical Description of Accelerator



- Pelletron 3 MV Electrostatic Generator
- **Particle velocities: ≤ 100 km/s**
- Active selection of particles (charge/velocity)
- Particle materials: Fe, Al, Ag, Olivine, Latex, ???
- **Particle diameters: 50 nm – 5 μm**

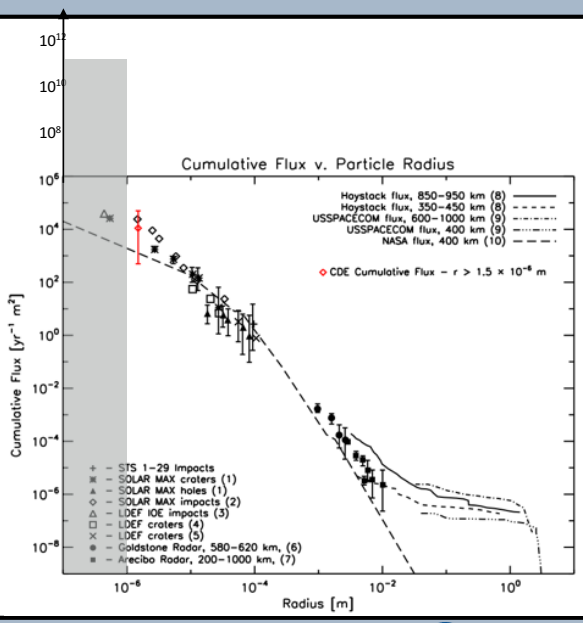
Particle Mass and Velocity Distribution



Highest velocity so far: 115 km/s

>50 km/s

Equivalent Dust Flux

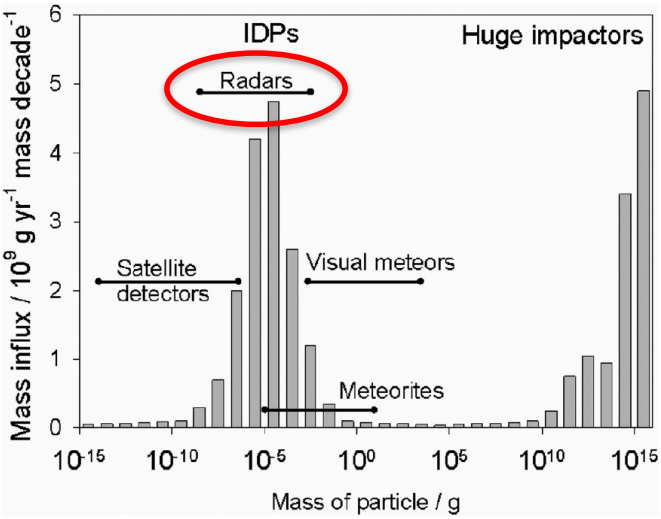


Accelerator (a > 10 nm)
~ 10^3 cm^{-2} / hour
~ 10^{11} m^{-2} / year

1 hour represents
~1,000 years

Ablation of Micrometeoroids in Earth's Atmosphere

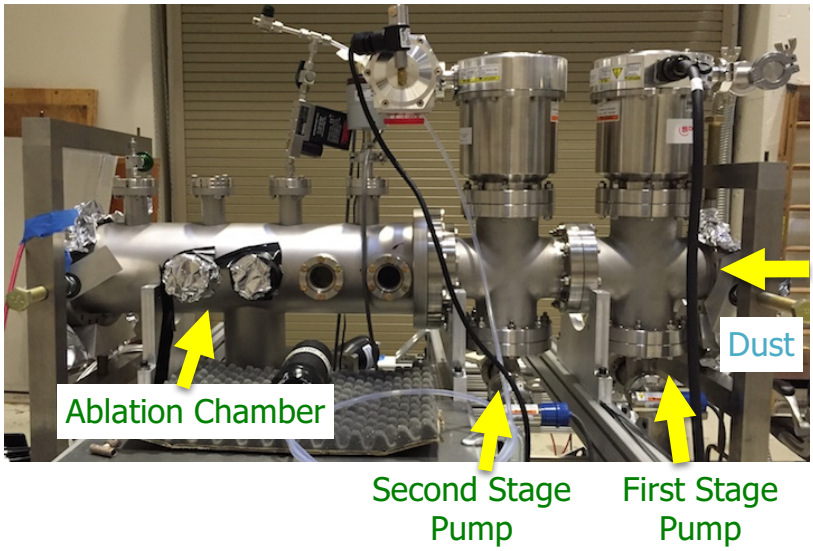
- Every day, billions of micrometeoroids ablate in Earth's upper atmosphere
- The ablated materials affect a wide variety of atmospheric phenomena (metal layers, noctilucent clouds, etc.)
- The micrometeoroids can inform us about the dust environment of the Earth
- Earth's atmosphere can be used a dust detector
- Interpretation of radar signals depends on knowing ionization coefficient (β)



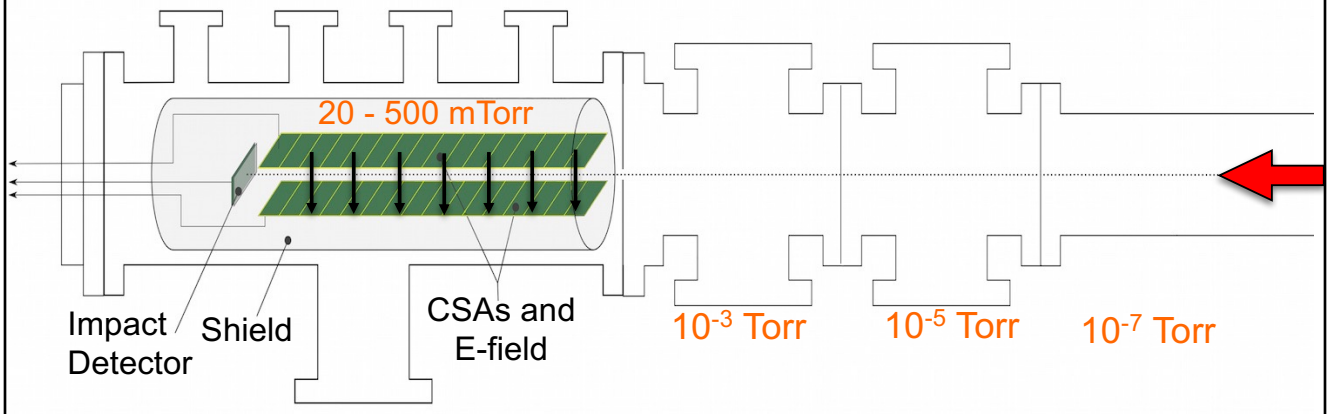
[J. Plane, Chem. Soc. Rev. 2012]

Gas Target/Chamber for Ablation Studies

- Differentially-pumped target capable of up to 0.5 Torr
- Complete / partial ablation of within 50 cm chamber
- Series of amplified electrodes with bias
  - ➢ **Measure Charge Production**
- Series of viewing ports, fiber-coupled optics, PMT's:
  - ➢ **Measure Light Production**



Ablation Process in the Lab



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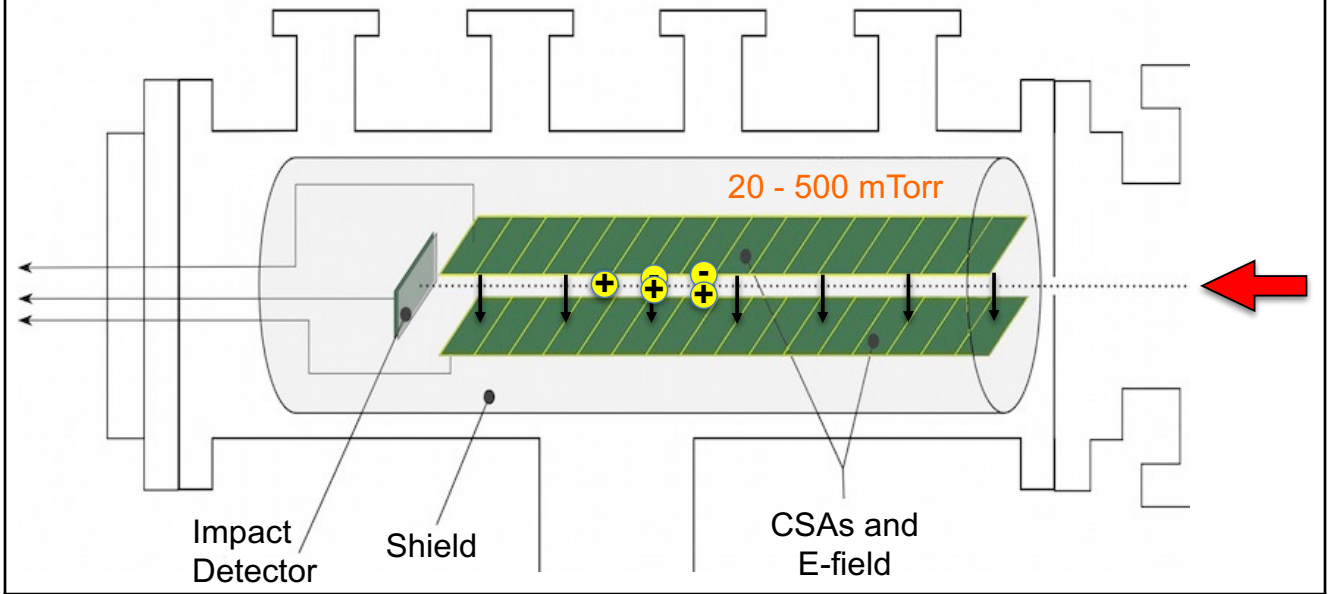

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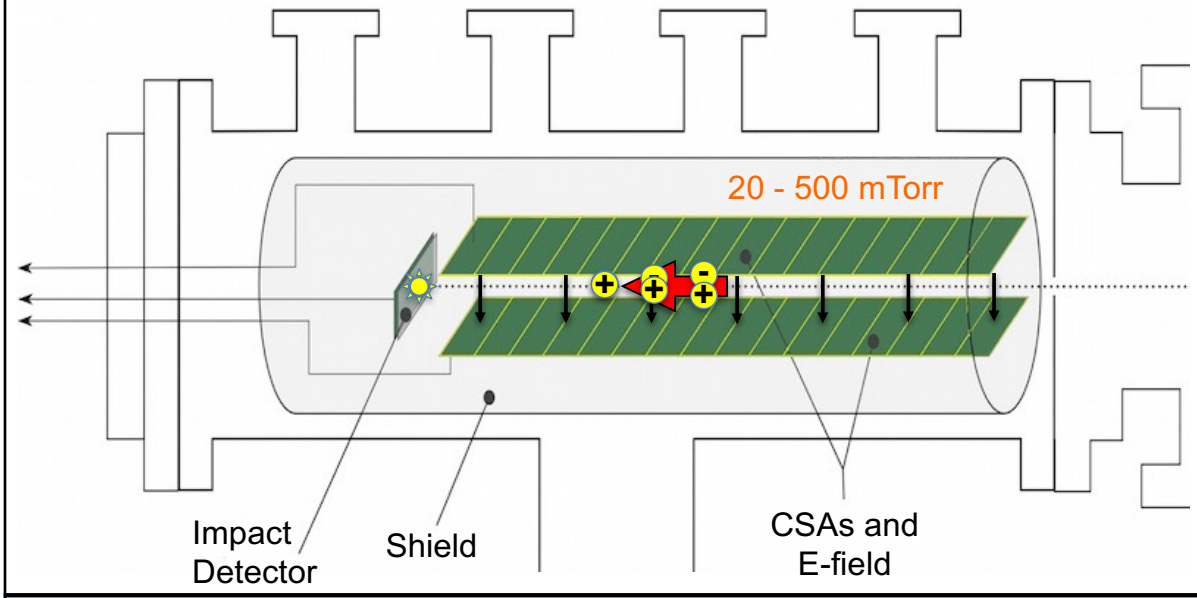
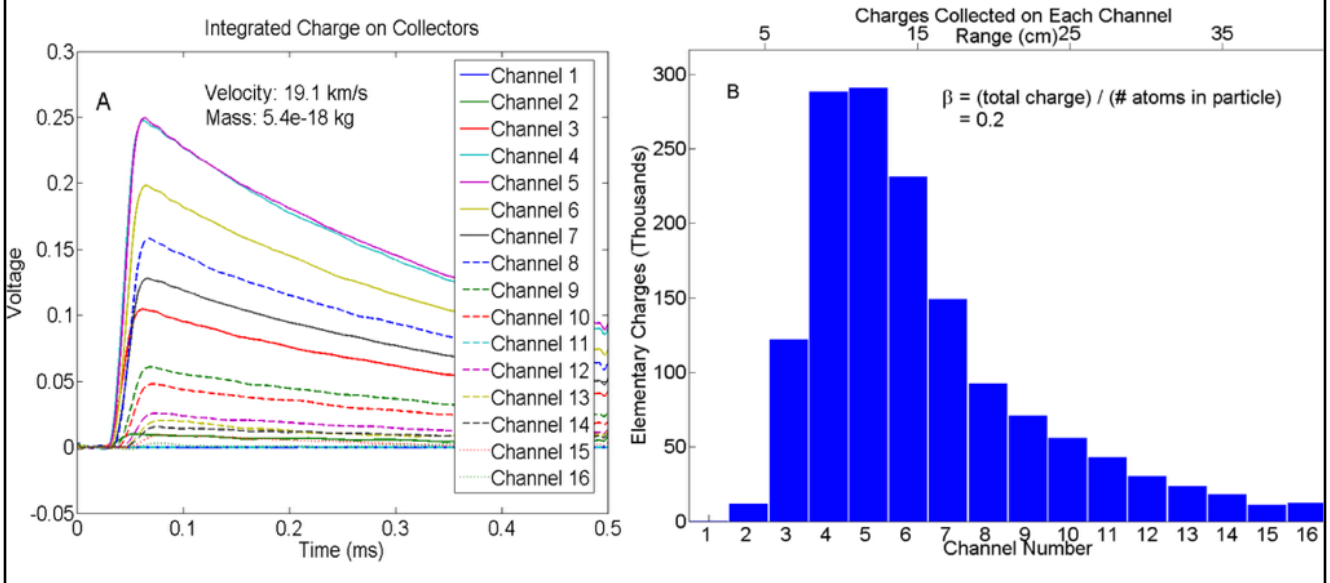
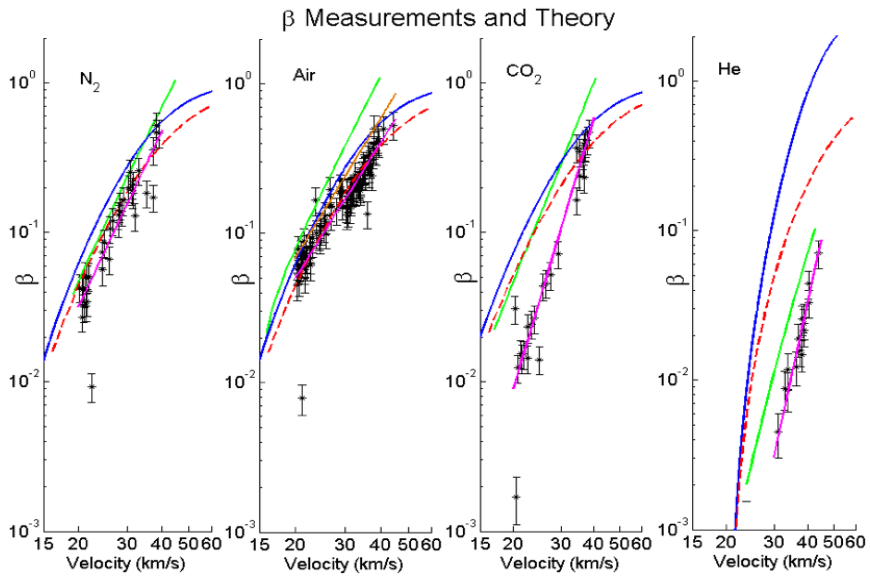


Title



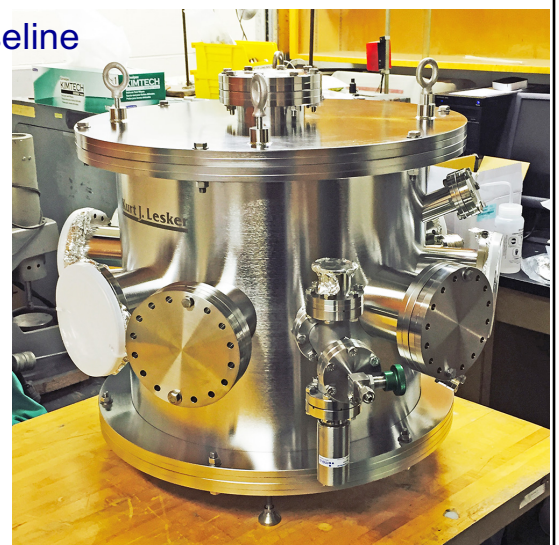
Measurements of β in a Variety of Target Gases

- Measurements of β value are now complete in multiple gas species
- Overall β behavior and details of spatial dependence constrains physical models used to interpret atmospheric measurements
- Future measurements will address different projectile species, differential ablation, etc.

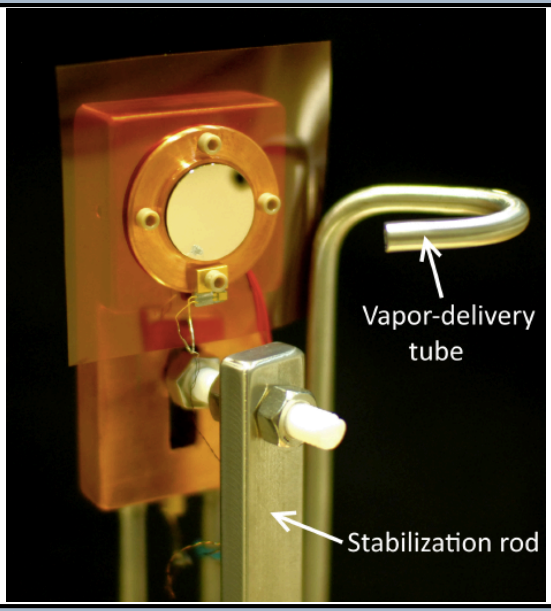


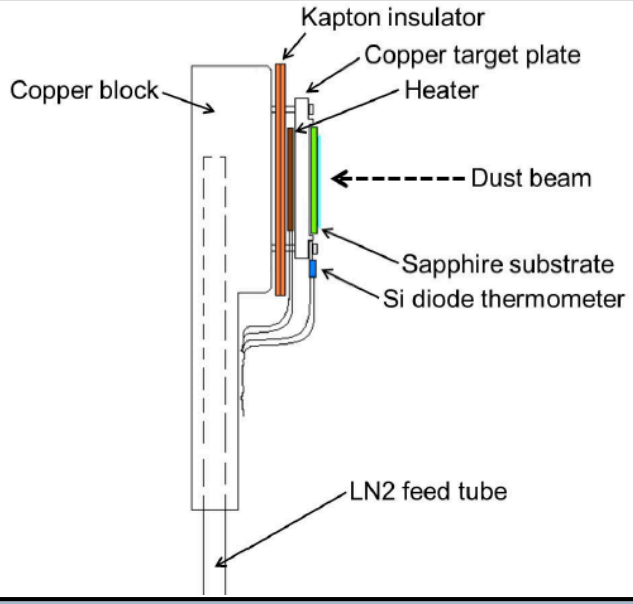
Cryogenic Target for Studies of Ice Impacts

- Cryogenic system based on LN_2 flow
- Embedded heaters control temperature baseline
- Target temperature ≥ 90K
- Two Separate Ice Targets:
  - **Frozen Liquid Target**
  - **Deposited Thin Films**
- UHV Chamber (oil-free vacuum systems)
- Ultimate Capabilities:
  - **Crystalline Ice**
  - **Ice / Dust mixtures**



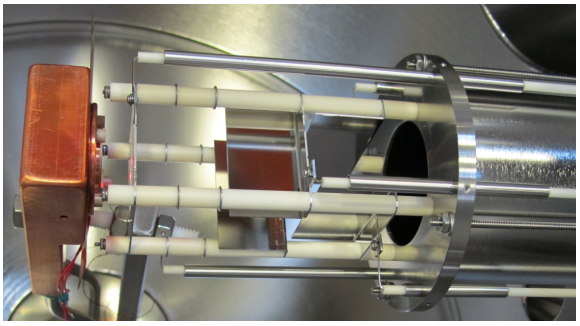
Details of Ice Deposition Substrate

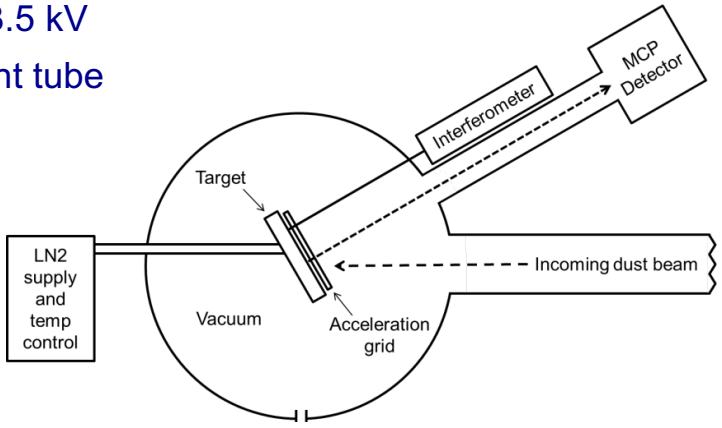




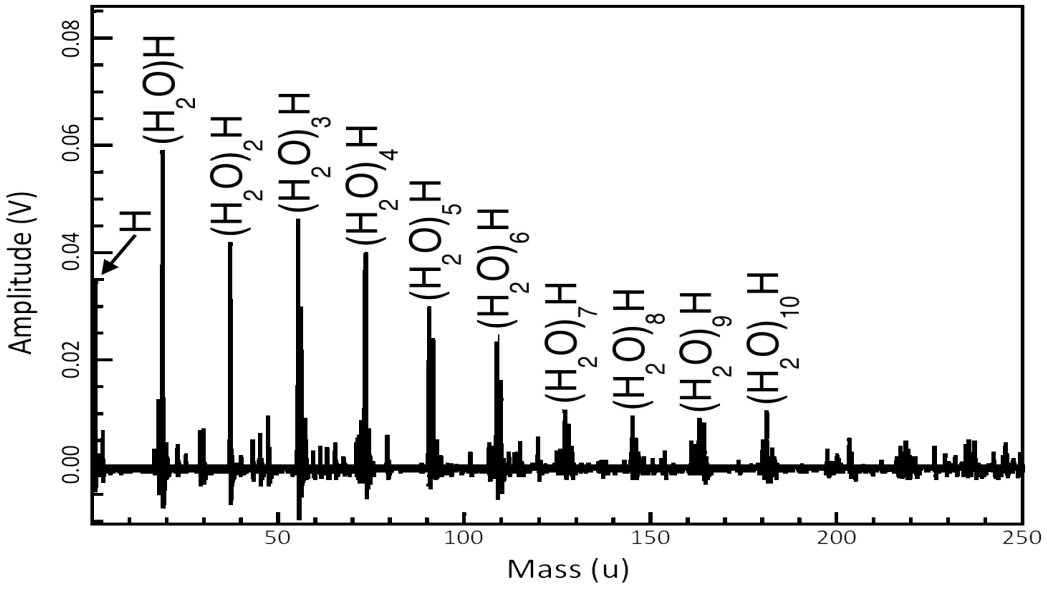
Analysis Tools for Ice Growth and Impact Products

- Fabry-Perot interferometer for measuring ice thickness during deposition
- Linear time-of-flight mass-spectrometer to assess impact products
- Target substrate biased up to ±3.5 kV
- Grounded grid & target, 1 m flight tube



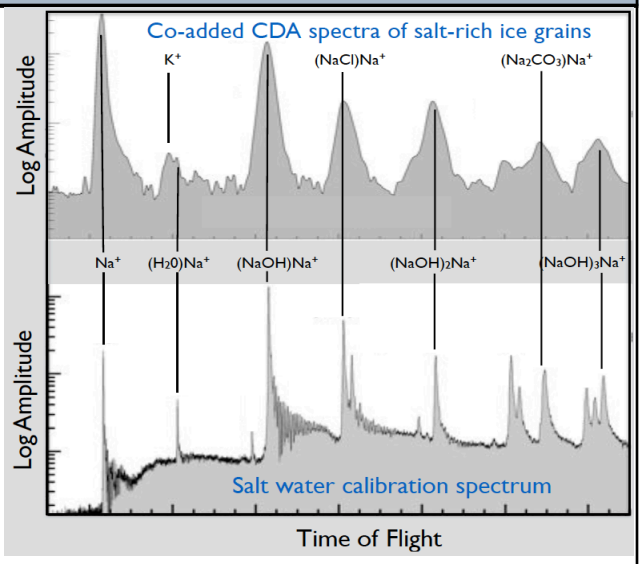


Fe Impact into H_2O ice: v_{dust} = 21.8 km/s



Shock Chemistry Studies with Mass-Spec Data

- Testing hypotheses of synthesis of complex organic materials based on micrometeoroid energy + material
- Comparing to previous laboratory studies using lasers and/or other radiation forms
- Interpretation of mass spectra from SUDA instrument on Europa mission
- Calibration of SUDA dust detector



[F. Postberg, Nature 2009]