LUNAR IMPACT DEBRIS PLUME: IS THE ENCELADUS PLUME A REASONABLE ANALOG?

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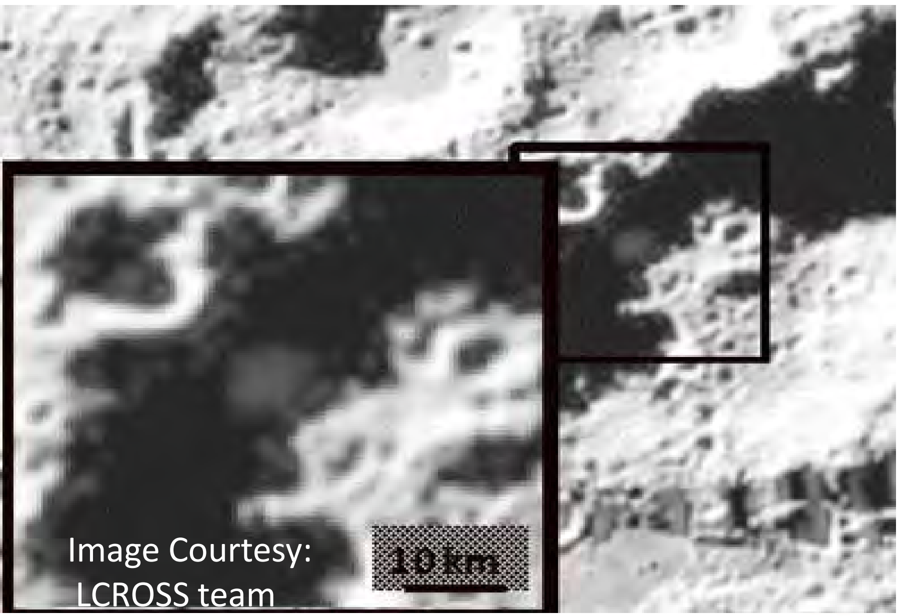
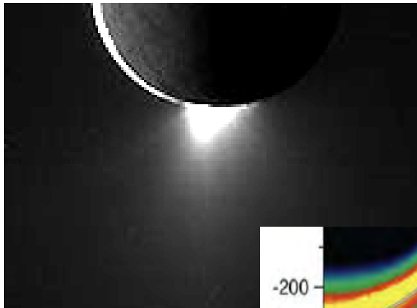
Impact Plume: Solar wind plasma/debris interaction



- LCROSS stimulated idea: What would plasma instruments detect?
- Comparative planetology
- Involves the field of ‘dusty plasma’ research
- Dumping a large mass of dust grains into the passing solar wind plasma
- Statement of problem: How does a flowing plasma behave when dust ‘chunks’ are introduced?

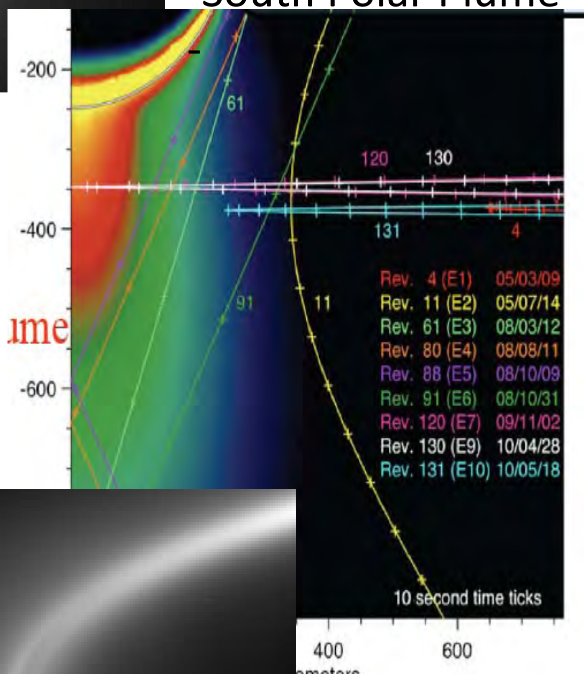
The Enceladus Analog

Enceladus:
-Icy moon
-250 km radius
- 4 R_s from Saturn
-South Polar Plume



South Pole Geysers

Cassini ISS images



Cassini Transits

Enceladus and E-ring

- Comparative Planetology
- Look at other 'chunky' plasma systems
- Enceladus plume ***may*** be close analog
- Nice thing about plume @ Enceladus: Steady State!
- Spews ~ 100-200 kg/sec
- Even forms the larger E-rings
- Many Cassini transits with dusty plasma 'gear' – CAPS, RPWS, CDA

Comparison

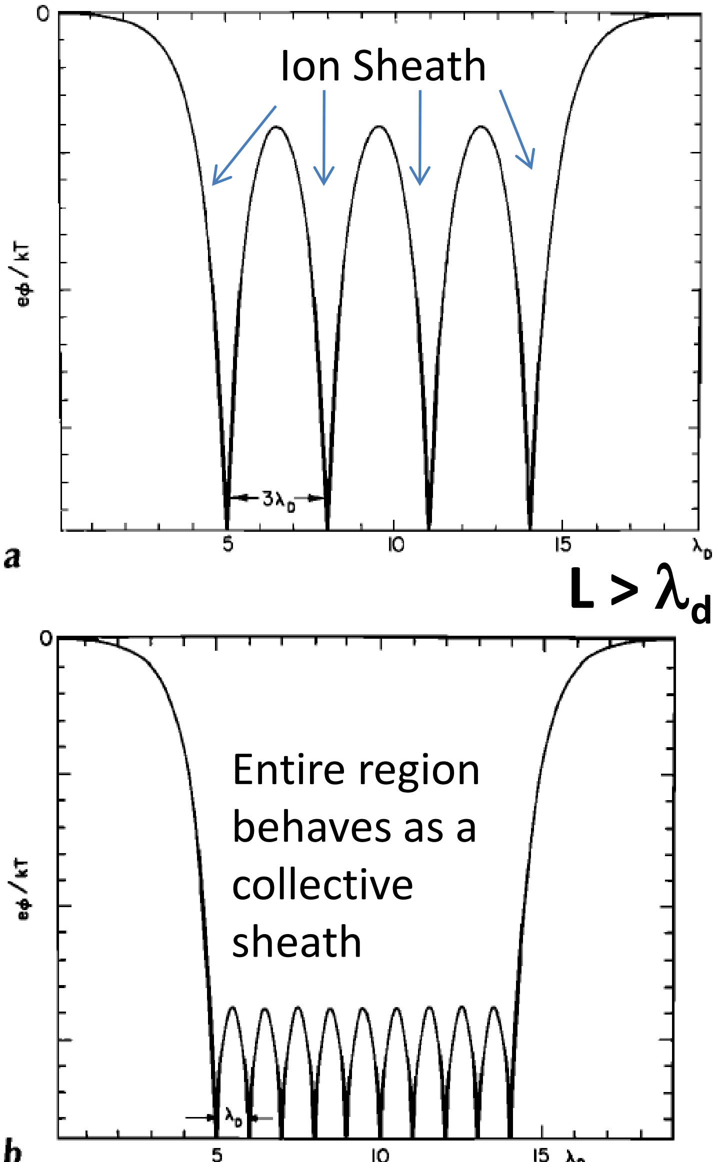
DREAM

	Enceladus plume	LCROSS-like impact plume
Ejection Character		
Release rate (kg/s)	~100-200 kg/s, steady	~300 kg/sec, over 10 sec
Dust-to-Gas Mass Ratio	> 0.1 (Gassy)	~10 (Chunky)
Gas density (m^{-3})	10^{13} *	10^{15} **
Dust density (m^{-3})	>0.2 for micron sized *	~1000 **
Grains speed	> 200 m/s	500 m/s
Grain composition	Ice	Regolith (some ice)
Grain charge	Negative	Negative (?)
Plasma Environment	Co-rotating magnetosphere	Solar wind
Plasma Density (m^{-3})	~10^8	5 x 10^6
Plasma flow (km/sec)	30	400
Plasma T (eV)	3-5	10
Debye Length λ_D (m)	2.5	~20
Grain Interspacing L (m)	< 1.7 **$L \leq \lambda_D$**	0.1 **$L << \lambda_D$**

* = in situ observation region ~400 km from source; **= Over 10kmx10kmx20km volume

Two Classes of Dusty-Plasma Interactions

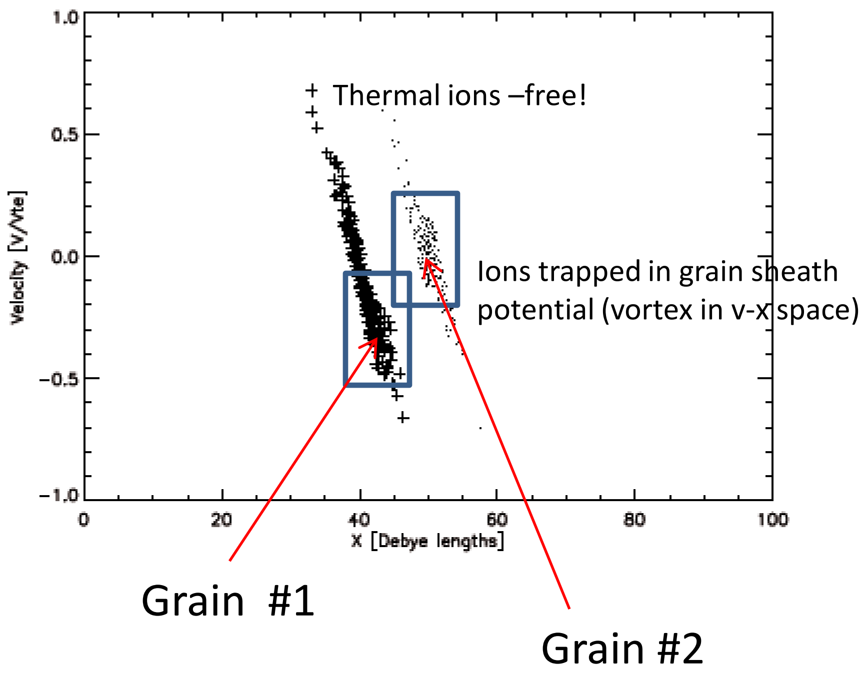
Goertz: DUSTY PLASMAS IN THE SOLAR SYSTEM • 2



Goertz, 1989, for (-) grains $L \cong \lambda_d$

- #1 : $L > \lambda_d$:Grains electrically isolated by sheath
  - Pockets of trapped ions in dust plasma sheath
  - Grains disconnected by steep potential
- #2 $L < \lambda_d$:Grains electrically connected…*both Moon and Enceladus fit this case!*
  - Debye sheaths of each grain overlap to form a **'mega-sheath'**
  - Plasma trapped in sheath can transport from grain to grain
  - Dust cloud behaves like an electrically-connected 'porous wall'
  - Can form a regional structure

Example: DREAM PIC plasma simulation code of two dust grains in a plasma

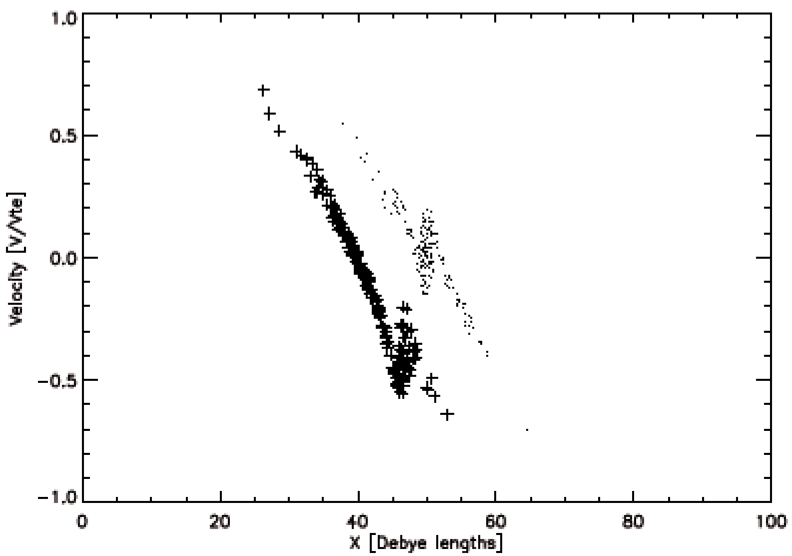


-Negatively charged grains initially isolated/separated by 10 λ_D s

- Have Grain #1 move past Grain #2 so that L < λ_D

-Ions are crosses and dots to keep track of merging effects

DREAM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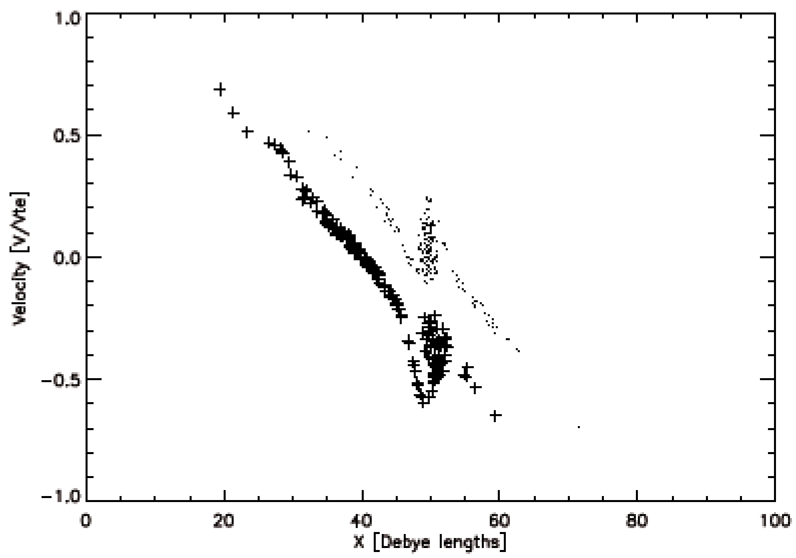
X [Debye lengths]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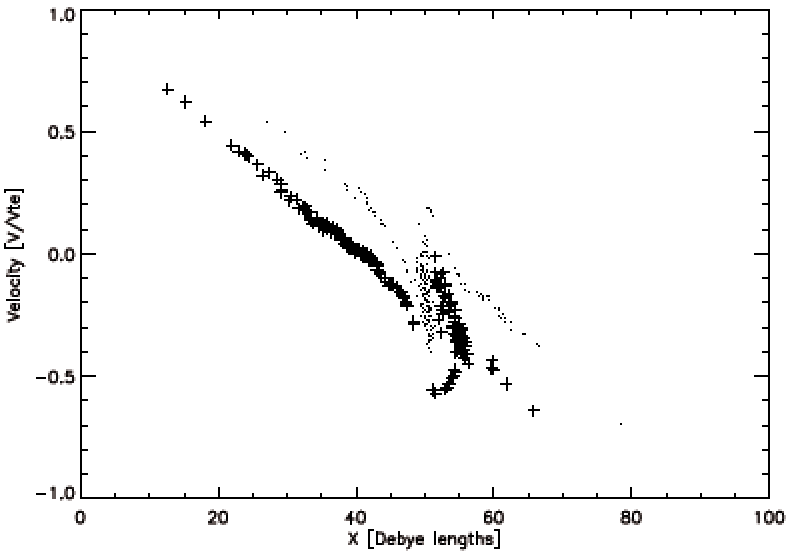
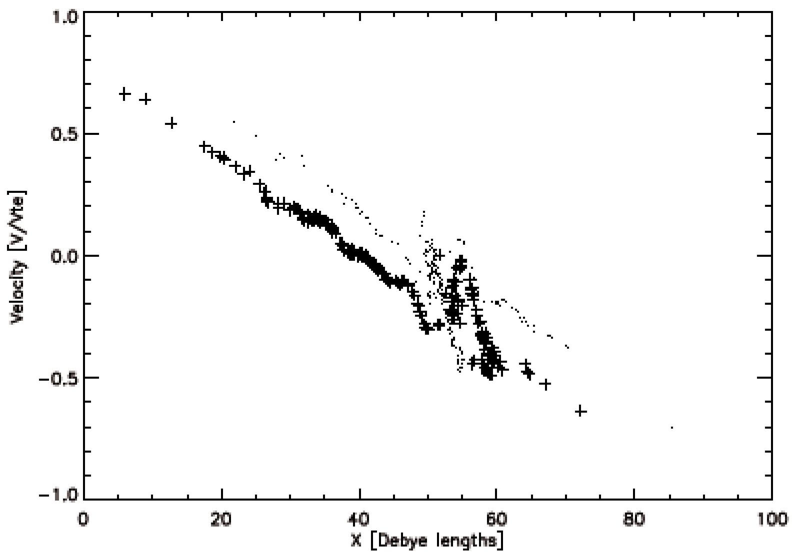


- Merging of sheaths and ion exchange!
-Create a merged sheath…temporarily!



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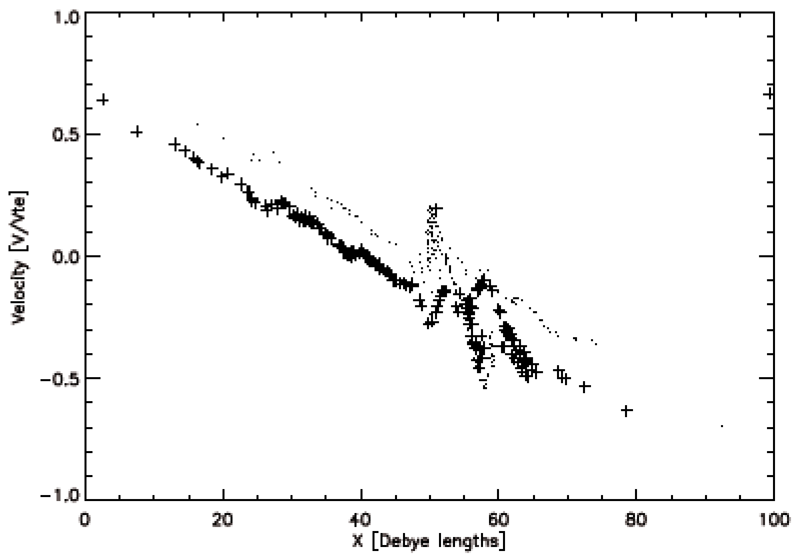

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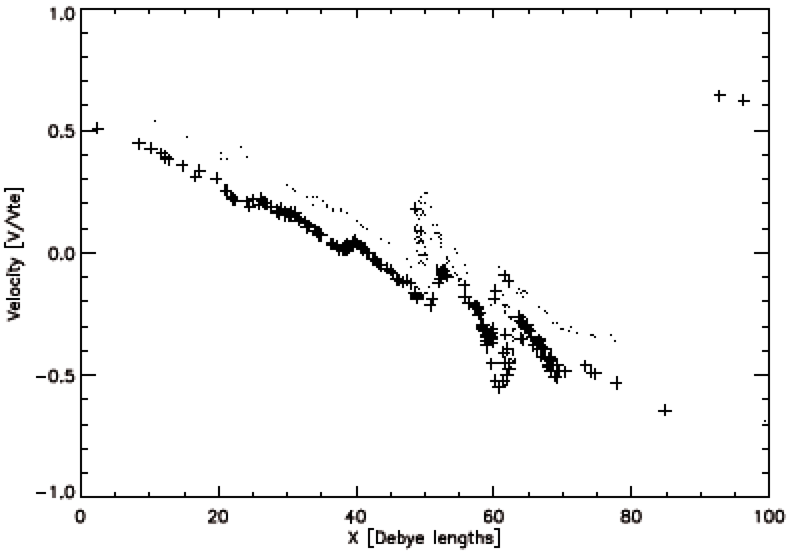

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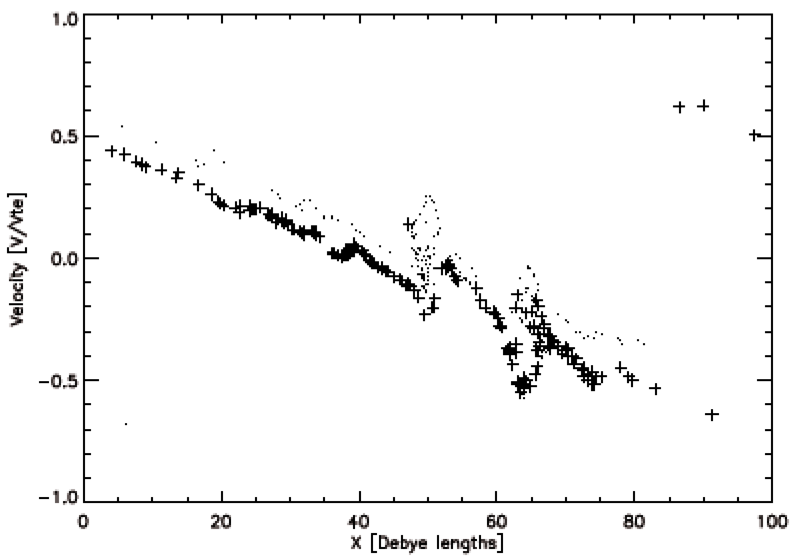
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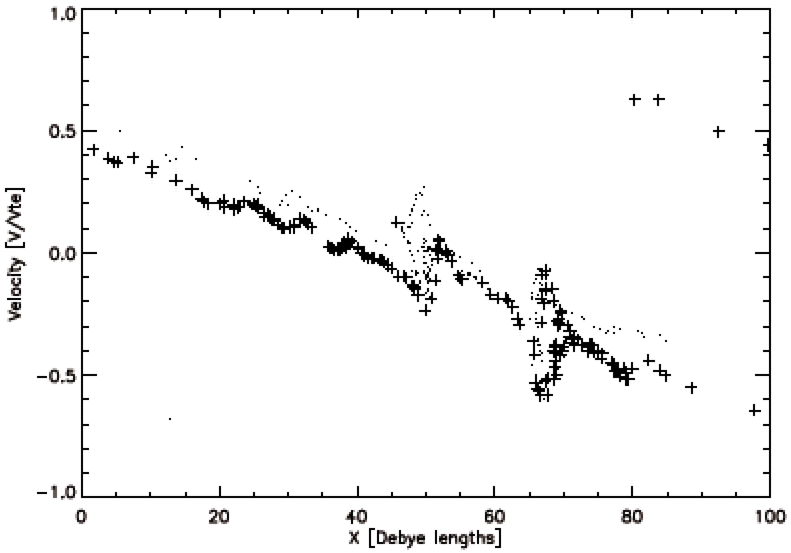

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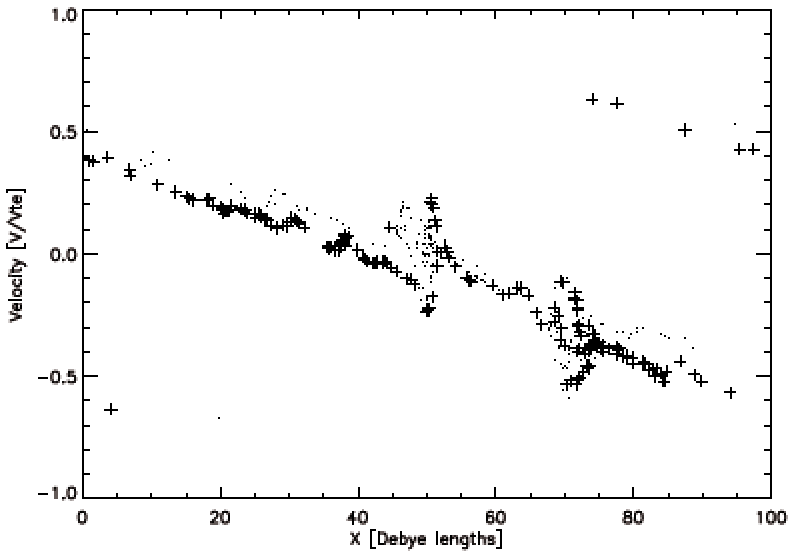

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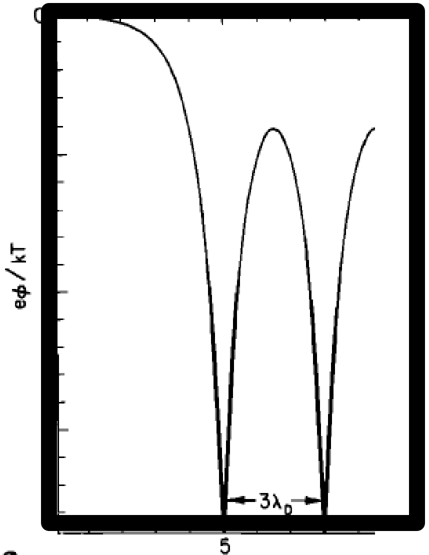
End

From Goertz 1989



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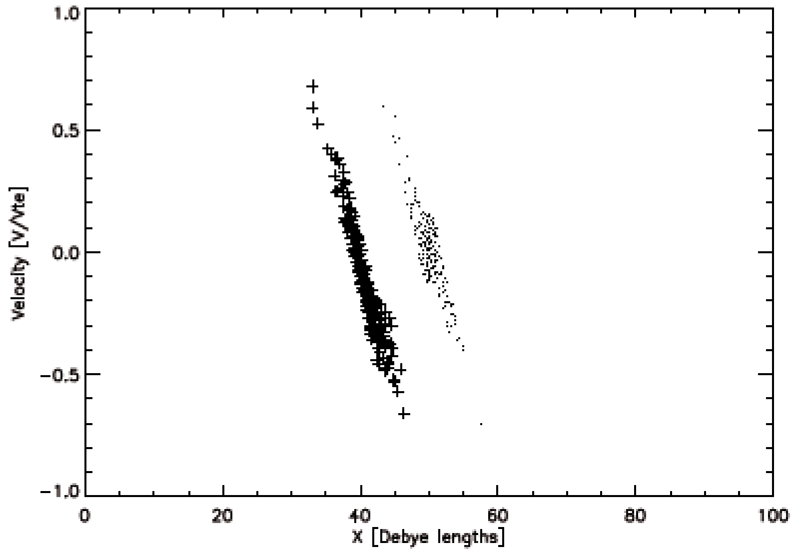
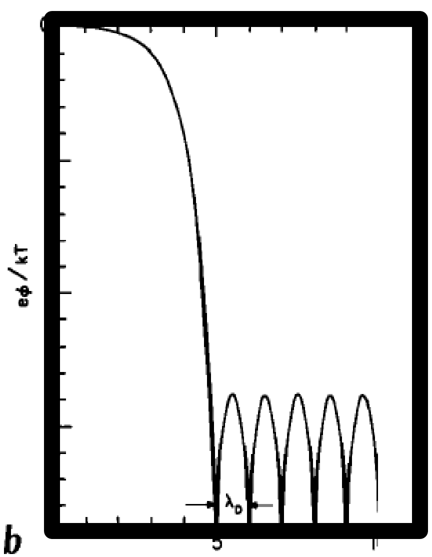


Going from this!



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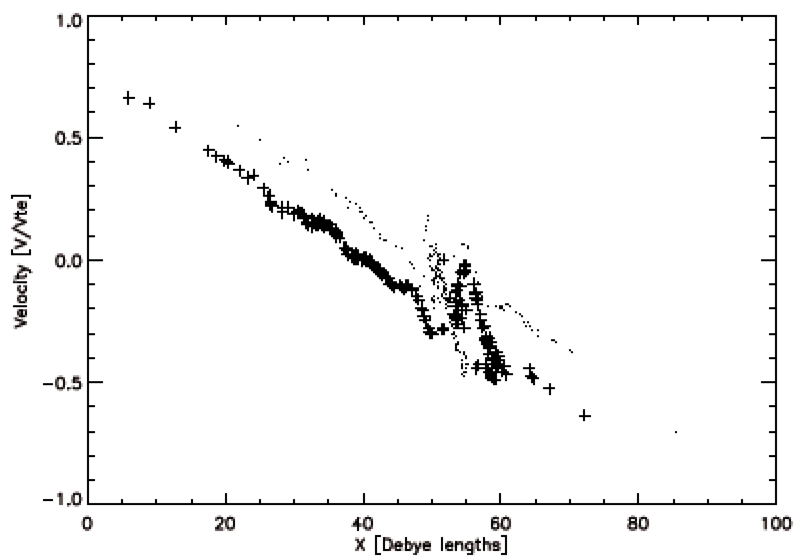
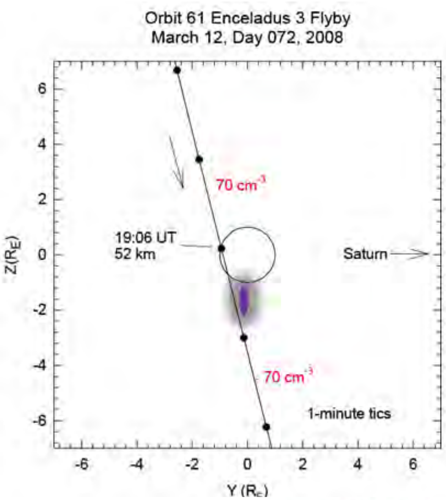


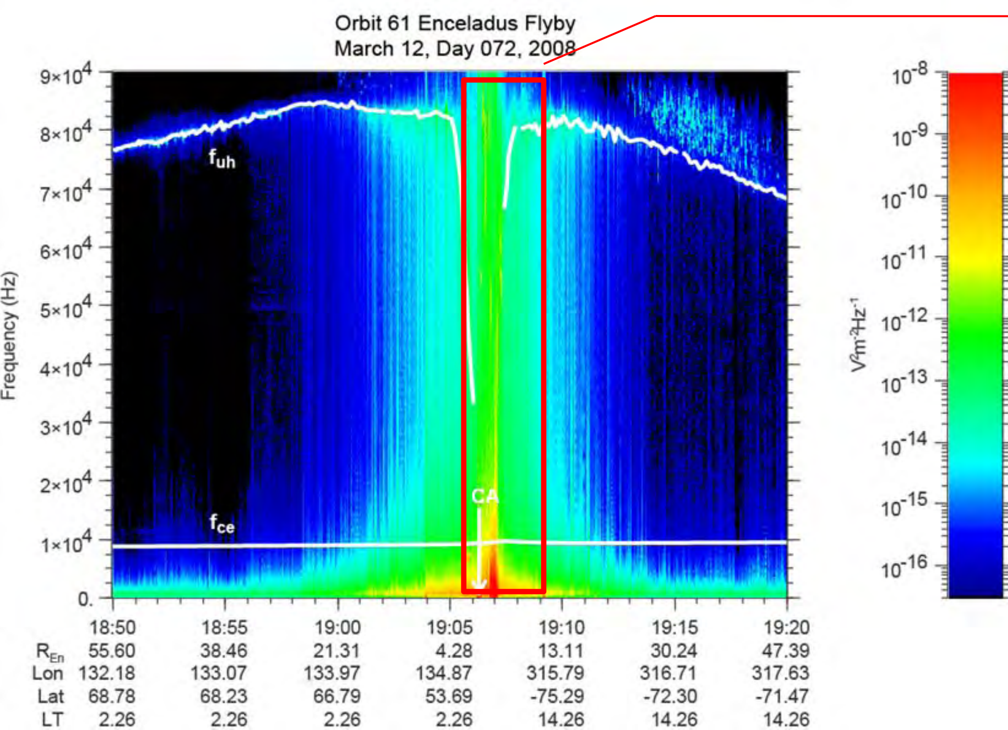
To This: Potential has dropped to allow ion flow between grains!

General collective dusty –plasma picture!

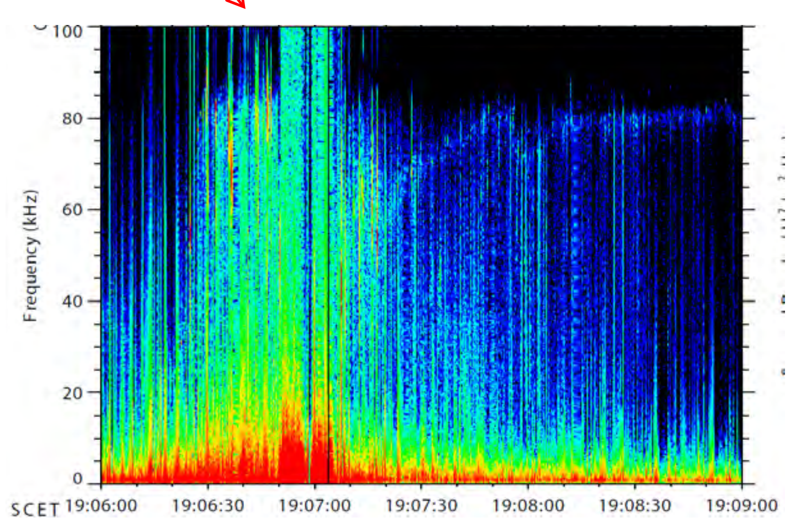
A Case Study: Cassini/Enceladus E3 passage



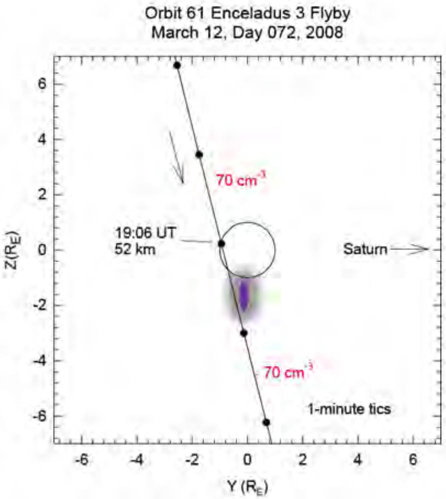
- How do we know there is dust around Enceladus?
- Cassini moving primarily southward at ~14 km/sec
- Dust detection via impact ionization that leaves a bipolar pulse on RPWS antenna system
- Appears as a broad 'spike'-like noise on radio frequency vs time spectrogram



Cassini RPWS



Cassini/Enceladus E3 passage



Observations of Plasma in Dust Cloud (surprise!):

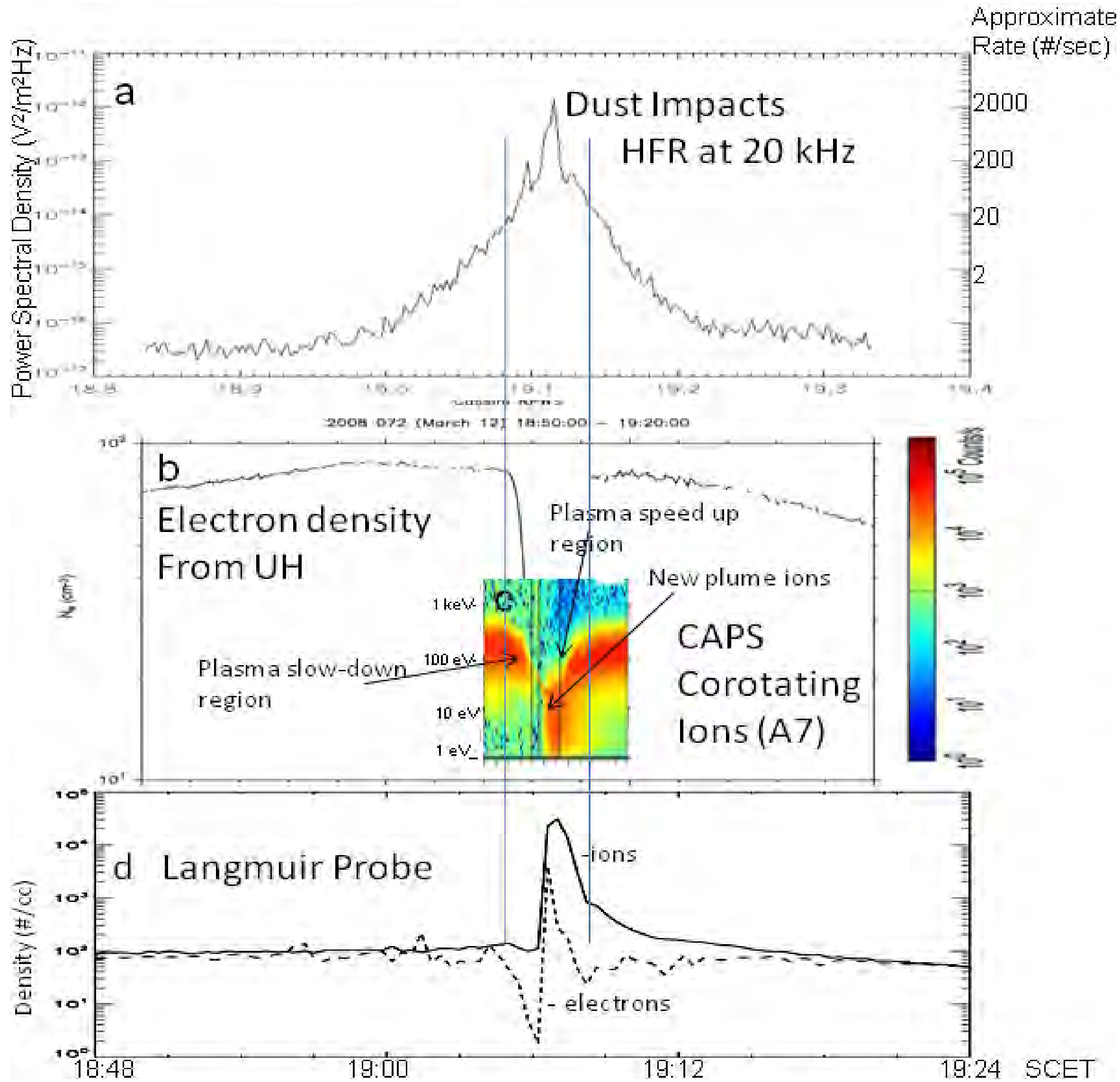
1) Dust absorption of electrons, like a sponge!

- **n_i / n_e ~ 30 (ion-rich)**
- Entire region a big 'sheath' – **mega-sheath**

2) Plasma slows down

Dust has an electrical effect on plasma!!!

[Shafiq et al, 2010, Omidi et al., 2010, Farrell et al., 2009, 2010; Tokar et al. 2009]



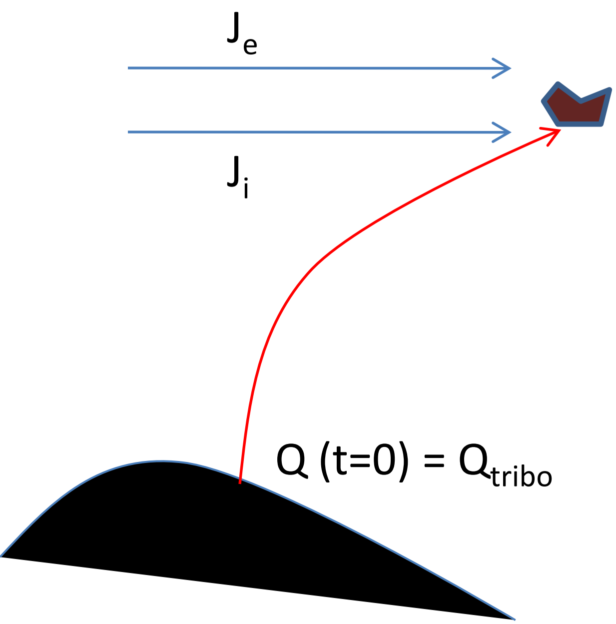
Lunar Applications of the Enceladus Analog

Since L << λ_D in both applications, might expect similar collective dusty plasma behavior:

- Dust concentrations are large
- Plasma electrons 'sucked' out of fluid - absorbed onto dust
- $n_i/n_e >> 1$

However, a complication occurs for a direct application

Grain Charge State & Plasma Equilibrium



$$\tau^{+} \sim (kT_e/e)(C/|J^{-}_{amb}|A)$$

$$\tau^{-} \sim (kT_i/e)(C/|J^{+}_{amb}|A)$$

Farrell et al., 2008

- Given a grain's initial tribo-charge state, it will come to equilibrium with the plasma on a time scale of τ
  - τ_{Enc} ~ 0.5 sec [Shafiq et al 2010]
  - τ_{Moon} ~ 50 sec
- At Enceladus, grains come to equilibrium very quickly
- At Moon, longer equilibrium times
- But LCROSS plume present for at least 4 min – did it reach equilibrium in last few mins?
- Analog gets more complicated!

Prediction for Flowing Solar Plasma at a Lunar Impact

Grain Charge State	Location	Character of Flowing Plasma	n_i/n_e	Like Enceladus ?
Equilibrium negative	Just behind terminator	Electrons absorbed from plasma – Ion rich region	>>1	Yes
Equilibrium Positive (photoelectrons)	Dayside	Electron concentrations increased to offset added positive grains – electron-rich plasma	<<1	Converse case
Triboelectric negative	Any	Dust absorbs protons to get to equilibrium – electron-rich plasma; Early in plume lifetime	<<1	
Triboelectric positive	Any	Dust absorbs electrons to get to equilibrium – ion-rich plasma; Early in plume lifetime	>>1	

For a real impact, plasma environment may have changed with time! Complicated plasma structure!

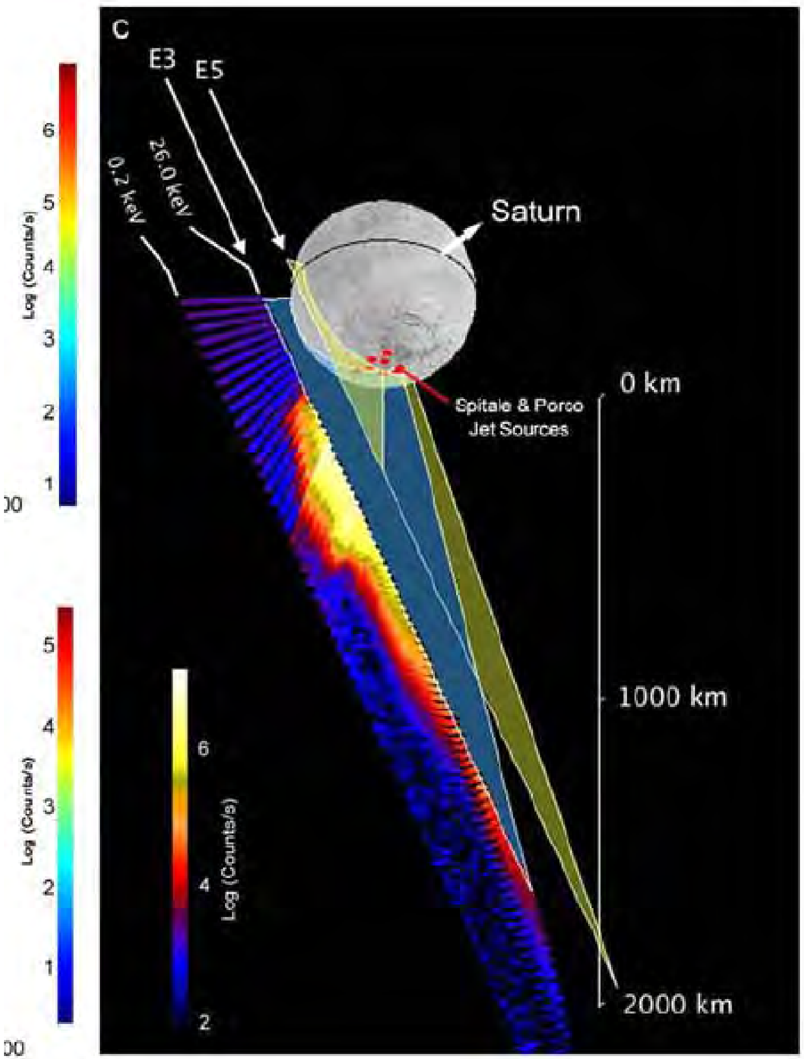
DREAM

Is Enceladus plume an analog to a lunar impact?

- As we learn about Enceladus' plume, it provides insight on lunar impact/plasma interactions
- Comparative planetology: Moon ⟷ Enceladus
- **Both cases:** collective dusty plasma state ($L < \lambda_d$)
- Conclude: System acts as a 'porous wall'…a 'mega-sheath'
- Conclude: Solar wind should be affected – but the nature is dependent upon the charge state of the grains
- If grains are in equilibrium, the analog is stronger
- System may start in a tribocharged state but evolve towards equilibrium and the Enceladus model
- Next time LCROSS2- in situ dusty plasma instruments

Backup slides

Grain Initial Charge

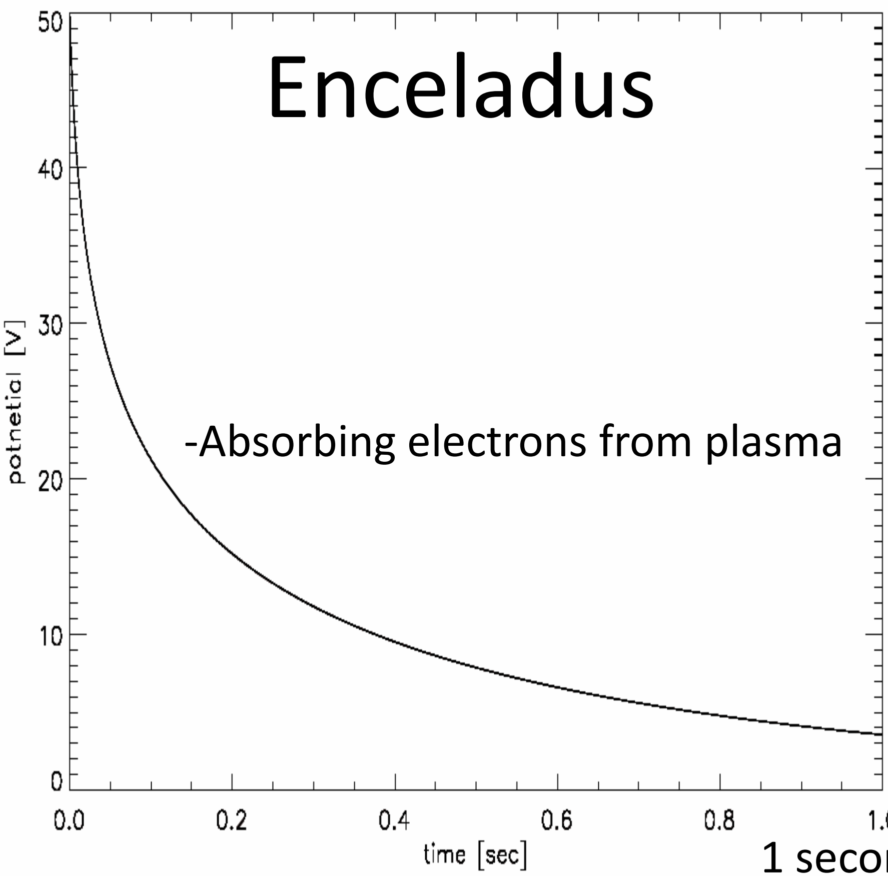


- Jones et al 2009 suggested that the grains detected at Cassini contain original tribo-charged from jets source
- However, plasma equilibrium times in jets are ~ 0.3-3 s [Shafiq et al 2010; Farrell et al 2010]
- Grains must be in equilibrium w/ plasma by time they reach Cassini
- Also consistent with plasma electron absorption

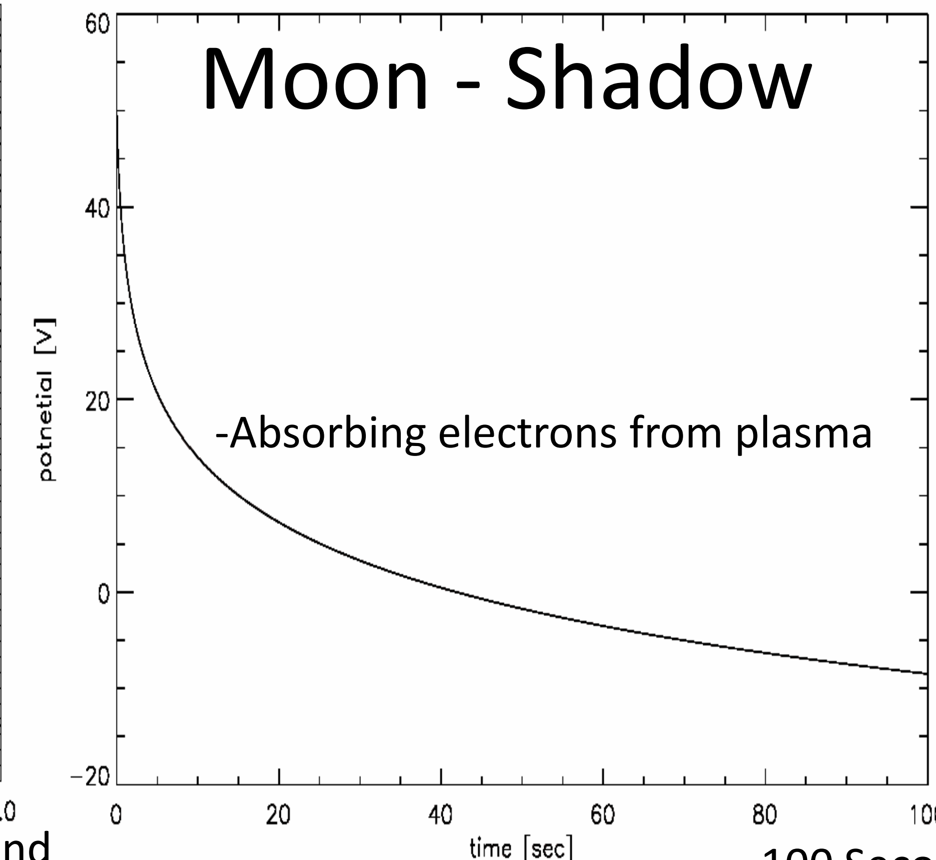
Grain Discharge to Equilibrium

-1 micron grain

-Grain initially tribocharged to +50V



1 second



100 Seconds

DREAM