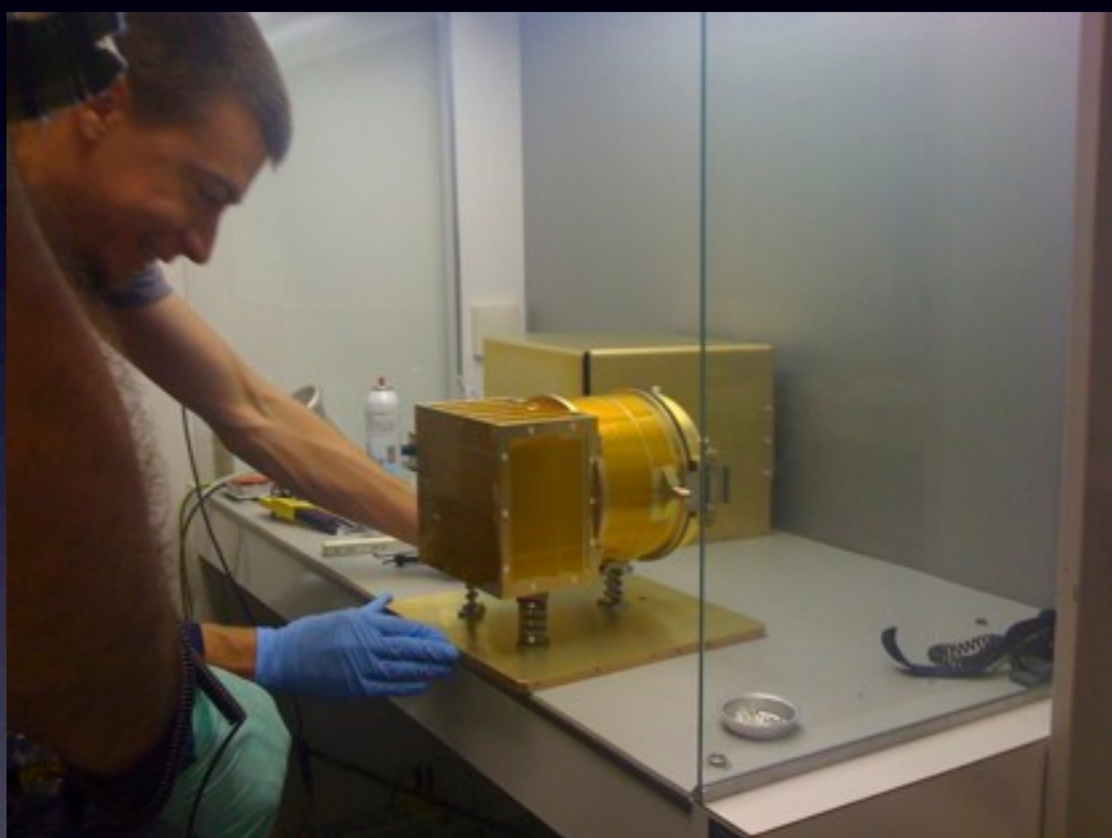
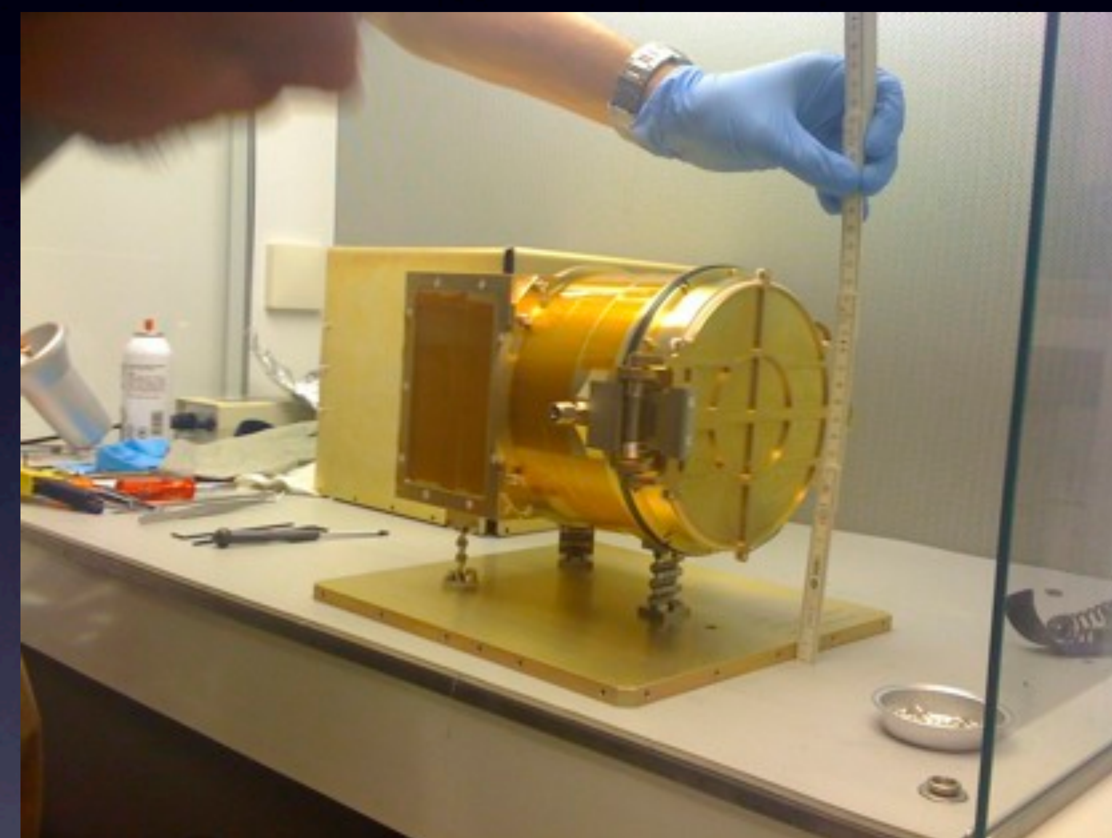
The Lunar Dust Cloud

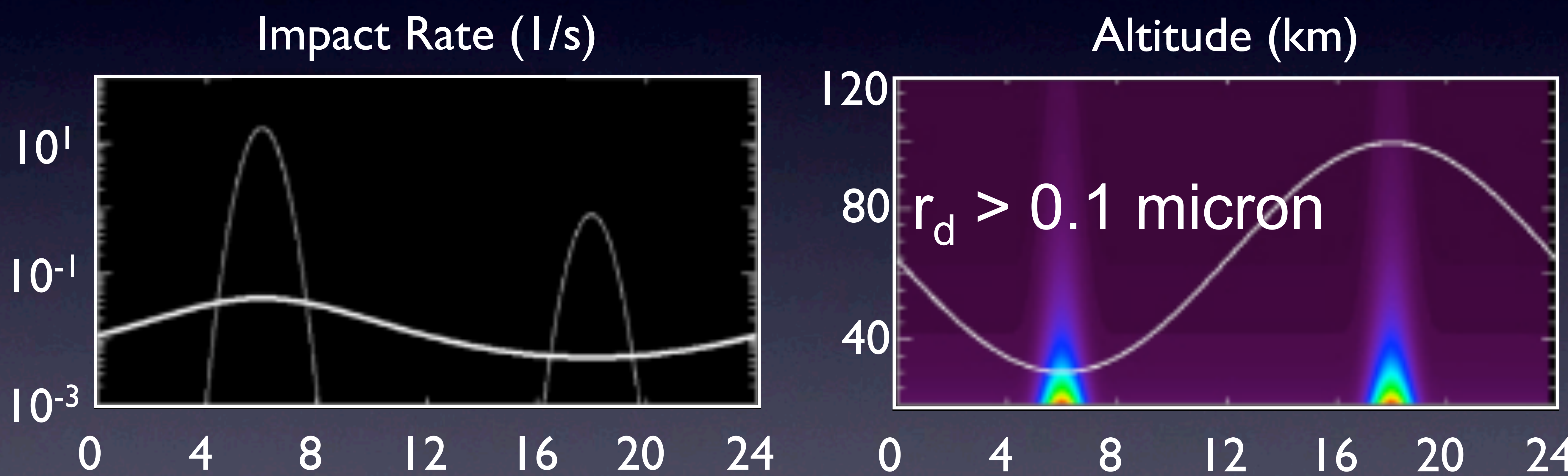
Sascha Kempf[1,2], Mihaly Horanyi[1,2], Zoltan Sternovsky[1,2],
Jürgen Schmidt[3], and Ralf Srama[4]

LDEX





LDEX Prediction



Sternovsky, NLSI Meeting, 2009

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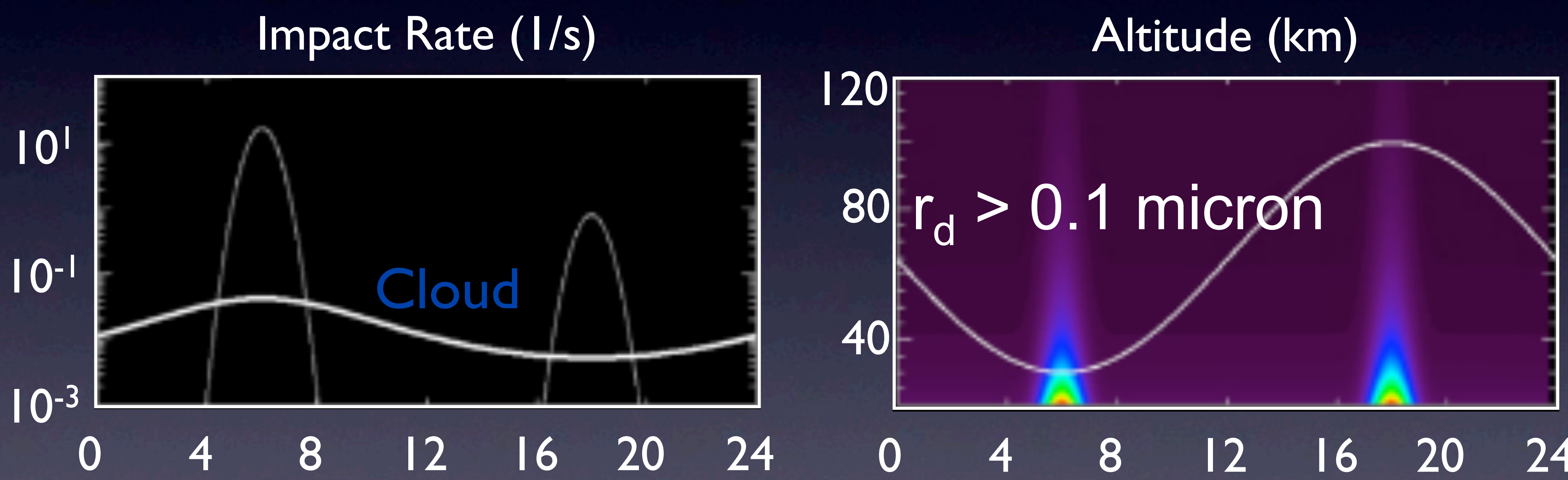
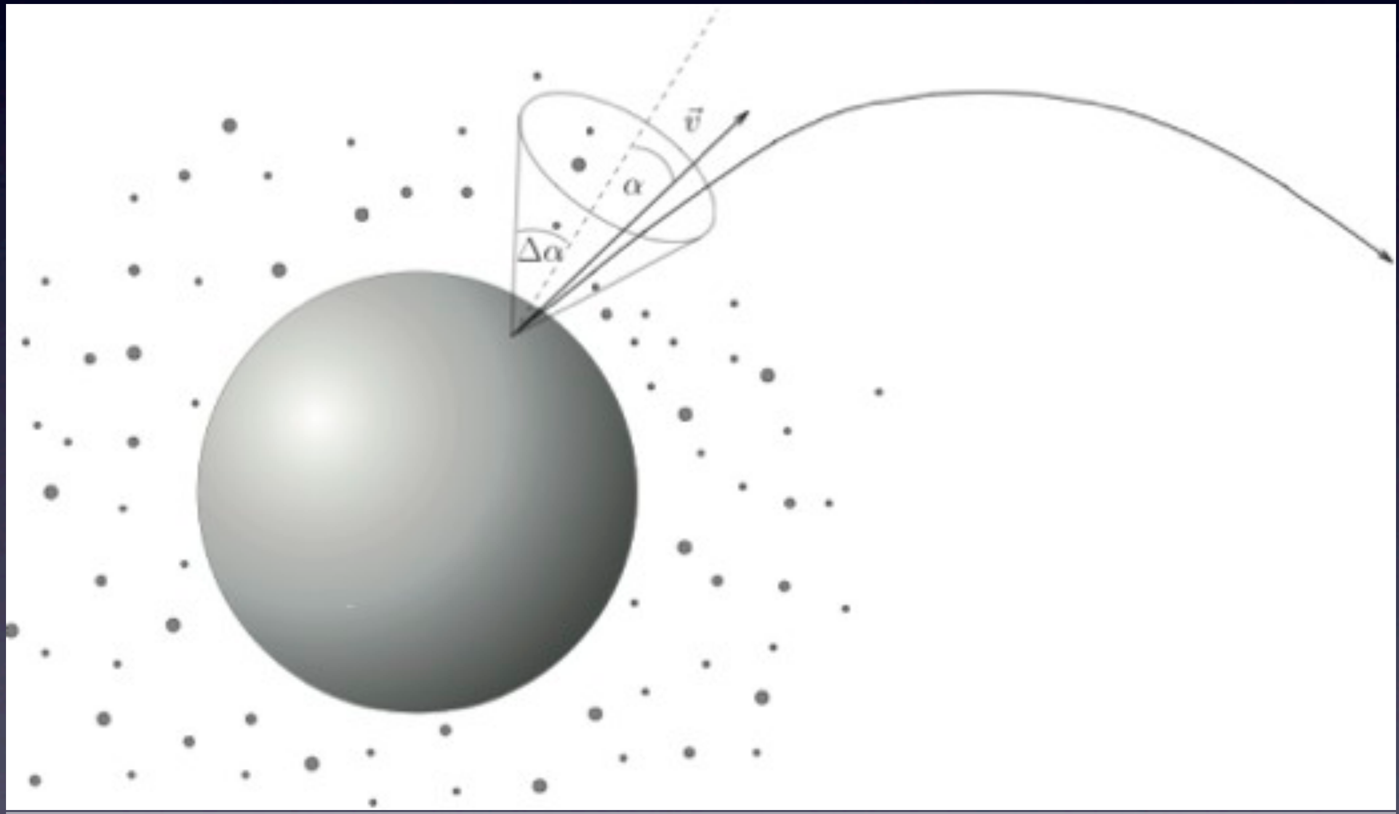


Sternovsky, NLSI Meeting, 2009

How is the Lunar dust produced?

Dust Production

Meteoroid Impacts Produce Ejecta



Sremcevic et al., Icarus, 2005

Lunar Mass Yield ~ 1000

Koschny & Grün, Icarus, 2001; Krivov et al., Icarus, 2003

Dust Production

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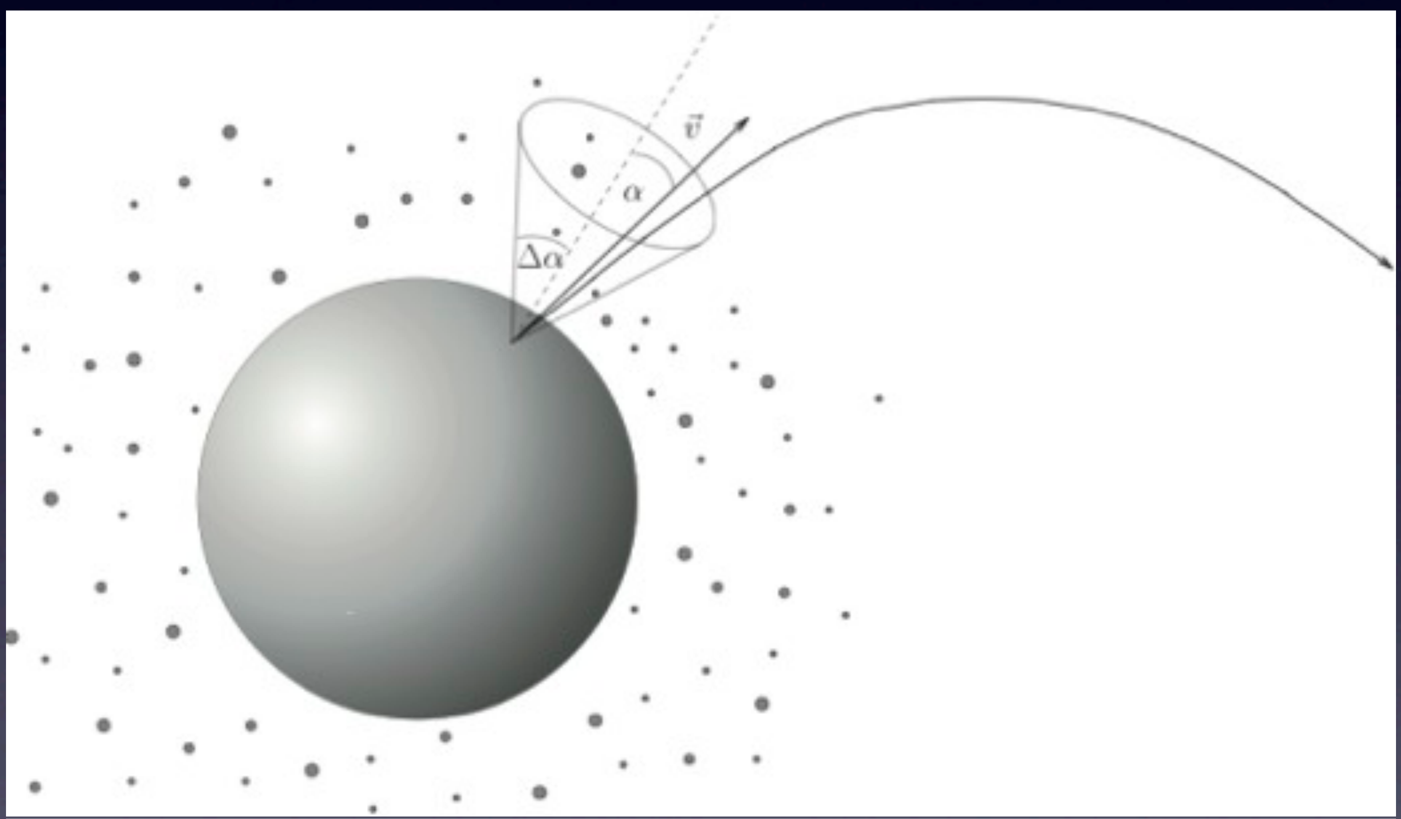

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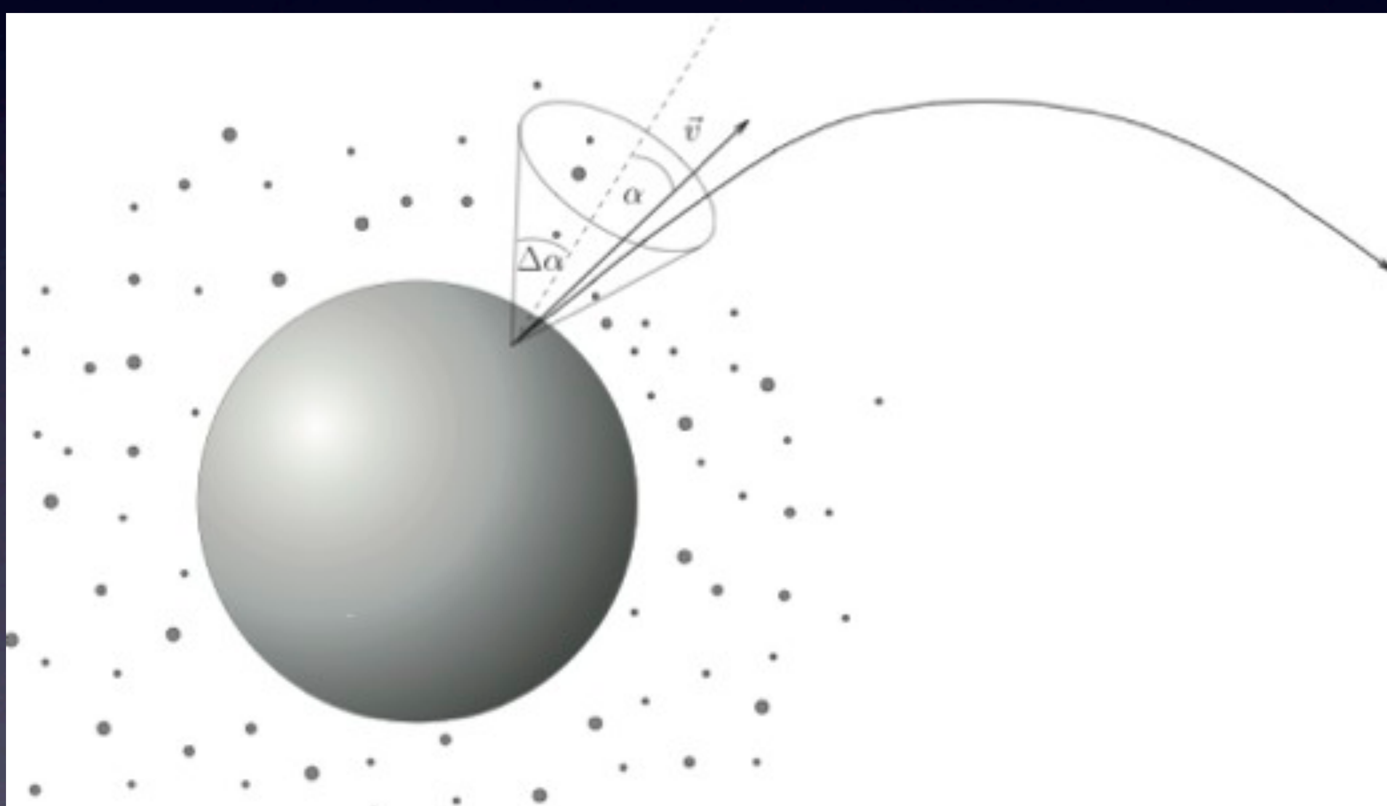

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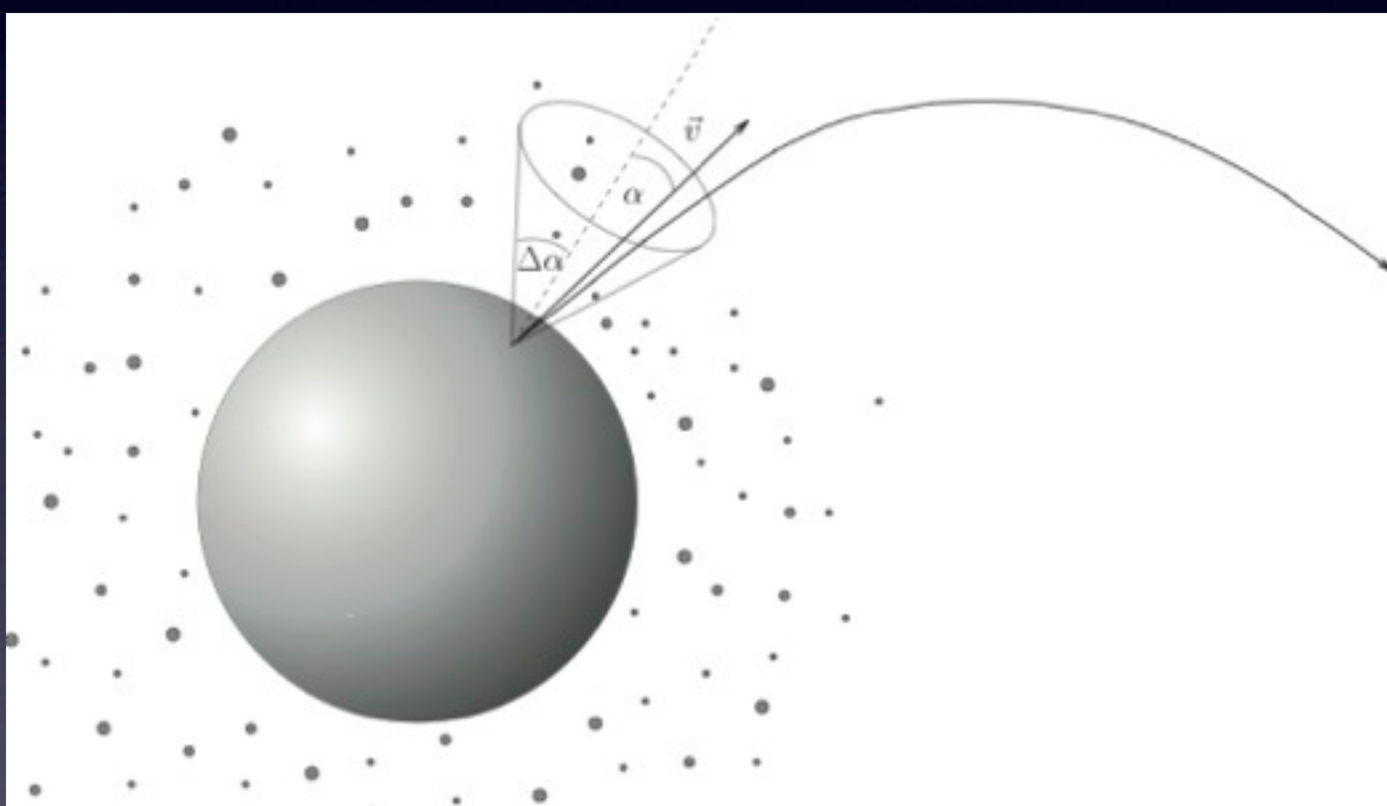

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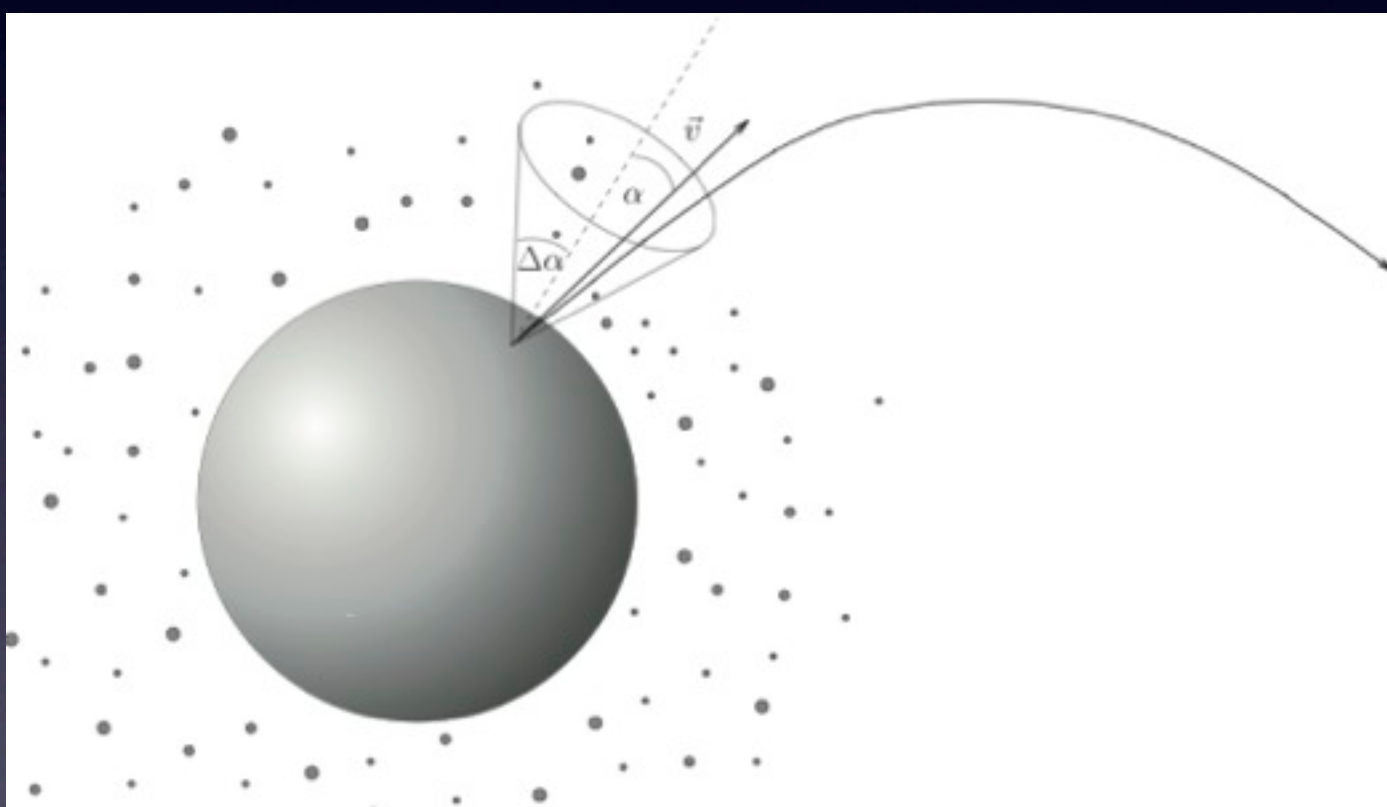

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- Some Ejecta Escape:
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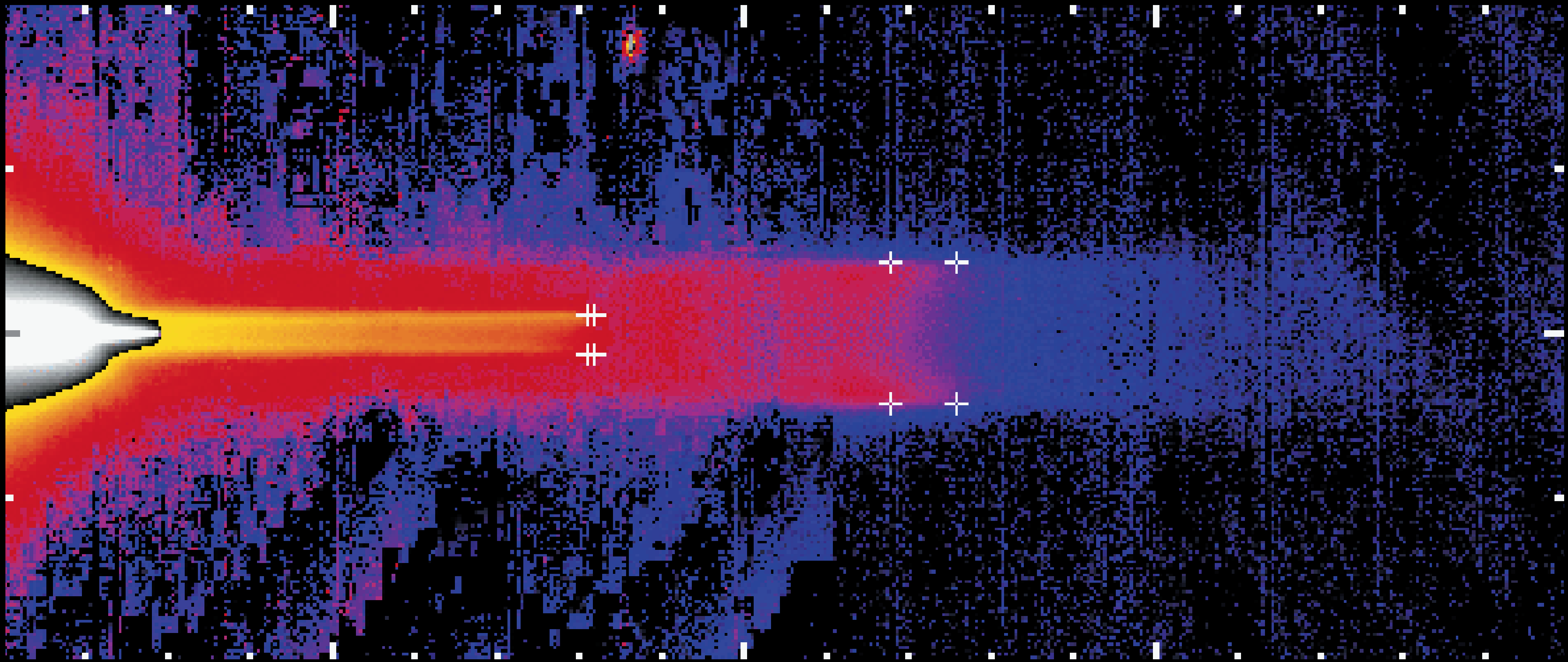
  - Moon Mass Loss Mechanism

Dust Moon „at Work“

Jupiter‘s Gossamer Rings



Burns et al., Science, 1999

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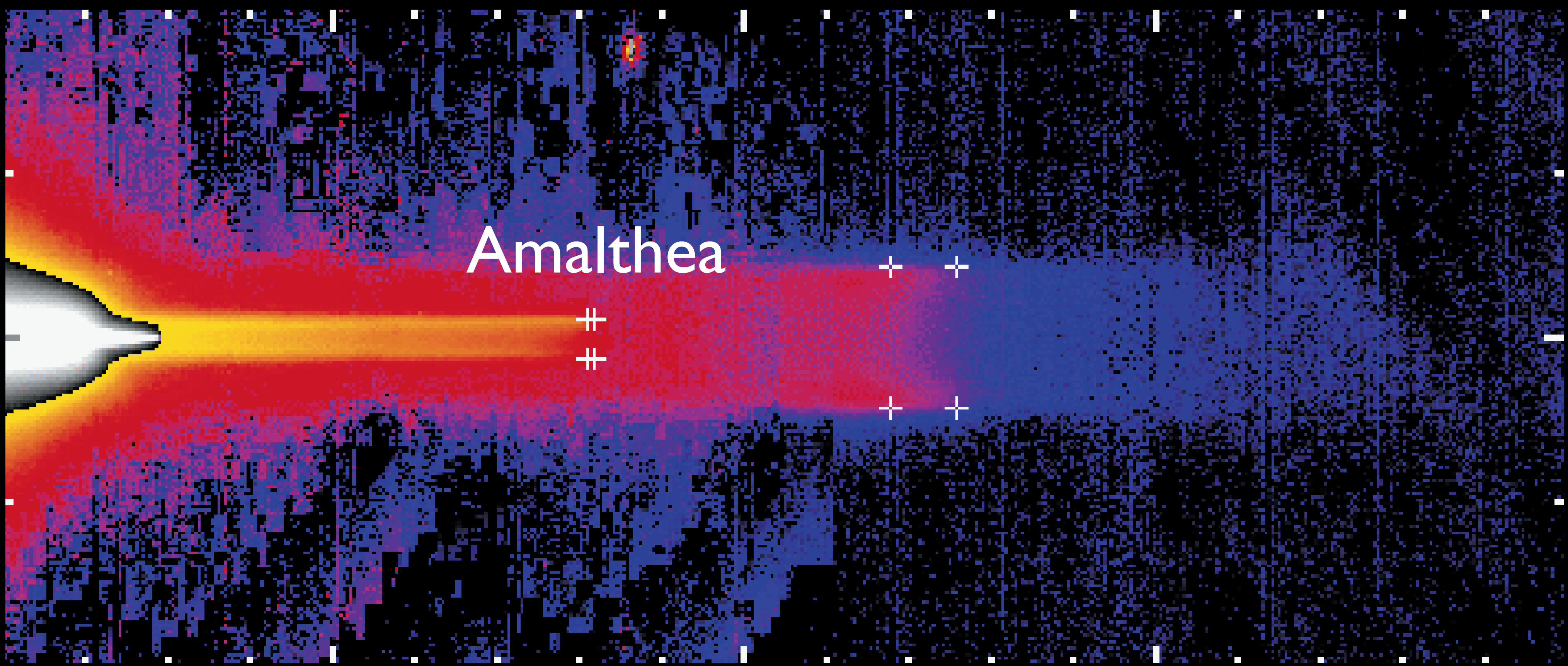

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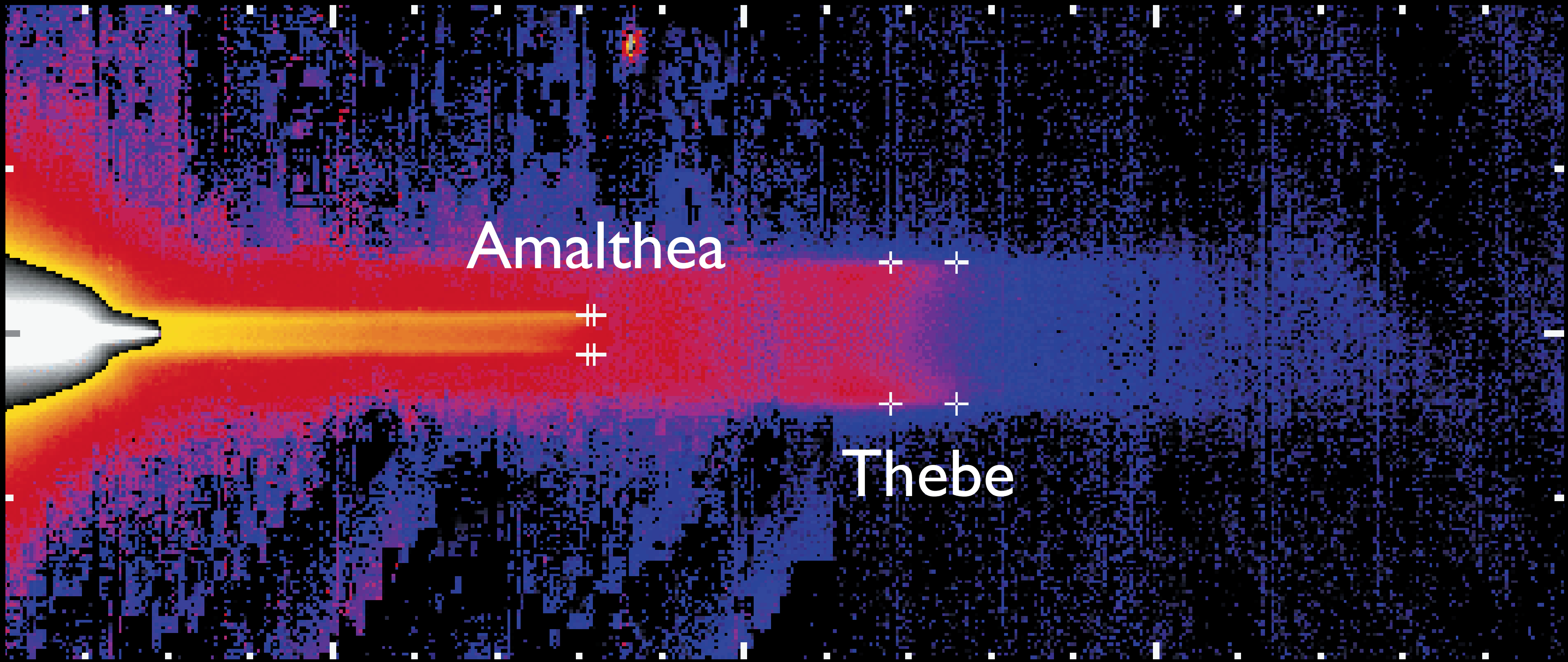

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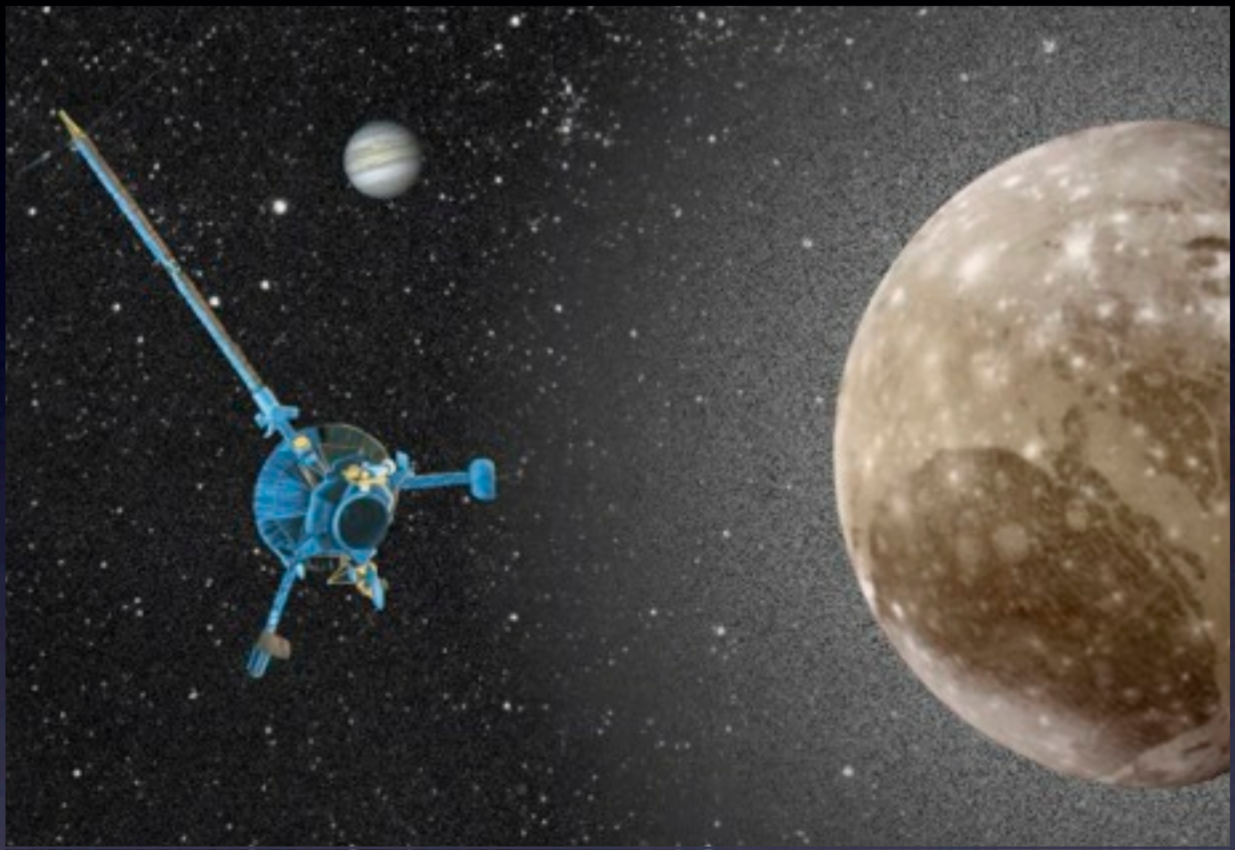
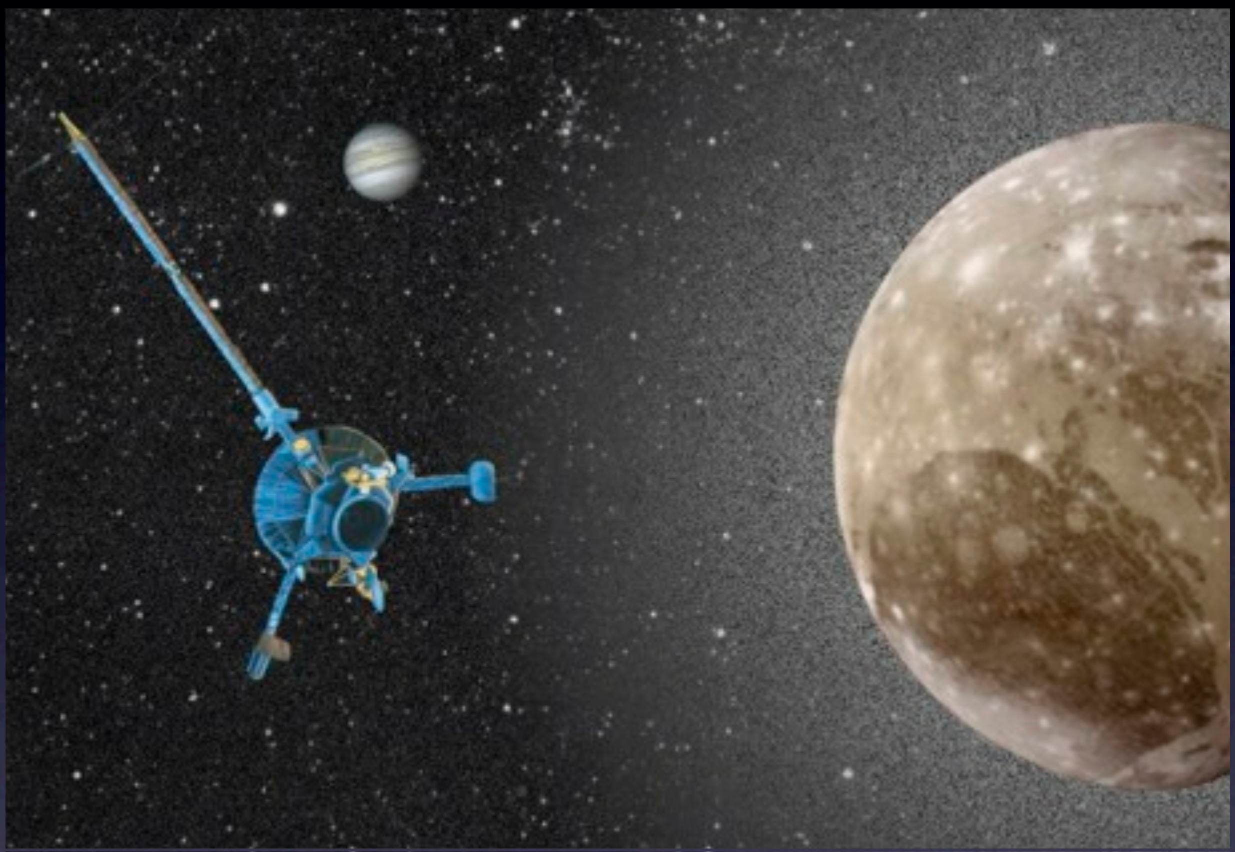
Ejecta Clouds

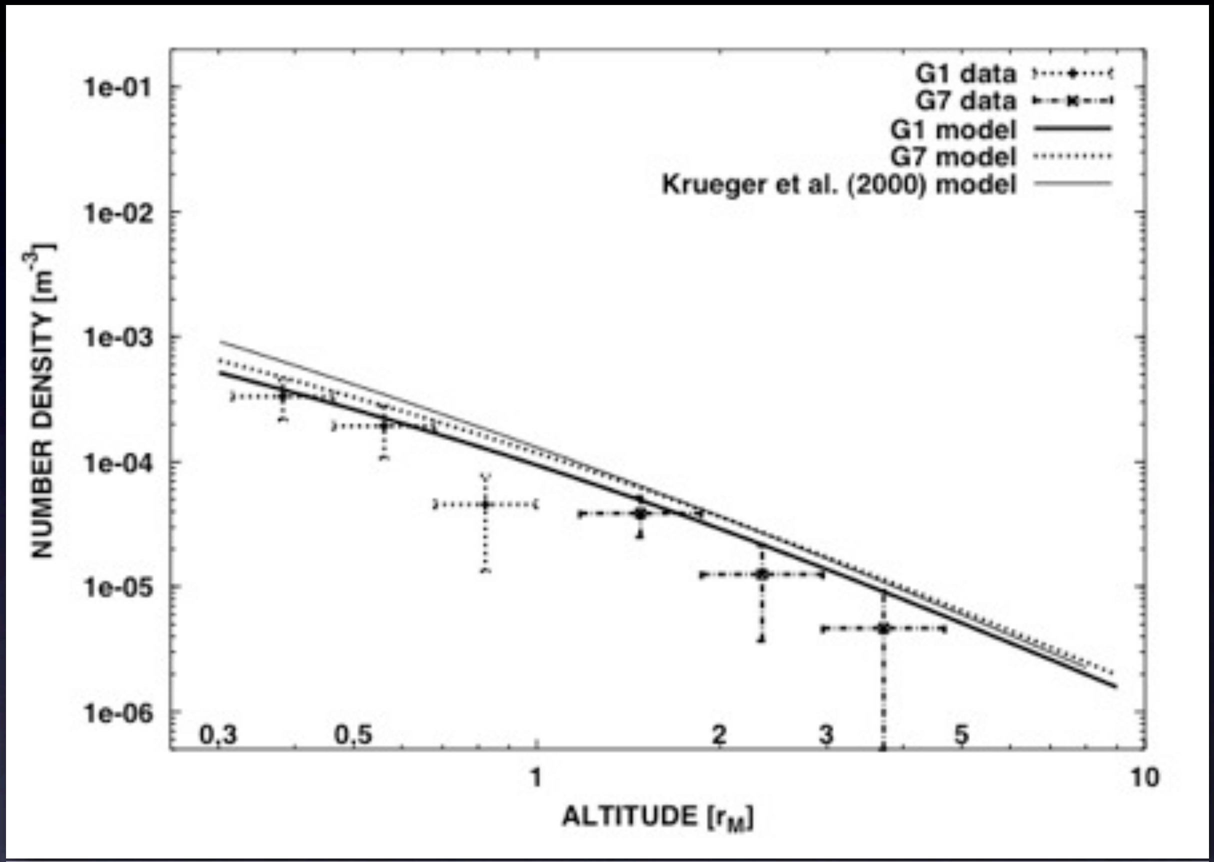


Galileo Dust Detector:
Galilean Satellites
Wrapped in Dust Clouds
(Krüger et al., Nature, 1999)

Ejecta Clouds



Krivov et al., PSS, 2003

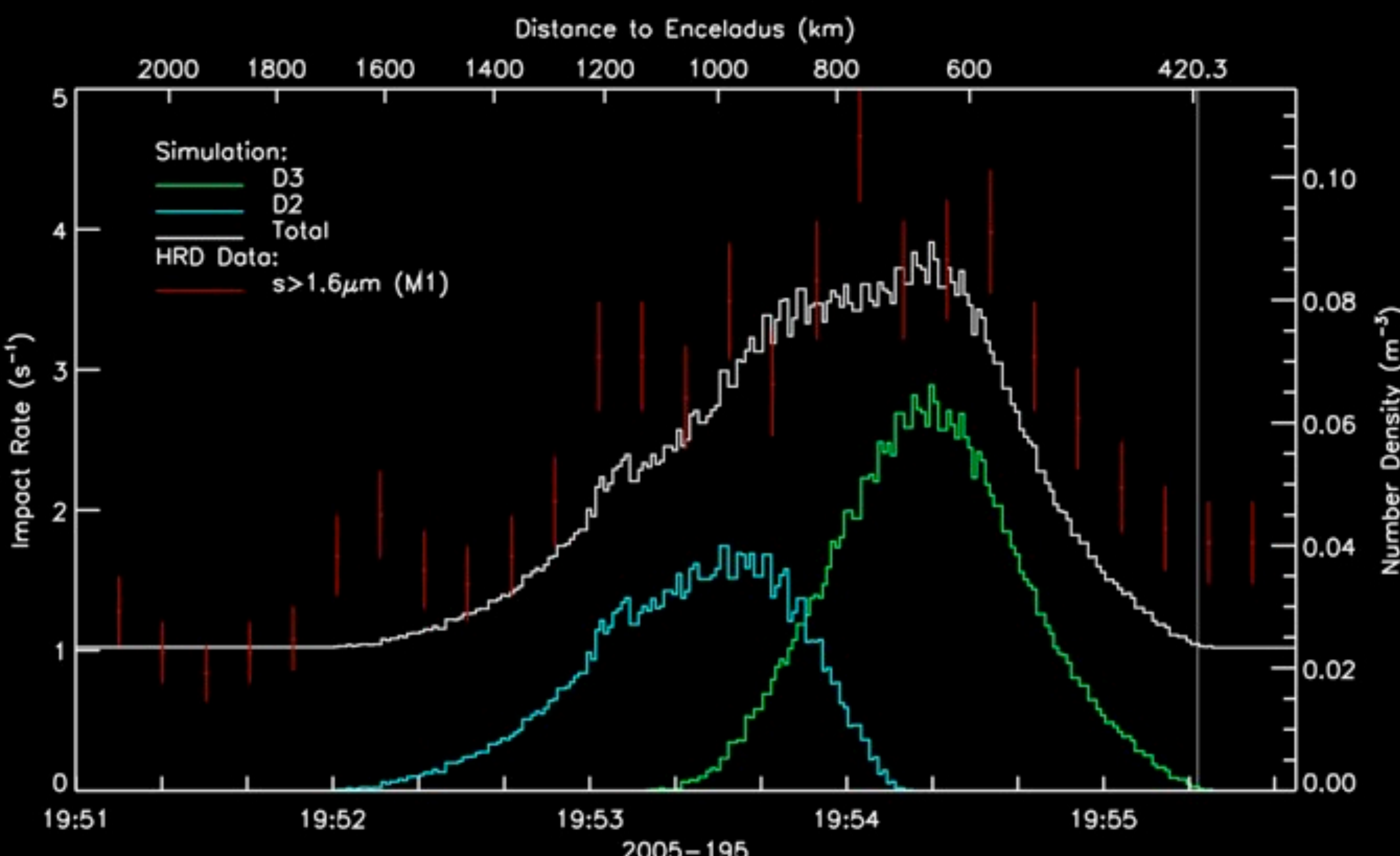


Galileo Dust Detector: Galilean Satellites Wrapped in Dust Clouds

(Krüger et al., Nature, 1999)

Almost Isotropic Clouds Composed of Surface Ejecta

Evidence for Enceladus Dust Exosphere



Kempf et. al., Icarus, 2010

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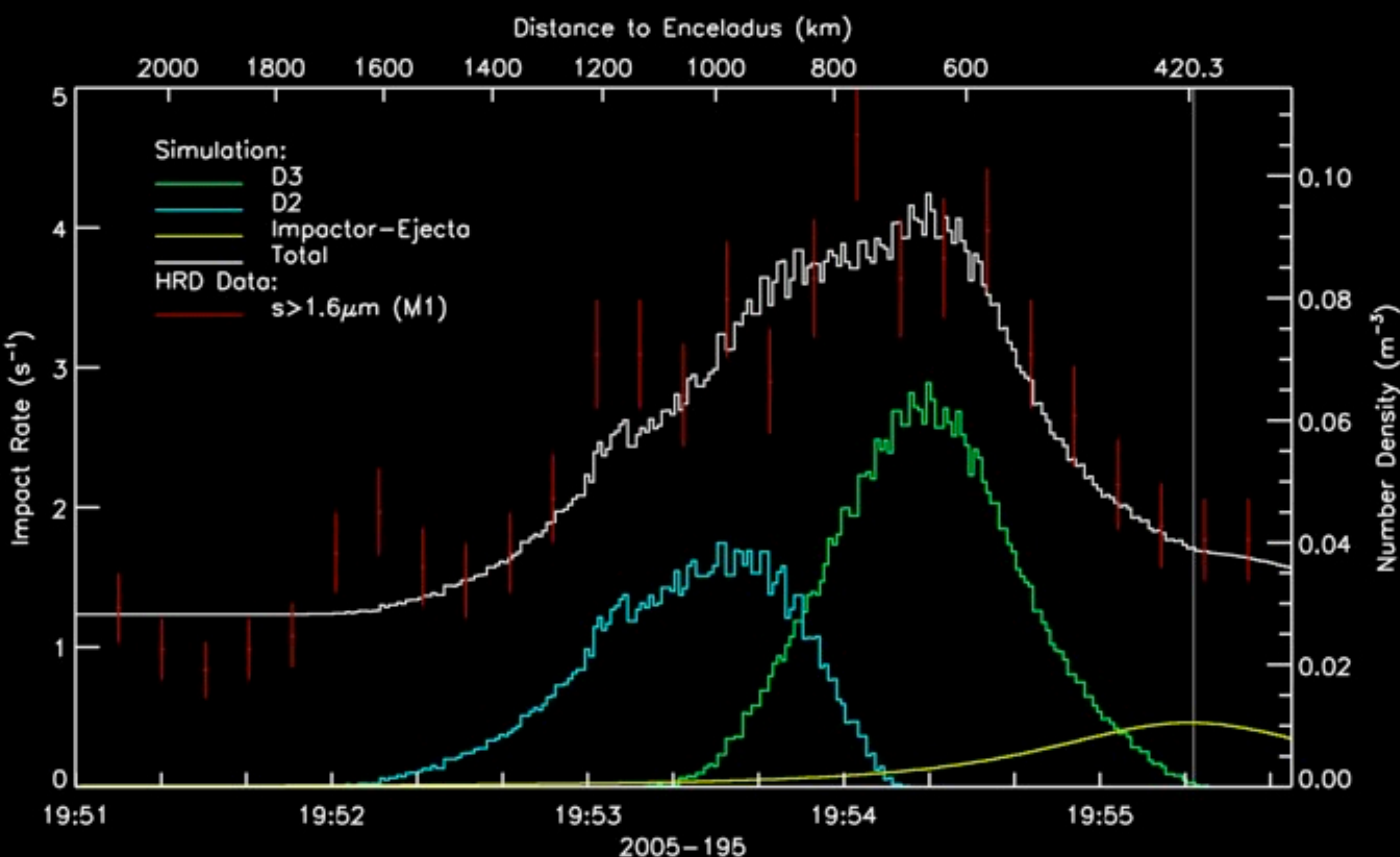
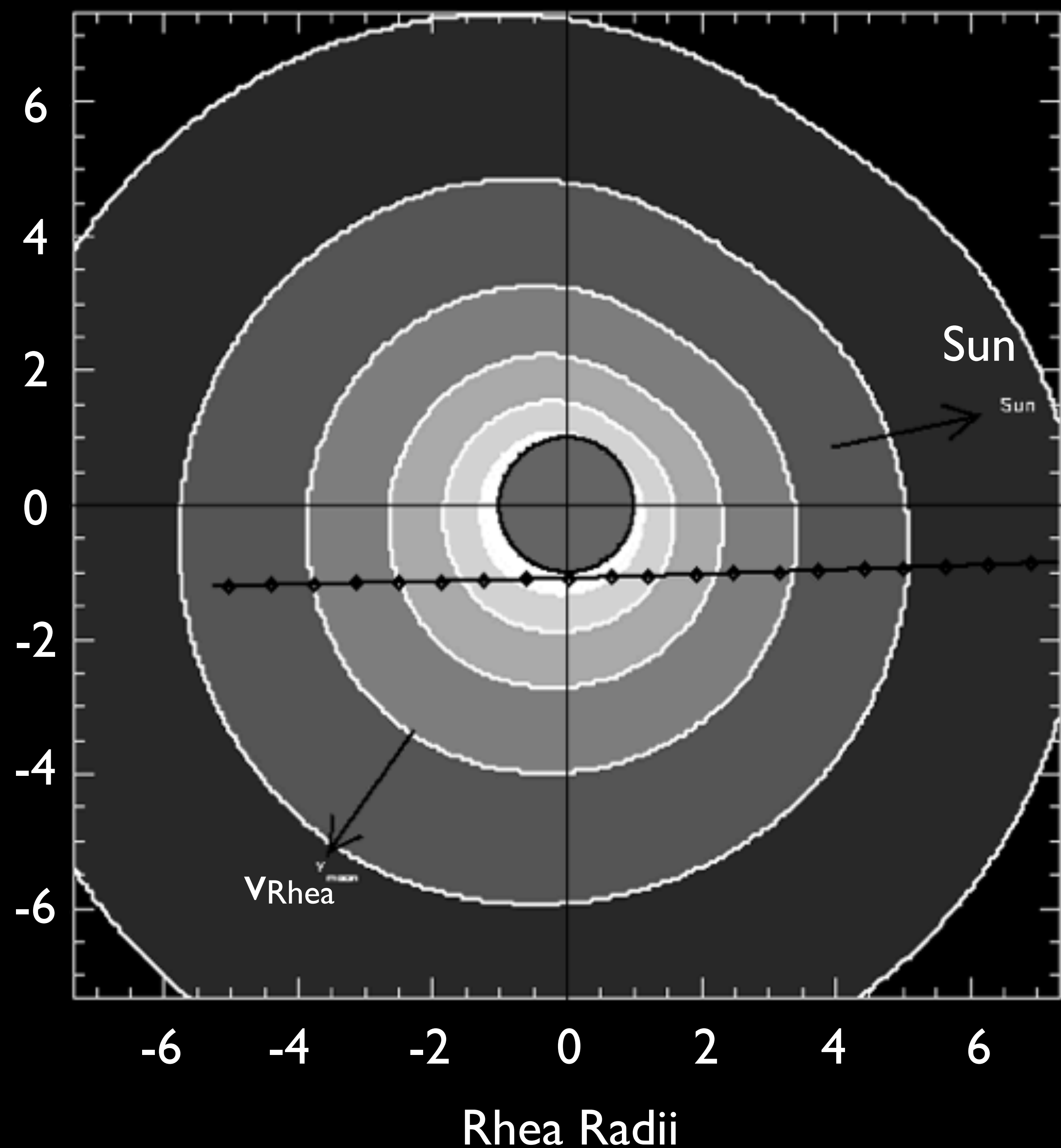
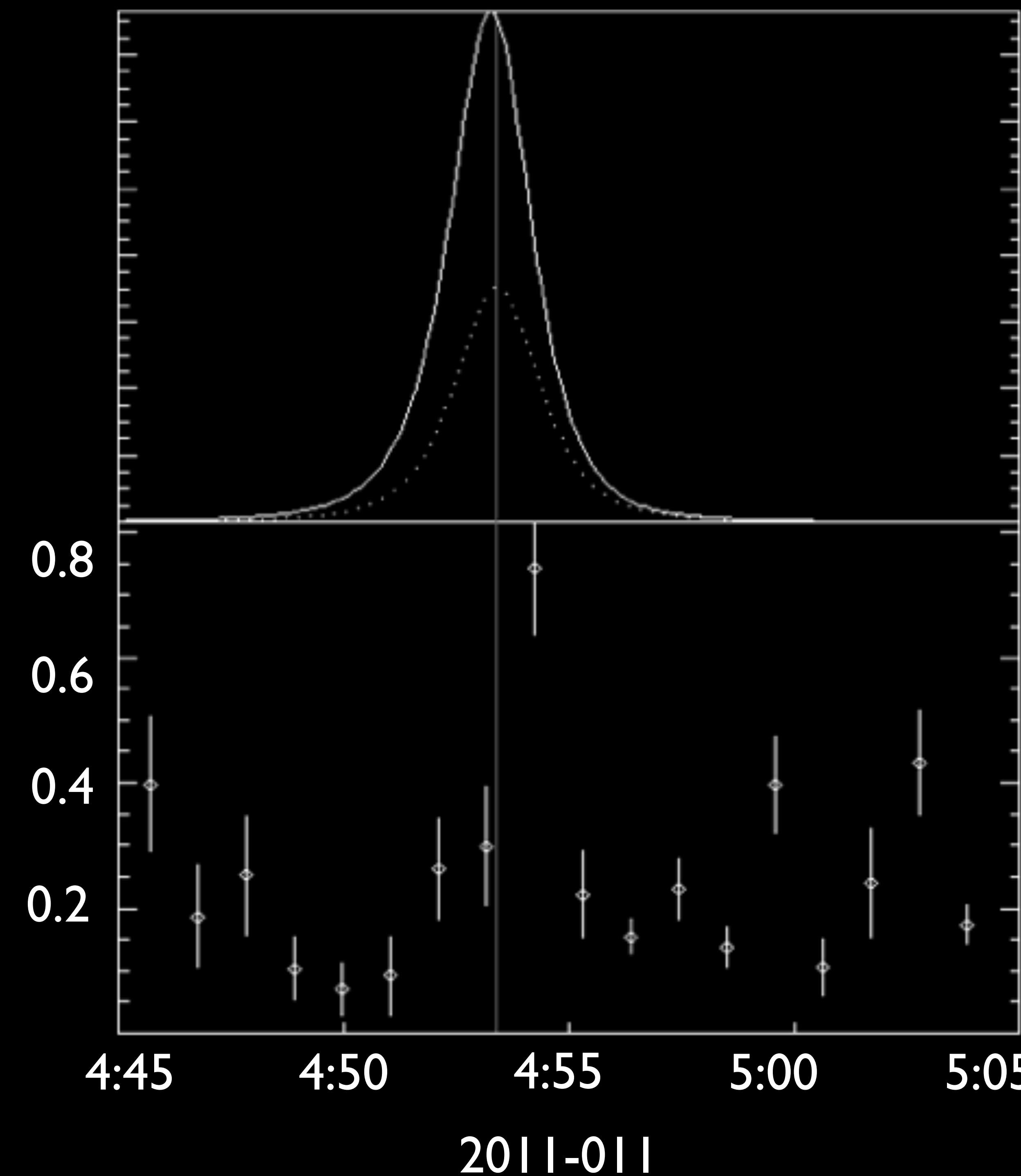


Kempf et. al., Icarus, 2010

Rhea Dust Exosphere

Model: Isotropic Impactors





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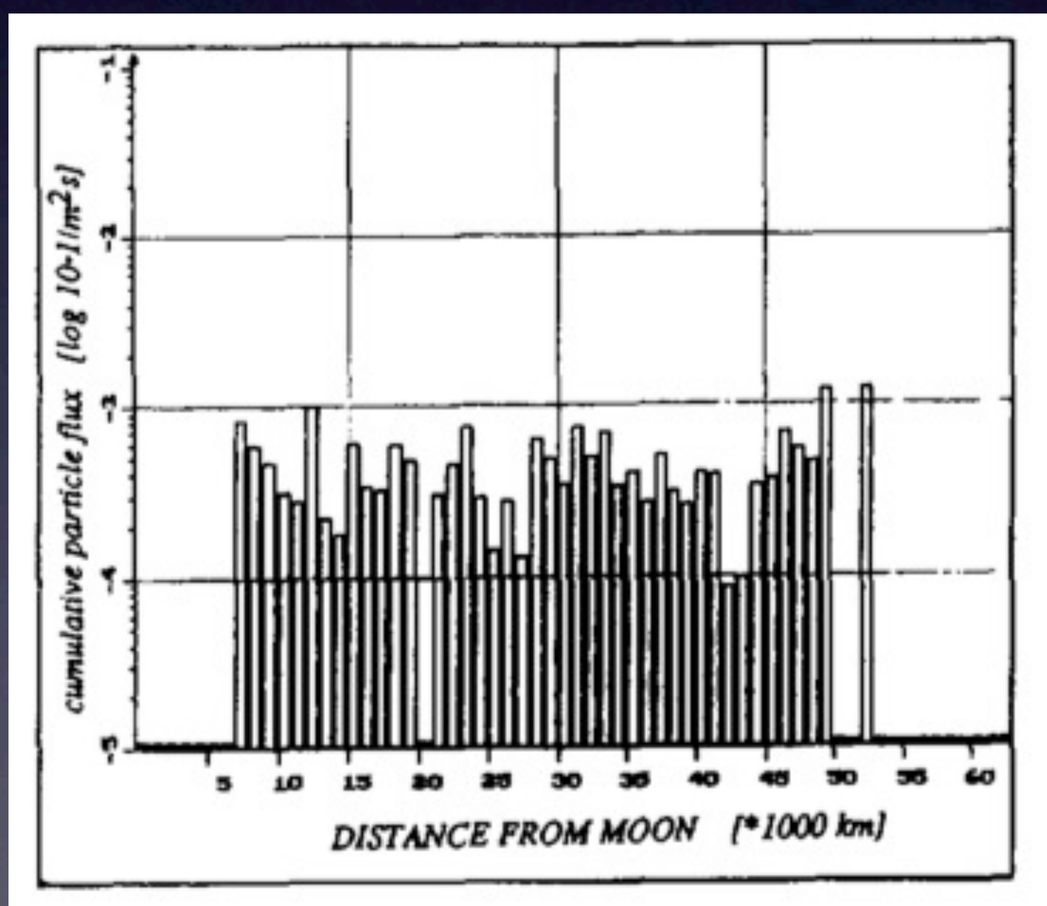
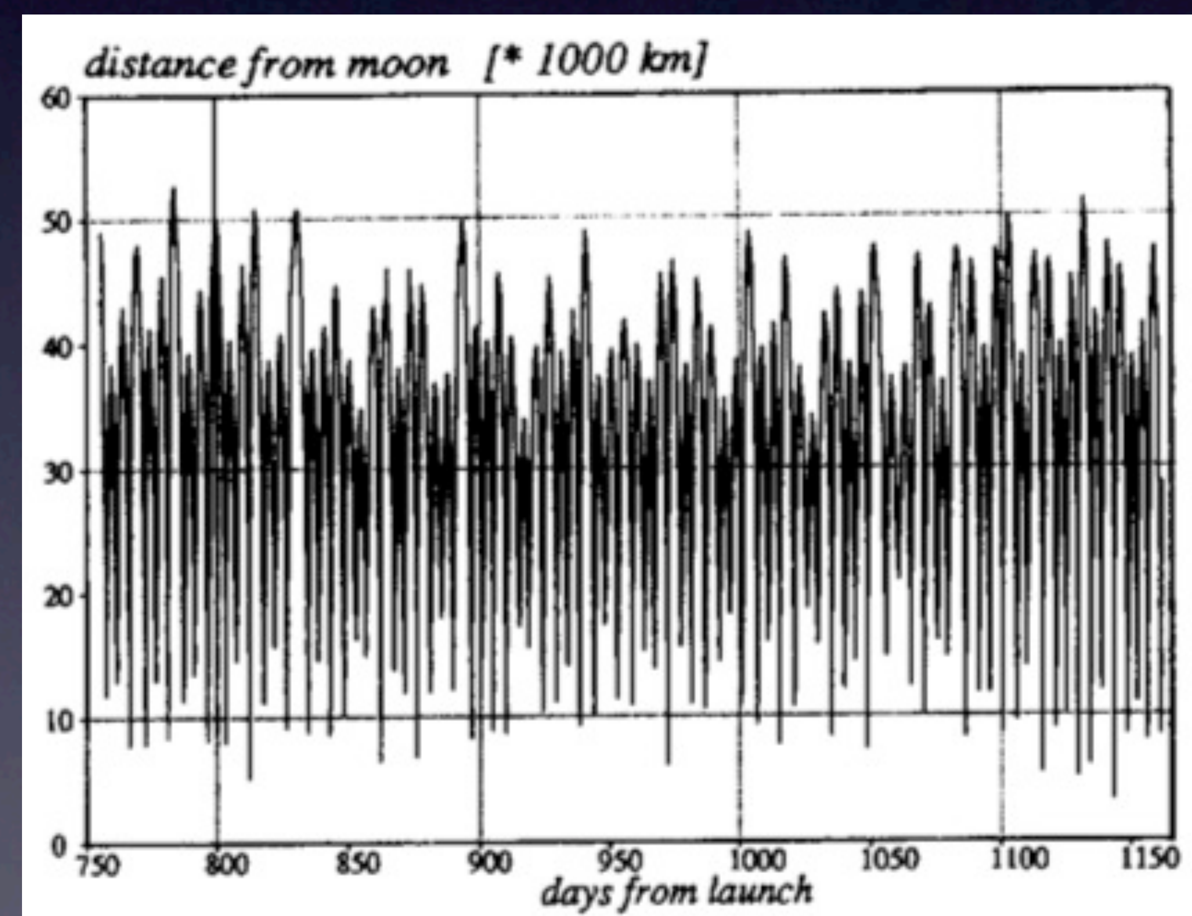
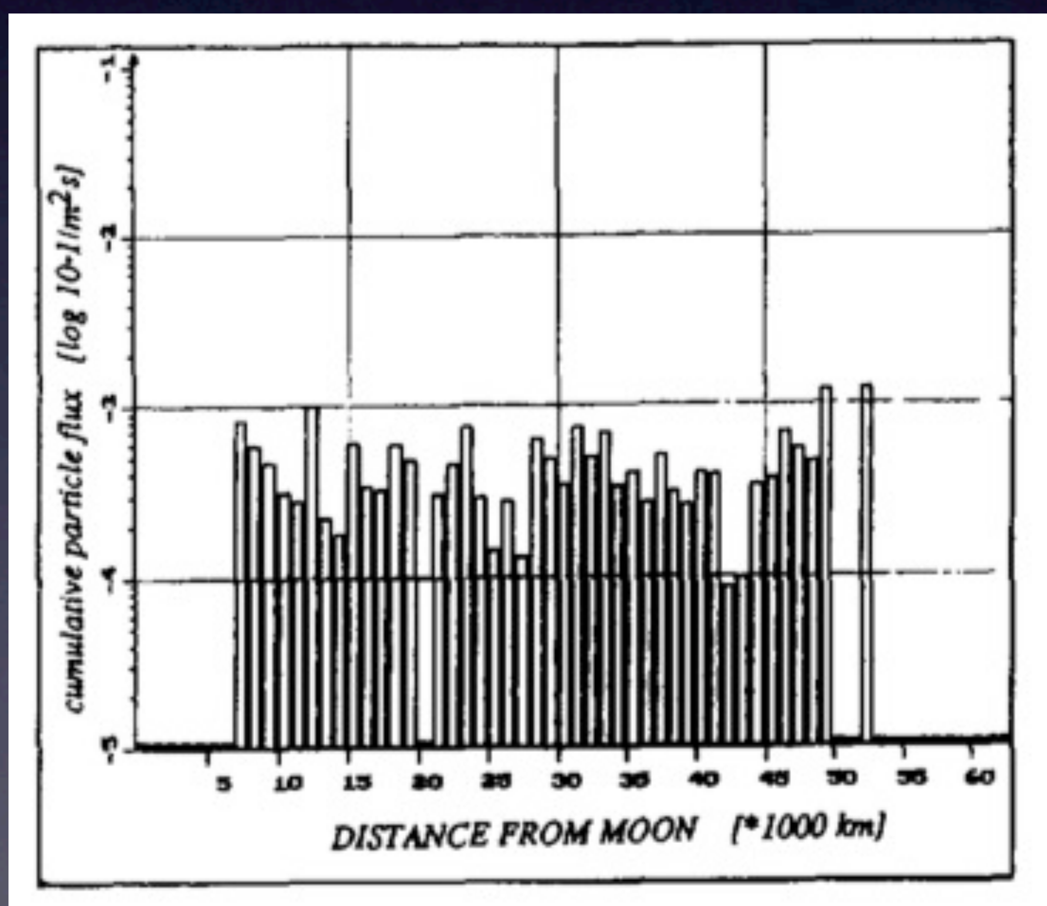


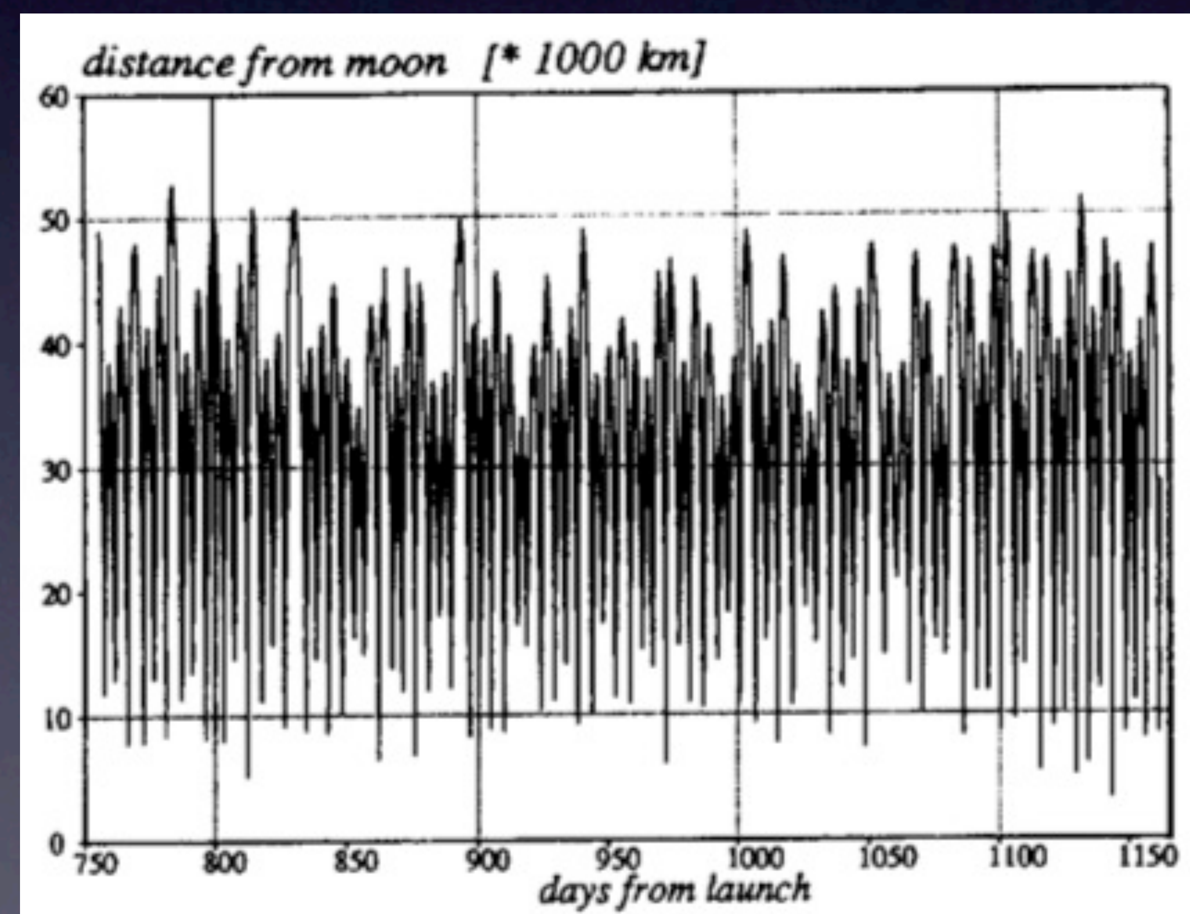


Iglseder et al., 2006, Adv. Space Res.

Evidence Lunar Exosphere?

- Hiten was the only Lunar orbiter equipped with a dust detector (MDC)





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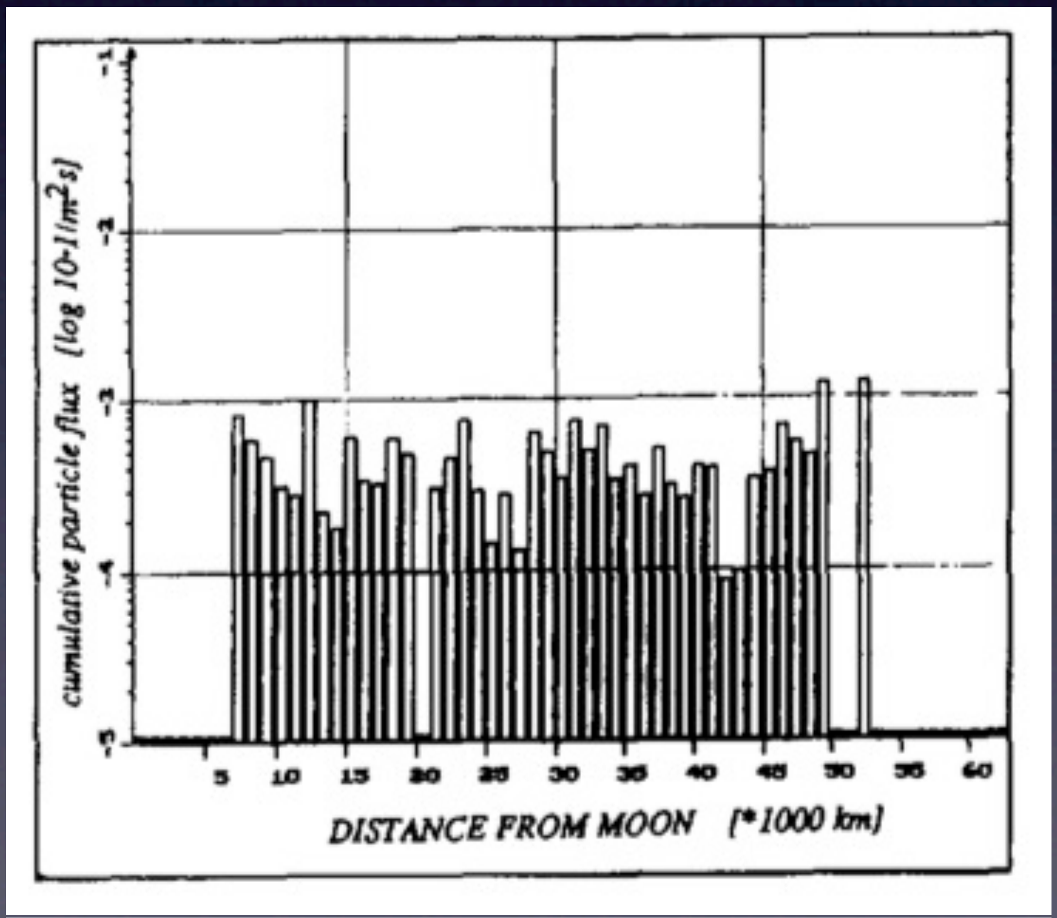

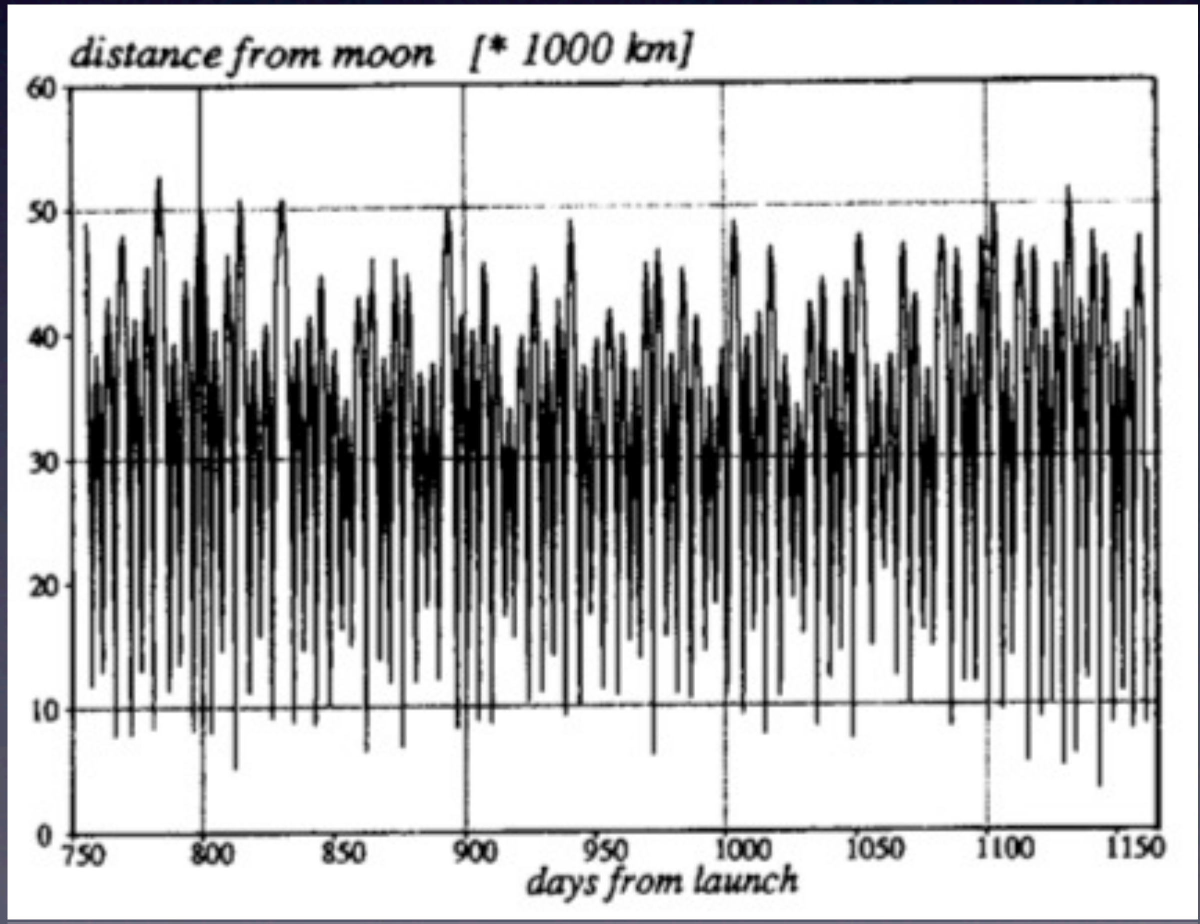

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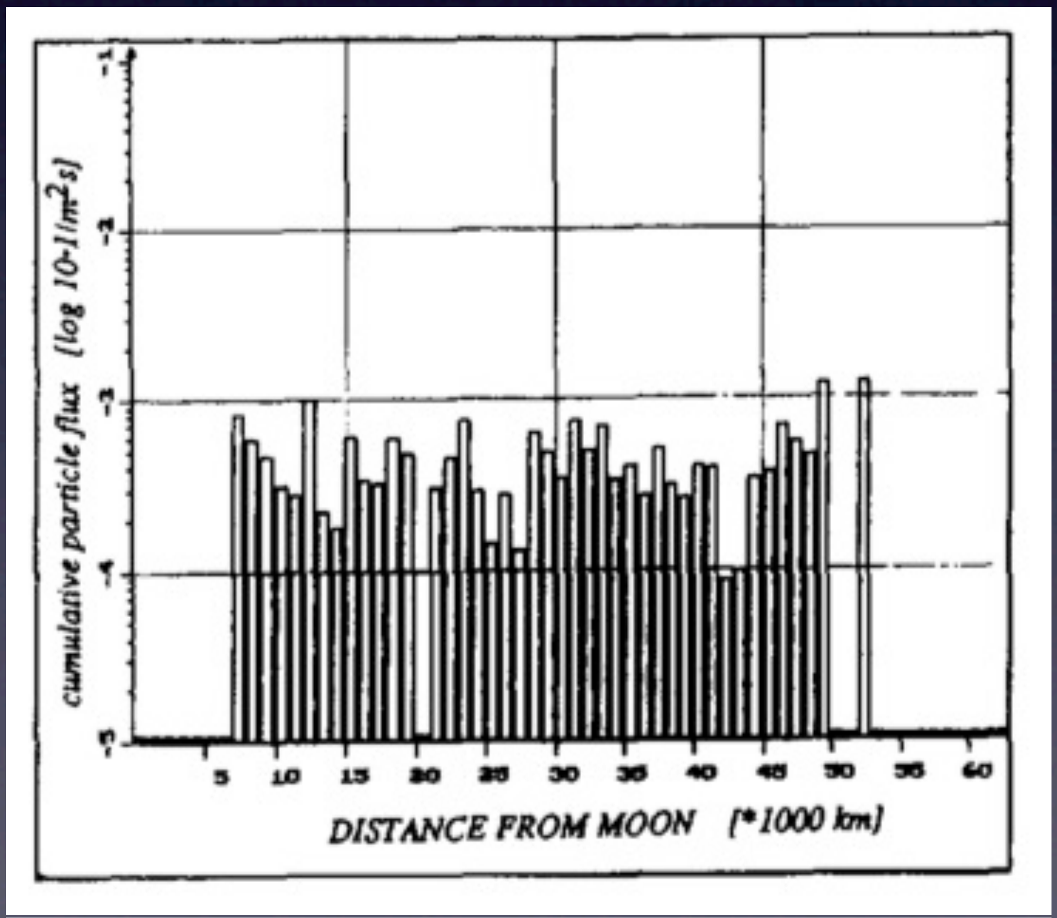

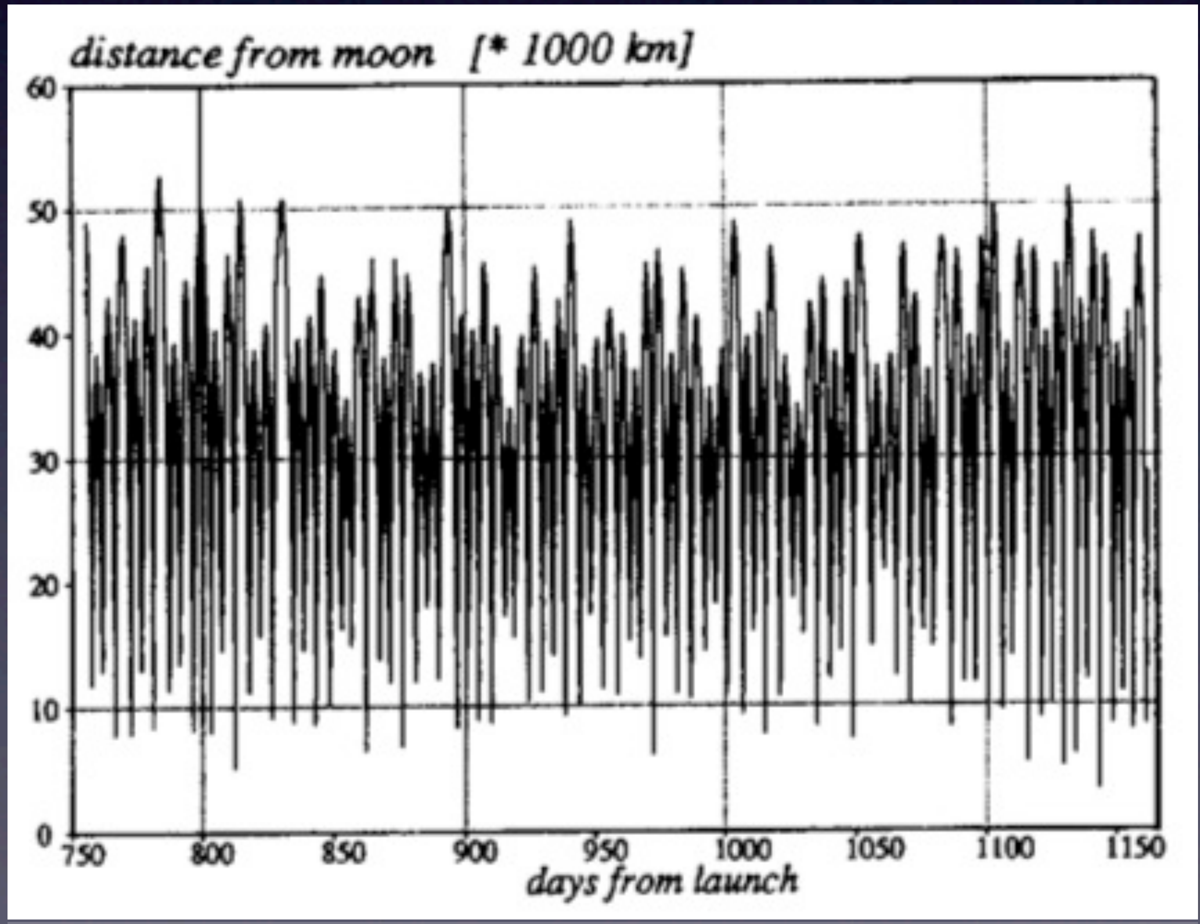

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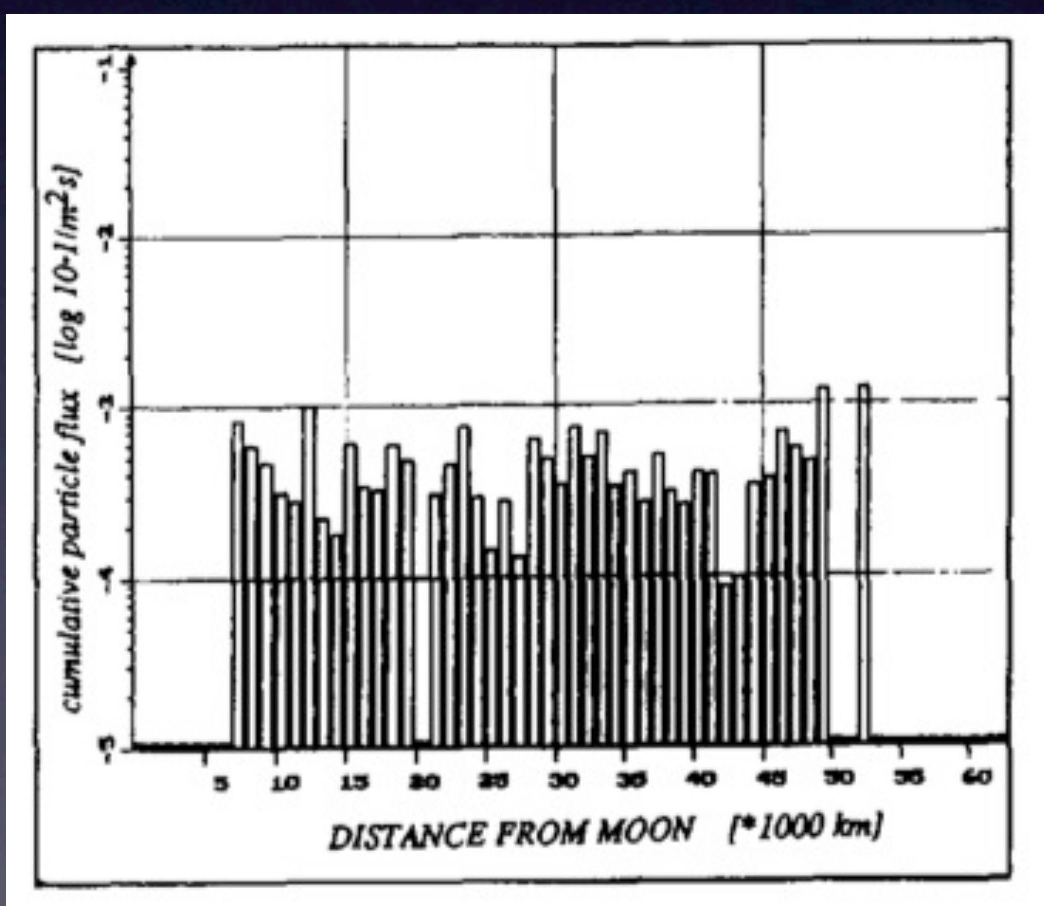

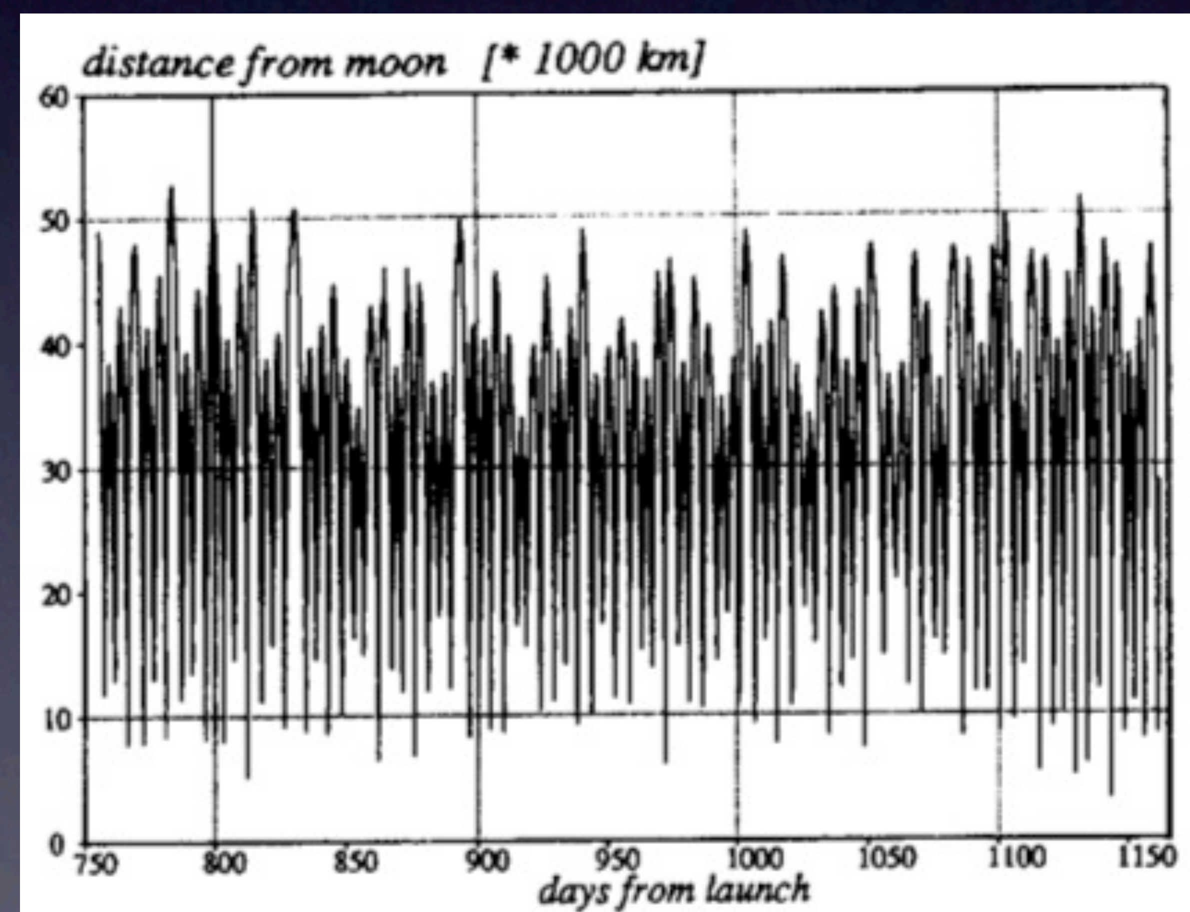

Iglseder et al., 2006, Adv. Space Res.

Trajectory and dust data are lost!

Prediction is very difficult,

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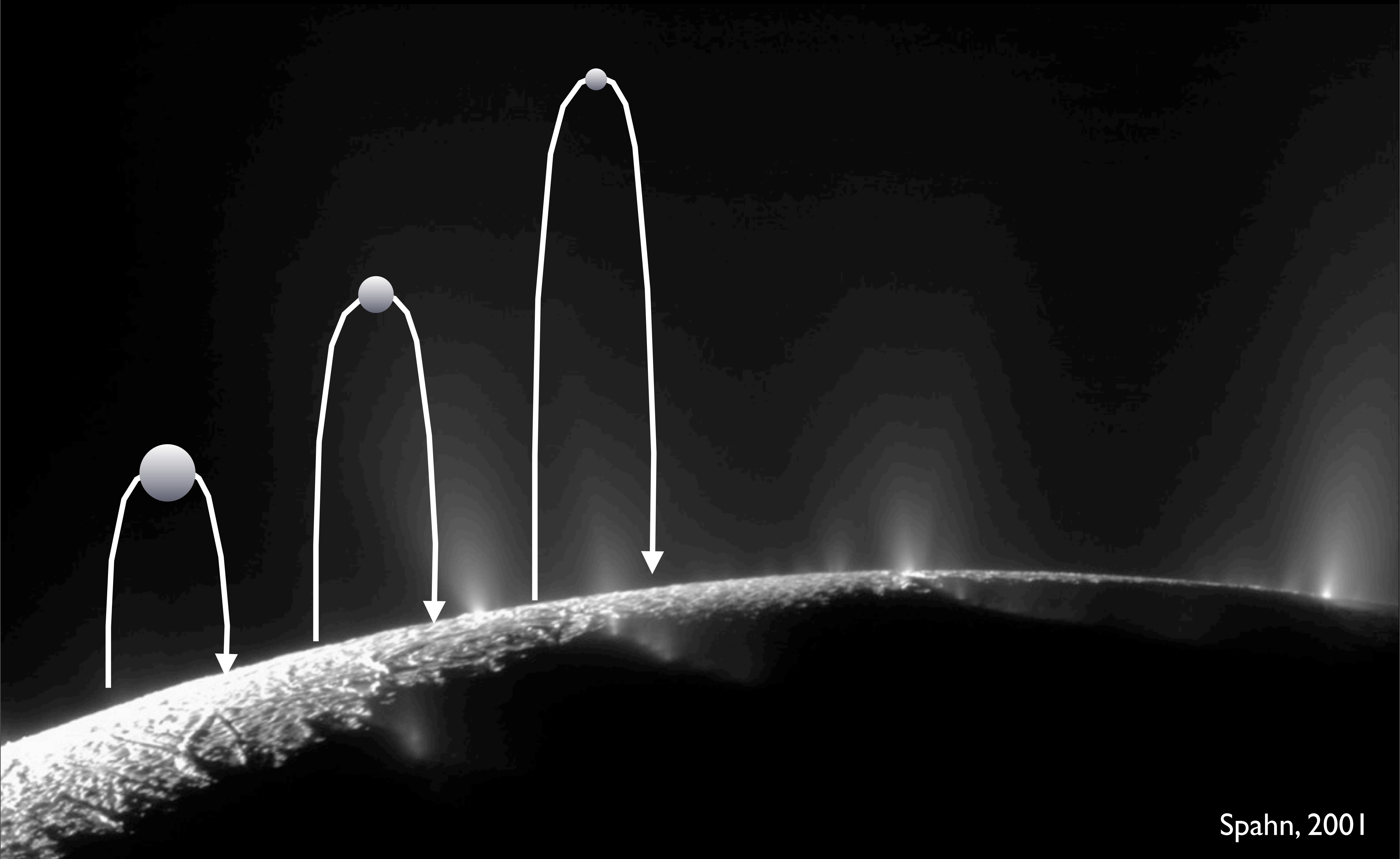
especially about the future

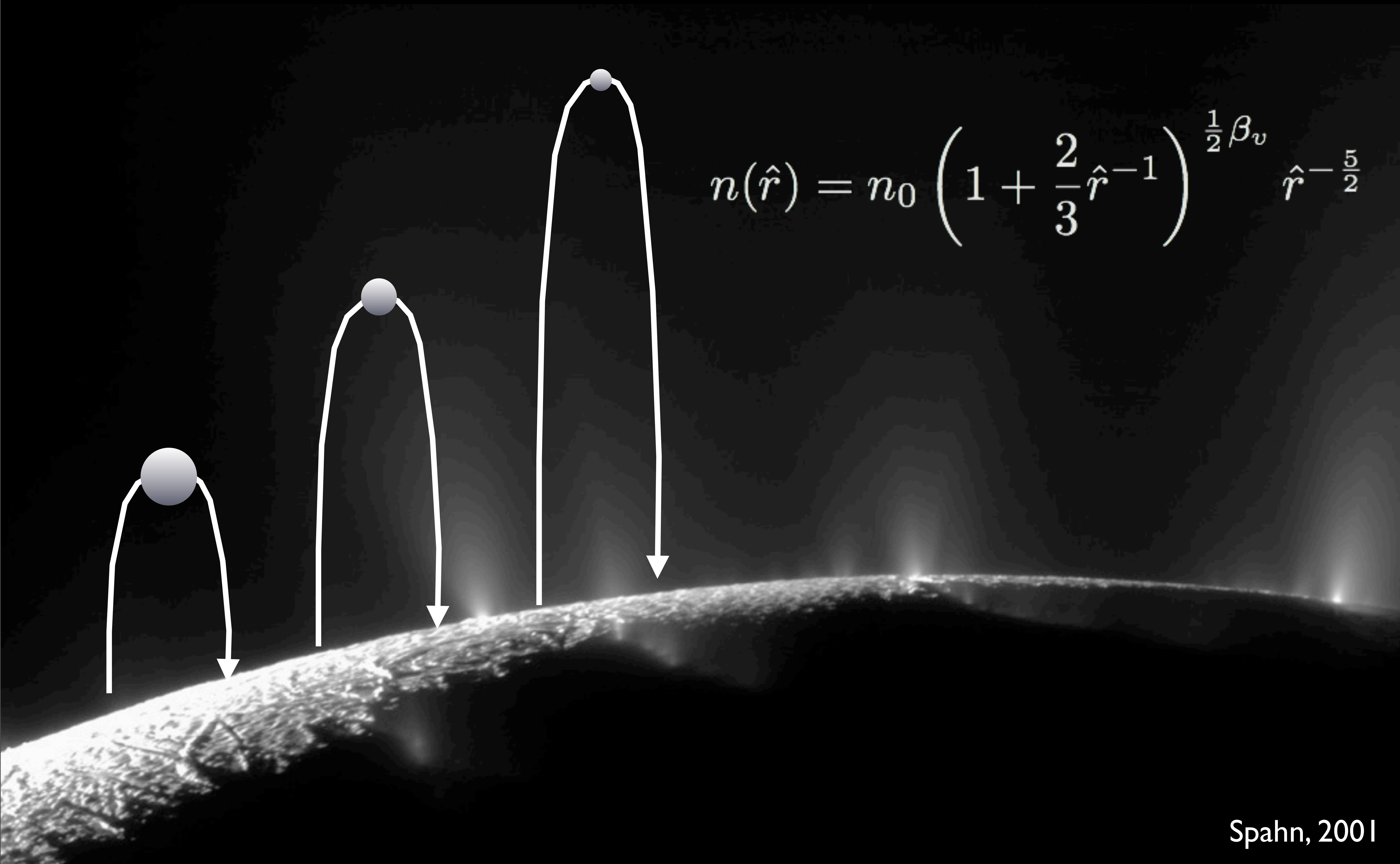
Nils Bohr

Ballistic Dust Clouds



Spahn, 2001

Ballistic Dust Clouds



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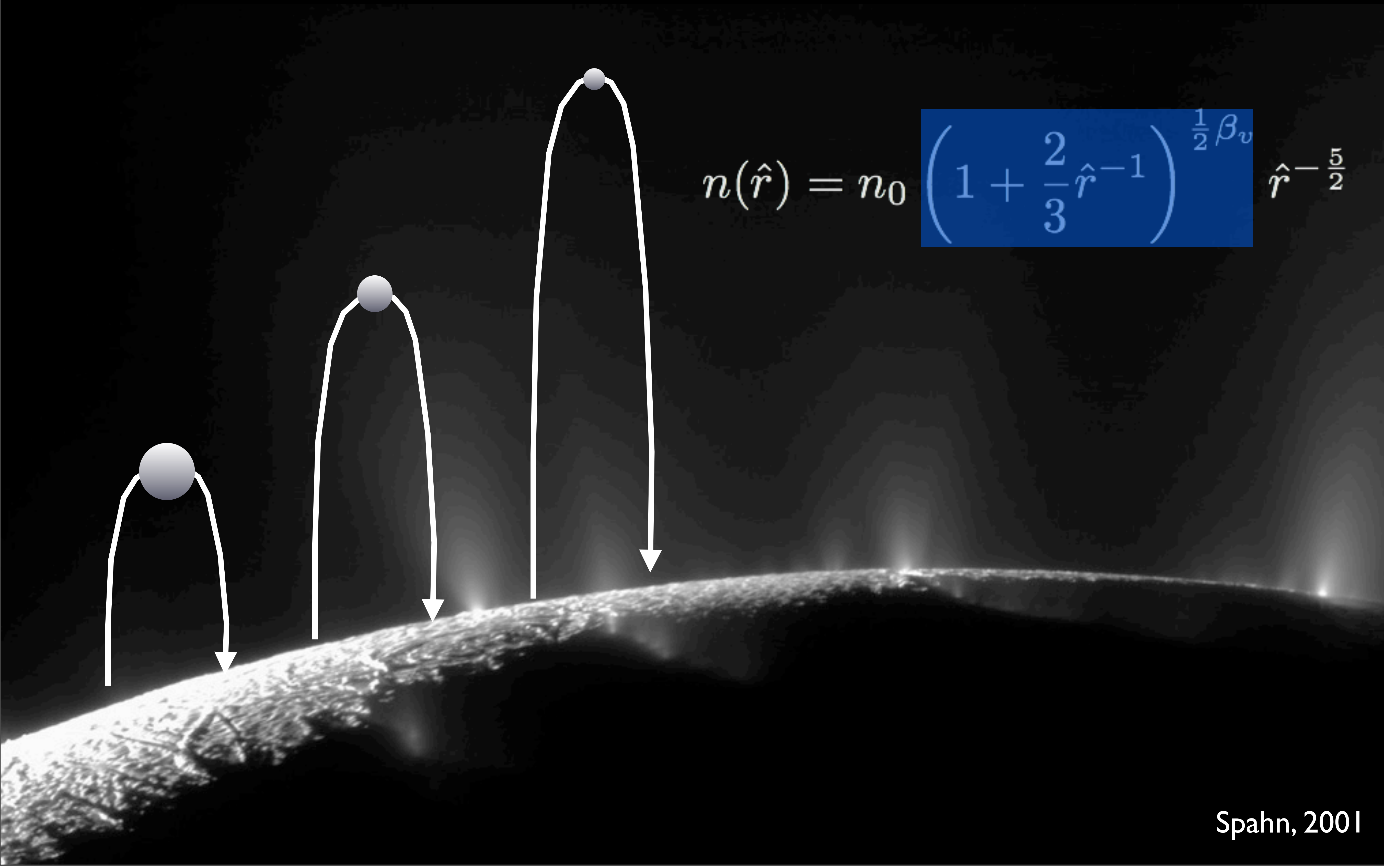
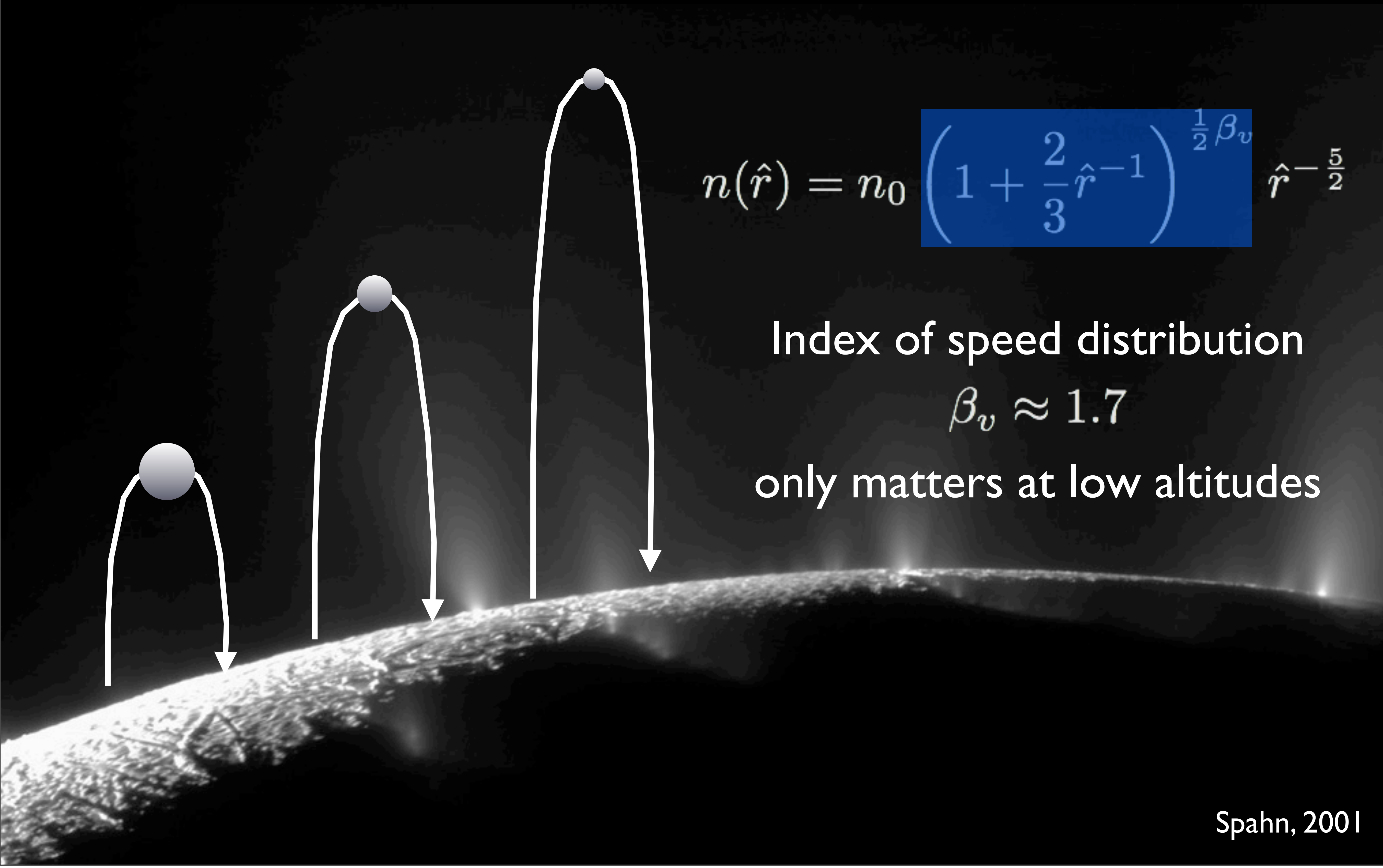


$$n(\hat{r}) = n_0 \left(1 + \frac{2}{3}\hat{r}^{-1}\right)^{\frac{1}{2}\beta_v} \hat{r}^{-\frac{5}{2}}$$

Spahn, 2001

Ballistic Dust Clouds



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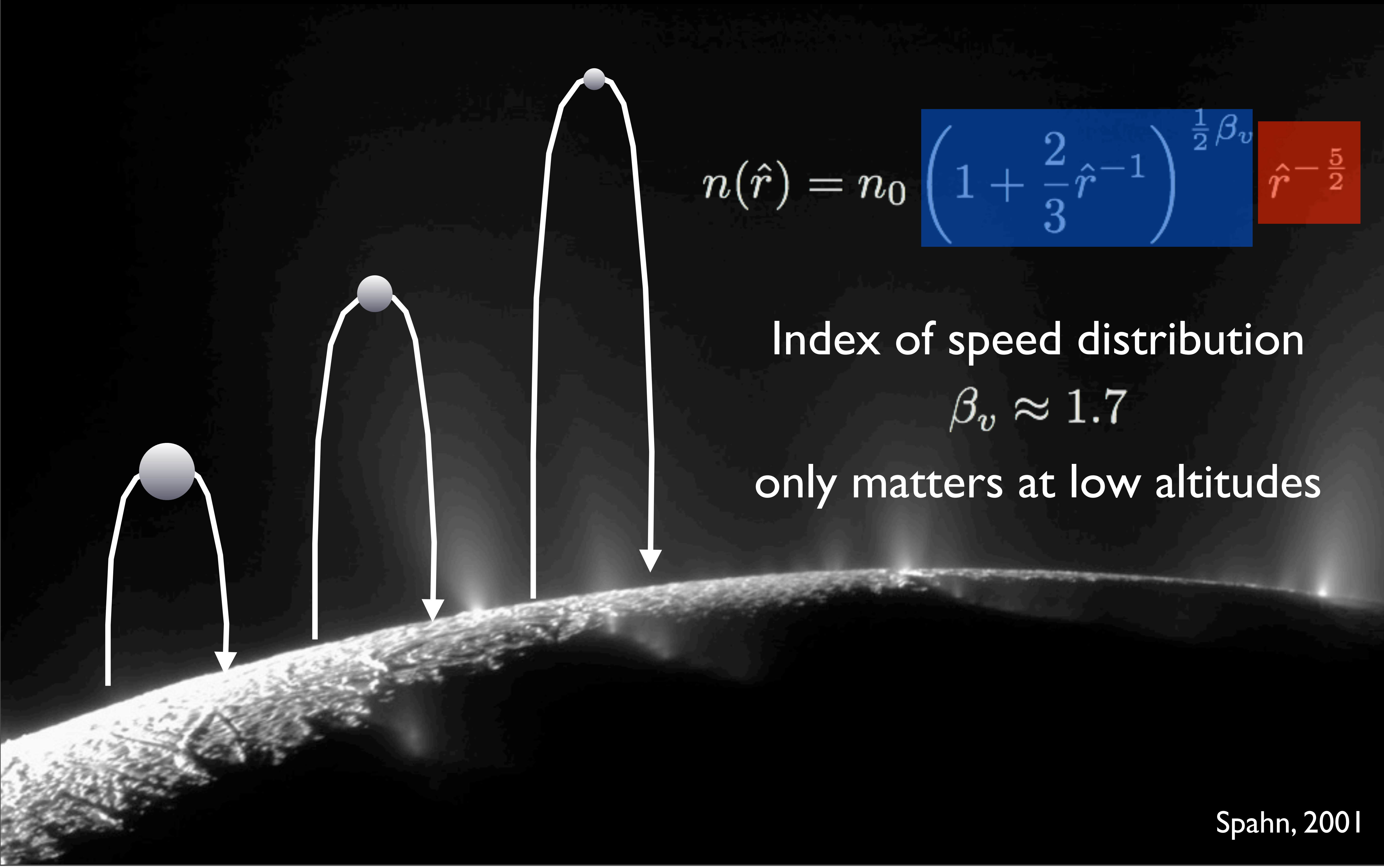
Index of speed distribution

$$\beta_v \approx 1.7$$

only matters at low altitudes

Spahn, 2001

Ballistic Dust Clouds



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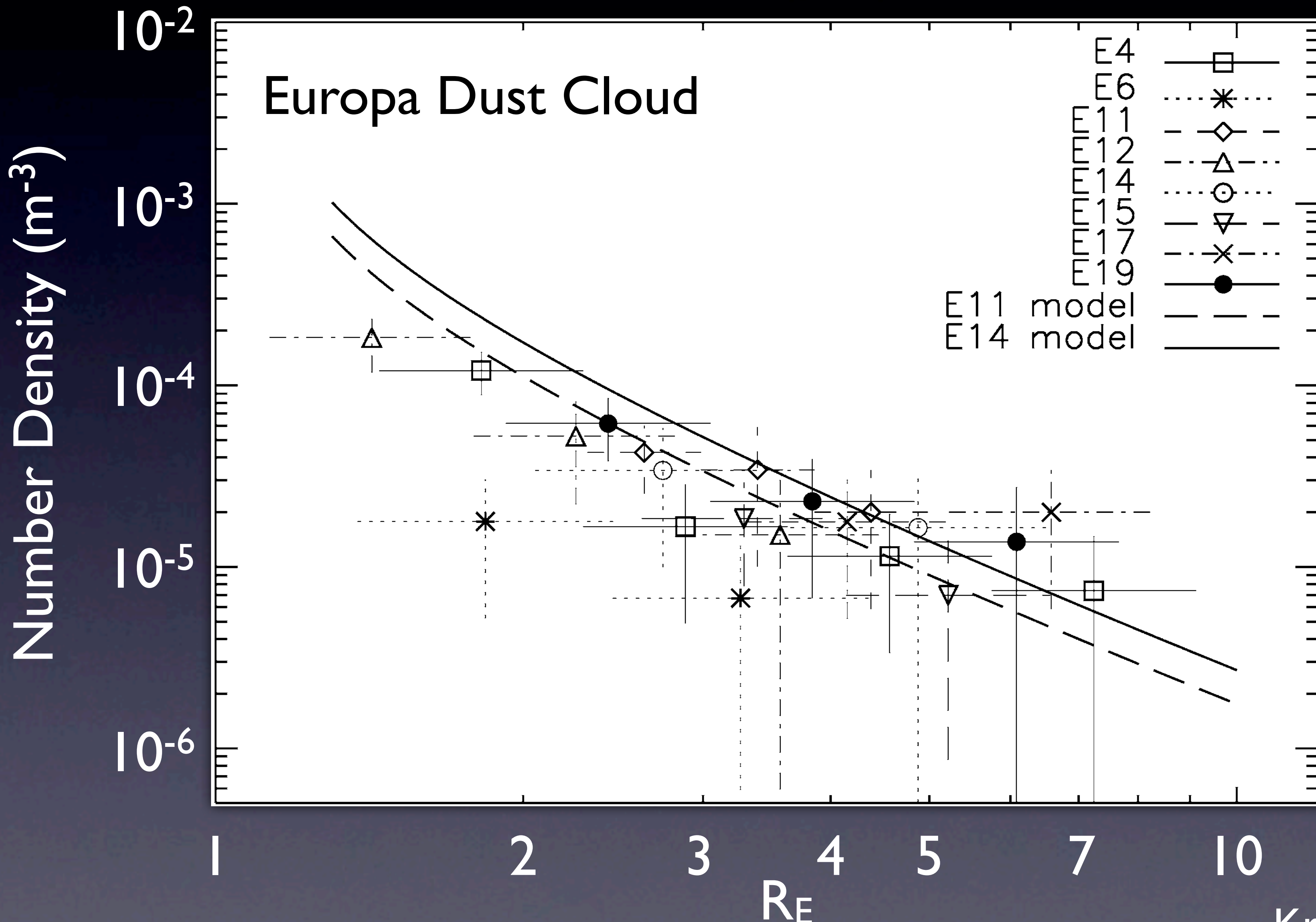
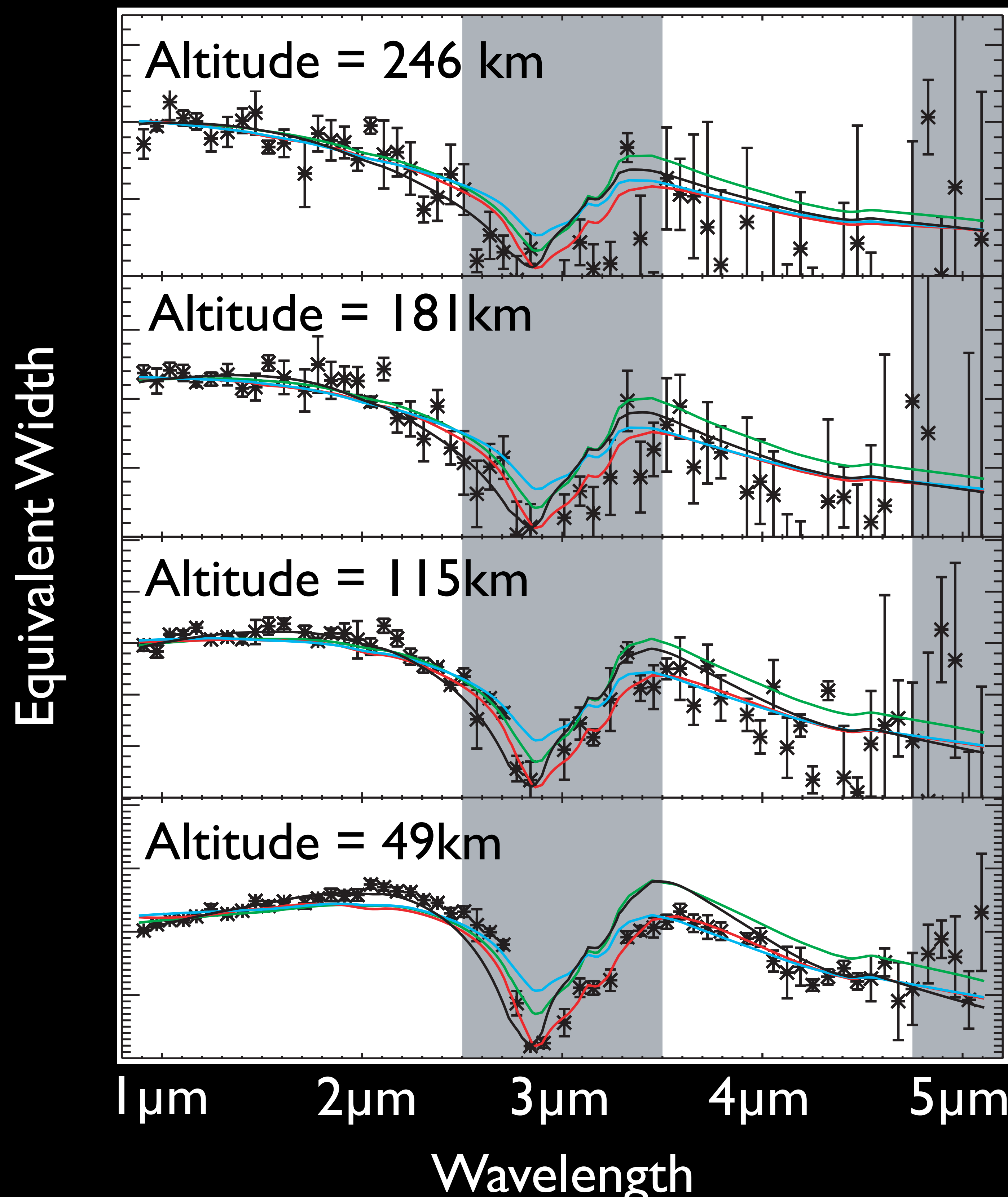
Reproduces Cloud Data

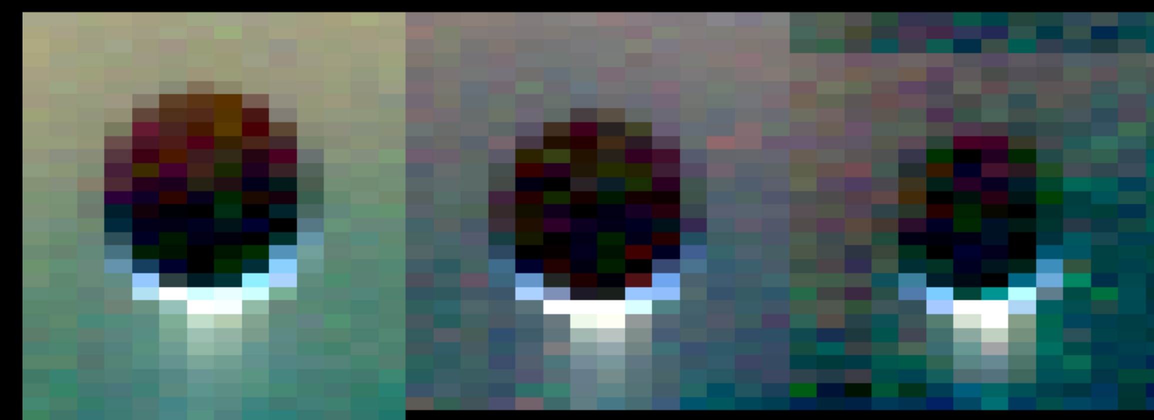


Krüger et al., PSS, 2003

Enceladus Dust Plume



VIMS Images of Enceladus



Hedman et. al., AJ, 2009

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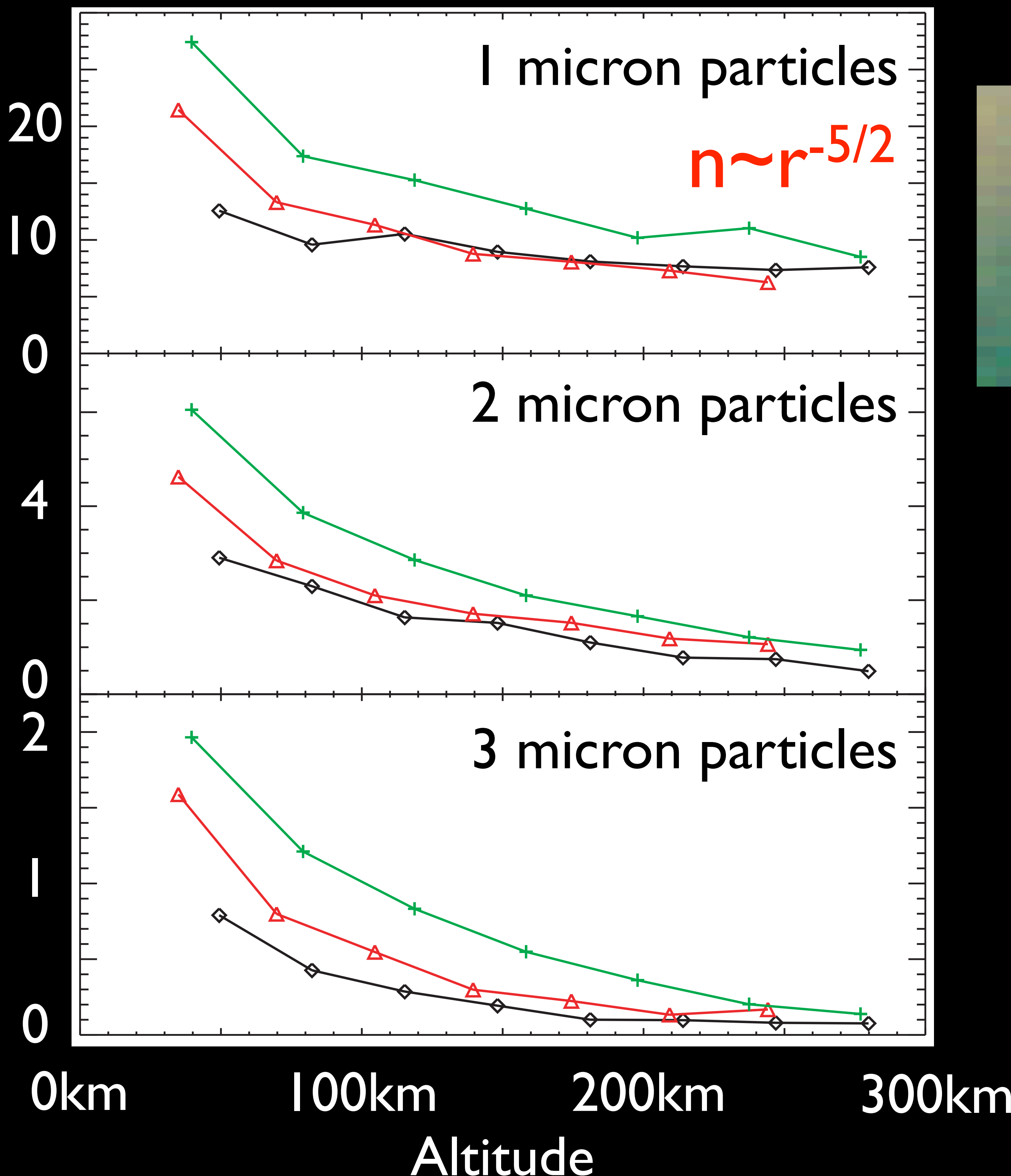
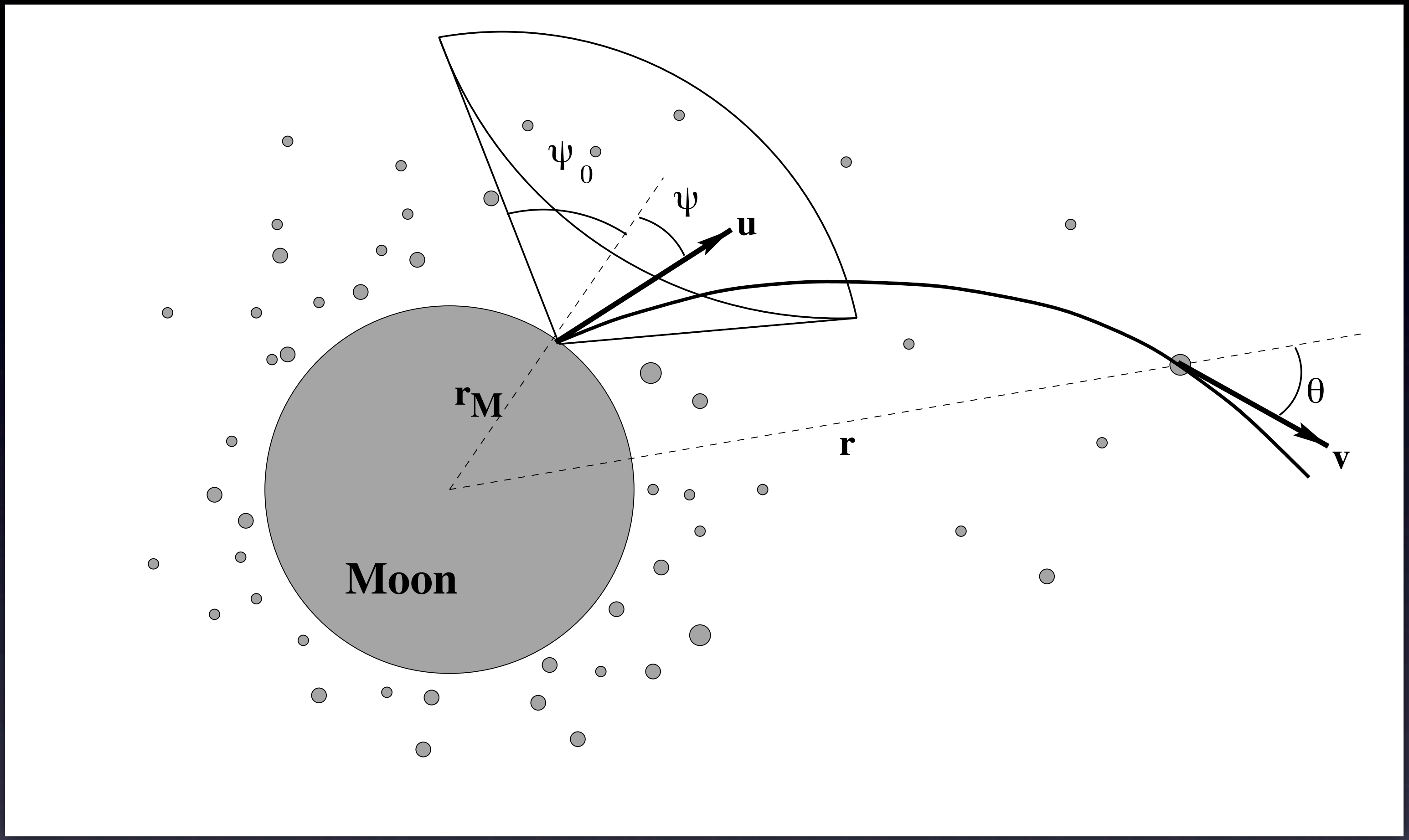


VIMS Images of Enceladus

Density Profile of 3 µm Grains is much Steeper

General Case

Include ejectas' angular distribution:



$$n(r, v, \theta) = \frac{N^+}{8\pi^2}\frac{1}{r^2}\frac{1}{|\dot{r}|}\frac{1}{v^2 sin\theta} f(u, \psi)\left|\frac{\partial(u, \psi)}{\partial(v, \theta)}\right|$$

Krivov et al., 2003 Sremcevic et al., 2003, 2005

Ejecta Cloud Profile

Bound Ejecta:

$$n_b(r) = \frac{N^+}{2\pi r_M^2 v_{esc}} \gamma u_0^\gamma r^{-5/2} K_b(r)$$

Unbound Ejecta:

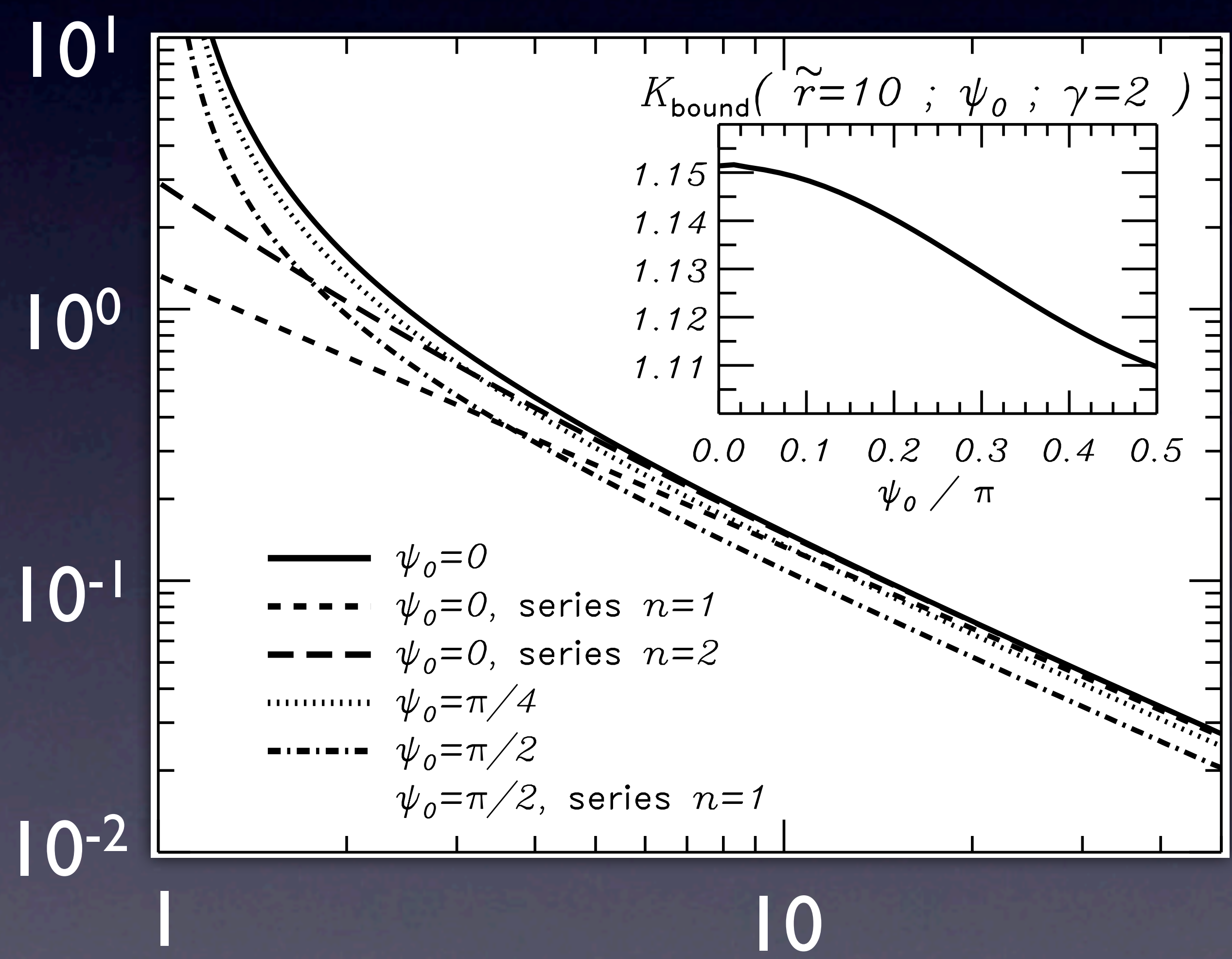
$$n_u(r) = \frac{N^+}{4\pi r_M^2 v_{esc}} \gamma u_0^\gamma r^{-2} c_0(\gamma) K_b(r)$$

Krivov et al., 2003 Sremcevic et al., 2003, 2005

Angular Distribution

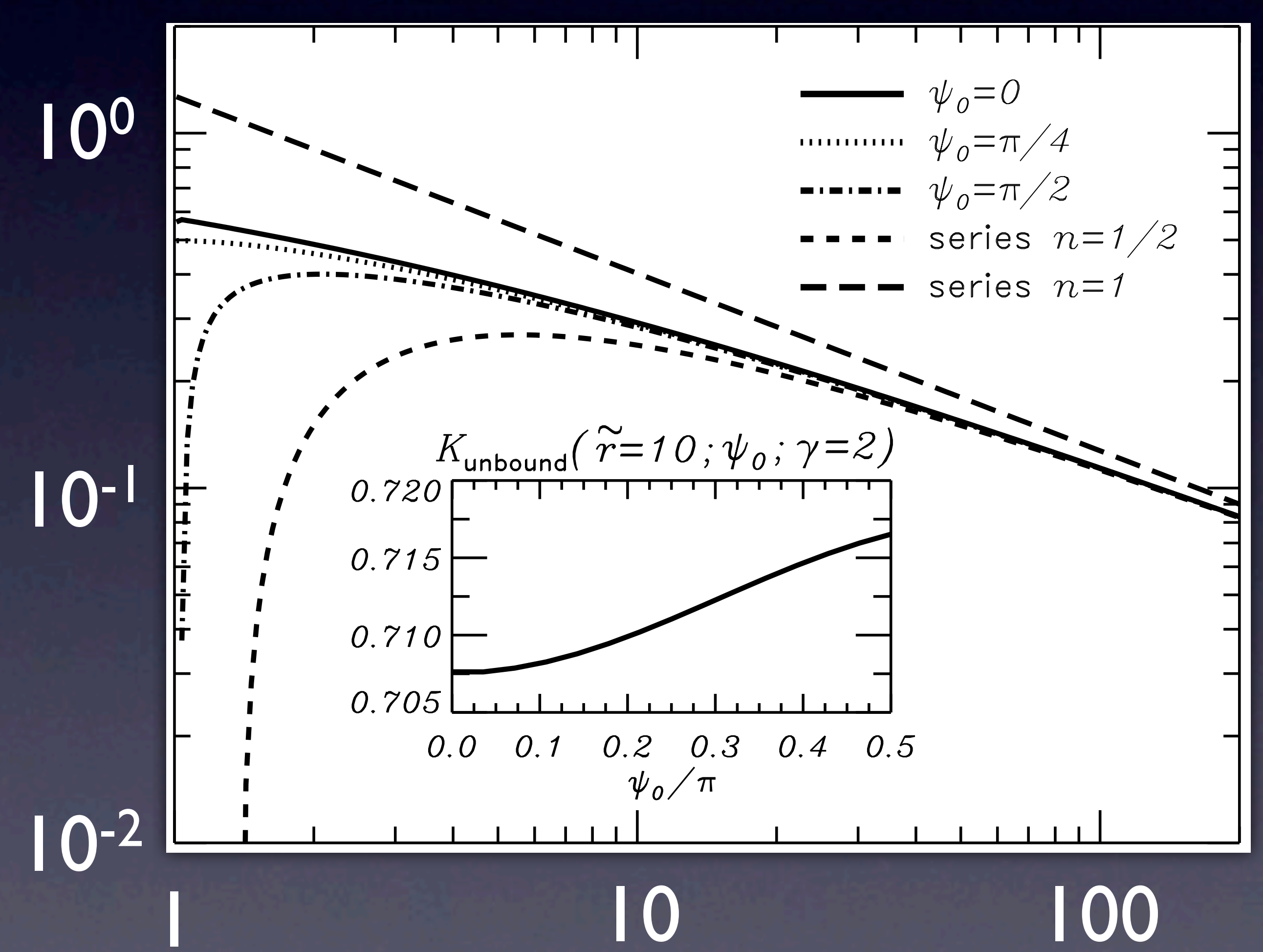
Bound Ejecta:

$K_{bound}-1$



Unbound Ejecta:

$1-K_{unbound}$



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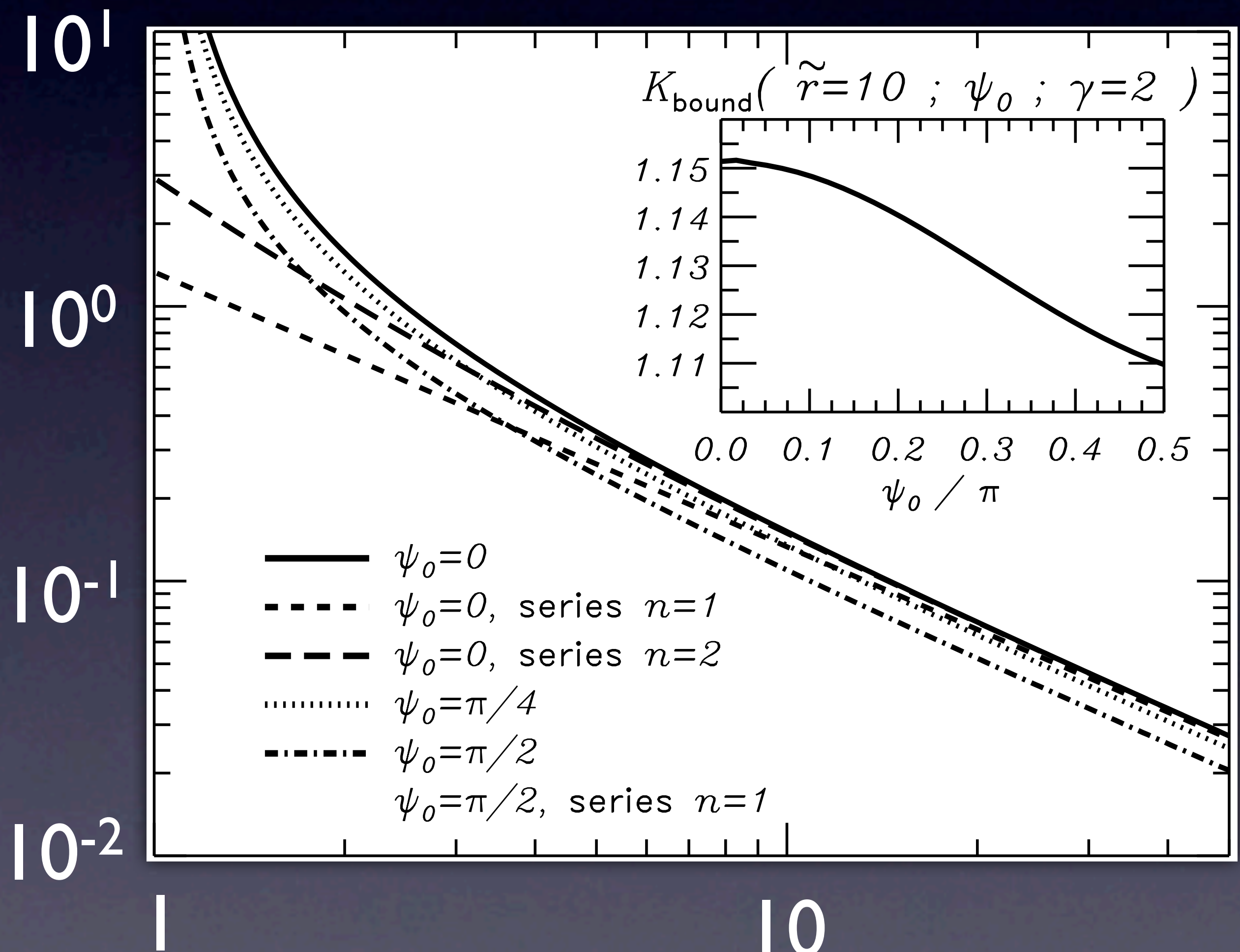

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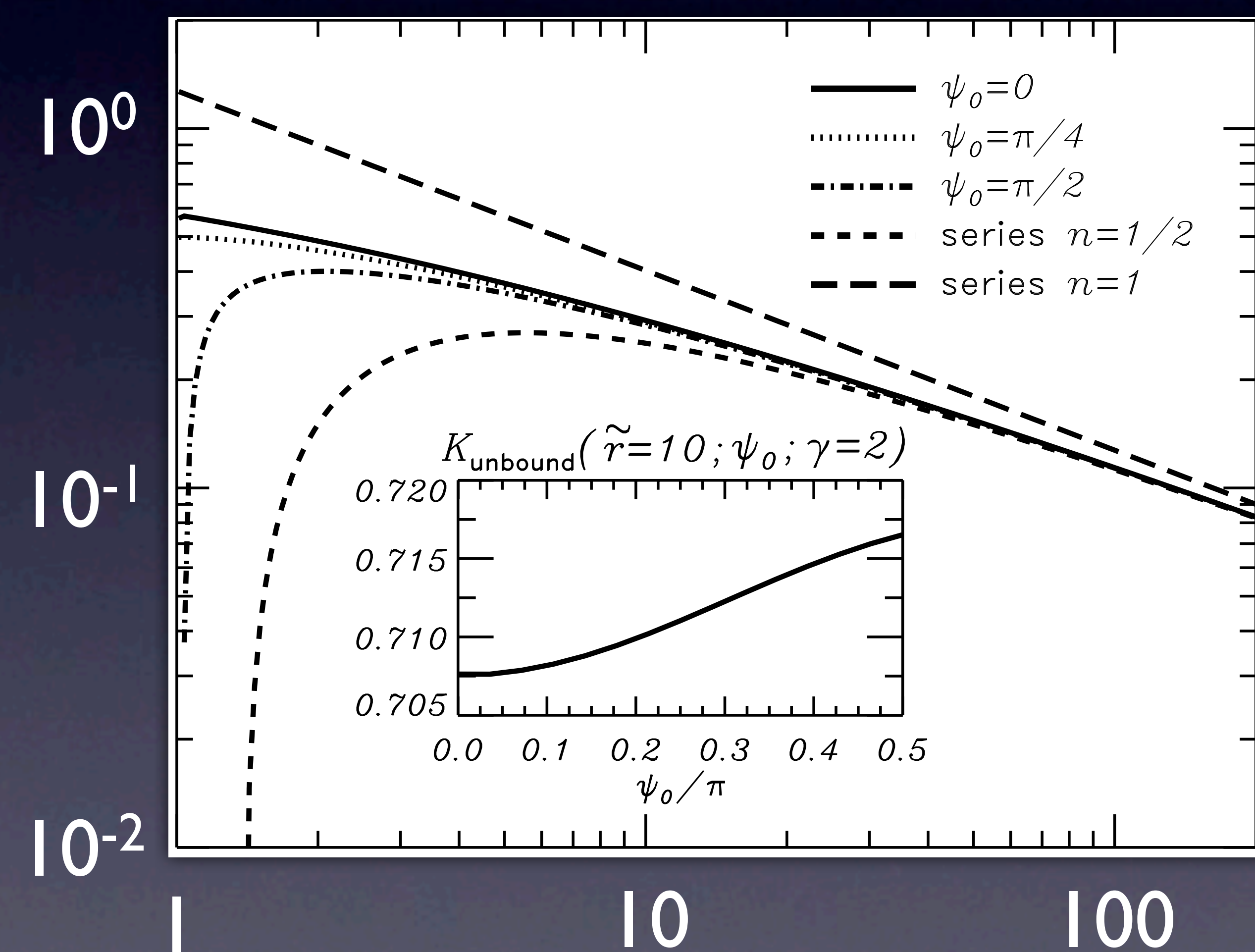
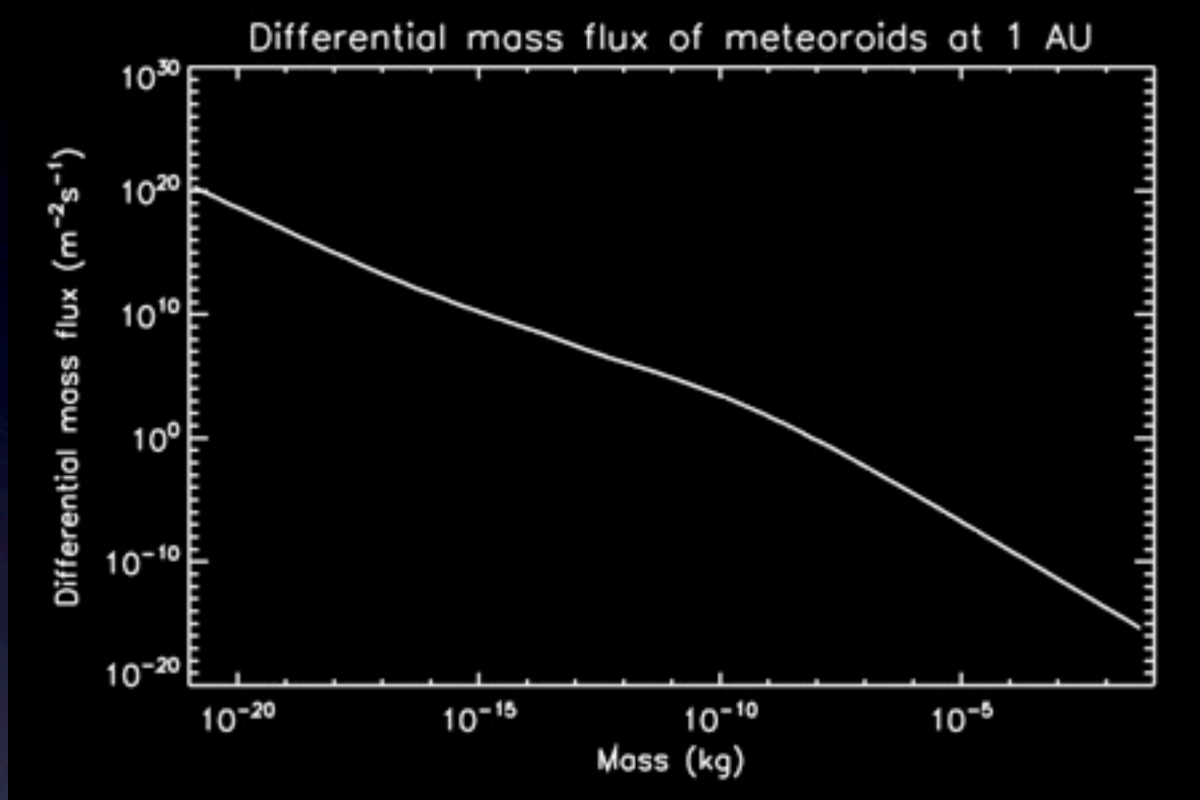


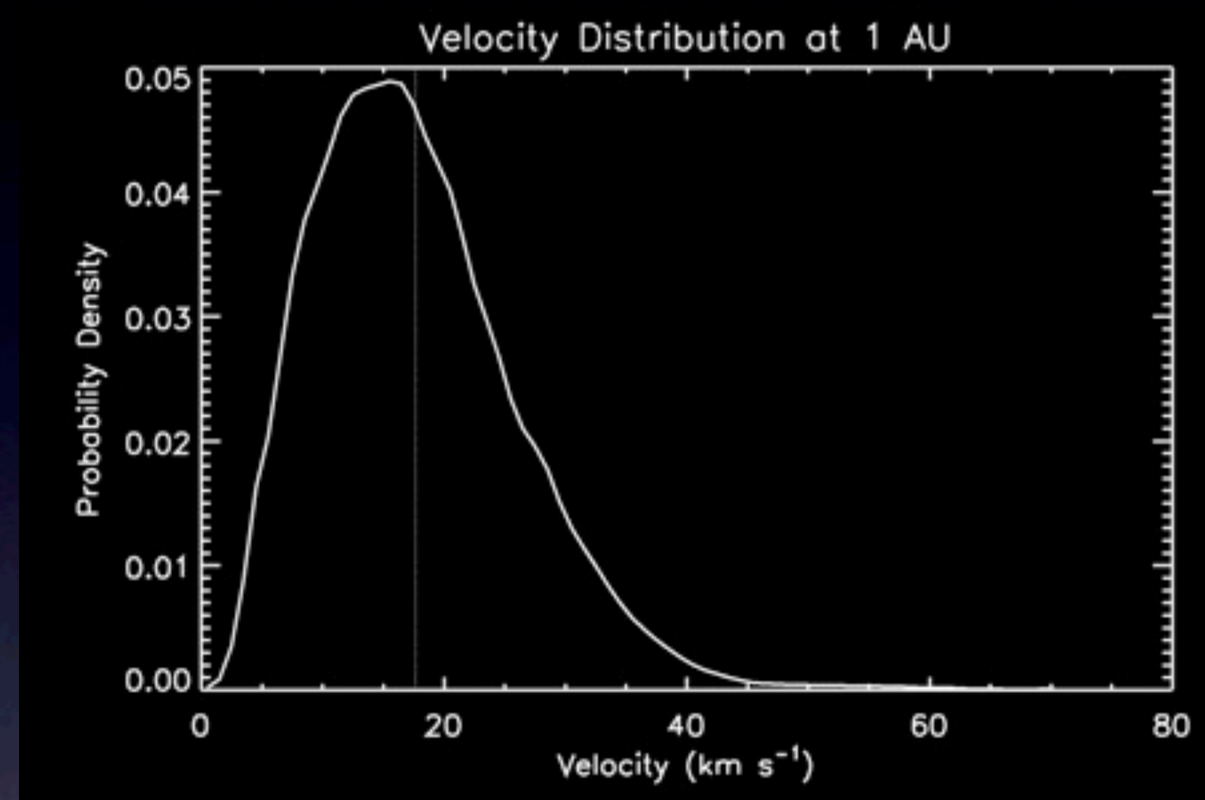
Angular Distribution can be Deduced from Density Profile

How About the Impactor Flux?

1985: Interplanetary Dust @ 1 AU



Grün et al., Icarus, 1985

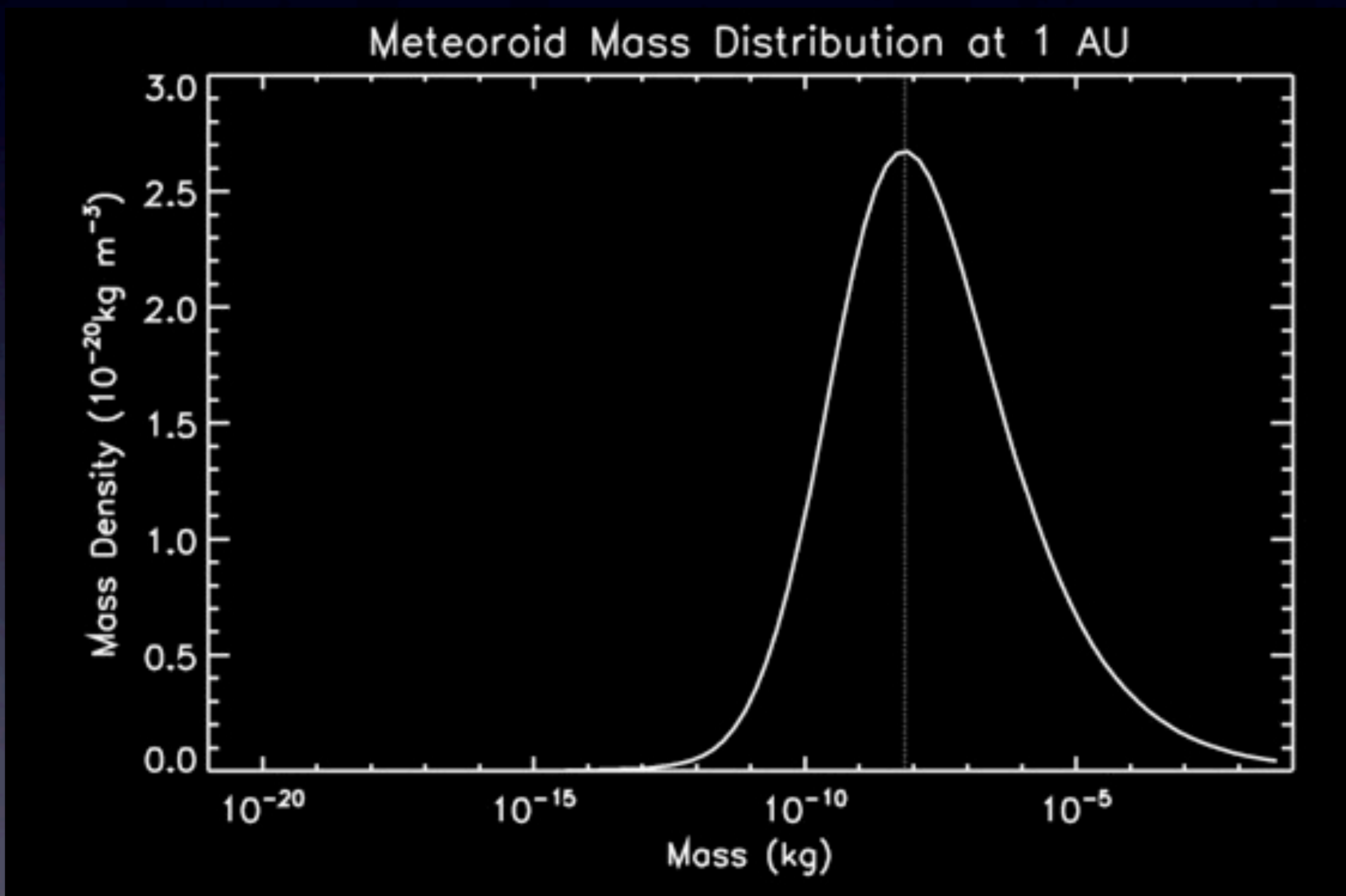


Taylor, Adv. Space Res., 1995

- Cumulative mass flux on plate spinning orthogonally to ecliptic plane
- based on spacecraft data and lunar crater size distribution

- derived from radio meteors data
- mean speed: ~ 17 km/s

Mass Distribution @ 1 AU

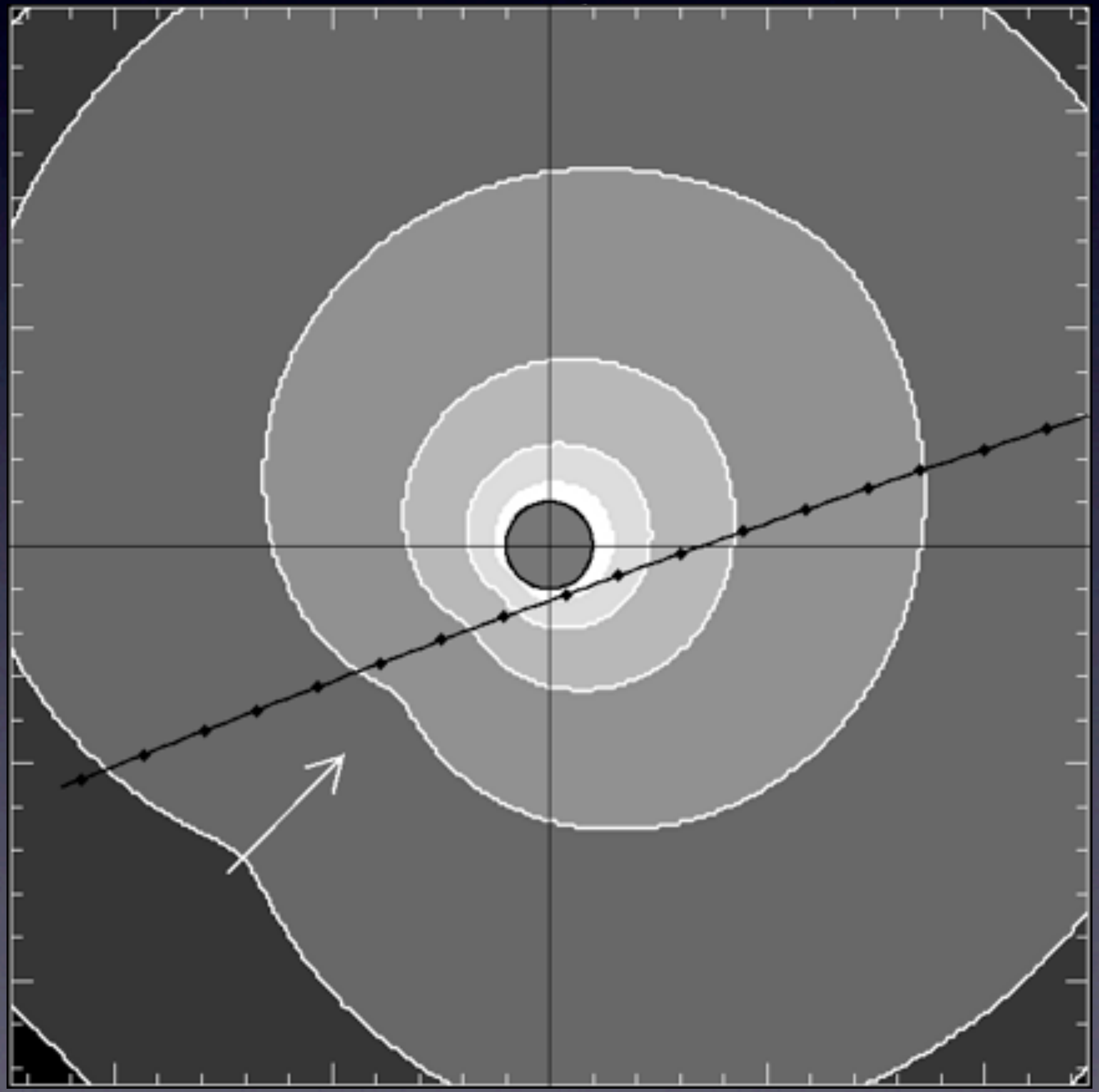


- Spatial mass density:

$$\rho(m_d) = 4\frac{\mathrm{d}F_{imp}}{\mathrm{d}m_d} m_d^2 \langle v_d \rangle^{-1}$$

- Grün flux and Taylor speed distribution
- the largest fraction of the IDP mass is in particles of mass 10^{-11}kg to 10^{-4}kg

Isotropic Impactor Flux - Really?



Sremcevic et al., (2003, 2005)

Induced Dust Cloud Anisotropy

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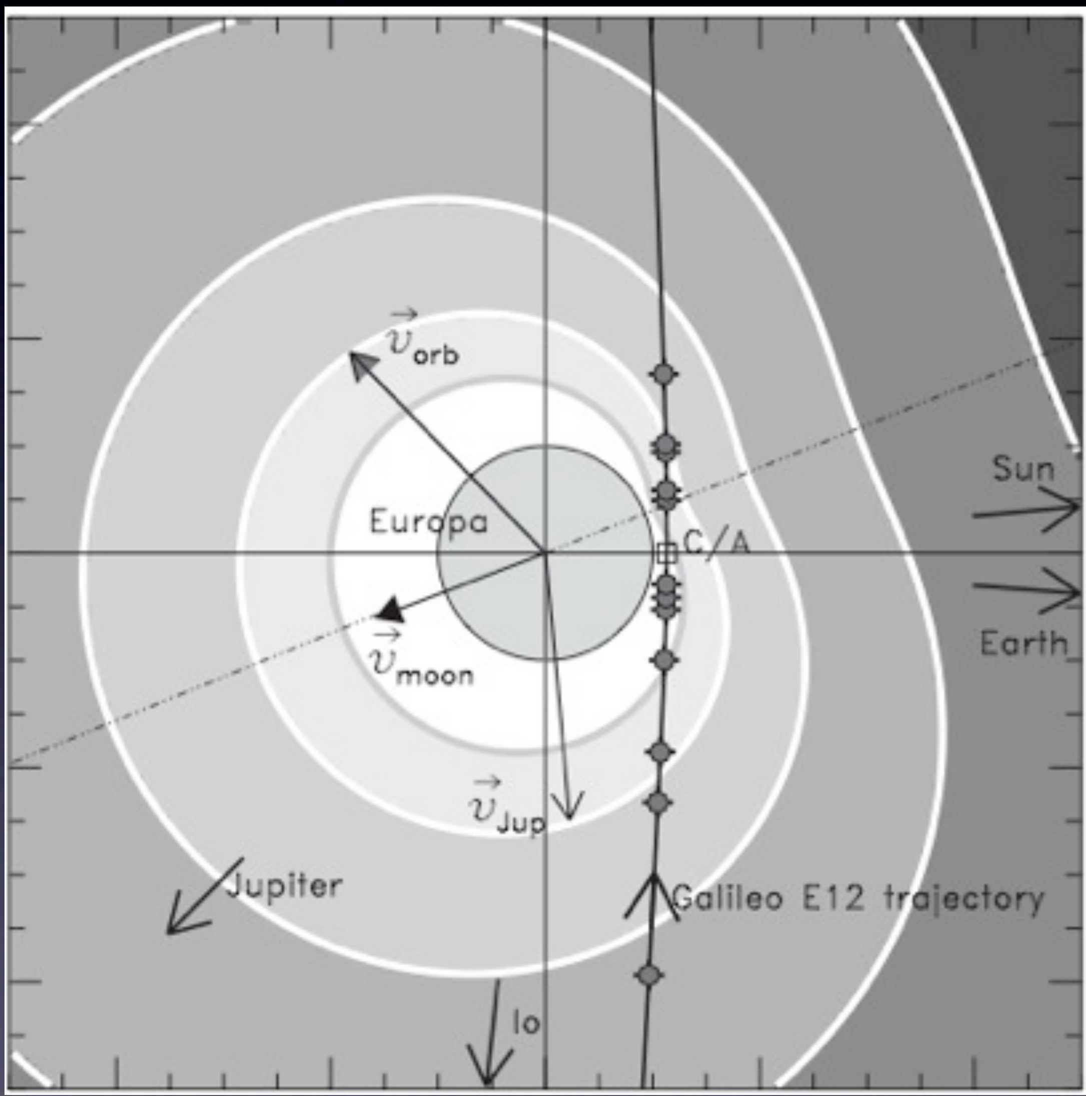
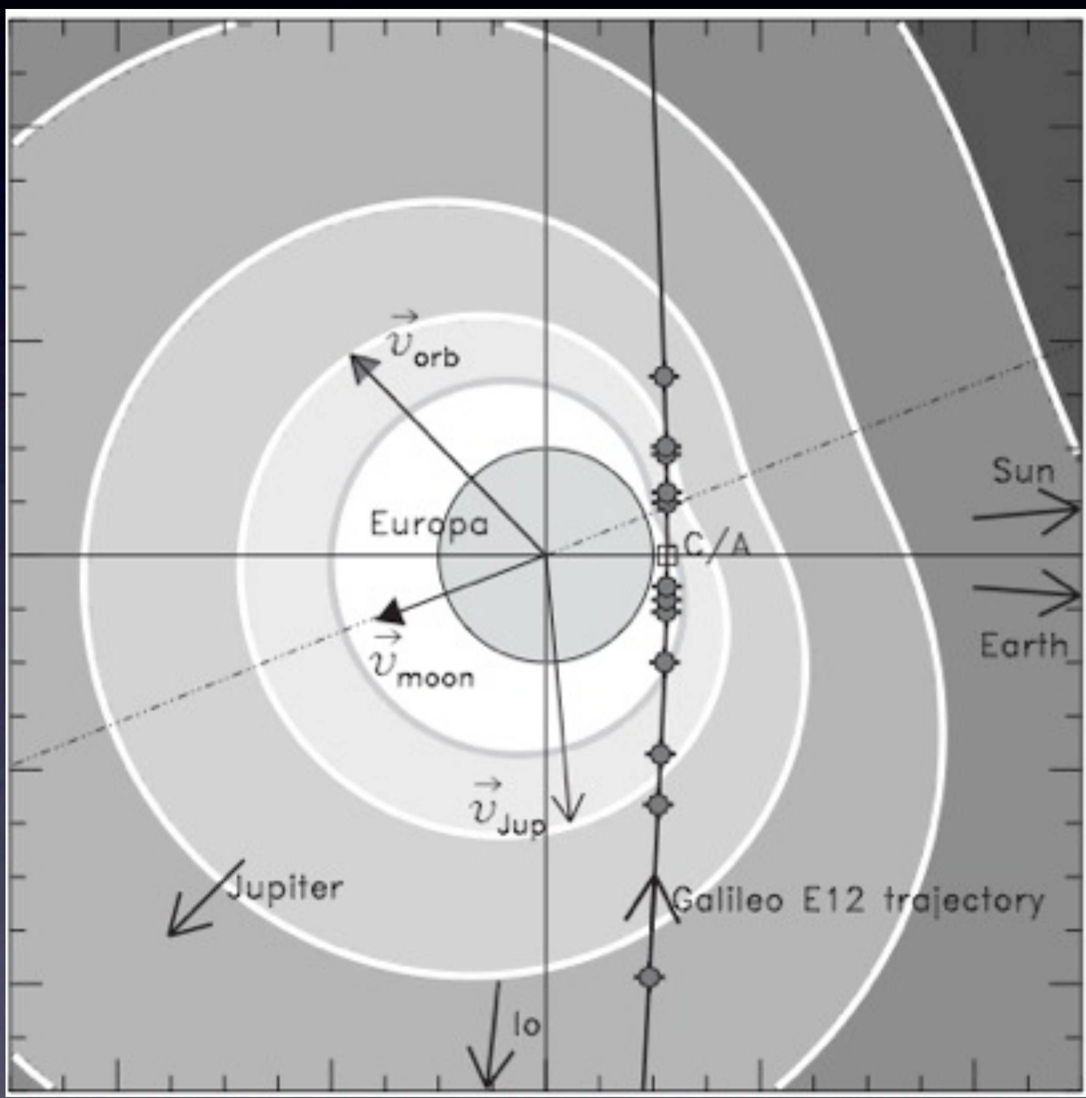
Induced Dust Cloud Anisotropy



Sremcevic et al., *PSS* **53**, 2006

- Anisotropic impactor flux causes anisotropic ejecta clouds:
- Anisotropy provides information about the directionality of the impactor flux
- Example: Ejecta cloud of the Jovian moon Europa:
  - generated by IDPs with an isotropic speed distribution and by IDPs in retrograde orbits

Cloud Anisotropy



Sremcevic et al., *PSS* **53**, 2006

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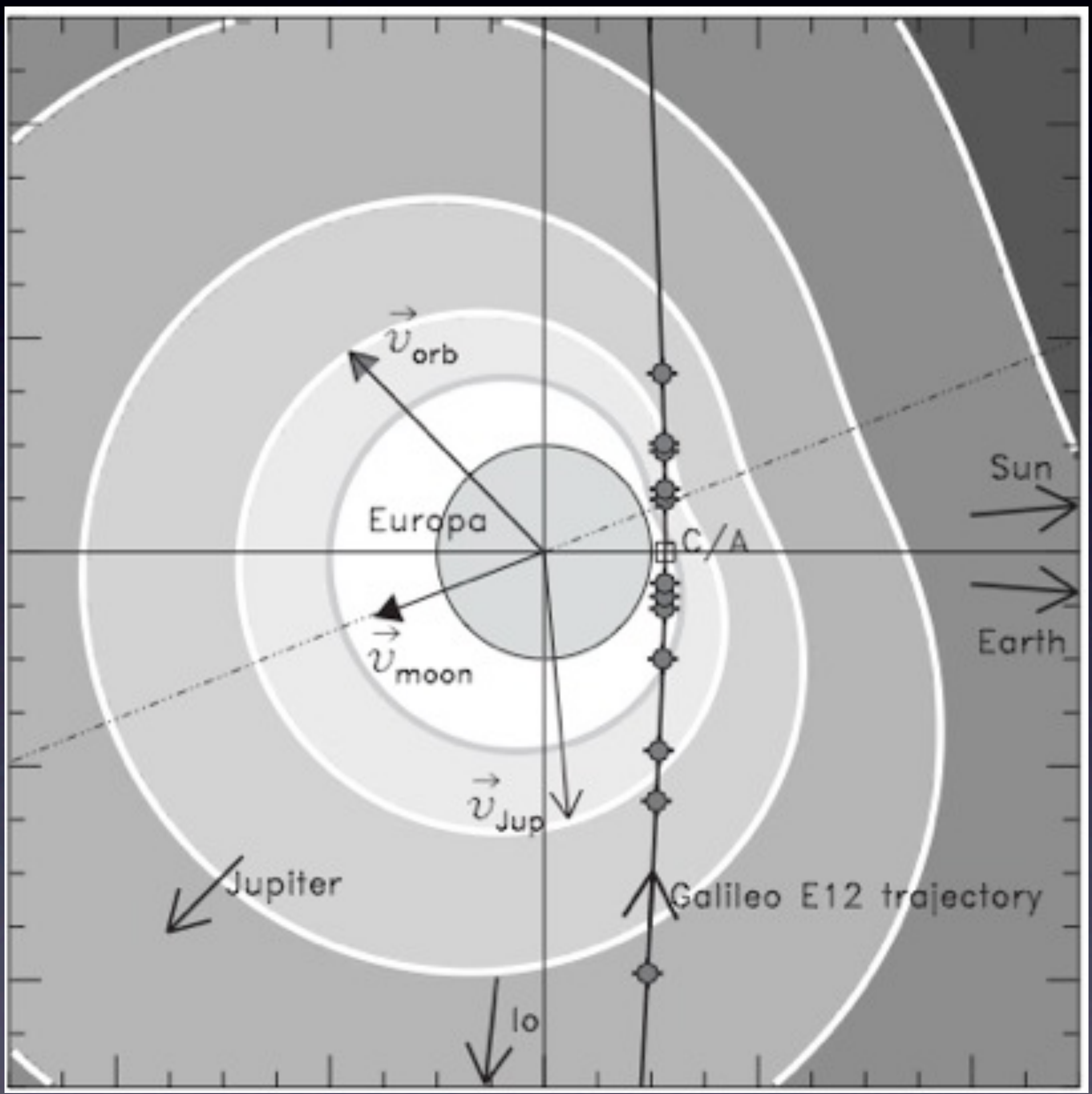

Sremcevic et al., *PSS* **53**, 2006

- Moon „magnifies“ weak impactor streams

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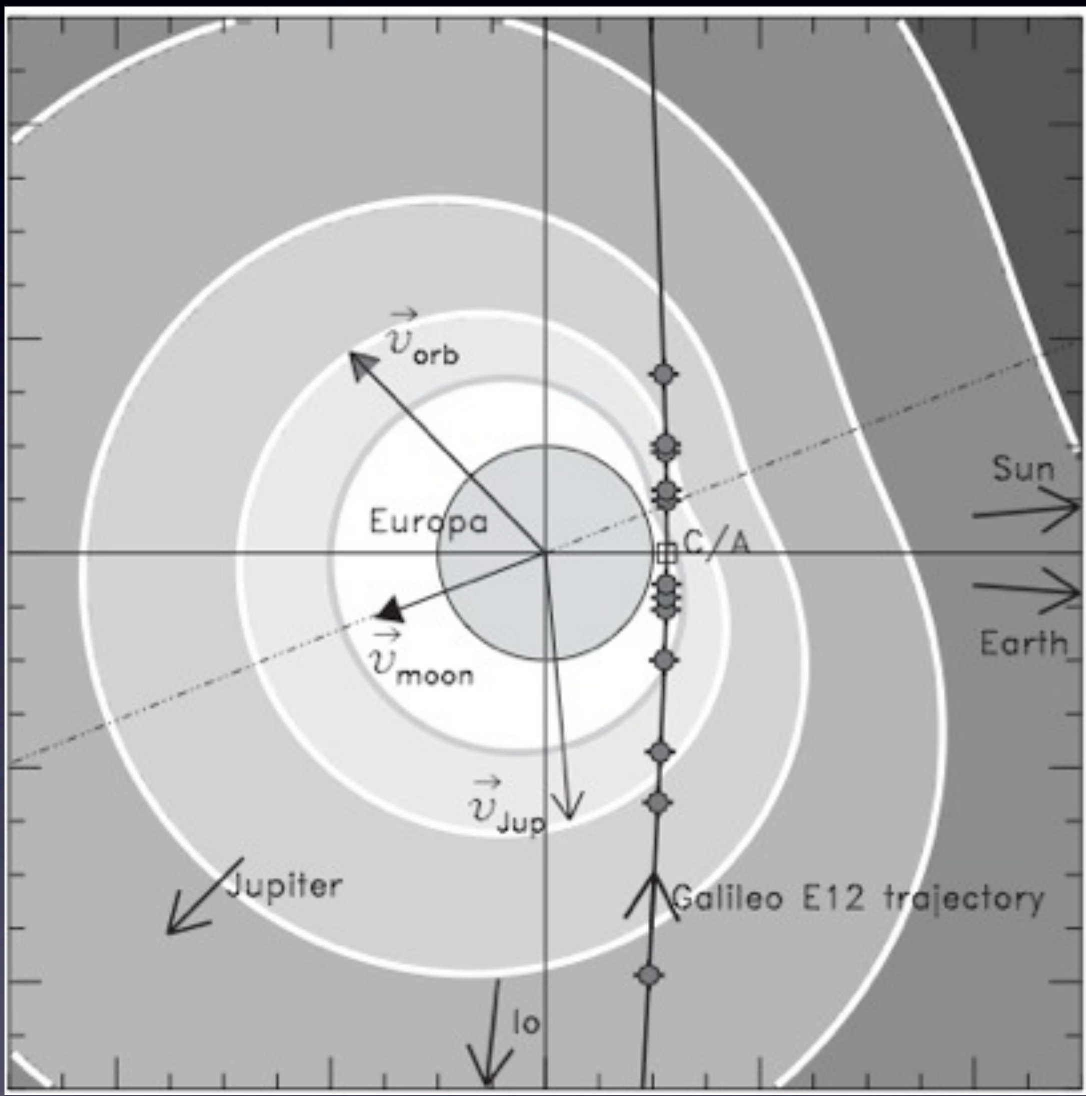

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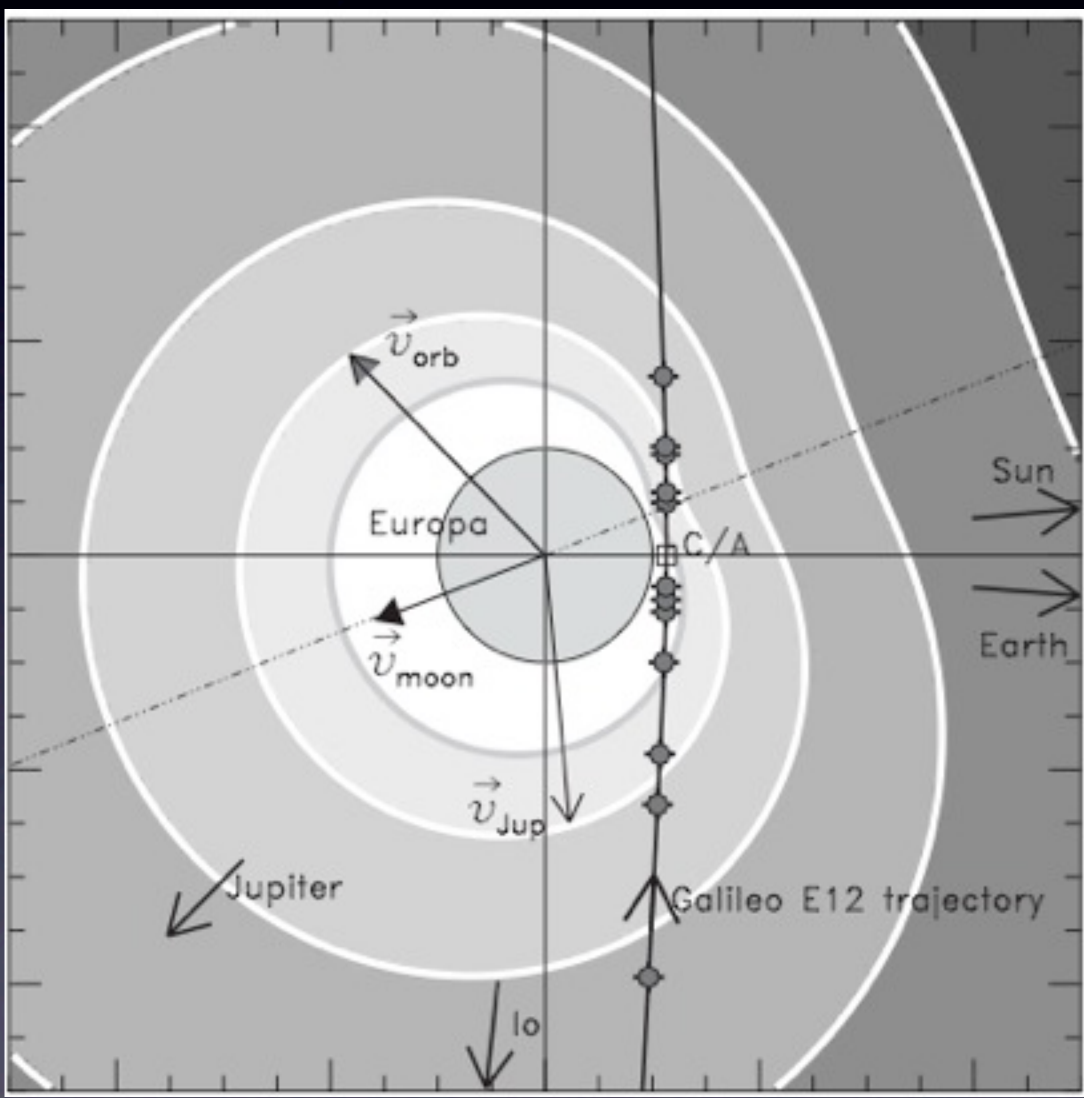

Sremcevic et al., *PSS* **53**, 2006

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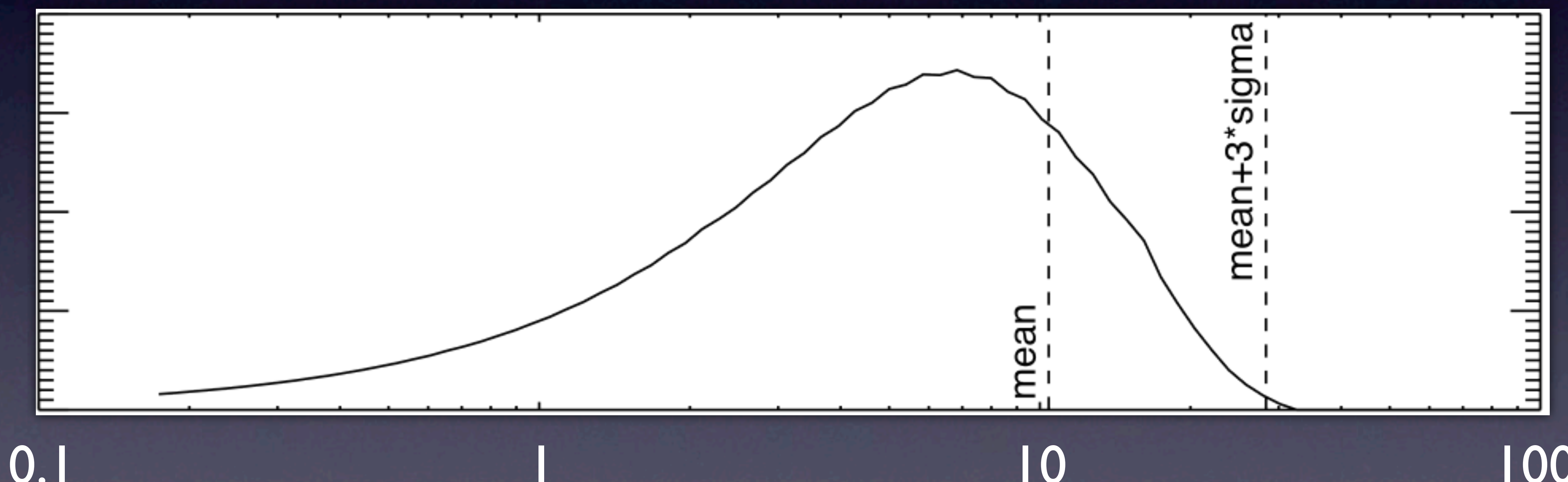
- Acts as an large area dust detector
- Galactic dust streams should appear in LDEX data

Ejecta Production Map (Erosion Map)

Ejecta detected by LDEX at 100 km altitude

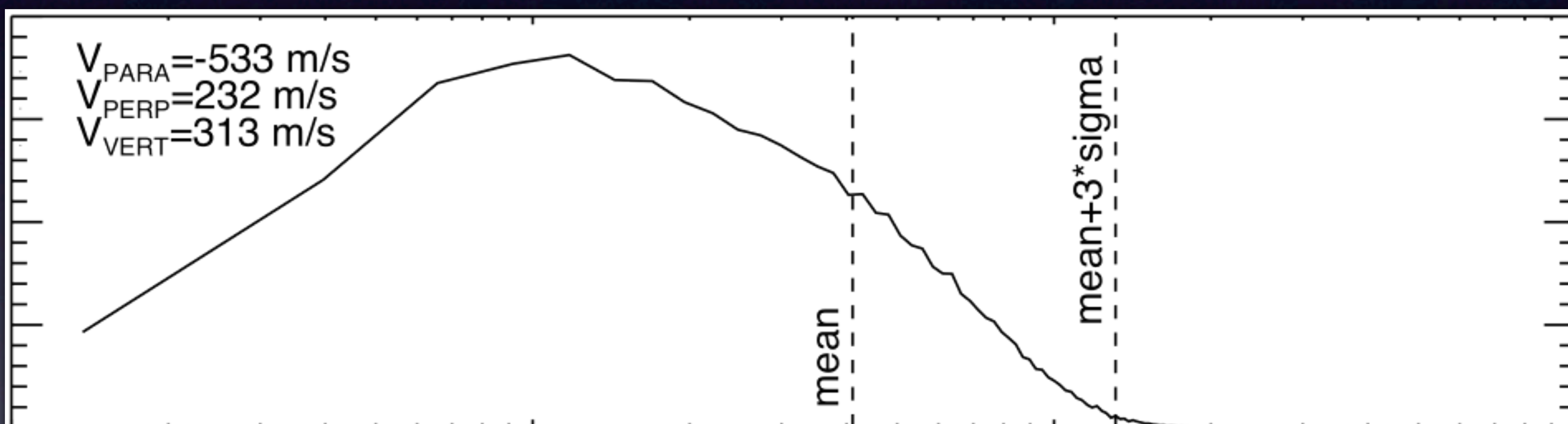


Distance from most probable ejection point (km)

Postberg et al., Plan. Space Sci., subm.

Ejecta Production Map (Erosion Map)

Ejecta detected by LDEX (with trajectory sensor) at 100 km altitude



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Weakness: Ejecta Production

Ejecta mass production:

$$M^+ = F_{imp} Y S_{sat}$$

Ejecta Yield:

$$Y = 2.85 \cdot 10^{-8} \cdot 0.0149^{G_{sil}} \left(\frac{1 - G_{sil}}{927} + \frac{G_{sil}}{2\,800} \right)^{-1} m_{imp}^{0.23} v_{imp}^{2.46}$$

Koschny & Grün, 2001

Ejecta Production

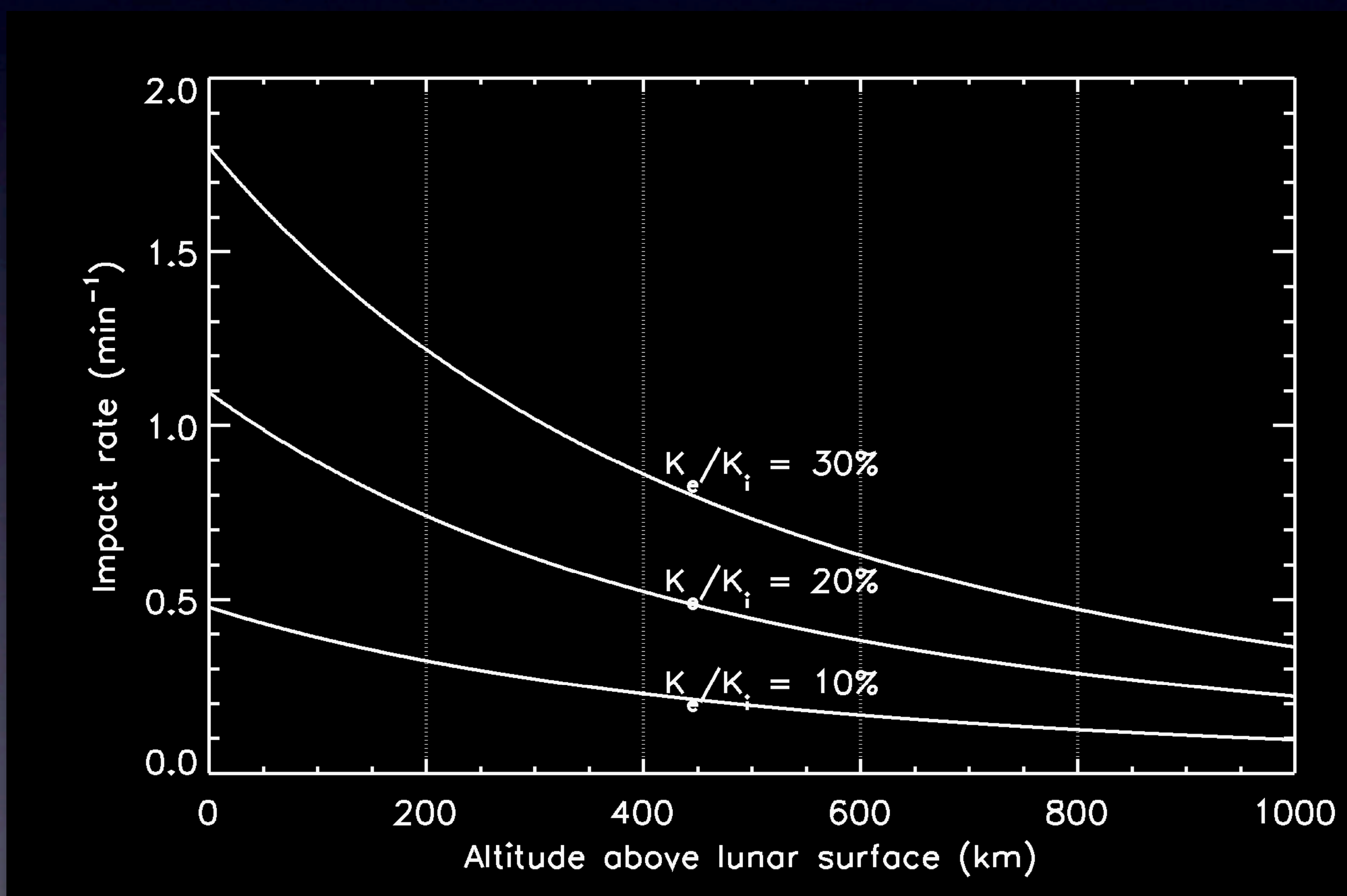
Production Rate of Ejecta > s:

$$N^+(>s) = \frac{3-\gamma}{\gamma}\frac{M^+}{m_e^{max}}\left(\frac{s_e^{max}}{s_e}\right)^\gamma$$

Energy Transfer:

$$K_e/K_i = Y\left(\frac{v_e^{min}}{v_{imp}}\right)^2 \begin{cases} \frac{\beta-1}{3-\beta}\left[\left(\frac{v_e^{min}}{v_e^{max}}\right)^{\beta-3} - 1\right] & \beta < 3, \\ 2\ln\left(\frac{v_e^{min}}{v_e^{max}}\right) & \beta = 3 \end{cases}$$

Lunar Dust Cloud



- Grains > 0.5μm
- 0.1m^2 detector
- 100 km orbit:
  - 100 000 / 3 month

CCLDAS Accelerator at CU Boulder

3 MV Pelletron