Rings around a moon?

The puzzling case of Rhea.

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and the MIMI and CAPS teams.

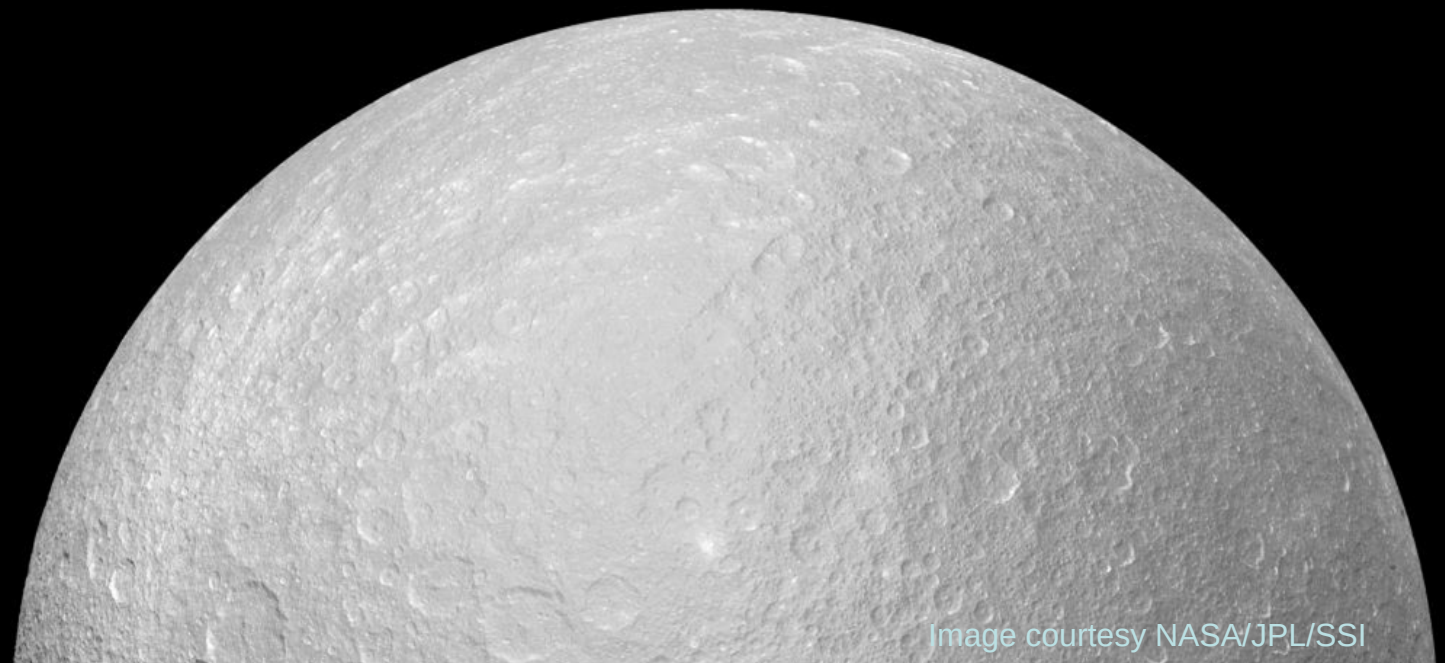

Image courtesy NASA/JPL/SSI

Acknowledgements…

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- Other colleagues on the UVIS, RPWS, MAG, and CDA teams.

Cassini MIMI-LEMMS instrument

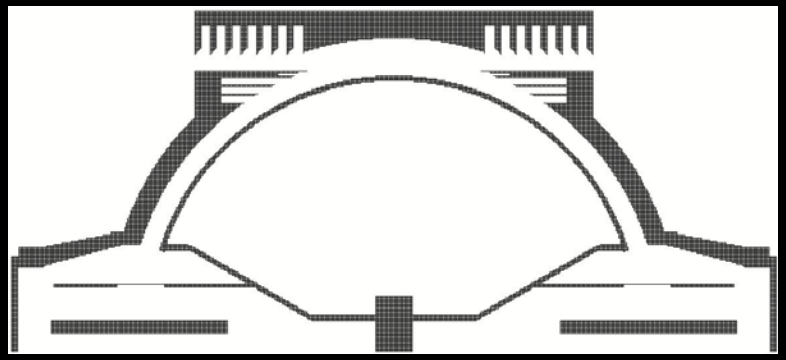
Low Energy Magnetospheric Measurement System

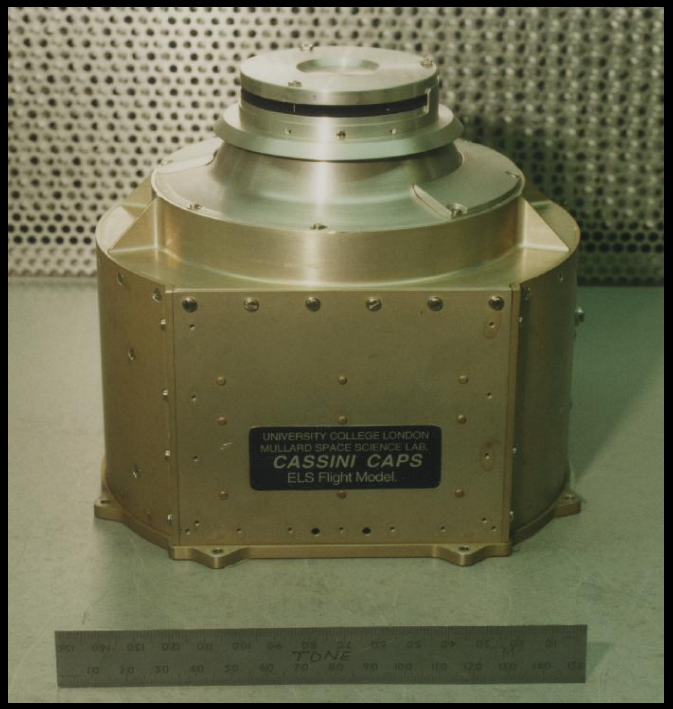
Detects:

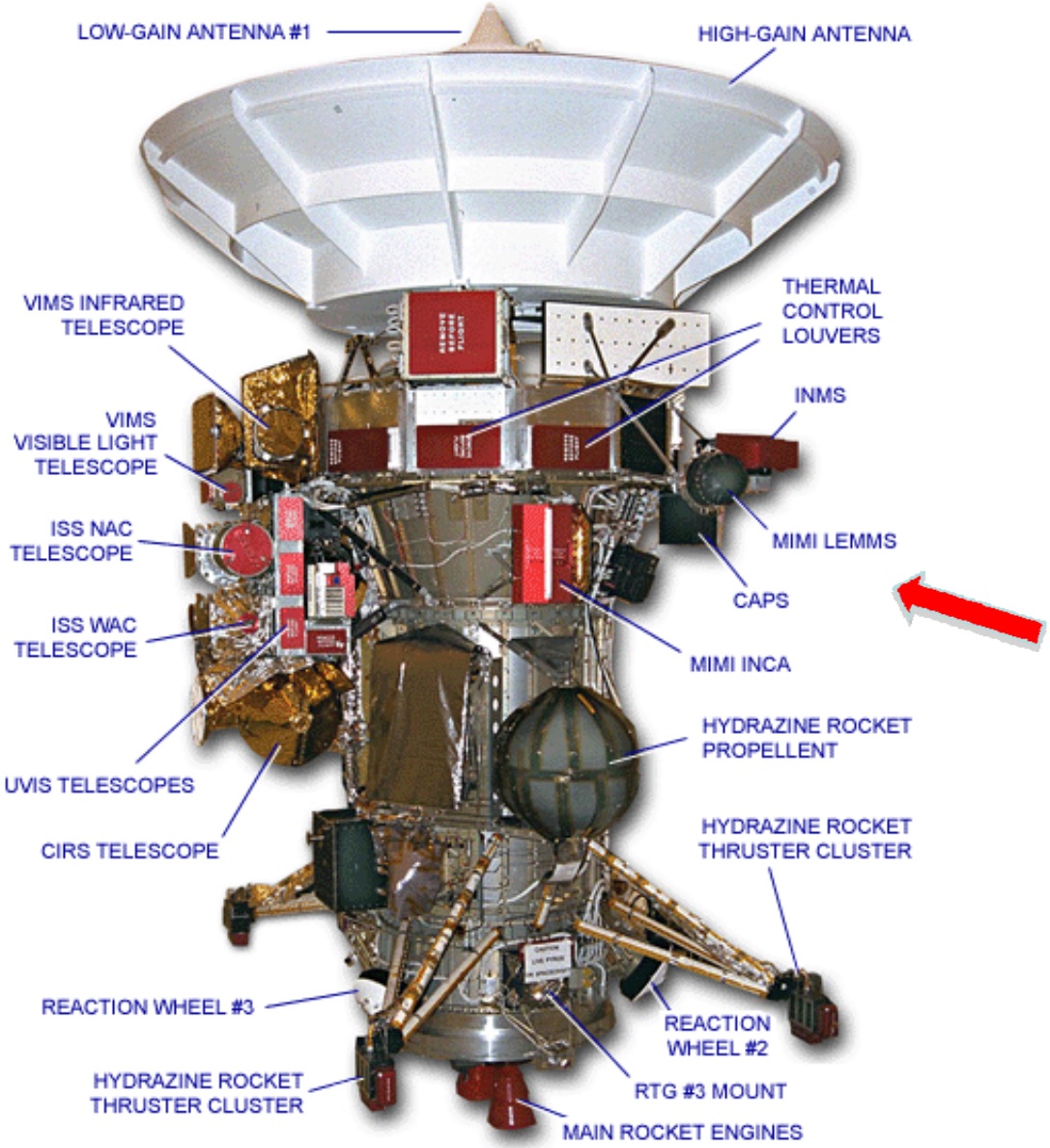
30 keV - 160 MeV ions

15 keV - 5 MeV electrons

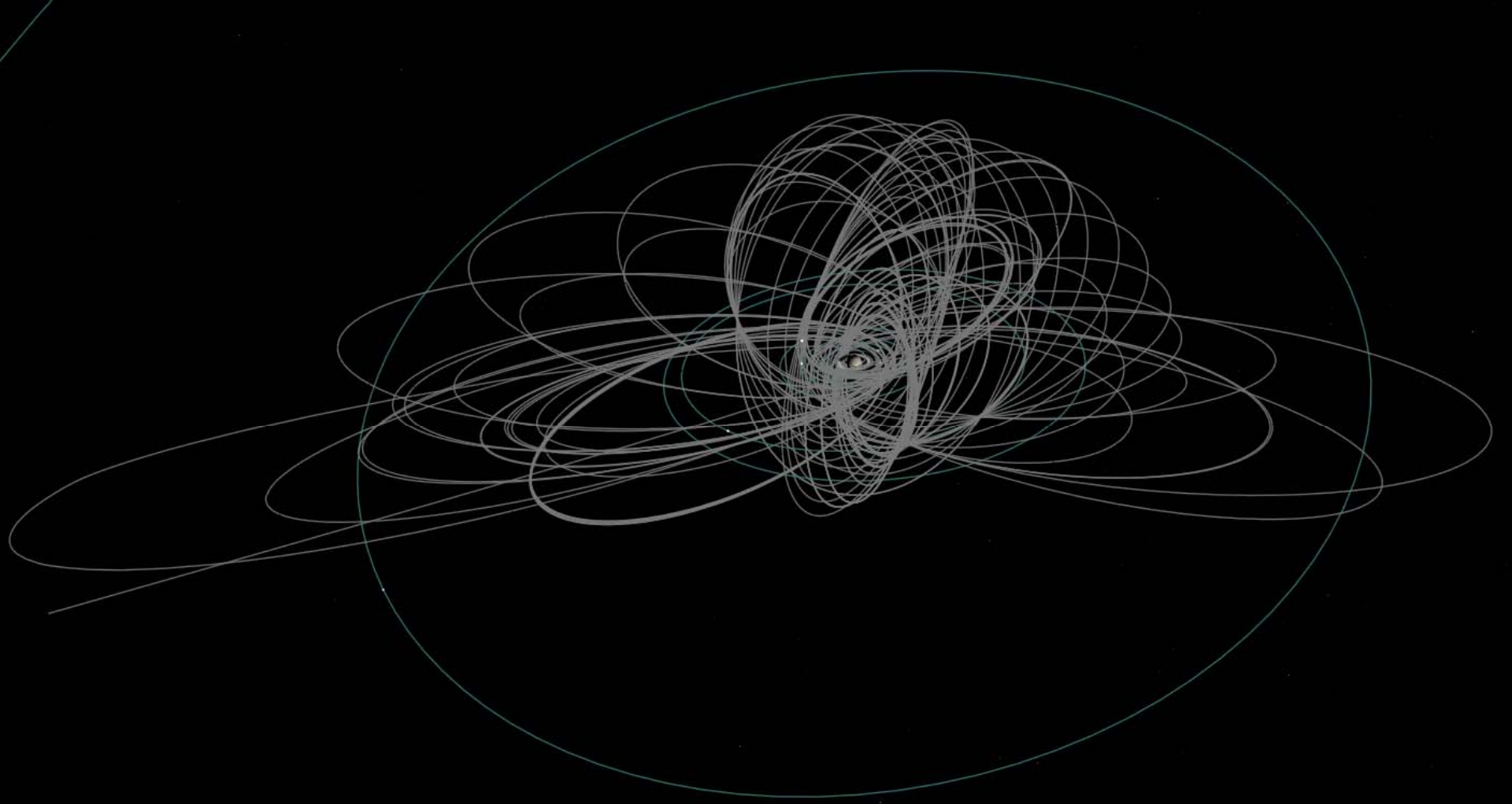
- Cassini Plasma Spectrometer's (CAPS) Electron Spectrometer (ELS)
- An electrostatic top hat analyser.
- Mounted on an actuator
- 8 anodes (20° each)
- Covers energy range from 0.5eV – 26 keV







CAPS and MIMI-LEMMS are mounted on the fields and particles pallet

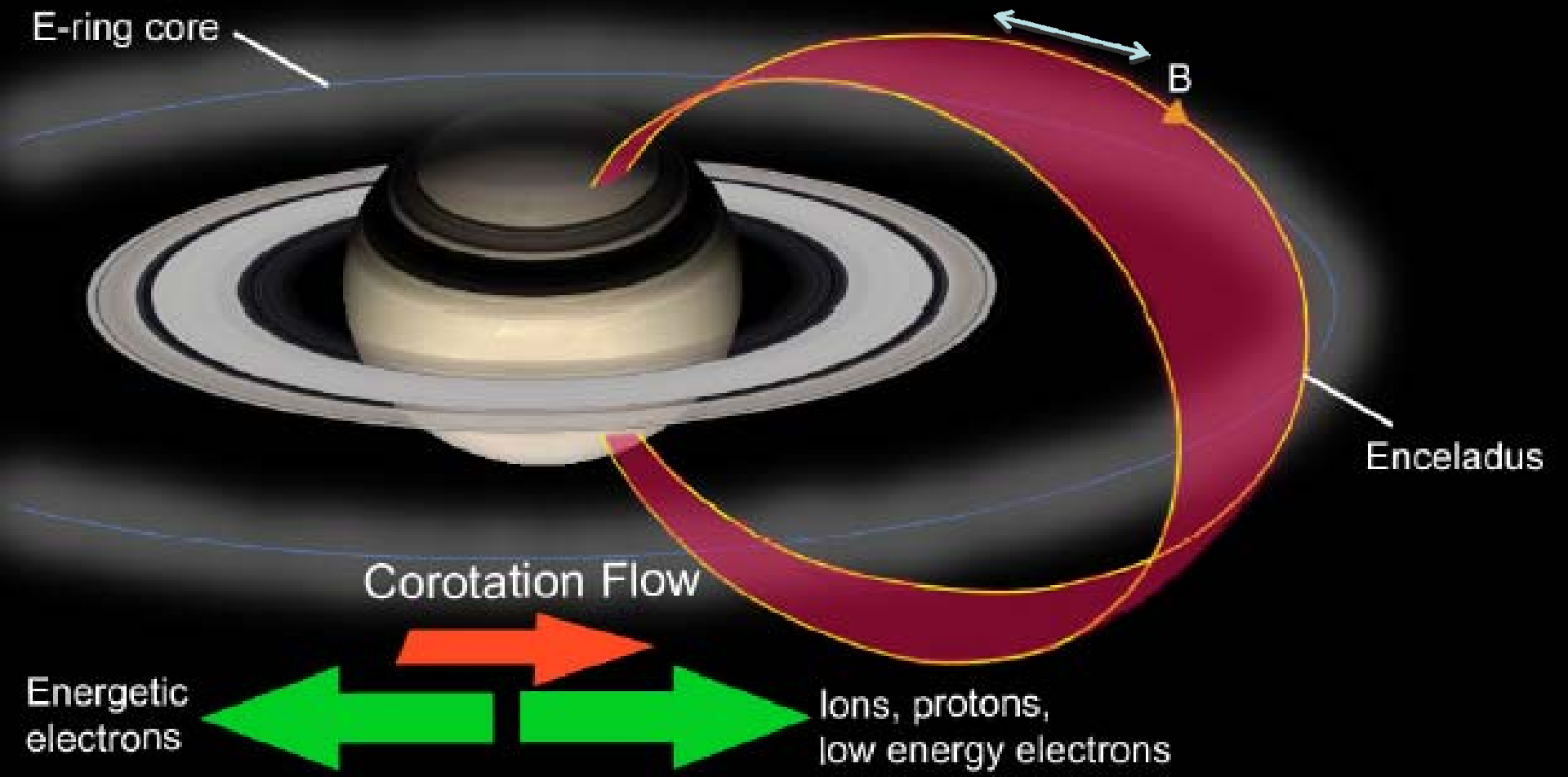


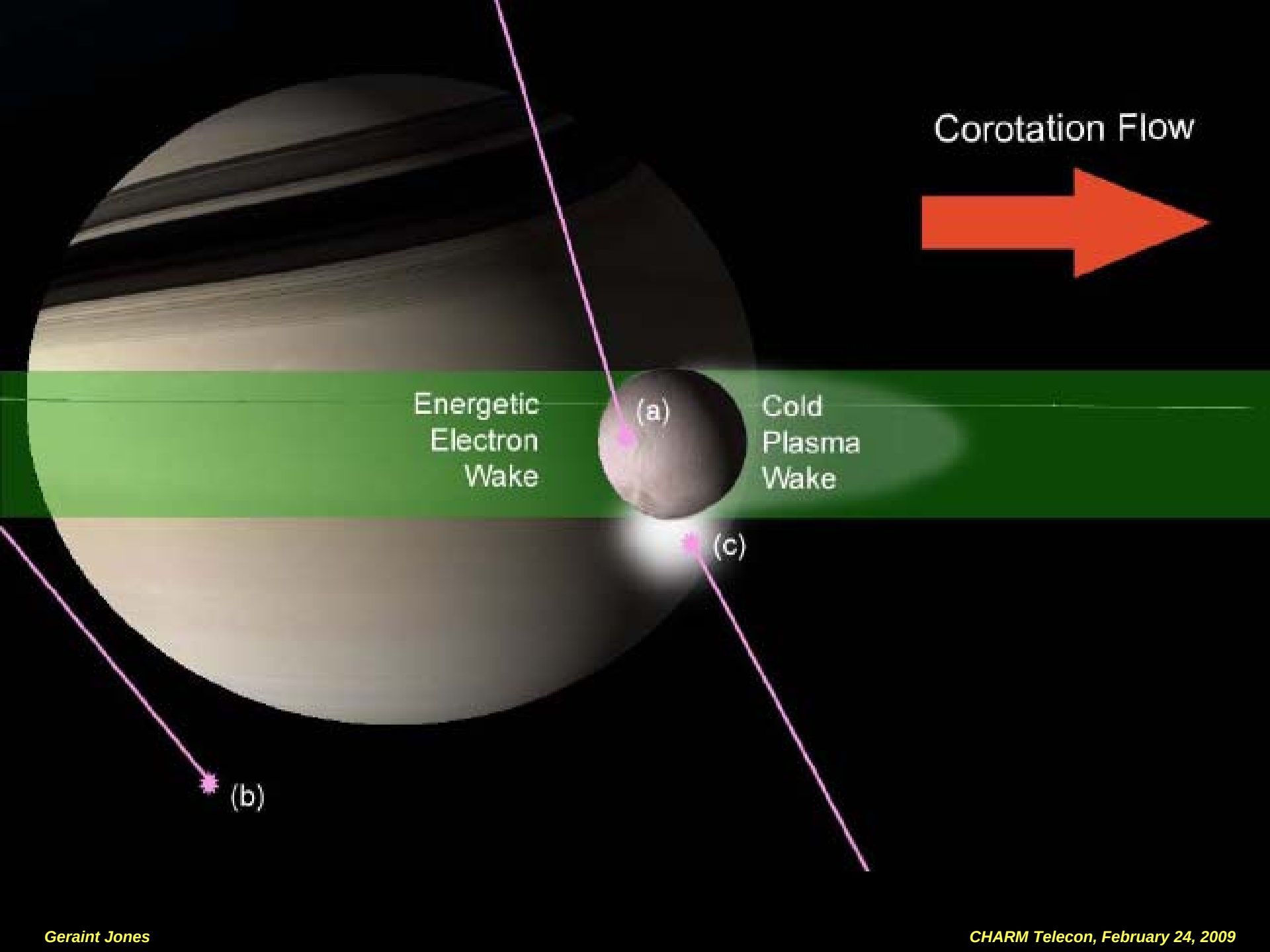
Cassini’s prime and equinox mission tours

Saturn's Satellites and Ring Structure

Most of the icy moons reside inside Saturn's radiation belts…

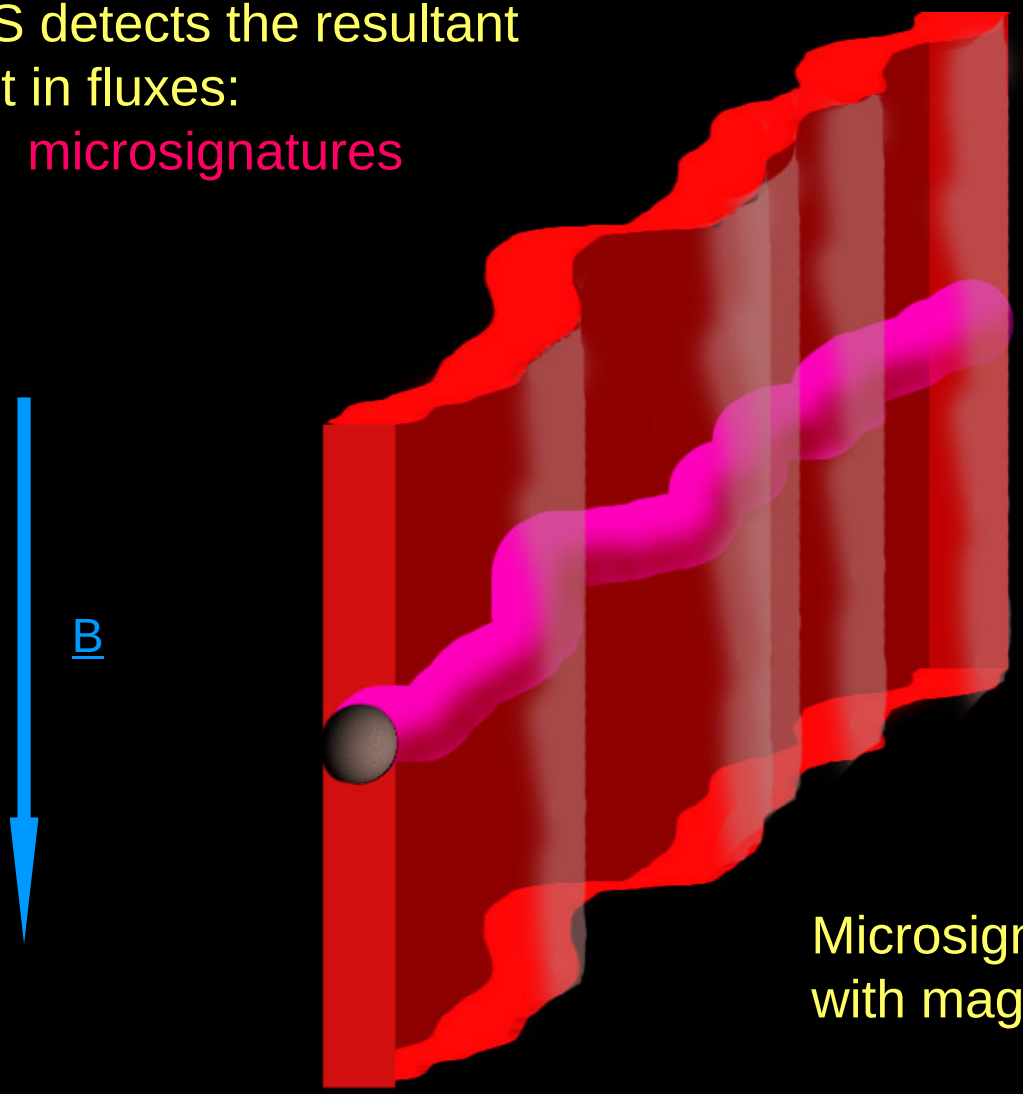
Trapped energetic electrons and ions bounce north and south, guided by Saturn's magnetic field




Corotation Flow
Energetic
Electron
Wake
(a)
Cold
Plasma
Wake
(b)
(c)

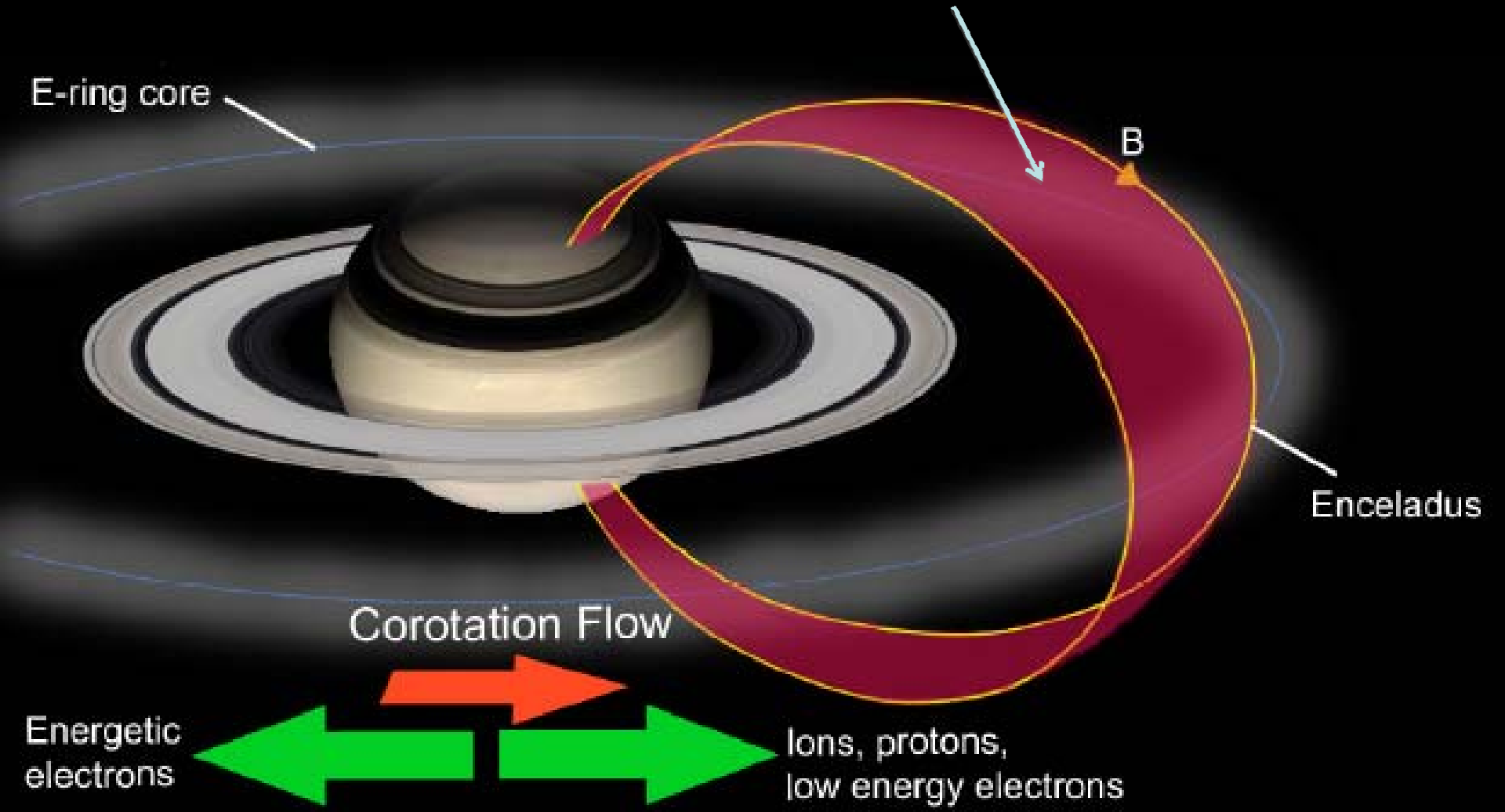
When trapped energetic particles strike a moon or other obstacle, LEMMS detects the resultant dropout in fluxes:

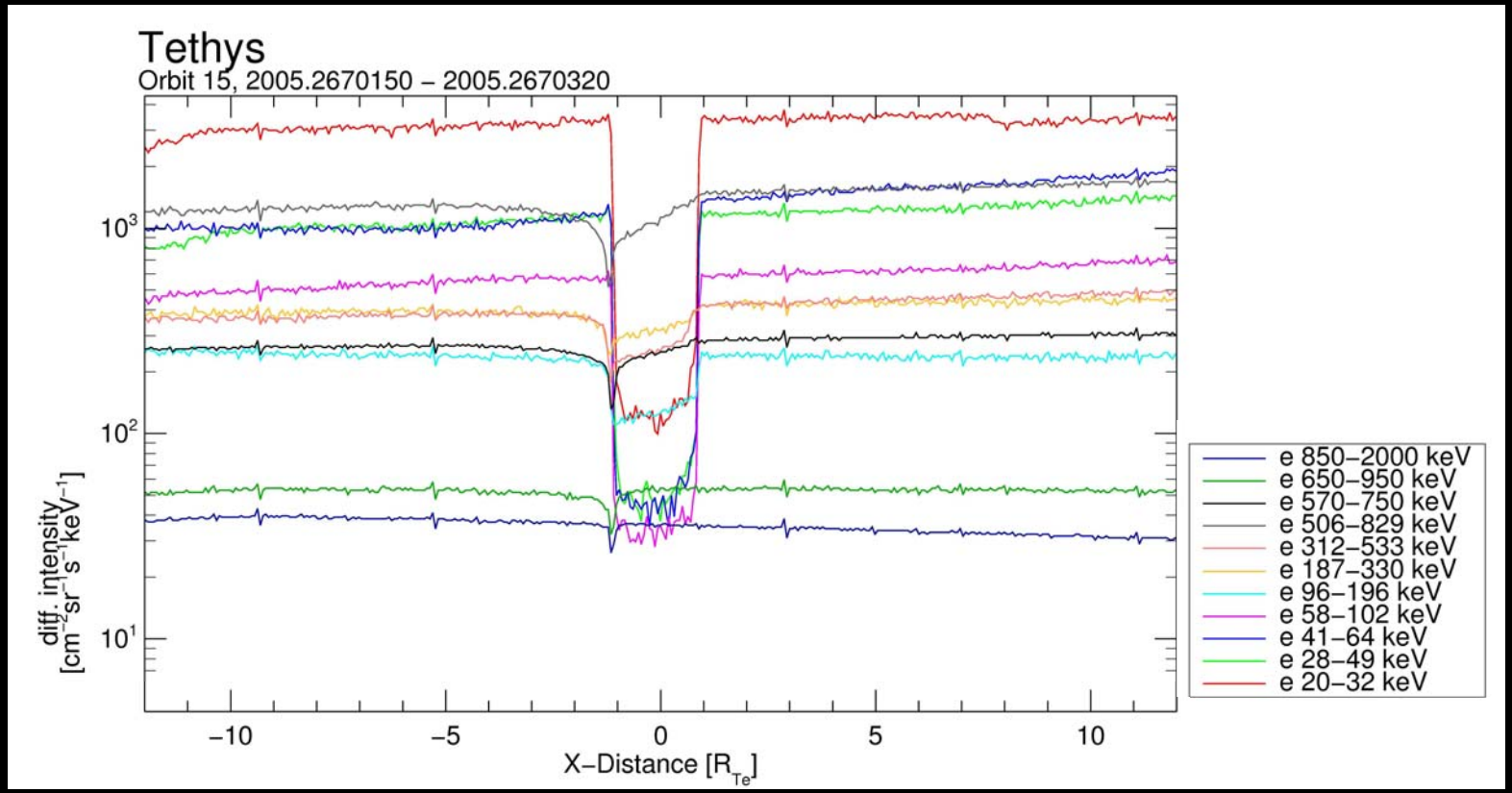
microsignatures



Microsignatures eventually refill with magnespheric particles.

Depletion in ions and electrons where magnetic field has passed through a moon (the moon's L-shell).

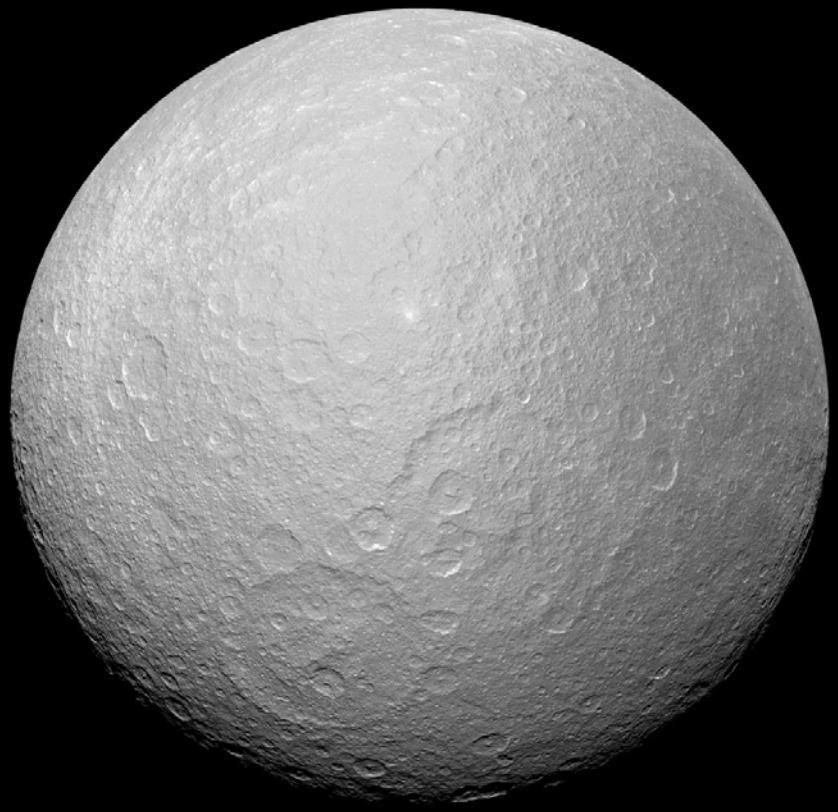




Flybys of Tethys reveal a sharp microsignature, as expected.

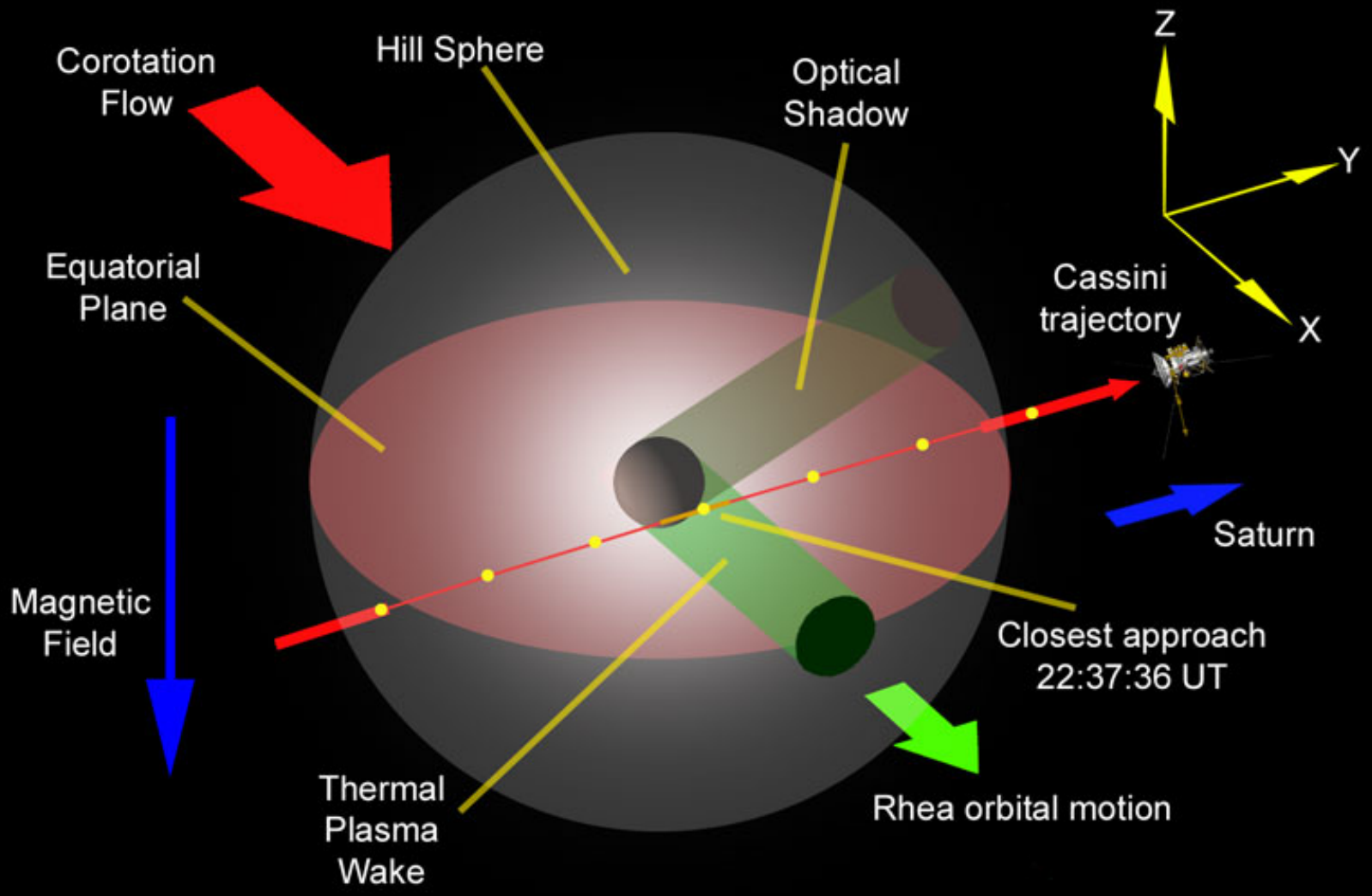
Rhea

- 764 km radius
- Orbits at 524300 km, 8.7 Saturn radii (Rs).
- Close flyby on 2005:330 (November 26)
- Closest approach 500 km altitude, directly downstream of moon in corotation flow (ahead of Rhea's motion about its orbit)
- More distant flyby on 2007:242 (August 30); 5700 km downstream

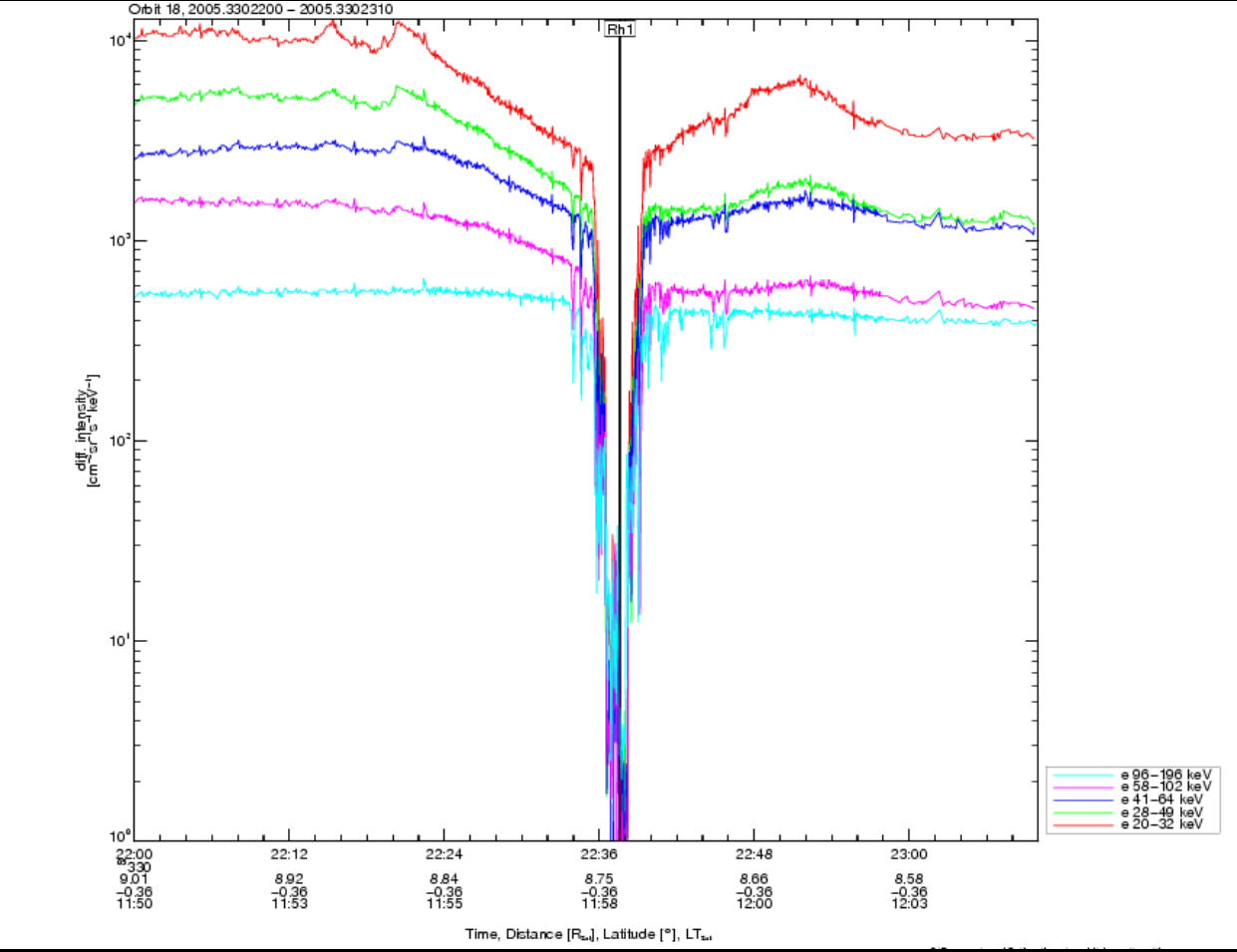


NASA/JPL/Space Science Institute

November 2005 encounter geometry

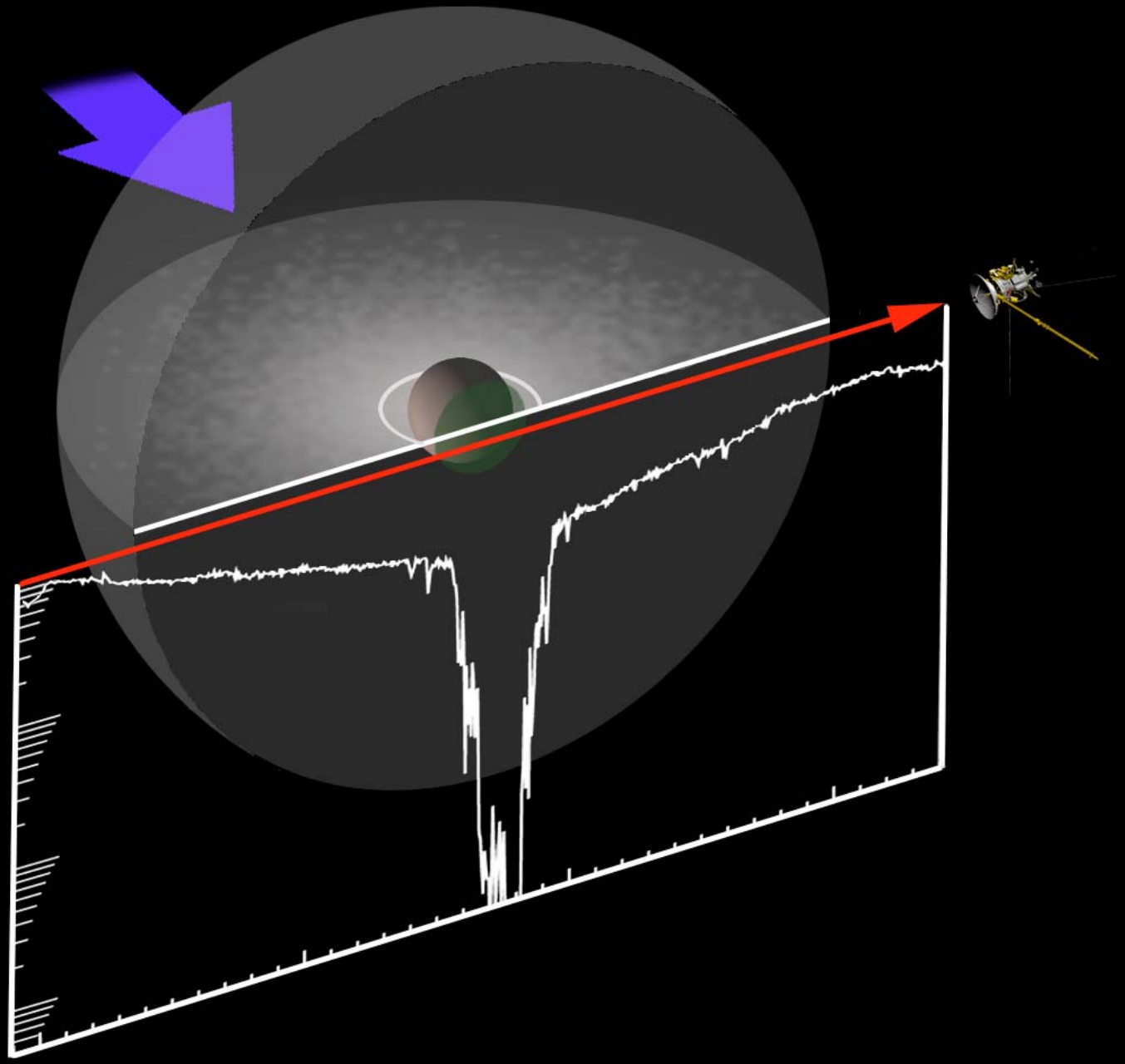


MIMI-LEMMS electron fluxes at Rhea



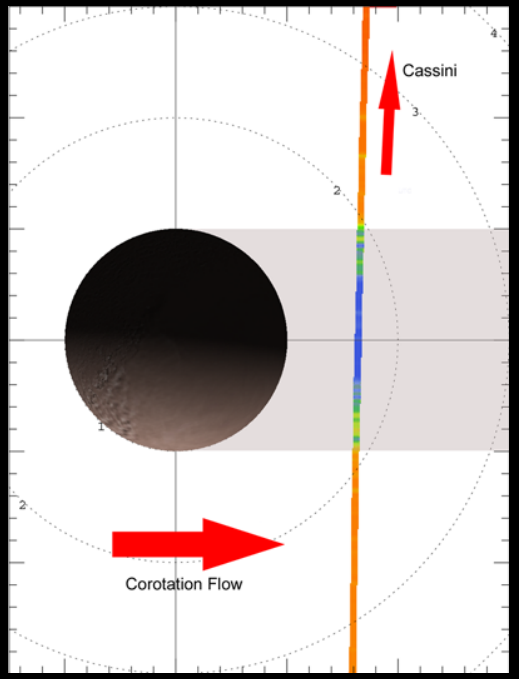
Deep electron flux dropout at centre expected: wake of Rhea itself.

“Wings” of dropout unexpected.



- Central dropout in electron fluxes simply due to loss of corotation flow plasma to the moon's surface.

What causes the extended low energy electron interaction region?

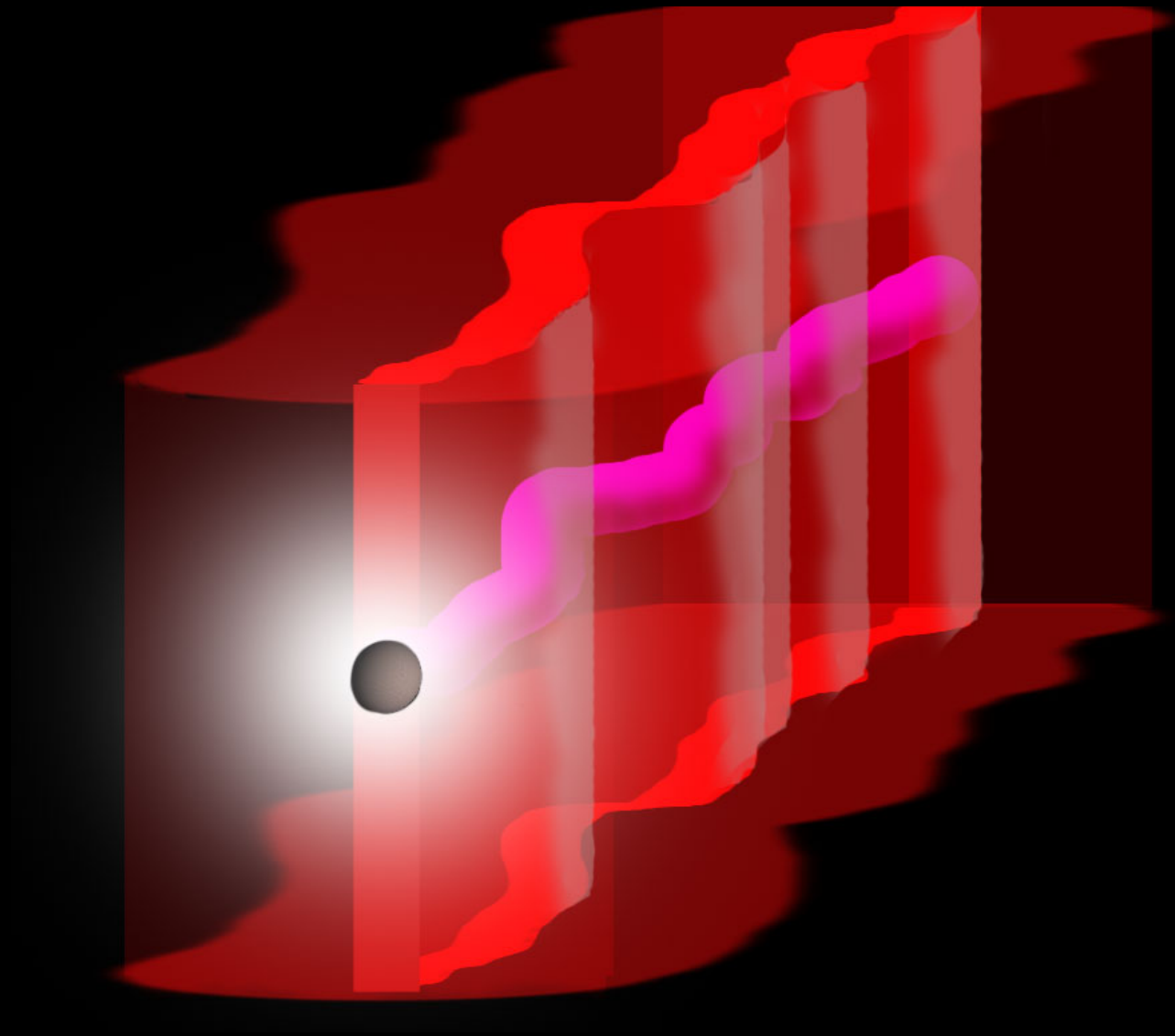


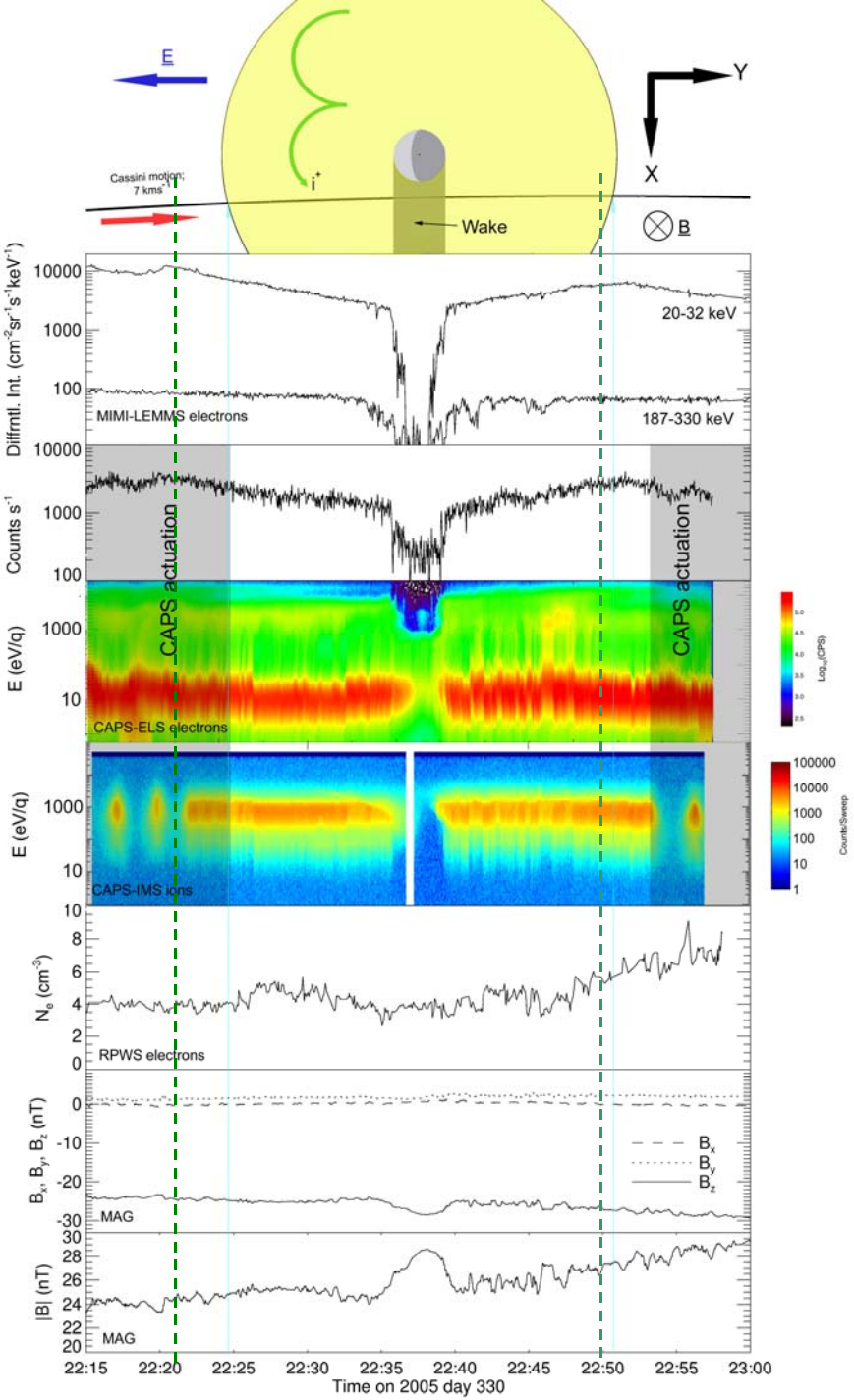
- Inbound "boundary" ~22:22 UT, outbound ~22:52 UT

- Hill sphere radius= 5823 km, or 7.61 R_{Rh}

- Crossed at ~22:25 UT inbound, ~22:51 UT outbound

- Interaction region may therefore signify crossing into region where material gravitationally-bound by Rhea





Multi-instrument view

MIMI-LEMMS (C0 & C5) (10° pitch angle)

CAPS electrons 24-28 keV (90° p.a.)

CAPS electron spectrogram (90° p.a.)

CAPS IMS spectrogram (90° p.a.)

RPWS electron densities

MAG Magnetic field components and magnitude

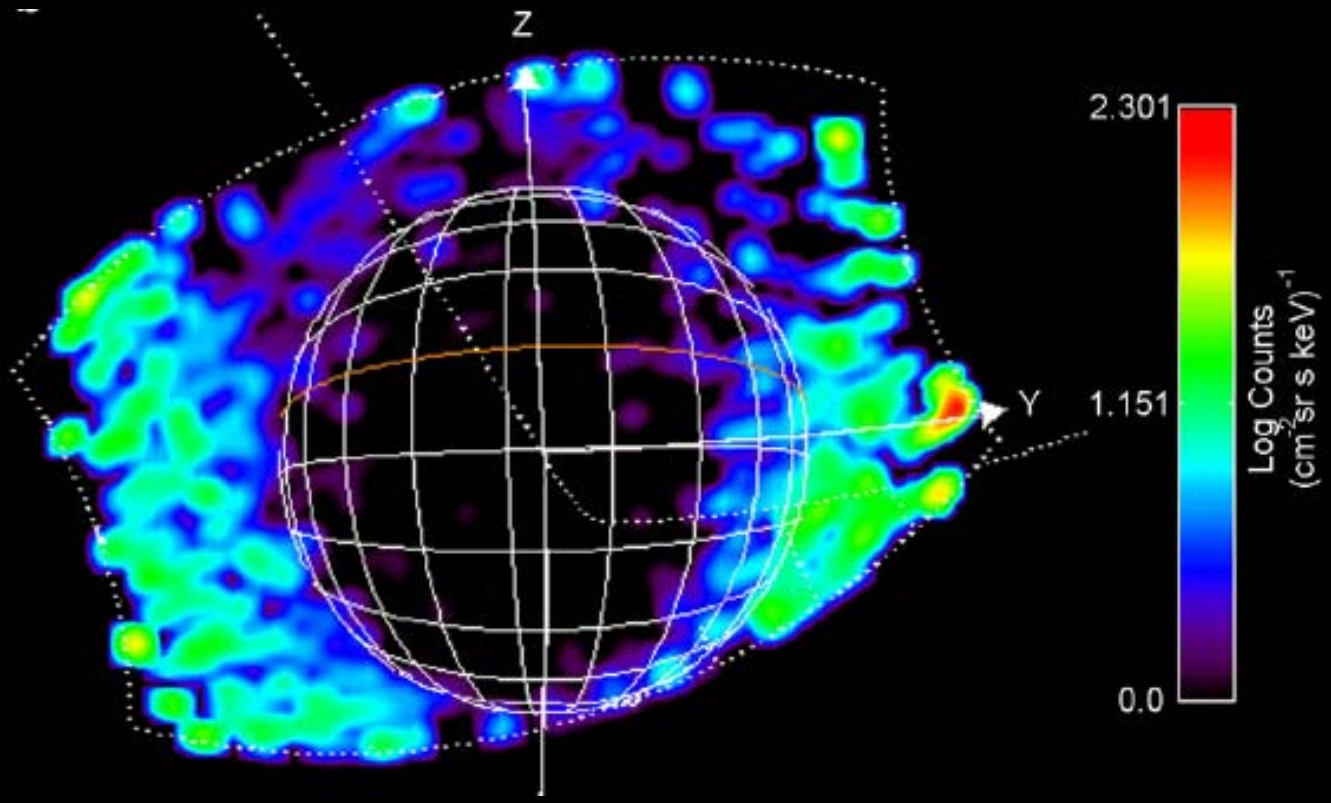
Nature of absorbing medium?

Neutral gas?

- Mainly from sputtering.
- Electrons lost to ionization and molecular dissociation.
- Saur & Strobel (2005) inferred that Rhea could possess a thin atmosphere/exosphere.

Dust cloud?

- Meteoroid impacts (interplanetary + E-ring particles) could produce cloud, as seen at Galilean satellites (Krueger et al. 1999)
- Modelling for Saturn's moons: Krivov et al. (2003), Sremcevic et al. (2003.)



MIMI-INCA images:

Upper limit for neutral gas column density ~10^{12} cm^{-2}

UVIS observations:

Upper limit for column density ~10^{13} cm^{-2} (O) and ~10^{14} cm^{-2} (O_2)

Required column densities: ~10^{18} cm^{-2}

+ large scale height (not possible for low temperature of the atmosphere)

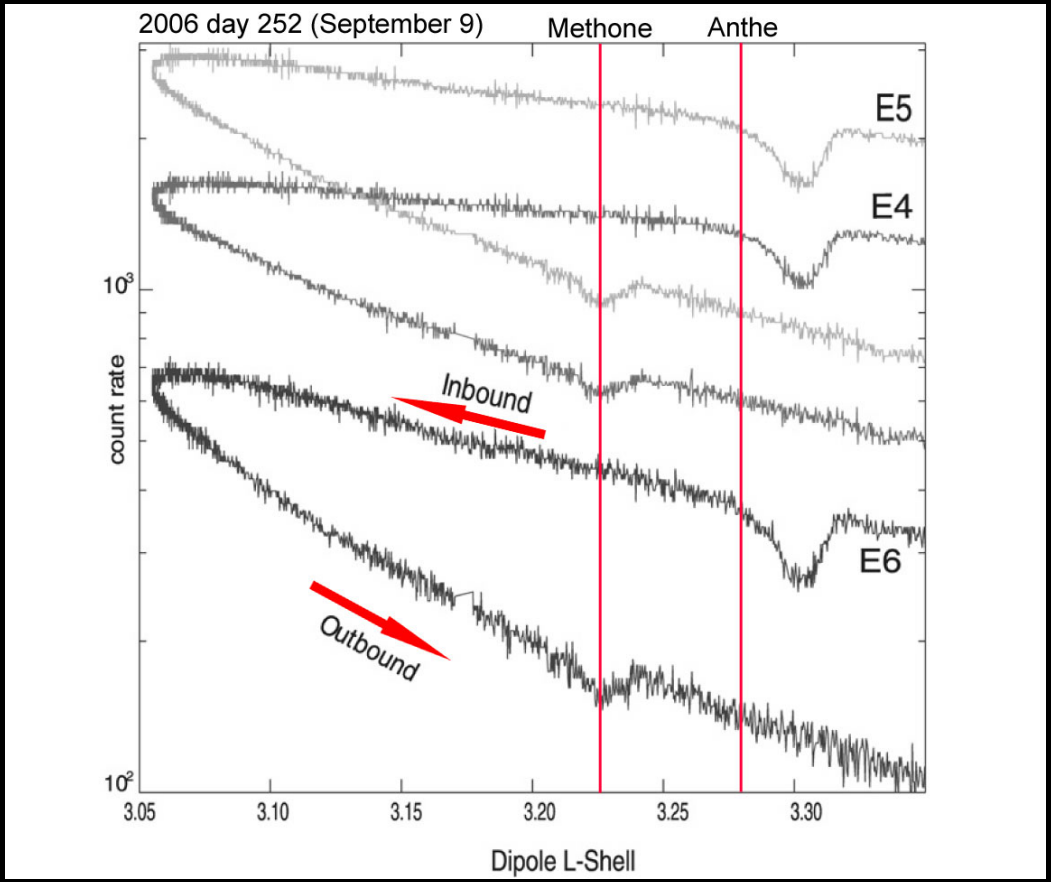
In addition, such an atmosphere would have optical depth >>1

→ Neutral gas is not the absorbing medium

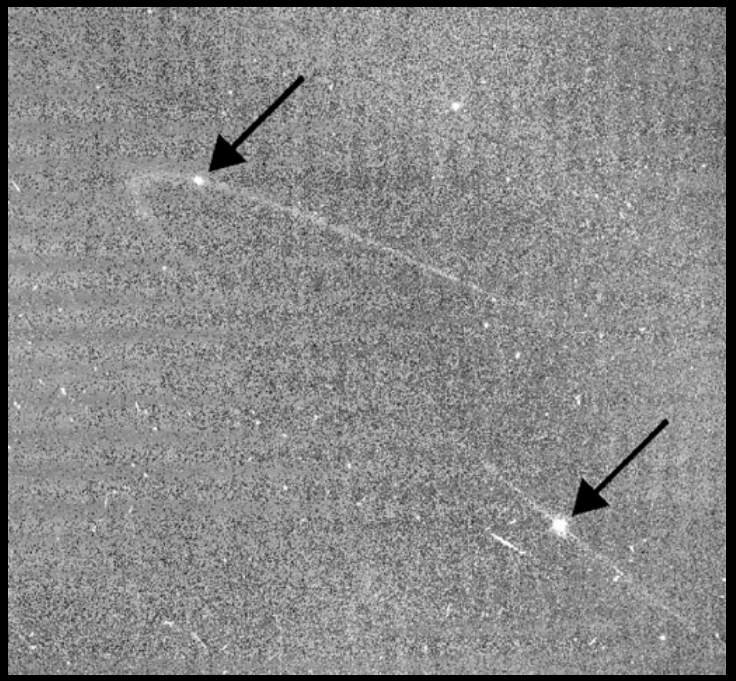
Solid grains/bodies as electron absorbers

Energetic particle absorption by solid particles a common occurrence

For example, detection of unseen material near the orbits of Methone and Anthe
Roussos et al., IAU Circular 8773 (2006) & Icarus (2008)



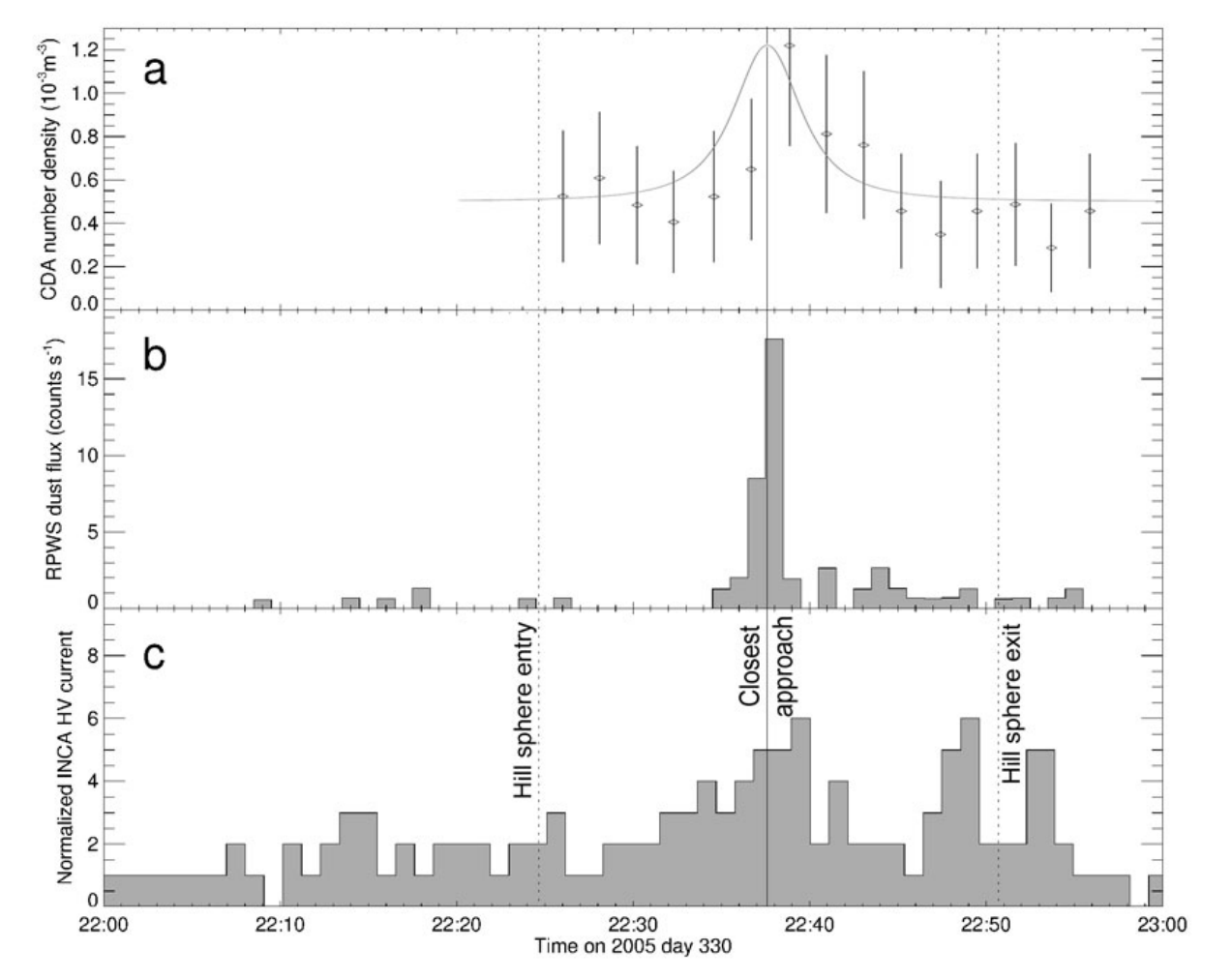
Each dropout around 1000 km across – far too wide to be explained by the moons themselves.



Anthe and Methone arcs, October 27, 2007

Anthe arc July 3, 2008

Dust in Rhea's Hill sphere

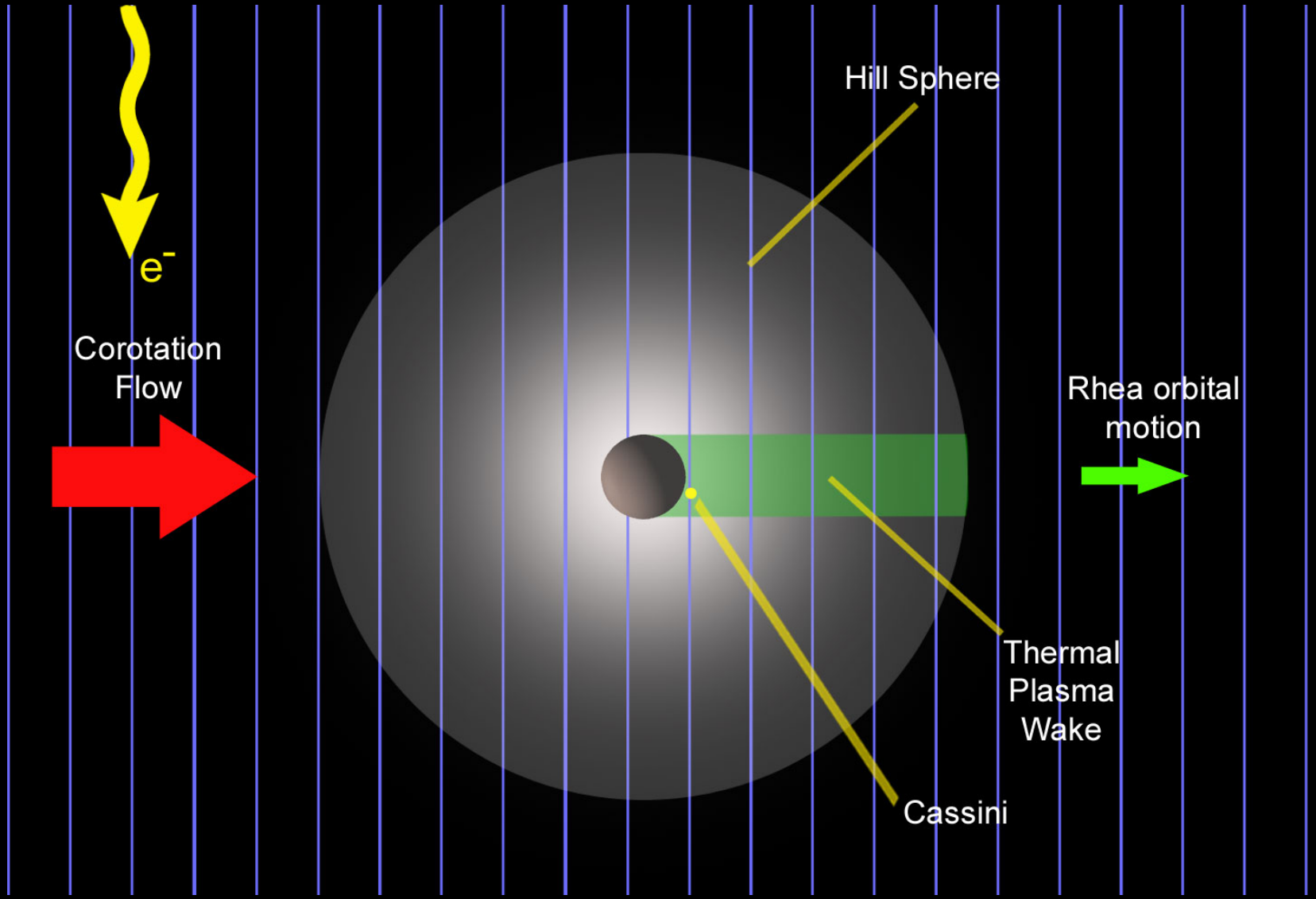


CDA 1-10 μm number density

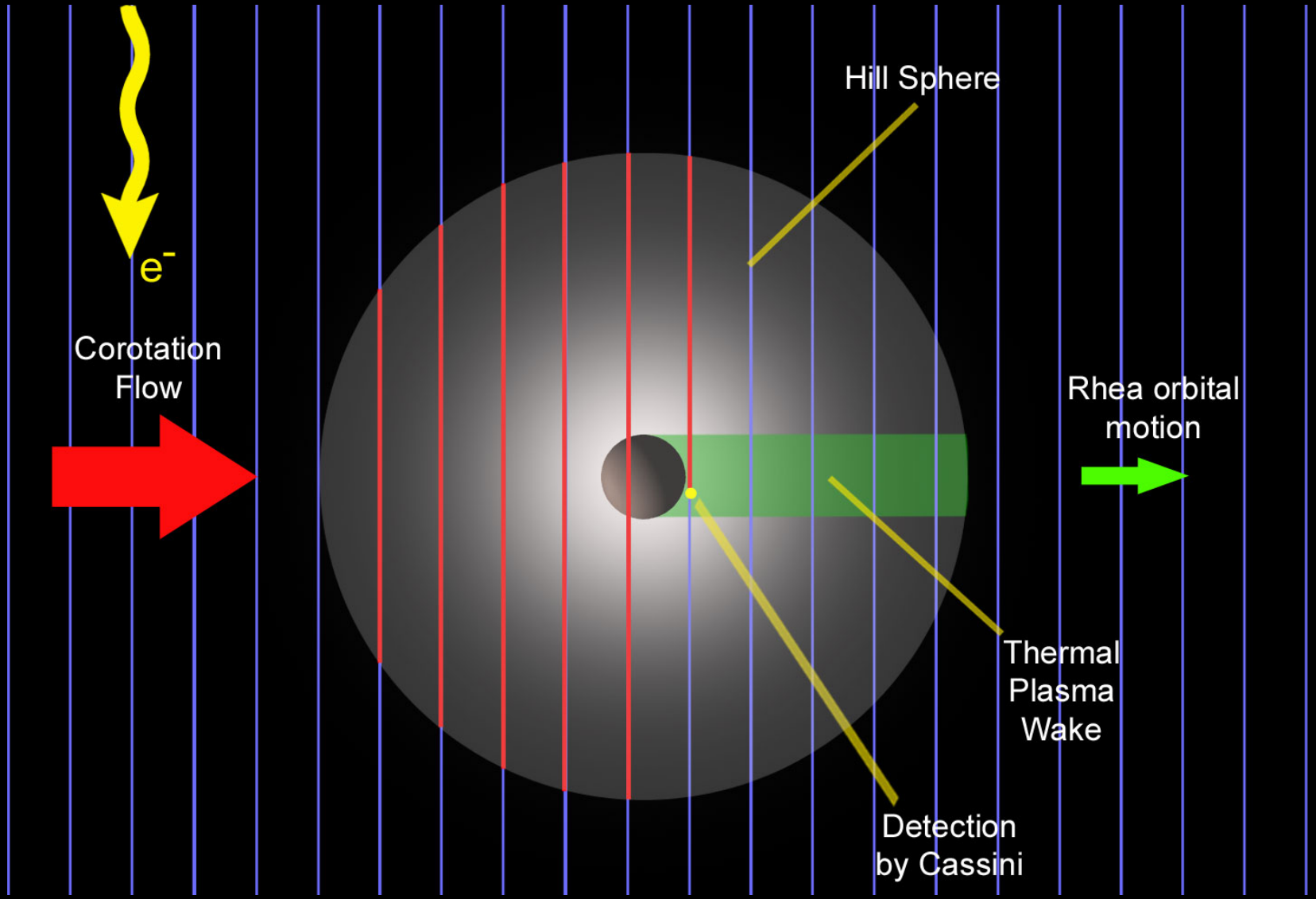
RPWS dust impact count rate

INCA HV current

Calculation of effective electron path length



Calculation of effective electron path length

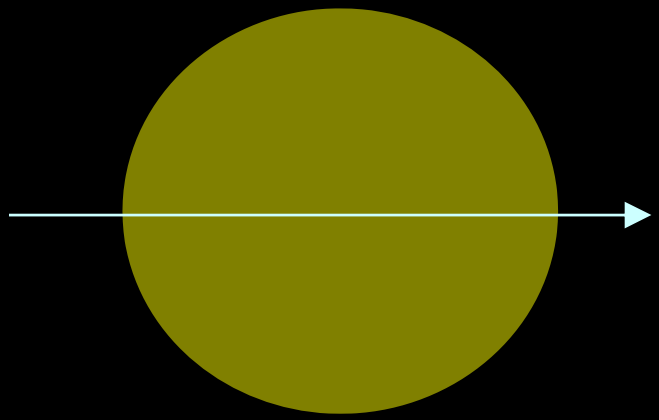


Peak number density in the Hill sphere ~ E-ring peak number density

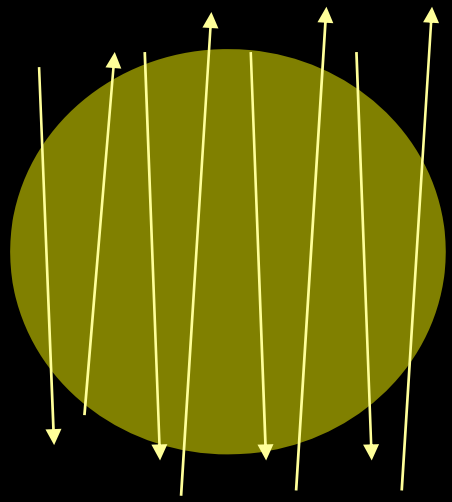
Observed CDA dust flux not the source of the absorption

Other problems:

- Scaling of the spherical dust cloud: $\sim r^{-2.5}$ *(fall-off too rapid with distance)*
- LEMMS absorption depth similar to that of CAPS, in the overlapping energy range



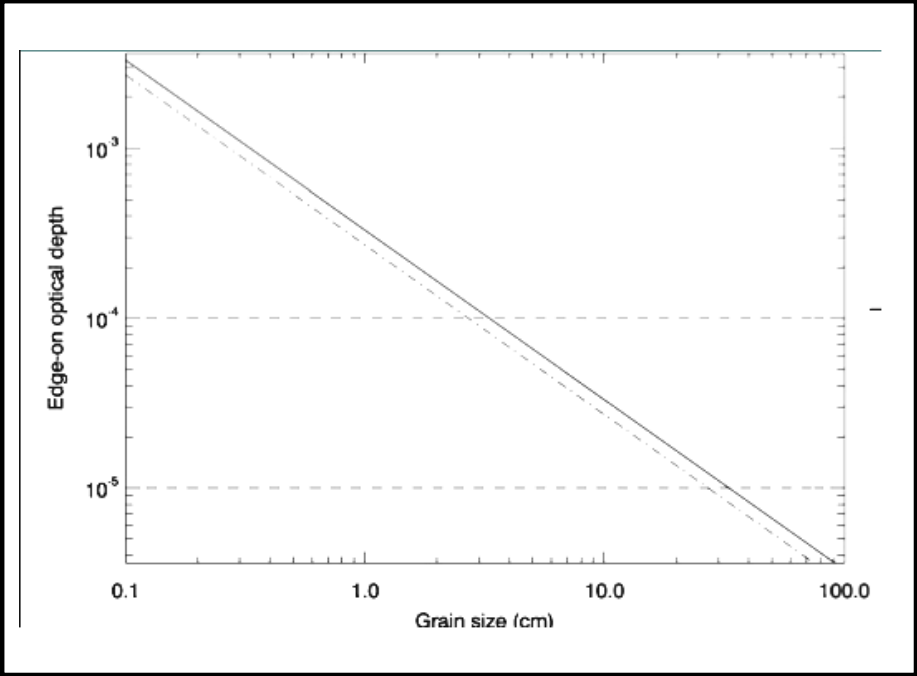
CAPS e^- path through Hill sphere



LEMMS e^- path through Hill sphere (bouncing particles)

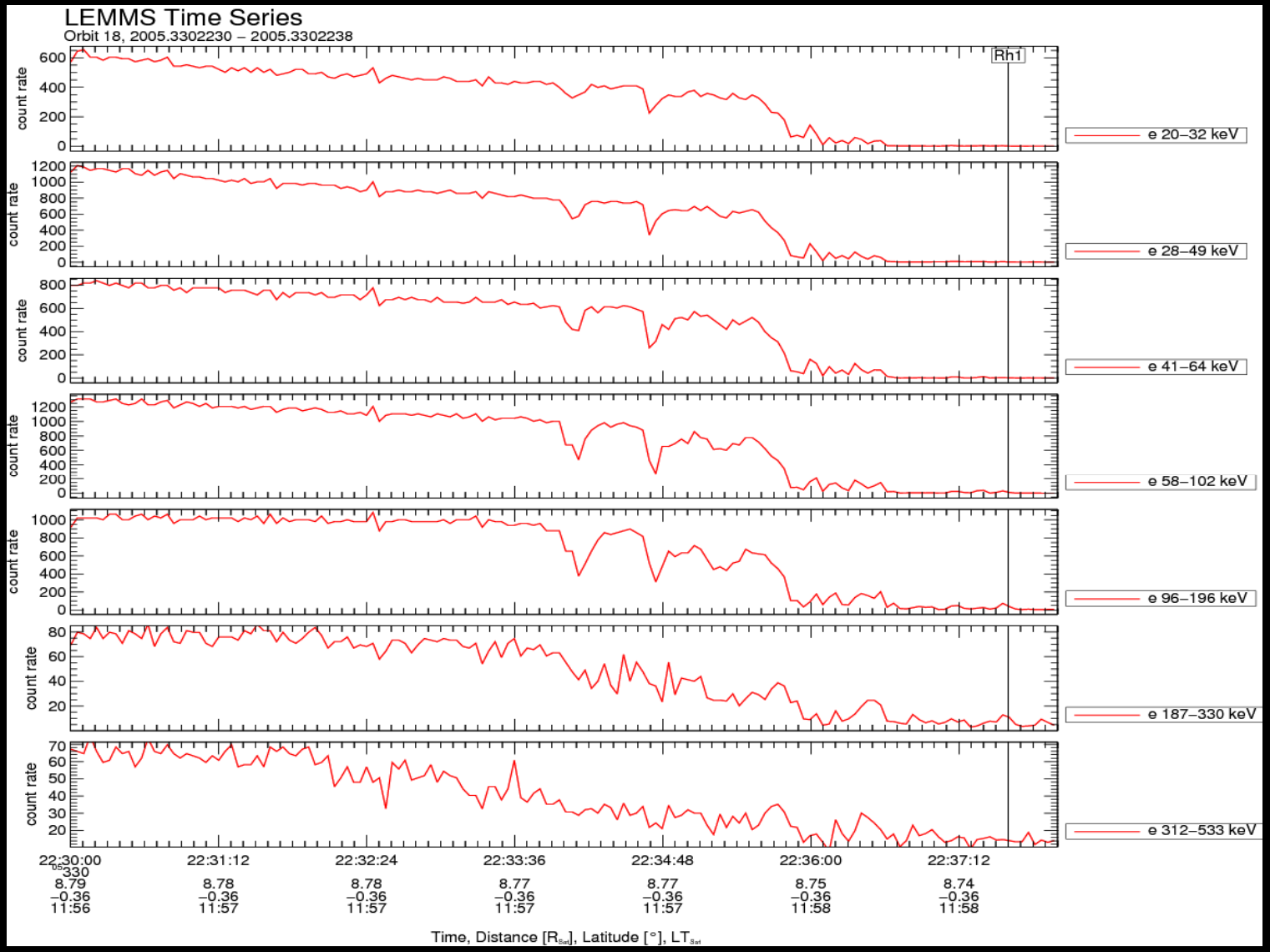
Solution: equatorial, thin debris disk with large mass scale height

- Cassini was south of Rhea's equatorial plane (didn't cross it)
- Equatorial orbits are more stable
- Debris disk would be mainly observable by its effects in charged particles, these travelled through the disk before reaching Cassini's detectors
- Can be of low optical depth
- For a thin equatorial debris disk, path length of CAPS and LEMMS electrons is similar

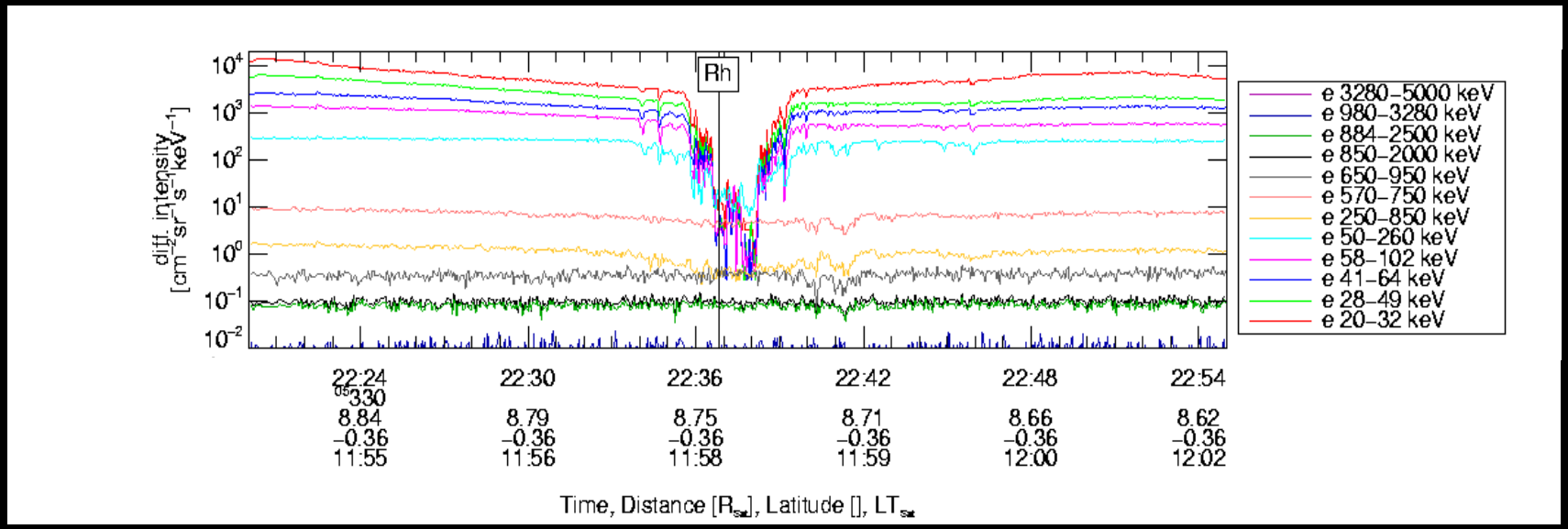


Expected mean particle size > 1 cm, or even larger

Flux dropouts' behaviour as a function of energy consistent in several respects with absorbing obstacles.

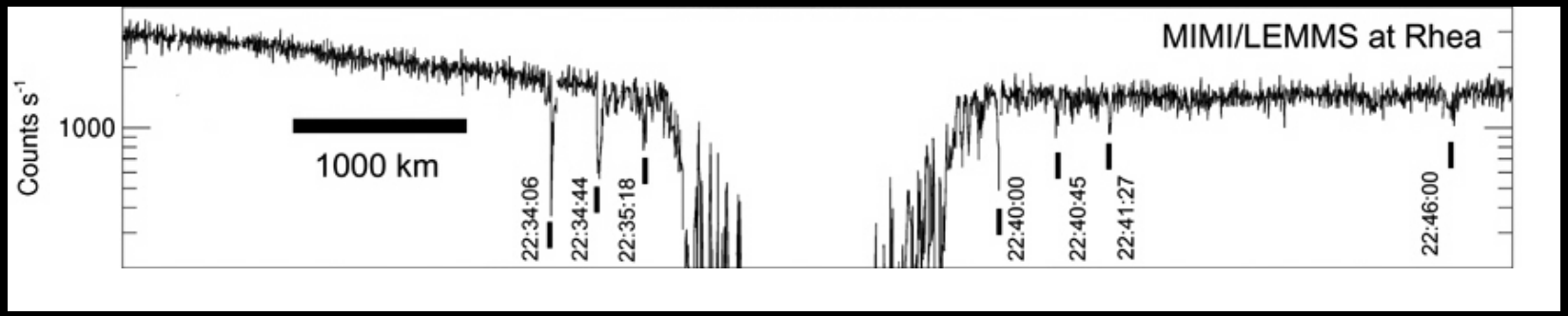


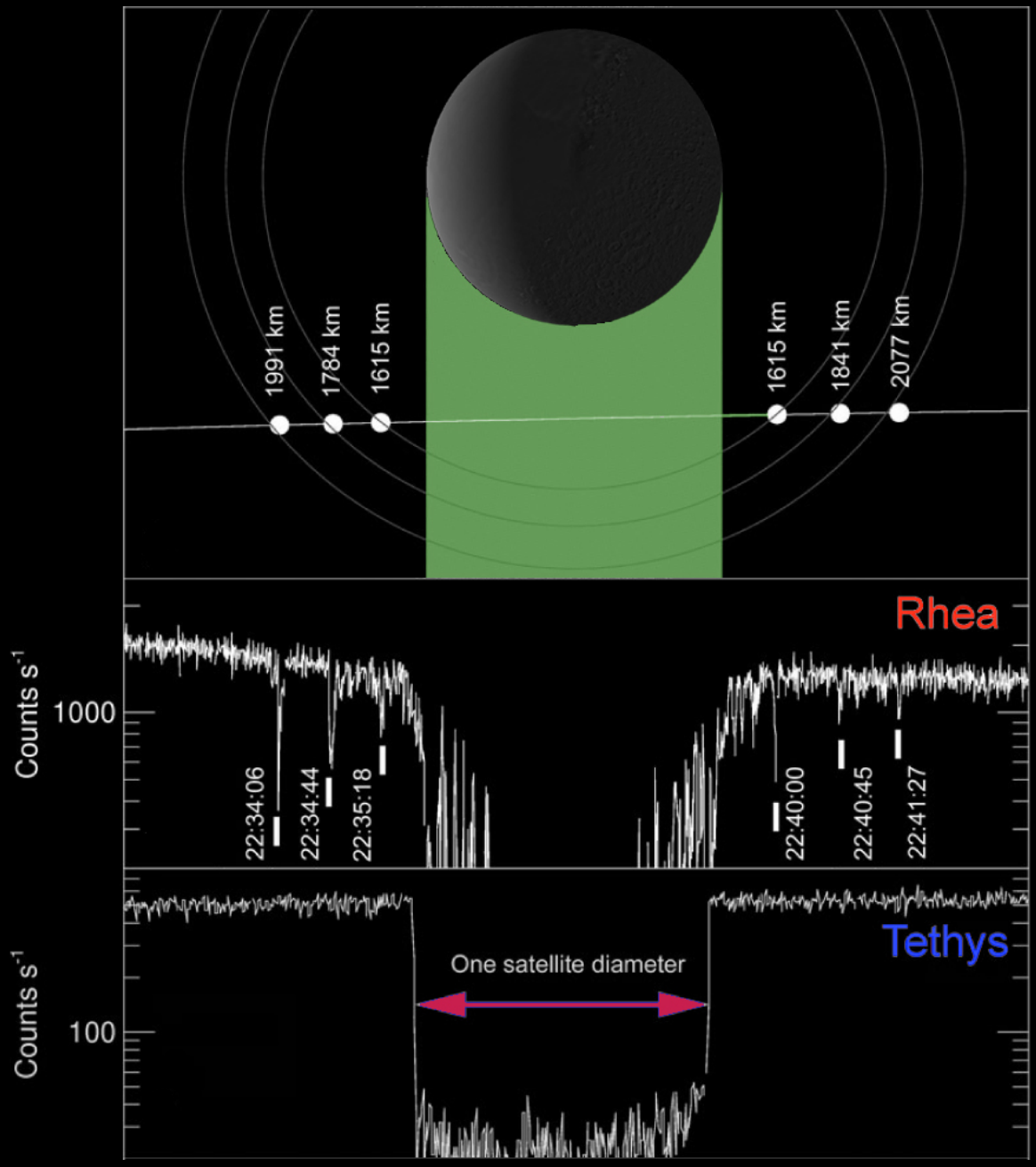
Small-scale dropouts



Detected by MIMI-LEMMS and CAPS-ELS

Dropouts persist for several seconds, or tens of km along the spacecraft track





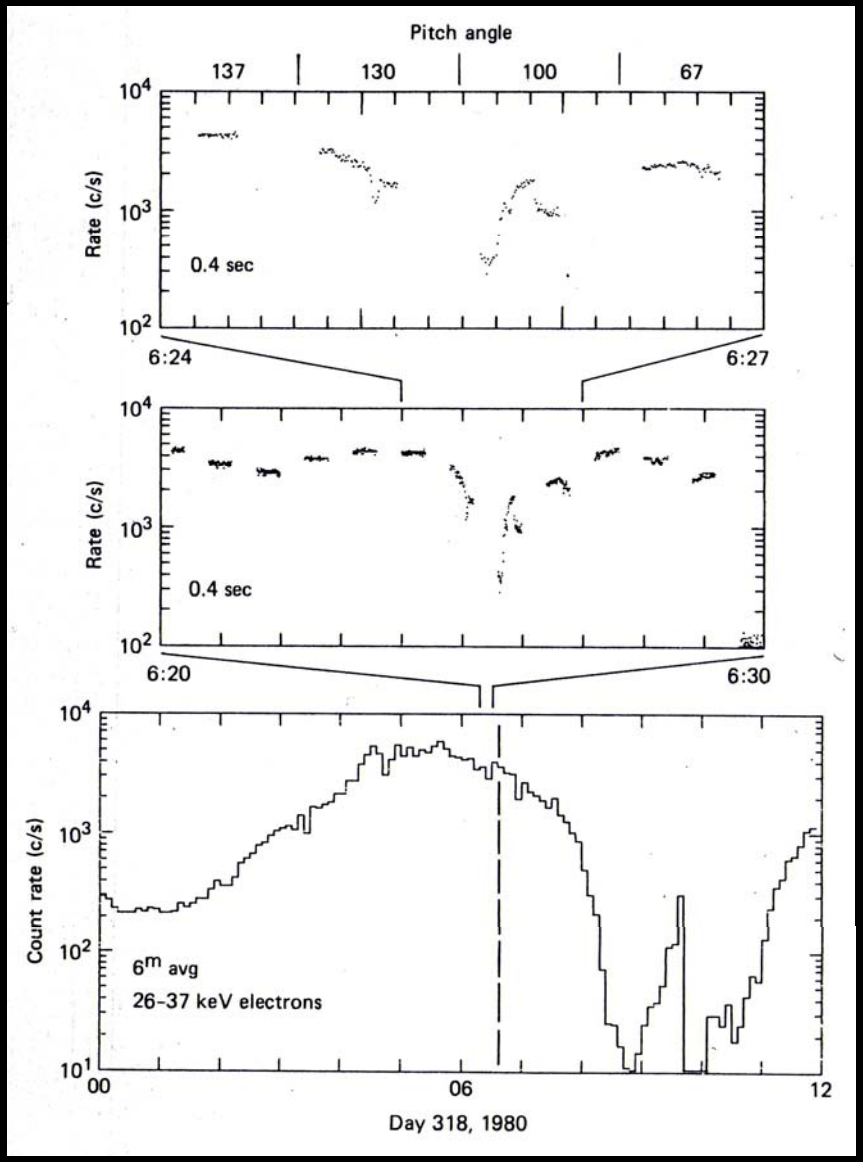
Simplest explanation:

Extended arcs or rings of material orbit Rhea in its equatorial plane.

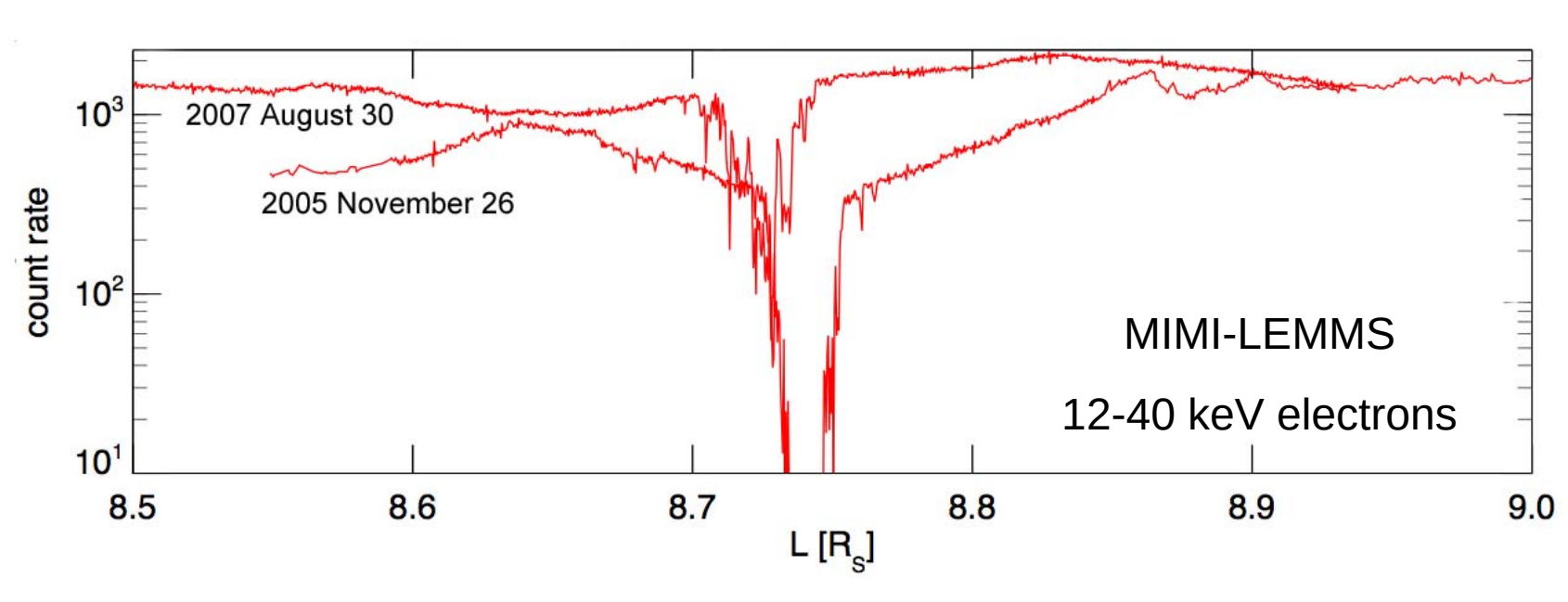
Dropouts consistent with ring radii of ~1610, ~1800, and ~2020 km.

Symmetry of dropouts a coincidence?

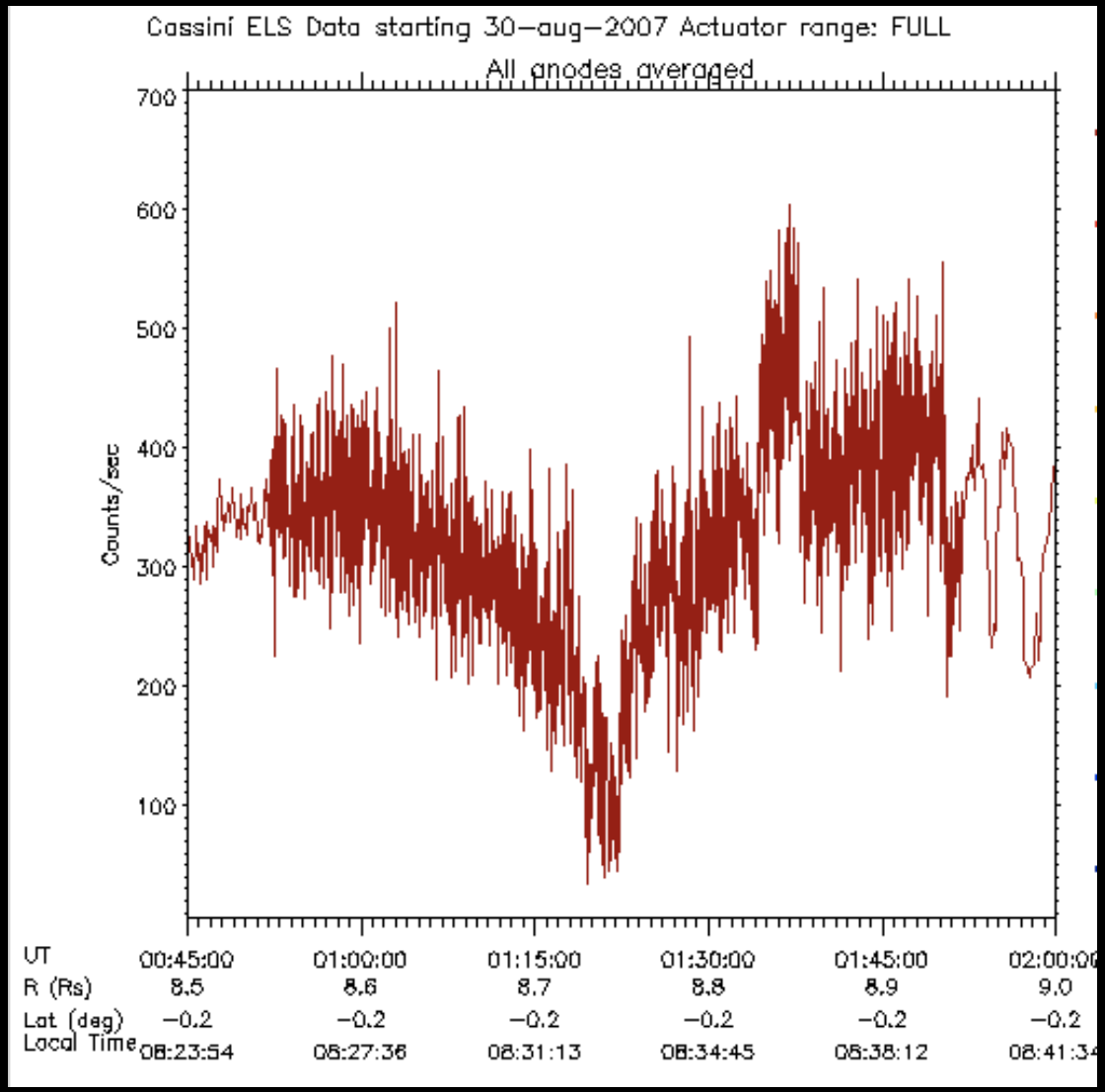
Voyager 1 LECP also detected fine-scale structure around Rhea wake signature [Carbary et al. 1983]



How do 2007 flyby data compare?



- 5700 km downstream (550 km in 2005), just outside the Hill Sphere
- Broad depletion region present; shifted radially
- Short-period dips again surrounding dropout from Rhea itself



- CAPS-ELS detected presence of broad depletion in electrons

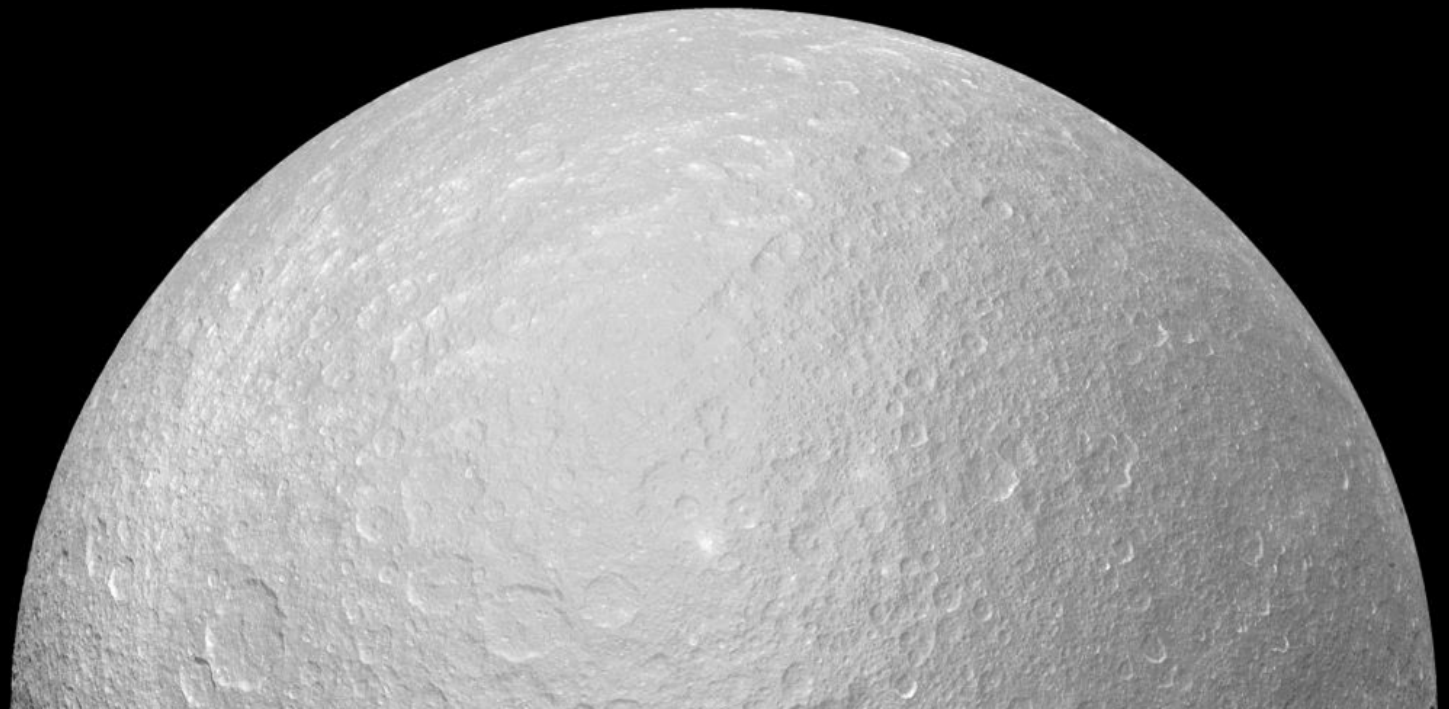
Future Plans

- March 2, 2010: Targeted flyby to within 100km of surface.

- 8.6 km/s flyby speed, close to Rhea's north pole.

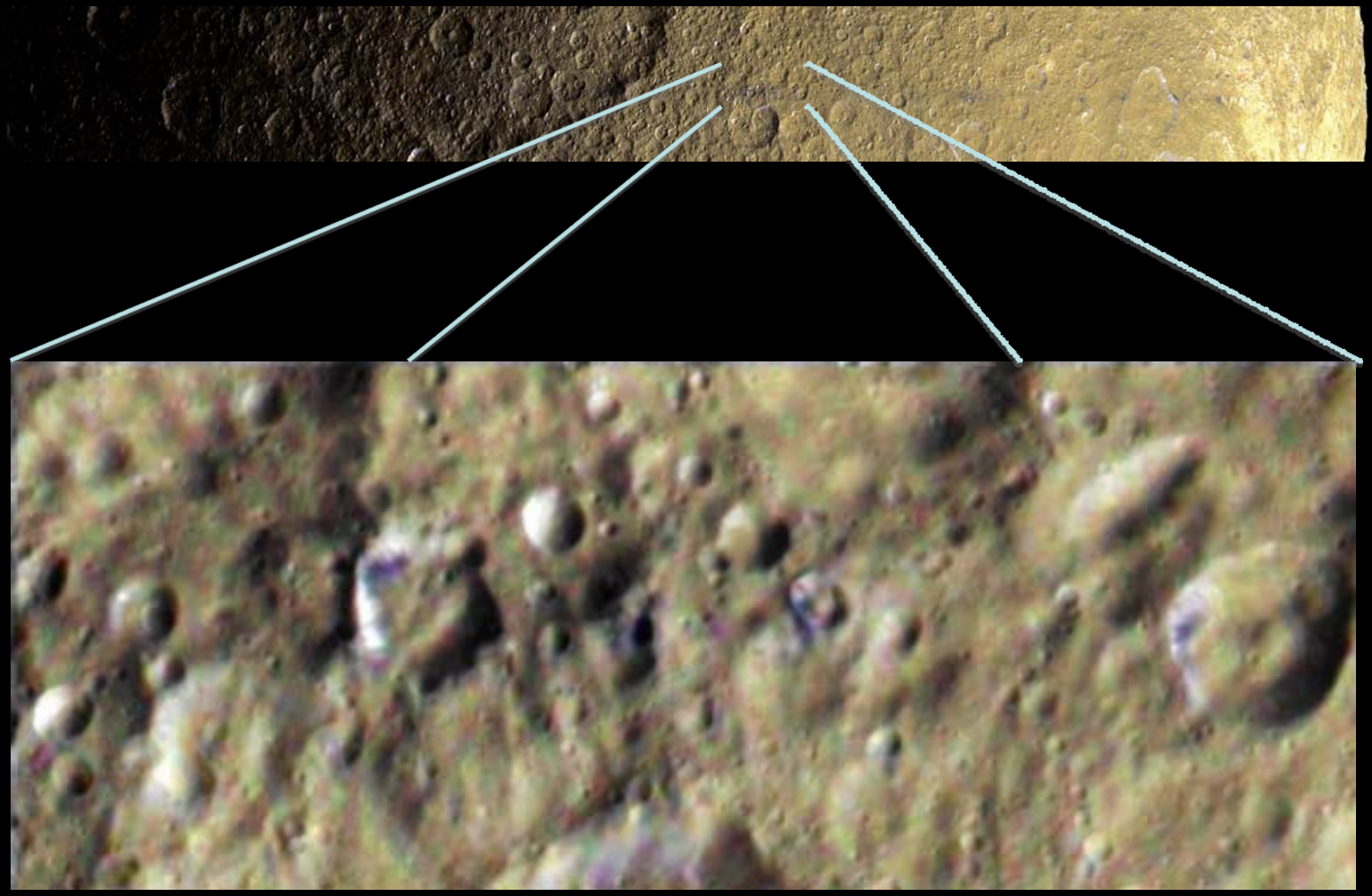
- Rhea will be on night side of Saturn, Cassini travelling inbound.

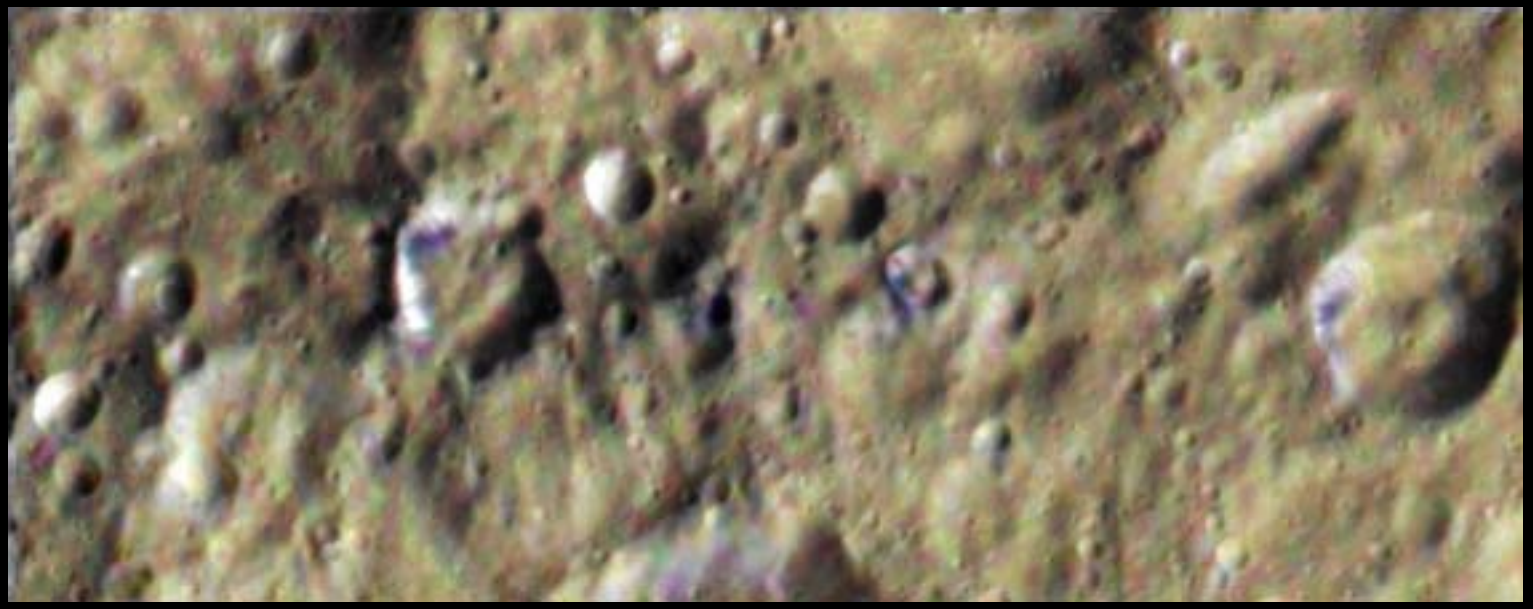
- MIMI-LEMMS and CAPS-ELS orientations designed to check for recurrence of features detected in 2005… wide wake already seen again, in 2007. Will small-scale dips be present again, and at similar distances?



Any other evidence?


Image of Rhea captured by ISS on August 30, 2007





• Equatorial patches appear to predominantly occur on eastward-facing slopes or local plateaux

• Not inconsistent with material in near-zero-inclination, circular, but decaying orbits

• If scenario correct, impact velocity ~460 m/s. Impactors would fragment without forming large craters.

• Study of these features continuing.

Summary

- MIMI LEMMS and CAPS-ELS clearly show a deficit of electrons near Rhea.
- Only explanation currently available to us: Rhea is surrounded by an electron-absorbing population of solid material
- Causes an apparently unique moon-magnetosphere interaction
- Three components:
  - Anticipated spherical ejecta cloud
  - Flat equatorial disk
  - Discrete rings/arcs at low altitudes?
- However, no supporting evidence for the debris disk's existence from remote observations.
- Equatorial surface features and further absorption signatures currently undergoing analysis