Dust Observations at Rhea and Enceladus using Plasma Instrumentation

Geraint Jones

With thanks to: Chris Arridge, Elias Roussos, Norbert Krupp, Andrew Coates

and the Cassini CAPS and MIMI Teams

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2) The Centre for Planetary Sciences at UCL/Birkbeck

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Talk Outline

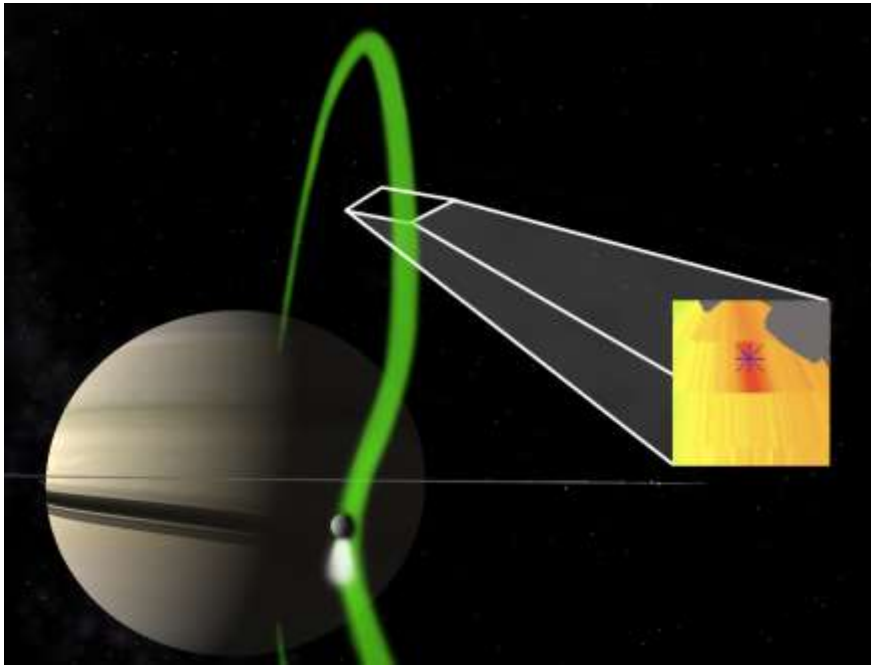
- Why study dust?
- How can it be detected by plasma instrumentation?
- Remote observations
  - Rhea
  - Enceladus
- In situ observations
  - Enceladus

Why study dust?

- At Enceladus, dust characteristics indicate interior and near-surface processes at the moon

- Charged dust can have a significant effect on plasma dynamics: mass loading of corotating plasma by particles in a mass range not easily detectable

- Presence of dust significantly affects electrodynamic interaction at Enceladus (Simon et al. 2011; this meeting)



The detection of dust with plasma instrumentation

- **Remote observation**:
  - dust absorbs magnetospheric plasma; absorption signature detected remotely (MIMI, CAPS background)

- **Direct detection**:
  - Signature of dust impact on spacecraft (RPWS) or direct entry into instrument (CAPS, MIMI-LEMMS, MIMI-INCA)

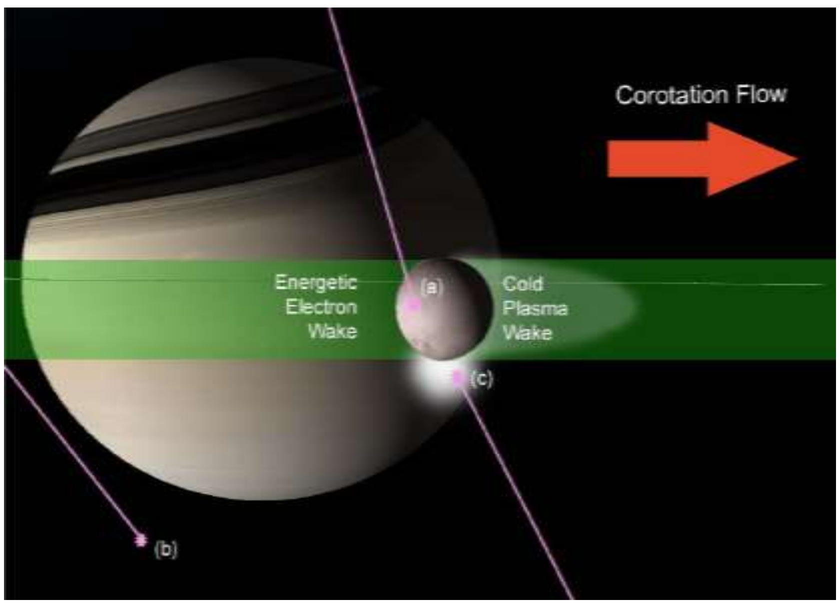
- Characteristics of dust also inferred from local plasma parameters [e.g. Farrell et al. 2010; Shafiq et al. 2011; Morooka et al., submitted]

Cassini MIMI/LEMMS instrument

Low Energy Magnetospheric Measurement System

Detects:

30 keV - 160 MeV ions
15 keV - 5 MeV electrons



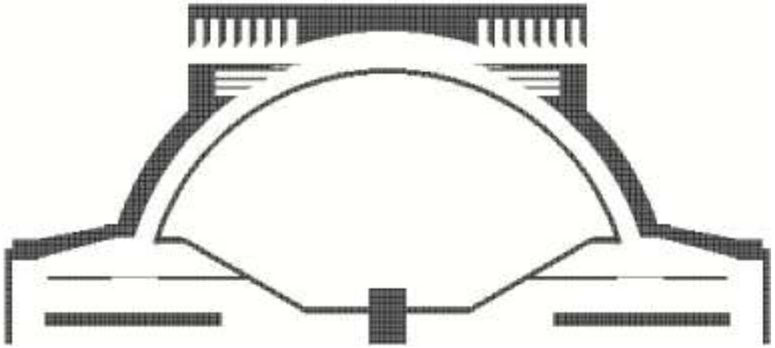
When trapped energetic particles strike a moon or other obstacle, LEMMS detects the resultant dropout in fluxes:

microsignatures

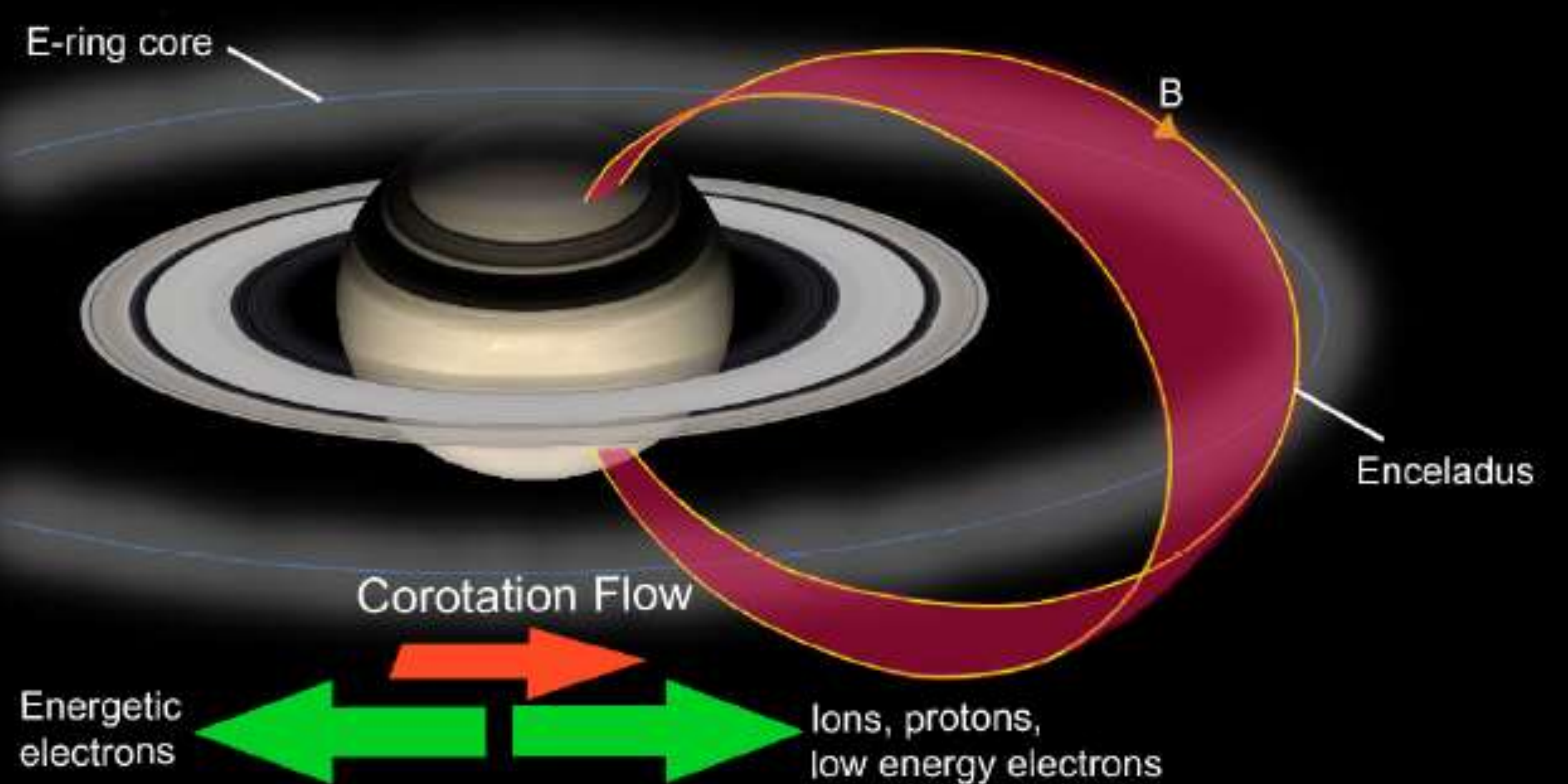
Cassini Plasma Spectrometer - CAPS

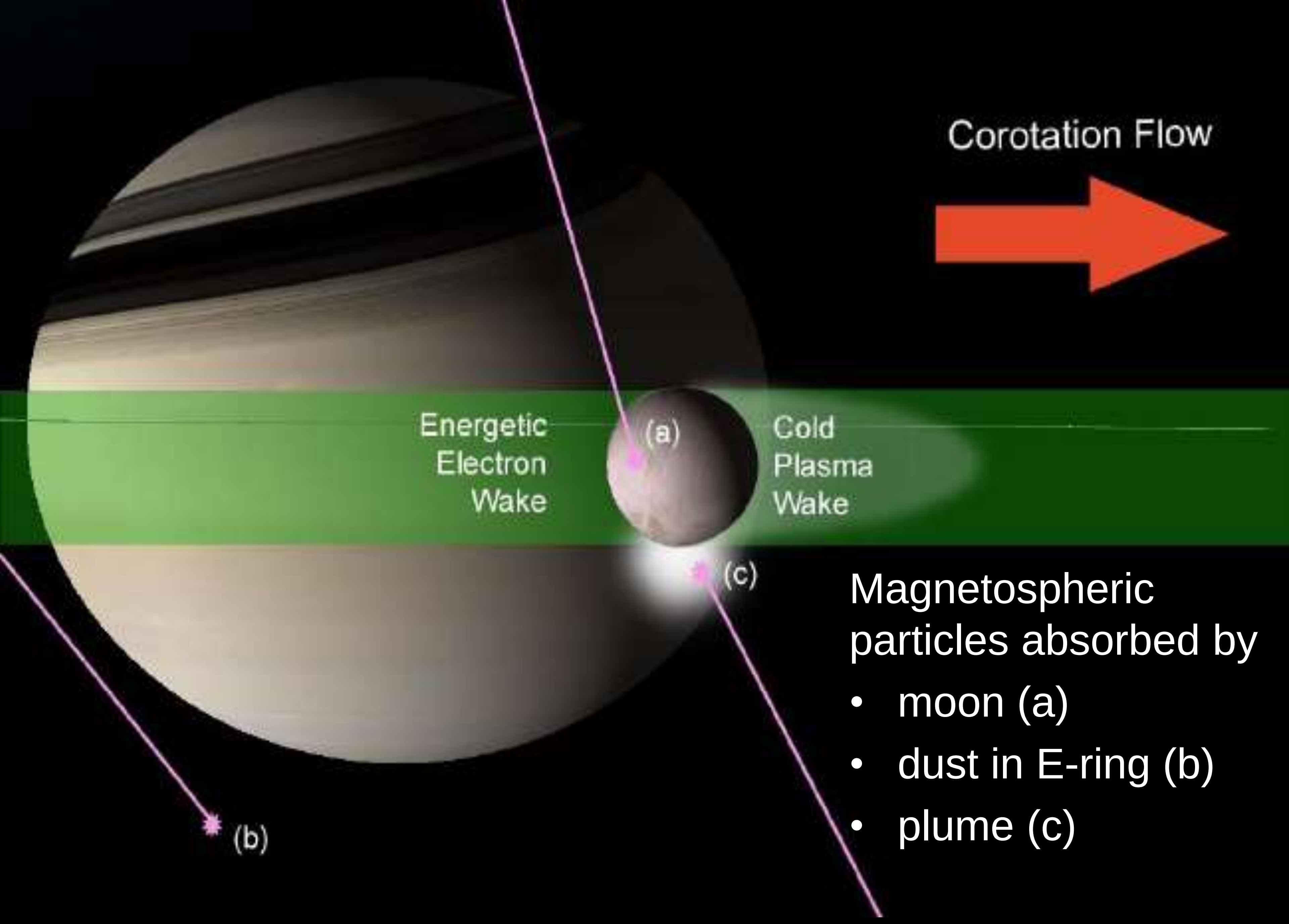
Electron Spectrometer (ELS): an electrostatic top hat analyser.

- Mounted on an actuator
- 8 anodes (20° each)
- Covers energy range from 0.5 eV – 26 keV
- Positive ions observed by Ion Mass Spectrometer and Ion Beam Spectrometer



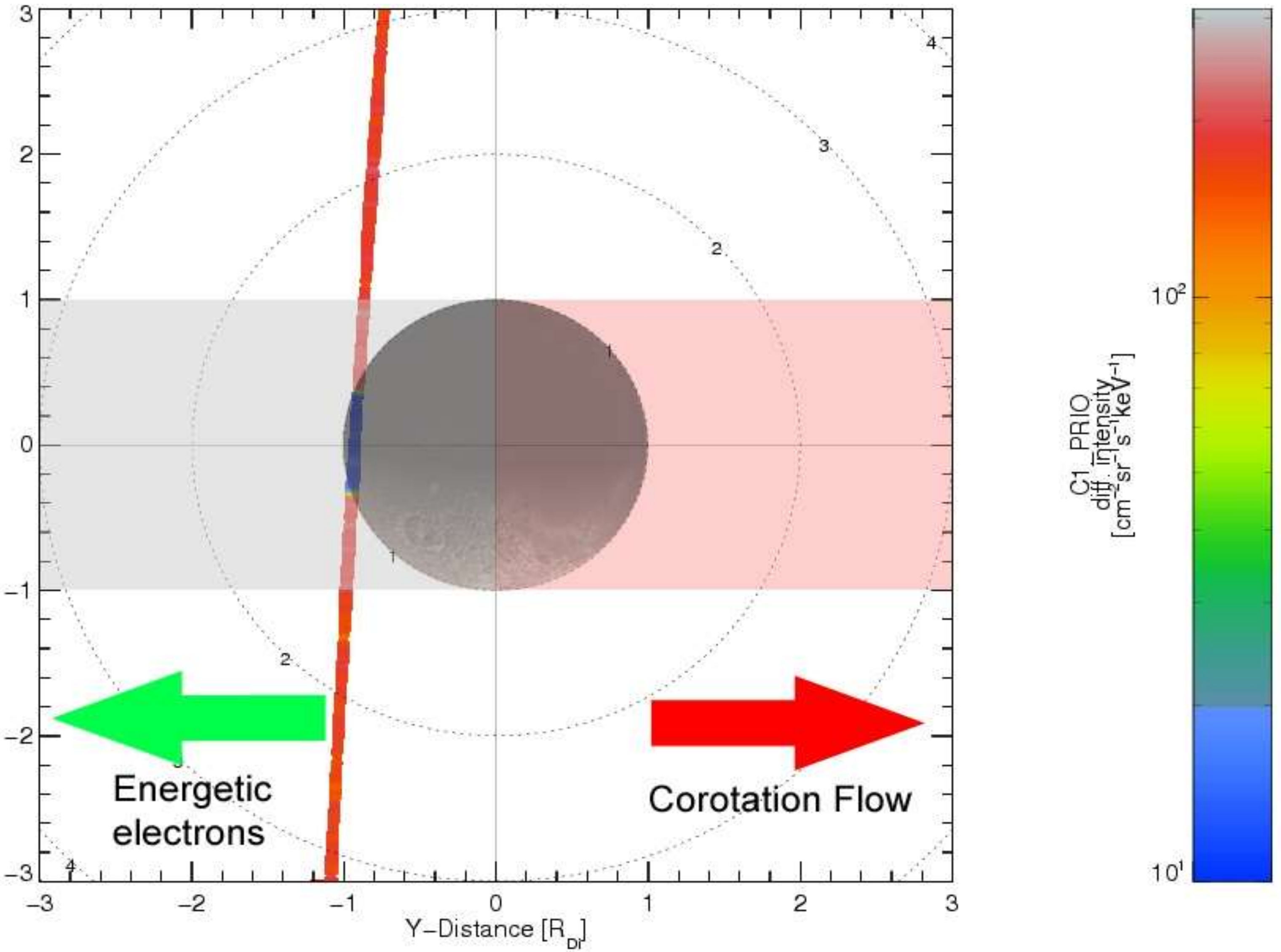
Remote observations


E-ring core
B
Enceladus
Corotation Flow
Energetic
electrons
Ions, protons,
low energy electrons

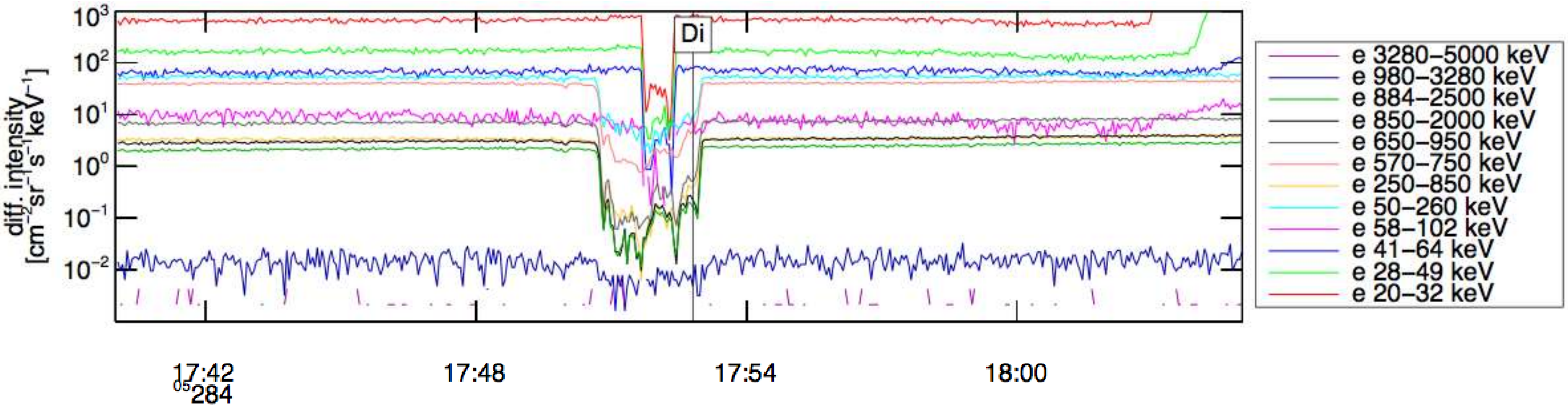


Magnetospheric particles absorbed by

- moon (a)
- dust in E-ring (b)
- plume (c)

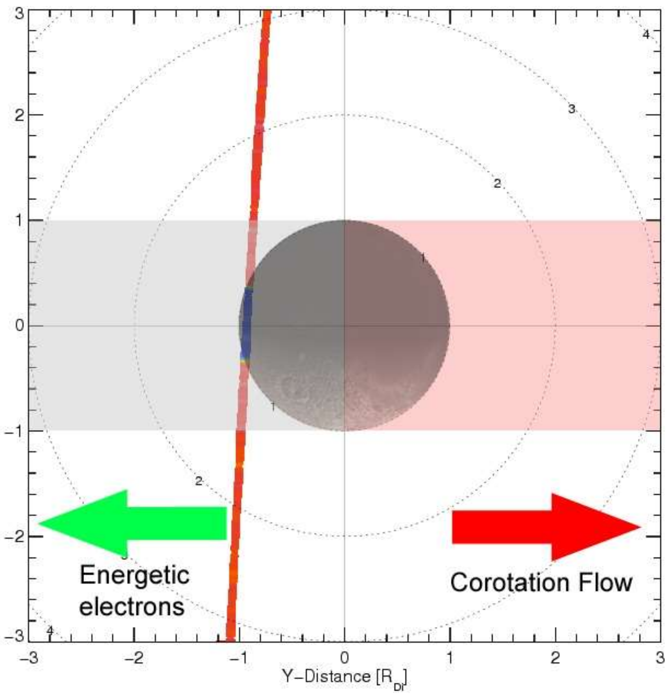


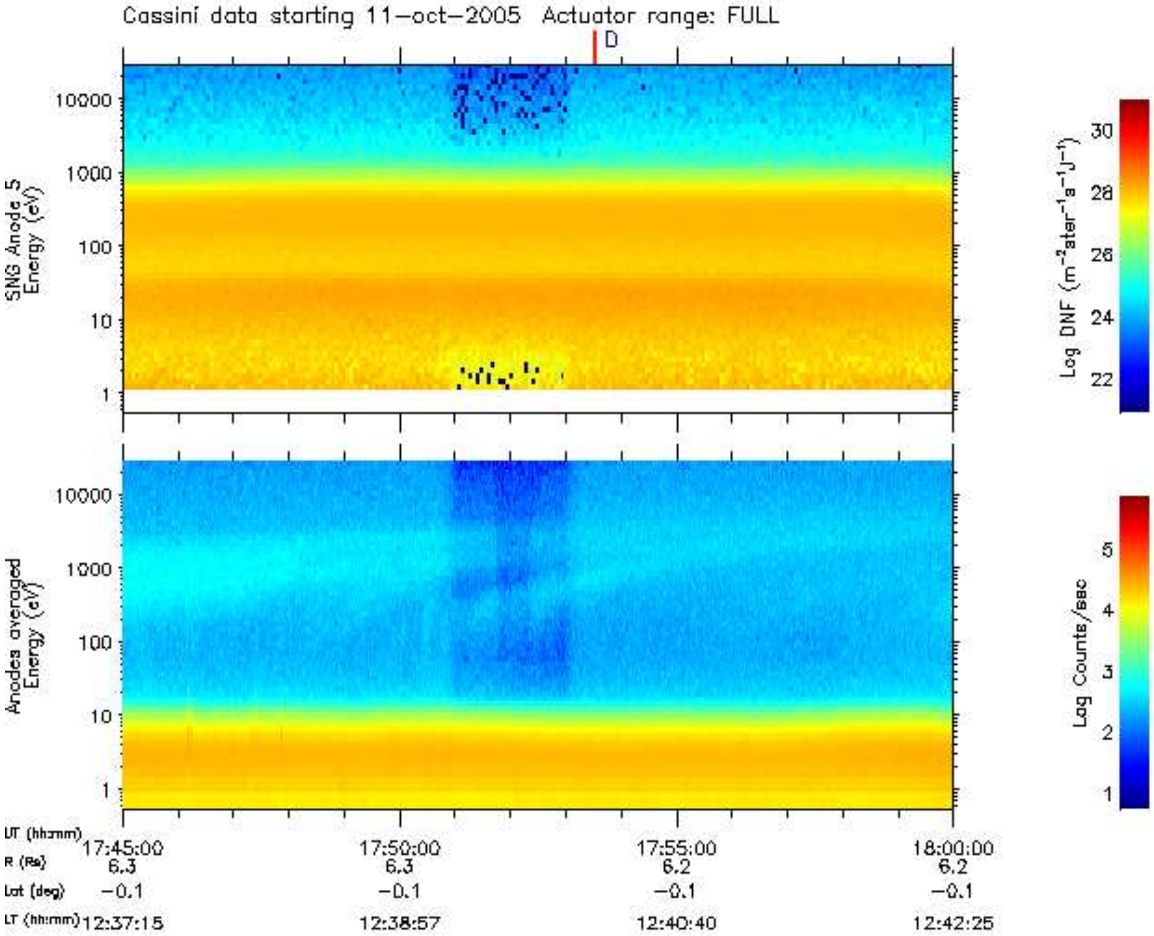
Microsignature of Dione observed by MIMI-LEMMS

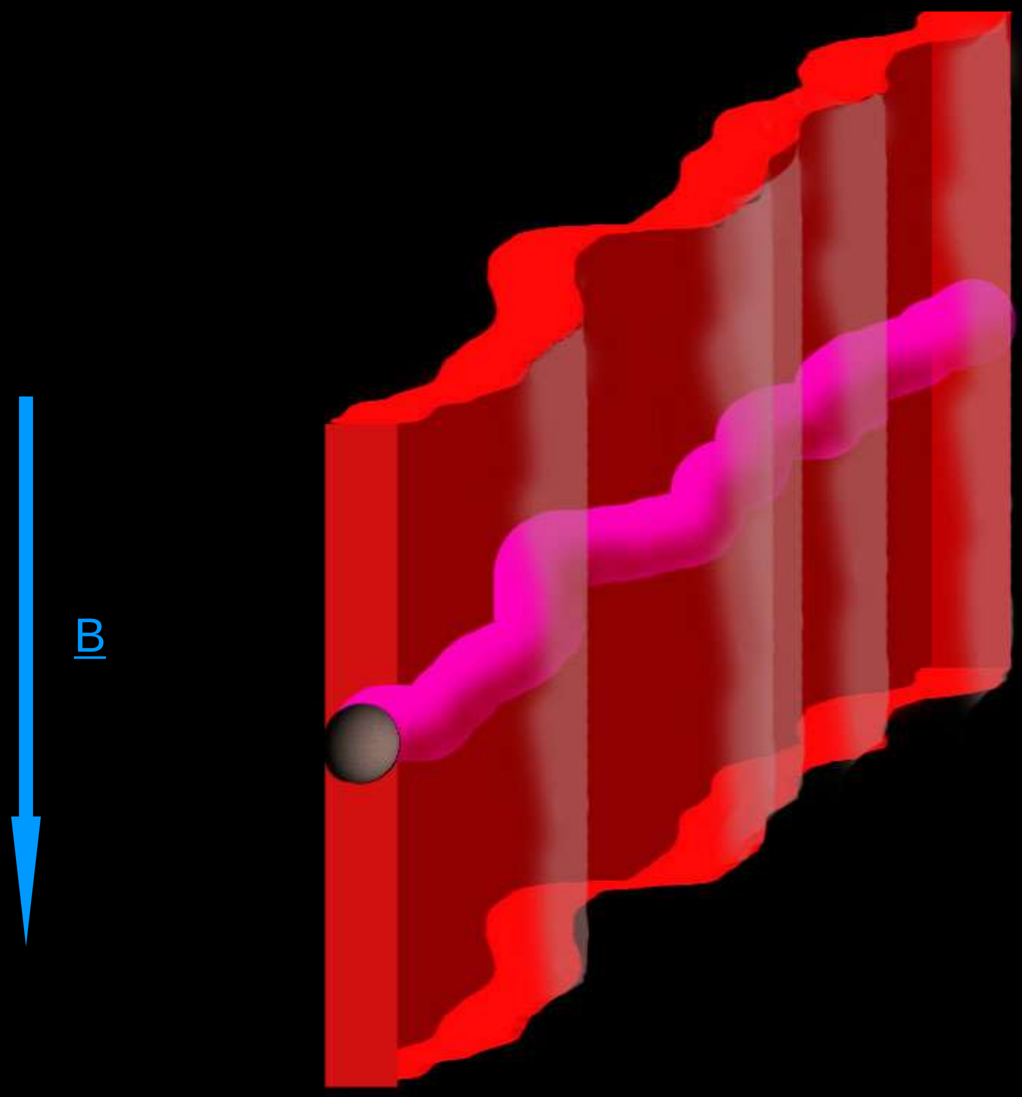


diff. intensity [cm⁻²sr⁻¹s⁻¹keV⁻¹]
10³
10²
10¹
10⁰
10⁻¹
10⁻²
Di
17:42
05 284
17:48
17:54
18:00
e 3280–5000 keV
e 980–3280 keV
e 884–2500 keV
e 850–2000 keV
e 650–950 keV
e 570–750 keV
e 250–850 keV
e 50–260 keV
e 58–102 keV
e 41–64 keV
e 28–49 keV
e 20–32 keV

Microsignatures also observed by CAPS as a change in background level

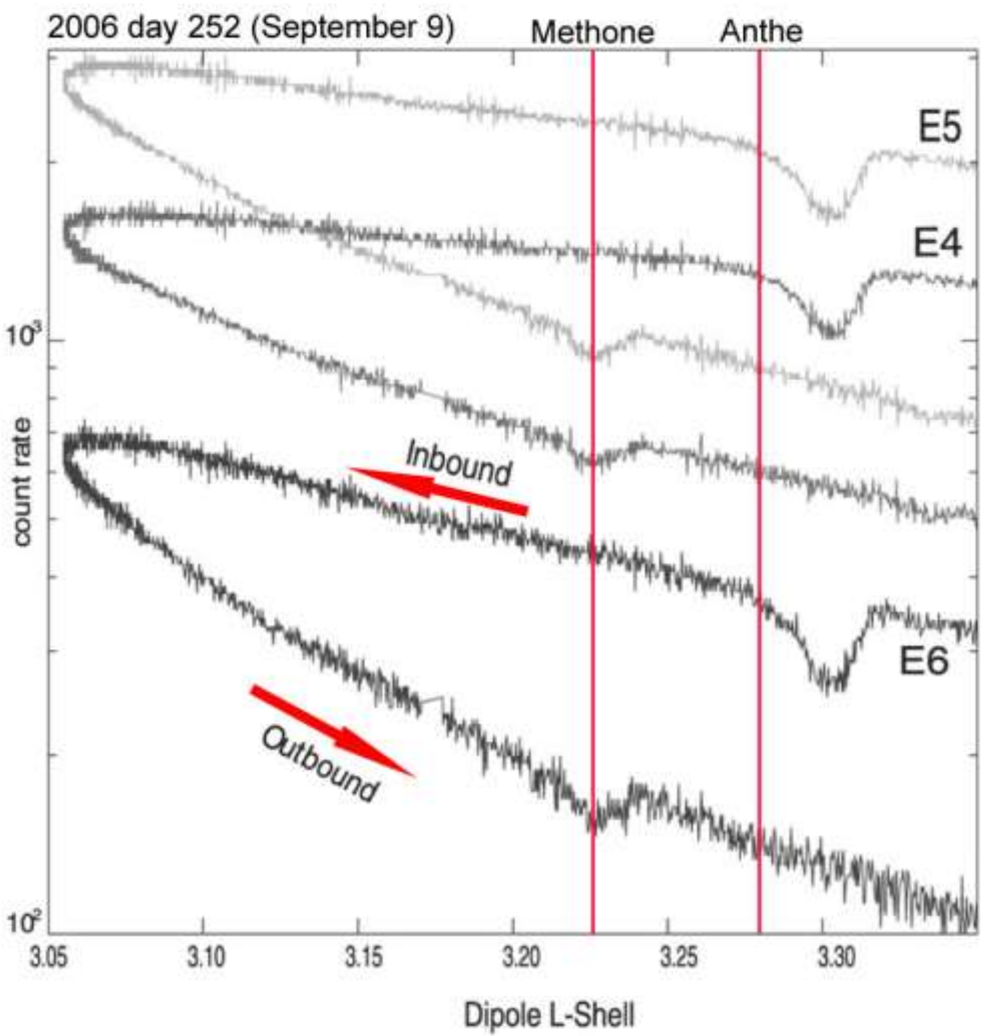


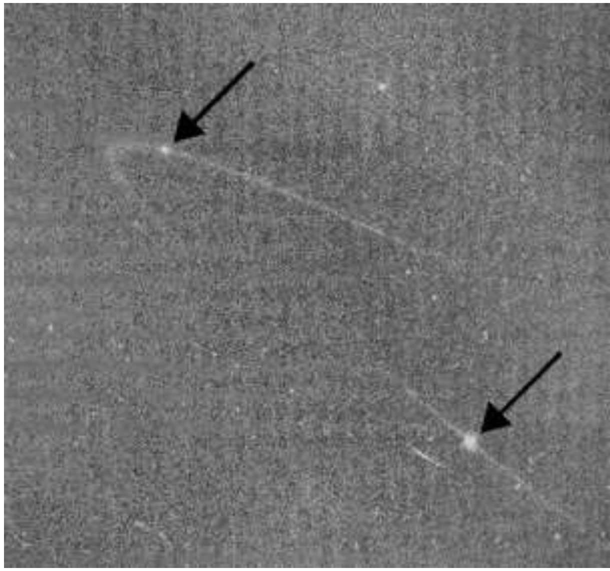



B

Detection of unseen material near the orbits of Methone and Anthe (Roussos et al., 2008).

Moons ~3km across; depletions ~1000 km wide.

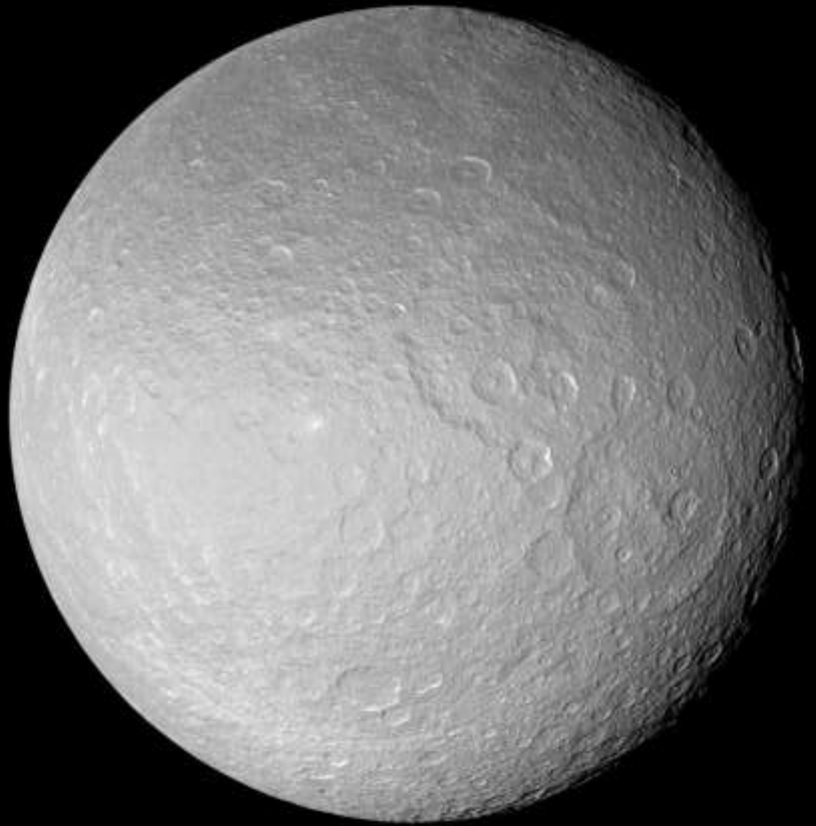




Hedman et al. (2009)

Rhea

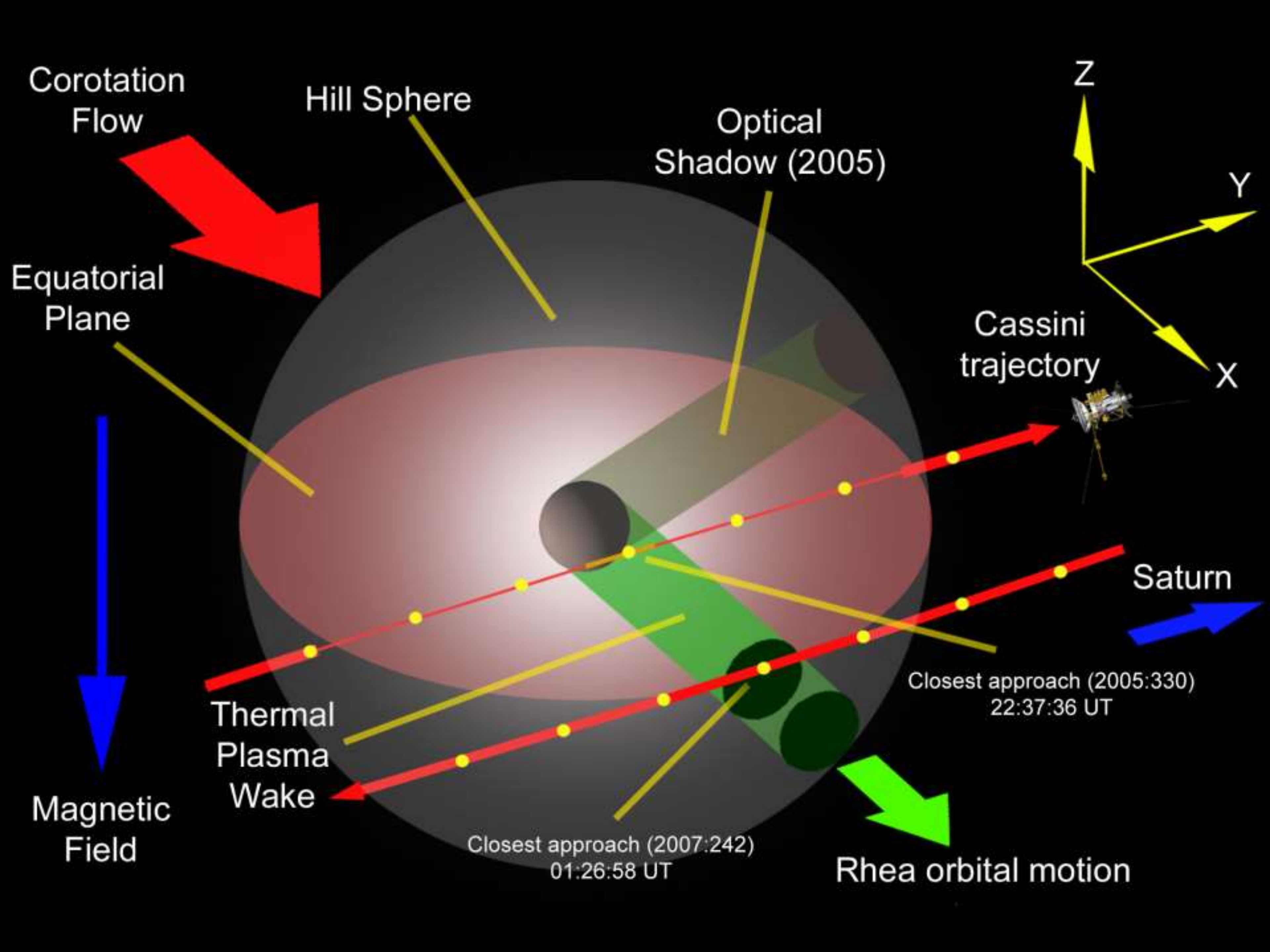
- 764 km radius
- Orbits at 524 300 km, 8.7 Rs.
- Very tenuous atmosphere (Teolis et al. 2010)
- 3 Cassini close encounters to date (and one more distant)



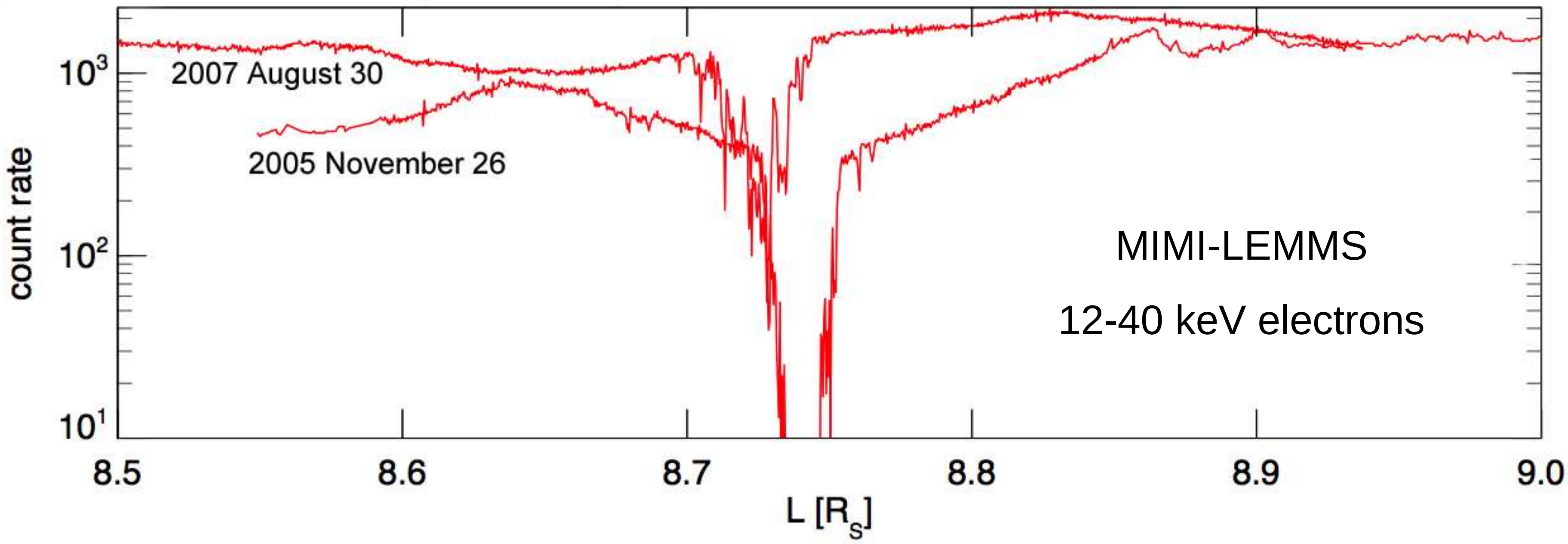
Enceladus

- 252 km radius
- Orbits at 238 000 km, 3.94 Rs
- Active
- 14 Cassini close encounters to date

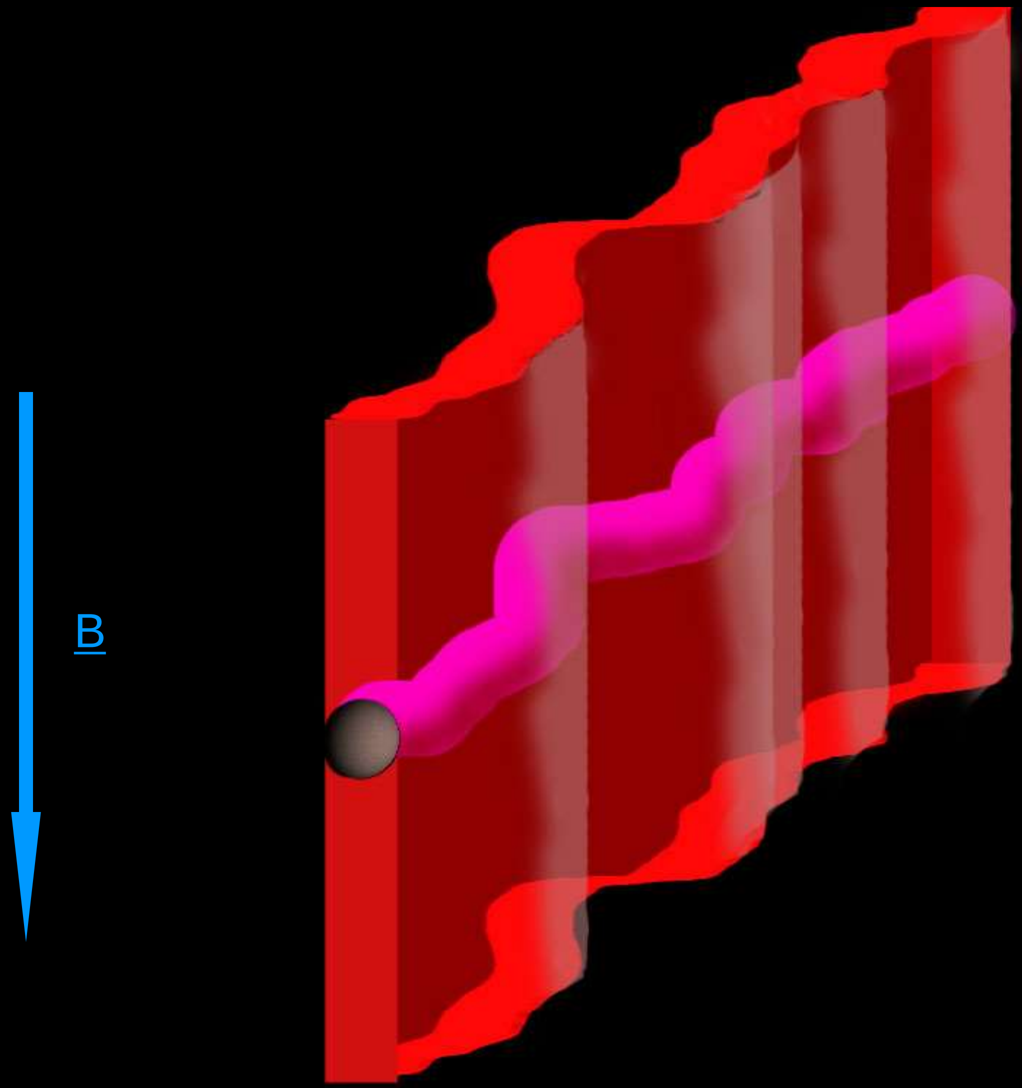
NASA/JPL/Space Science Institute


Corotation
Flow
Hill Sphere
Optical
Shadow (2005)
Z
Y
X
Equatorial
Plane
Cassini
trajectory
Saturn
Closest approach (2005:330)
22:37:36 UT
Thermal
Plasma
Wake
Magnetic
Field
Closest approach (2007:242)
01:26:58 UT
Rhea orbital motion

2005 and 2007 Rhea encounters



- Broad electron depletion region present surrounding moon’s microsignature
- Short-period dips surrounding dropout from Rhea itself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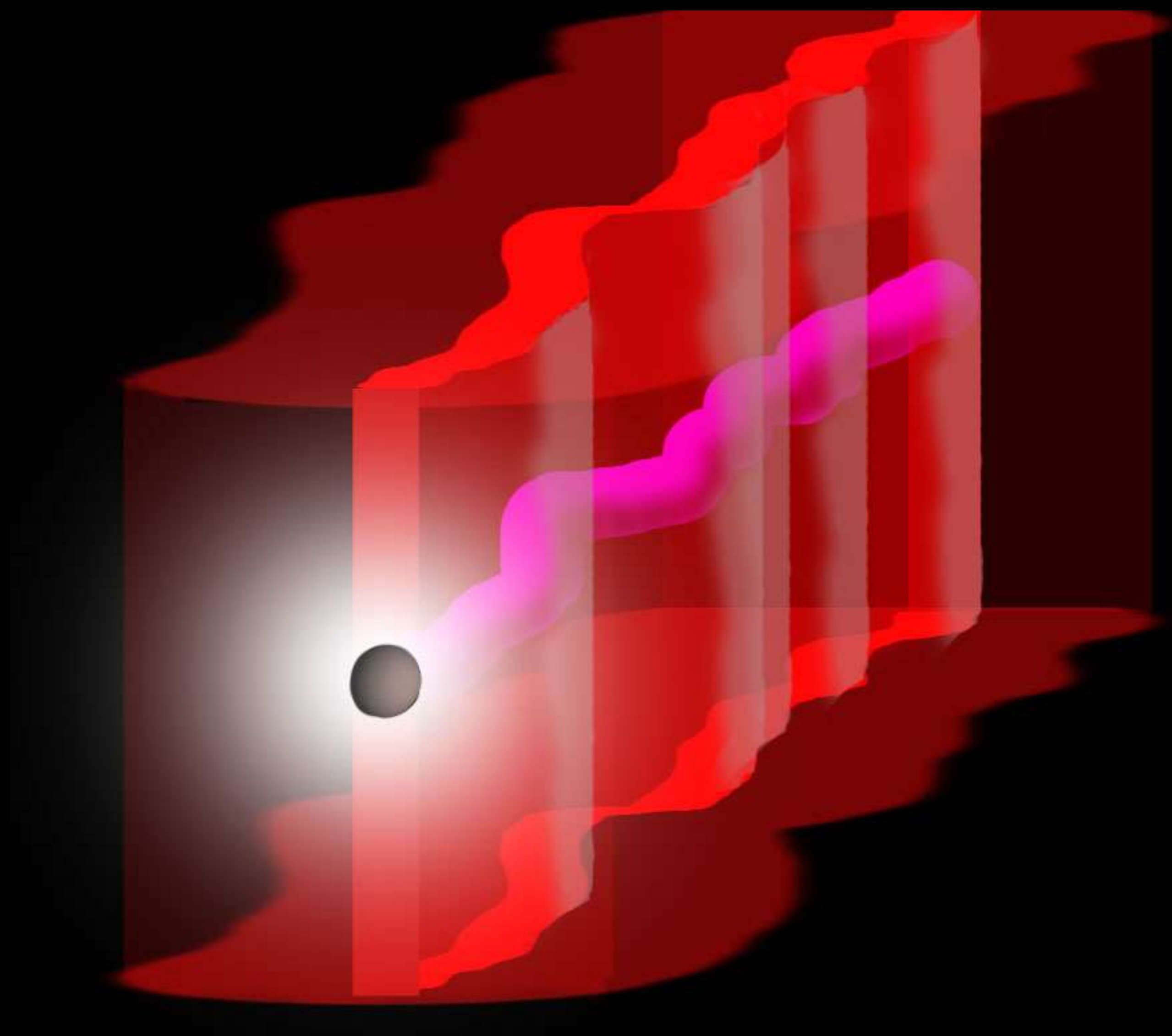
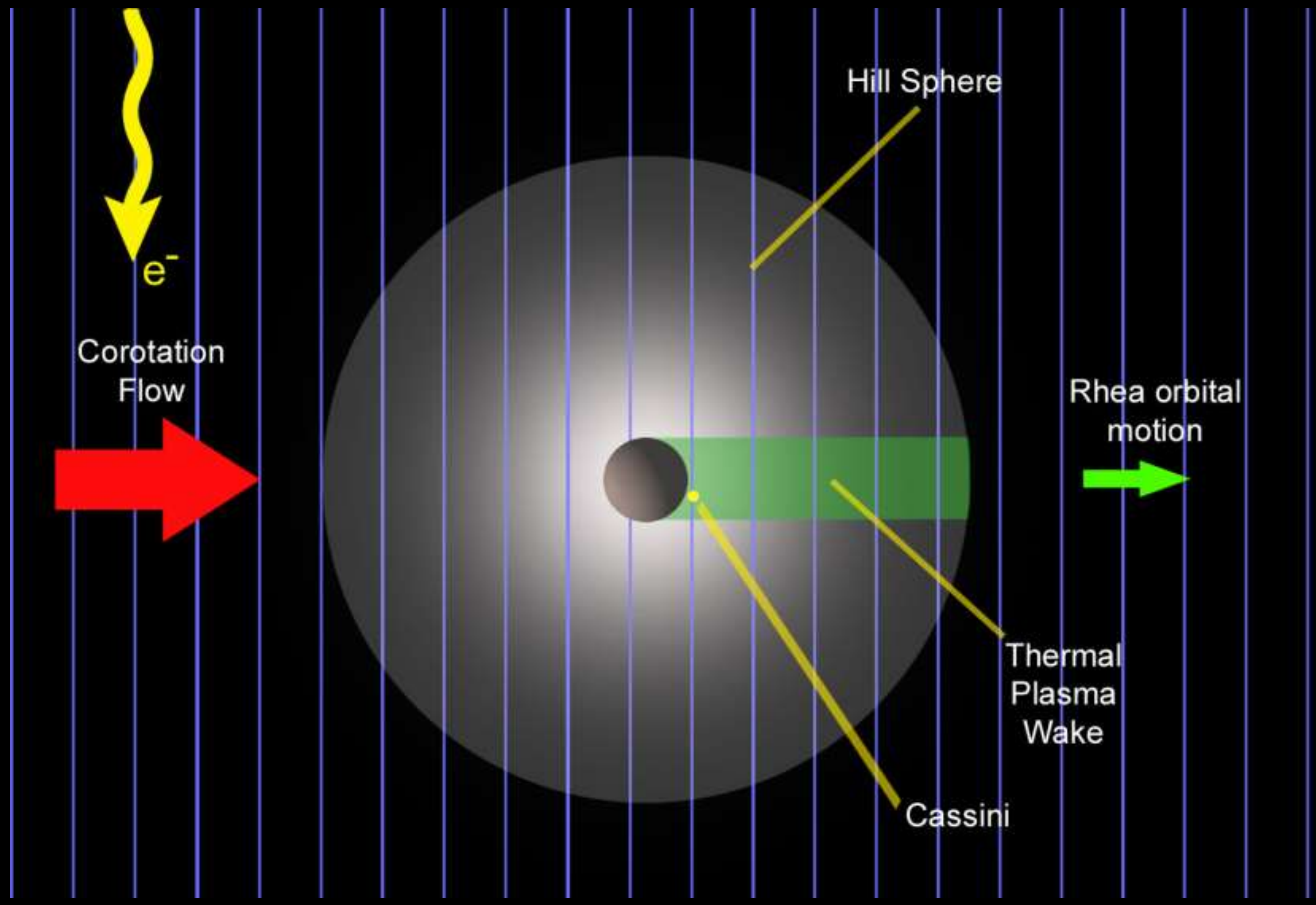
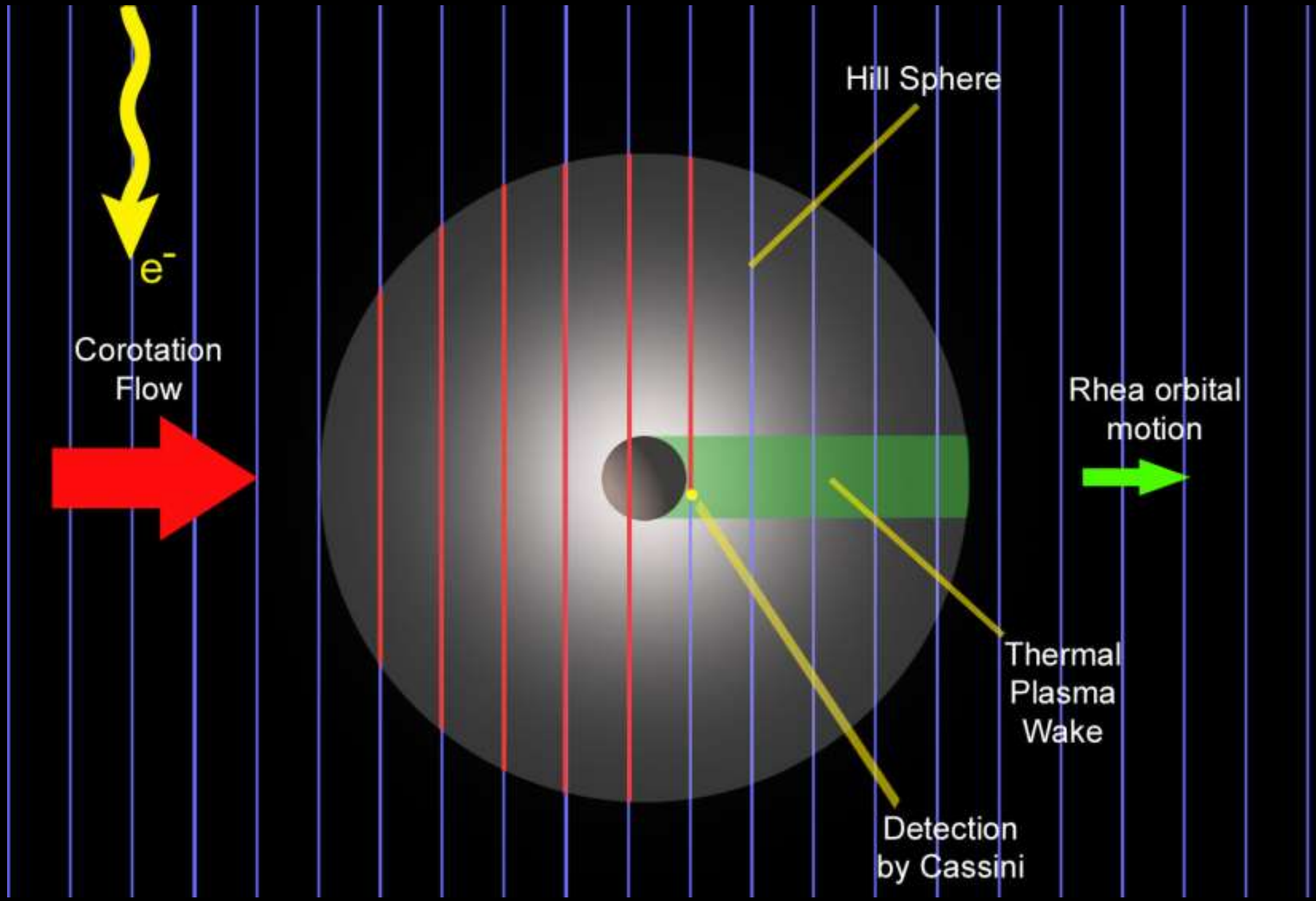
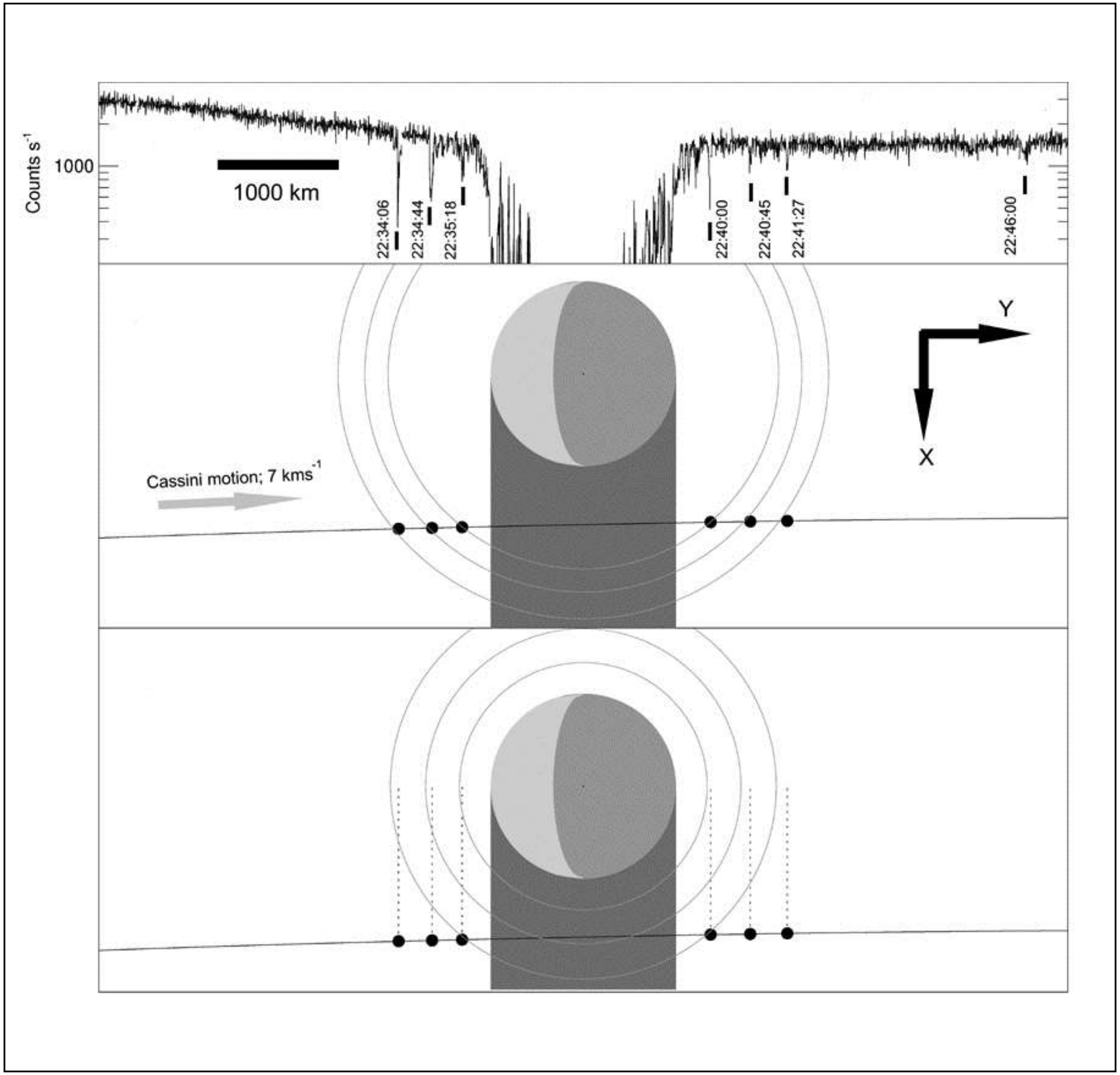


Calculation of effective electron path length





Only solid particles surrounding Rhea were estimated to absorb enough electrons to explain observed signature



Discrete, small-scale depletions also present.

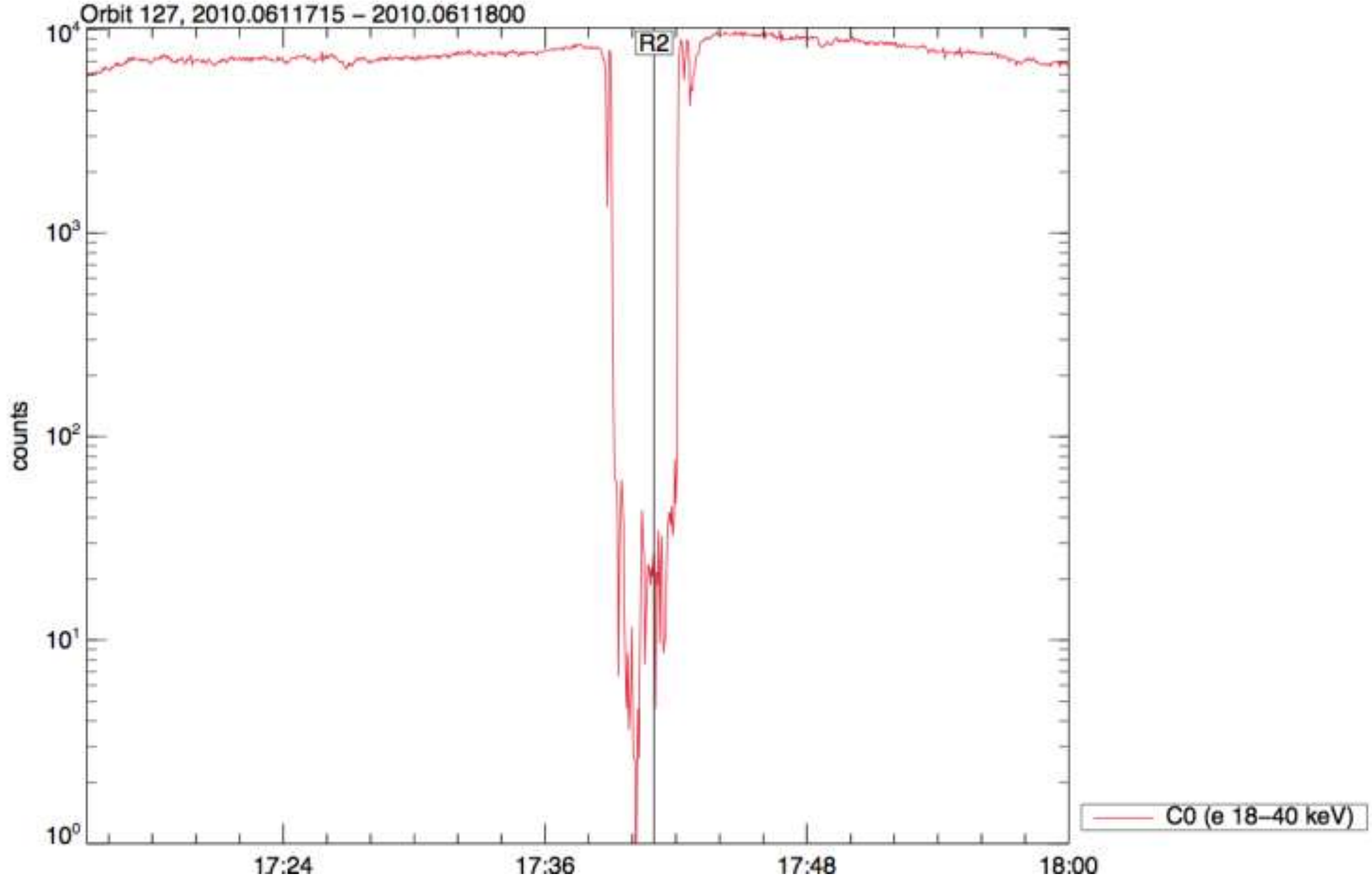
Simplest explanation:

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

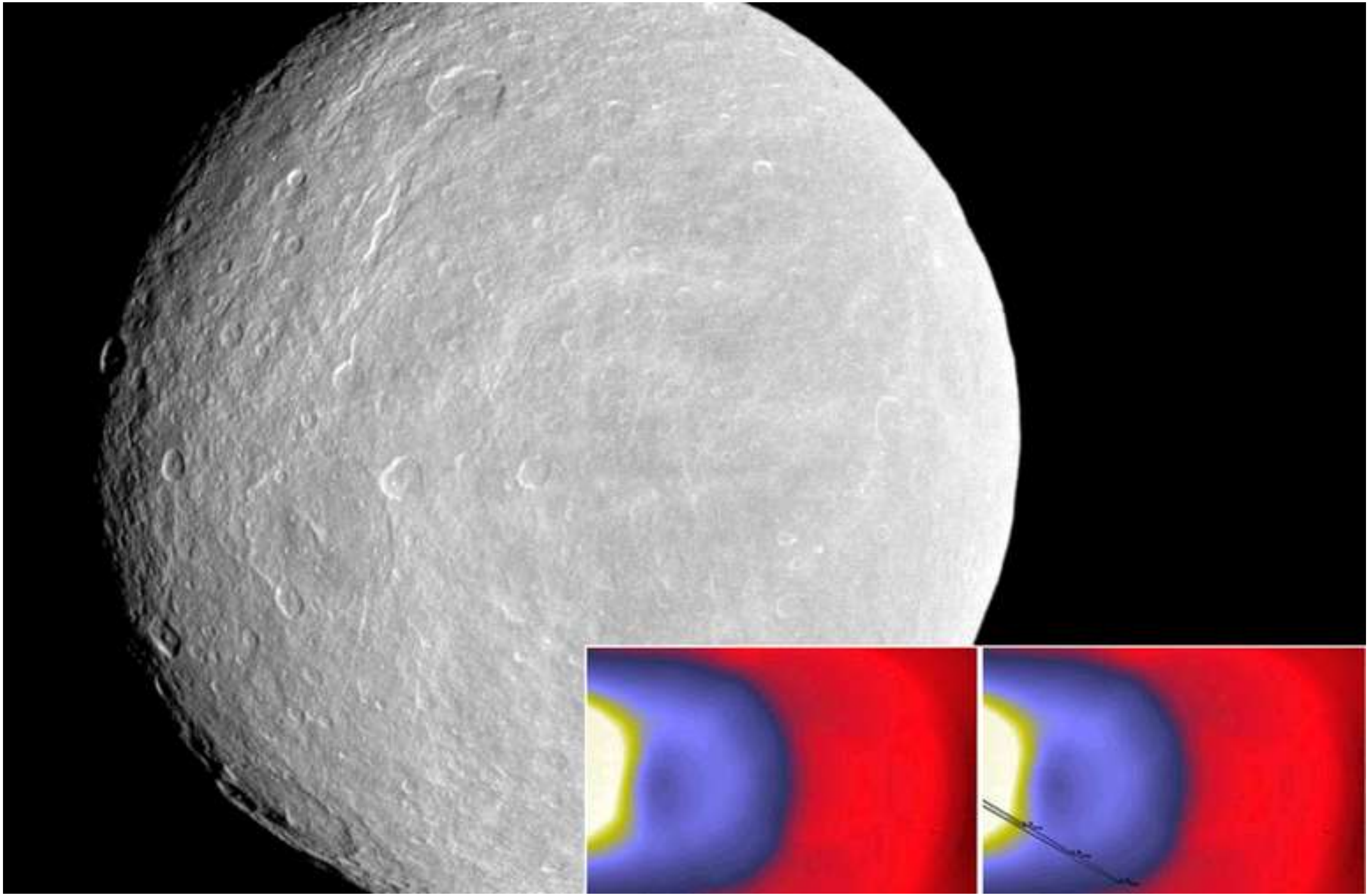
Dropouts consistent with ring radii of ~1610, ~1800, and ~2020 km.

Alternative picture has lower-altitude rings/arcs with ansae upstream of dropout locations.

Jones et al. 2008.

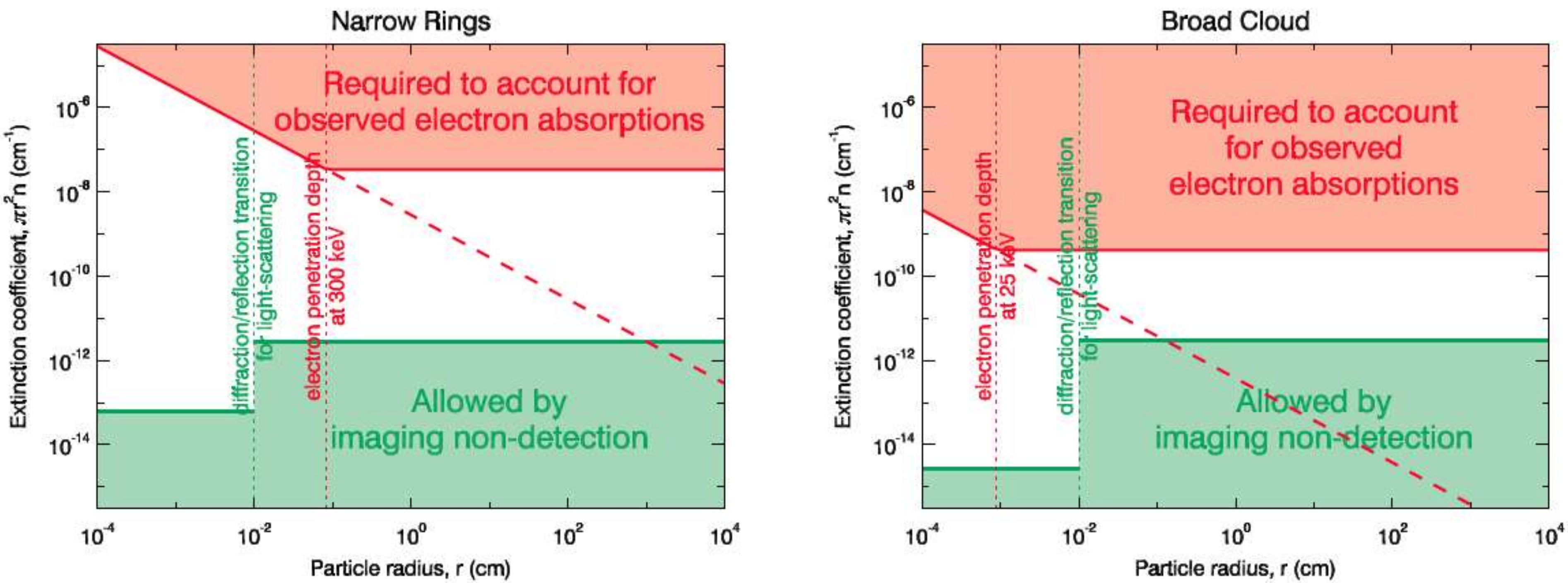


March 2010 encounter: no near-symmetrical electron flux decrease.



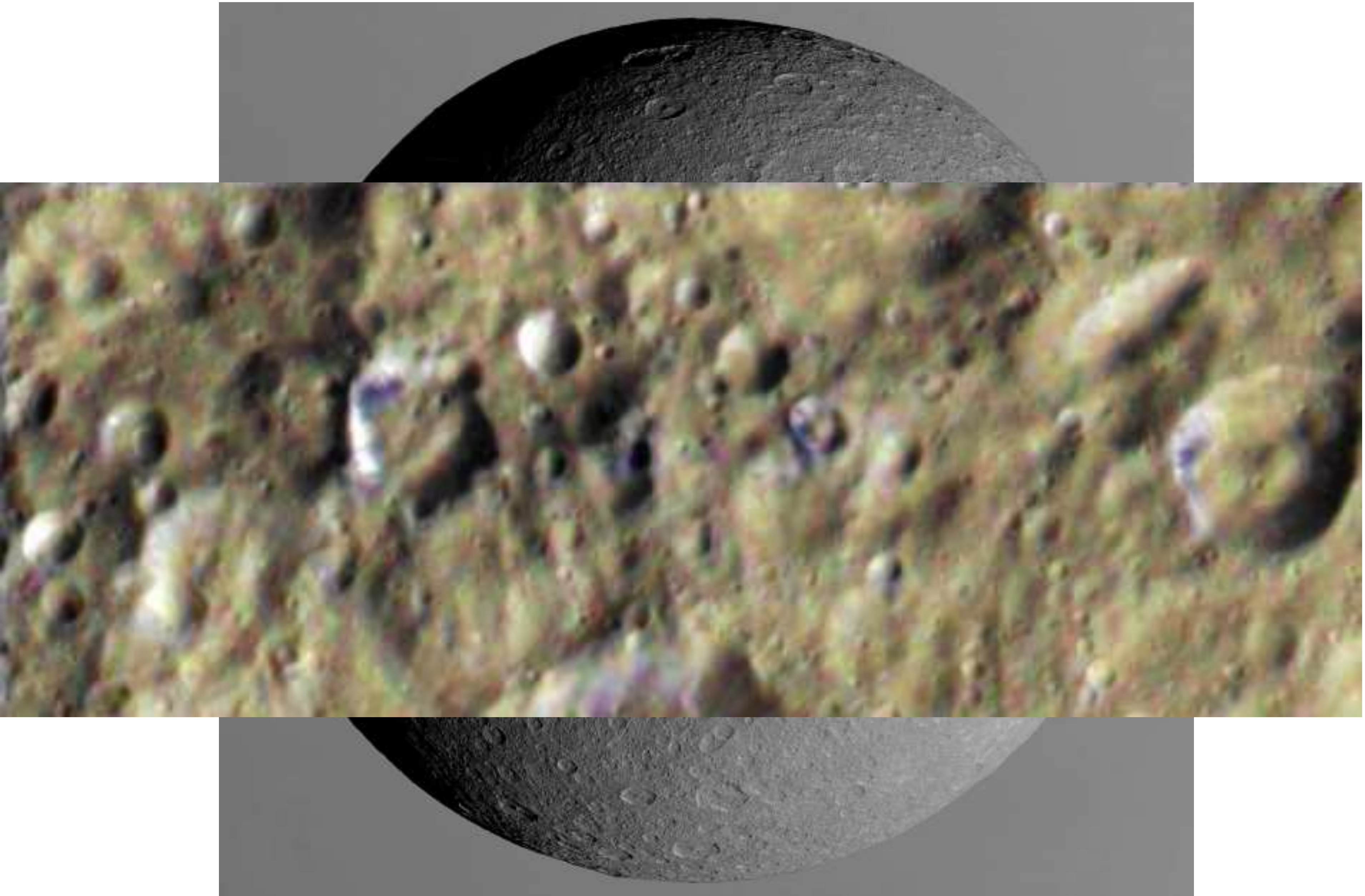
No evidence of debris disk/rings in ISS images.

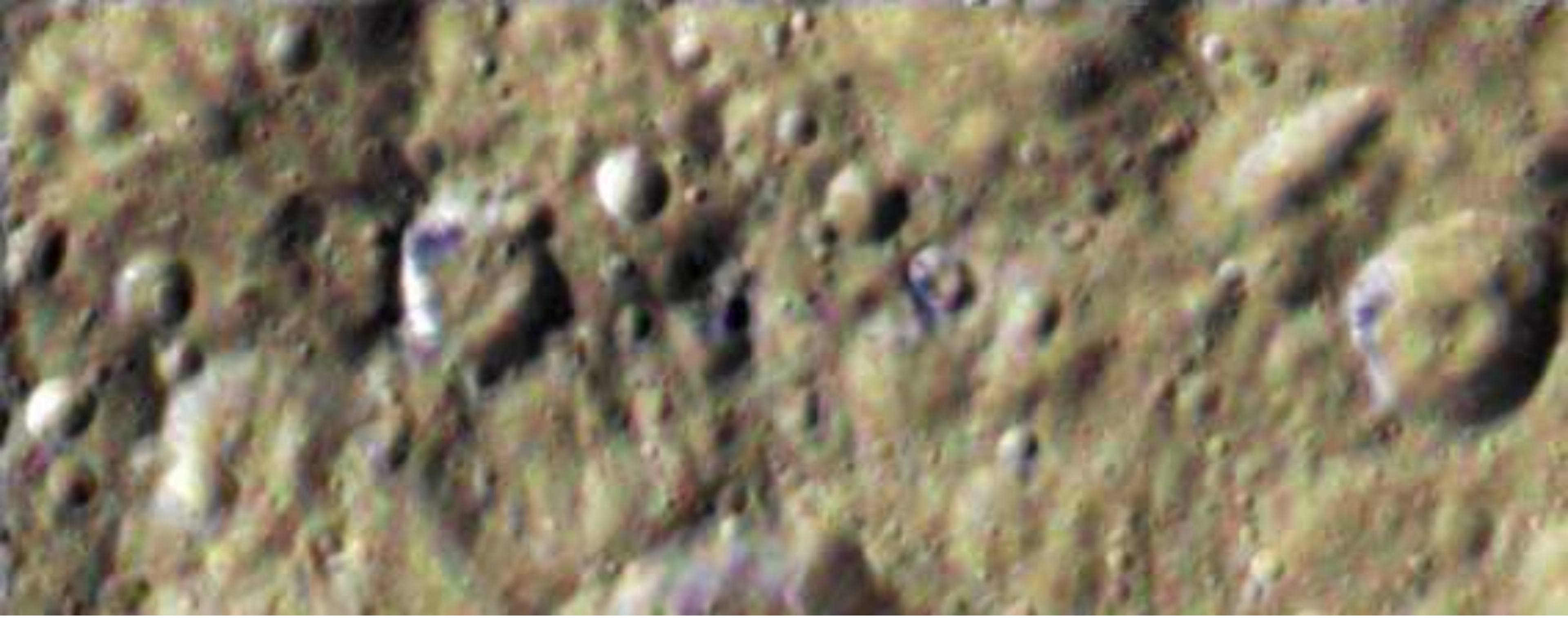
Tiscareno et al. 2010



Tiscareno et al. 2010

Any other evidence for rings?



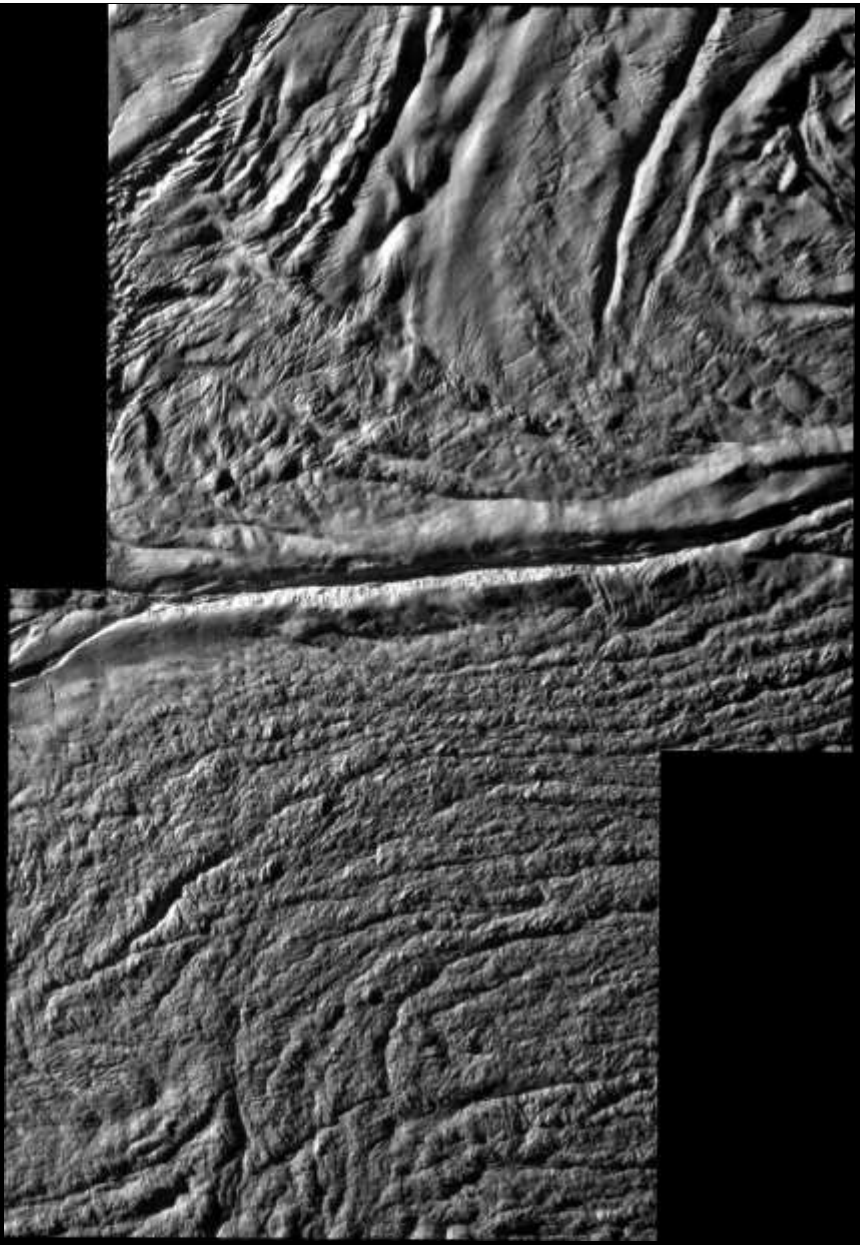


- Equatorial patches appear to predominantly occur on eastward-facing slopes or local plateaux

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

- If scenario correct, impact velocity ~400 m/s. Impactors would fragment without forming large craters.

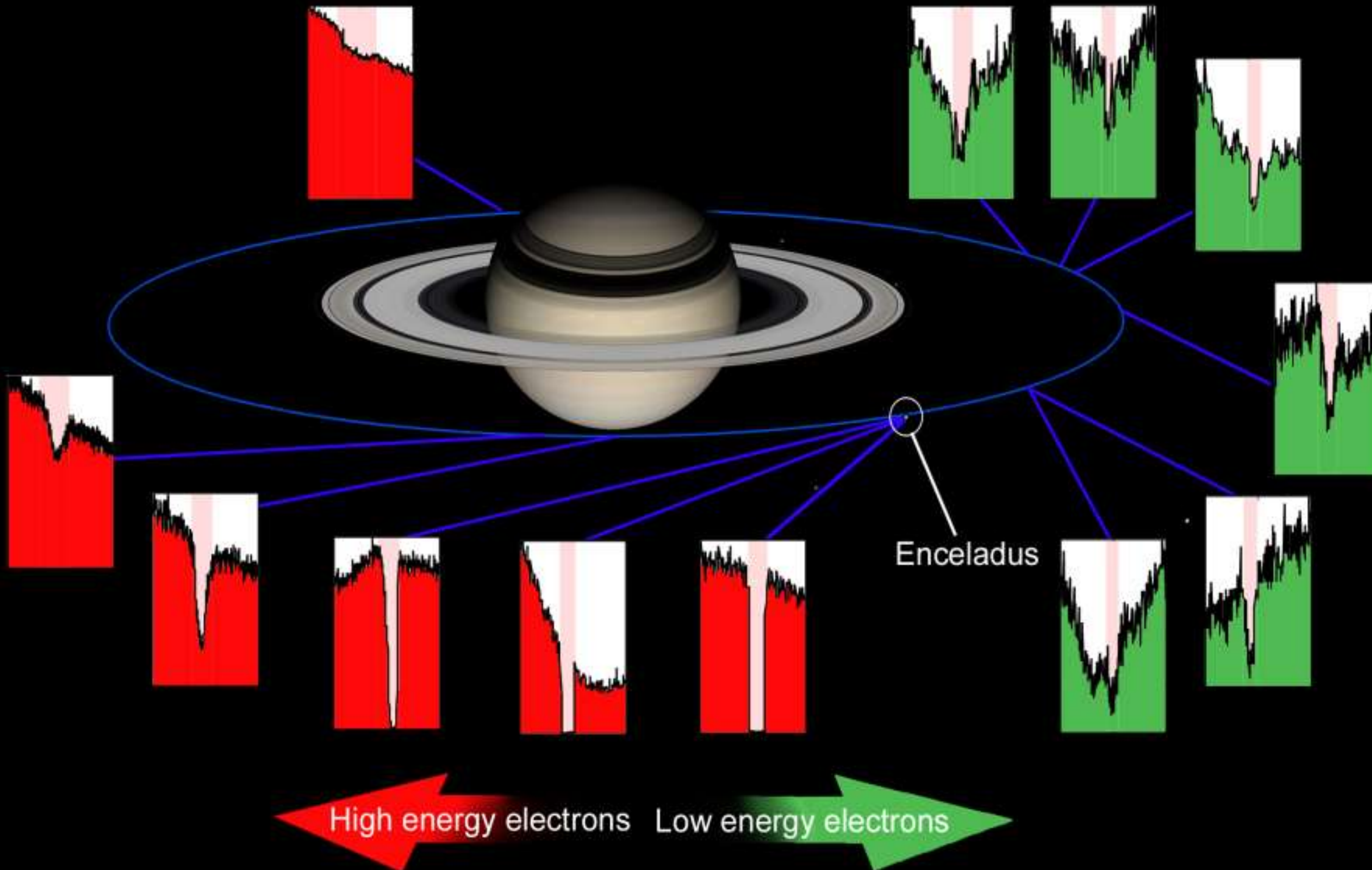
- Schenk et al. (2010)



Enceladus

Images courtesy NASA/JPL/Sp.Sci.Inst.

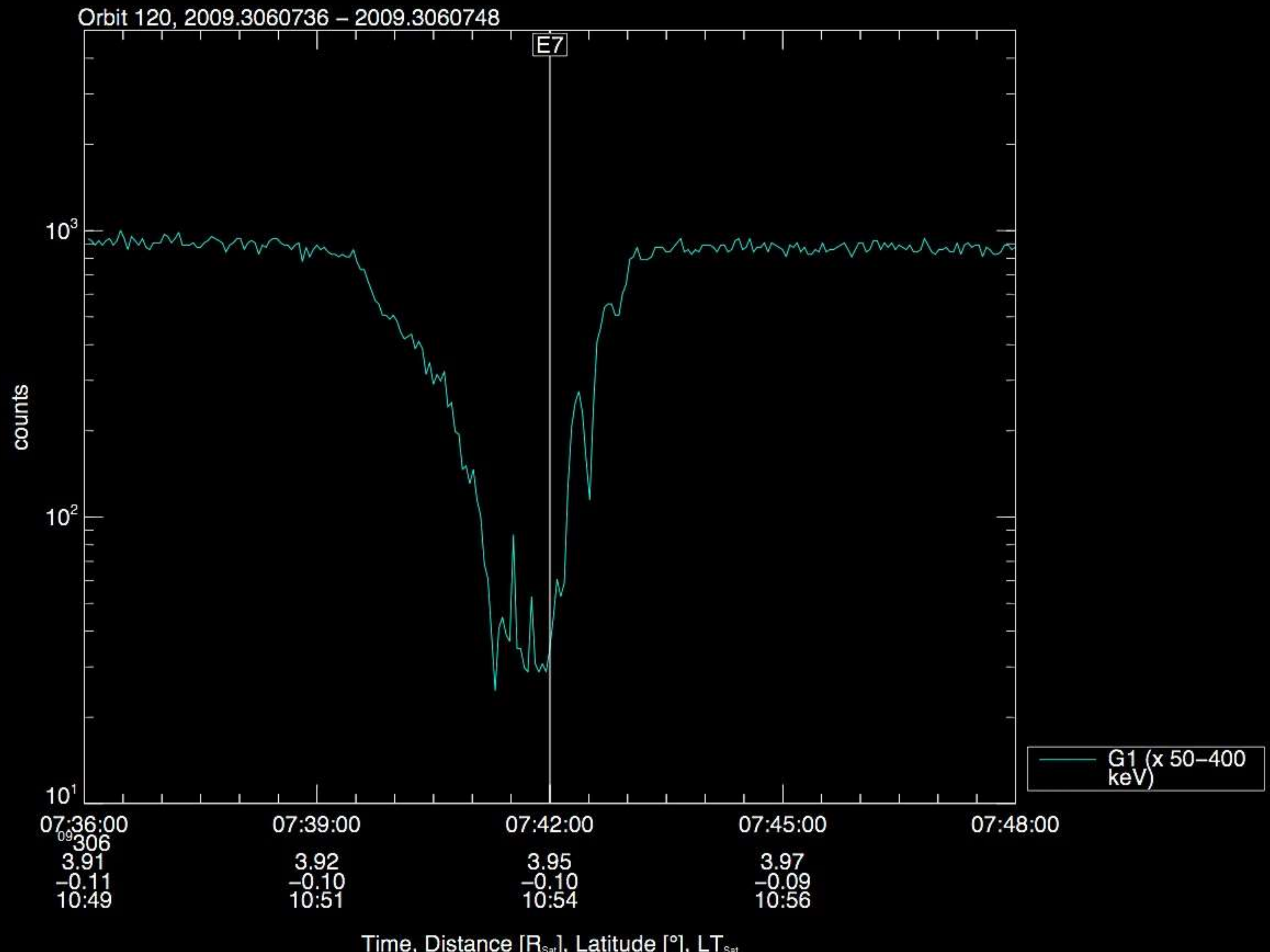
Plume absorbs low energy electrons (<1 MeV)



Profile of plume absorption differs: evidence of plume variability

Plume structure is remotely detecable

MIMI-LEMMS channel G1 (~omnidirectorional energetic electrons)



In situ observations

In situ observations:
CAPS detects charged dust

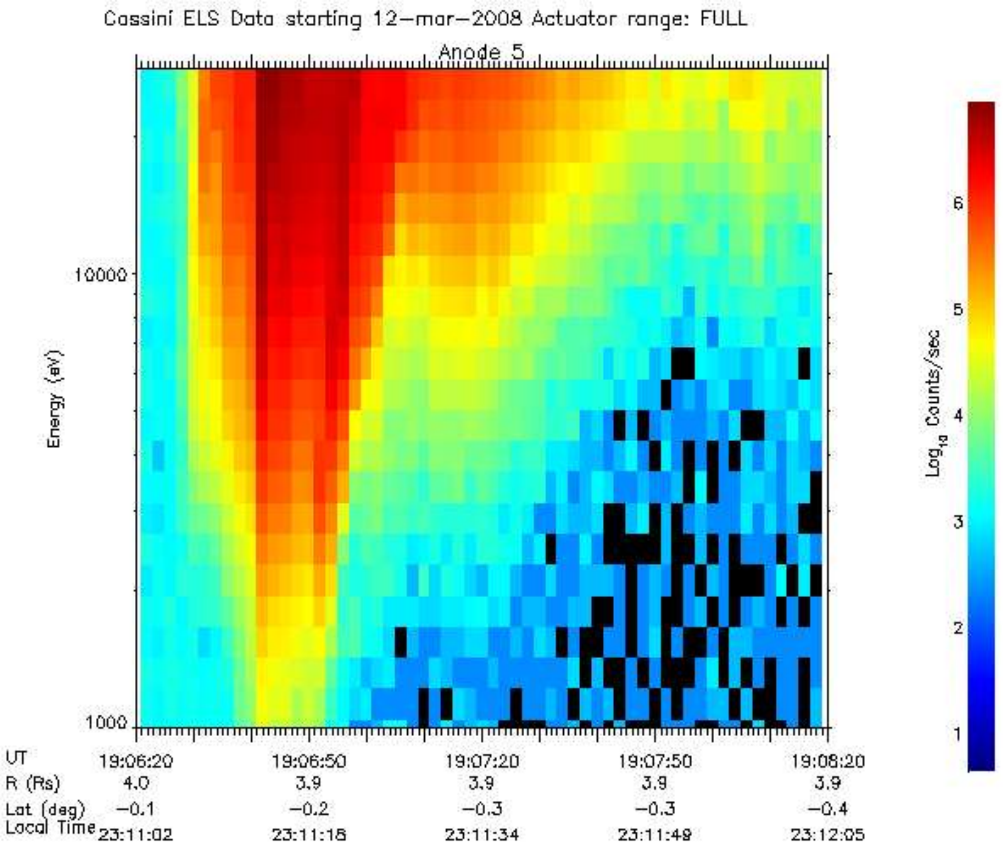
• First observed during E3, then again during E5

• High energy features appear in anodes pointing in ram direction.

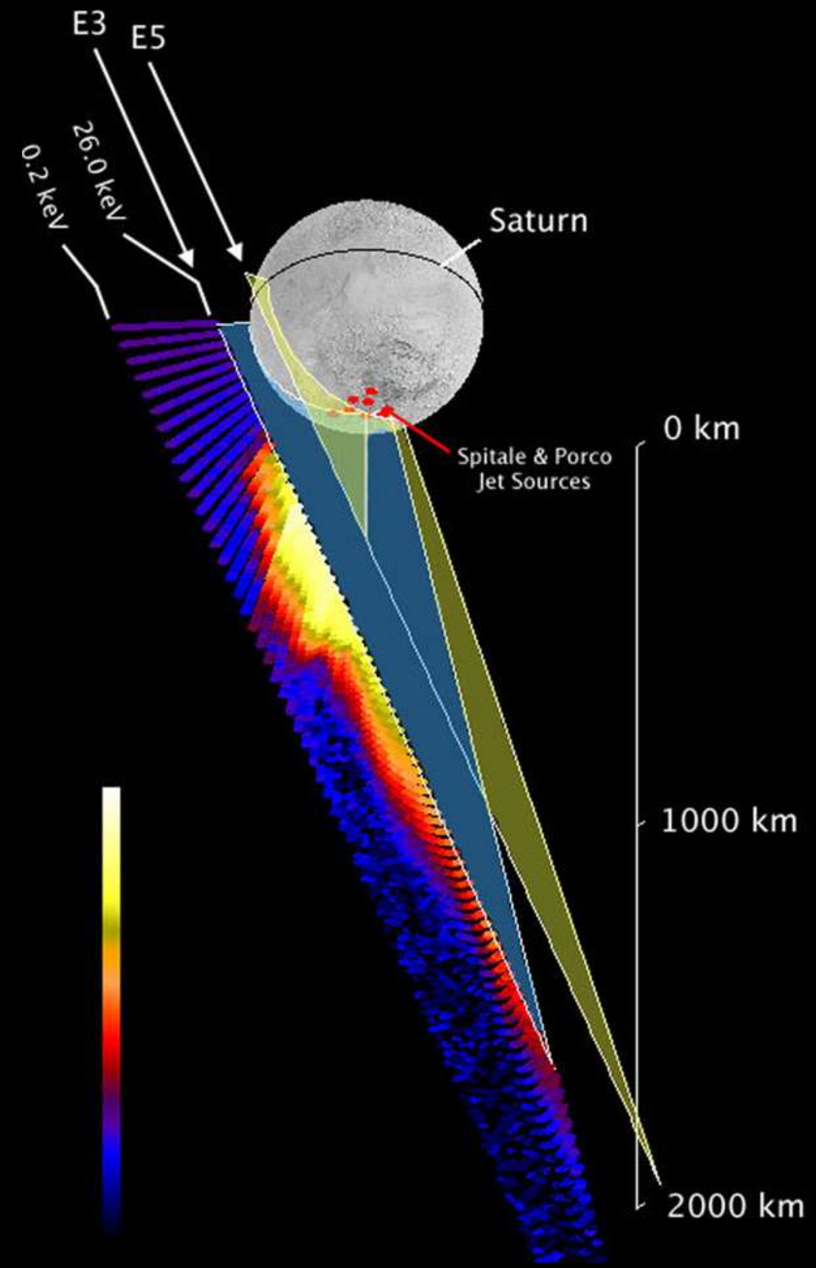
• Negatively-charged dust enters instrument and its E/q value measured

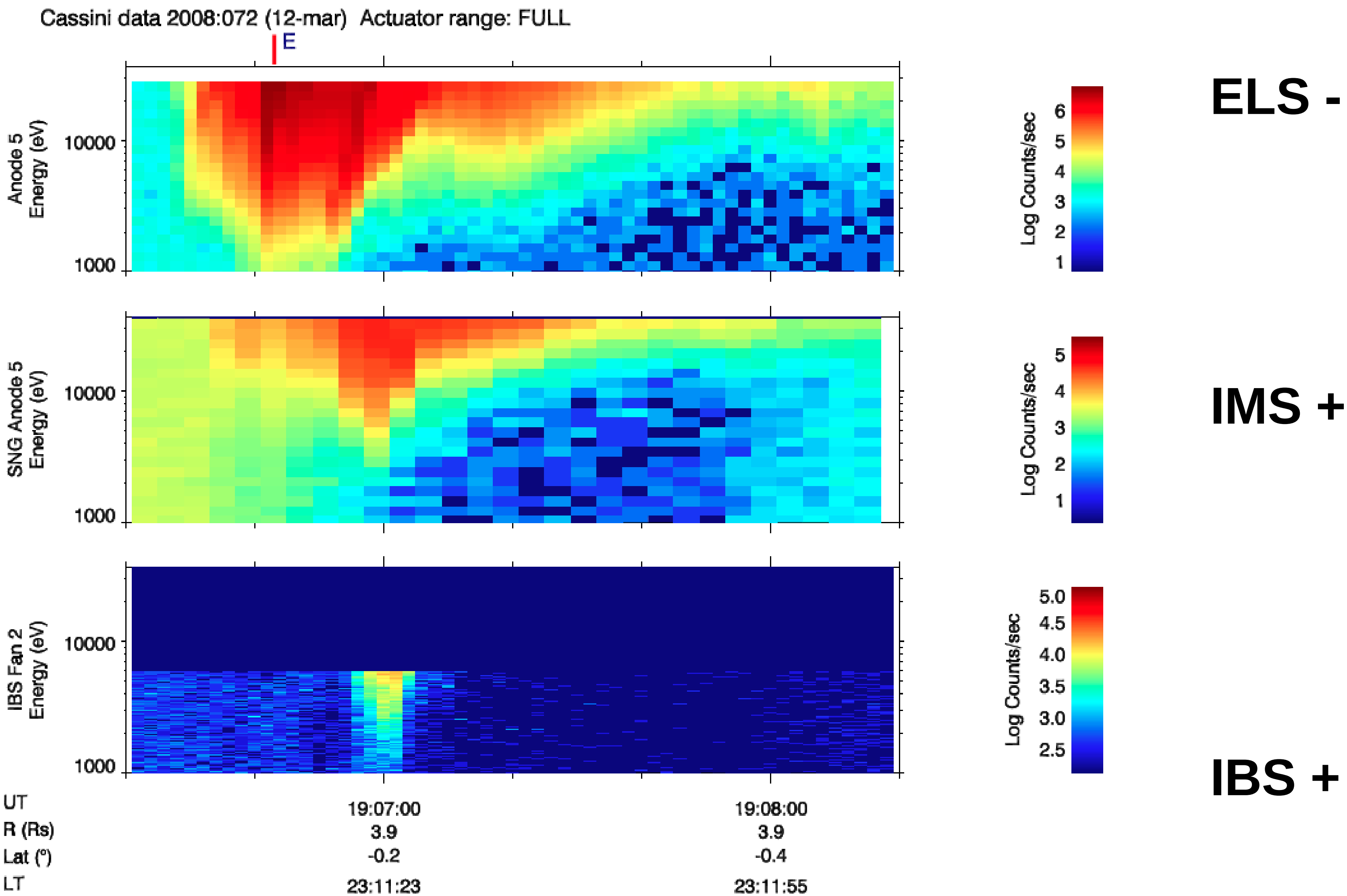
• As we know spacecraft velocity in Enceladus frame (8-18 km/s), can convert kinetic energy to mass/charge

• Particles ~nm scale



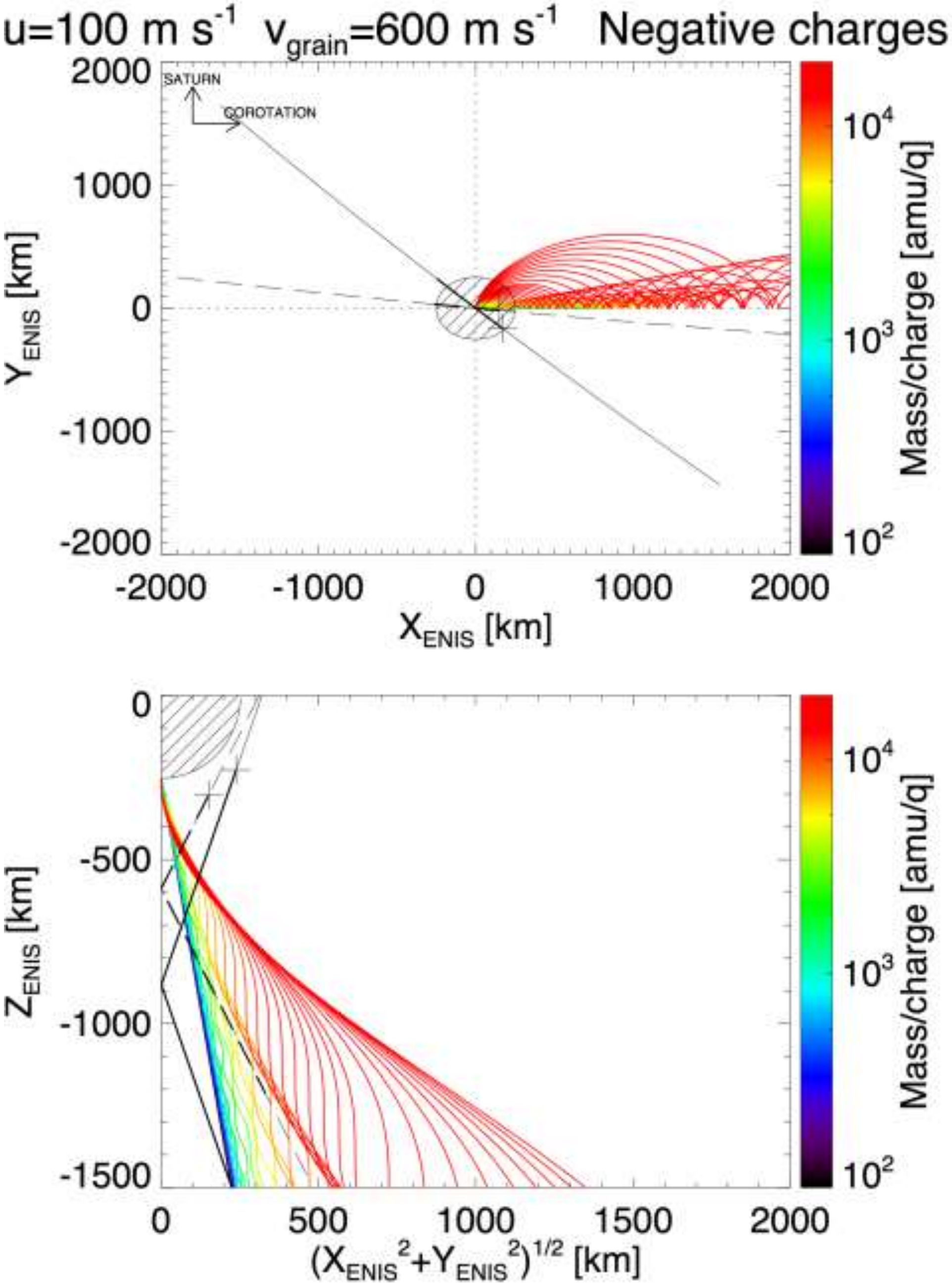
Jones et al., GRL, 2009





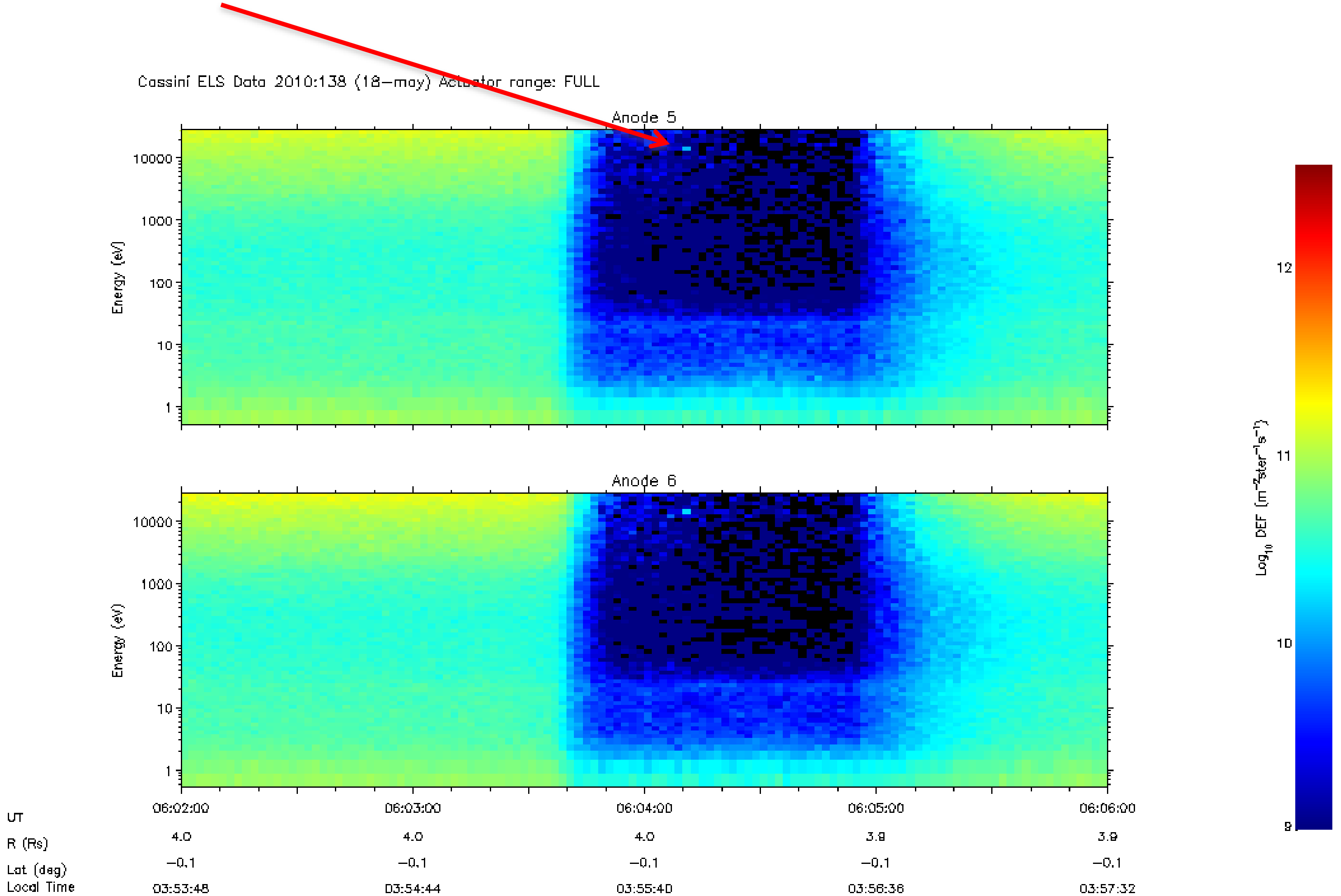
Detected by CAPS ELS, IMS, and ELS. Peak times and strengths differ: information about charging processes (Hill et al, this meeting), and grain trajectories.

- Chris Arridge leading trajectory modelling effort
- CAPS observations shows the magnetospheric flow to be very slow and almost stagnated near the plume.
- Initial modelling indicates that a single jet will separate according to m/q: plume acts as a large-scale mass spectrometer



When away from core of plume, charged dust still observed

E10: Signatures weak, but dust detected again in ram direction. If singly-charged, mass ~50 000 - 70 000 amu.



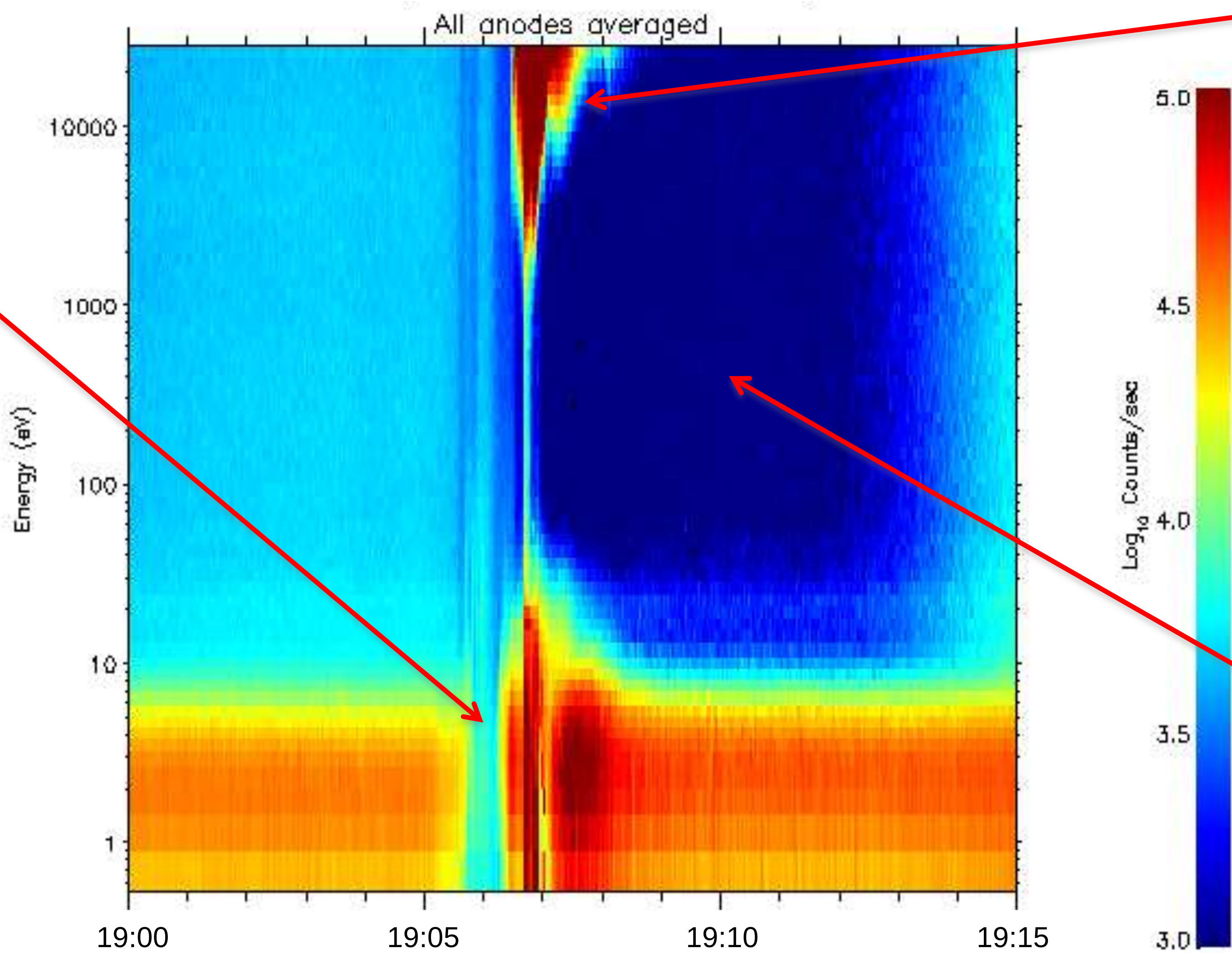
Summary

- Plasma instrumentation on Cassini provide valuable information on the dust environments of Saturn’s moons, both remote and in situ observations.
- CAPS observations bridge gap between heavy molecules and micron sized grains measured by dedicated dust instrumentation.
- Rhea puzzling: rings probably not present. Alternative explanations needed (e.g. Santolik et al., submitted)
- Enceladus plume variable; currently searching for cyclical changes in activity

Backup Slides

E3: March 12, 2008

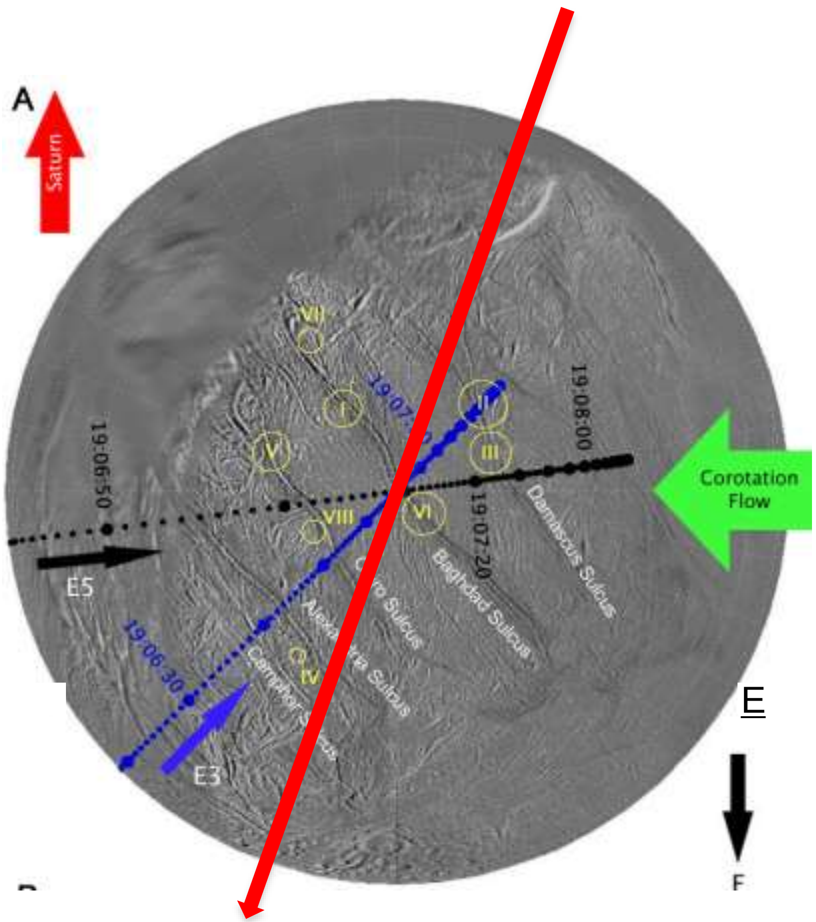
Cold plasma wake

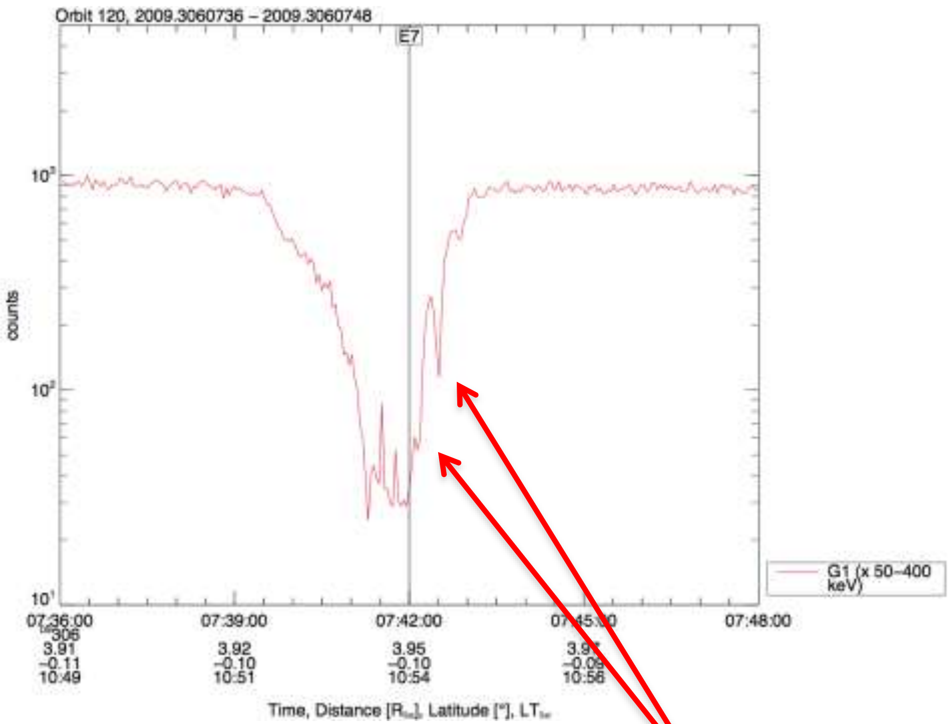


Unexpected, high-energy features when inside plume

Drop in penetrating radiation once upstream of Enceladus

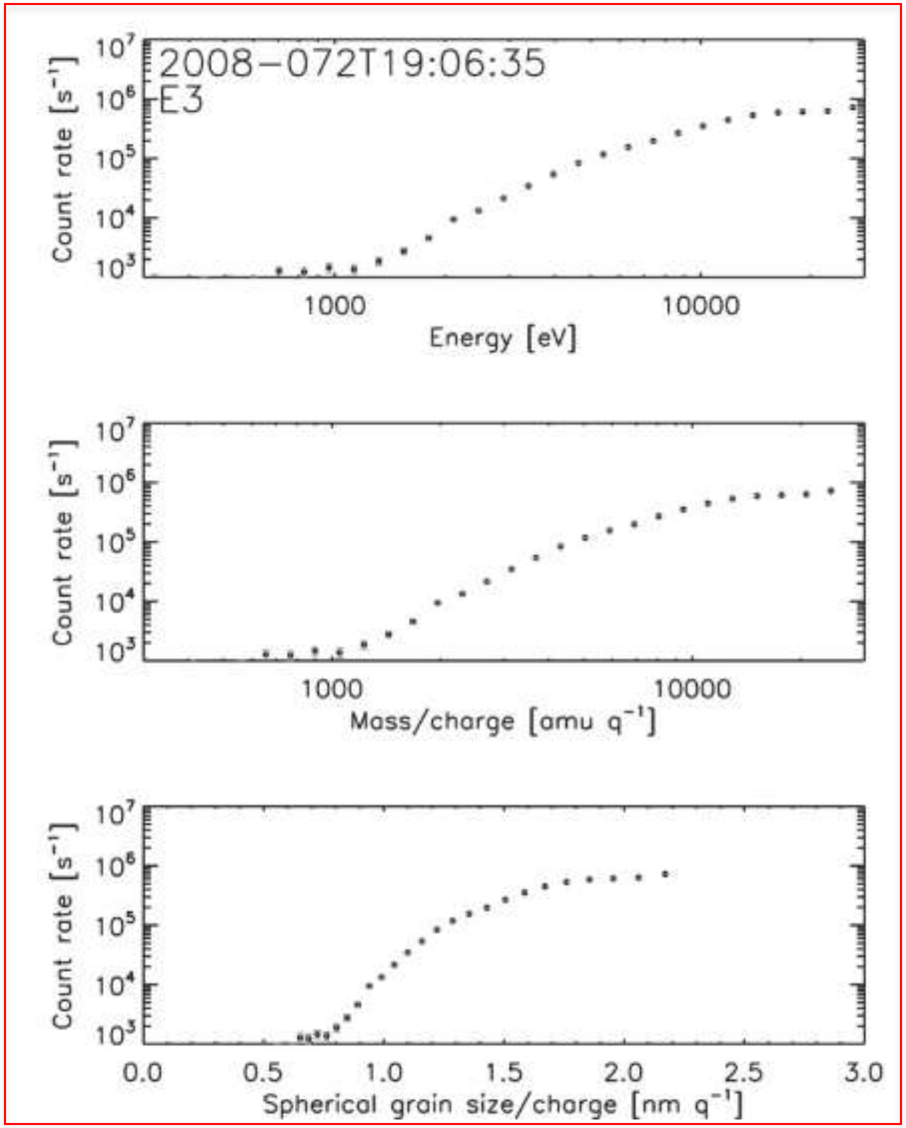
E7

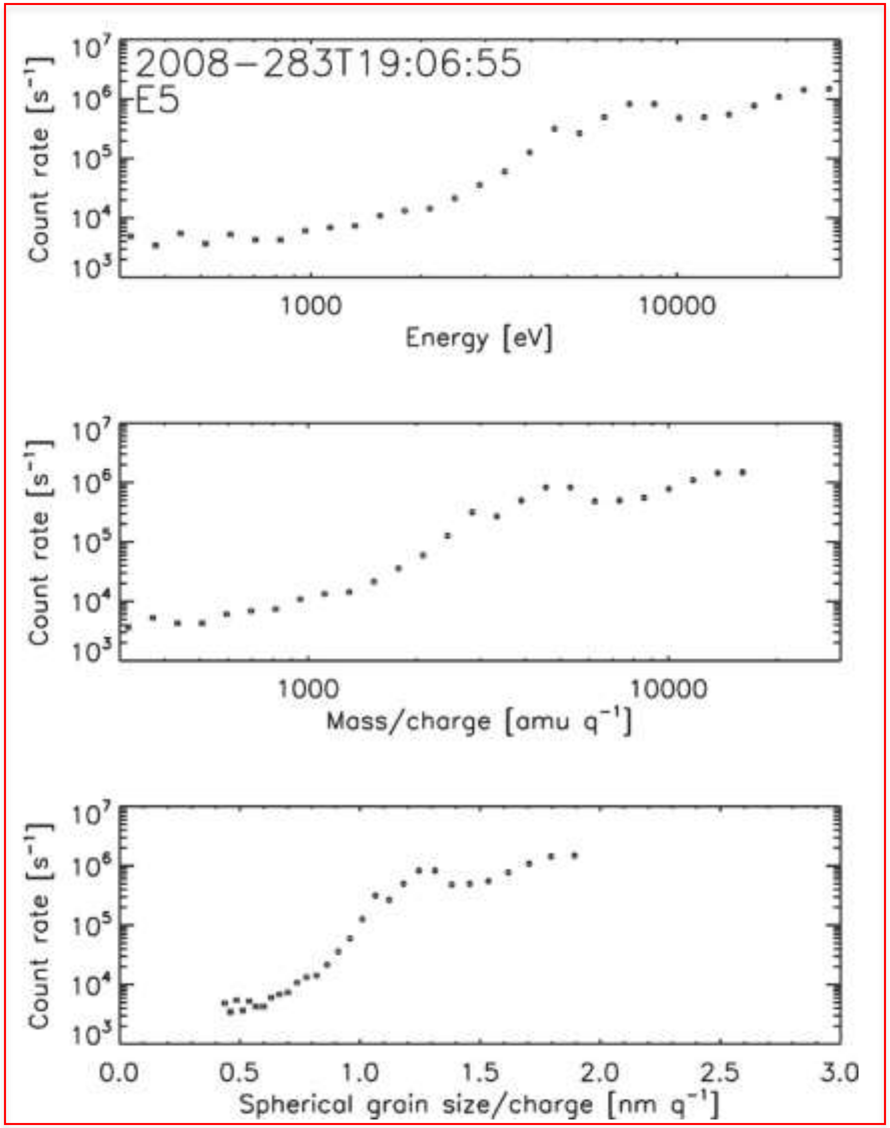




Signatures of individual jets

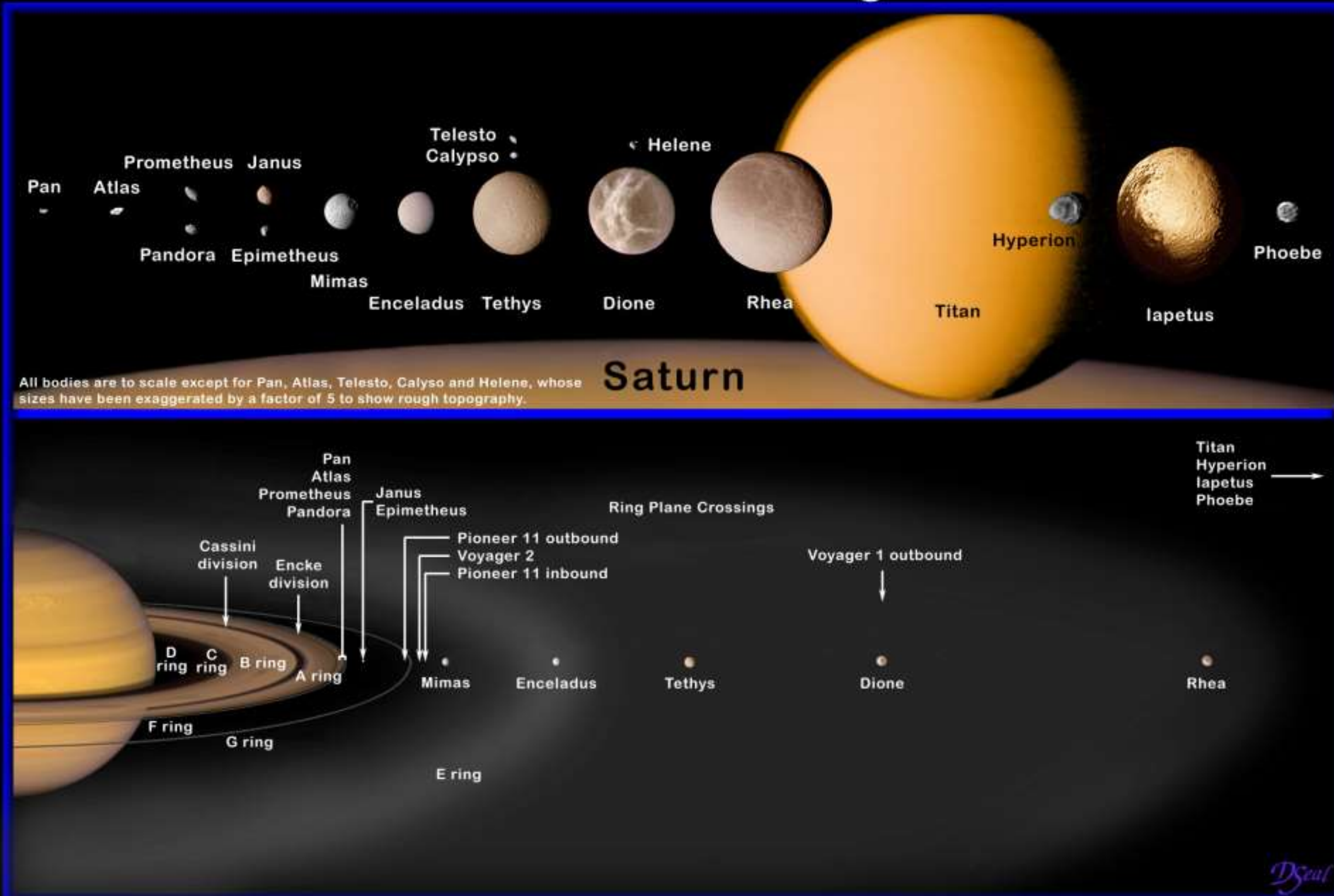
Conversion of E/q spectra to particle size (assuming single electron charge)





Upper detectable limit of size/charge determined by flyby velocity.

Saturn's Satellites and Ring Structure

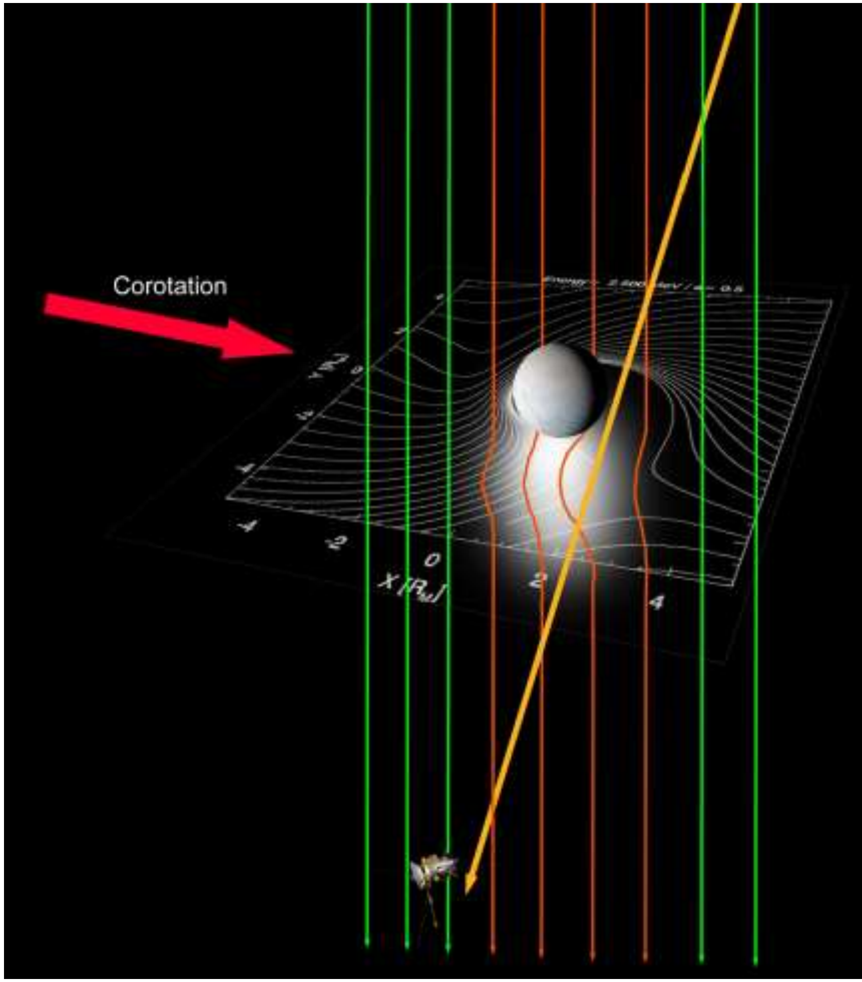


Complications

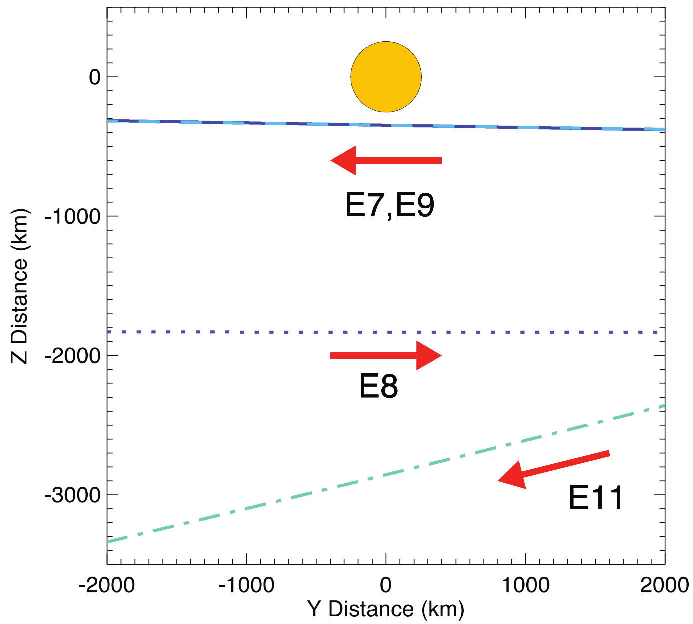
Most MIMI-LEMMS channels dependent on spacecraft orientation

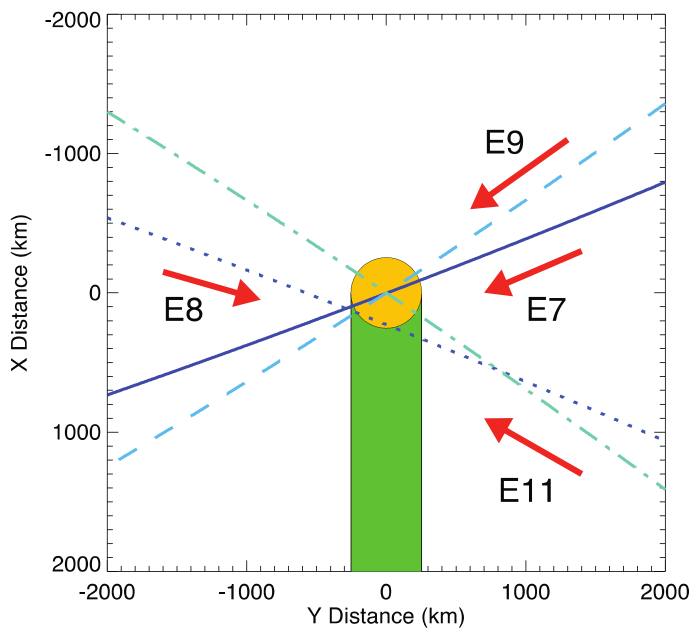
Plasma flow past Enceladus is not a straight line - modelling of deflection needed

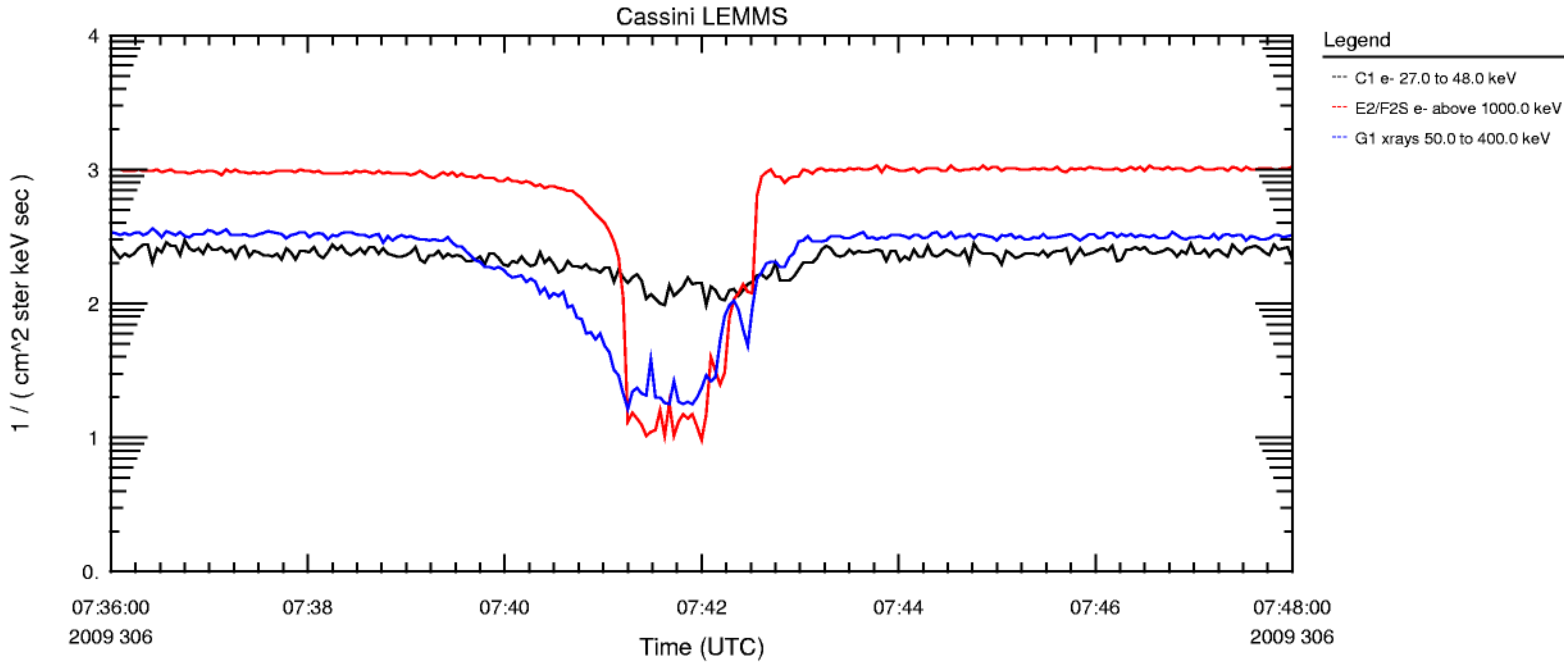
Combination of observations from several energy channels, plus CAPS background measurements should help constrain degree of variability in plume



Southern Encounters







Signatures are a function of particle energy

- Electron energy controls drift speed and direction
- - Energies just above/below resonant energy spend longest in plume
- - Bounce rate north-south through plume also increases with increasing electron energy
- - Path length through cloud of grains also a function of energy

- Dust Observations at Rhea and Enceladus using Plasma Instrumentation
-

- Jones, G.H.[1,2]
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- The dust environments of Saturn's icy moons can be probed by several of Cassini's instruments. As well as the dedicated dust instrument, CDA, and the radio and plasma wave instrument RPWS, both of which have, as expected, proven highly successful in making observations of dust in the Saturnian system, other Cassini instruments have also proven their great worth in making measurements of dust using complementary techniques. Following the successful detection of heavy negative ions in Titan's upper atmosphere by the Cassini Plasma Spectrometer's electron spectrometer, all of the CAPS sensors were found to be effective detectors of charged nanograins in the plume of Enceladus. When oriented in the ram direction, both positive and negative charged grains entering the instrument at the relative encounter speeds of ~6-18 km/s can be detected by the three CAPS sensors. A review is given of these direct charged nanodust observations at Enceladus, and their implications for our understanding of the plume. Dust can absorb energetic charged particles, and the resulting absorption signatures can be detected by CAPS and very effectively by the magnetospheric imaging instrument, MIMI. An overview of absorption signatures caused by the Enceladus plume will be presented, changes in them indicate variations in the activity of the plume. At Rhea, a broad energetic electron depletion was observed by MIMI, which was suggested to be caused by absorption of the electrons by a debris disk surrounding the moon. Our interpretation of this and other perplexing signatures observed near Rhea will be presented, in the context of a lack of supporting imaging evidence of a dust population surrounding Saturn's second-largest moon.

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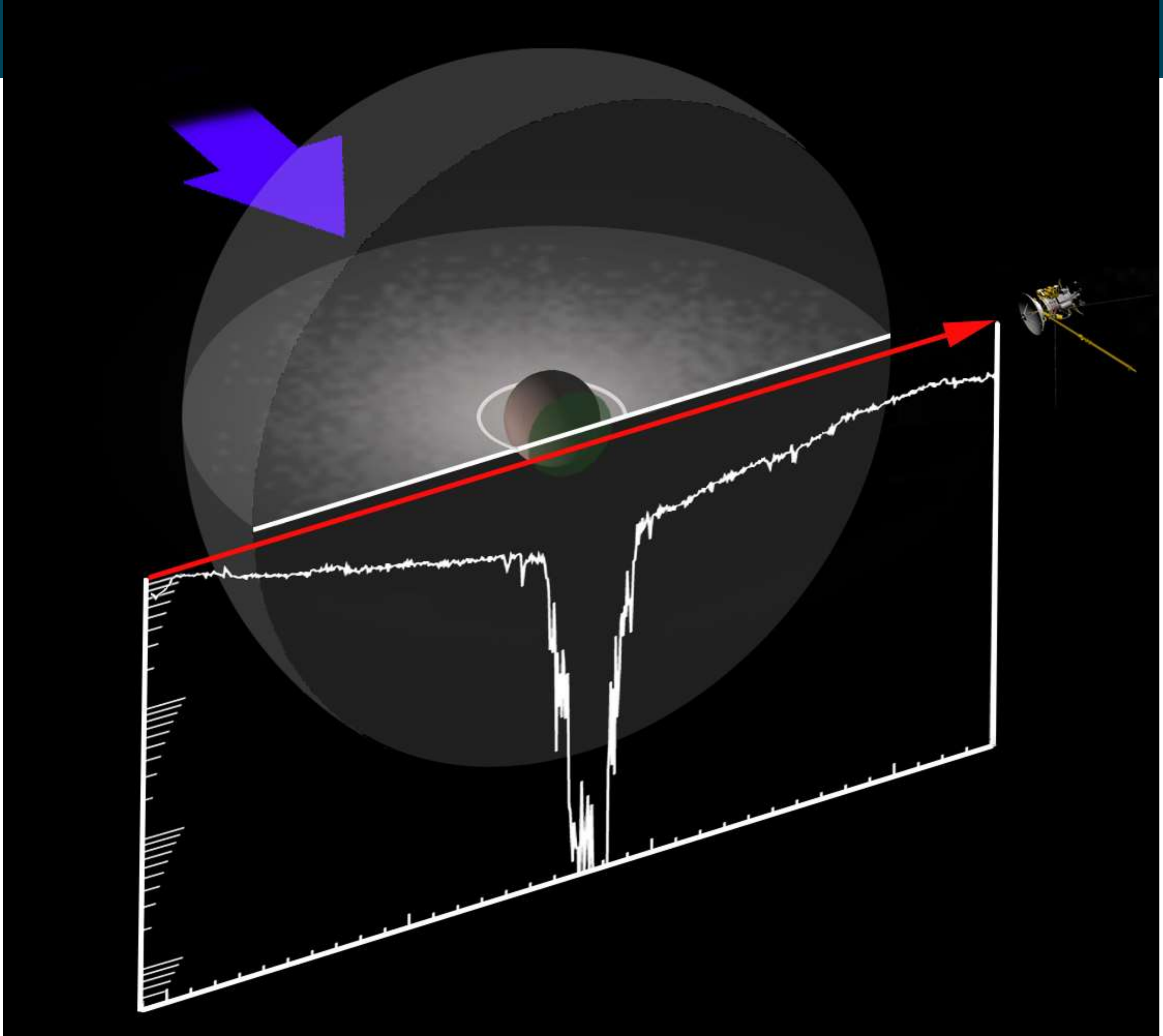
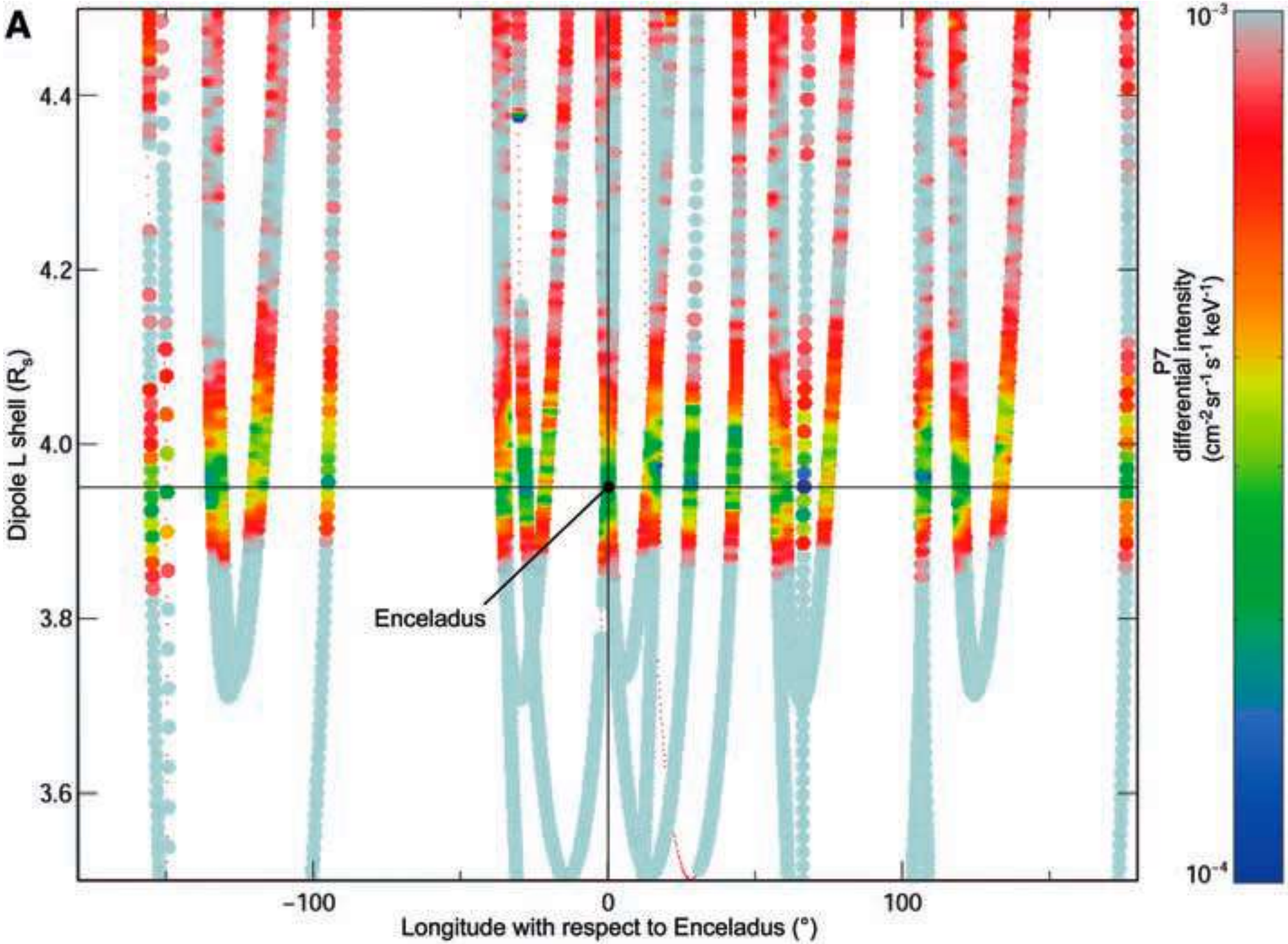




Jones et al. 2006

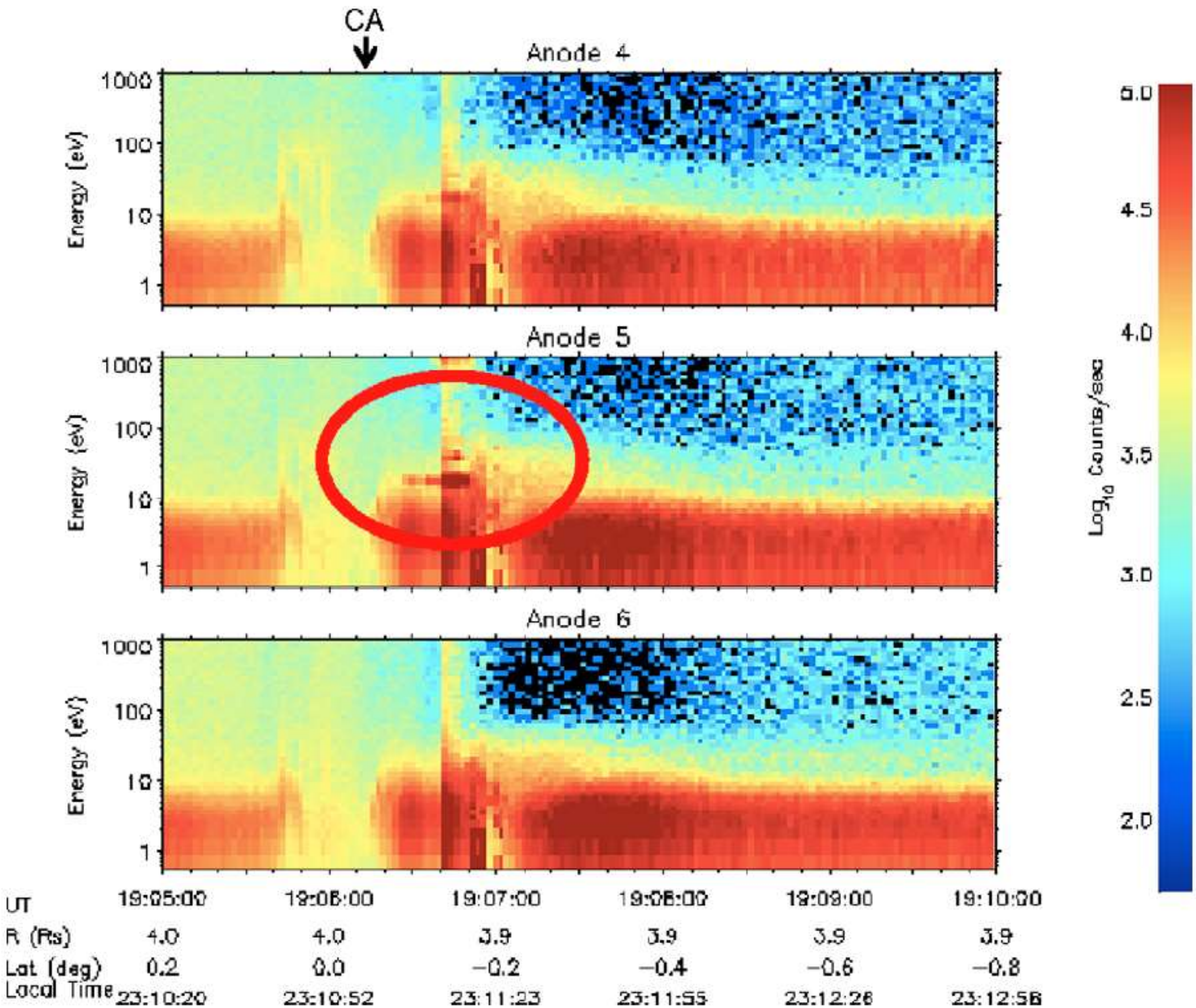
Only during E3 and E5 were very high nanodust fluxes observed. Weak signal during E7 due to low oplevel selection for that encounter.

However, negatively-charged dust observed during other flybys well away from the core of the plume, but at discrete E/q (and hence m/q) values:
E2 (2005:195), E10 (2010:138), E13 (2010:355).

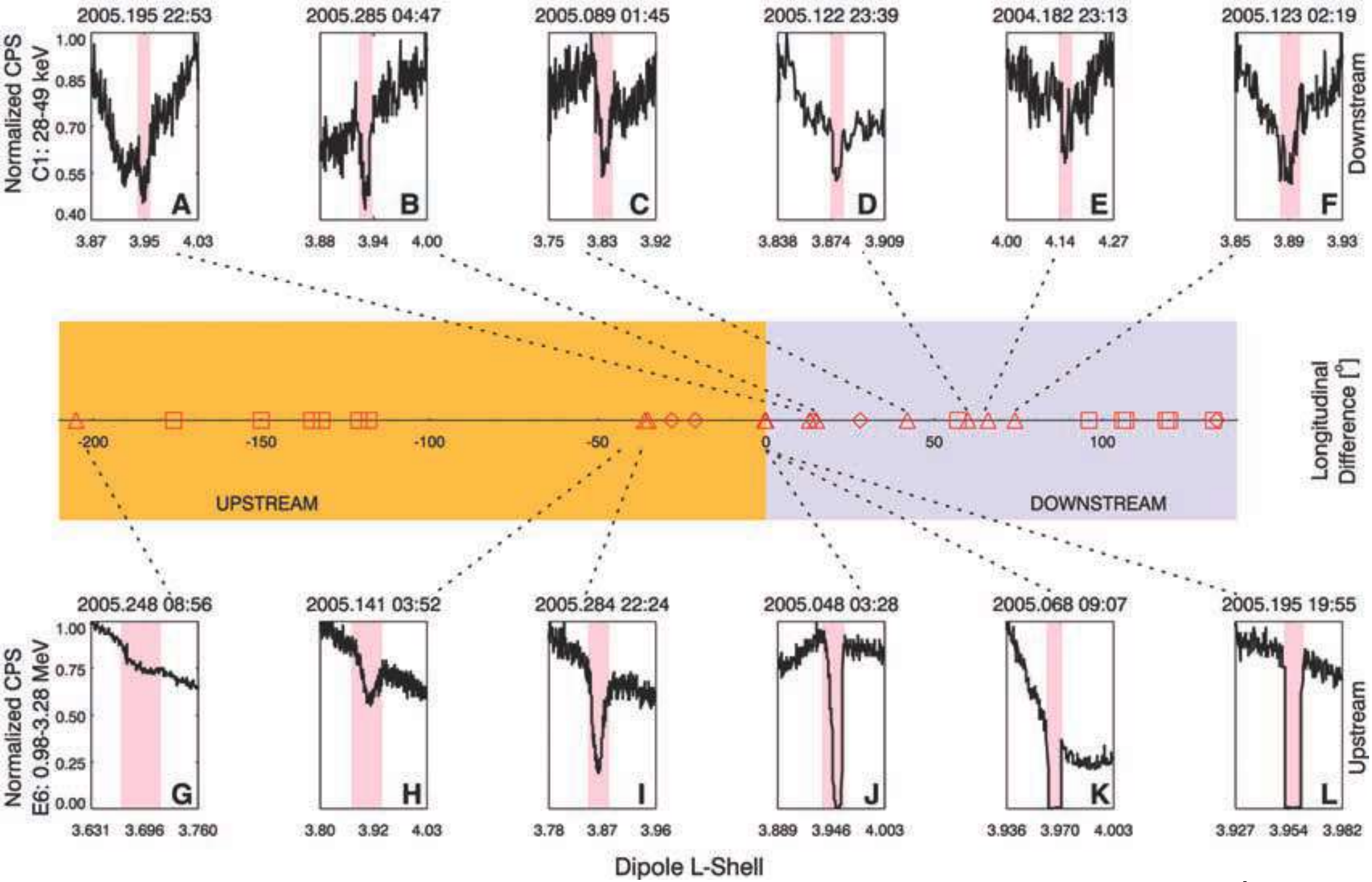
E7: dust observed arriving well away from ram direction.

Strong evidence for strong deflection of charged nanoscale dust by EM forces.

Suggests that at nanoscales, plume jets are modified into near-planar sheets of dust.

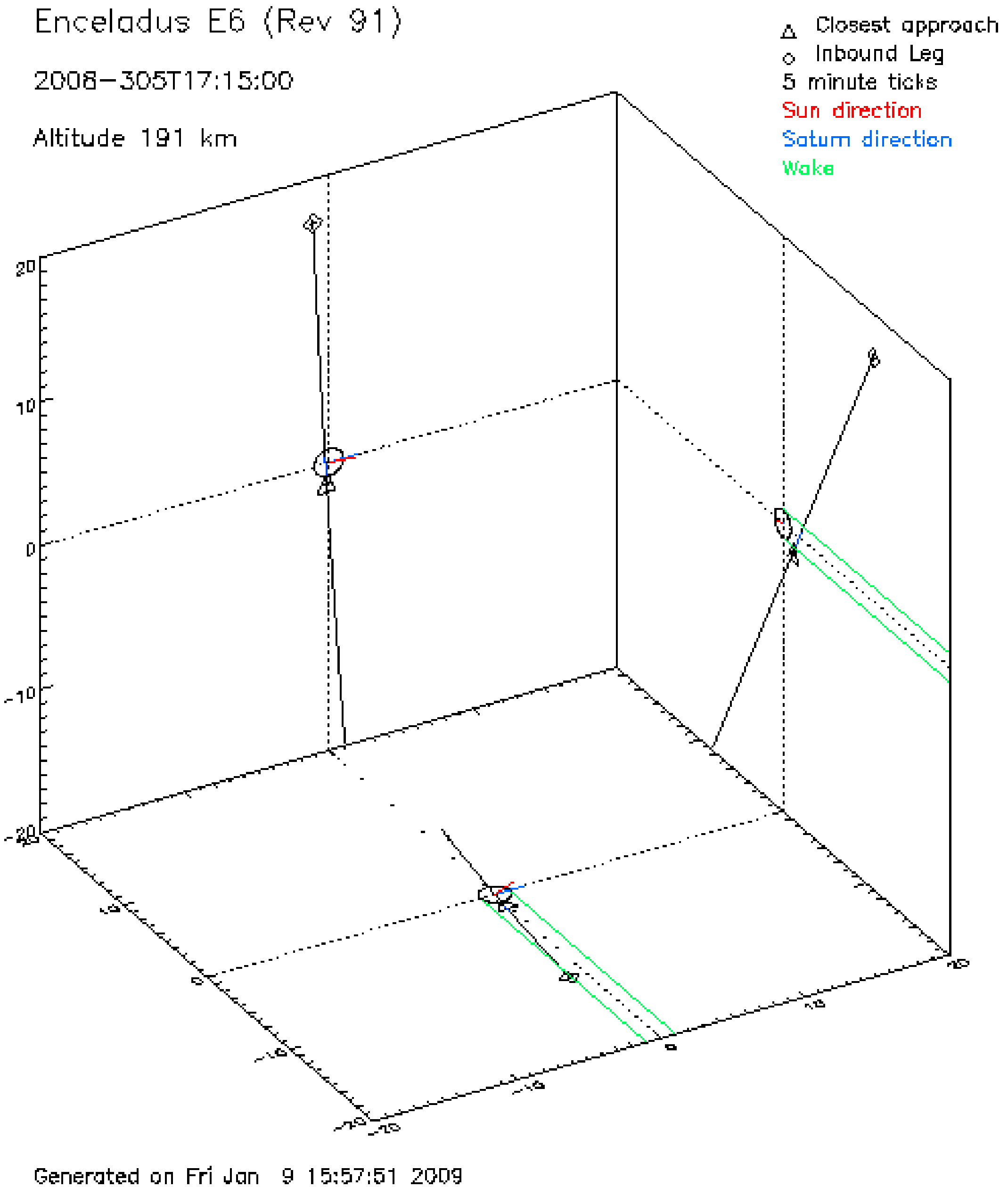


E3 and E5: low mass negative ions observed in ram direction when crossing the plume



Jones et al. 2006

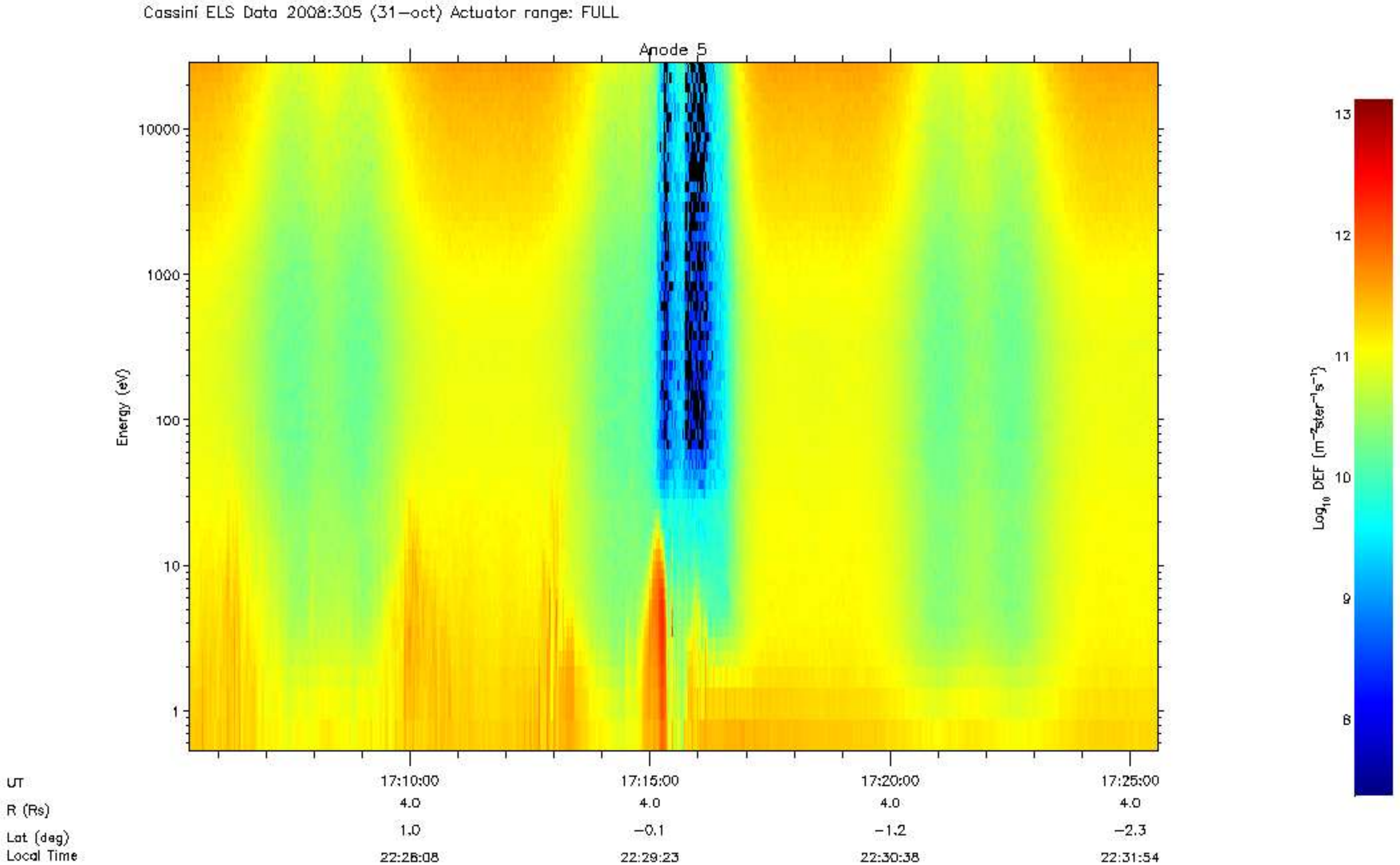
E6

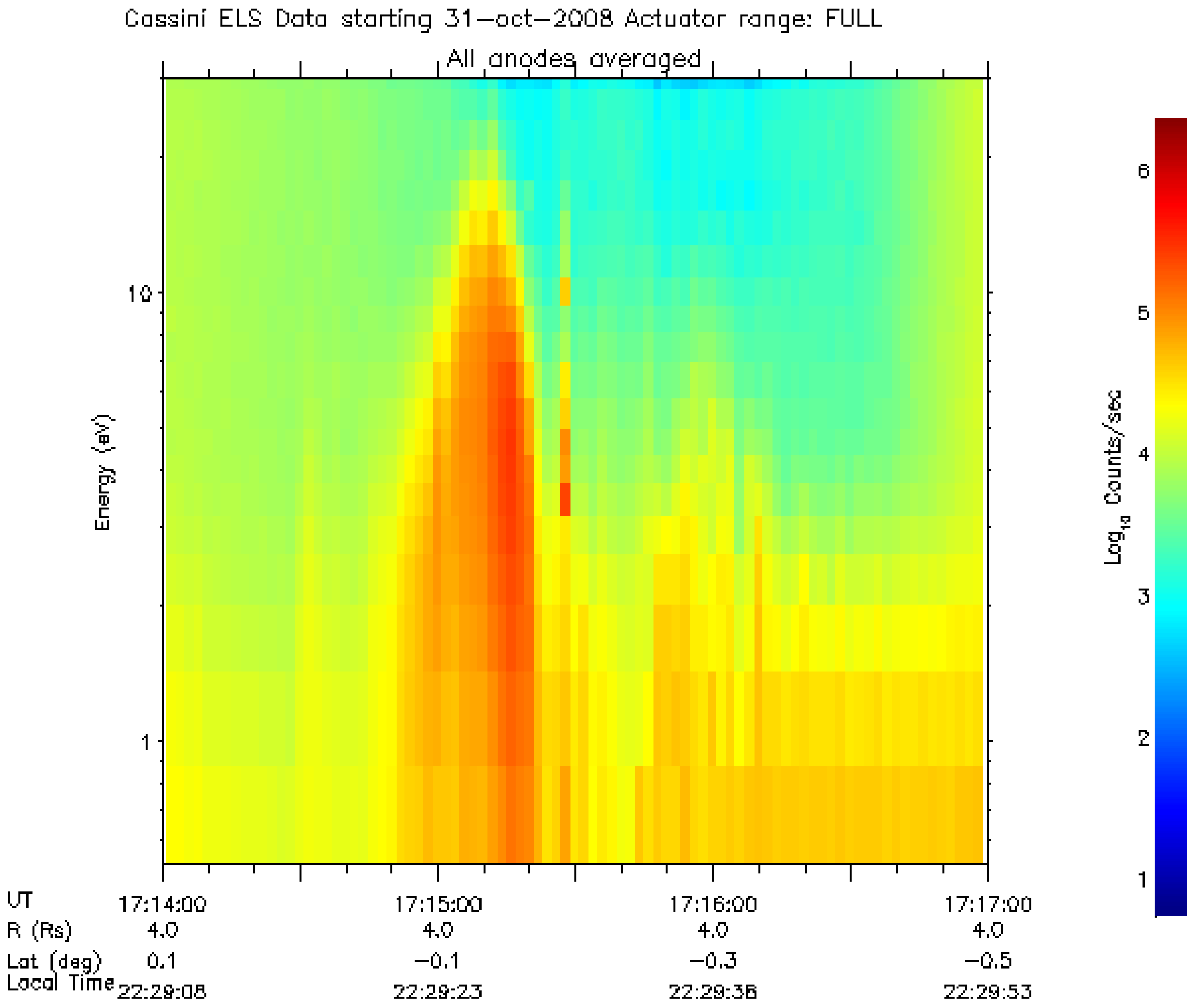


Enceladus E6 (Rev 91)
2008−305T17:15:00
Altitude 191 km
Closest approach
Inbound Leg
5 minute ticks
Sun direction
Saturn direction
Wake
20
10
0
-10
-20
Generated on Fri Jan 9 15:57:51 2009

E6

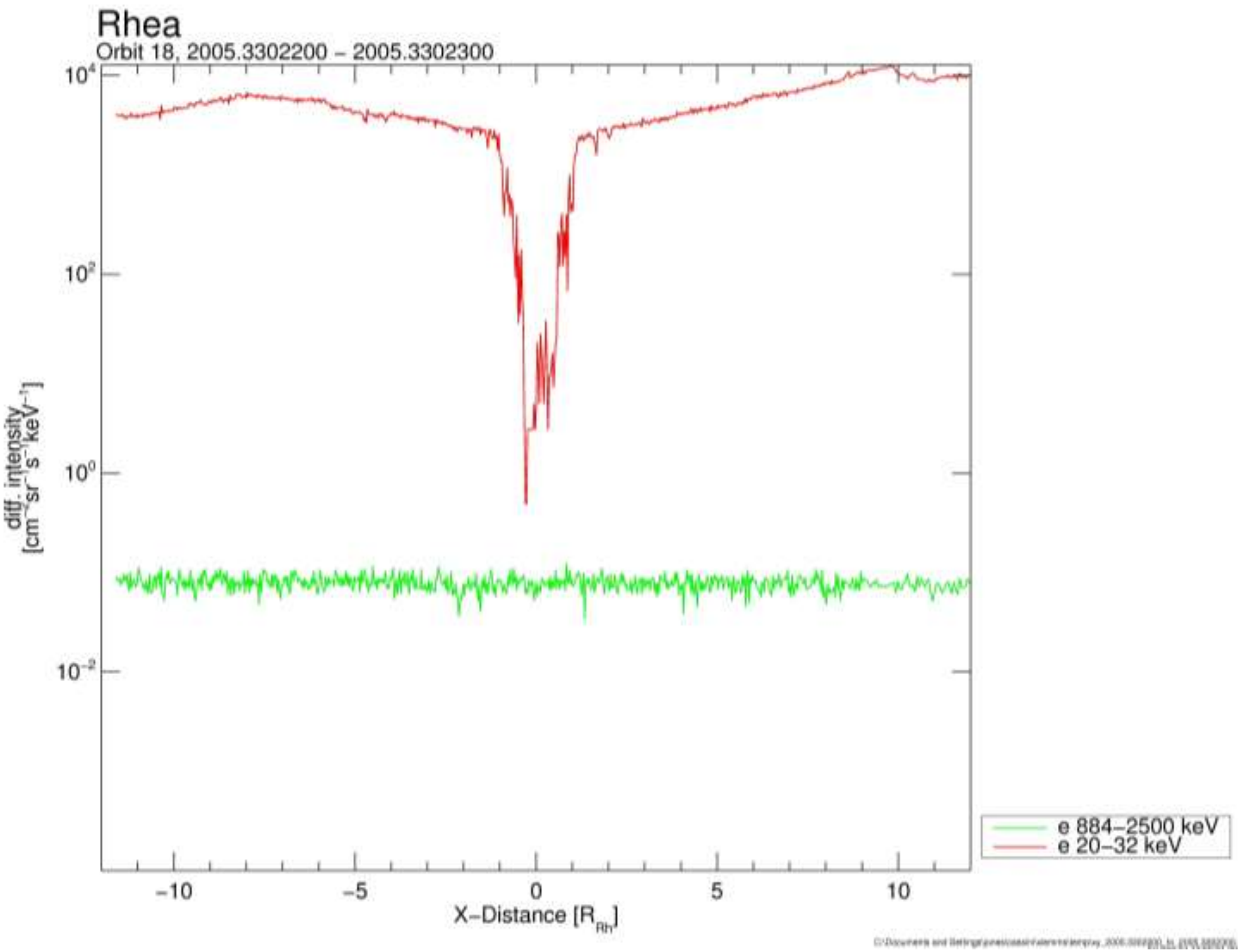
Negative ions detected in multiple anodes during single energy sweep; 17:15:28 UT.





Cassini ELS Data starting 31-oct-2008 Actuator range: FULL
All anodes averaged
Energy (eV)
10
1
UT
R (Rs)
Lat (deg)
Local Time
17:14:00
4.0
0.1
22:29:08
17:15:00
4.0
−0.1
22:29:23
17:16:00
4.0
−0.3
22:29:38
17:17:00
4.0
−0.5
22:29:53
Log_{10} Counts/sec
6
5
4
3
2
1

Electr


Rhea
Orbit 18, 2005.3302200 – 2005.3302300
diff. intensity [cm⁻²sr⁻¹s⁻¹keV⁻¹]
10⁴
10²
10⁰
10⁻²
−10
−5
0
5
10
X–Distance [R_Rh]
e 884–2500 keV
e 20–32 keV

CAPS actuating during E6 encounter: negative ions not only seen in ram direction; negative ion pickup ring observed.

Production of negative ions may only be very short-lived in Enceladus plume, confined to limited region.

Problem for very low mass negative ions: spacecraft negatively charged; affects observed E/q of particles – some uncertainty in inferred masses.

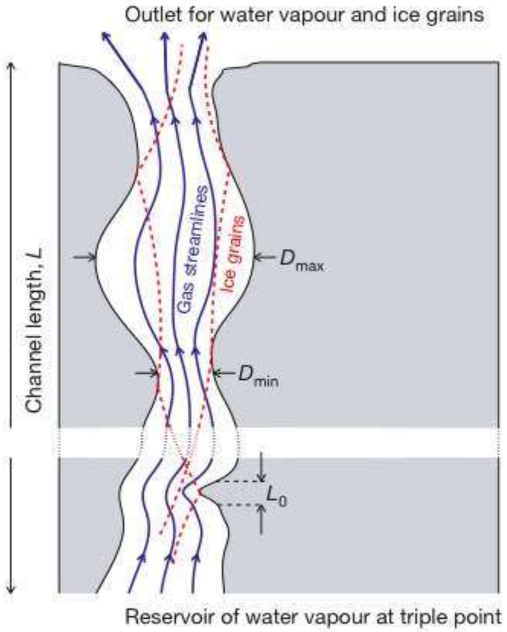
Perplexing upstream electrons observed during E13

Why do we see a mix of charges?

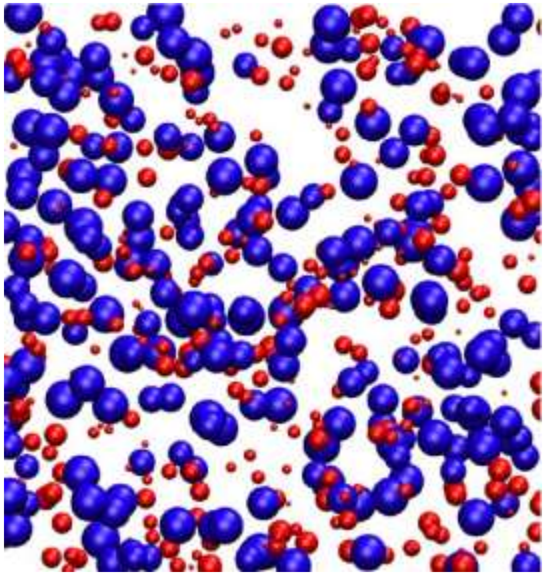
Schmidt et al (2007): grains condense within vents as gas travels towards surface. Range of grain sizes; frequent grain-grain and grain-wall collisions.

Simplest explanation for charge mix: triboelectric (frictional) charging within the plume vents.

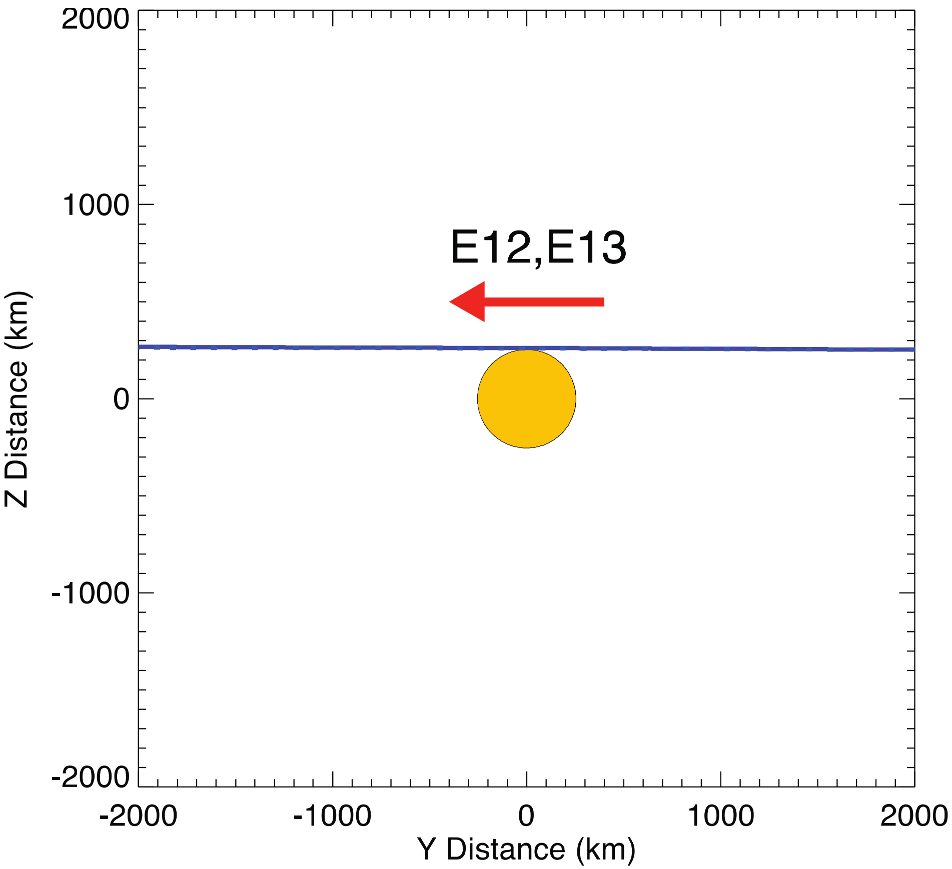
Flows of insulating grains can result in charging to both negative and positive states (e.g sandstorms); successfully modelled (e.g. Duff & Lacks, 2008).

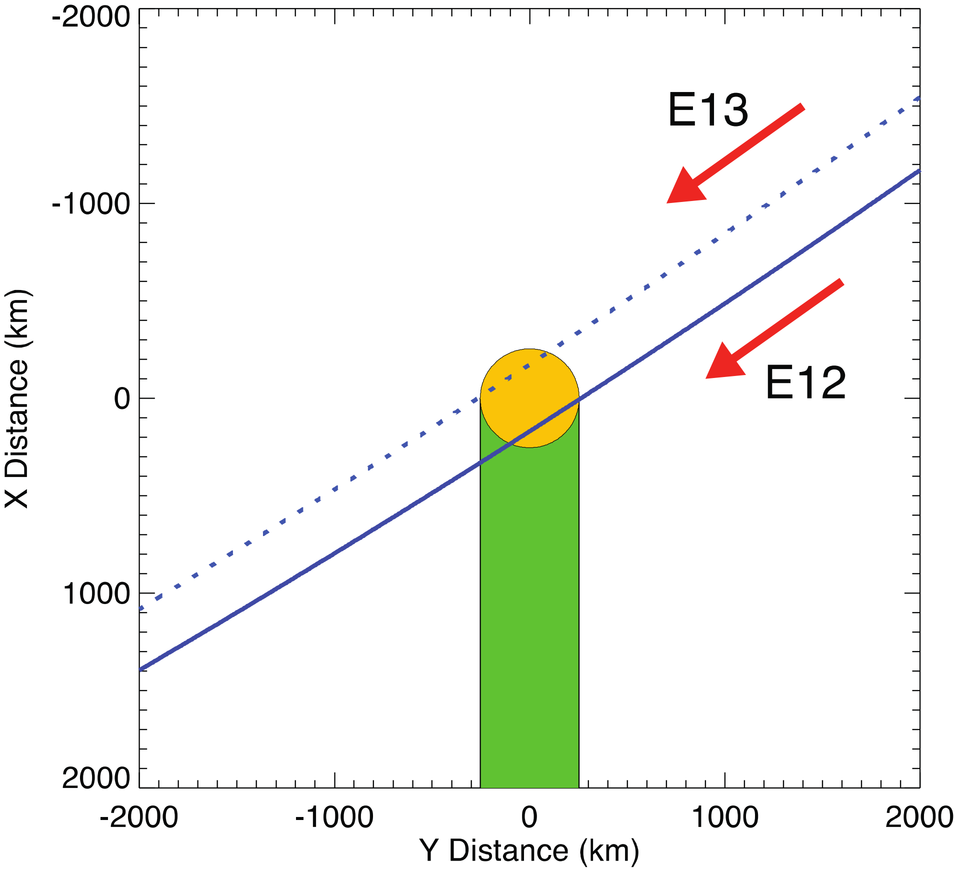


Smaller grains tend to charge negative, larger ones positive.



Appears correct to qualitative level in CAPS data; needs quantitative analysis



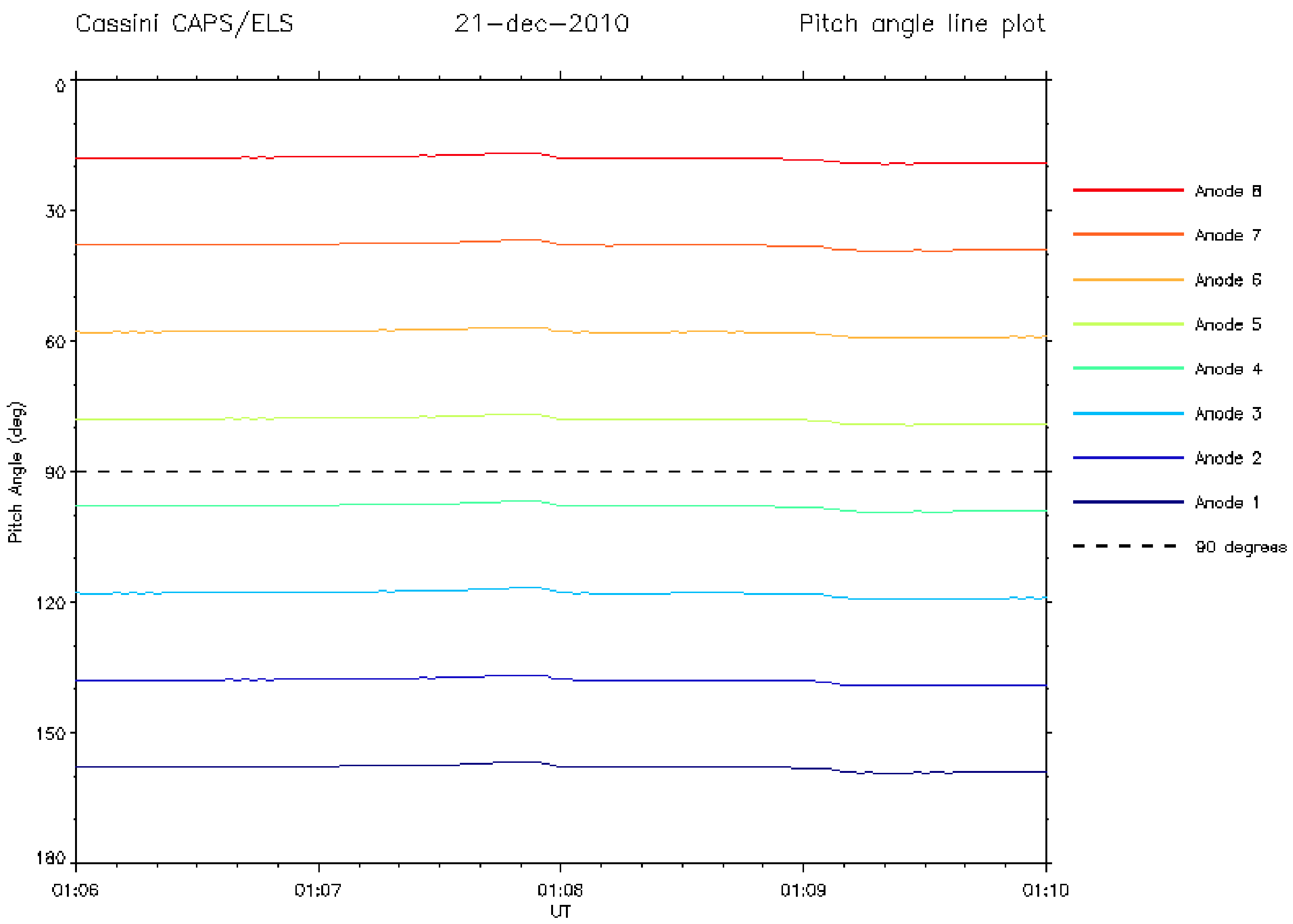


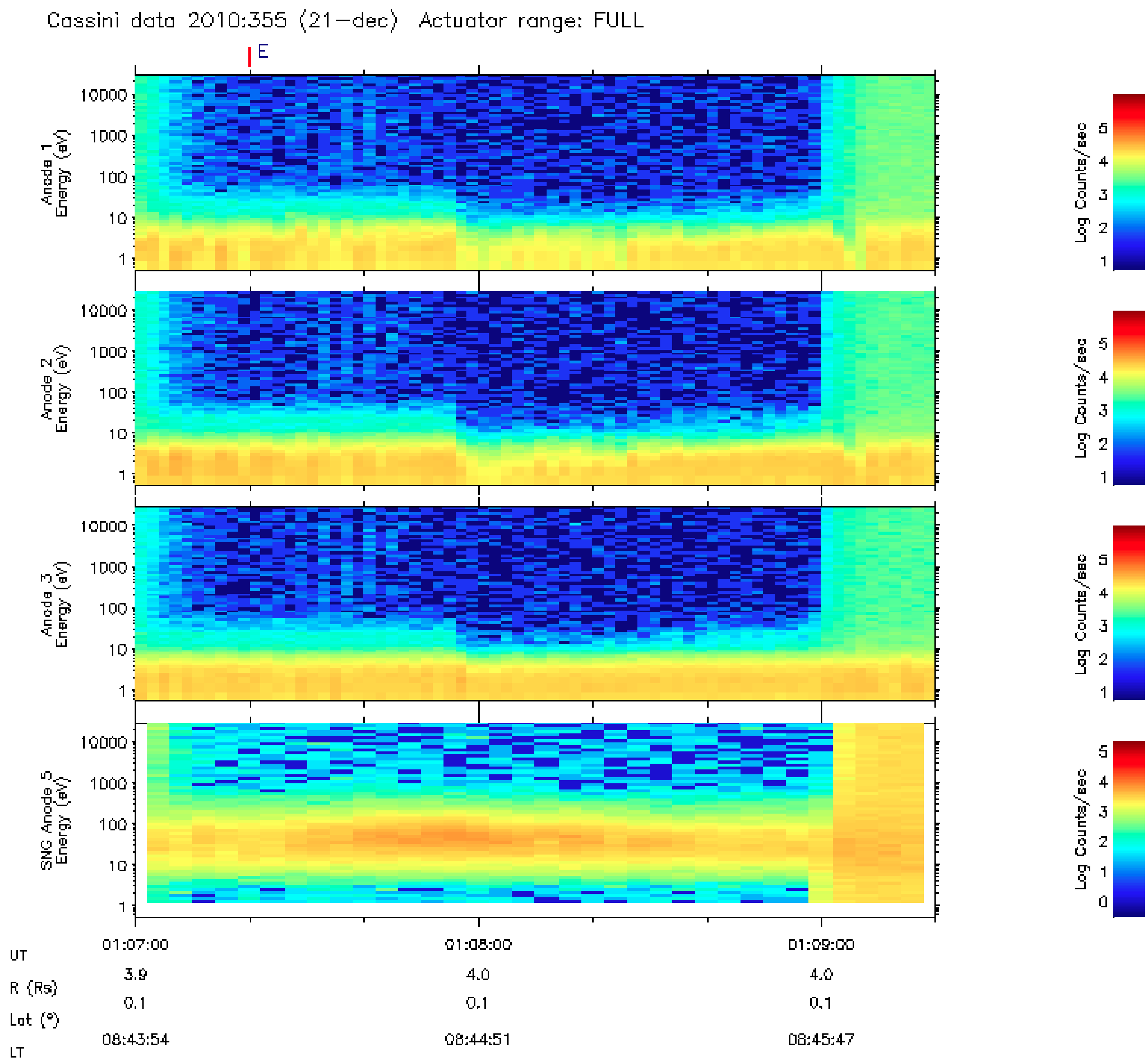
E12: 2010-11-30 (334)

E13: 2010-12-21 (355)

Approach from upstream direction (i.e. Keplerian trailing side)

Excellent pitch angle coverage

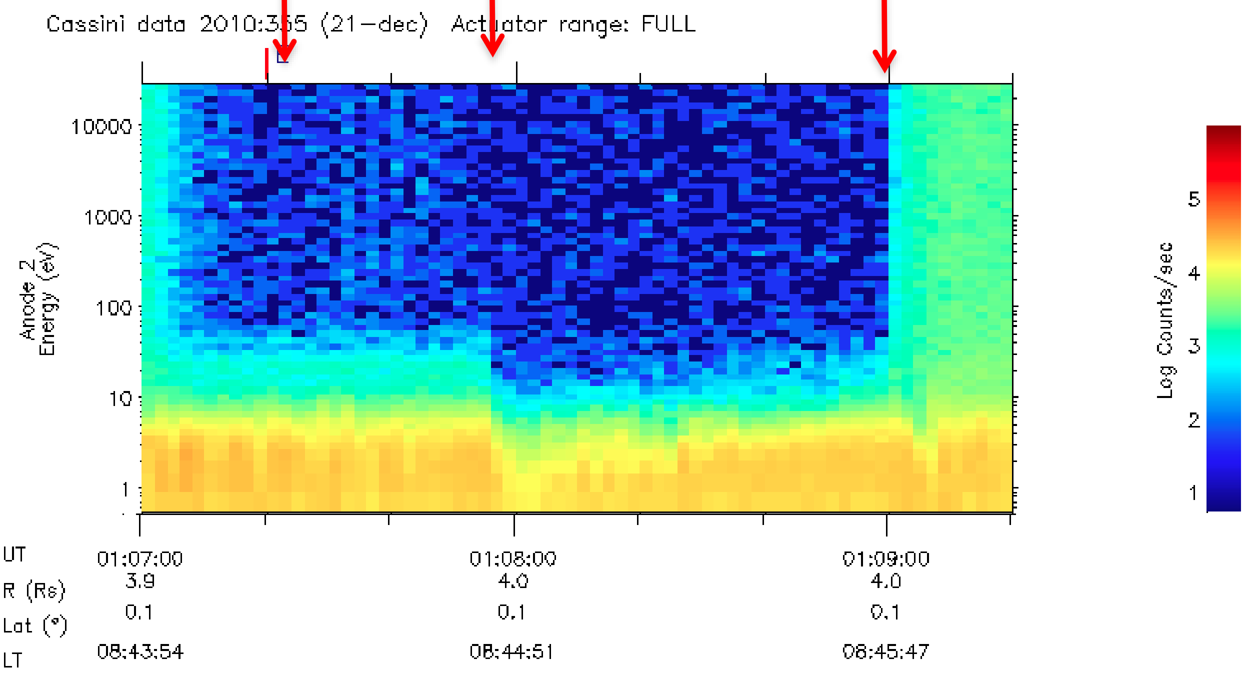


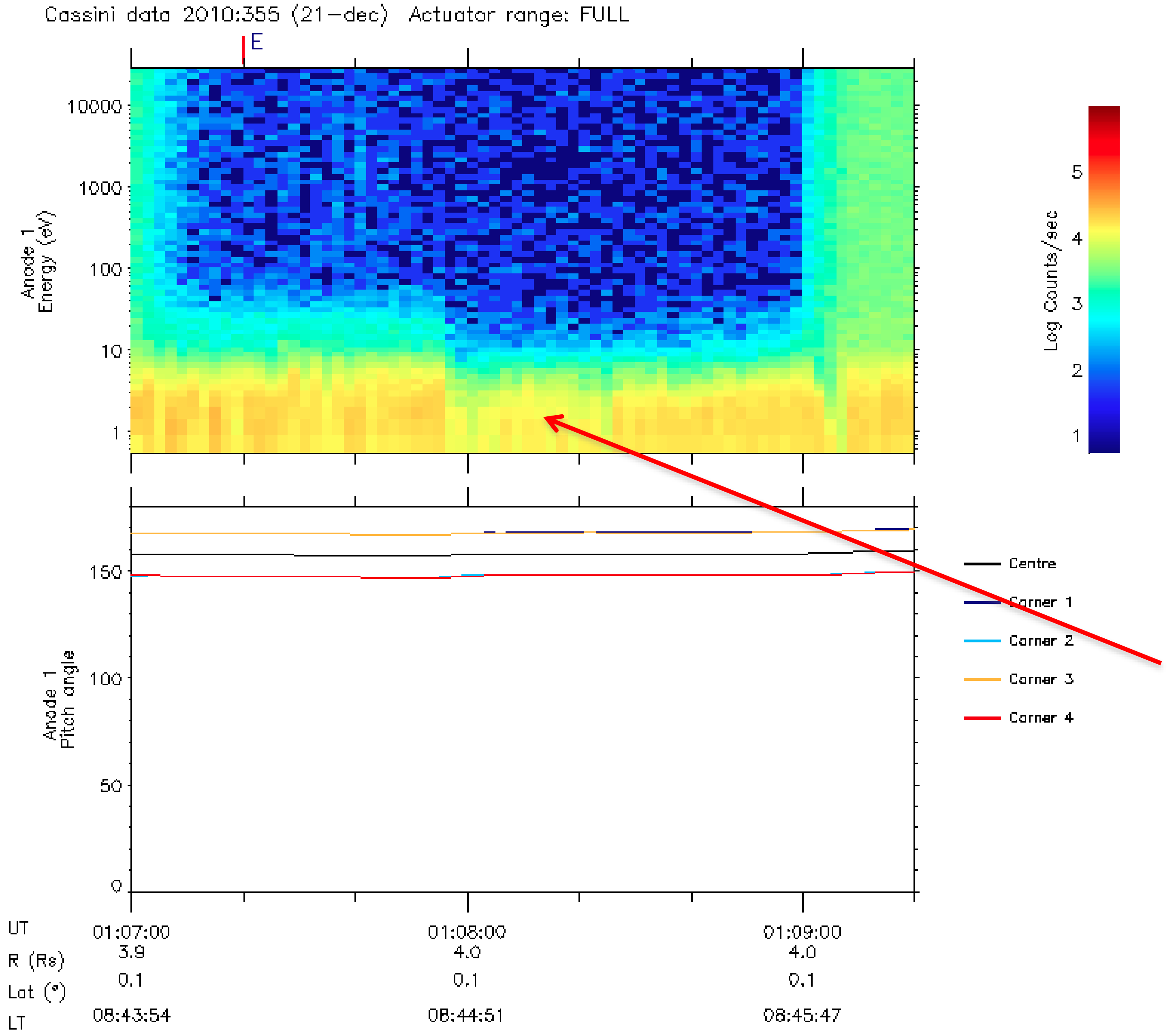

Cassini data 2010:355 (21-dec) Actuator range: FULL
E
Anode 1 Energy (eV)
Anode 2 Energy (eV)
Anode 3 Energy (eV)
SNG Anode 5 Energy (eV)
10000
1000
100
10
1
Log Counts/sec
UT
R (Rs)
Lat (°)
LT
01:07:00
01:08:00
01:09:00
3.9
4.0
4.0
0.1
0.1
0.1
08:43:54
08:44:51
08:45:47

Moves north of
Enceladus disk 01:07:53

Entering
Microsignature 01:07:23

Leaving
Microsignature 01:08:59





These electrons from direction of Enceladus surface: secondary electrons or reflected by negative surface potential.