Electrons in the Plume of Enceladus and the Role of Grain Interactions

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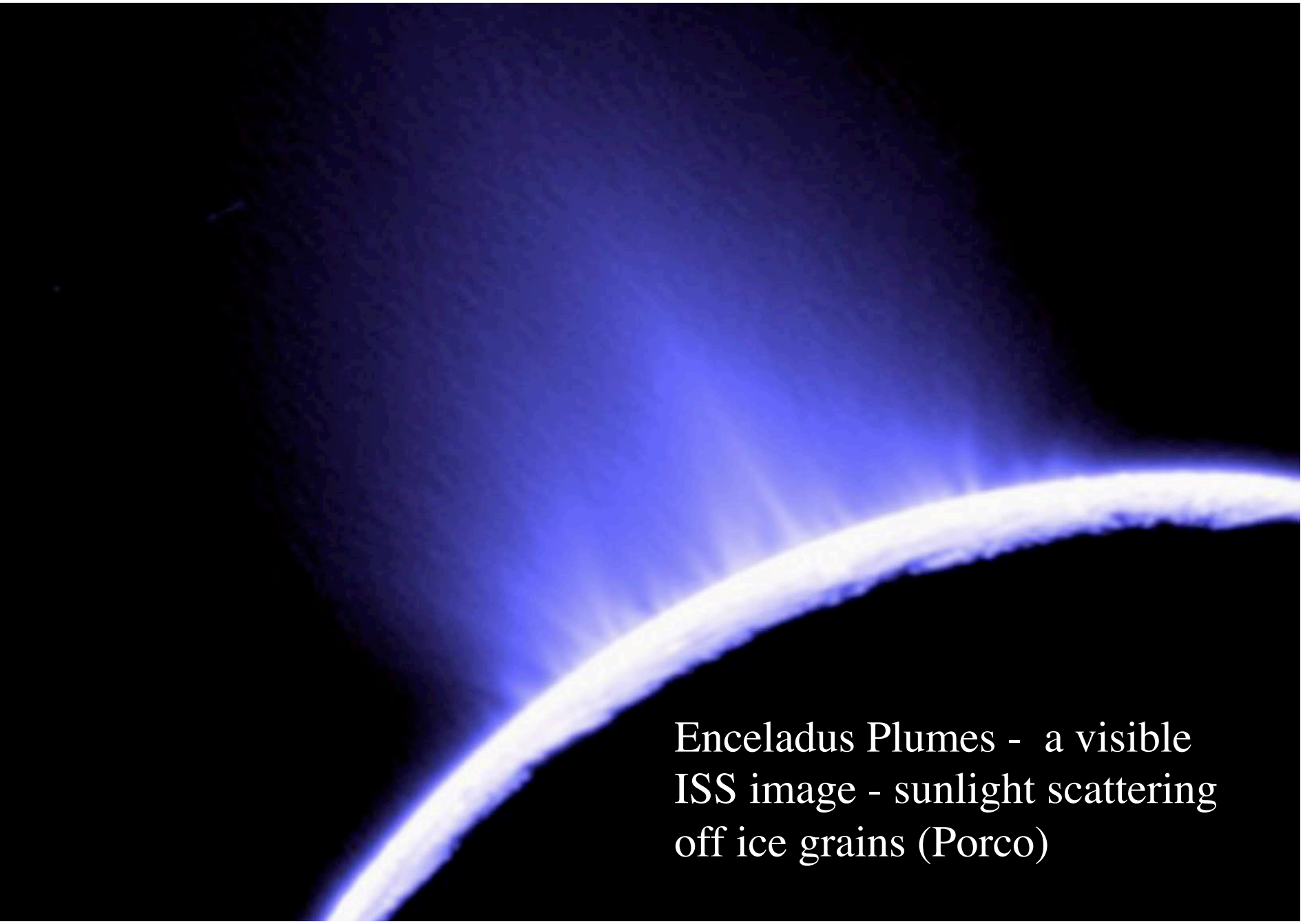
Plume and Torus Electrons and Ions - some references

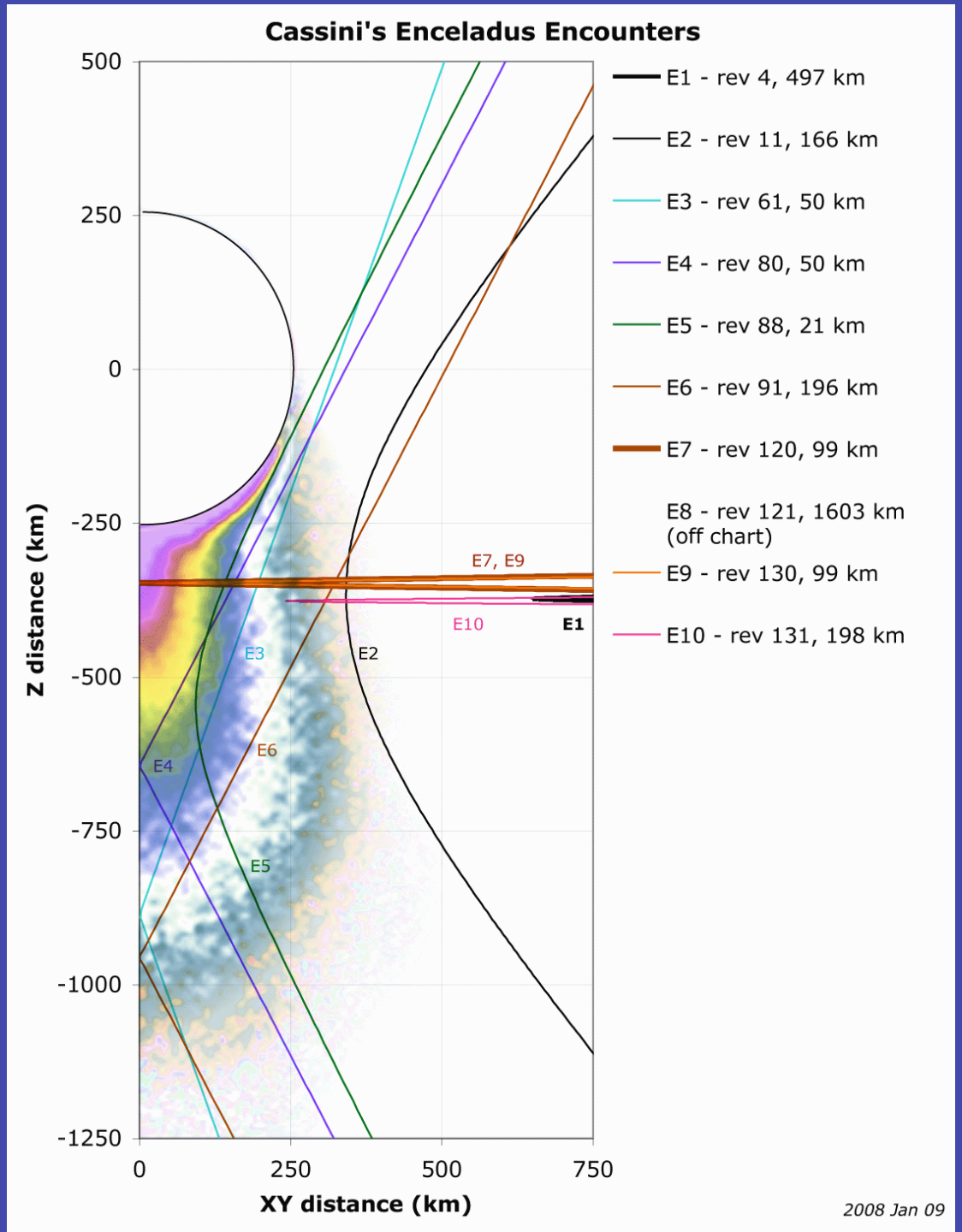
- Cravens et al. (2011) (torus electrons)
- Ozak et al. (2012) (plume electrons)
- Cravens et al. (2009) (plume ion composition)
- Pothapragada - poster here at DAP (plume ions and grains)

Grains in the Enceladus Plume (and E-ring) - some references

- Kempf et al. (2008)
- Hsu et al. (2011, 2012)
- Hill et al. (2012)
- Jones et al. (2009)
- Morooka et al. (2011)
- ……



Enceladus Plumes - a visible ISS image - sunlight scattering off ice grains (Porco)



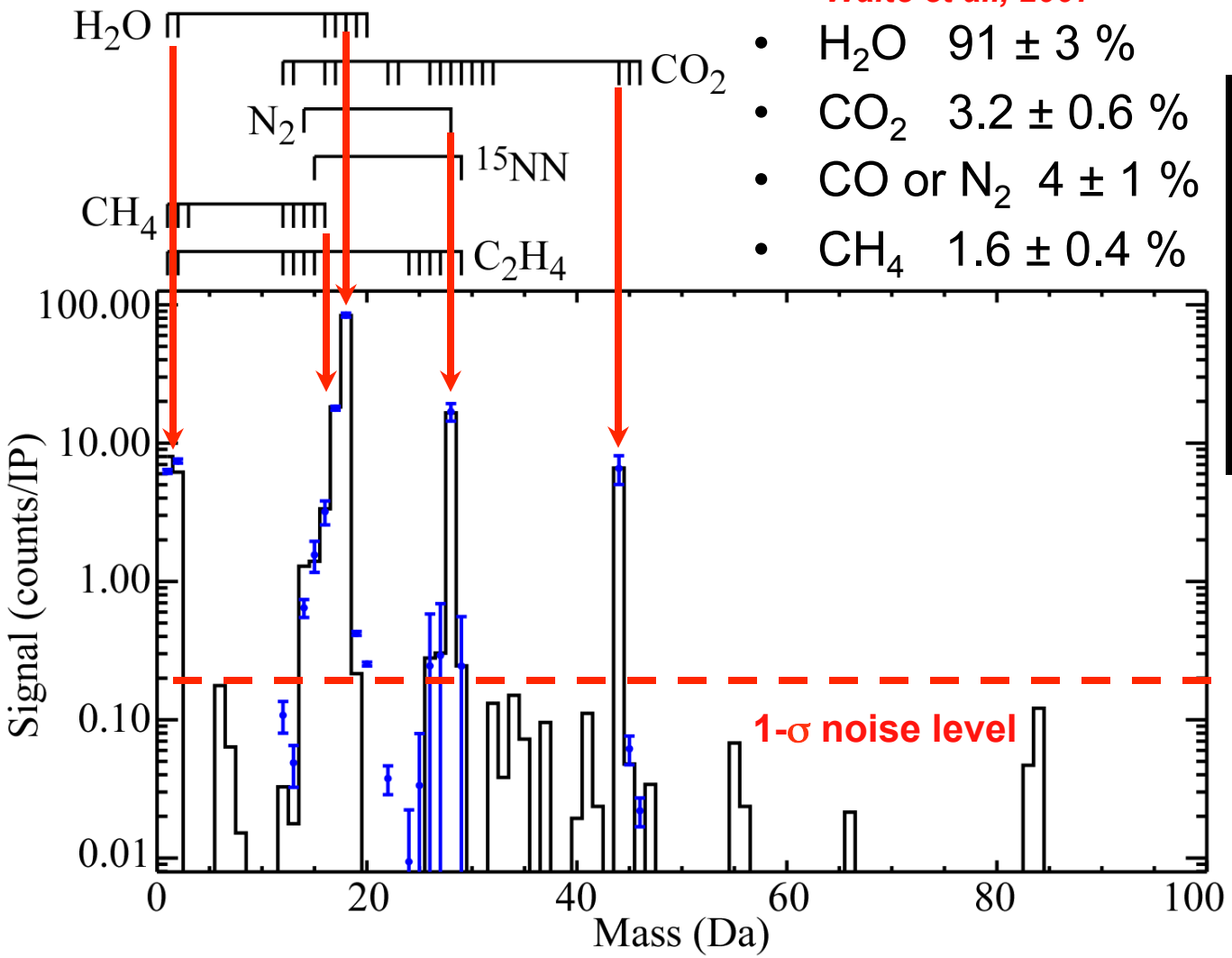
Cassini-Enceladus Plume Encounter Geometry.

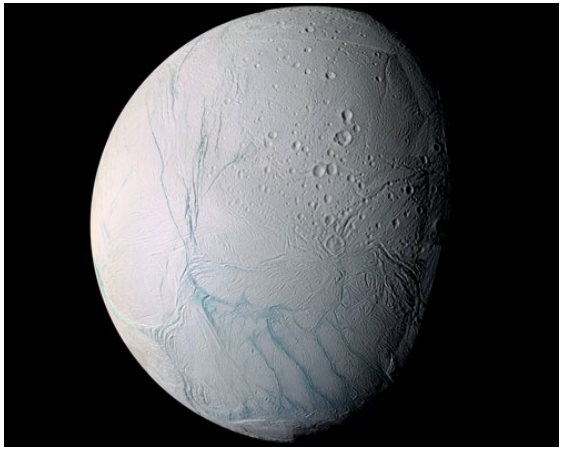
The E3 and E7 passes are the focus of this talk.

Enceladus: Cassini INMS Mass Spectra of the Atmosphere of Enceladus (E2) - Waite et al. 06

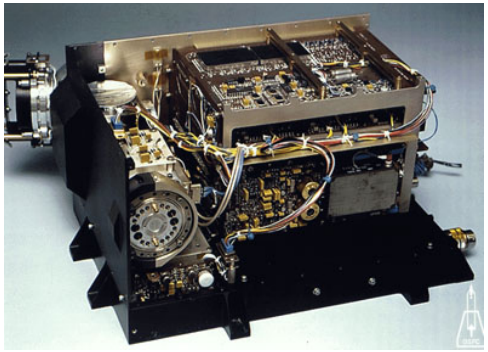
Waite et al., 2007

- H_2O 91 ± 3 %
- CO_2 3.2 ± 0.6 %
- CO or N_2 4 ± 1 %
- CH_4 1.6 ± 0.4 %



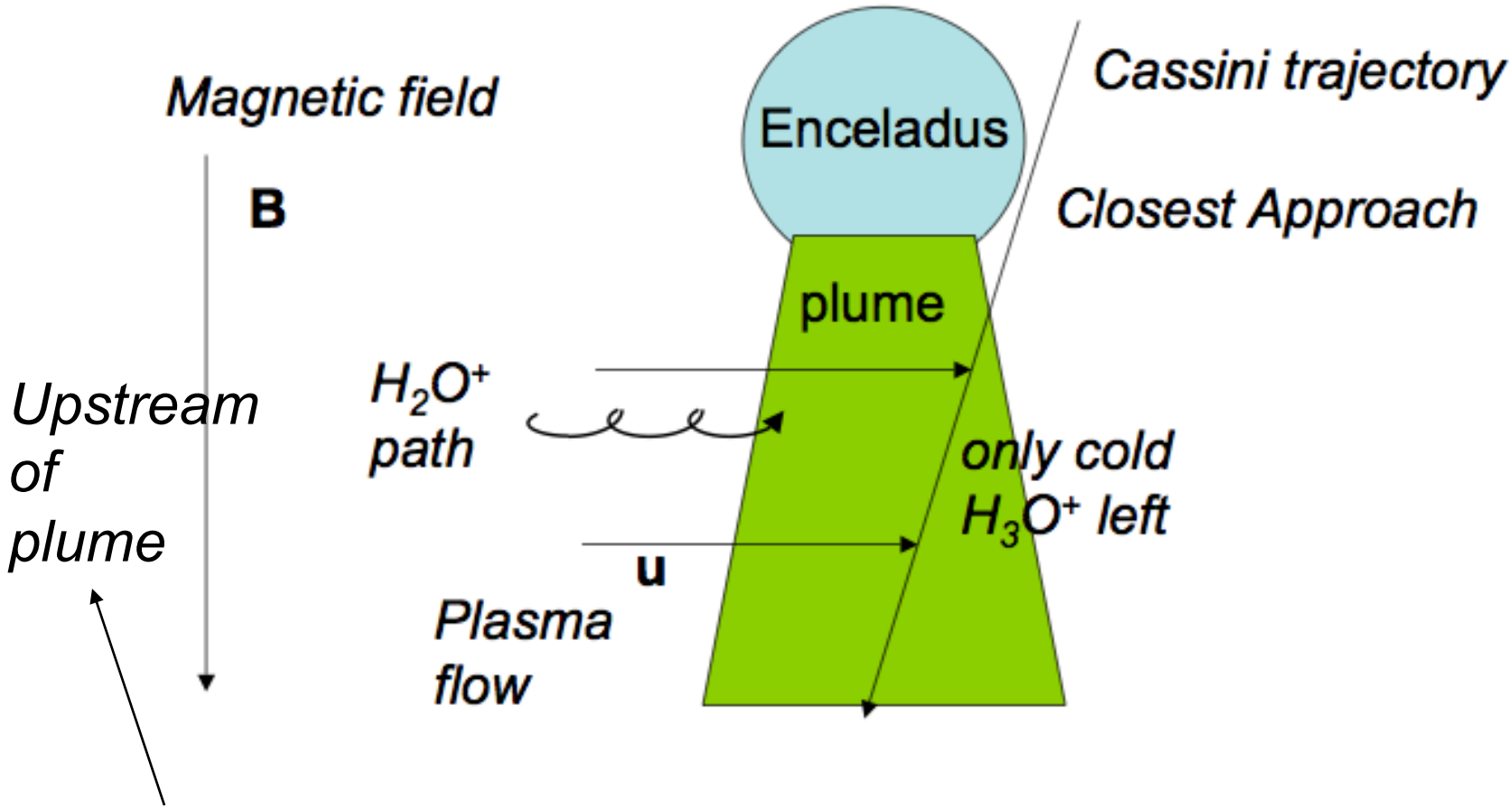


2 micron false color image from VIMS; fresh crystalline ice is blue



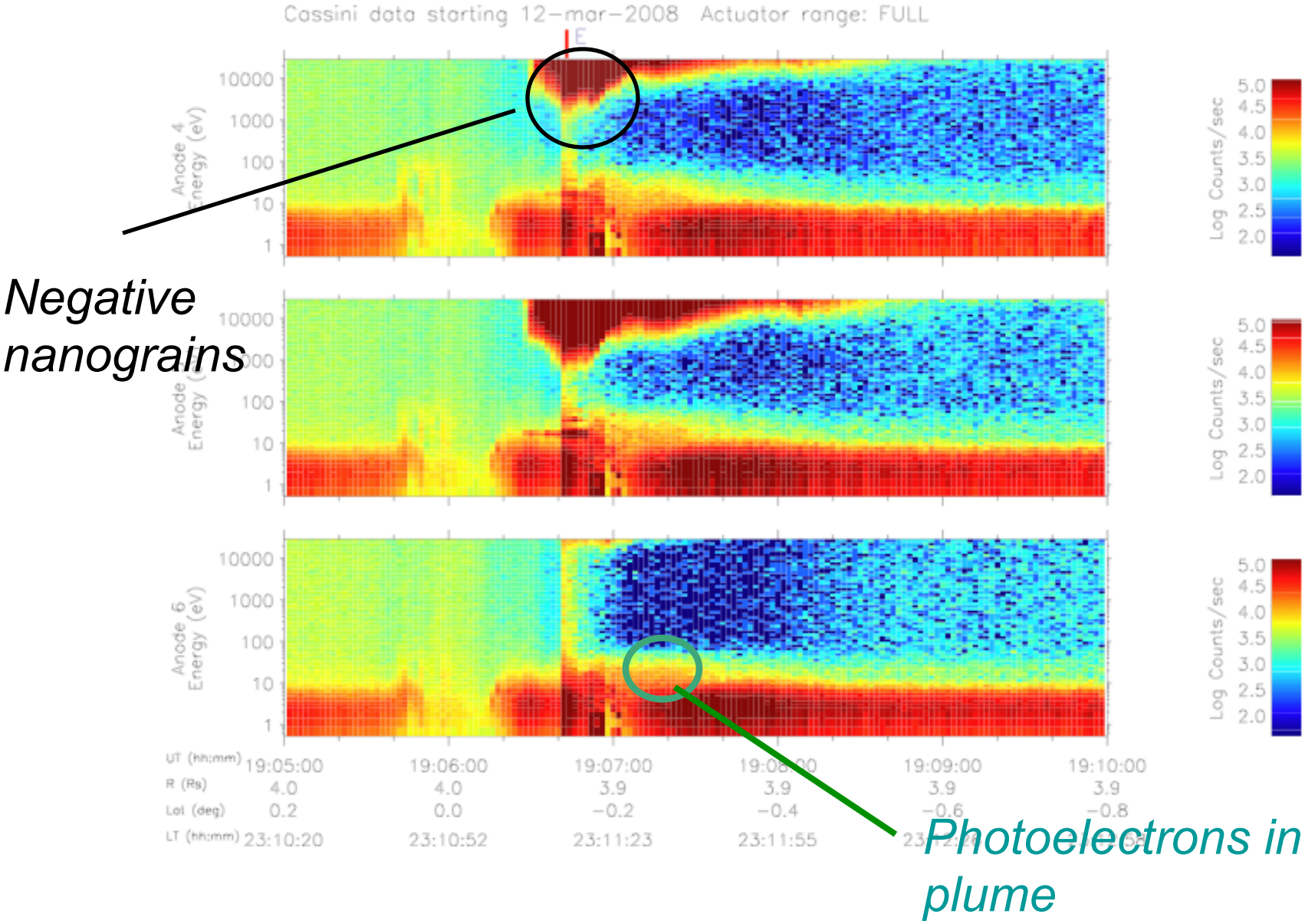
- INMS

Schematic of Ion Flow in the Enceladus Plume



$n_e \approx 80\ cm^{-3}$ and $V_{cor\text{-}enc} = 26$ km/s (corotation speed relative to Enceladus). Mainly water group ions (O^+, OH^+, H_2O^+, H_3O

CAPS ELS data for E3 - electrons must be distinguished from negative ions.

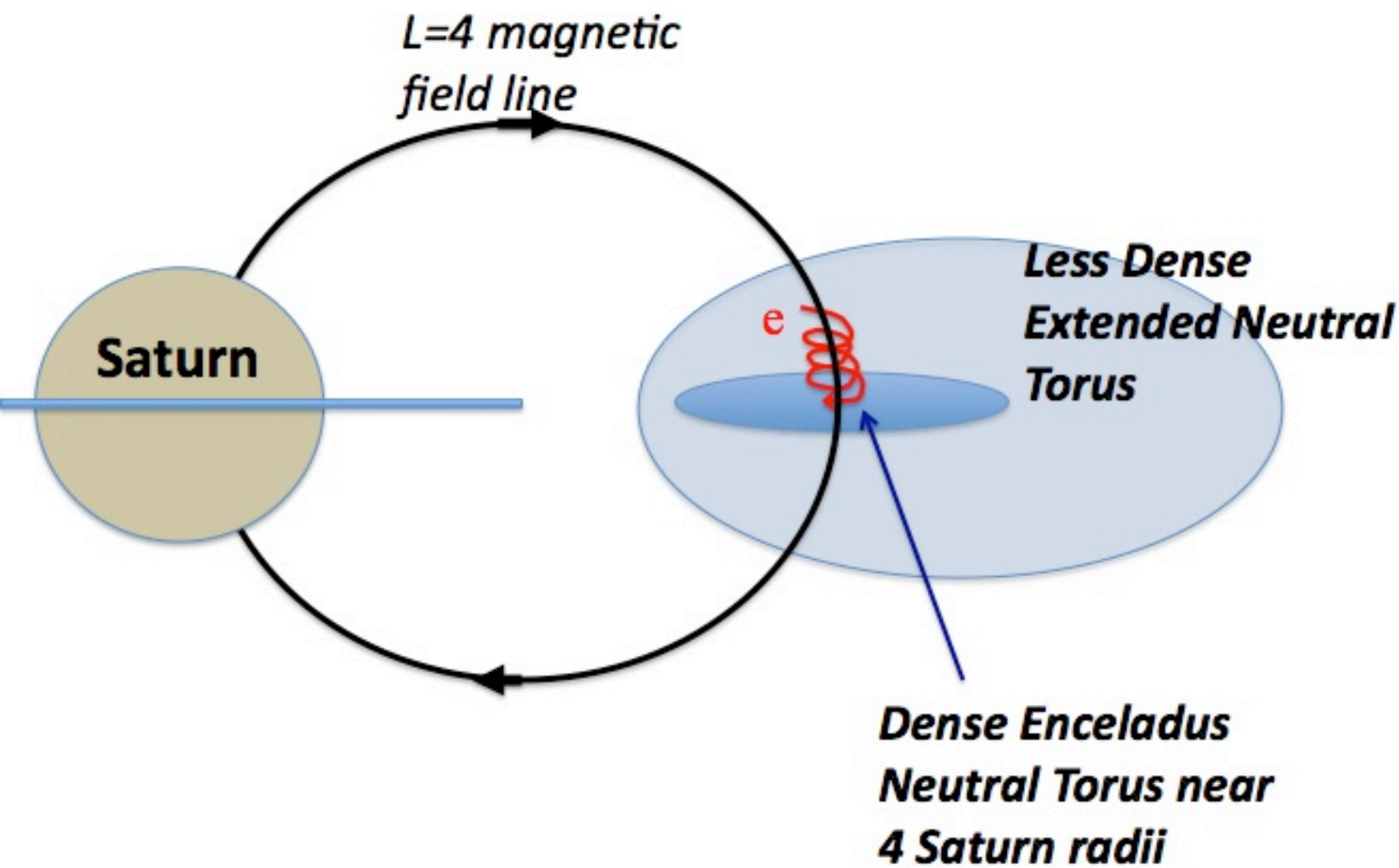


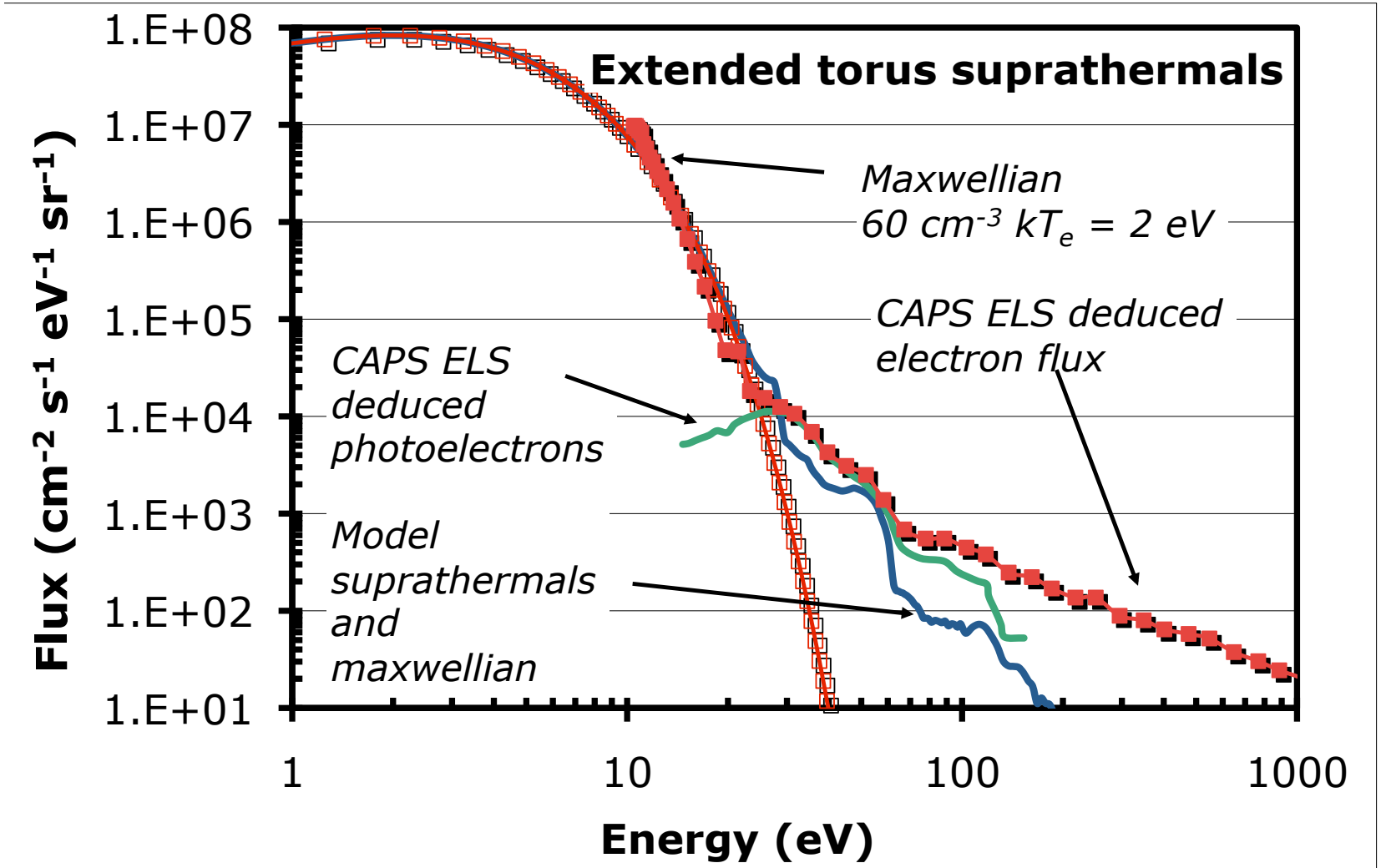
Plume Particle Populations

- Positive (and negative) ions (H_3O^+), both from magnetosphere and locally produced.
- Suprathermal electrons (E≈10eV) from magnetosphere and photoionization.
- Thermal electrons (2 eV) from thermalized suprathermals.
- Negative (and positive and neutral) nanograins.
- Larger grains (negatively charged).

Plume Particle Populations contd.

- Neutral density ≈ 10^8 cm^{-3} at r ≈ 2-3 R_{enc}.
- Ion density ≈ 80 cm^{-3} outside and 1000 - 10000 cm^{-3} inside.
- Electron density ≈ 80 cm^{-3} outside and 20 cm^{-3} inside.
- Suprathermal electron (> 10 eV) density ≈ 1 cm^{-3}.
- Negative nanograin density ≈ 10^3 cm^{-3}.
- Larger grains (micron), density ≈ 10^{-7} cm^{-3}.


L=4 magnetic
field line
Saturn
e
Less Dense
Extended Neutral
Torus
Dense Enceladus
Neutral Torus near
4 Saturn radii



Extended Torus Suprathermals (and thermal electrons): Data (Schippers et al., 2009 - CAPS ELS) and Model (Cravens et al, 2011).

Electrons In Torus *and Plume*

- Two electron populations (hot and cold) are evident in Saturn' s inner magnetosphere (Voyager and Cassini data).
-
- (1) ***Cold*** -- recent data: Cassini RPWS/LP electron temperatures of 1- 3 eV near L ≈ 4 (*Gustaffson and Wahlund*, 2010).
- (2)***Hot*** -- suprathermal electrons with a photoelectron component observed by the Cassini CAPS ELS (*Schippers et al*., 2009).

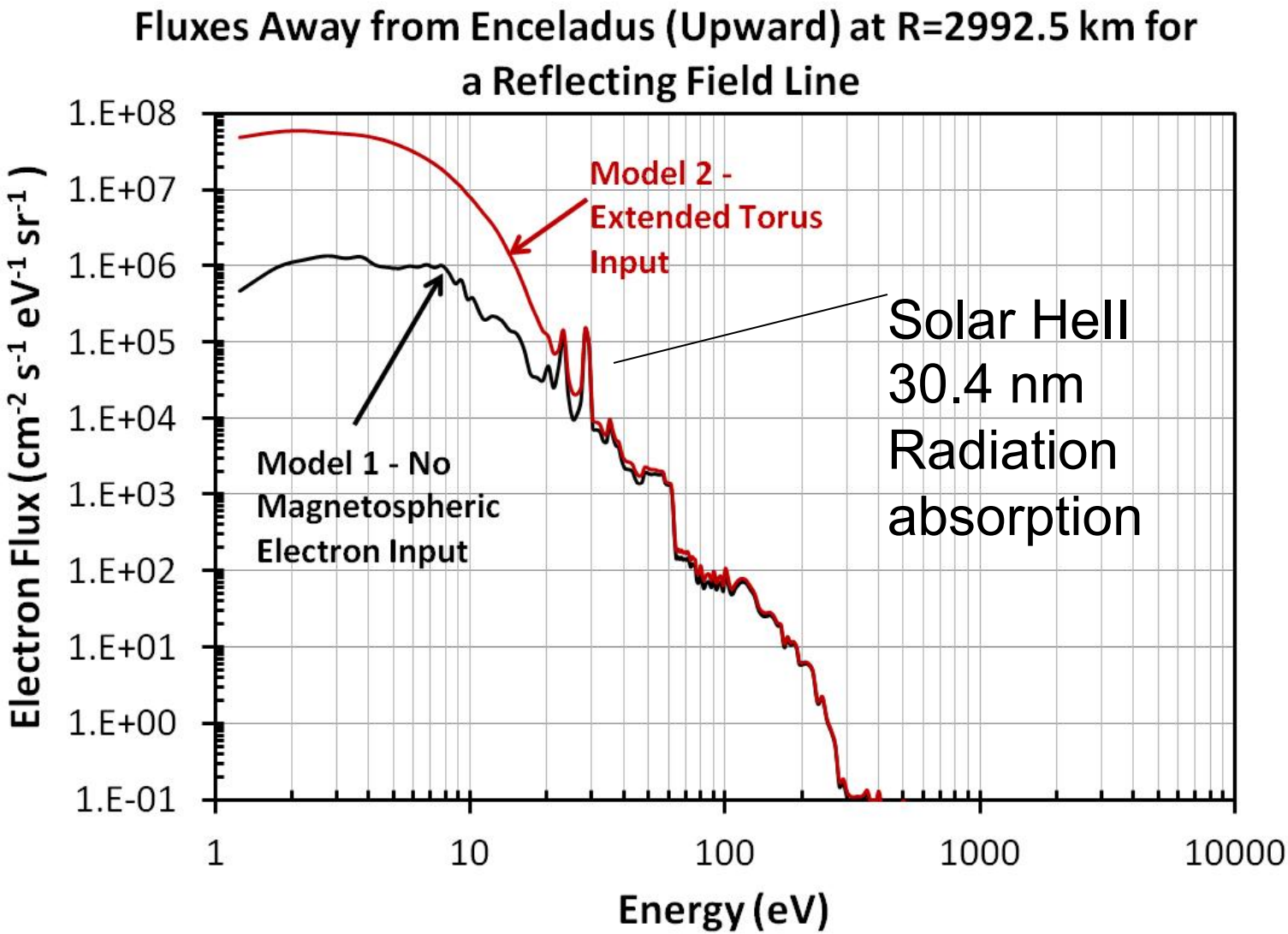
Processes - Suprathermal Electrons

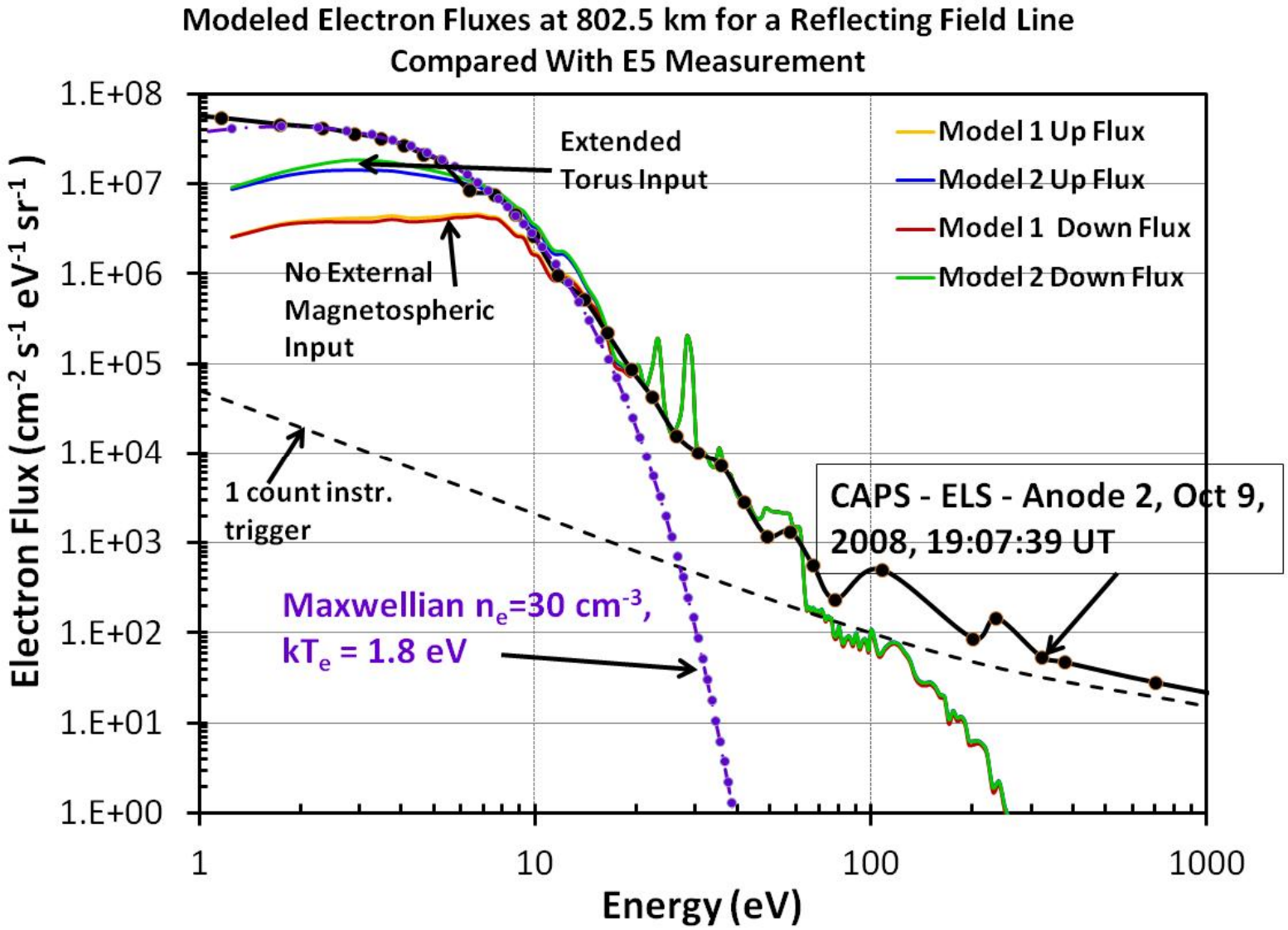
- Creation of photoelectrons by photoionization of neutrals by solar radiation
- Transport along magnetic field
- Elastic scattering
- Collisions: ionization (secondary electrons)
- Collisions: electronic excitation
- Collisions: rotational and vibrational excit.
- Coulomb collisions - heat thermal electrons
- (collisions with neutral and charged grains)

Model Cases for Plume 2-Stream Code

- *External electrons inputs:*
- (1) zero incident flux at outer boundary
- (2) torus model electron spectrum used as boundary condition

- *Surface Boundary Conditions*
- (1) all electrons aborbed
- (2) all electrons reflected


Fluxes Away from Enceladus (Upward) at R=2992.5 km for a Reflecting Field Line
Electron Flux (cm-2 s-1 eV-1 sr-1)
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1
10
100
1000
10000
Energy (eV)
Model 2 - Extended Torus Input
Model 1 - No Magnetospheric Electron Input
Solar HeII 30.4 nm Radiation absorption


Modeled Electron Fluxes at 802.5 km for a Reflecting Field Line
Compared With E5 Measurement
Electron Flux (cm-2 s-1 eV-1 sr-1)
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1
10
100
1000
Energy (eV)
Extended
Torus Input
No External
Magnetospheric
Input
1 count instr.
trigger
Maxwellian ne=30 cm-3,
kTe = 1.8 eV
CAPS - ELS - Anode 2, Oct 9,
2008, 19:07:39 UT
Model 1 Up Flux
Model 2 Up Flux
Model 1 Down Flux
Model 2 Down Flux

Plume Electron Conclusions

- Photoelectrons produced by solar radiation from the plume gas are important within a few R_{enc}.
- The energy spectra look similar to the torus electron spectra - photoelectrons from solar ionization of neutrals.
- External inputs (I.e., torus electrons) also seem to be important outside of a few R_{enc} but not near the surface where the mean free path is small.
- *Role of grains? Beams?*

Electron Absorption by Nanograins?

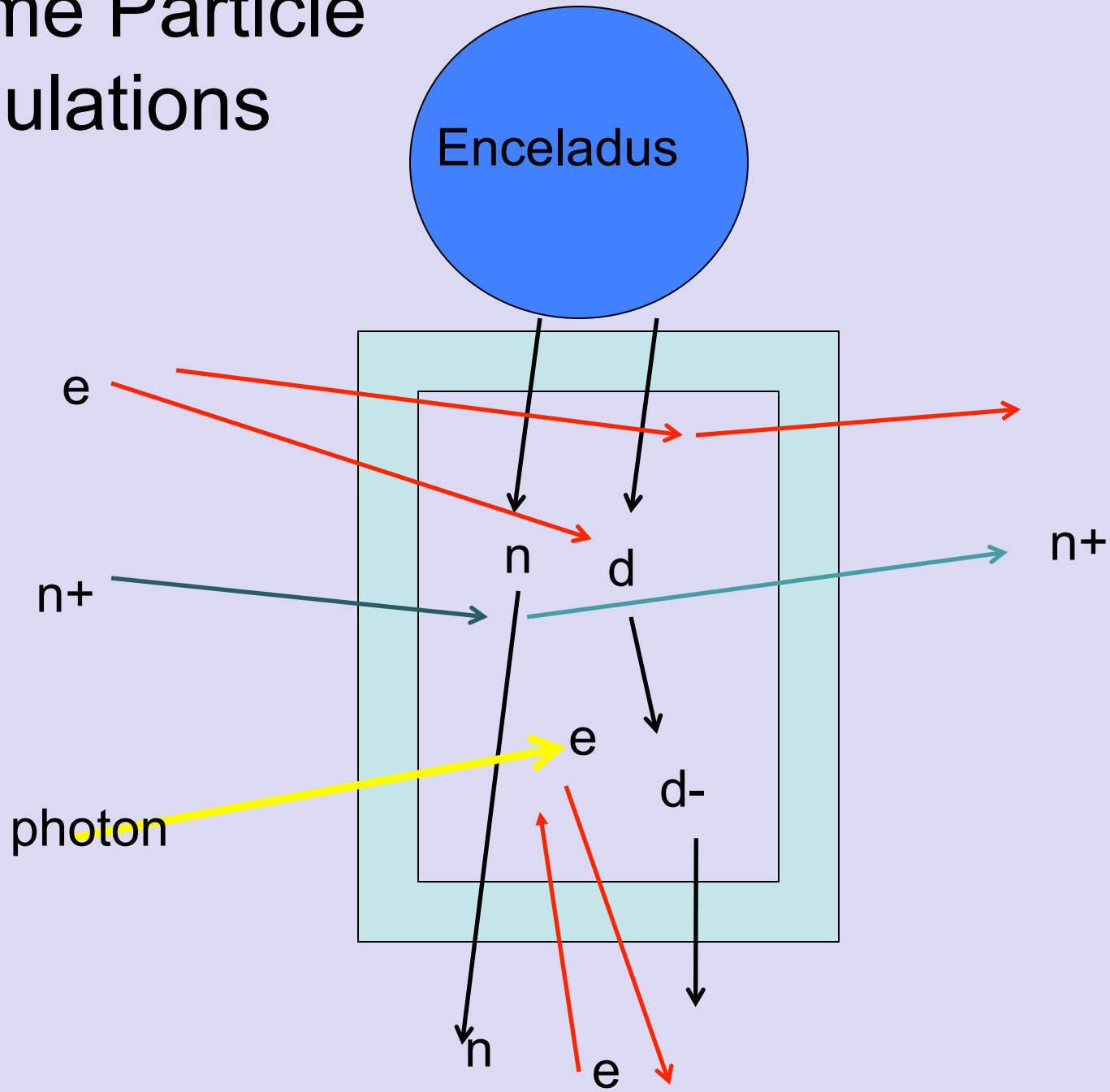
- Grain absorption should affect the electron spectrum if $n_d\sigma_d$ is equal to, or exceeds $n_g\sigma_g$. For nanograins this translates to $n_d / n_g > .003$
- Or $n_d > 10^5$ cm^{-3} (Hill et al., 10^3 cm^{-3})
- But low energy electrons could be affected much more than suprathermal electrons.
- UV absorption by grains (and grain photoelectron production) could also affect the suprathermal electron spectrum in the plume.

Plasma-Grain Processes

- Photon + d --> d^+ + e
- n^+ + d ---> d^+ (or d^- for energetic ion)
- e + d ---> d^- (important)
- e + d^- <---> e + d^- (scattering)

- *Our calculations show that grains cannot have important effects on hot, suprathermal electrons, but..*
- *Electron depletion in plume plus presence of negative nanograins indicates that colder ("thermal"?) electrons must collide with grains and are probably trapped (polarization electric field?) in the plume.*

Plume Particle Populations



Plasma-Grain Process Times

- convection time ≈ $2R_{enc} / u \approx 20 - 3 \times 10^2$ s
- parallel elec transp ≈ $3R_{enc}/u_e \approx 1$ s
- nanograin transport time ≈ $3R_{enc}/u_d \approx 1000$ s
- ion charge exchange ≈ $1/n_n v\sigma_{cx} \approx 10$ s
- 20 eV inelastic elec-neutral ≈ 1 s
- 2 eV inelastic elec-neutral ≈ 10 - 30 s
- 2 eV elastic elec-neutral ≈ 0.2 s (300 s diffusion transport time)
- elec -nanograin coll time ≈ 300 s
- nanograin charging time ≈ $e / I_e \approx 10^4$ s
- Ion density prod time ≈ $n_i / In_n \approx 10^3$ s