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Title:	CAPS: Ion Sources and Pick-Up Near Enceladus, Rhea and Dione
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Form 836 (7/06)

CAPS: Ion Sources and Pick-Up Near Enceladus, Rhea and Dione

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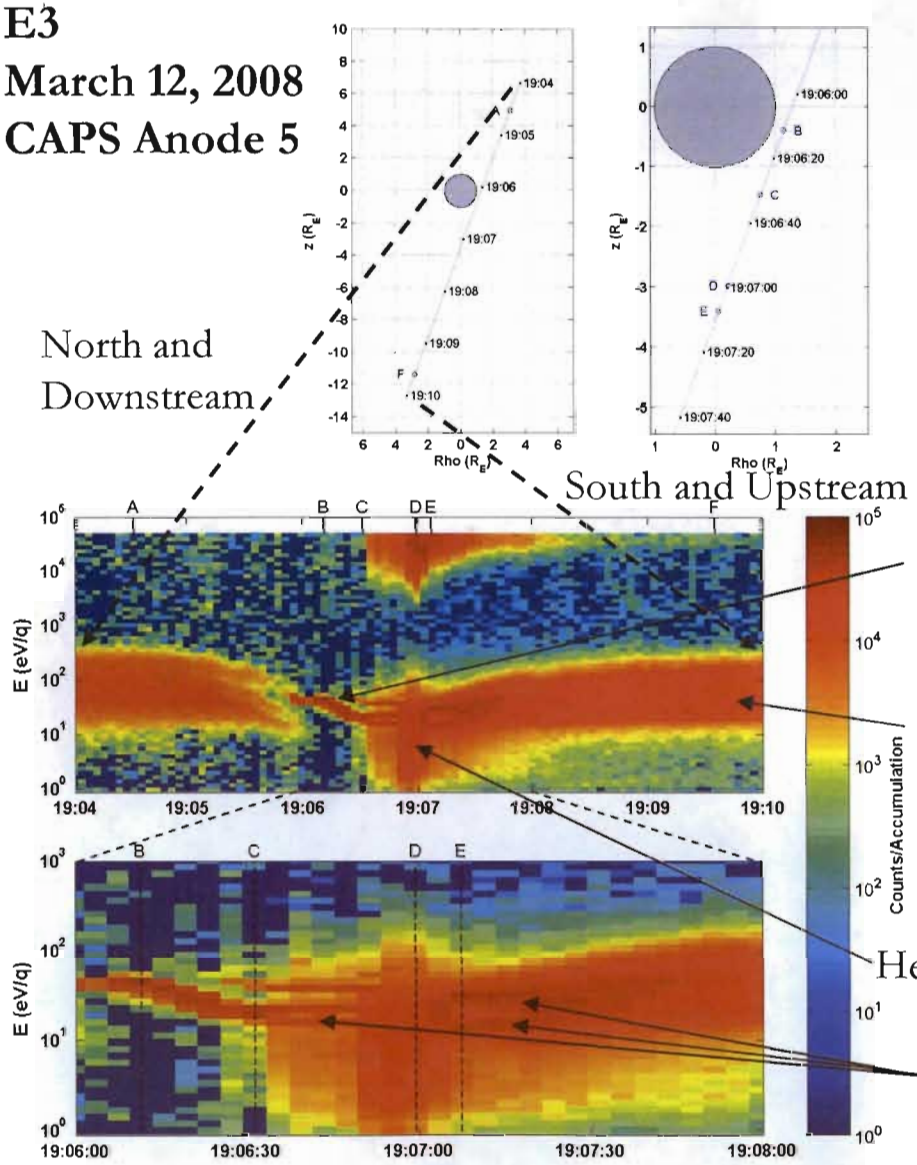
Los Alamos National Laboratory

MAPS Workshop, Annapolis, April 2011

Main Points

- Enceladus Plume
  - Stagnant plasma flow.
  - Detection of fresh ions within plume.
  - Pick-up ion acceleration into the ion core.
- Rhea Exosphere
  - Detection away from source.
  - Non-gyrotropic velocity distribution.
- Dione Exosphere
  - Detection near wake boundary.
  - Ring velocity distribution.

E3
March 12, 2008
CAPS Anode 5



- Anode 5 detects ions ~at rest wrt Enceladus
- Pitch angle viewing
- 4 s resolution, S/C moves 0.23 R_E
- Ram speed is 14.4 km/s yielding 1.08 eV/AMU
- e.g. H_2O^+ ram energy is 19.44 eV
- Early and Late times (North and South):
  - Water group corotating core,
  - Water group pick-up shell,
  - Local ion production south.

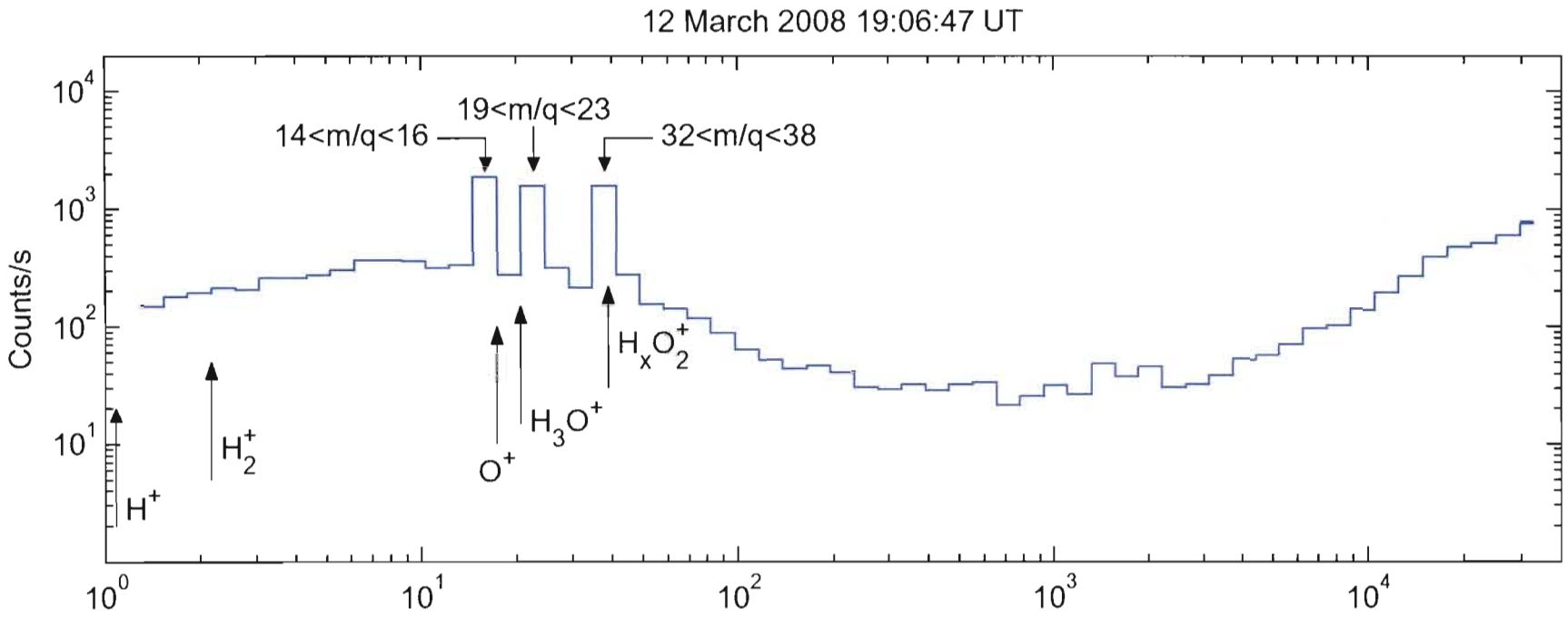
Acceleration beyond obstacle.

Persistent local ion production far south.

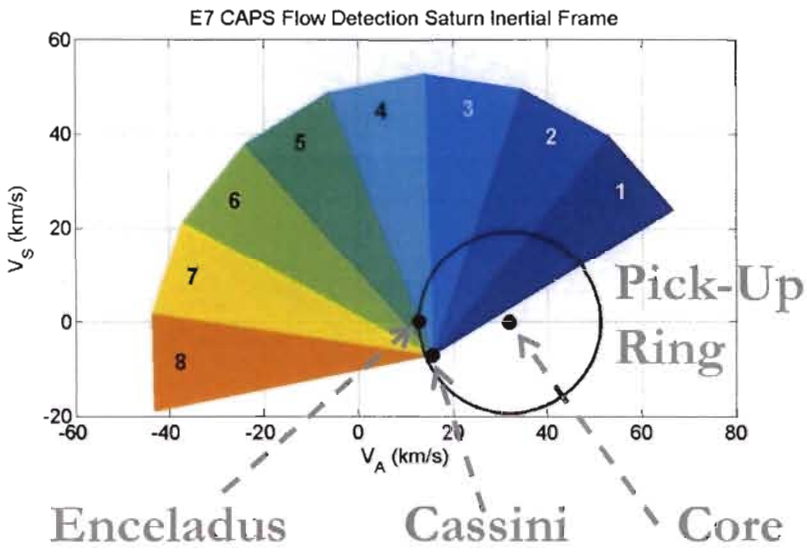
Heavy dust impacts.

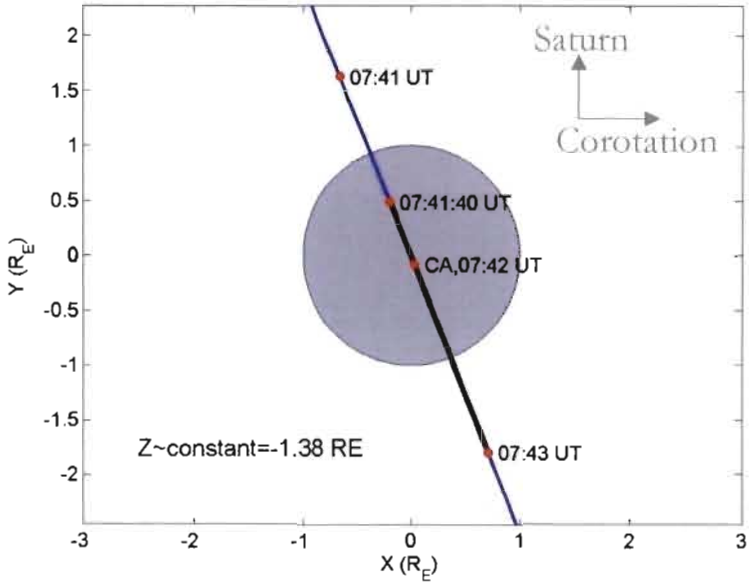
Cold, at rest, locally produced.

Within the Plume the Observed Energies of the Cold Ions Correspond to Water Group and Water Clusters – This indicates a stagnant plasma flow within the plume +- 3 km/s.



E7, Nov 7, 2009: CAPS Viewing Perpendicular to B



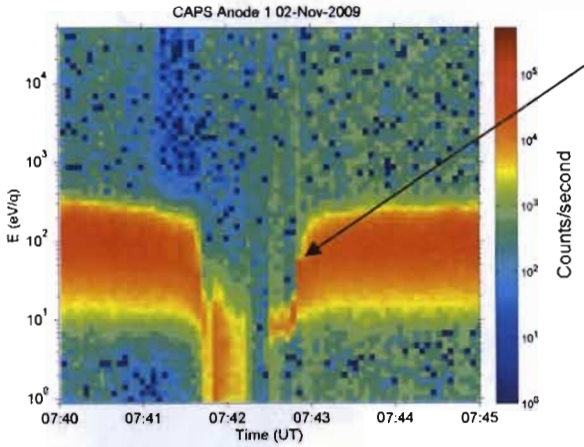


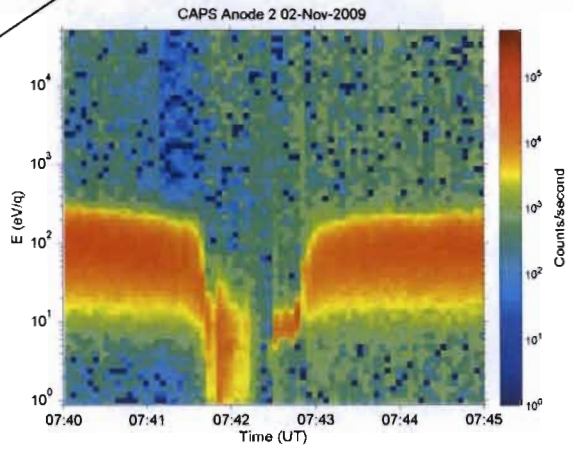
Anodes 4 and 5 Sensitive to Rammed Ions at Rest wrt Enceladus.
Note that the pick-up ring collapses as the flow decreases.
Anode 1 Clips the Ion Core.
Anodes 1-3 Sample the Ring.

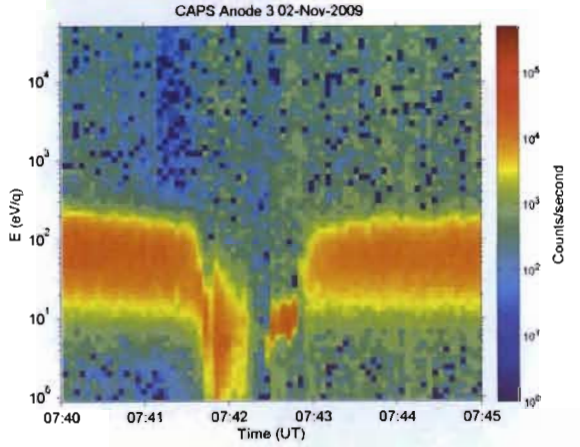
V_S, Y : Positive Toward Saturn.
V_A, X : Positive in the Azimuthal-Corotation Direction.

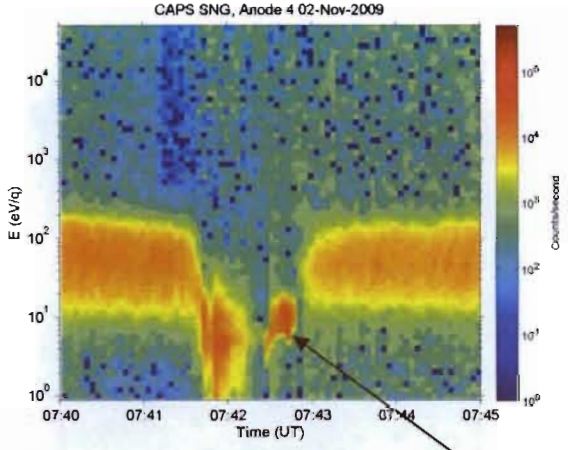
E7: CAPS Ions Anodes 1-4

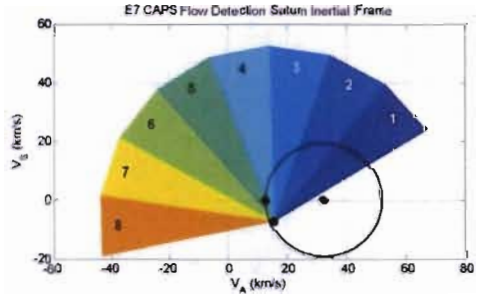
Acceleration into ion core.

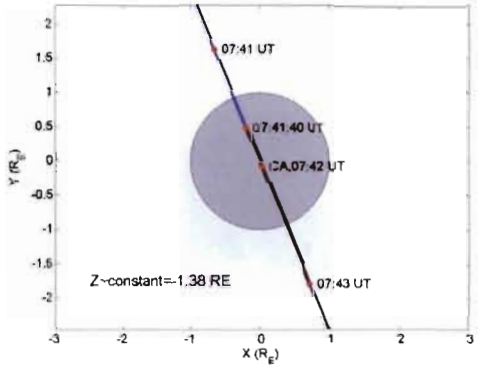






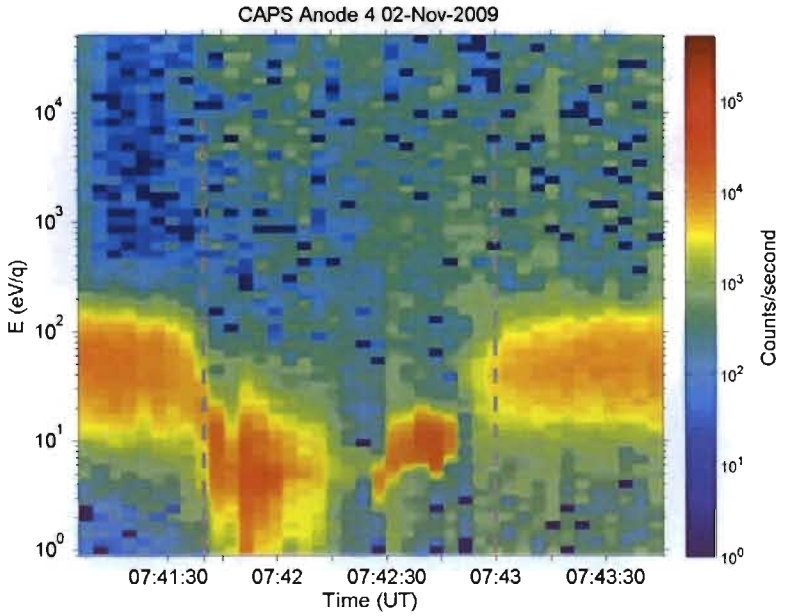


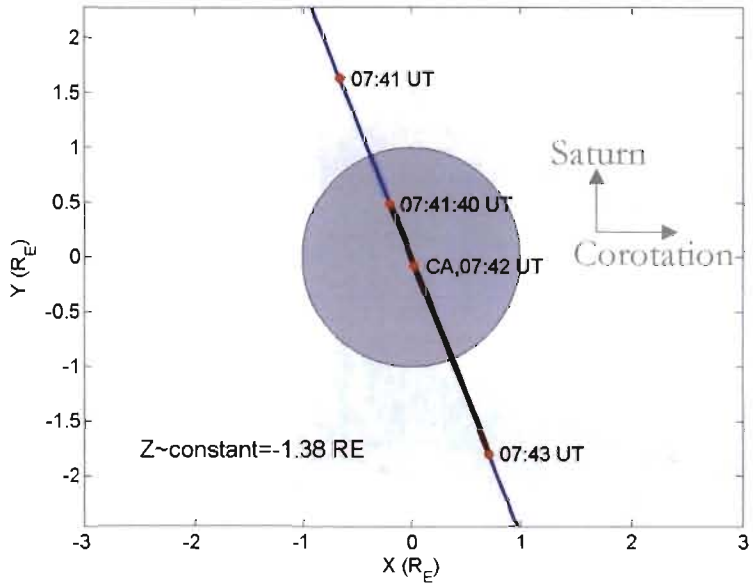




Rammed ions within plume source region ~at rest with respect to Enceladus.

E7: Strong Plume Ion Interaction Region Is 2.5 R_E Across and Displaced Away From Saturn



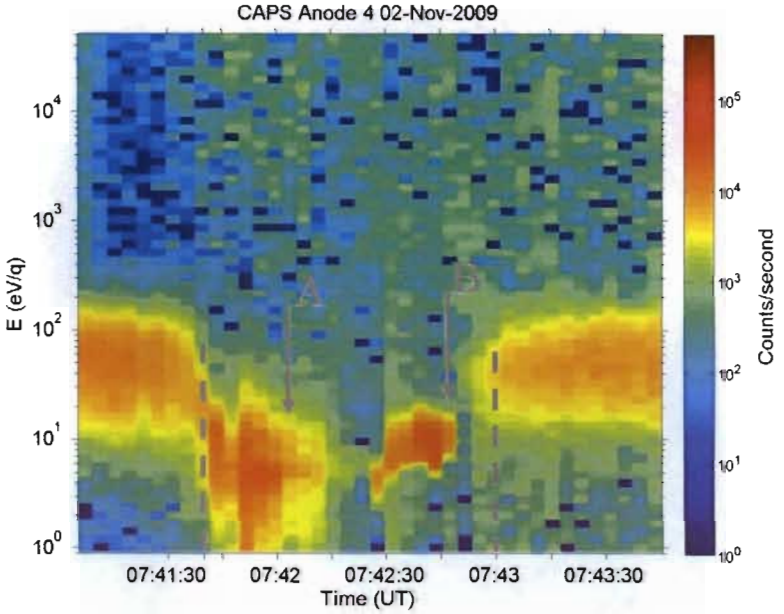


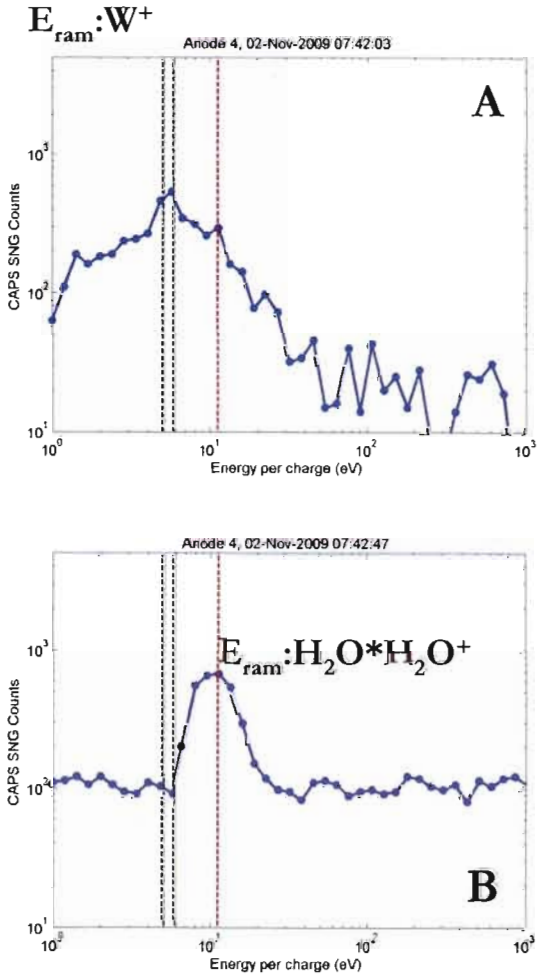
Black Line = Strong Plume Interaction Region:

Traversal time ~ 80 s.

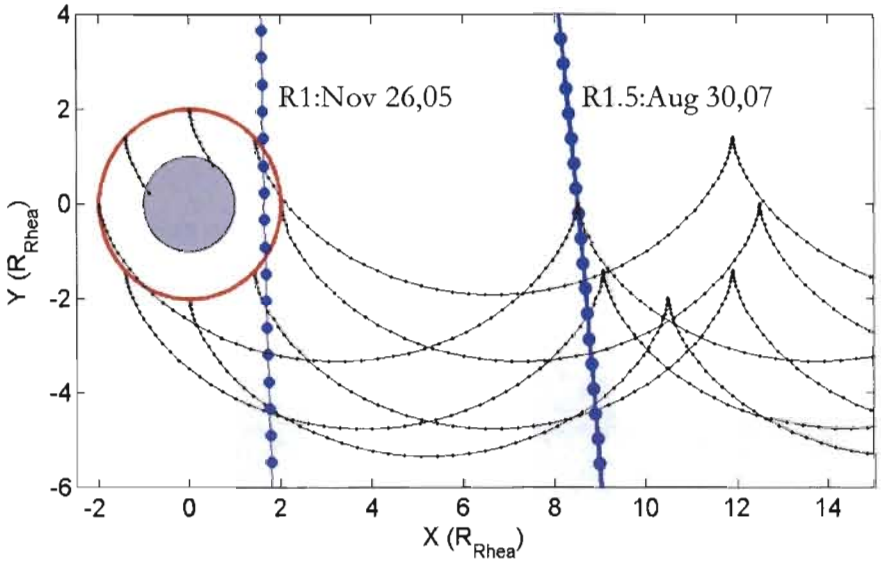
Length = 2.46 R_E at Z ~ -1.38 R_E

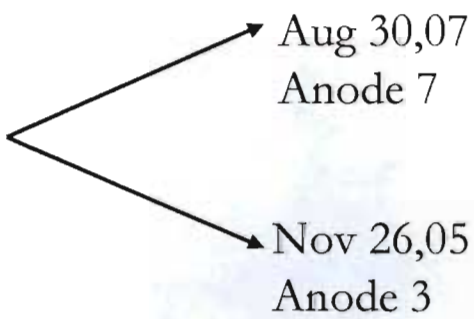
E7: CAPS Detects Water-Group Ions and Water Clusters within the Plume Source Region – Similar to E3 and E5





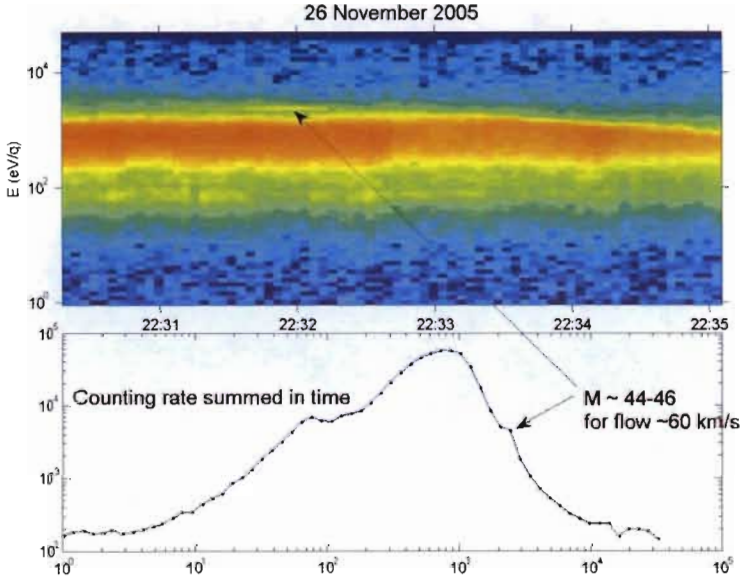
Pick-Up Ions Near Rhea Consistent with CO_2^+ From Exospheric Source Region



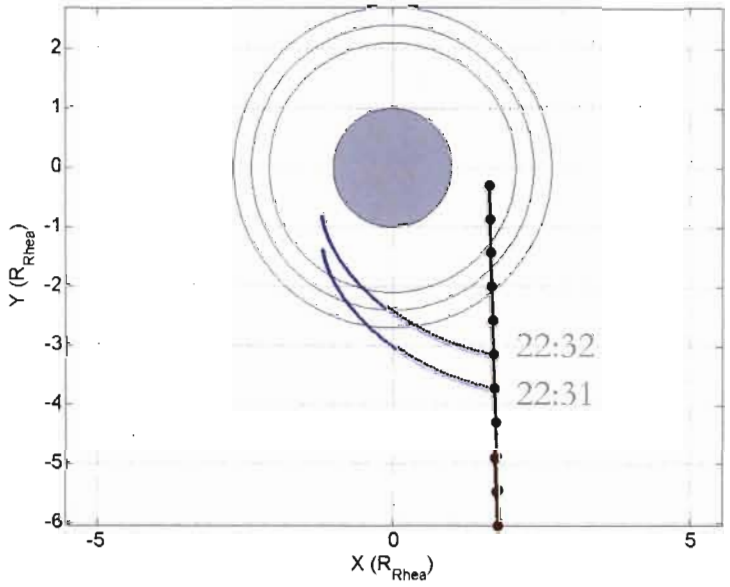


- Cold ions observed in CAPS SNG data during two Rhea flybys do not exhibit a velocity space ring structure as would be expected for gyrotropic pick-up ions.
- These ions most likely originate from localized exospheric source.
- The neutral exosphere of O_2 and CO_2 was discovered by INMS during R2 (Teolis et al., 2010).
- CAPS yields ion masses and source locations from the R1 and R1.5 data.

R1 Pick-Up Ions: Consistent with CO_2^+ and Exosphere Source



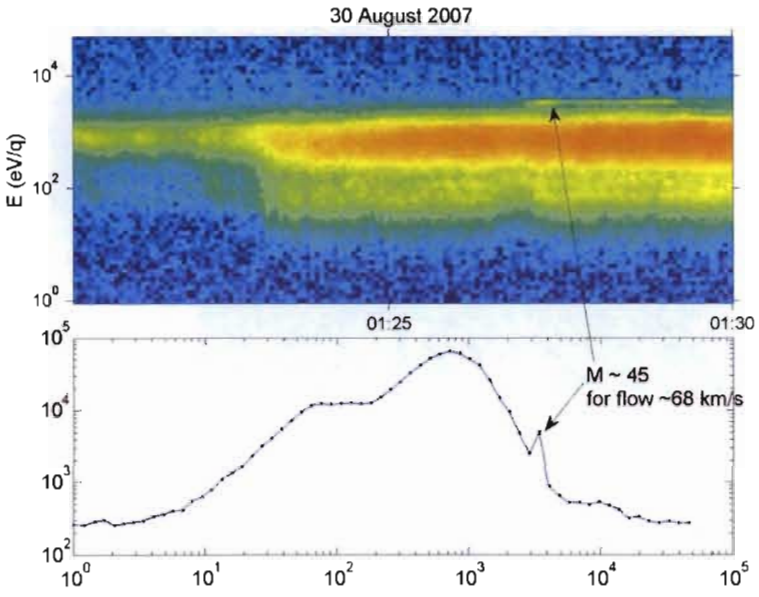
Note: Z ~ -0.34 R_{Rhea}



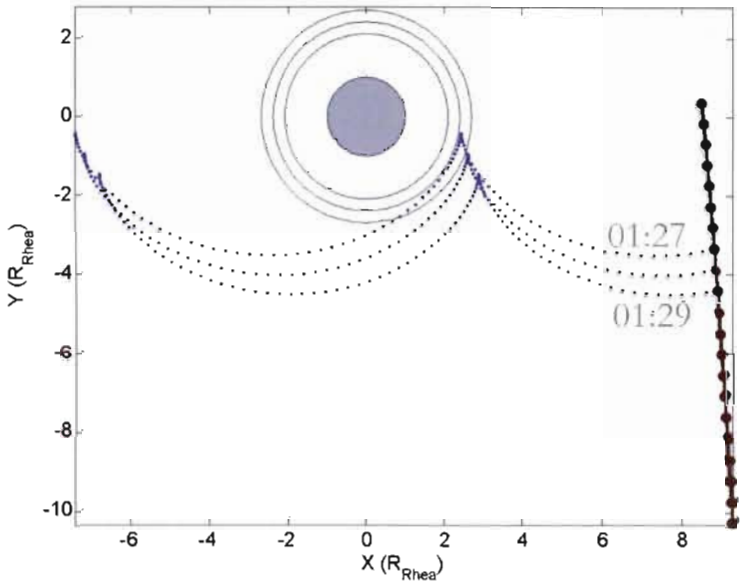
Mass ~ 44

Look Center Anode 3

R1.5 Pick-Up Ions: Consistent with CO_2^+ and Exosphere Source



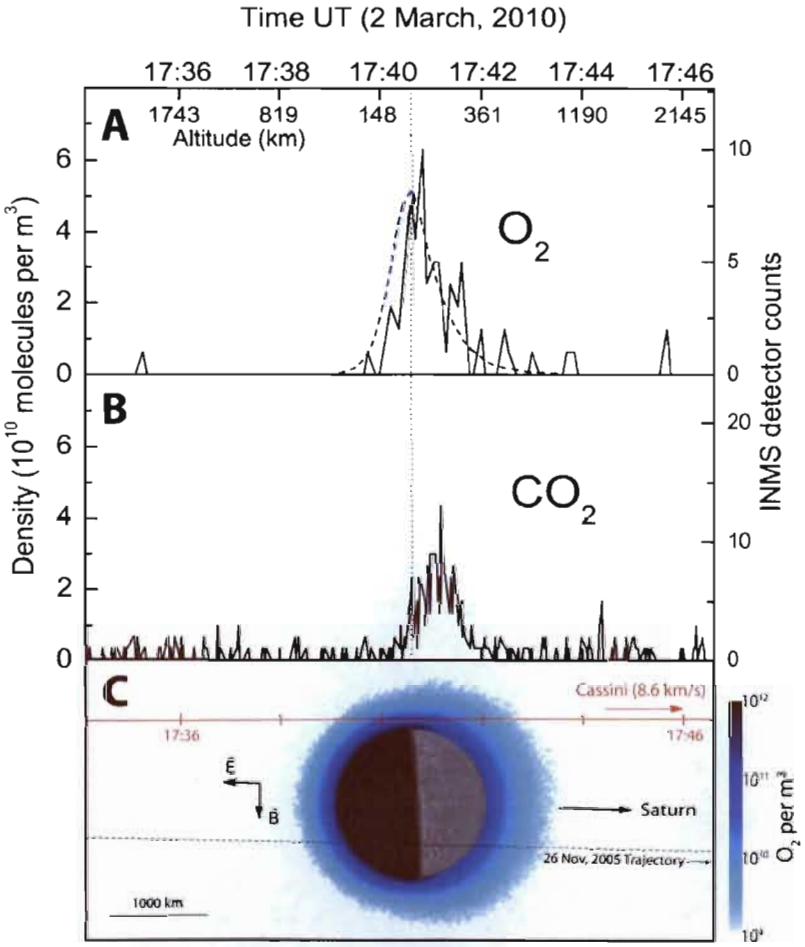
Note: Z ~ 0.82 R_{Rhea}



Mass ~ 47

Look Center Anode 7

R2: INMS Neutral Exosphere Detection



Sittler et al. (2004) CAPS Predictions for Dione

Table 3. Photoionization Rates

Reaction	Enceladus-Dione	References
$H + h\nu \rightarrow H^+ + e$	8.0E-10	*Huebner and Giguere* [1980]
$H_2 + h\nu \rightarrow H^+ + H + e$	1.0E-10	*Huebner and Giguere* [1980]
$H_2O + h\nu \rightarrow H^+ + OH + e$	1.4E-10	*Huebner and Giguere* [1980]
$NH_3 + h\nu \rightarrow H^+ + NH_2 + e$	3.7E-11	*Huebner et al.* [1992]
$H_2 + h\nu \rightarrow H_2^+ + e$	5.9E-10	*Huebner and Giguere* [1980]
$H_2O + h\nu \rightarrow H_2O^+ + e$	3.7E-9	*Huebner and Giguere* [1980]
$O + h\nu \rightarrow O^+ + e$	2.3E-9	*Huebner and Giguere* [1980]
$H_2O + h\nu \rightarrow O^+ + H_2 + e$	6.4E-11	*Huebner and Giguere* [1980]
$O_2 + h\nu \rightarrow O^+ + O + e$	5.8E-10	*Huebner and Giguere* [1980]
$CO_2 + h\nu \rightarrow O^+ + CO + e$	2.8E-10	*Huebner et al.* [1992]
$O_2 + h\nu \rightarrow O_2^+ + e$	5.6E-9	*Huebner and Giguere* [1980]
$OH + h\nu \rightarrow OH^+ + e$	3.7E-9	*Huebner and Giguere* [1980]
$CO_2 + h\nu \rightarrow CO_2^+ + e$	2.6E-9	*Huebner et al.* [1992]
$CO_2 + h\nu \rightarrow CO^+ + O + e$	1.68E-10	*Huebner et al.* [1992]
$CO_2 + h\nu \rightarrow C^+ + O_2 + e$	1.2E-10	*Huebner et al.* [1992]
$NH_3 + h\nu \rightarrow NH_3^+ + e$	6.8E-9	*Huebner et al.* [1992]
$NH_3 + h\nu \rightarrow NH_2^+ + H + z$	1.96E-9	*Huebner et al.* [1992]
$NH_3 + h\nu \rightarrow NH^+ + H_2 + e$	7.66E-11	*Huebner et al.* [1992]
$NH_3 + h\nu \rightarrow N^+ + H_2 + H + e$	3.6E-11	*Huebner et al.* [1992]

given above. Referring to Figure 4a for Dione, the H_2O^+ densities reach peak values of about 1.0 ions/cm^3 near the surface. H_2^+ has the lowest density, while H^+ and O_2^+ have peak densities of about 0.06 ions/cm^3 and 0.08 ions/cm^3, respectively. Pickup O^+ is relatively low in abundance relative to ambient densities and will probably be difficult to detect since the dominant ambient ion is expected to be O^+. The relatively flat profile for O^+ at all heights, except near the surface, indicates we are primarily seeing pickup ions produced by ambient neutral oxygen. Figure 4b shows pickup ion densities at Dione for OH^+, CO_2^+, NH_3^+, H_3O^+, and NH_2^+. Within 560 km in height all ions should be detectable. OH^+ dominates relative to the other ions in this figure and surprisingly, H_3O^+ is relatively abundant. Near Dione's surface the total pickup ion density is about 1.4 ions/cm^3, which is about 5.6% the ambient density and we may expect to see a modest interaction at Dione. Here we note that because of the detection of ozone, O_3, at Dione [*Noll et al.*, 1997] we may see significant fluxes of pickup O_2^+ and O_3^+ within a few hundred kms above Dione's surface only for a wake pass. Therefore a strong interaction may occur similar to that observed by Voyager 1 at Titan [*Neubauer et al.*, 1984].

[23] In the case of Enceladus, H_2O^+ clearly dominates over all other ions with peak densities near the surface of 2.2 ions/cm^3. The next most important ion is O_2^+ with peak densities near 0.15 ions/cm^3 at the surface. The other ions H^+, O^+, and H_2^+ are of low abundance and will only be detectable close to the surface. Again, because of the high

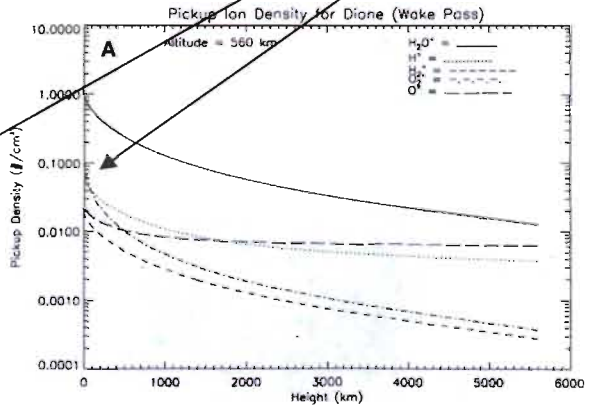
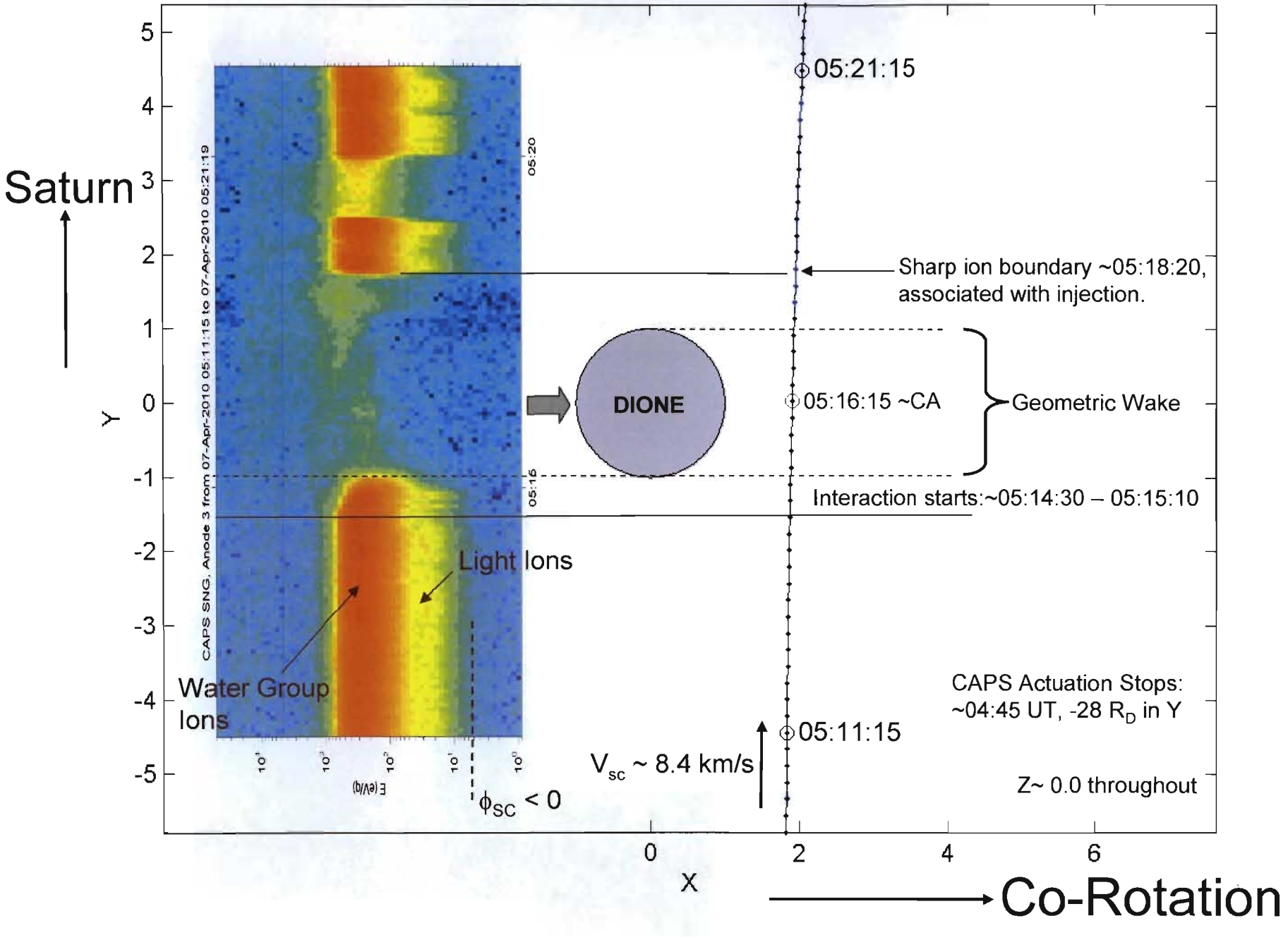


Table 4. Steady State Densities and Steady State Ion Electron Temperatures of Enceladus Torus and Dione Torus

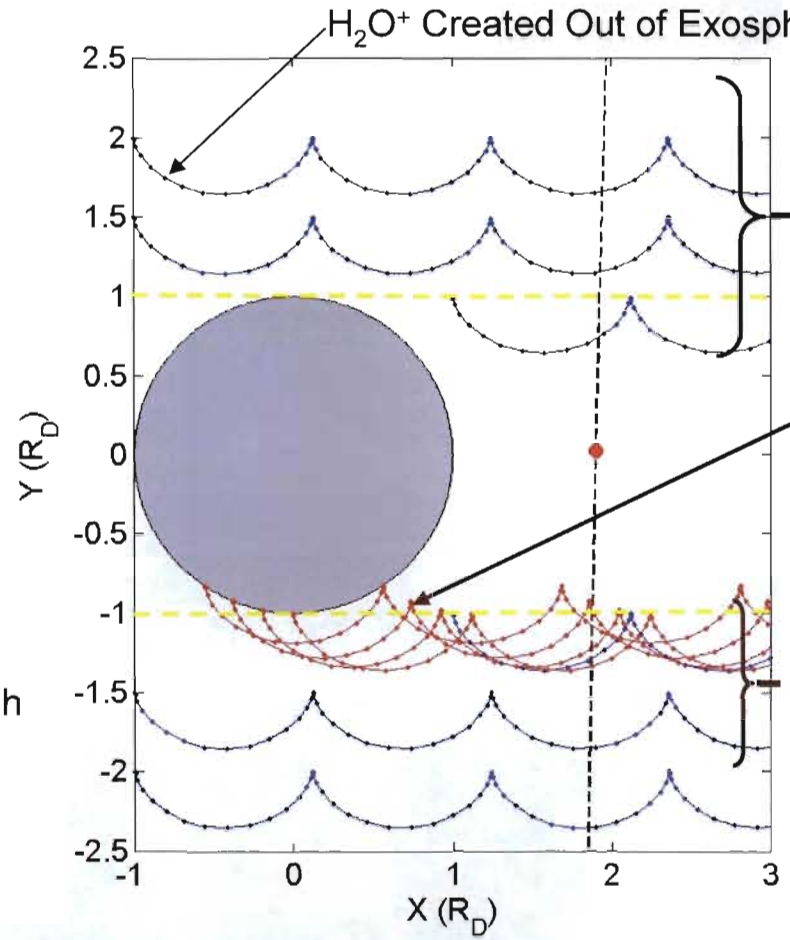
O_2^+ Peak Density (Edge of Wake) ~0.08 cm^{-3}

April 7,2010 : D2 Encounter Geometry and CAPS Ion Data



CAPS Anodes Sensitive to Corotation May Detect Freshly-Produced Pick-Up Ions with a Ring Velocity Distribution Before Entering Geometric Wake

Sample Pick-Up Trajectories
For H_2O^+, O_2^+ Similar



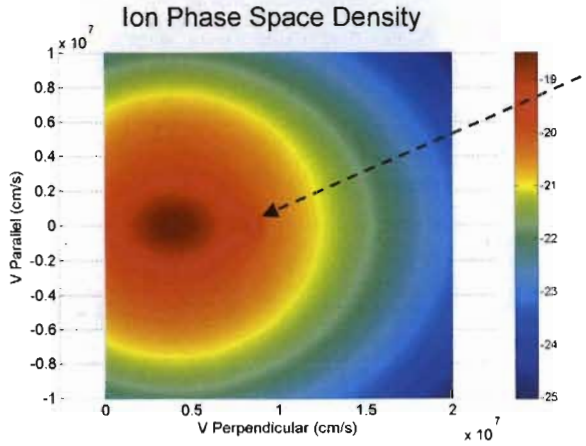
Contaminated by Injection/Interchange, trajectories hit surface.

H_2O^+ Pick-Up
On or Near Surface

Favorable Time for CAPS Detection.

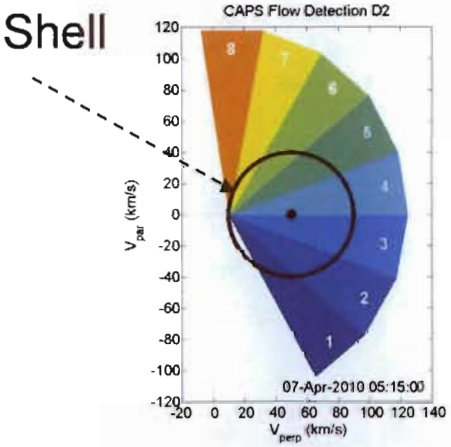
Ambient Ions Flow Through
Neutral Exosphere

Detection of Pick-Up Ring Velocity Distribution During D2 Possible for O_2^+ by CAPS Anodes 3/4

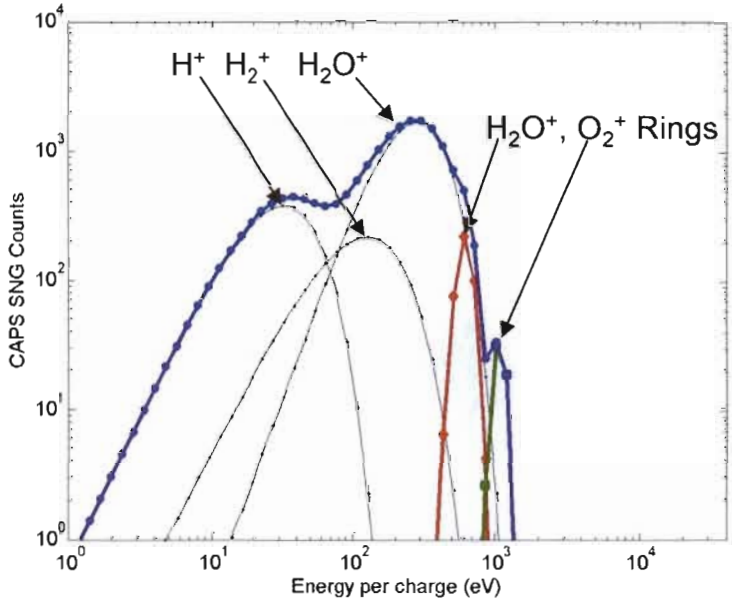


Pick-Up Ring

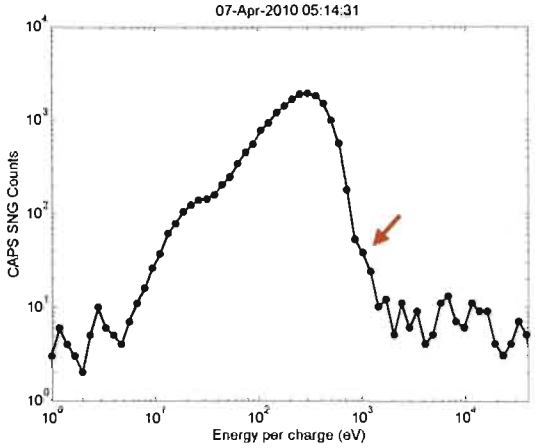
Pick-Up Shell

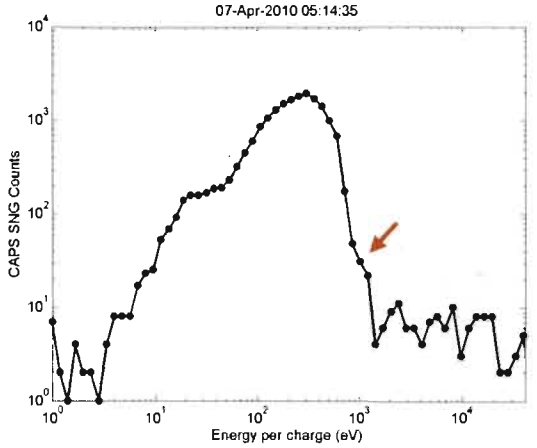


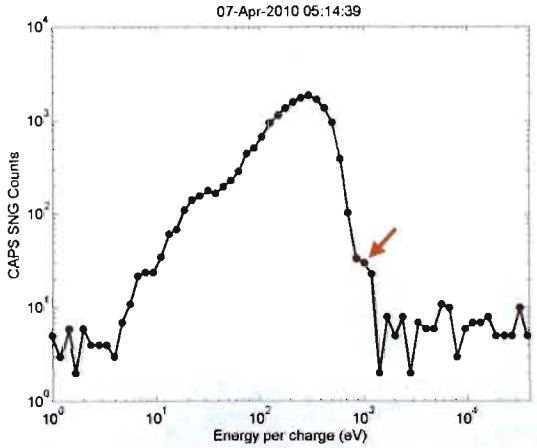
Simulated CAPS Counts

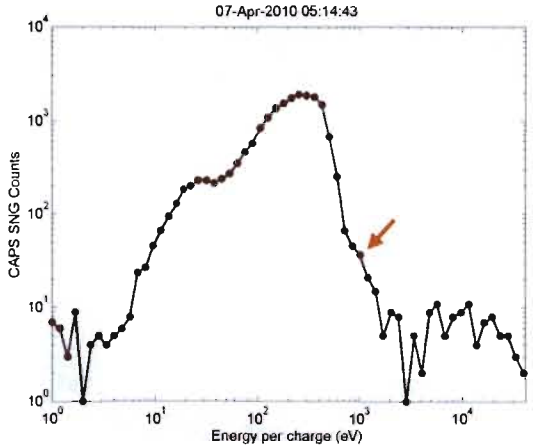


The Ring Signature is Observed in Multiple Sweeps from ~14:31 to 14:59 UT all Close to Dione's Wake Boundary

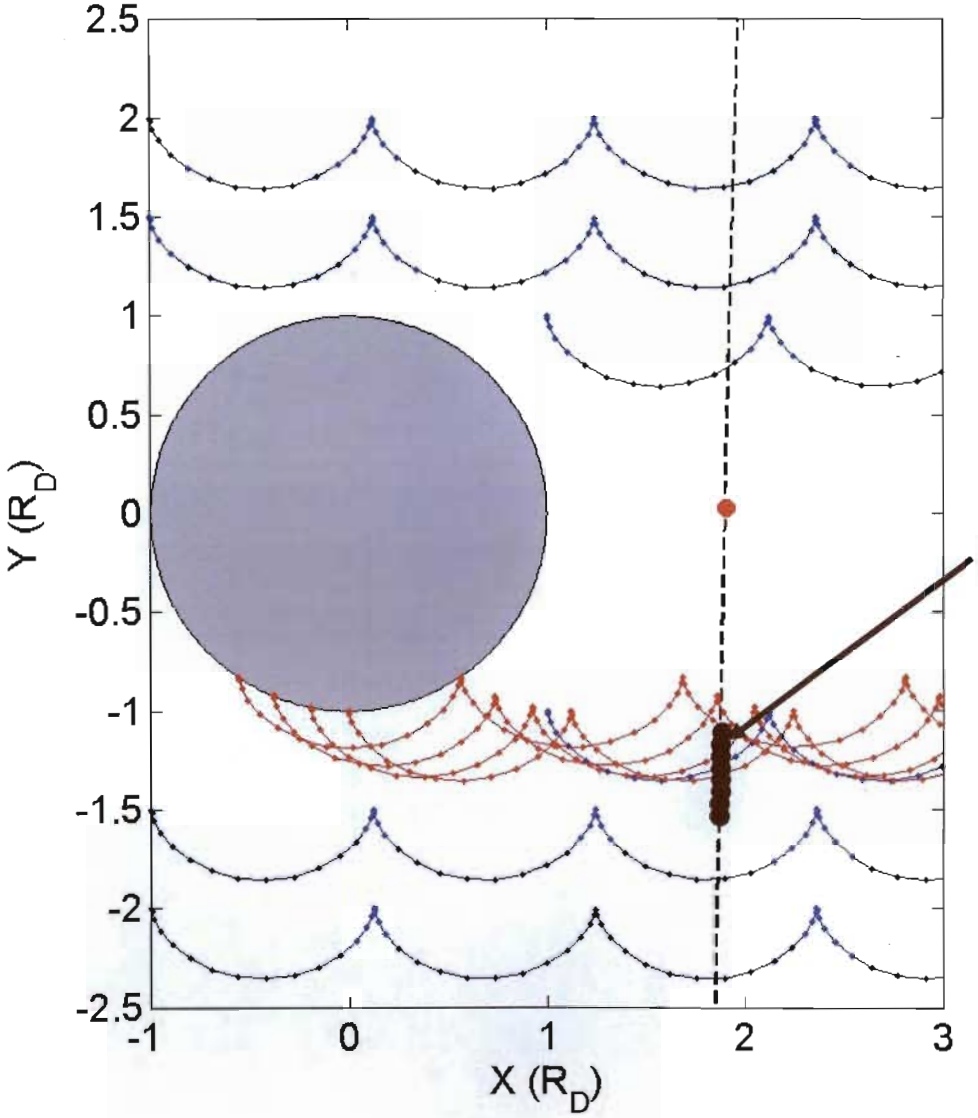








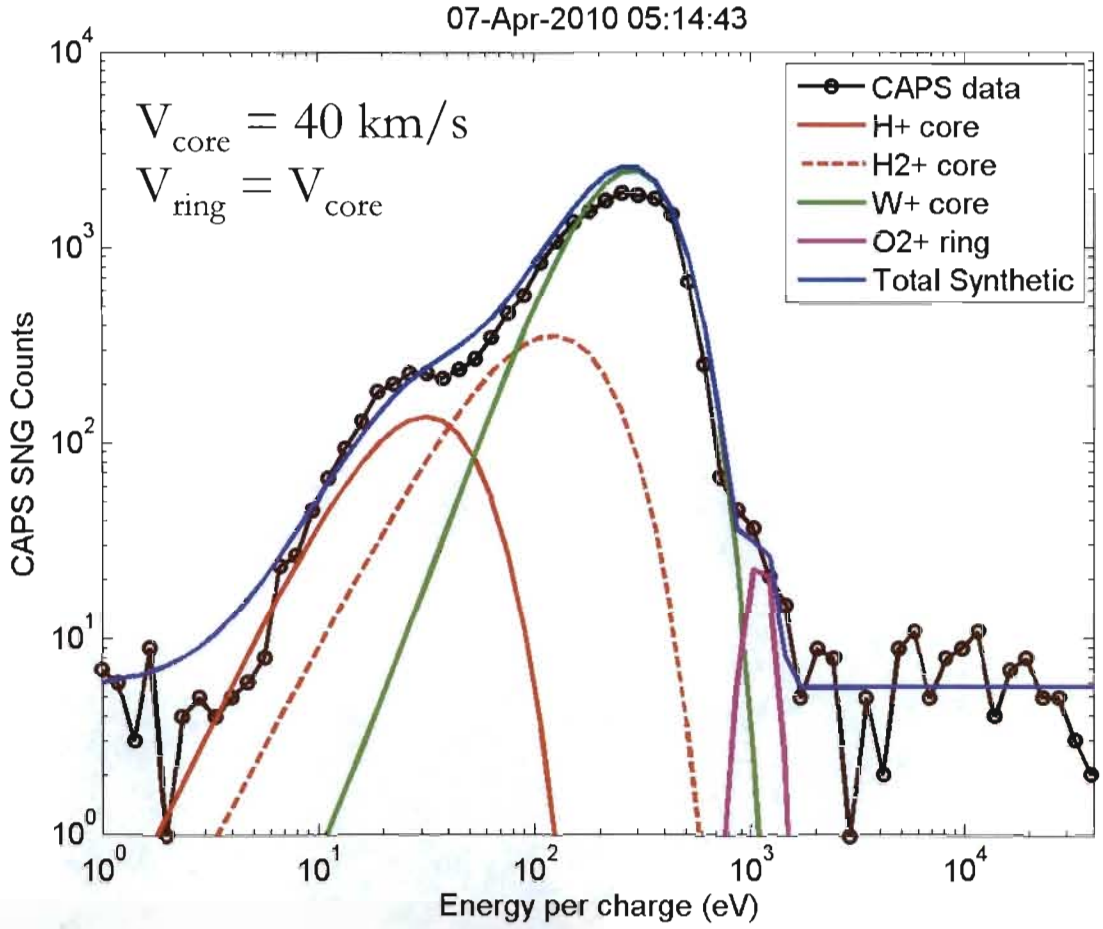
These Observation Times Favor a Surface or Near-Surface Source



Region With Enhanced Pick-up Counts

14:31 to 14:59 UT or 28 s or ~0.4 R_D

The Pick-Up Ions Observed by CAPS Are Most Likely O_2^+ With H_2O^+ Hidden in the W^+ Ion Core



Range of O_2^+ Pick-Up Density

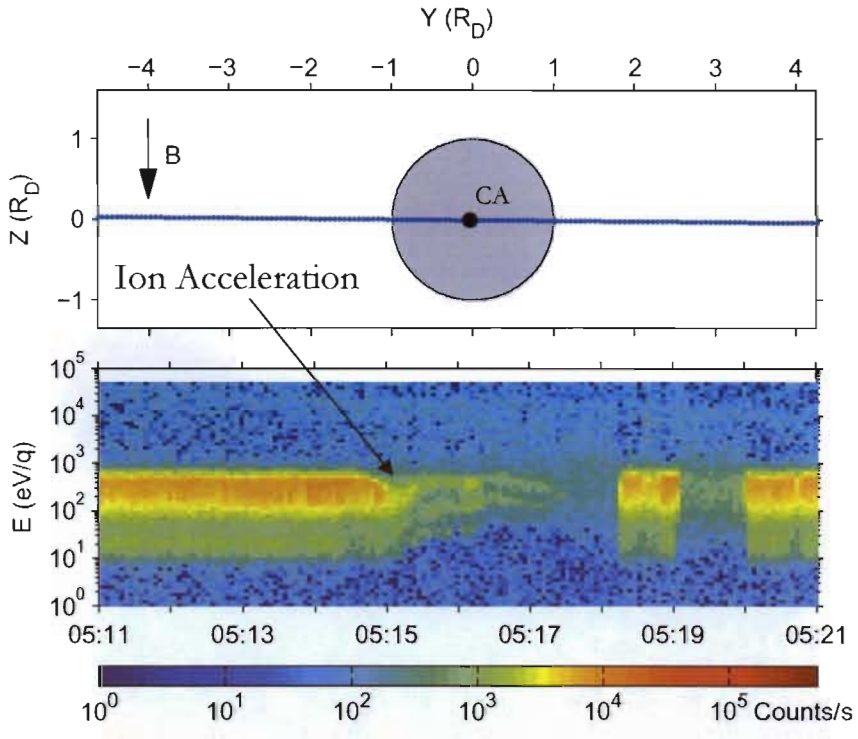
- For a ring velocity distribution (most likely):

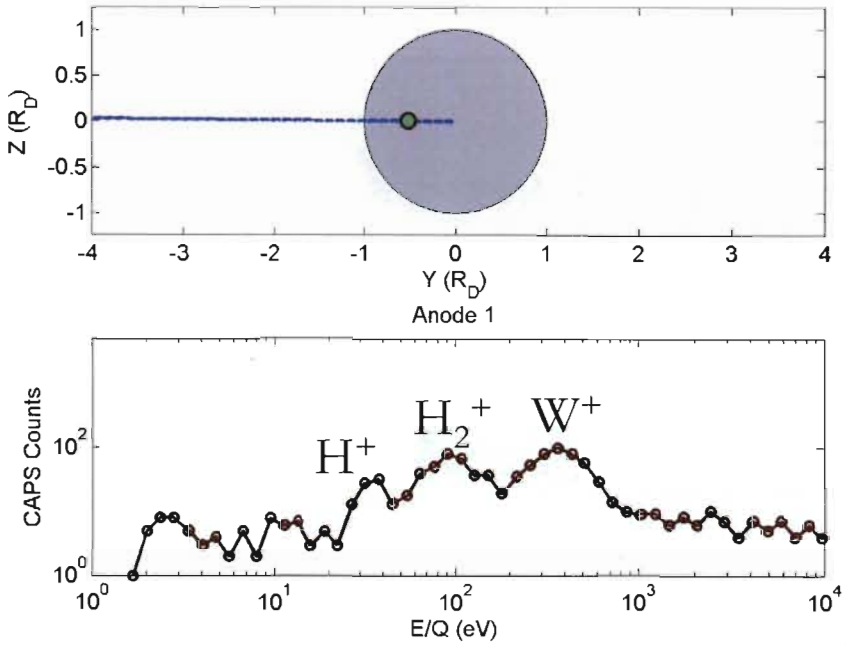
$$N_{ring} \cong f_{peak} * \pi v_r^2 * 2\pi V_R = 0.01 \pm 0.002 cm^{-3}$$

- For a shell velocity distribution:

$$N_{shell} \cong f_{peak} * \frac{4}{3}\pi * \left[\left(V_R + v_s \right)^3 - \left(V_R - v_s \right)^3 \right] = 0.08 \pm 0.013 cm^{-3}$$

Ion Expansion Into Dione's Wake Void Region Along B





Summary

- Enceladus:
  - CAPS provides strong evidence for a nearly stagnant plasma flow in the plume.
  - Water group ions and water clusters are detected, produced by charge exchange reactions between the incoming water group plasma and the plume water vapor.
  - Heavy dust impacts near due South.
  - Pick-up ions out of plume are accelerated into the ion core.
- Rhea:
  - Neutral exosphere detected by INMS, consists of O_2 and CO_2. Strongest source of neutrals is sputtering of icy surface by incoming water group ion flow.
  - CAPS detects non-gyrotropic CO_2^+. O_2^+ pick-up may be present.
  - Pick-up ions observed by CAPS track back to an exospheric source.
  - R3 analysis difficult but promising.
- Dione:
  - Exosphere production similar to Rhea.
  - Ice has trapped O_3 (HST), indicative of larger concentrations of trapped O_2.
  - O_2^+ on ring velocity distribution detected by CAPS near the wake boundary.
  - Results are consistent with overall picture from Sittler et al. study.
  - O_2^+ pick-up density is ~ 0.01 cm^{-3}.