Activity Dependent O^+ Transport Paths From the Ionosphere to the Ring Current

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Outline

- What do we know about O^+ in the ring current?
- What do we know about O^+ transport and energization during quiet and active times?
  - New information about the O^+ source in boundary related coordinates at quiet times.
- O^+ plasma sheet observations at quiet and active times
- Plasma sheet O^+ from multi-fluid model runs at quiet and active times
- **Conclusion: There are two distinct pathways for the energization and transport of O^+ from the dayside ionosphere to the plasma sheet and from there into the ring current.**

What do we know about O^+ in the ring current?

- Energetic O^+ in the ring current dynamically alters the pressure balance during geomagnetic storms.
- Changing pressure in the ring current modifies its evolution.
- Almost all of our knowledge about pressure variations in the ring current and their effects comes from directly from models or inversions of ENA or magnetometer data.

- Large scale models are required to tease out O^+ transport paths, energization mechanisms, and ring current pressure distributions from sparse data.
  - Available *in-situ* observations are too sparse to tease out the pressure variations over a storm cycle
  - Inversion of ENA images and magnetometer data is heavily model dependent…. .. especially on assumed initial conditions.

Here we take a critical look at energization and transport of O^+ in dynamic coordinates at active and quiet times from the ionosphere to the ring current.

What do we know about O^+ transport and energization during quiet and active times?

- Ionospheric source
  - Intensity increases with Dst --- Yau et al. 1988, Cully et al. 2003, and others
  - O^+ energy and flux at quiet times in boundary coordinates reviewed in this report
- Plasma Sheet
  - ISEE $-1 < R_E < 22$ reviewed in this report
  - Image ENA reviewed in this report
  - Multi-fluid code runs reviewed in this report
  - Cluster GSM_Z cuts at 19 R_E
- Ring Current
  - Sparse *in situ* observations -- inadequate temporal resolution.
  - ENA and magnetometer inversions
- The data and model outputs presented here suggest that the O^+ transport path from the ionosphere through the plasma sheet to the ring current is activity dependent.

Boundary Related Coordinates.

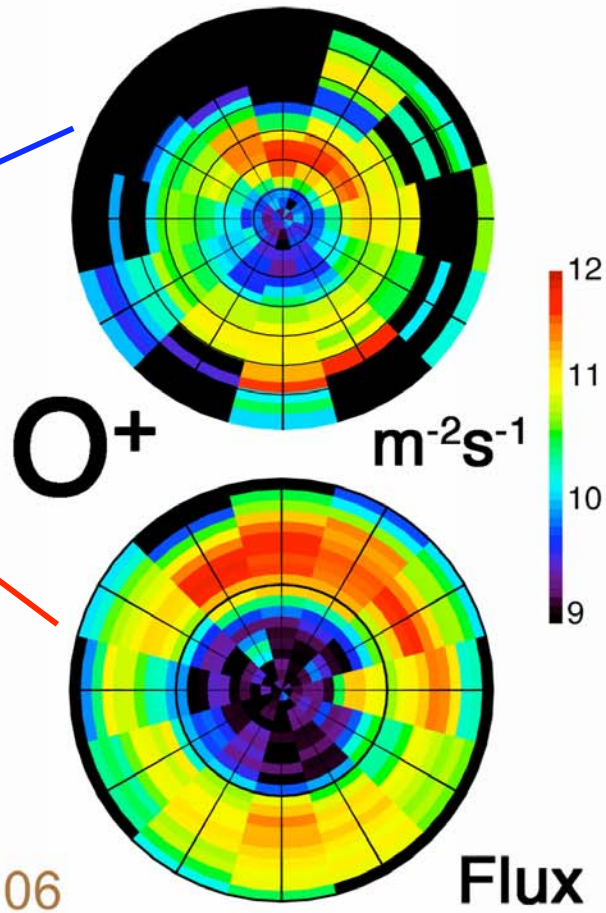
- Casting O^+ outflow in boundary related coordinates removes some of the "smearing" of average outflow data…allowing better mapping between the ionosphere and plasma sheet.
- How do we get boundary coordinates?
  - Polar boundary of the auroral oval identified in the energy and angular distribution of 100 eV electrons from Polar/Hydra.
  - Equatorward boundary of the auroral oval identified from loss cones in the ion distributions from Polar/Hydra.
  - Map observed O^+ outflow from Polar/TIMAS into auroral zone and polar cap pseudo latitudes based on the times of auroral boundary crossings and the time the satellite reached its maximum latitude.

Net O^+ Outflowing Flux above 15 eV

Geomagnetically Quiet (Dst > -50)
0.015 < E/q < 33 keV
acquired at ~ $2R_E$ during solar minimum

MLT vs. INVL
54° < INVL < 90°

MLT Vs Pseudo Latitude:
10 Auroral Zone Bins
10 Polar Cap Bins



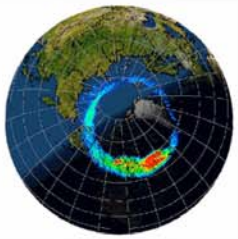
Most of the O^+ is on field lines connected to the flanks of the plasma sheet.

~3% of the observed O^+ energetic flux comes up in the polar cap.

Fraction of outflow by auroral zone MLT quadrant

40%
11% O^+ 22%
27%

12
18 **MLT** 06
24



9%
20% Area 24%
47%

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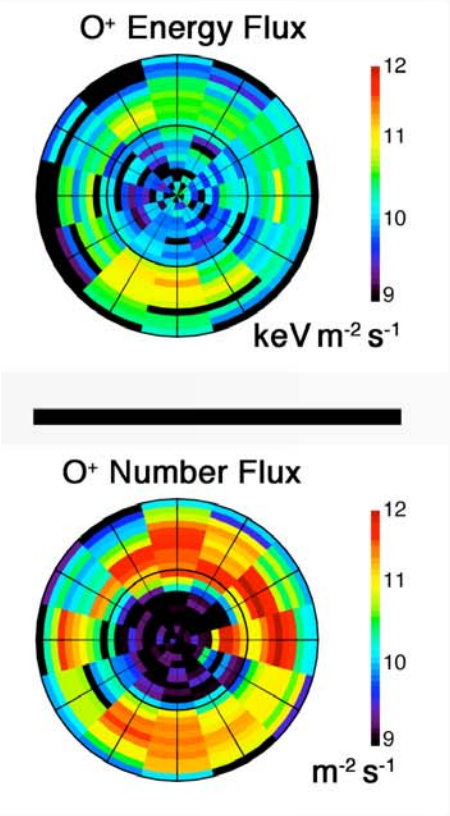
Estimating Characteristic Energy



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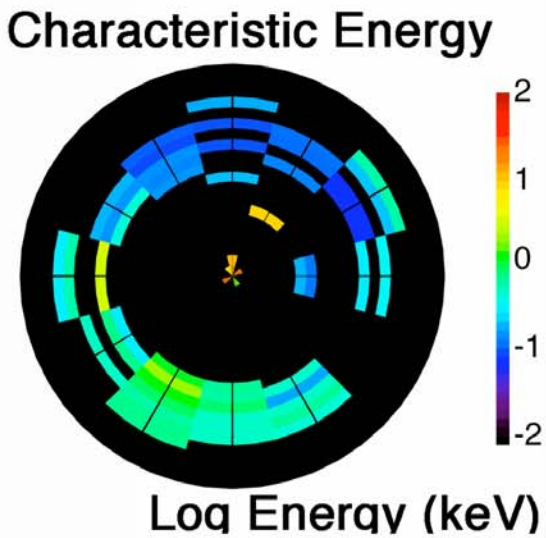
Pixel by pixel ratio



ONLY Energies more than 2σ above zero are displayed

Missing O+ fluxes below the TIMAS cut-off energy (15 eV) bias the energy upward…..but NOT THAT MUCH!!!

12
18 **MLT** 06
24

Quadrant average O+ energies in keV

0.12
0.33 **Energy** 0.17
0.59

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Fluxes below the TIMAS cut-off energy (15 eV)

bias the energy upward

…..but NOT THAT MUCH!!!

- Upflowing thermal O^+ flux at 50,000 km reported by Su et., al. (1998) is 8.3×10^4 ions/cm^2-s
- Assuming this flux is constant and has a characteristic energy of 1eV over the full auroral oval gives:

Quadrant average
O^+ energies in keV
at 6,000 km

12
18 **MLT** 06
24

0.09
0.08 **Energy** 0.06
0.15

Are comparable with the energy derived from Fluxes > 15 eV

0.12
0.33 **Energy** 0.17
0.59

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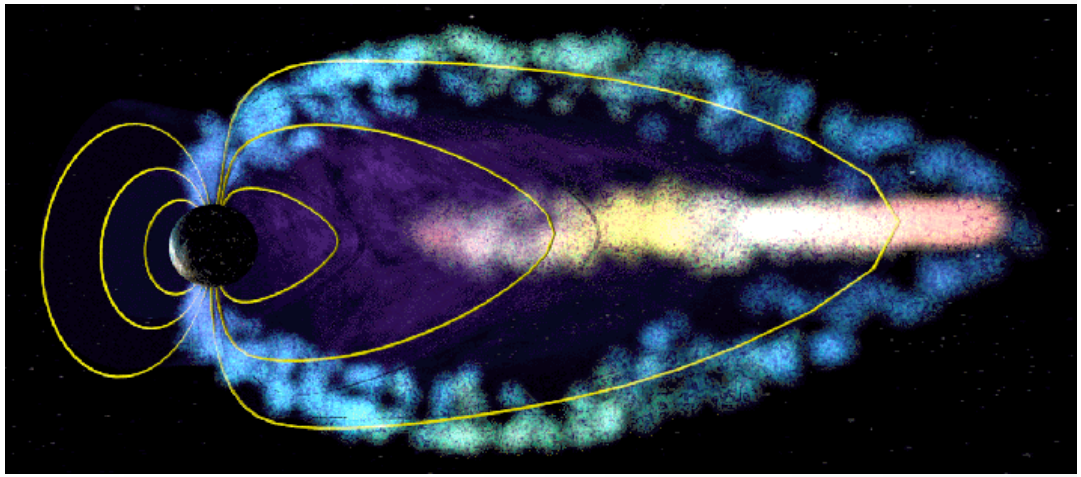
O^+ Outflow Observations During Storm Times (Dst < -50)

- During storms both the noon and midnight sectors have significantly more outflow but their ratio is not known.
- **The cartoon shows that O^+ is expected to populate the plasma sheet near local midnight.**



- The quiet storm time O^+ source population is not consistent with the cartoon

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Summary of O^+ Source Characteristics

- Quiet times (D_{ST} > -50)
  - Mostly from the dayside
  - On field lines connecting primarily to the plasma sheet flanks
  - Characteristic energy at 6,000 km: 100 -200 eV
- Active times
  - The source can be ten times more intense
  - All MLT sectors have increased outflow but their relative increases are not known.

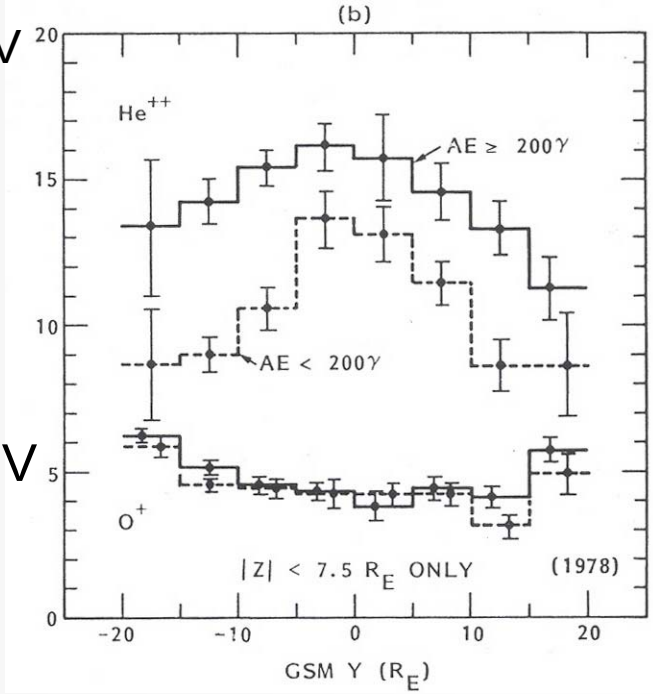
Plasma Sheet Observations

Lennartsson and Shelley (1986)

O^+ and He^{++} Energy (keV)

20 keV

5 keV

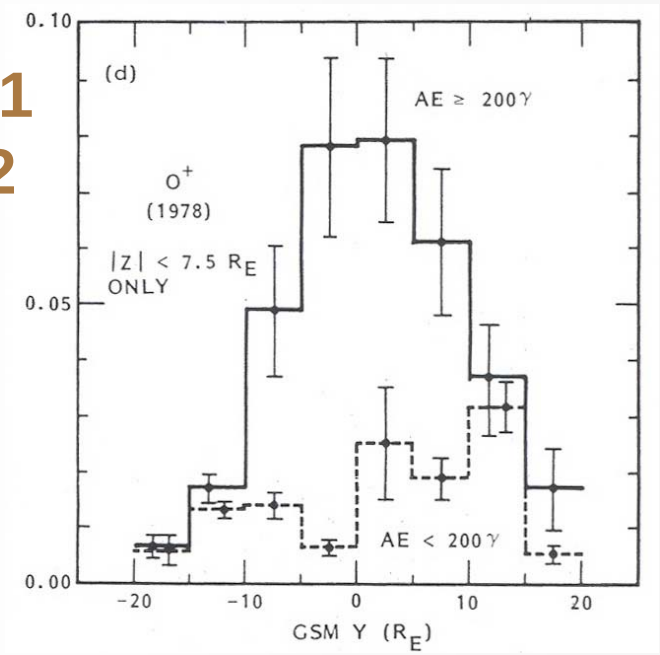


GSM_Y

From ISEE-1
$10 < R_E < 22$

--- AE < 200
__AE > 200

O^+ Density



GSM_Y

These data show that at quiet times the GSMy distribution of O^+ is low and uniform and at active times the distribution is high and peaked near GSMy =0.

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Multi-Fluid Model Runs

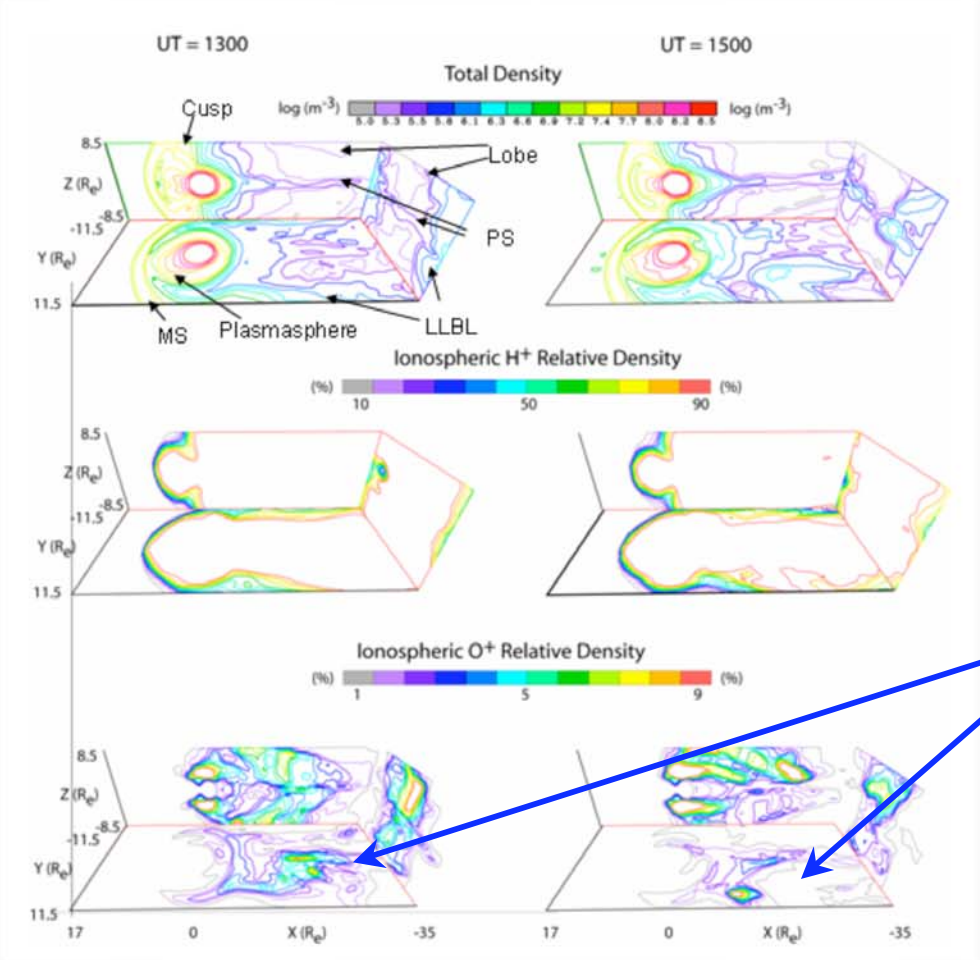
March 18, 1997 Dst > -25 all day (1300 UT left 1500 UT right)

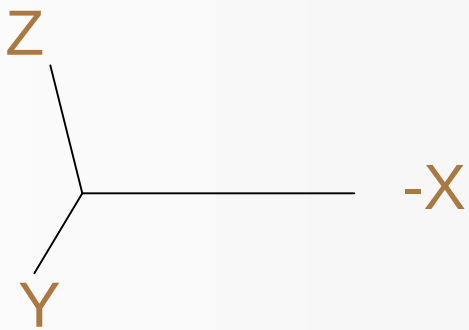
QUIET

Total density

Relative ionospheric H^+ density

Relative O^+ density





Note O^+ has a broad extent in the Y (dawn/dusk) direction

X 17 0 -35

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Multi-Fluid Model Runs

Oct. 29, 2003 Dst < -100 at 07:30 shown, larger later in the day

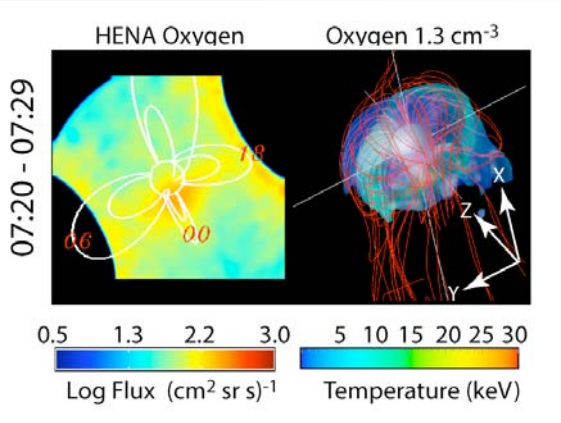
ACTIVE

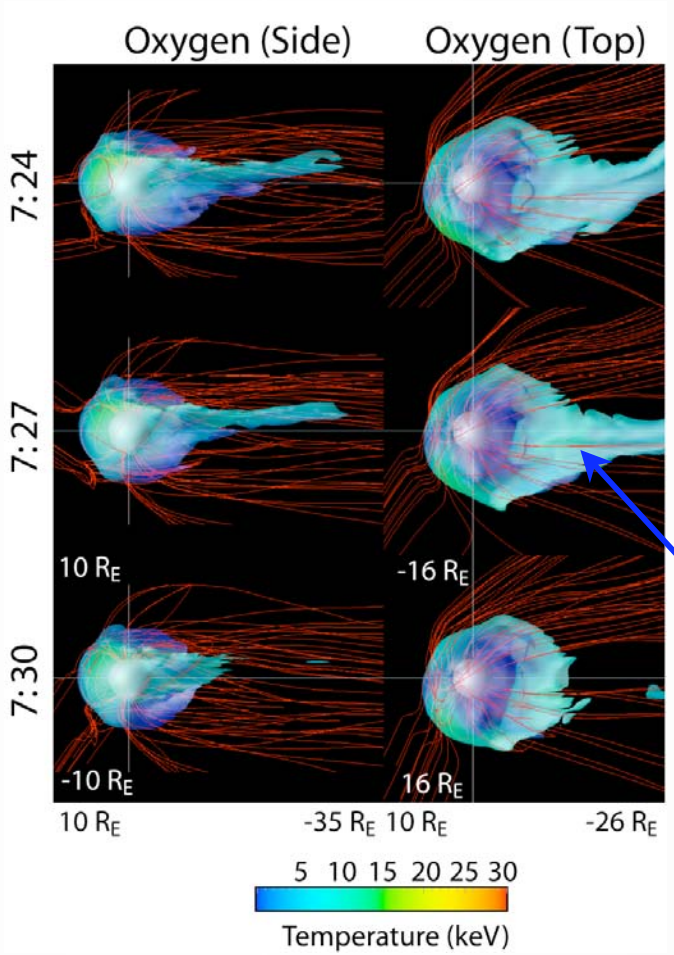
Z -X

Y -X

View from IMAGE is not ideal

HENA image of 52-100 keV O^+





Surfaces are at a total O^+ density of 1.3 cm^{-3}

Color indicates temperature

Note the narrow O^+ extent in the Y direction

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Summary of O^+ Plasma Sheet Characteristics

- Plasma Sheet Observations suggest
  - During geomagnetically quiet times ionospheric O^+ plasma convects primarily around the dawn and dusk sides of the magnetosphere.
  - During active times O^+ density and energy increase across plasma sheet but increase significantly more near the mid plane - GSM_Y=0.
- Multi-Fluid code results are consistent with the ISEE -1 observations

Summary of O^+ Source and Plasma Sheet Characteristics

- Observations and multi-fluid simulations show that there are two distinct pathways for the energization and transport of O^+ from the dayside ionosphere to the plasma sheet
- **O^+ in the the plasma sheet is**
  - **Less dense, less energetic, and approximately uniformly distributed in GSM_Y during quiet times.**
  - **More dense, more energetic, and occurring primarily near the $GSM_Y = 0$ meridian at active times.**

Conclusion/Discussion:

- The source of O^+ in the ring current is the plasma sheet.
- Models used to explore ring current dynamics:
  - have not yet explicitly included the complete O^+ activity dependent transport paths from the ionosphere to the ring current.
  - ***have not directly addressed the effects of the O^+ plasma in the pipeline between the ionosphere and ring current during transitions from quiet to active times.***
- **New multi-fluid codes are coming on line and will be useful in addressing the unexpected complication of activity dependent O^+ transport paths discussed here.**

Extra Slides

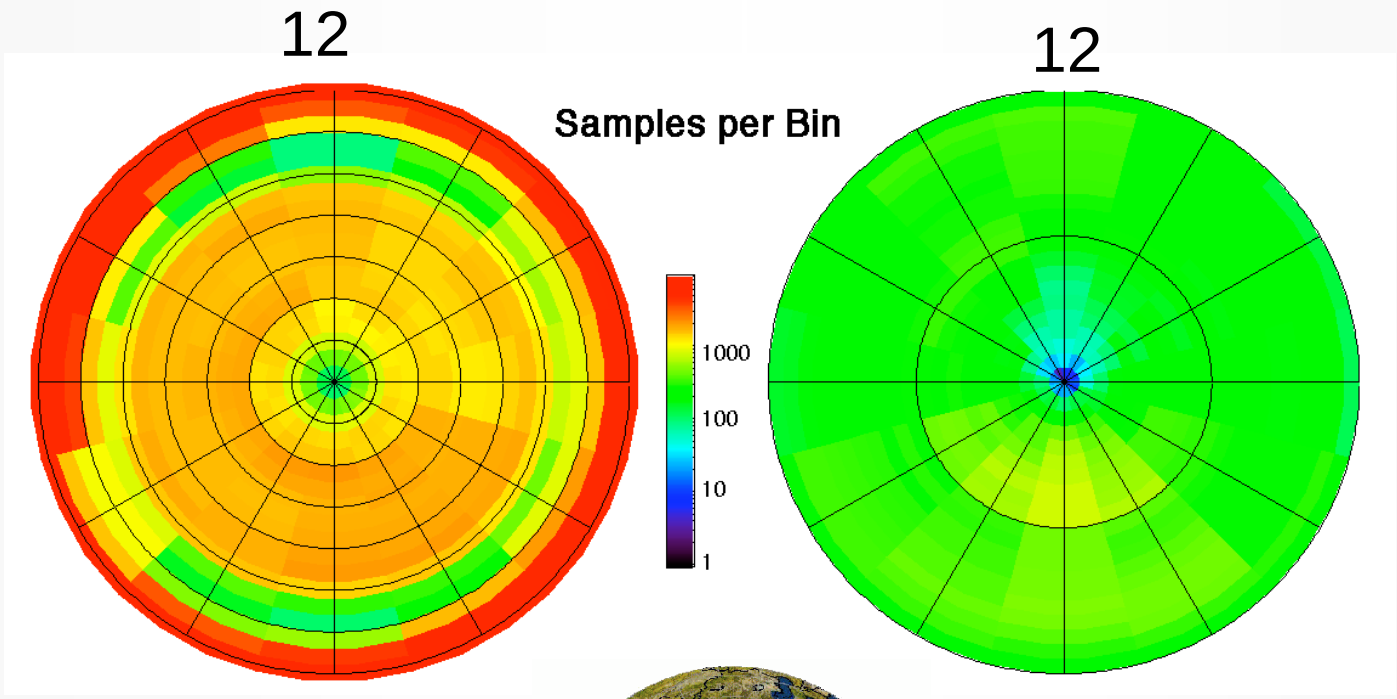
- It was not possible to identify both poleward and equatorward boundaries on every auroral zone crossing
- A file listing the auroral zone crossing times as well as the times that the Polar satellite reached its maximum southern latitude is available at

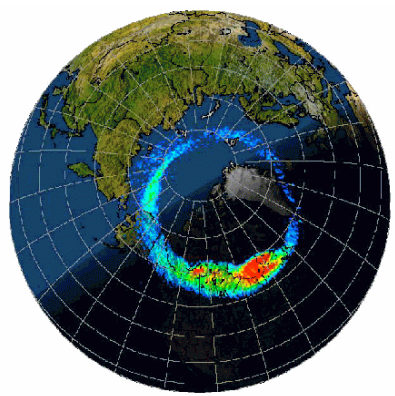
http://lasp.colorado.edu/timas/papers/Peterson/Polar_AZ_crossing_times.txt

Sampling

MLT vs. INVL
$54^o < INVL < 90^o$

MLT Vs Pseudo Latitude:
10 Auroral Zone Bins
10 Polar Cap Bins





There are big differences between the Pseudo and real ovals

9% of the auroral oval area is in the noon sector, 47% in the midnight sector.

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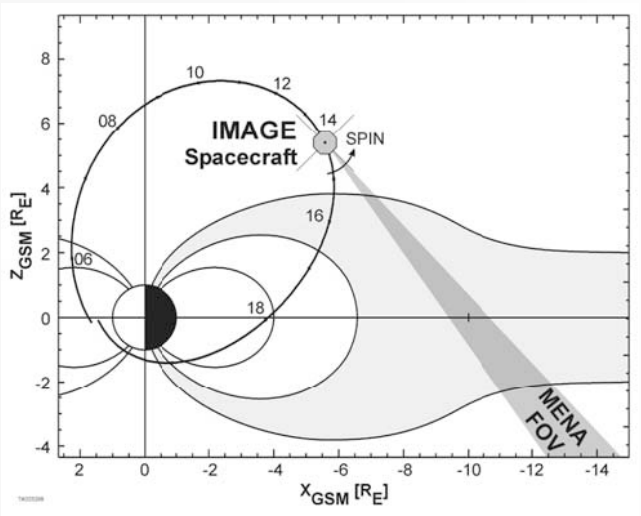
Plasma Sheet H^+ Observations

McComas et al. (2002)

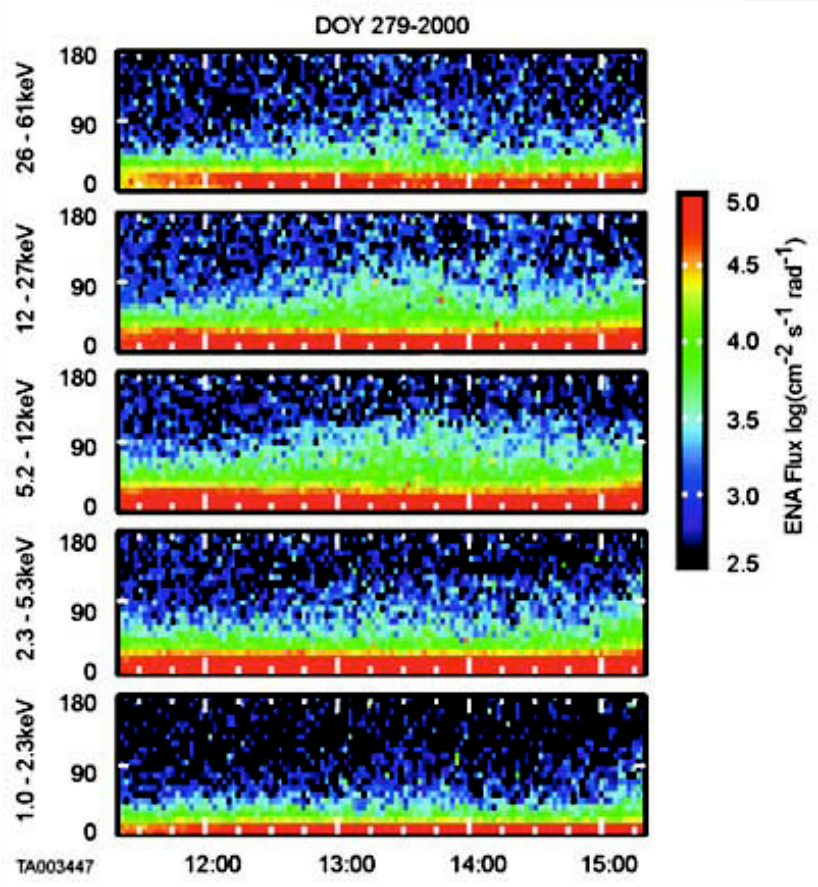
Two D_{ST} Maxima
07:00/-175 13:00/-182



Angular width of the plasma sheet at X -10 R_E for various energies

40keV

20keV



13:00 UT

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