

# Cluster observations of Earth's atmospheric escape

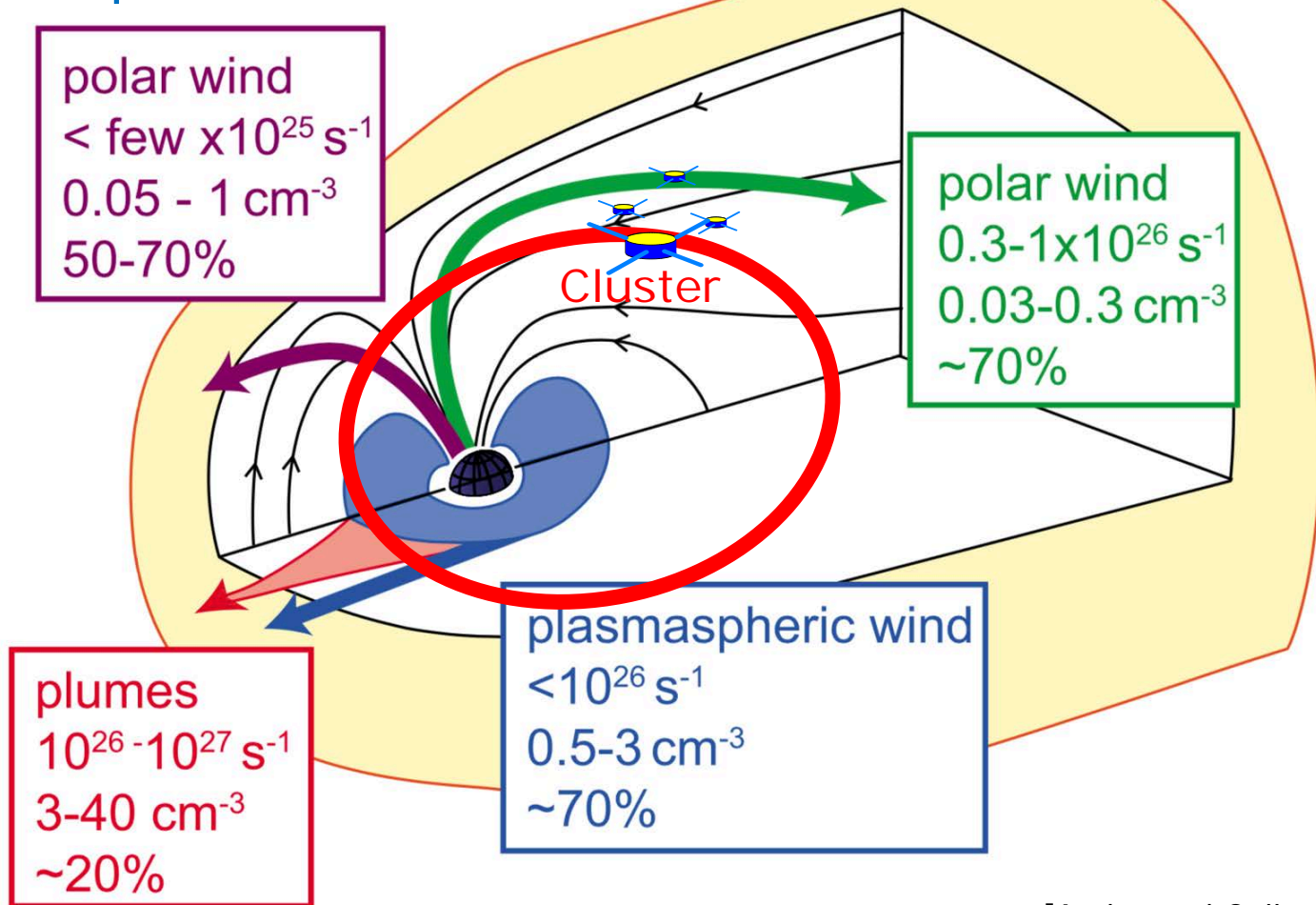
C. P. Escoubet<sup>1</sup>, H. Laakso<sup>2</sup>, A. Masson<sup>2</sup>, M. L. Goldstein<sup>3</sup>

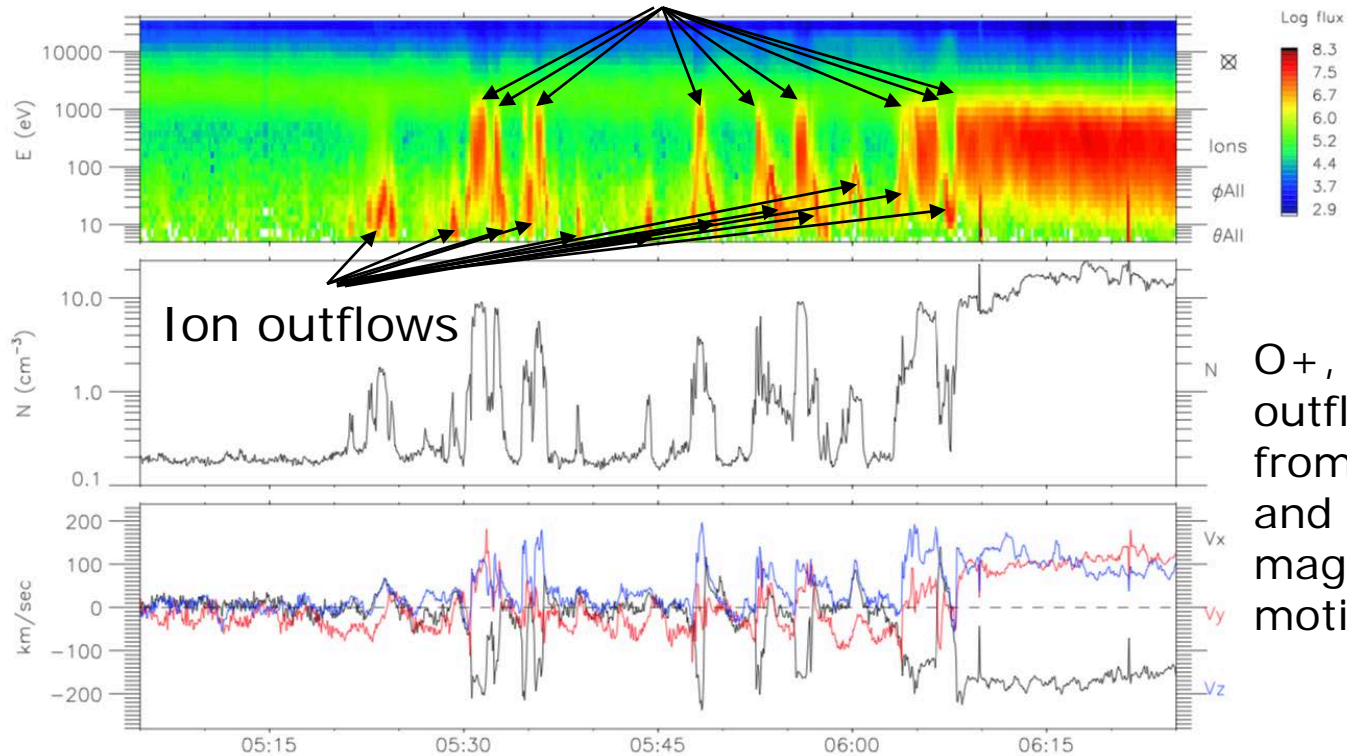
<sup>1</sup>ESA/ESTEC (The Netherlands)

<sup>2</sup>ESA/ESAC (Spain)

<sup>3</sup>SSI/GSFC (USA)

# Ion outflows paths





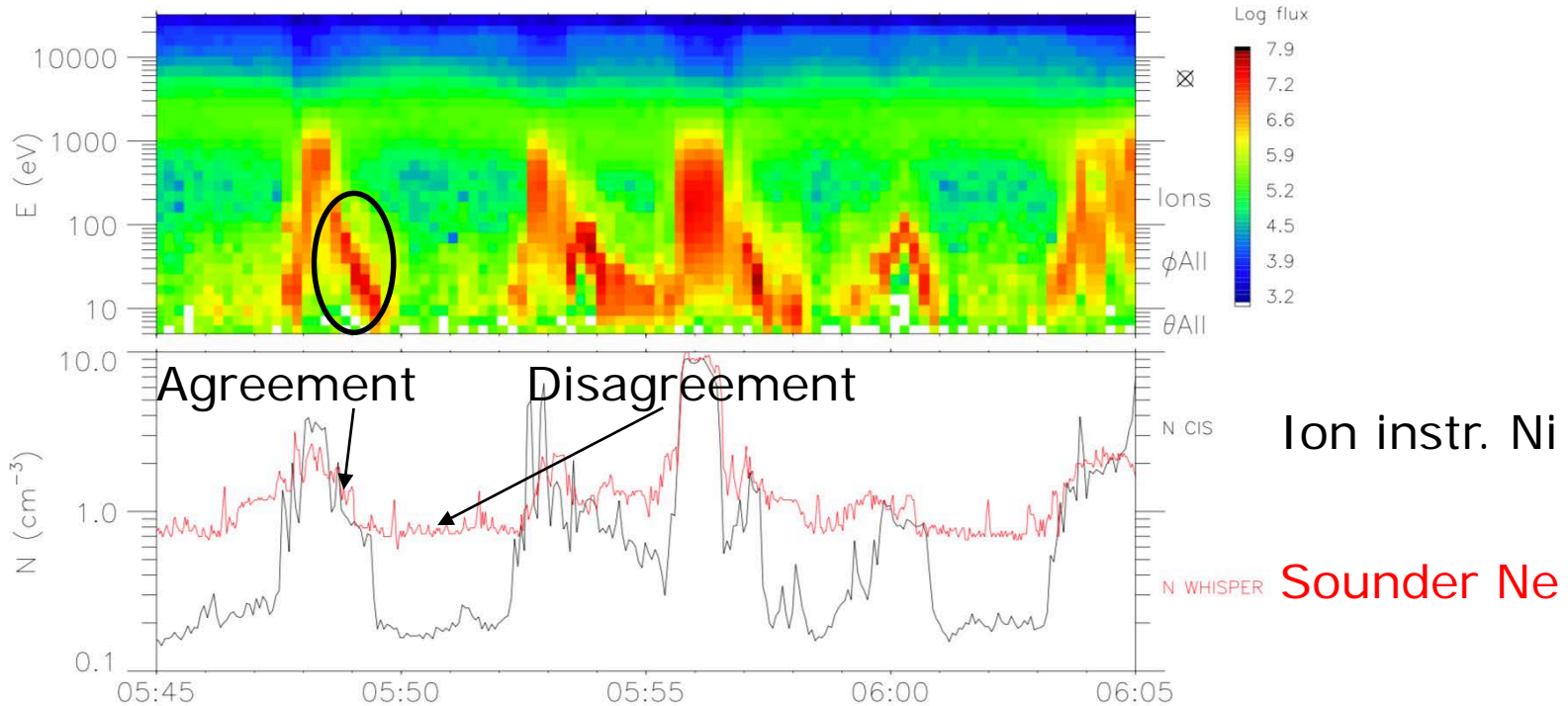
O<sup>+</sup>, He<sup>+</sup> and H<sup>+</sup> outflows coming from the Earth and accelerated by magnetopause motion

XGSE	5.74	6.08	6.41	6.74	7.06
YGSE	7.38	7.56	7.73	7.90	8.06
ZGSE	9.16	9.16	9.15	9.14	9.11
DIST	13.09	13.34	13.59	13.83	14.07

[Sauvaud et al., 2001]

# Indirect ion detection: sounder

31/Jan/2001

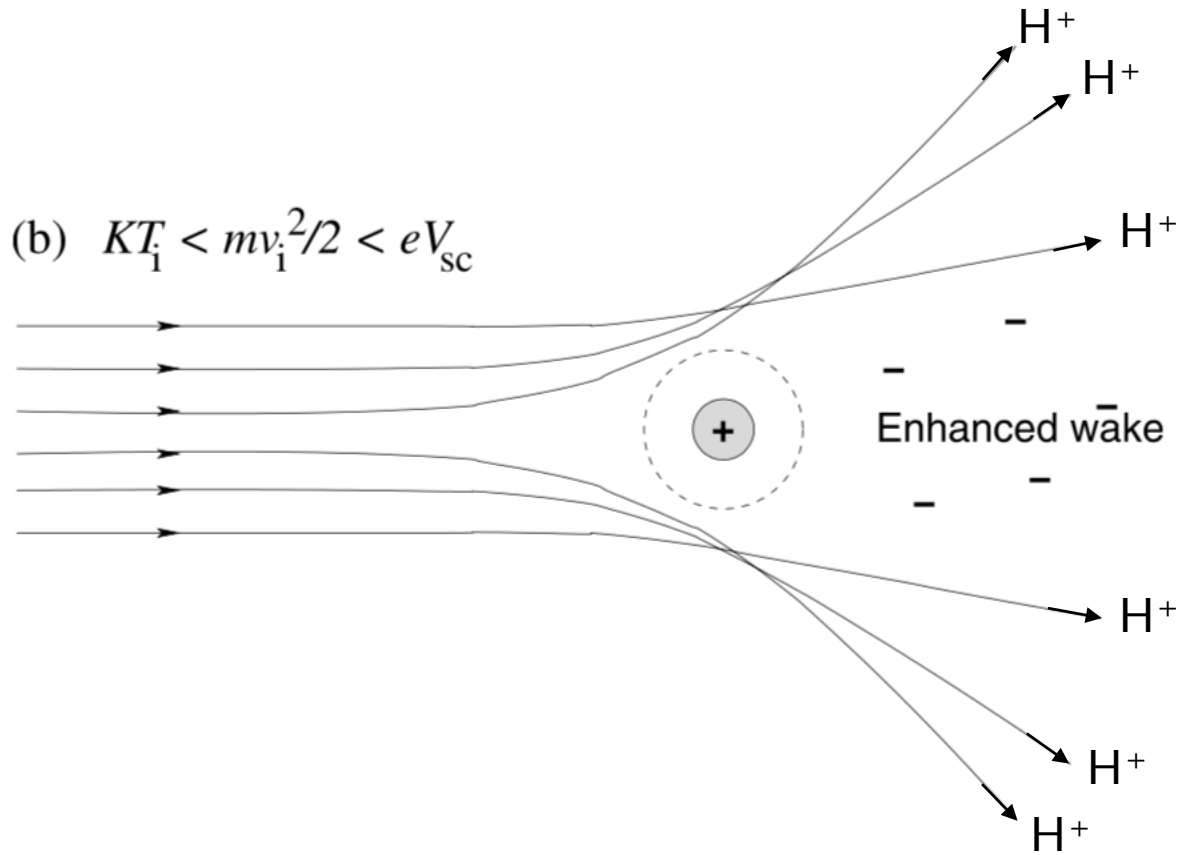


[Sauvaud et al., 2001]

Ion instrument cannot detect ion outflows with  $E_i$  below S/C potential



# Electric wake effect

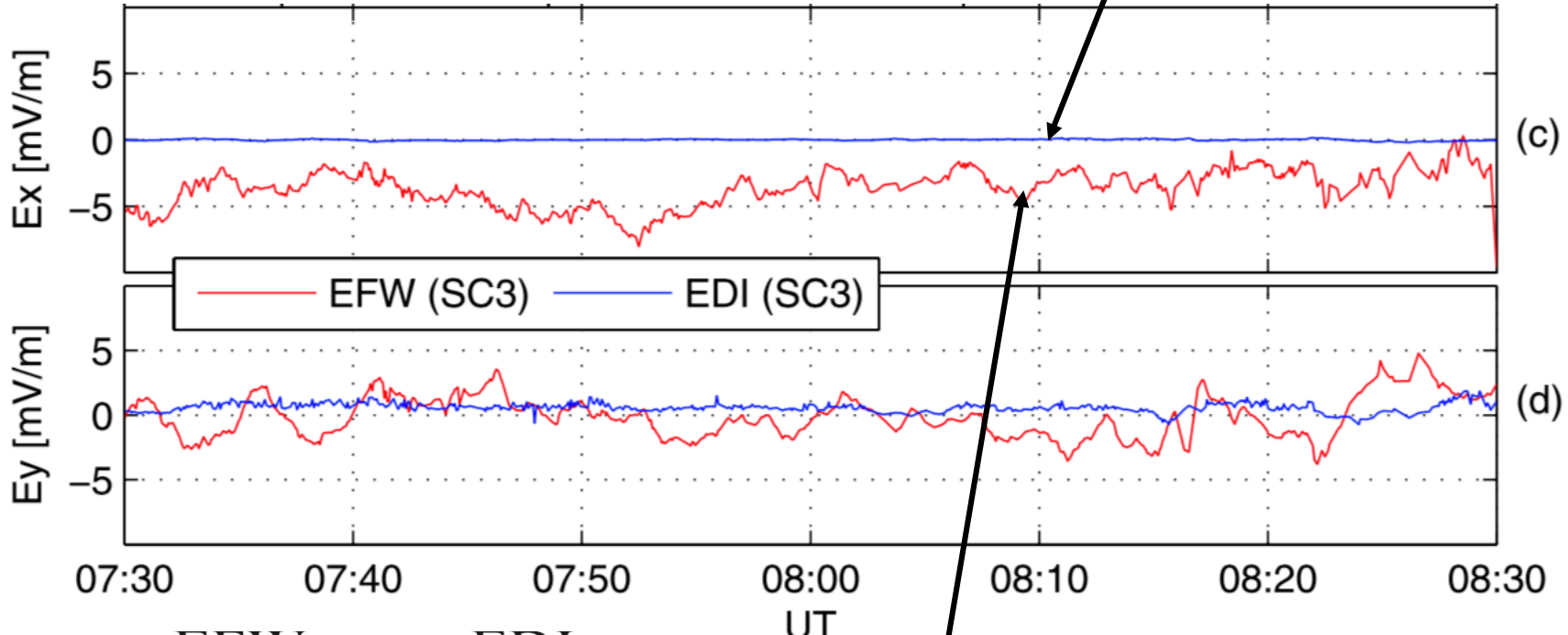


[Engwall et al., 2006]

# Wake electric field



EDI (electron gun)  
(not affected by wake)

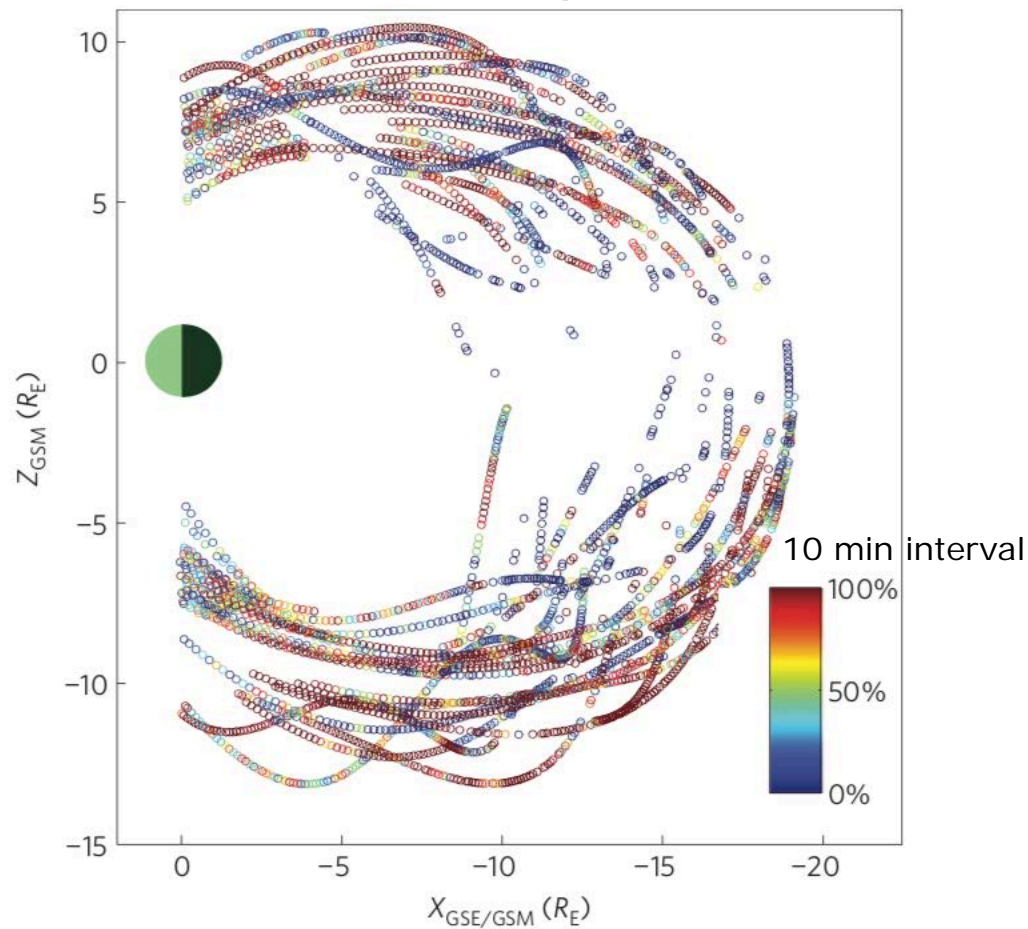


$$\mathbf{E}^w = \mathbf{E}^{EFW} - \mathbf{E}^{EDI} = g\mathbf{u}$$

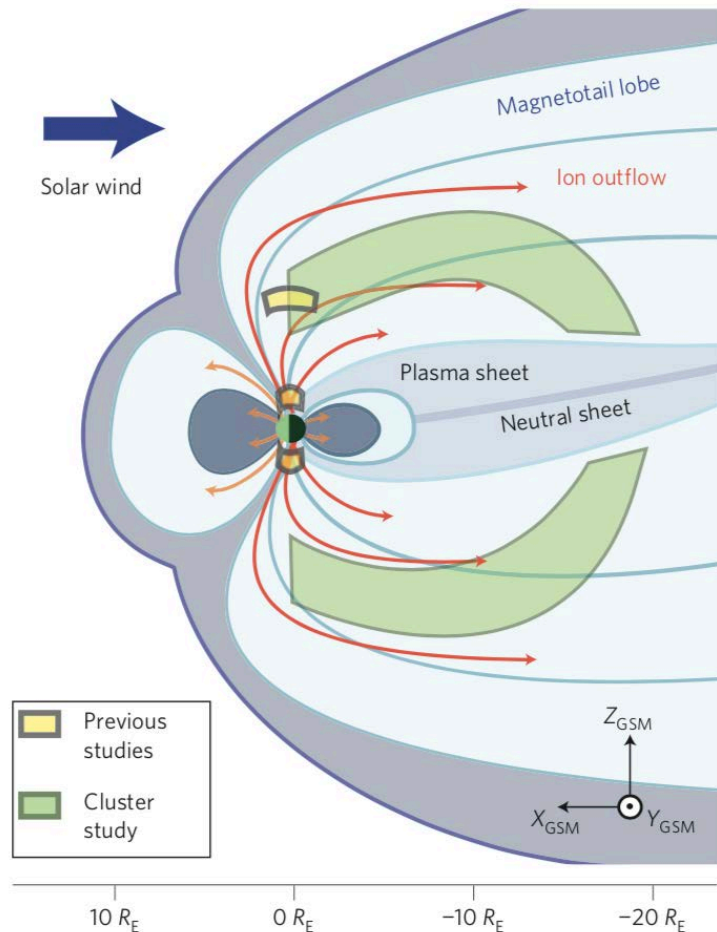
EFW (wire booms) (affected by wake) [Engwall et al., 2006]



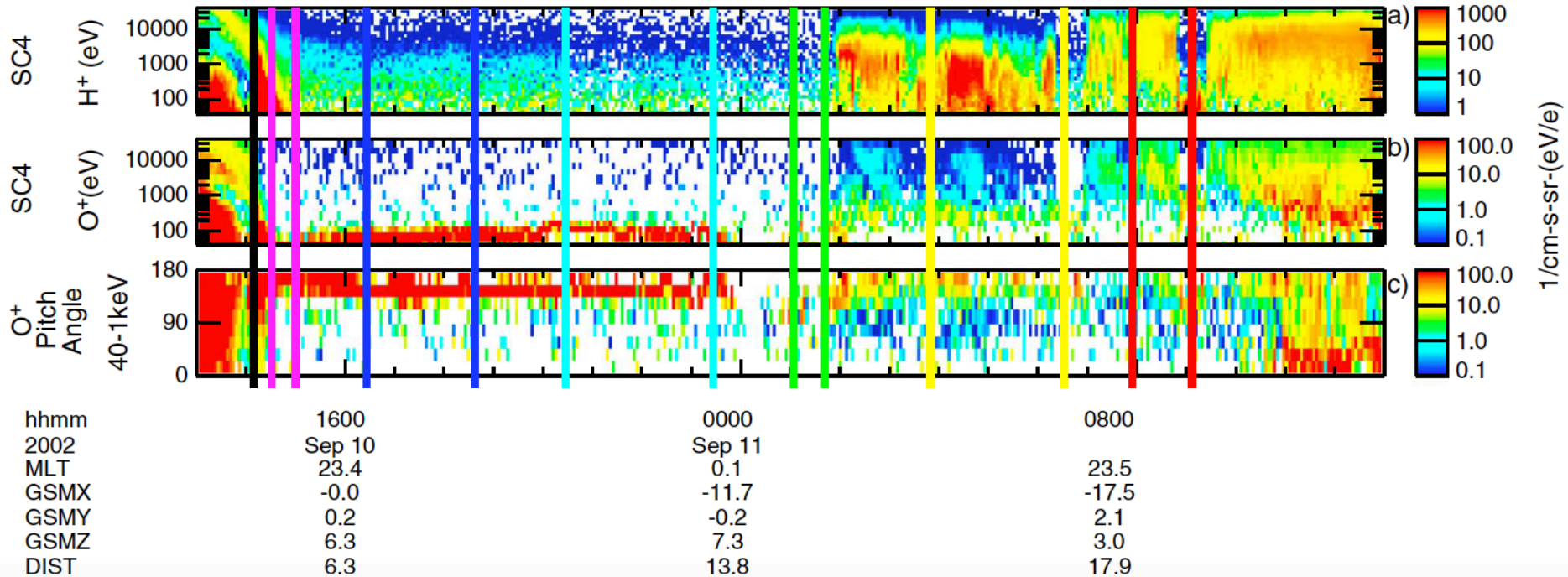
# Cold ion outflows up to 18 Re down tail



[Engwall et al., 2009]



# O<sup>+</sup> from cusp to lobes and plasmashsheet

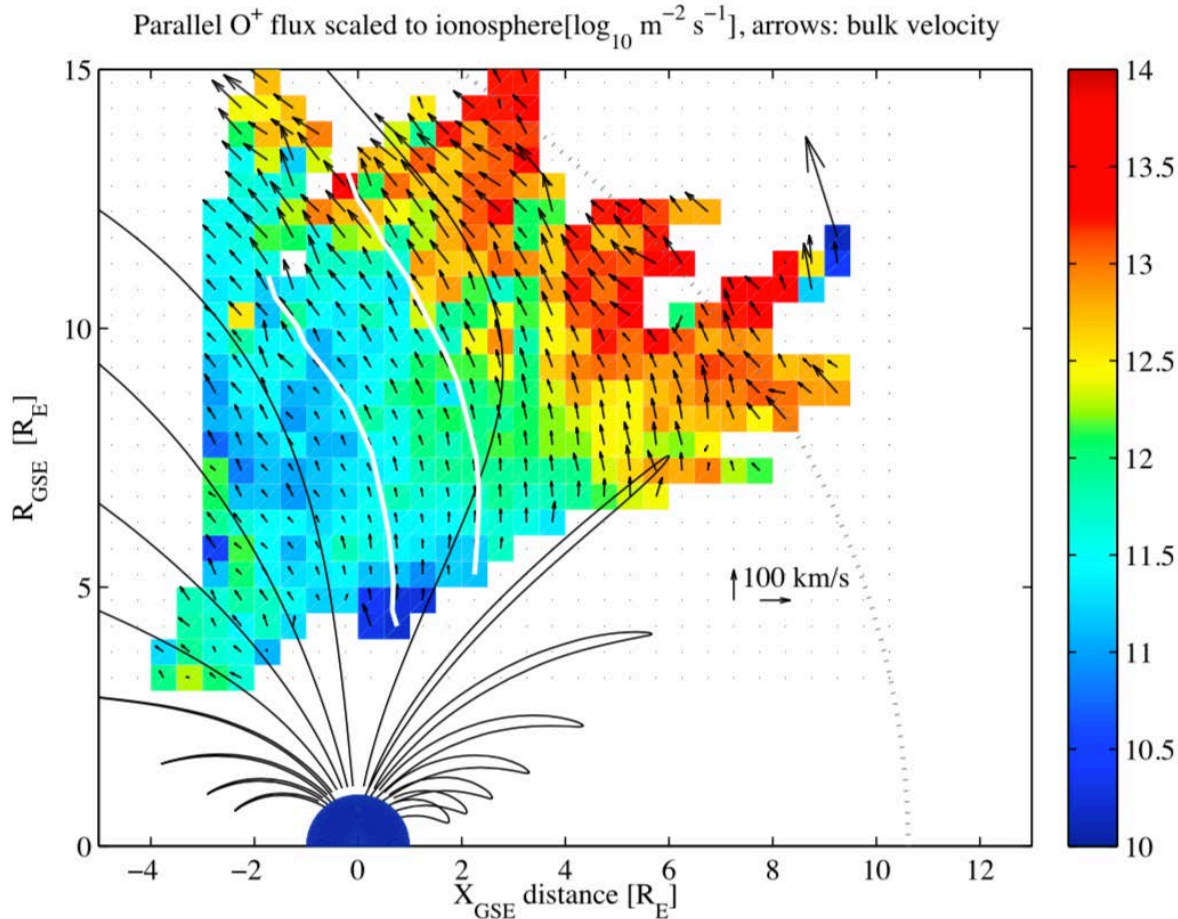


[Liao et al., 2015]

[Kistler et al., 2010]

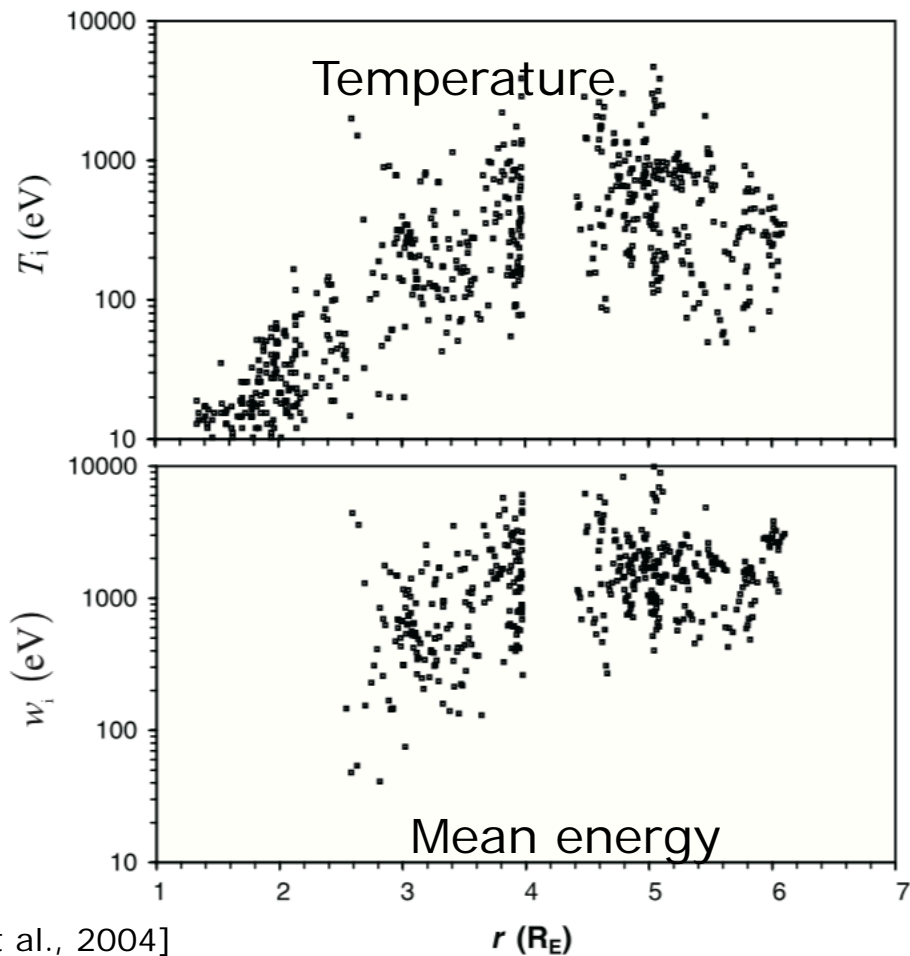
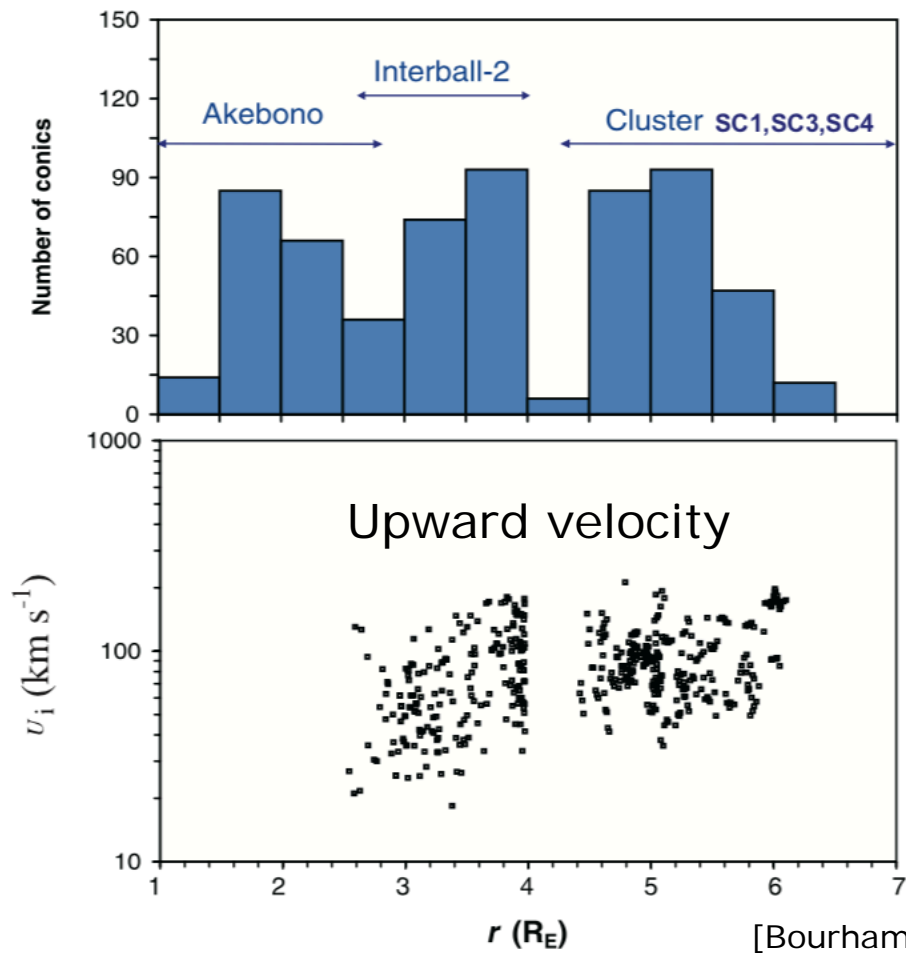


# O<sup>+</sup> outflows: bulk velocity and flux over polar region

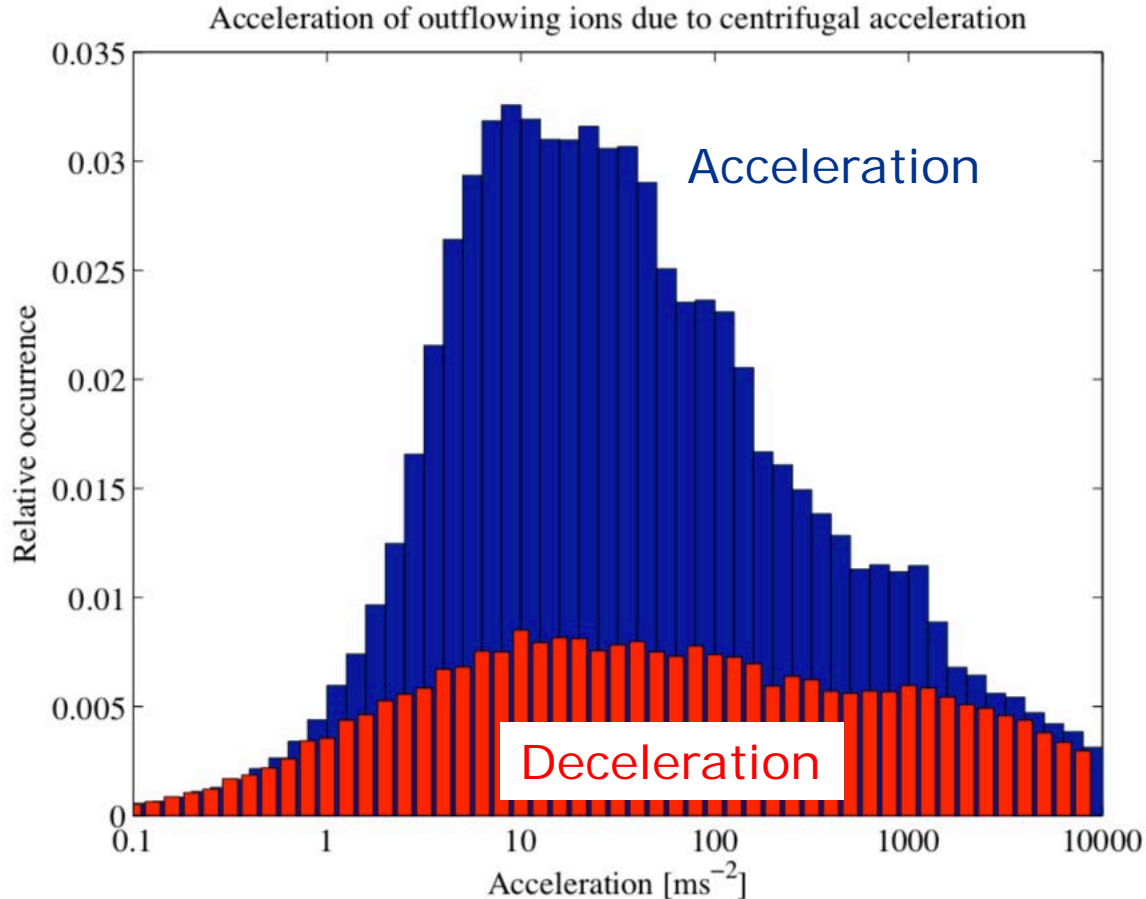


- cusp is the main source of oxygen ion outflow (strong wave heating)
- polar cap source would be consistent with cold ions observed in the lobes.

# O<sup>+</sup> outflows heating in cusp

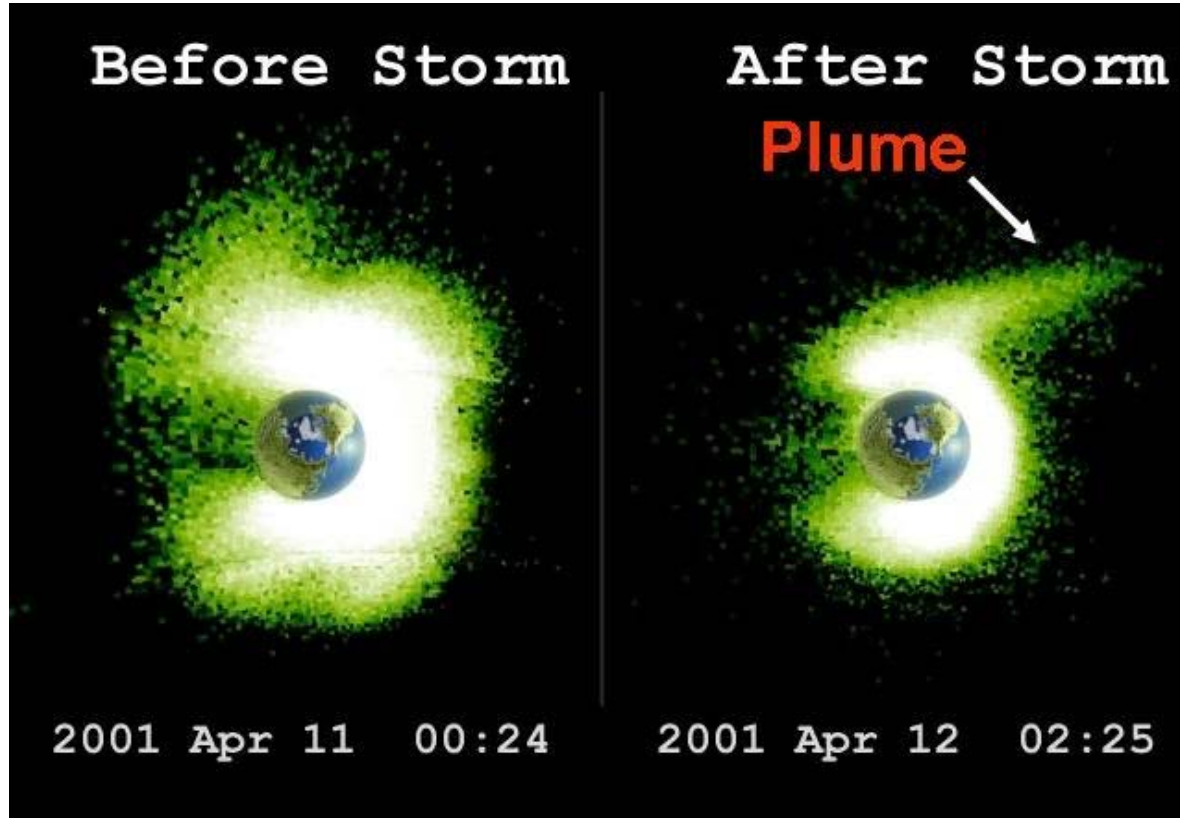


# O<sup>+</sup> and H<sup>+</sup> outflows centrifugal acceleration



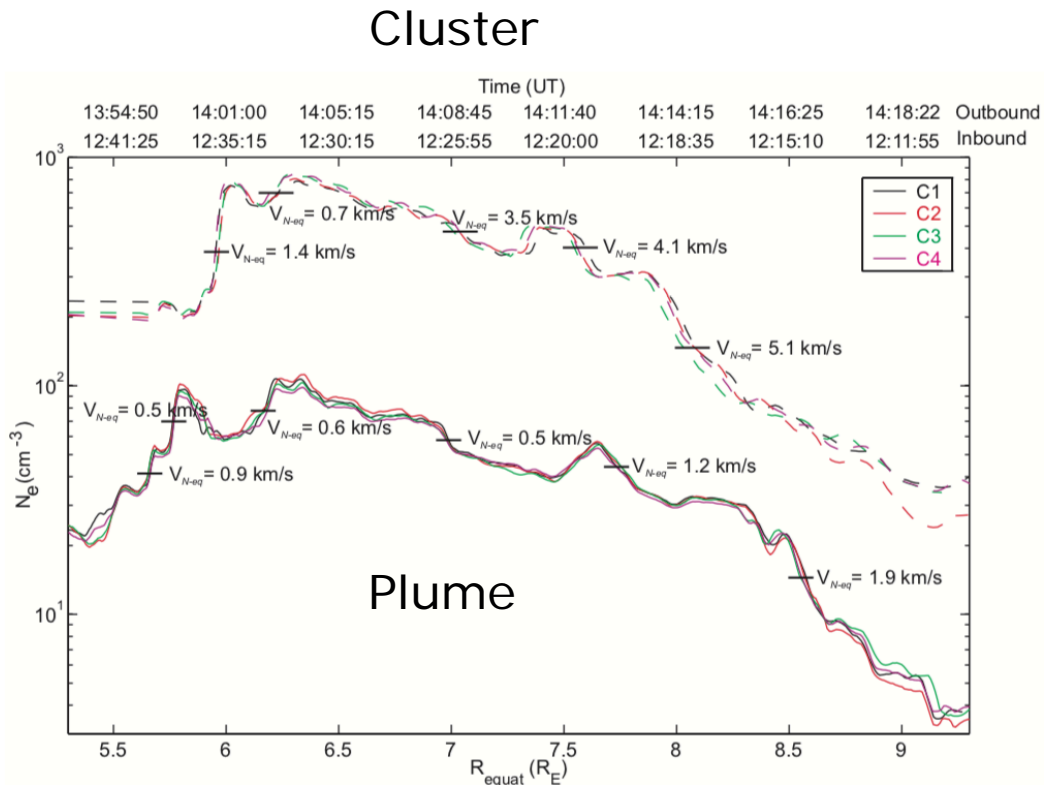
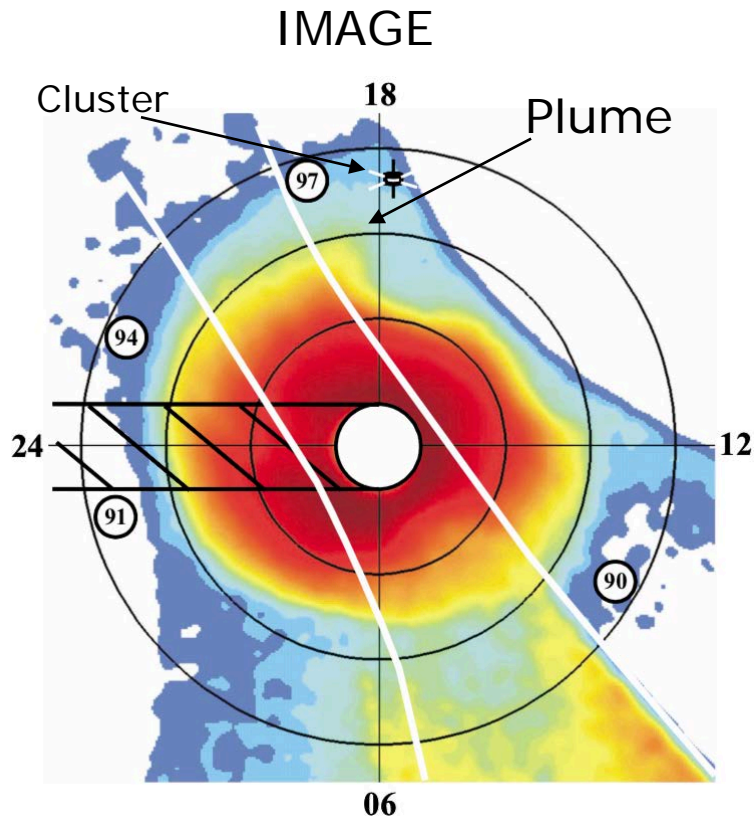
- Centrifugal acceleration is due to the change of shape of field lines over the polar cap
- Use four Cluster spacecraft to measure this change
- Acceleration around 10 ms<sup>-2</sup> and frequently reaches 100 ms<sup>-2</sup>

# Plasmasphere plume during geomagnetic storm



[Goldstein/SWRI/NASA]

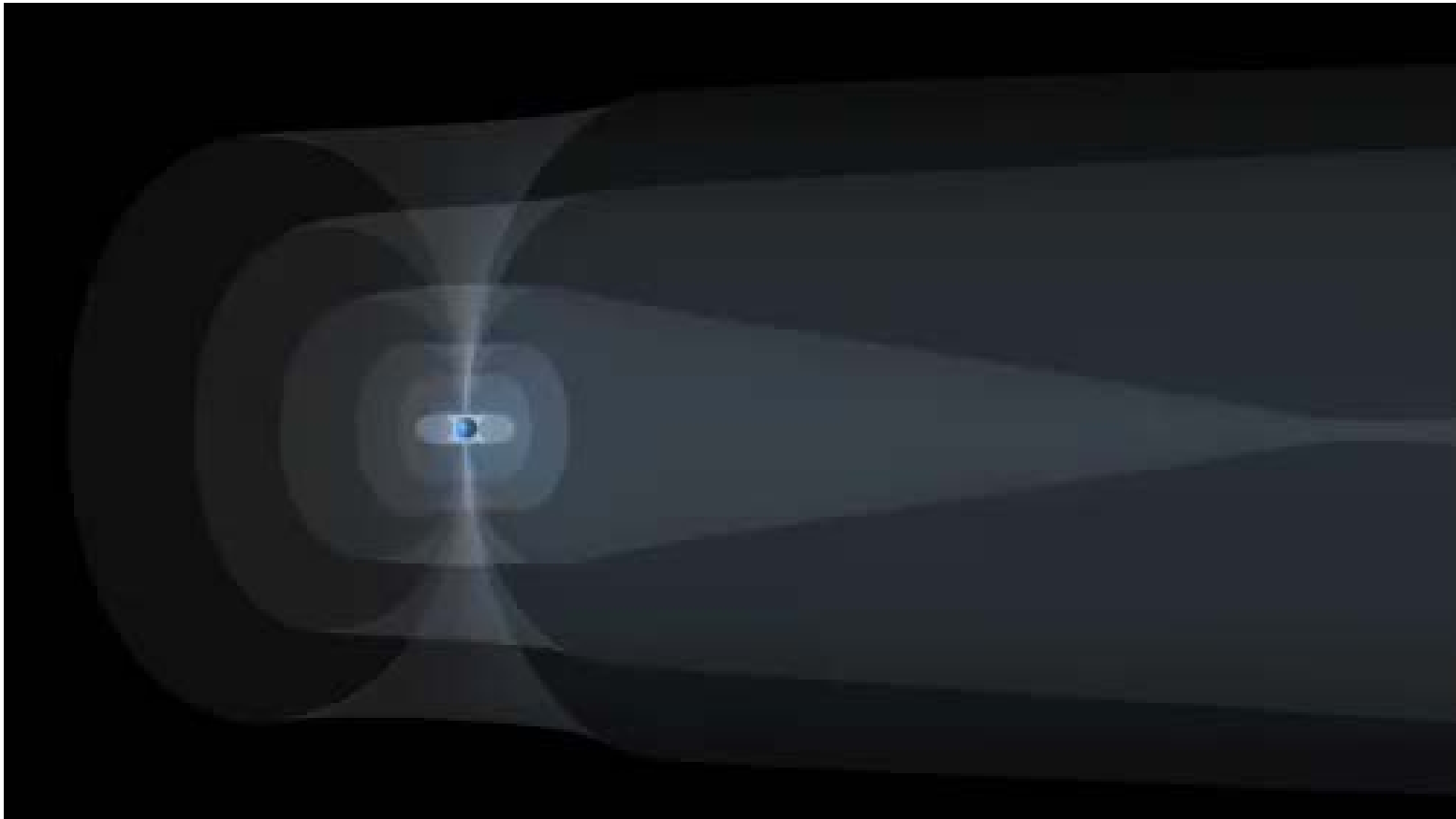
# Plasmaspheric plumes



Plasmaspheric plumes rotate around the Earth, with their foot fully co-rotating, but with their tip rotating slower and moving farther out

[Darrouzet et al., 2016]

# Plamosphere wind: predicted 25 years ago



Result from a plasma interchange motion driven by an imbalance between gravitational, centrifugal, and pressure gradient forces

[Lemaire and Schunk, 1992]

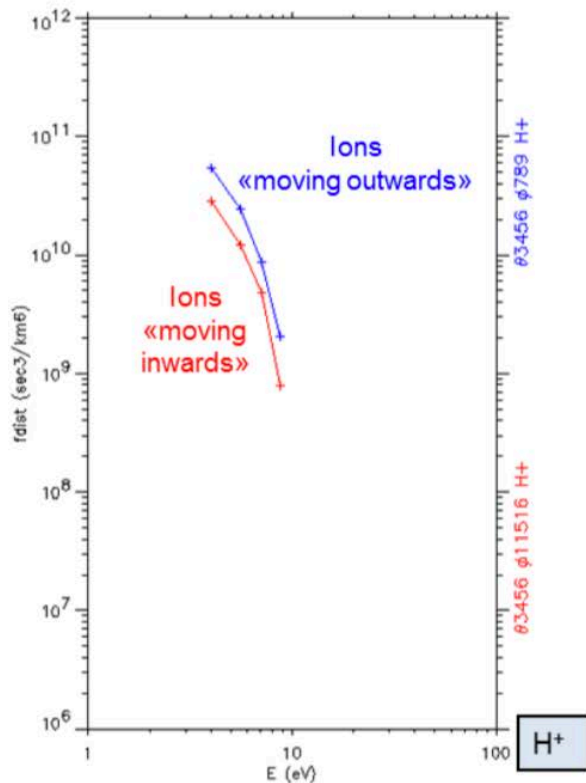


# Plasmaspheric wind: discovered

CIS-CODIF

SC 3

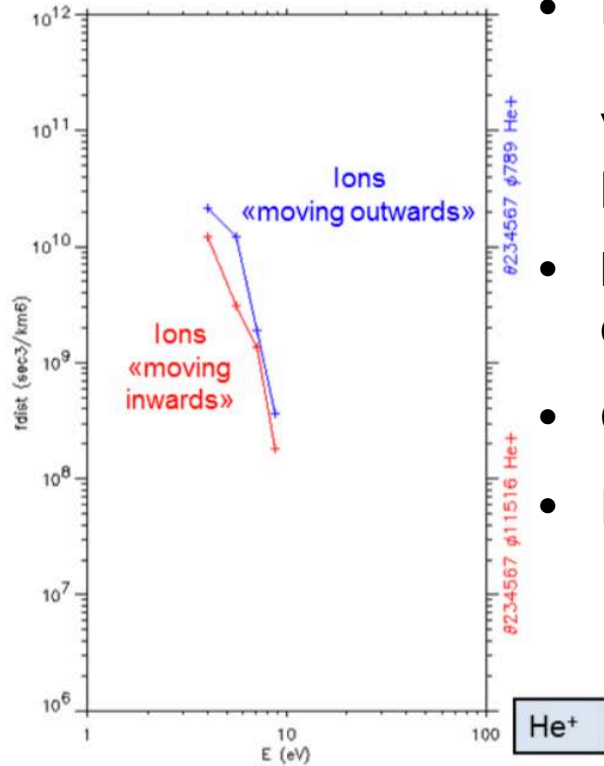
18/Mar/2002 10:52:00.



CIS-CODIF

SC 3

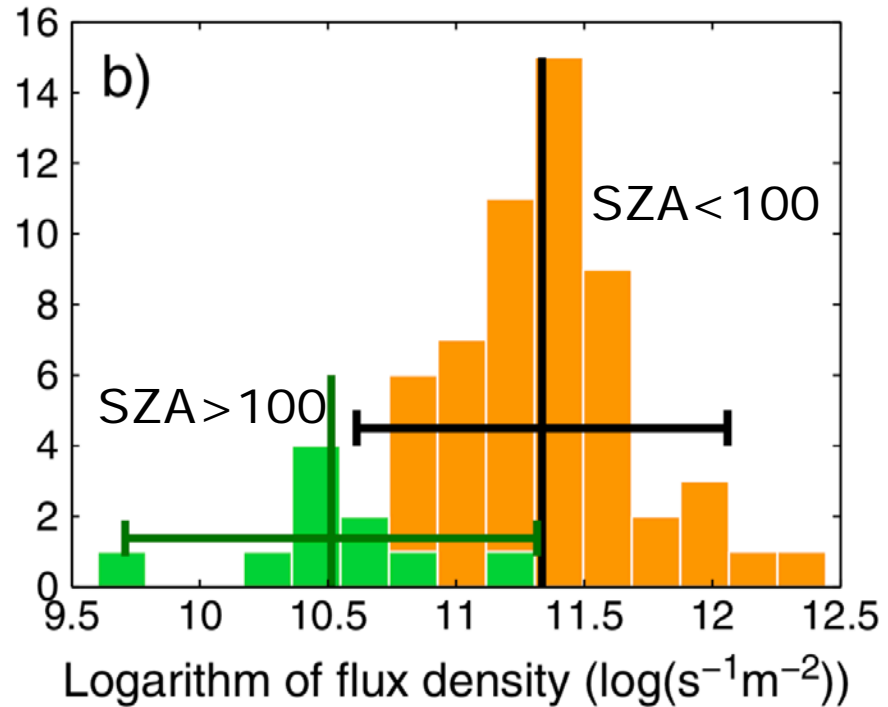
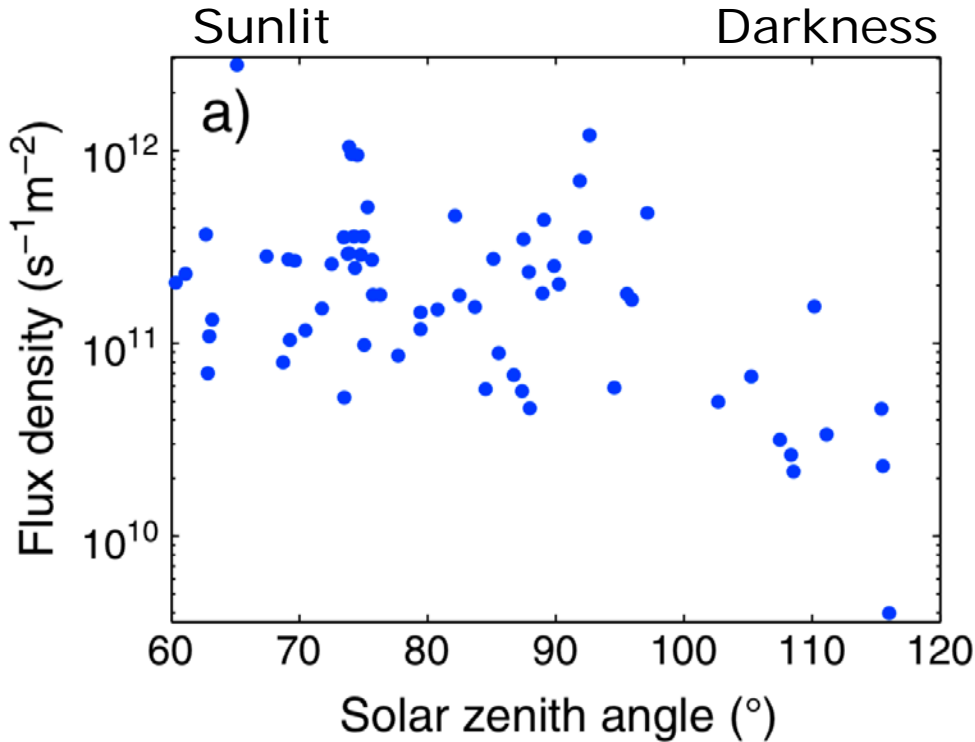
18/Mar/2002 10:52:00.



- Low energy mode (RPA) + SC potential very low in plasmasphere
- More ions moving outward than inward
- Continuous
- Flux:  $5 \times 10^{26}$  ions s<sup>-1</sup>

[Dandouras, 2013]

# Solar illumination effect on outflows

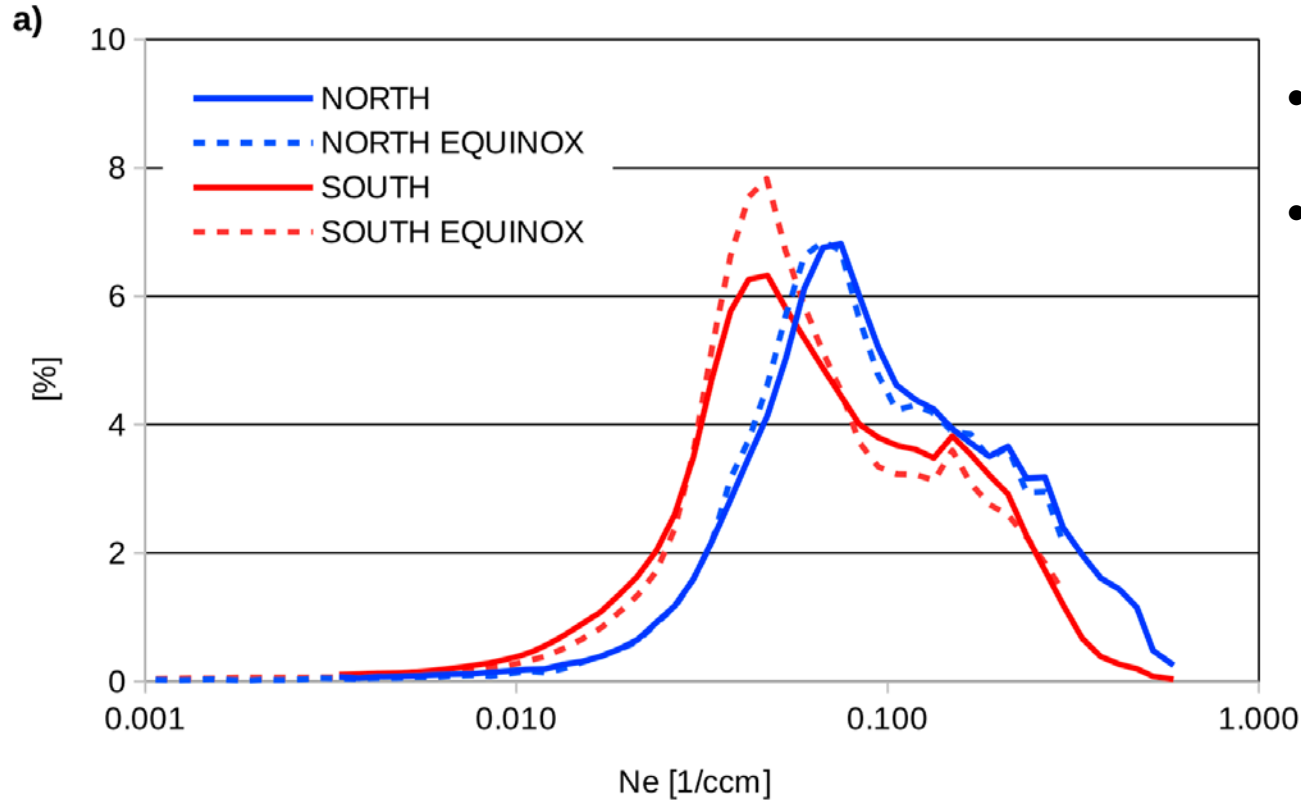


O+ flux higher above the sunlit ionosphere

[Maes et al., 2015]



# Cold plasma in the magnetotail lobes



- 16 years of Cluster data
- Asymmetry North-South: Northern hemisphere denser outflows

[Haaland et al., 2016]

# Cluster Science Archive Web Interface



**Cluster Science Archive**  
Cluster 2.0.1 Release Candidate 1

Mission  Cluster  DoubleStar

**DATA SEARCH**

Time (begin/end) [ ] - [ ] [ ]

Duration: 0 Days, 0 Hours, 0 Minutes

Clear Search

**CLUSTER MISSION EXPERIMENTS**

- All
- ASPOC active spacecraft potential control
- CIS ion spectrometer
- DWP wave-particle correlator
- ED1 electron drift instrument
- EFW electric field double probe antenna
- FGM fluxgate magnetometer
- PEACE electron spectrometer
- RAPID energetic electron and ion spectrometer
- STAFF search coil magnetometer and spectrum analyzer
- WBD radio receiver - electric field waveforms
- WHISPER relaxation sounder
- Auxiliary, MAARBLE and ECLAT support data

**DOUBLE STAR MISSION EXPERIMENTS**

- All
- ASPOC spacecraft potential control experiment
- FGM fluxgate magnetometer
- HEED high energy electron detector
- HIA ion spectrometer
- HID high energy heavy ion detector
- PEACE electron spectrometer
- STAFF/DWP search coil magnetometer / wave-particle experiment
- Auxiliary and support data

- ❑ This is an entry page of web-client for browsing and downloading datasets
- ❑ This GUI allows users to display pre-generated panels; other services will follow later



# CSA Distribution function Plotting Tool

Search View | Key Graphical Products | **Distribution Functions** | Quicklook Plots | Inventory Plots

**Distribution Function Plots**

Date Range:

Duration: Hours  Minutes

Plot Panel(s):

C1 C2 C3 C4

**CIS**

**PEACE**

- ANGLE-ANGLE DISTRIBUTION (HEEA)
- ANGLE-ANGLE DISTRIBUTION (LEEA)
- PITCH\_ANGLE/ENERGY PLOT
- SAUVAUD PLOT
- WHEEL PLOT
- WHEEL PLOT (FULL)

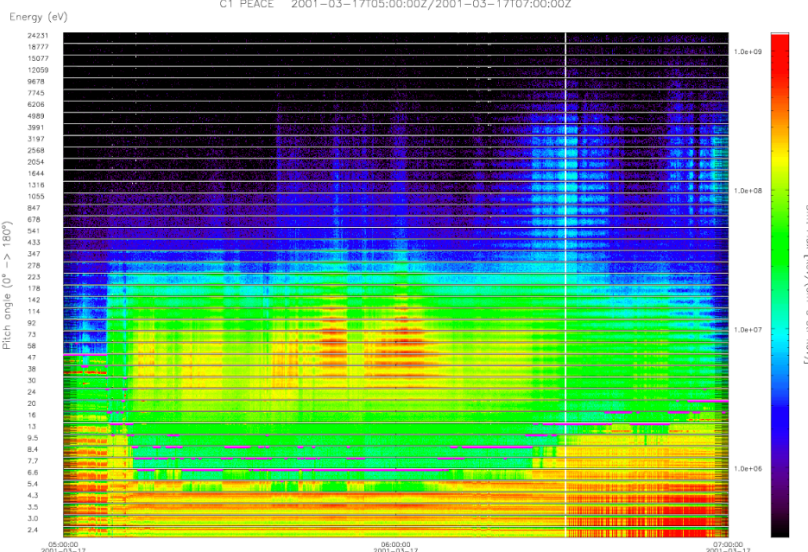
**RAPID**

This service allows users to visualize particle distribution functions in four different plot types; no other archive is able to provide this kind of service yet

**Plots**

C1\_CC\_PEA\_PITCH\_SPIN\_DEFlux\_CAA\_TIME\_20010317050000\_20010317070000\_20160519111431\_00.png

C1 PEACE 2001-03-17T05:00:00Z/2001-03-17T07:00:00Z



# Summary and conclusions



- Cluster with 17 years of accumulated data can be used in exhaustive statistical studies as well as event studies.
- Its specific instrumentation:
  - low energy detector modes
  - two complementary Efield instruments
  - spacecraft potential control and sounder
  - polar orbit

has returned crucial data sets for outflows understanding and atmospheric escape

- Cluster science archive allows easy and fast access to data
- Cluster has been extended up to end 2020 and a proposal up to end 2022 is in preparation

