Origine des ions magnétosphériques : mesures CLUSTER

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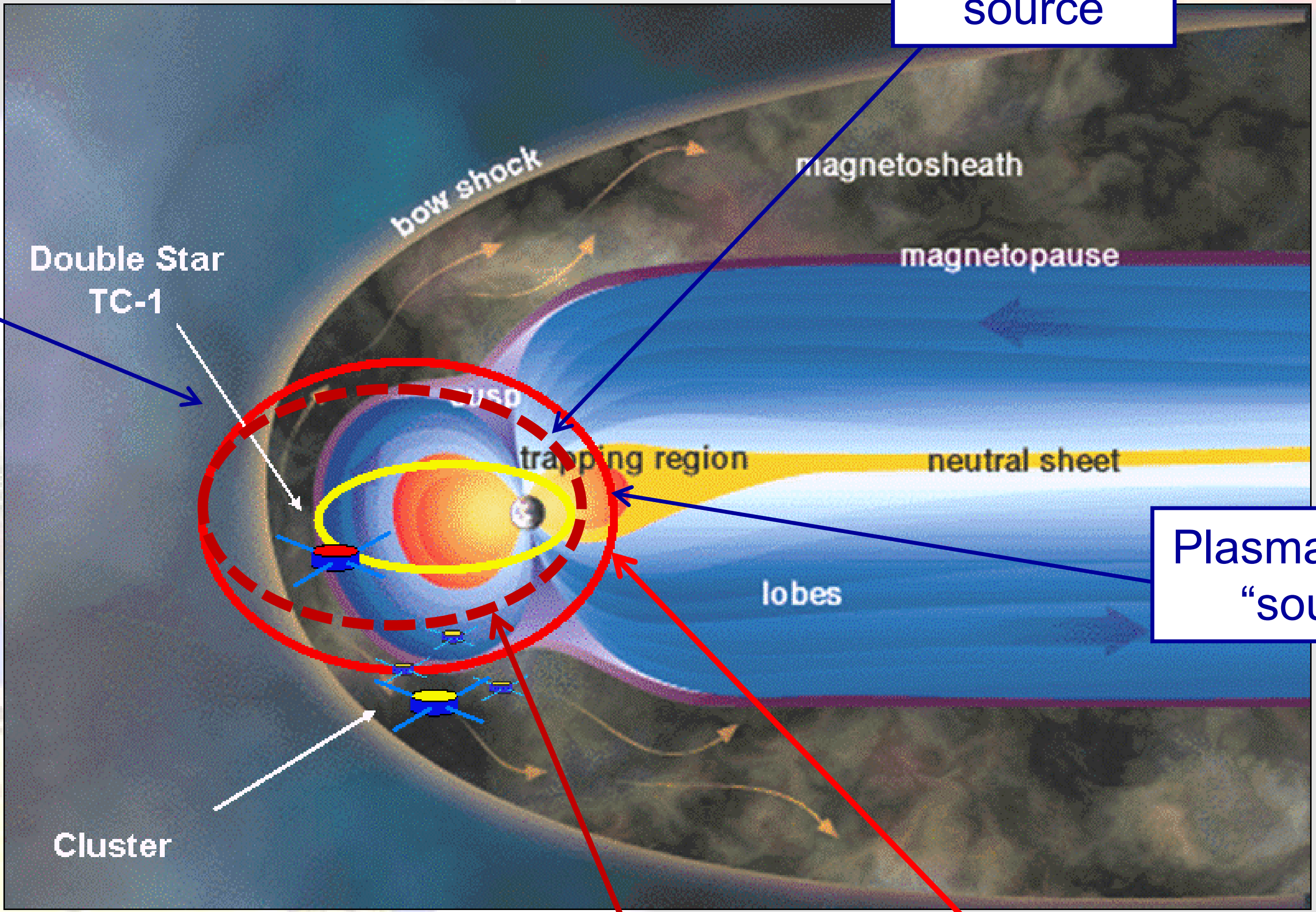
et l'équipe CIS

Colloque du PNST, Hendaye, 16 Mars 2016

Cluster orbit



Polar Ionosphere source

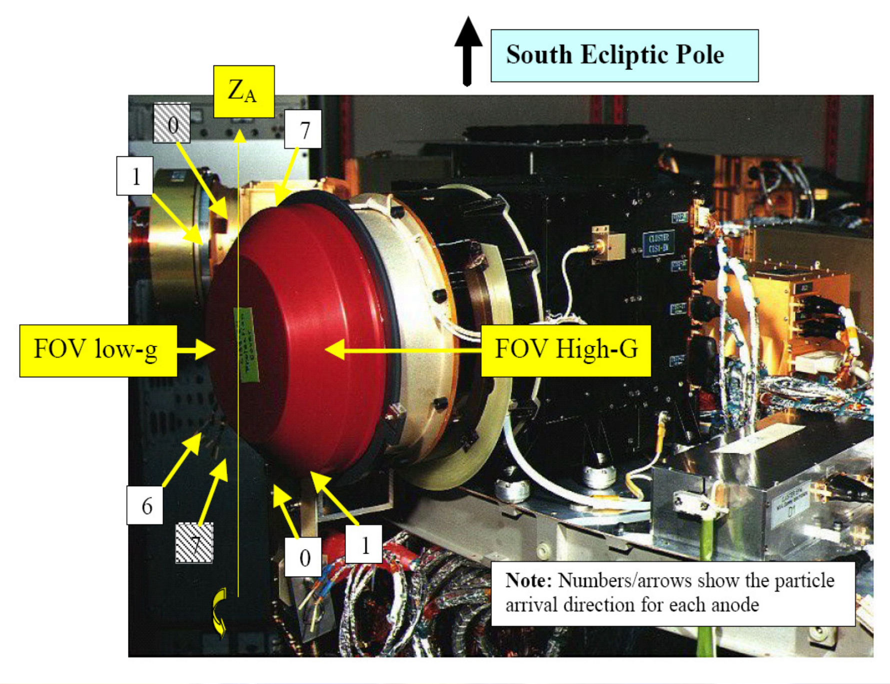
Solar Wind source

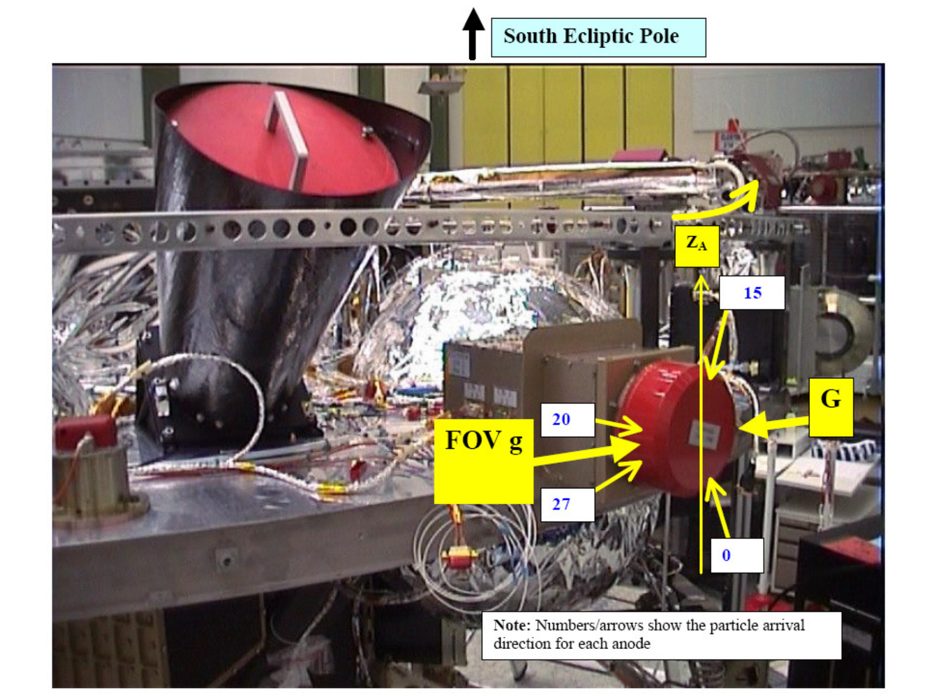
Plasmaspheric "source"

Cluster:
Orbit evolution
since 2007

Cluster:
the "early years"
(2000 – 2006)
4 x 19.6 R_E

The CIS Experiment onboard Cluster





CODIF (CIS-1)

Ion Composition and Distribution Function Analyser

3D ion distributions with mass-per-charge composition determination (Time of Flight)

25 eV/q - 40 keV/q Energy Range

+ RPA : 0.7 – 25 eV/q

HIA (CIS-2)

Hot Ion Analyser

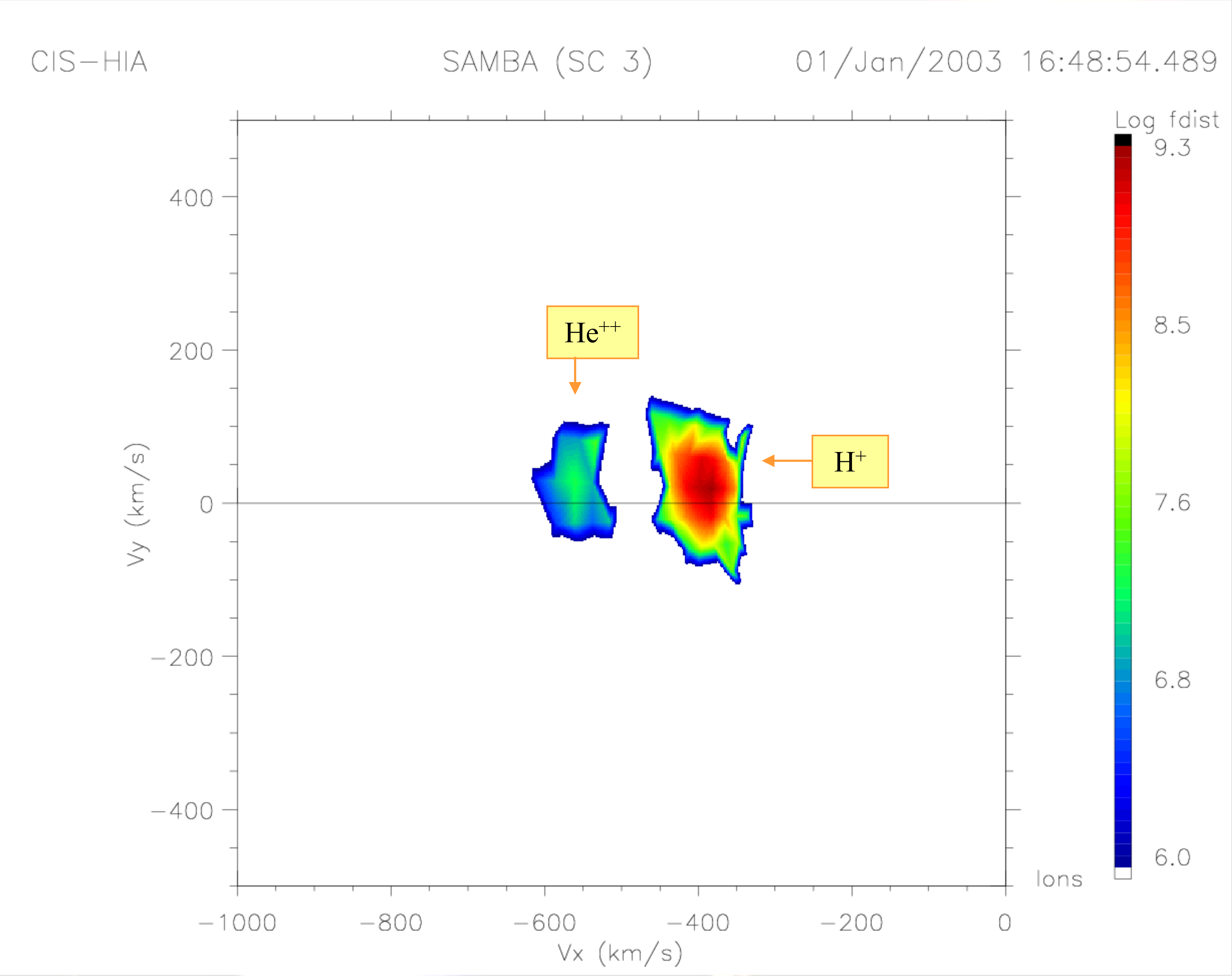
3D ion distributions with high angular resolution

5 eV/q - 32 keV/q Energy Range

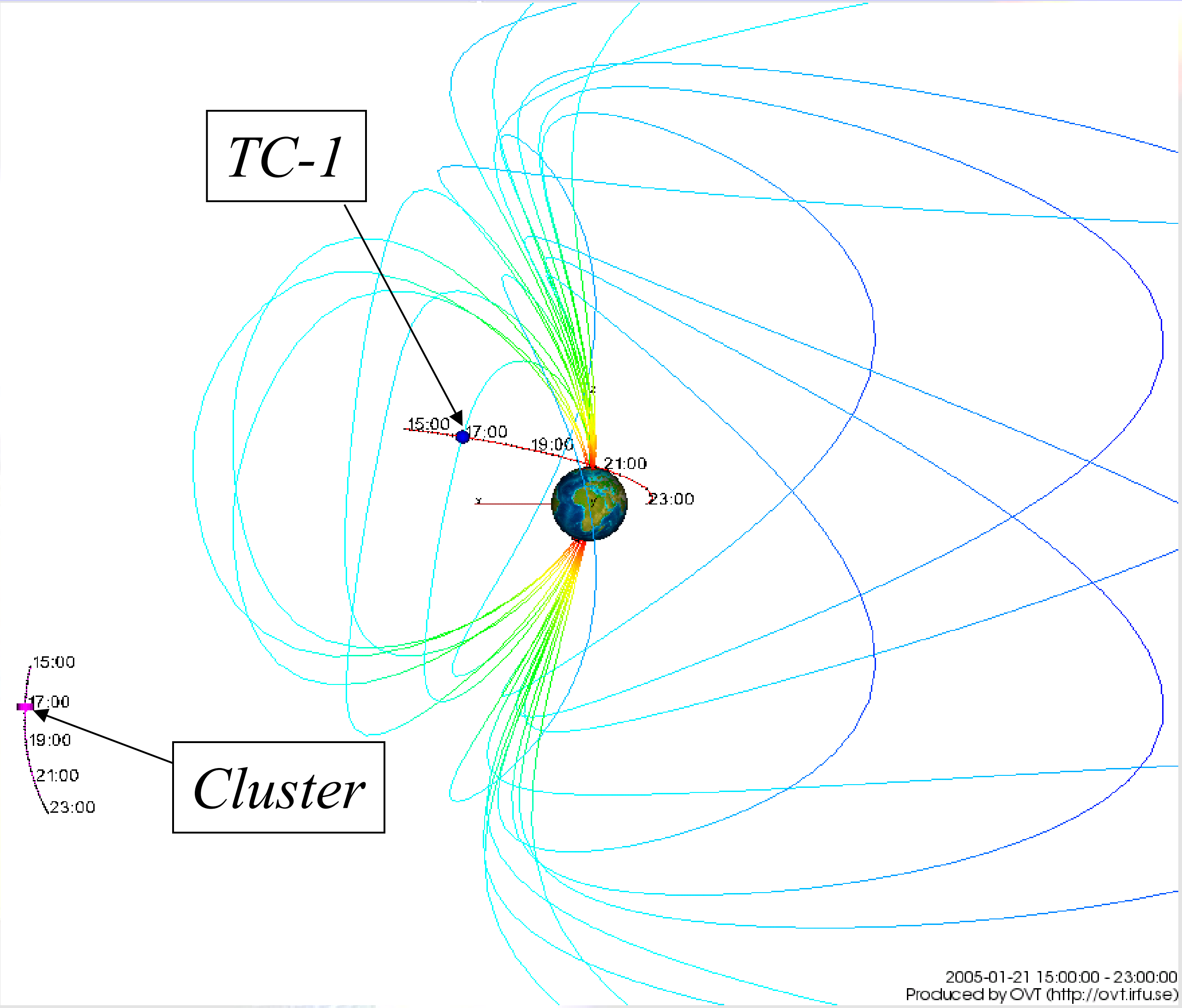
Rème et al., 2001

The Solar Wind Source

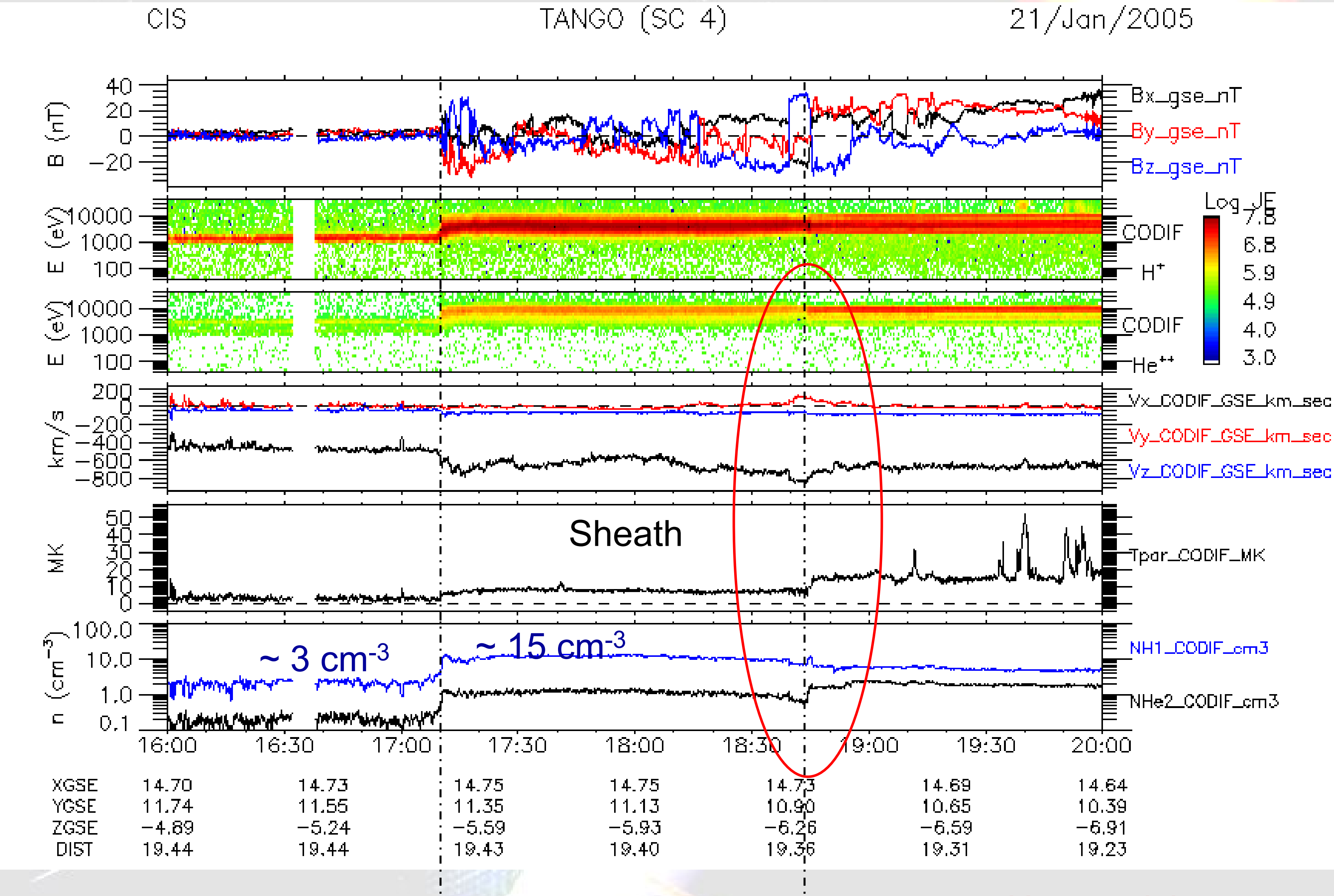
CIS – HIA Ion Distribution Function in the "Quiet" Solar Wind



21 January 2005 Extreme Solar Event: ICME Arrival



- Cluster SC4 was situated in the **solar wind** region, at MLT ~ 14.5 h.
- TC-1 was in the **Magnetosheath** region, at R ~ 8 R_E and at MLT~ 17.



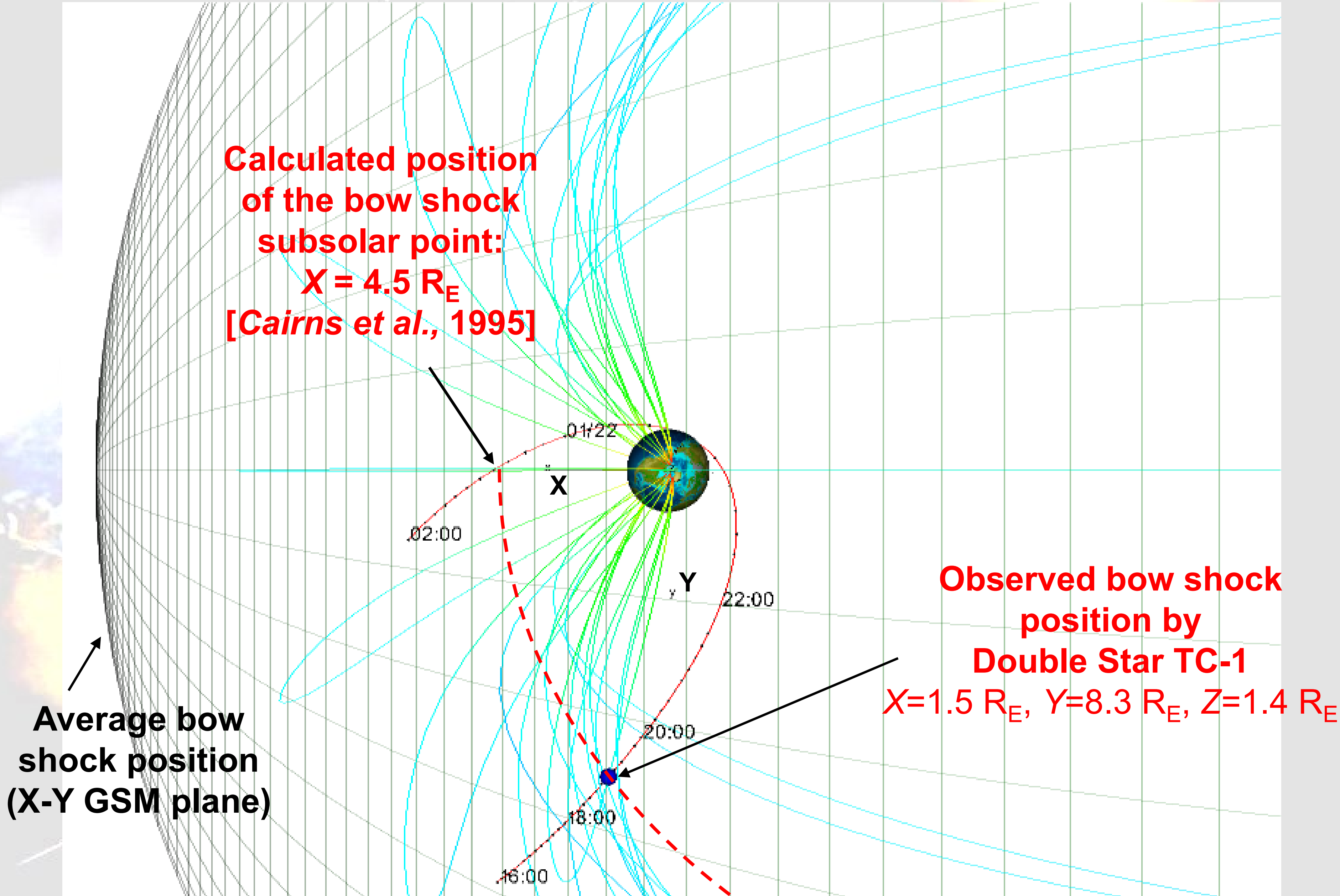
Dandouras et al., 2009

Foullon et al., 2007

17:10 : ICME shock arrival (hot pileup)

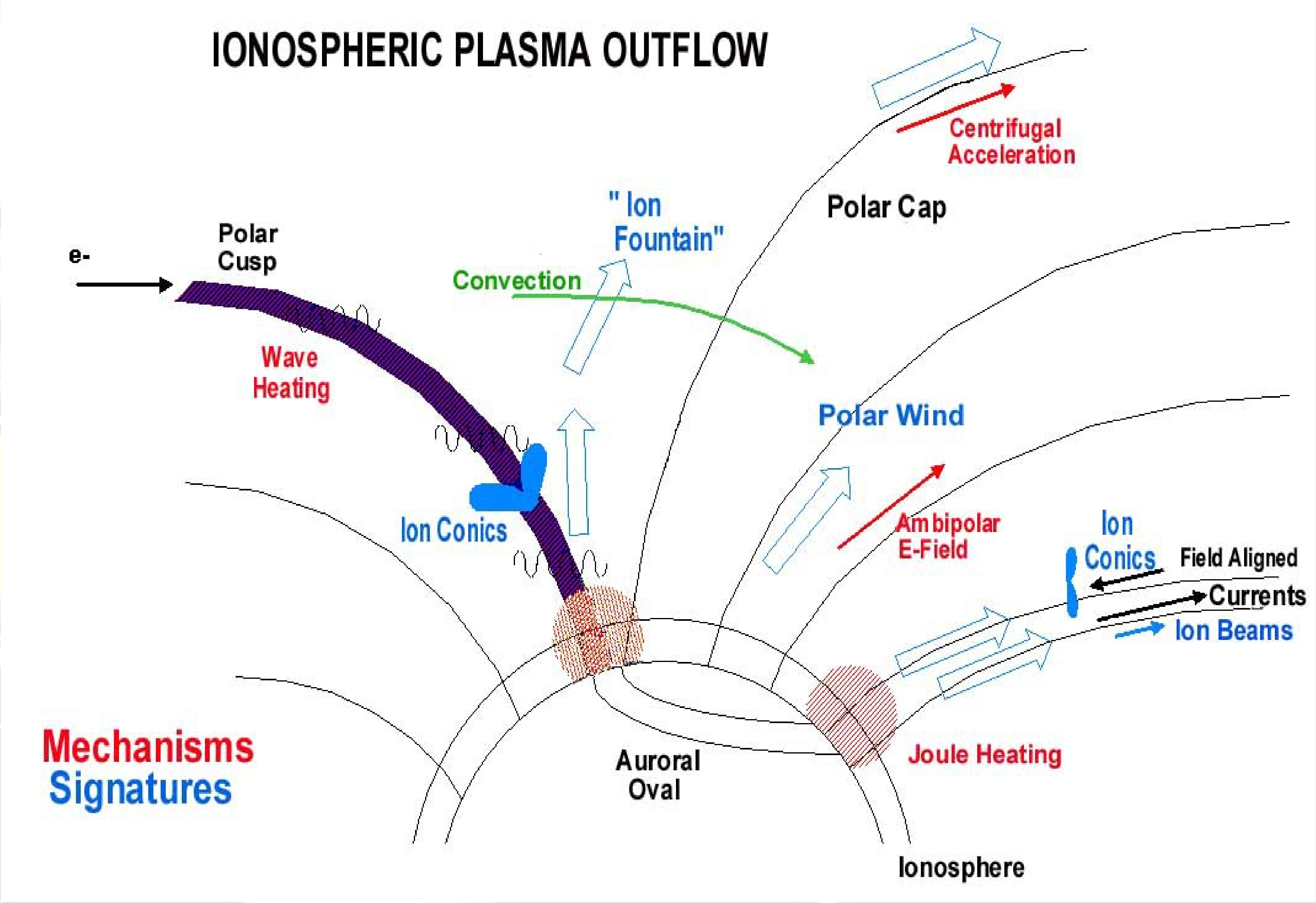
18:44: Secondary front arrival

He^{++} enrichment: arrival of the « flare driver gas »

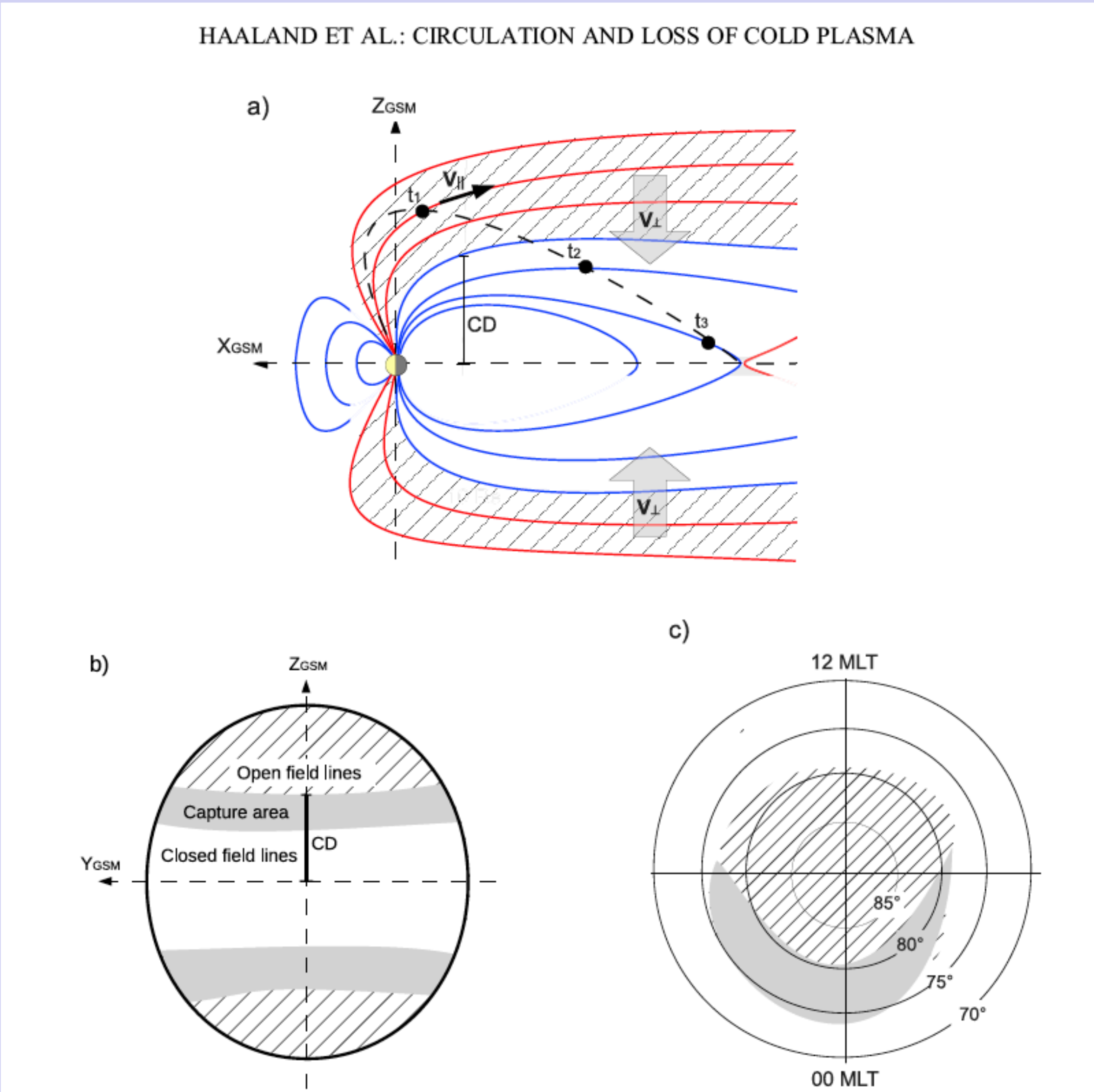


Large Magnetsosheath compression due to the extreme solar wind density and velocity increase

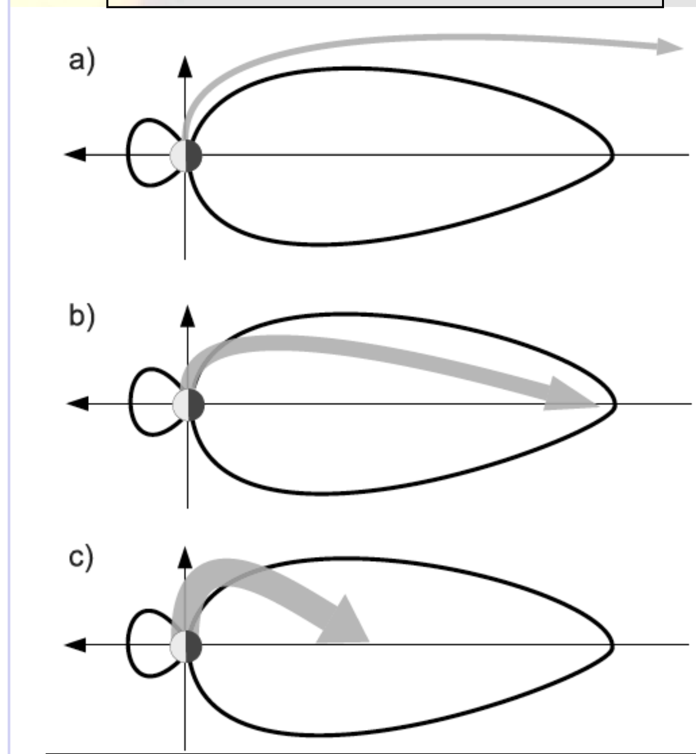
The Polar Ionosphere Source and Outflow Mechanisms



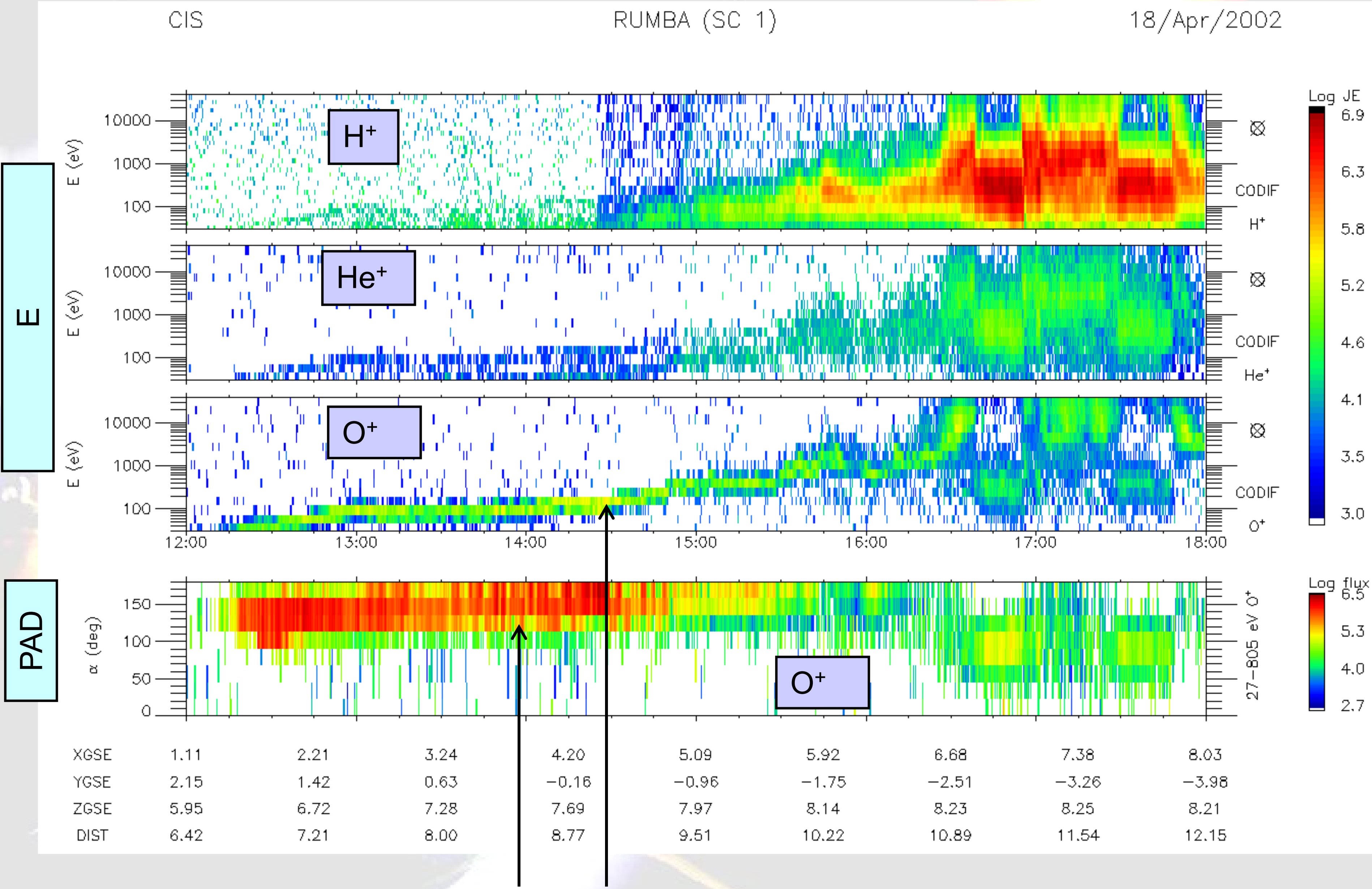
Ion Fate is a Strong Function of the Activity Level



a: Quiet conditions, direct loss downtail



c: Disturbed conditions, supply close to Earth



Typical upflowing O+ beam

Scaled Upflowing Ionospheric O^+ Flux

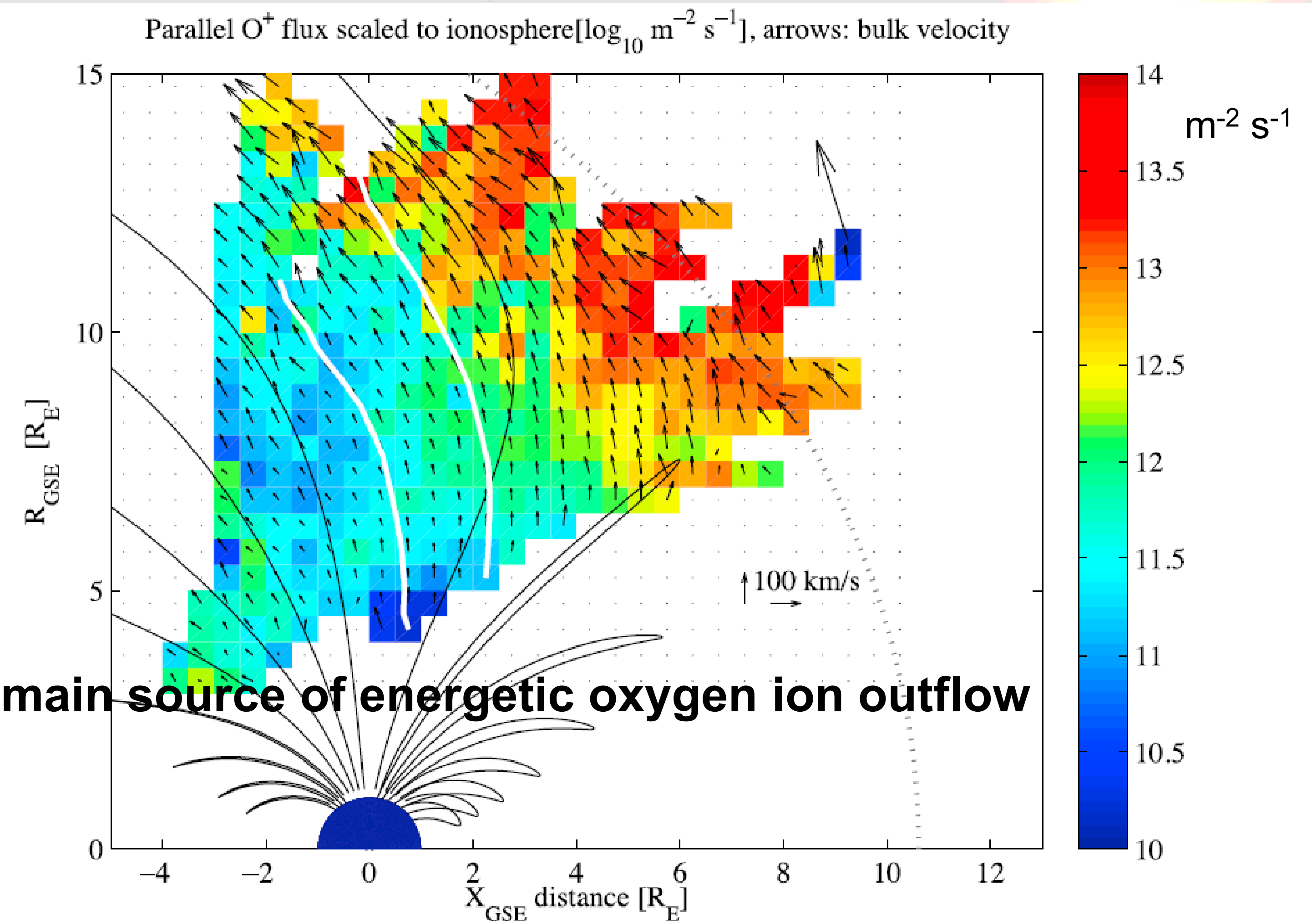
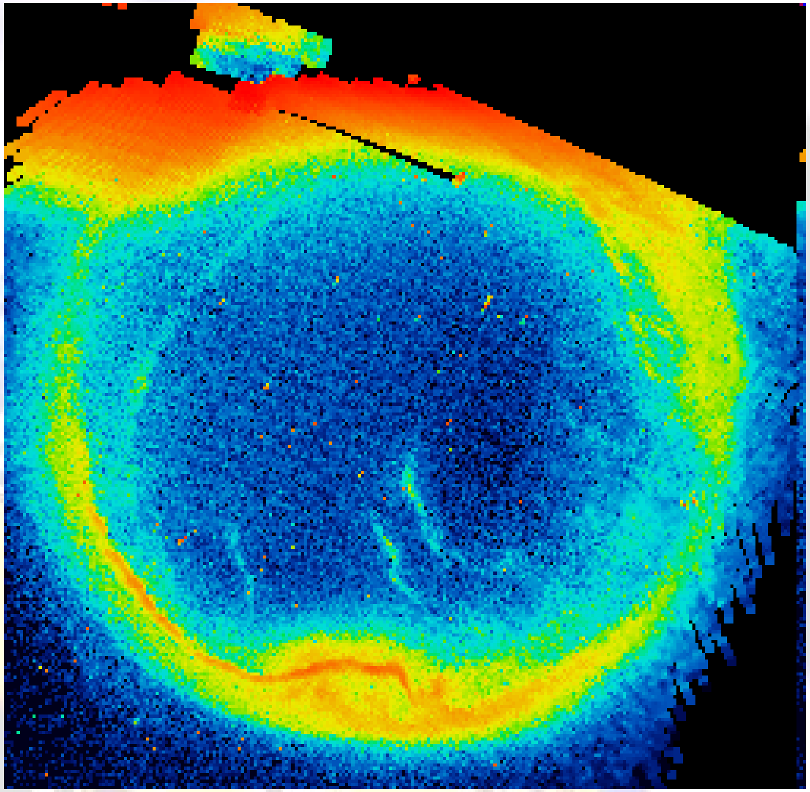
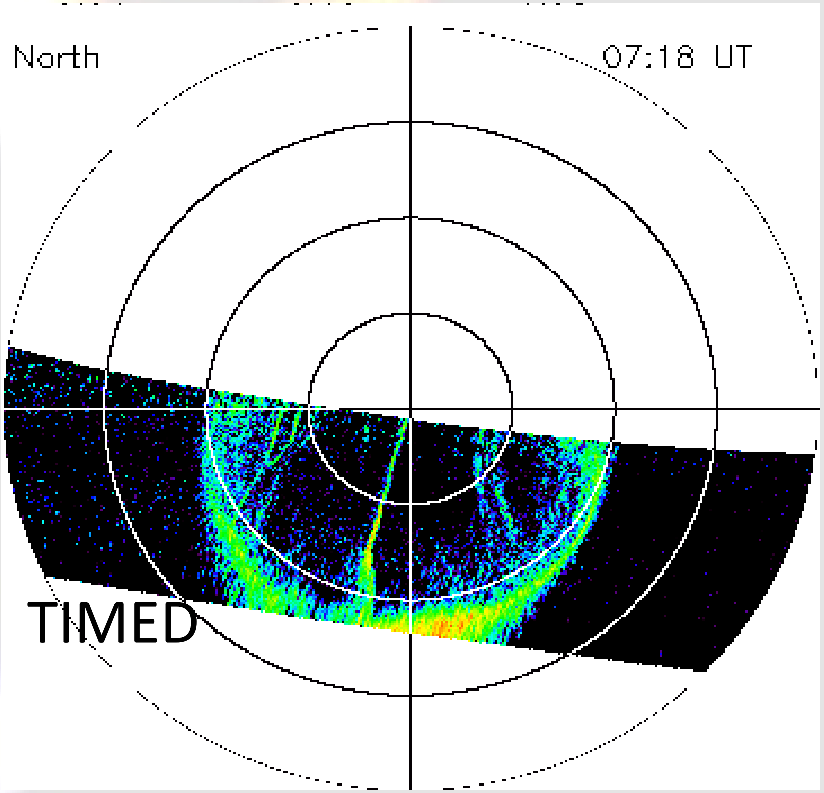


Figure 1. Parallel flux of O^+ scaled to ionospheric altitude shown in cylindrical GSE coordinates (R_E). The flux is shown with a color scale in units of $m^{-2}\ s^{-1}$. Black arrows indicate the direction and relative magnitude of the parallel bulk velocity of O^+. Solid black curves indicate sample field lines from the Tsyganenko T89 model, at $Y_{GSE} = 0$ and spaced 5° apart. A model magnetopause is indicated by the thick dotted line.

Nilsson et al., JGR, 2012

Magnetosphere-ionosphere coupling above the polar caps during periods of northward IMF: Small scale polar cap arcs





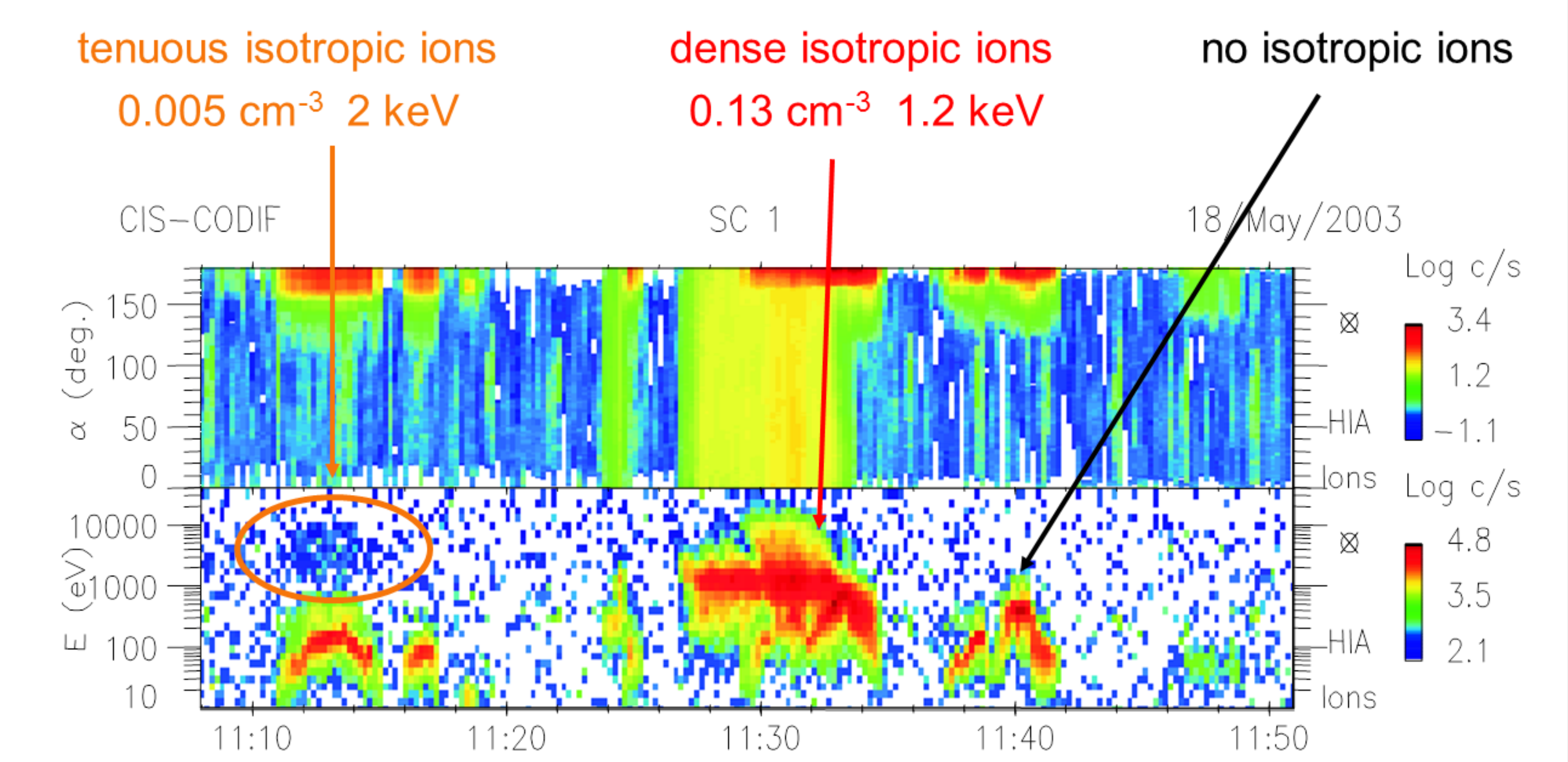
How many classes of small scale PC arcs?

Magnetic Field line topology: open or closed?

Generation of polar cap arcs, magnetospheric configuration?

Statistical properties of Polar Cap Ion Beams

~40 % of PCIB are associated with a warm isotropic ion population

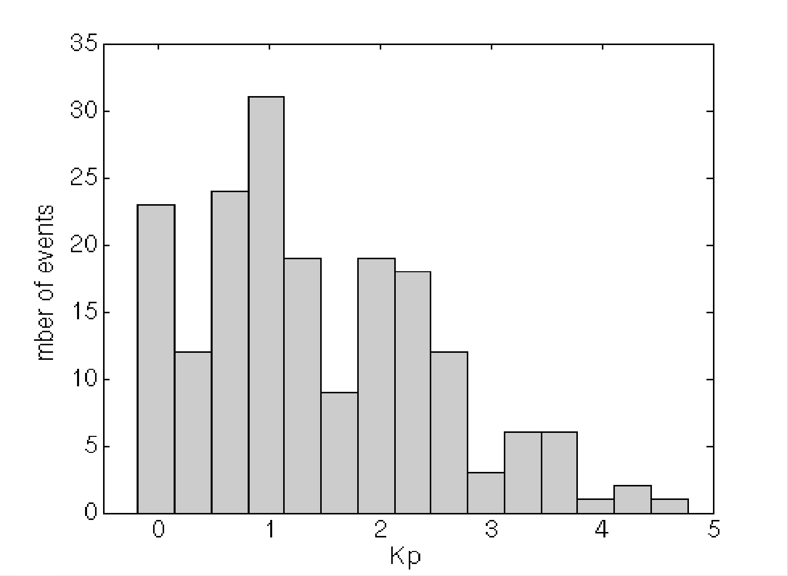


T~ 500-2000 eV

Density highly variable. Not correlated to temperature.

Maggiolo et al., 2011

Statistical properties of Polar Cap Ion Beams

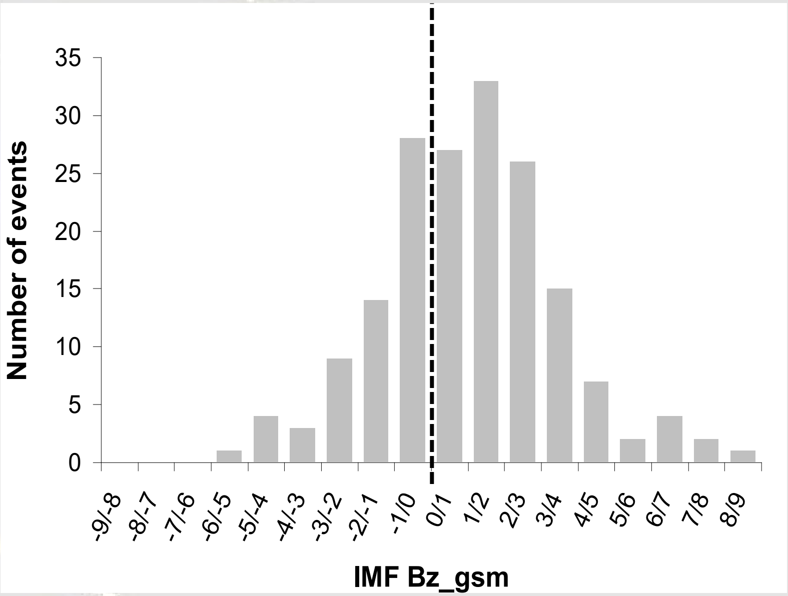


Quiet conditions

Mainly IMF $B_Z>0$

but

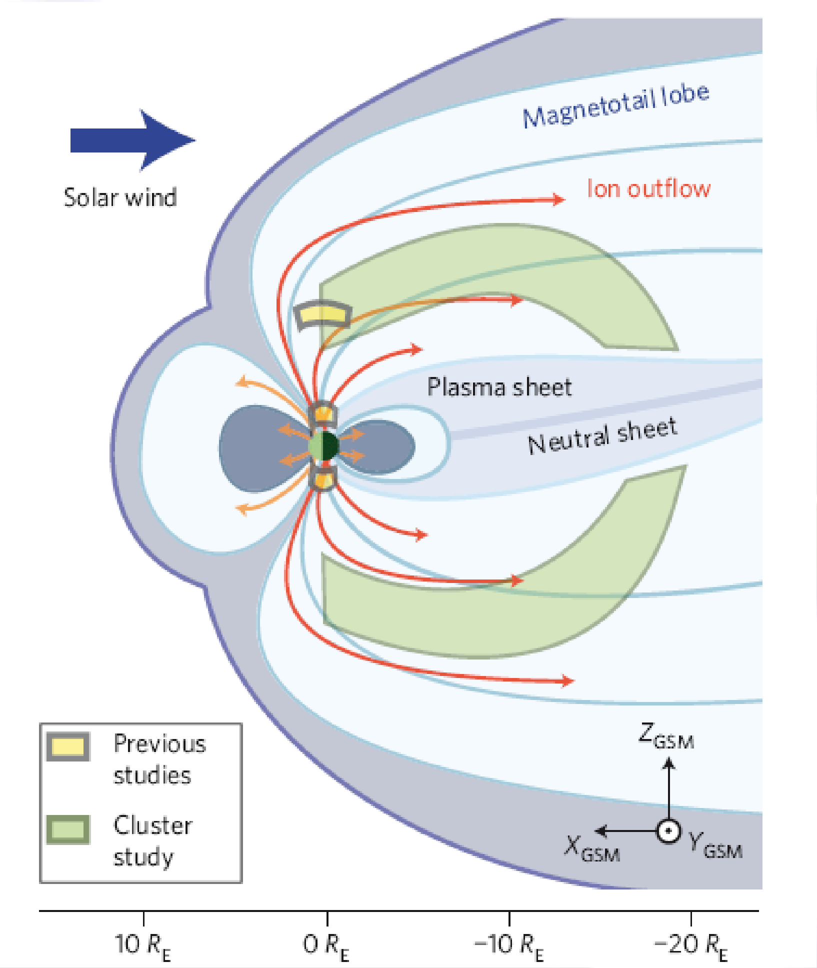
35% for IMF $B_Z<0$

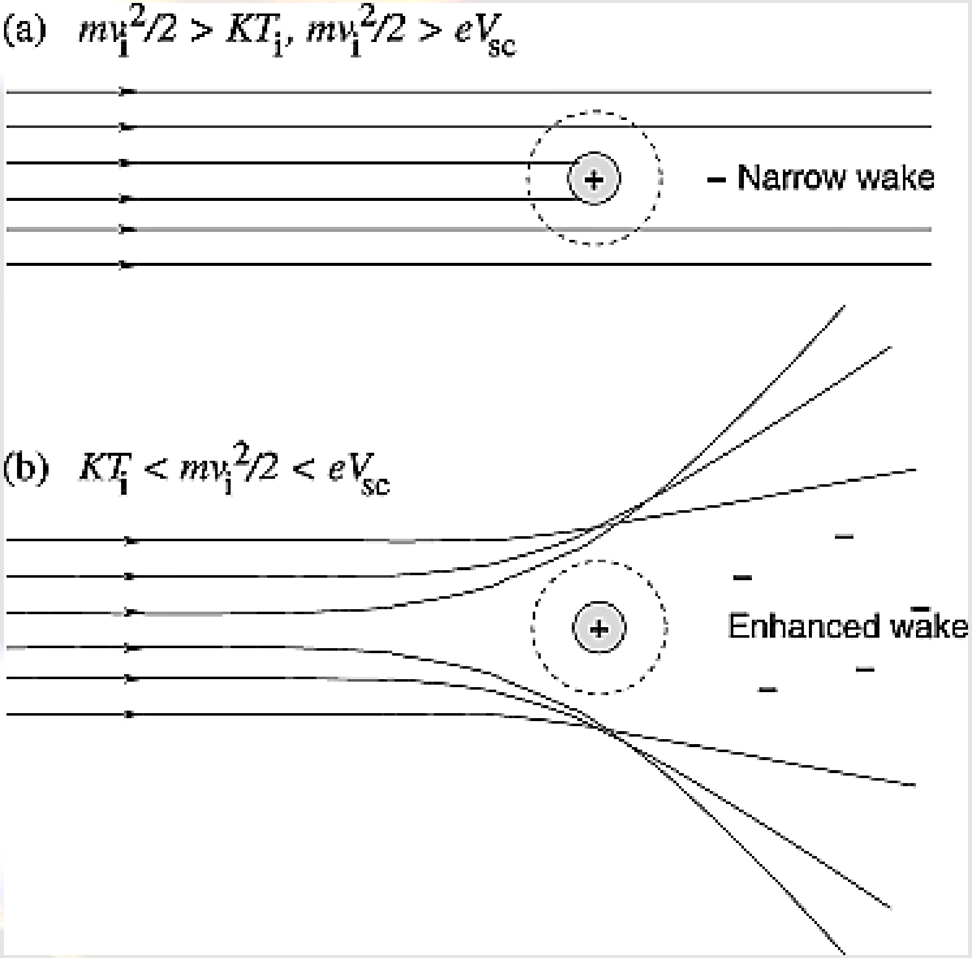


Maggiolo et al.,
Ann. Geophys. 2011

The Ionospheric Source Signatures in the Magnetotail Lobes

Low-energy (order 10 eV) ion flow in the magnetotail lobes: spacecraft wake



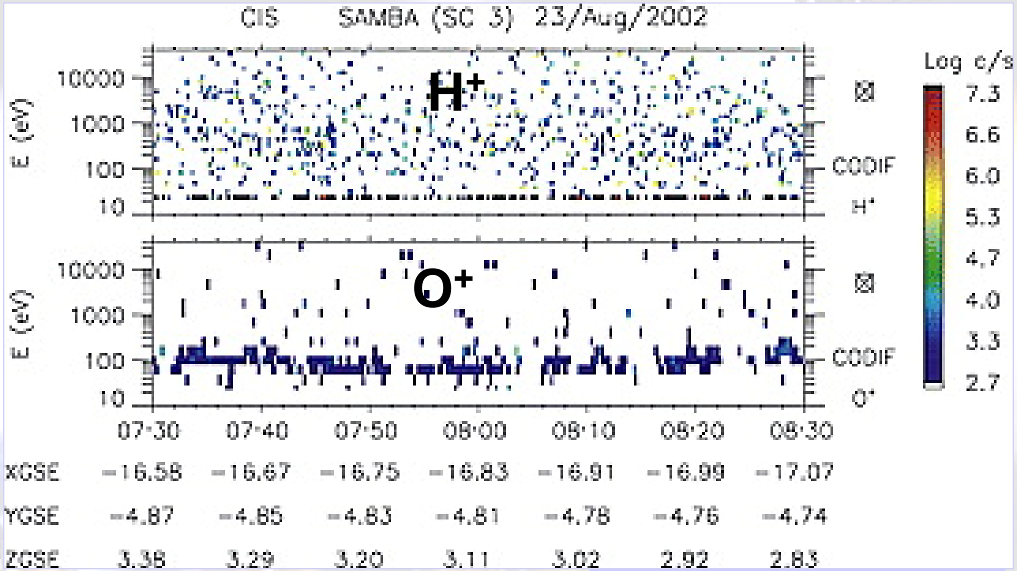


Engwall et al.,
Nat. Geosci., 2008

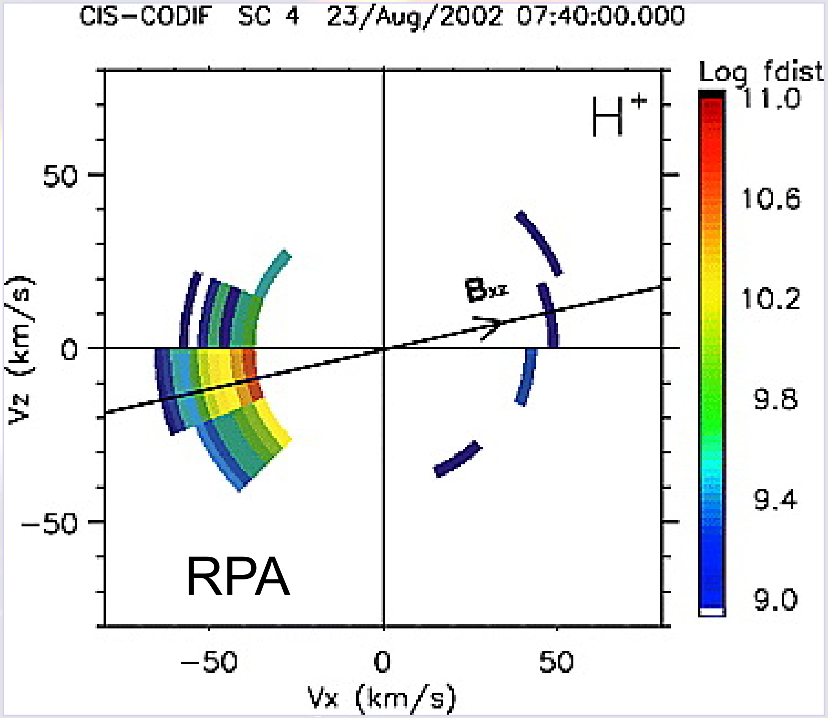
Engwall et al.,
GRL, 2006

sc3: ASPOC switched off: wake

sc4: ASPOC switched on: no wake



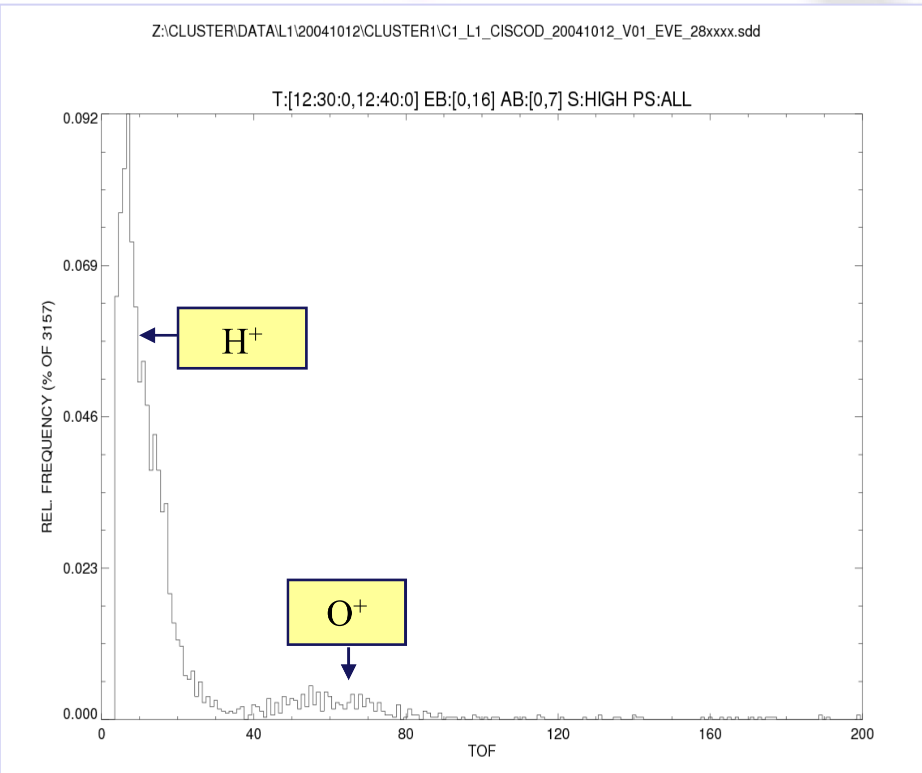
Engwall et al., GRL, 2006



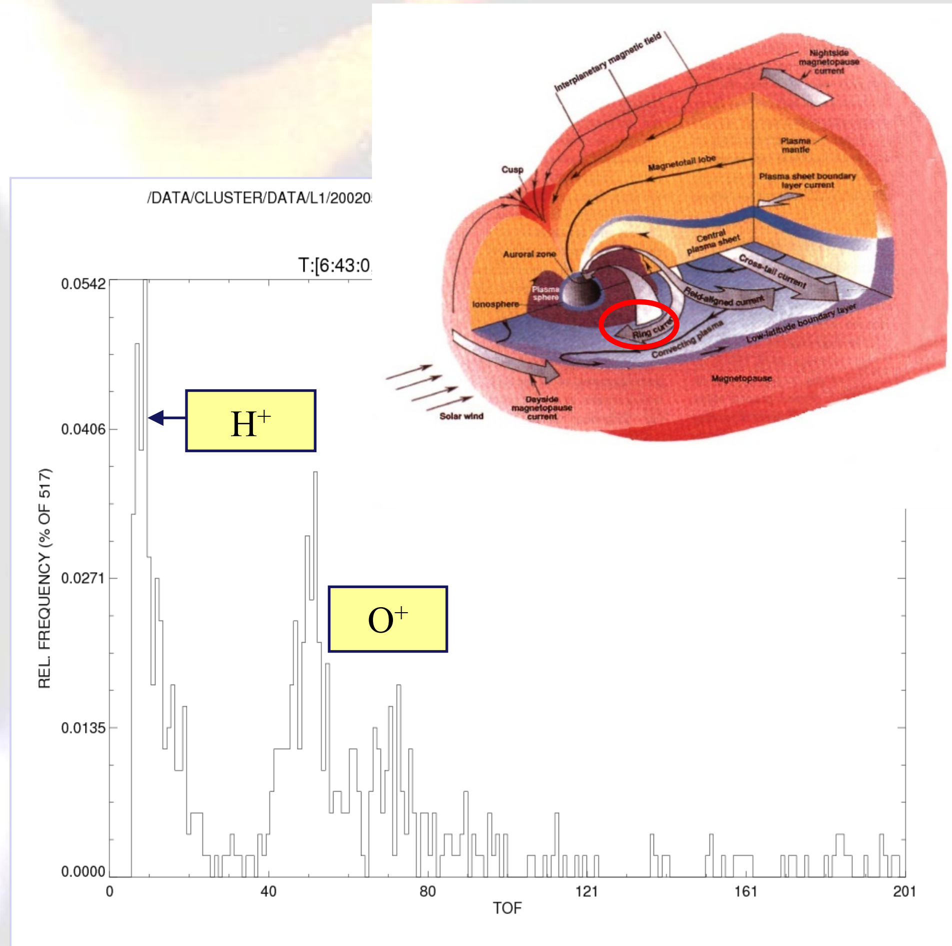
- CODIF has detected **an O+ ion beam**, in the **anti-sunward direction.**
- The **spacecraft potential (40 – 60 V)** is **too high for the detection of the H+ ions** which have typical energies around 10 eV: ~40 km/s ion outflow.
- The thin stripe around the lowest energy in the proton data is an artifact from onboard data compression.

- Distribution function for $\mathbf{H^+}$. Velocities have been **corrected for the spacecraft potential of 7 V**.
- The lowest velocities missing due to the instrument cutoff at 0.7 eV (w.r.t. spacecraft).
- B_{xz} is the magnetic field projected in the x–z-plane.

Ionospheric ions effect on the inner magnetosphere composition: Ion Time-of-Flight Spectra in the Ring Current



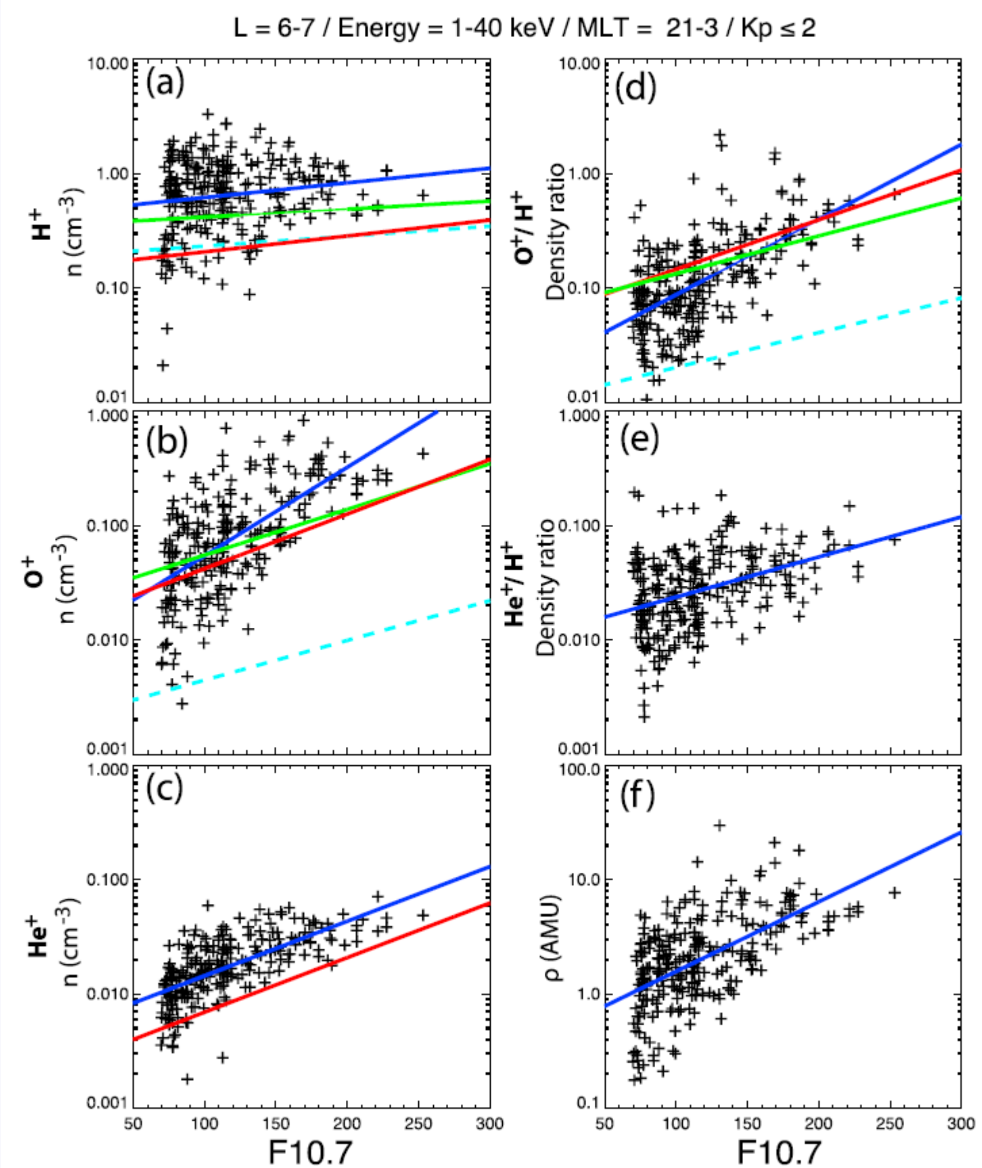
Quiet-time event

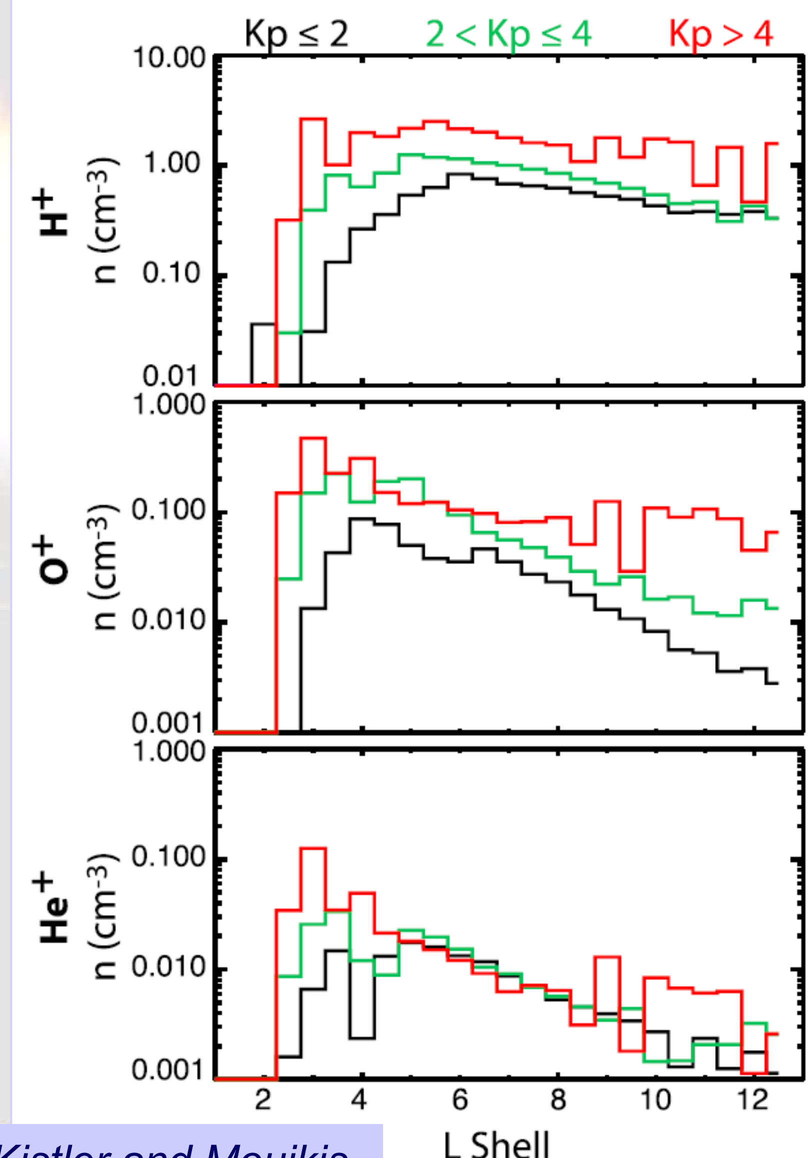


Moderate Storm time event

Dandouras et al., JGR., 2009

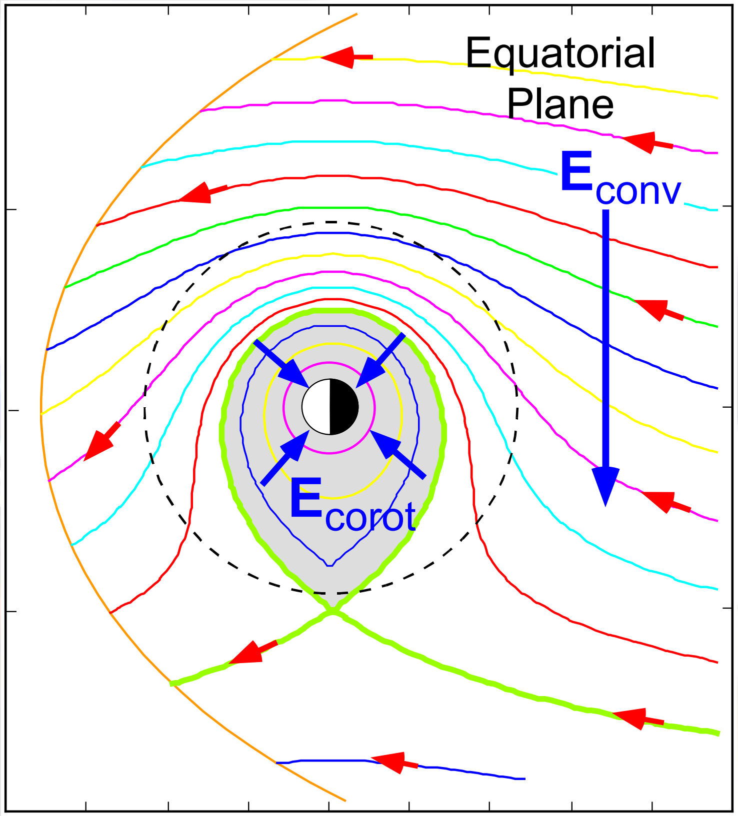
Ionospheric ions effect on the inner magnetosphere composition: Statistics over a solar cycle

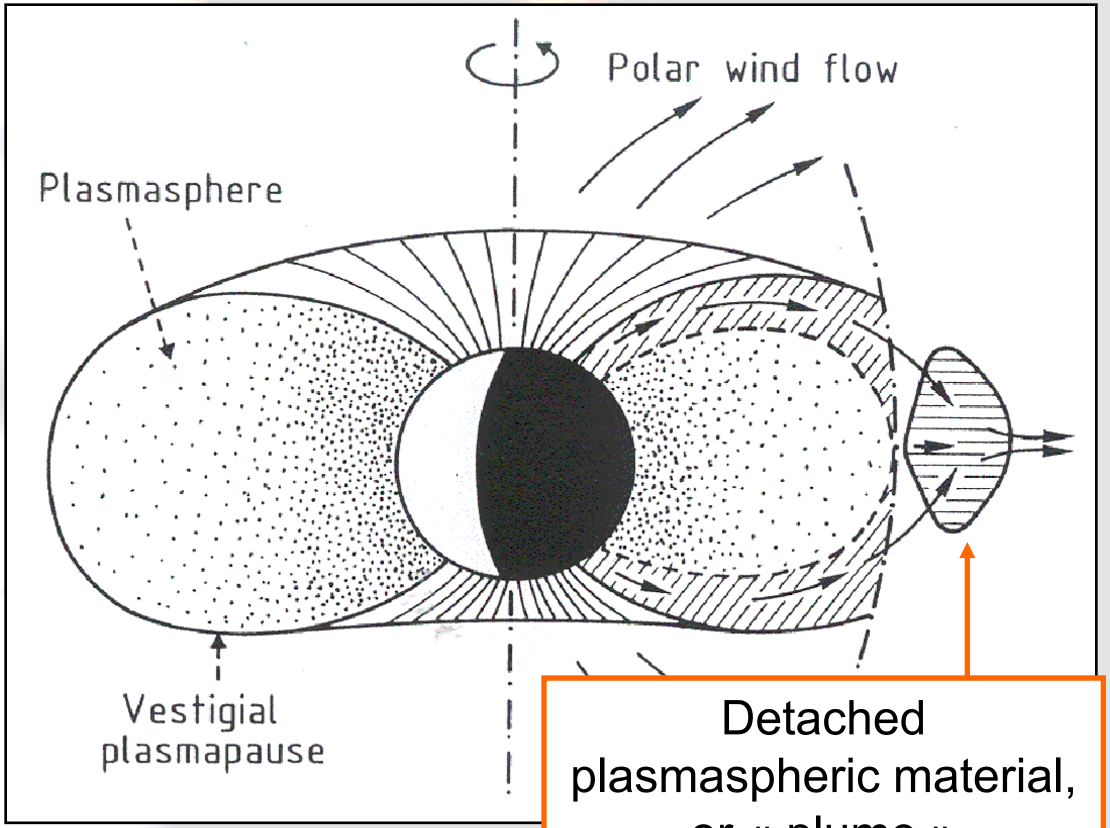




Kistler and Mouikis, JGR, 2016

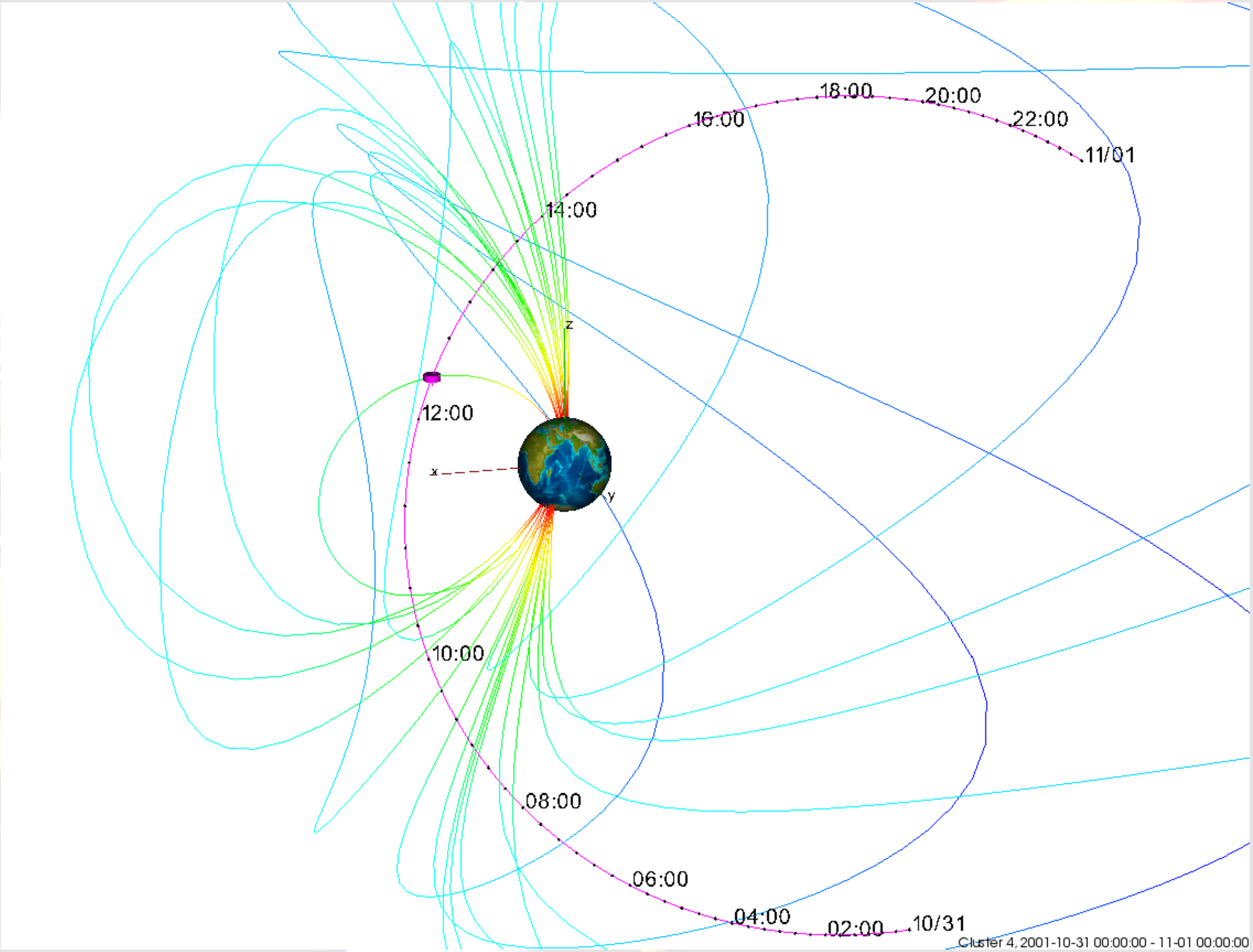
Plasmasphere



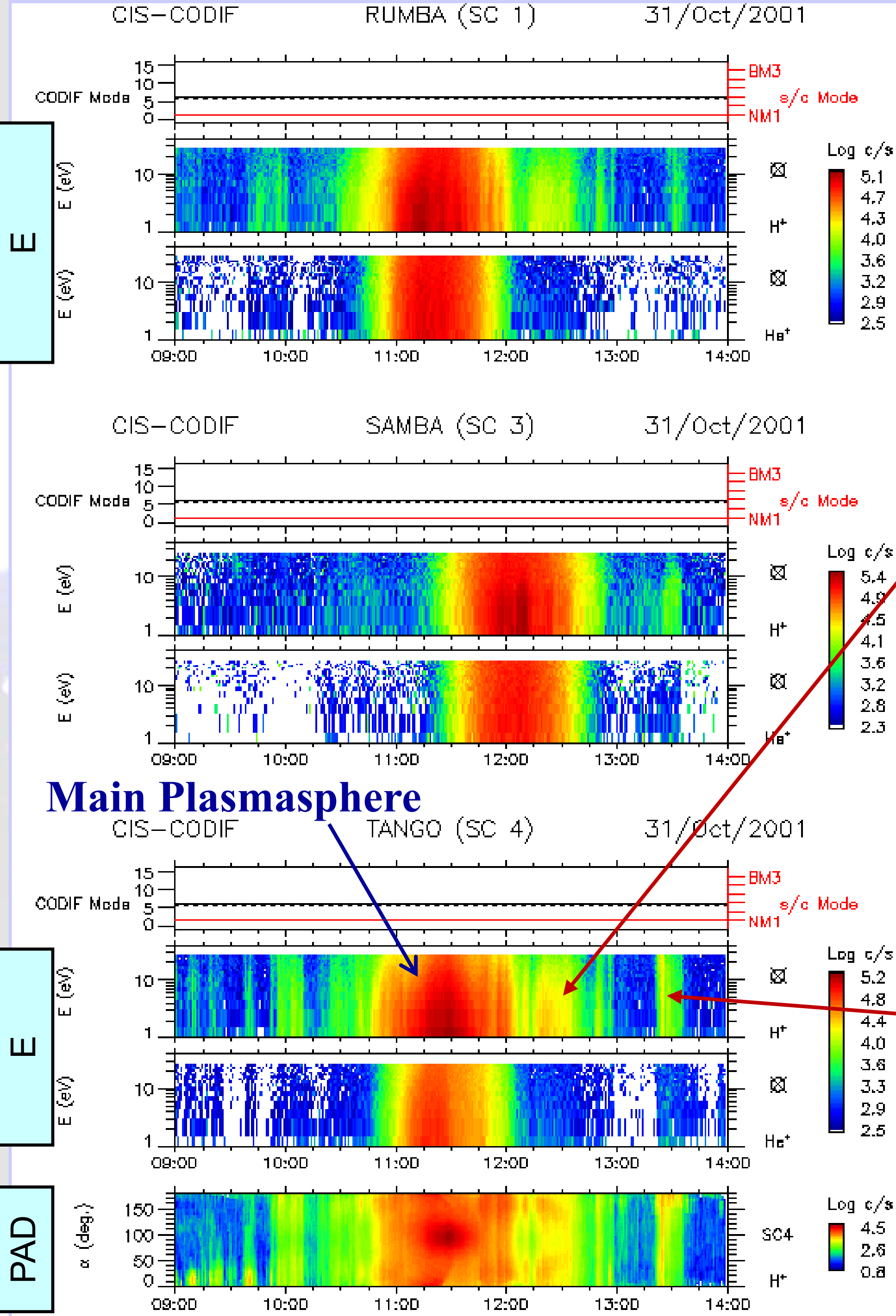


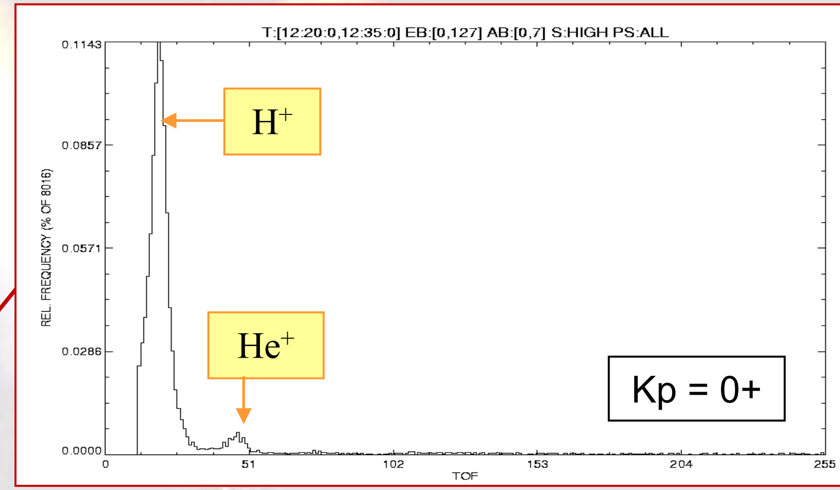
Detached
plasmaspheric material,
or « plume »

Plasmasphere Cut : Cluster Orbit

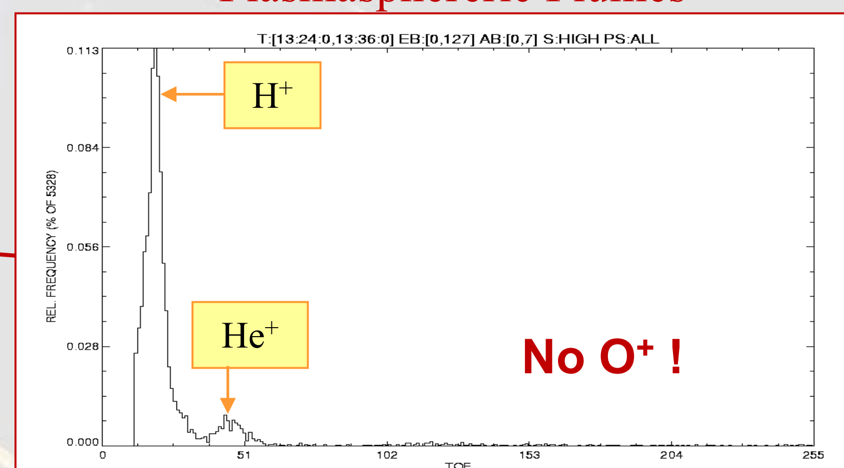


Low-Energy Ions in the Plasmaspheric Plumes

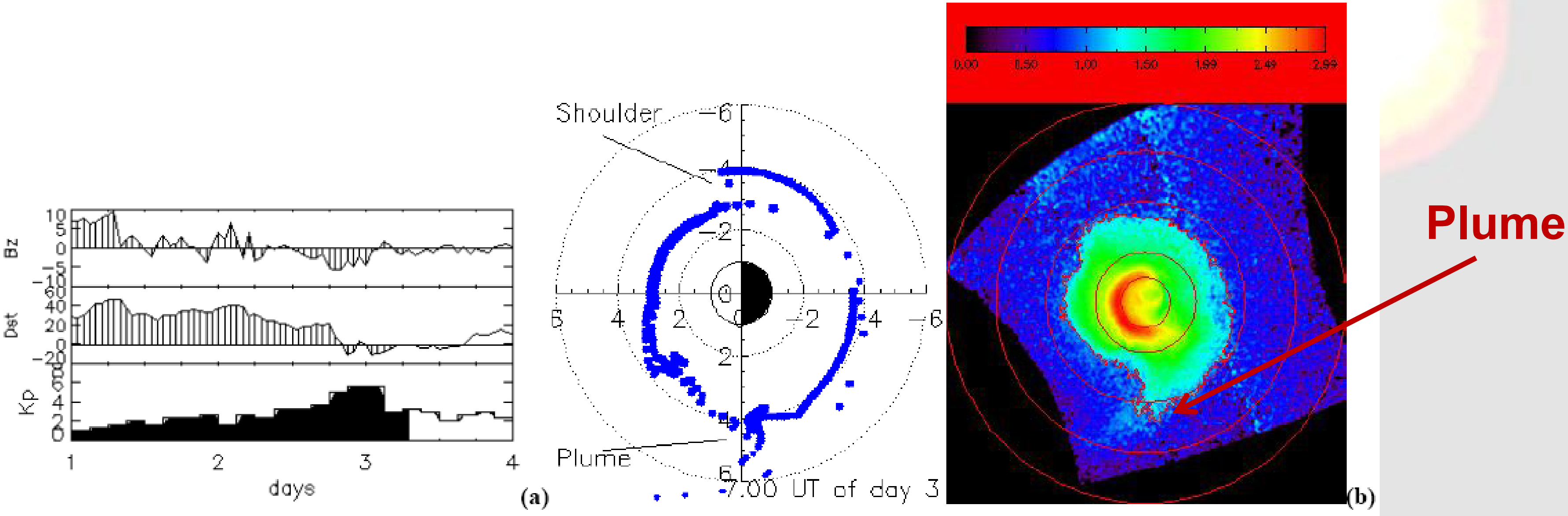




Ion mass spectra in the Plasmasphereric Plumes



Dandouras et al., *2005*



Simulation *EUV / IMAGE*

Pierrard and Cabrera, 2005

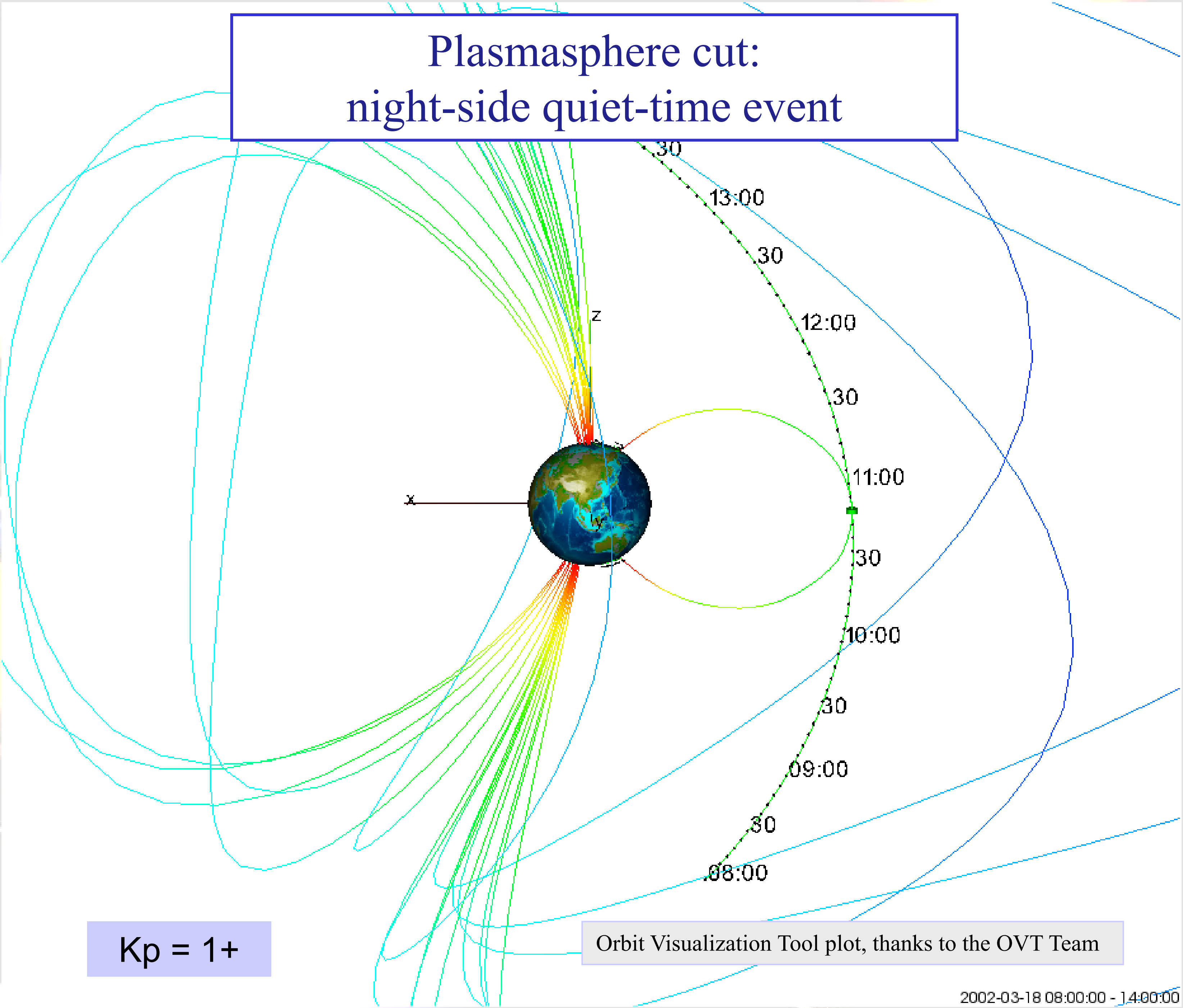
Are plasmaspheric plumes the only mode for plasmaspheric material release to the magnetosphere?

- Plasmaspheric plumes are associated to active periods: change of the electric field.
- In 1992 Lemaire and Schunk **proposed the existence of a plasmaspheric wind**, steadily transporting cold plasmaspheric plasma outwards **across the geomagnetic field lines**, even during prolonged periods of quiet geomagnetic conditions [*J. Atmos. Sol.-Terr. Phys.* 54, 467-477, 1992].

Plasmaspheric Wind: background

- This wind is expected to be a slow radial flow pattern, providing a **continual loss of plasma** from the plasmasphere, (for all local times and for L > ~2), similar to that of the subsonic expansion of the equatorial solar corona.
- The existence of this wind has been proposed on a **theoretical basis**: it is considered as the **result from a plasma interchange motion** driven by an imbalance between gravitational, centrifugal and pressure gradient forces:
  André and Lemaire, *J. Atmos. Sol.-Terr. Phys.* 68, 213-227 (2006).
- **Direct detection** of this wind has, however, **eluded observation** in the past.

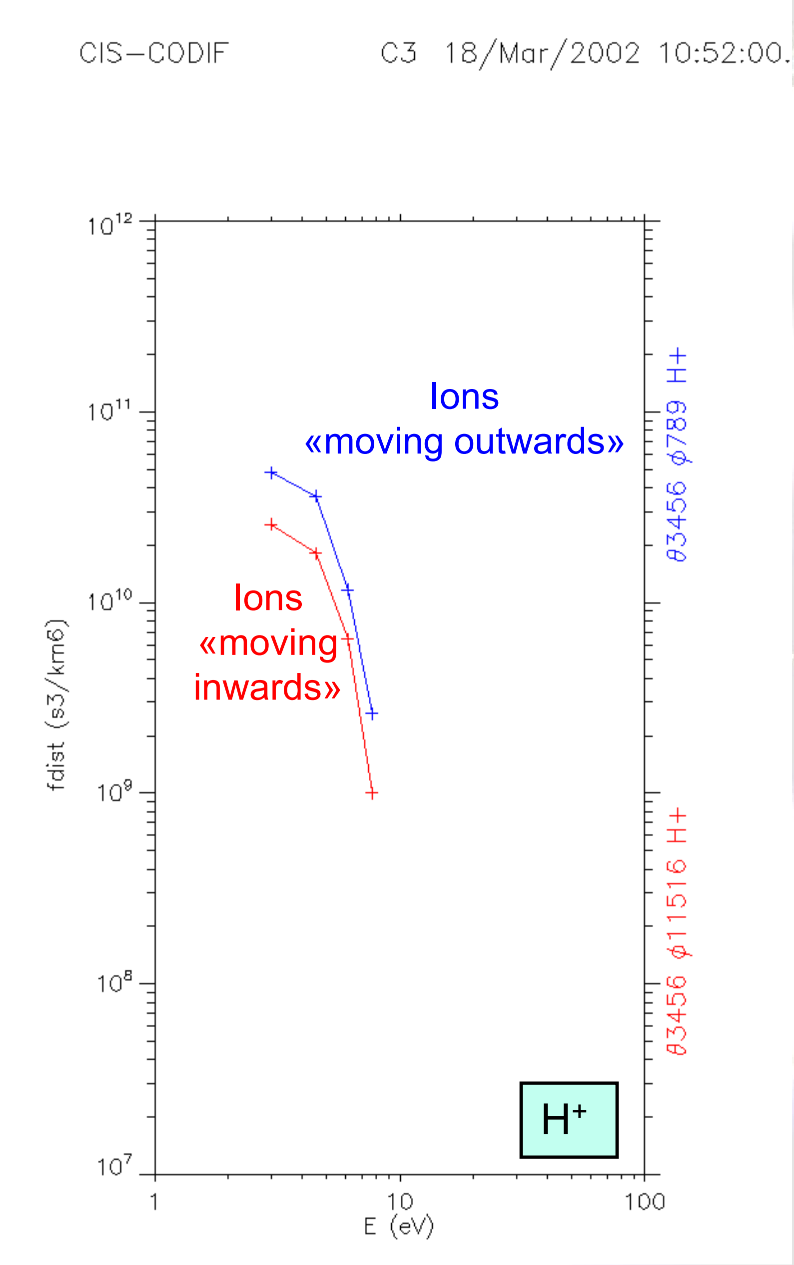
Plasmasphere cut: night-side quiet-time event

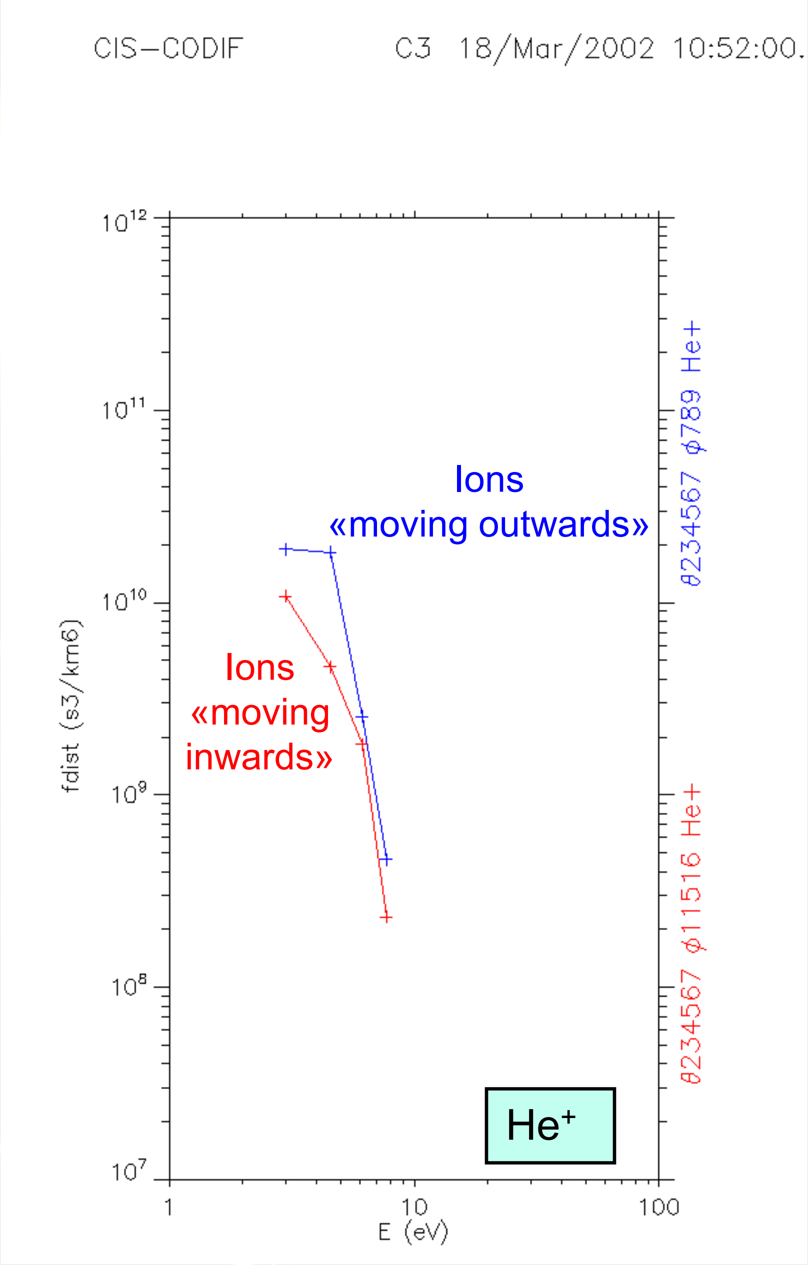


Kp = 1+

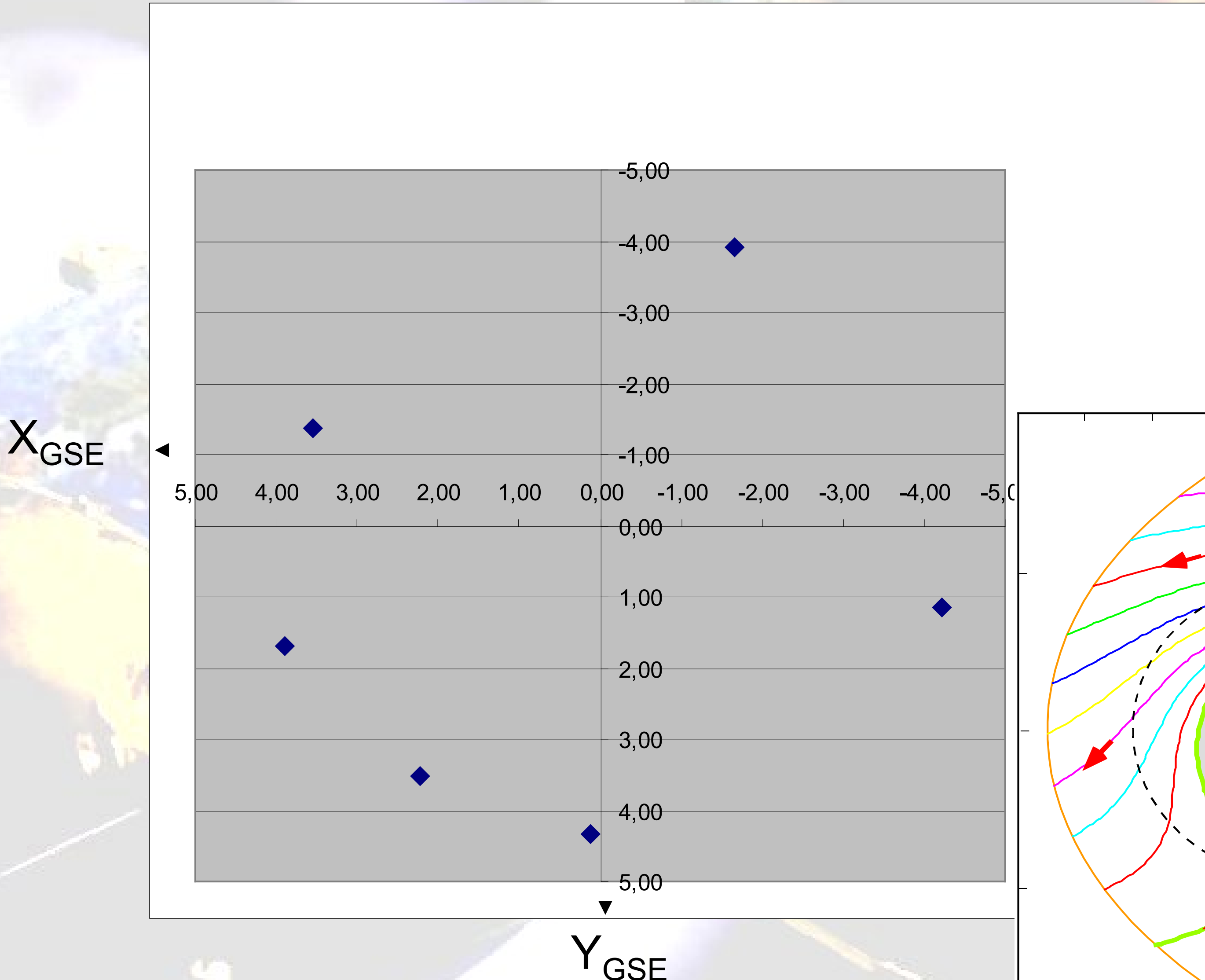
Orbit Visualization Tool plot, thanks to the OVT Team

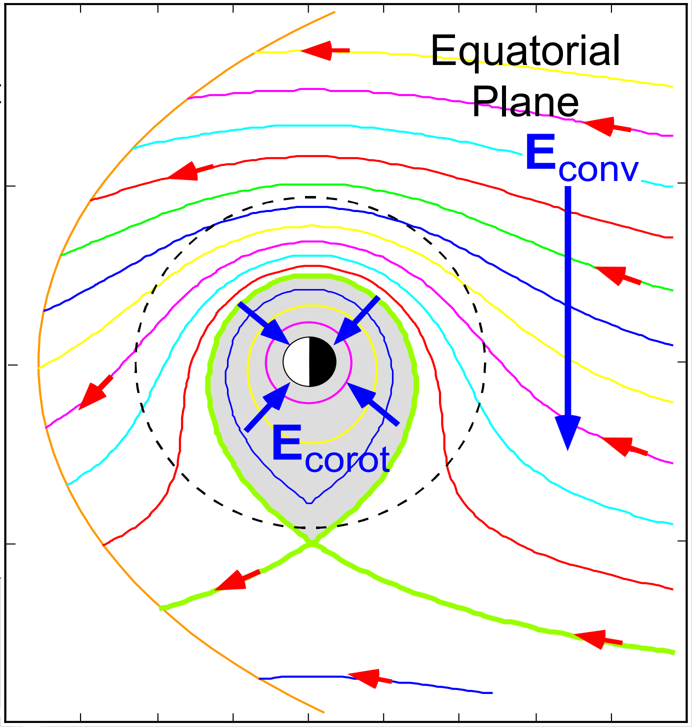
Search for Plasmaspheric Wind: comparison of the two partial (in azimuth) distribution functions





Analysed Plasmaspheric Wind observation events: Distribution in the equatorial plane





Dandouras, *Annal. Geophys., 2013*

Plasmaspheric Wind: Contribution to the Magnetosphere

Considering:

- V_plasmaspheric-wind ≈ 1.4 km s^{-1}
  (at 4 R_E, from the ion distribution functions)
- Plasmasmaspheric density ≈ 100 cm^{-3}
  (at 4 R_E, typical values from WHISPER: *Darrouzet el al.,* 2008)
- Escape over half a sphere (in latitude)

We get :

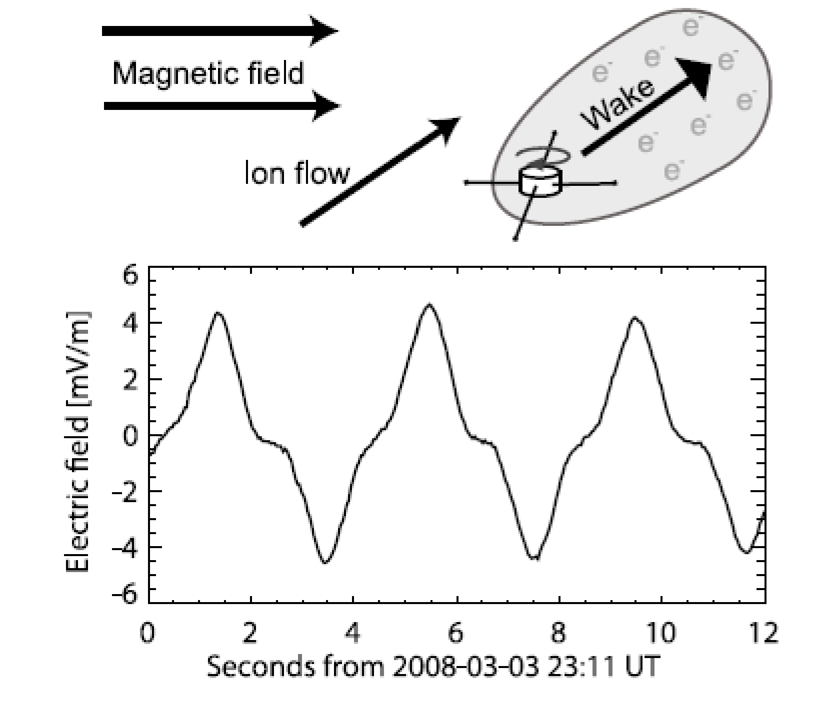
~5 x 10^{26} ions s^{-1} continuously escaping from the Plasmasphere and contributing to the Magnetosphere

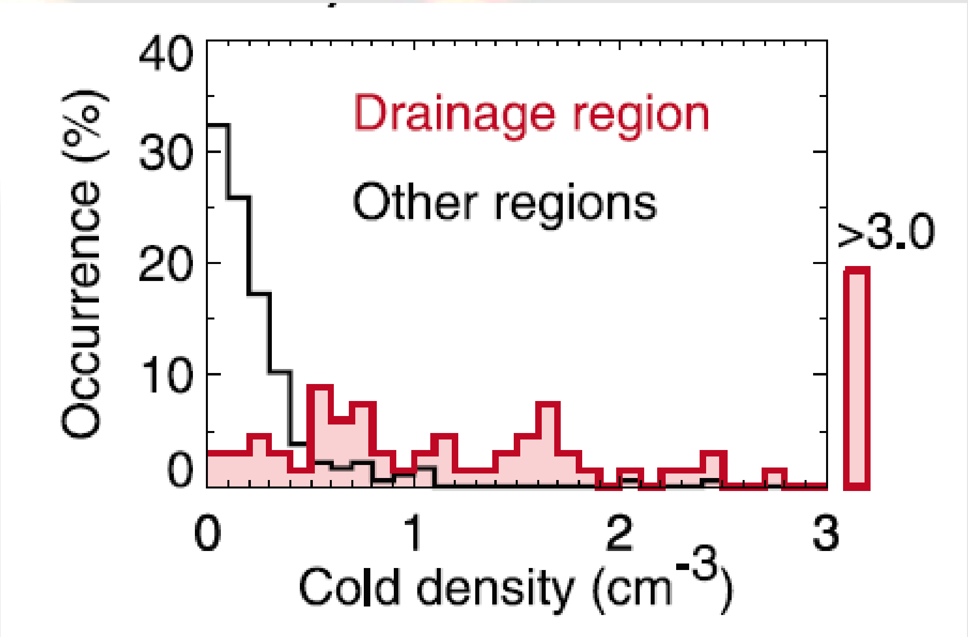
Dandouras, *Annal. Geophys., 2013*

For comparison :

- the solar wind source is ~10^{27} ions s^{-1}
- the high-latitude ionospheric source is ~10^{26} ions s^{-1}
  [*Moore et al.,* 2005; *Haaland et al.,* 2009; *Li et al.,* 2012]
- the plumes source is up to ~ 2x10^{26} ions s^{-1} (active periods)
  [*Borovsky and Denton,* 2008]

Plasmaspheric Wind Contribution to the Magnetosphere: Where does it go?





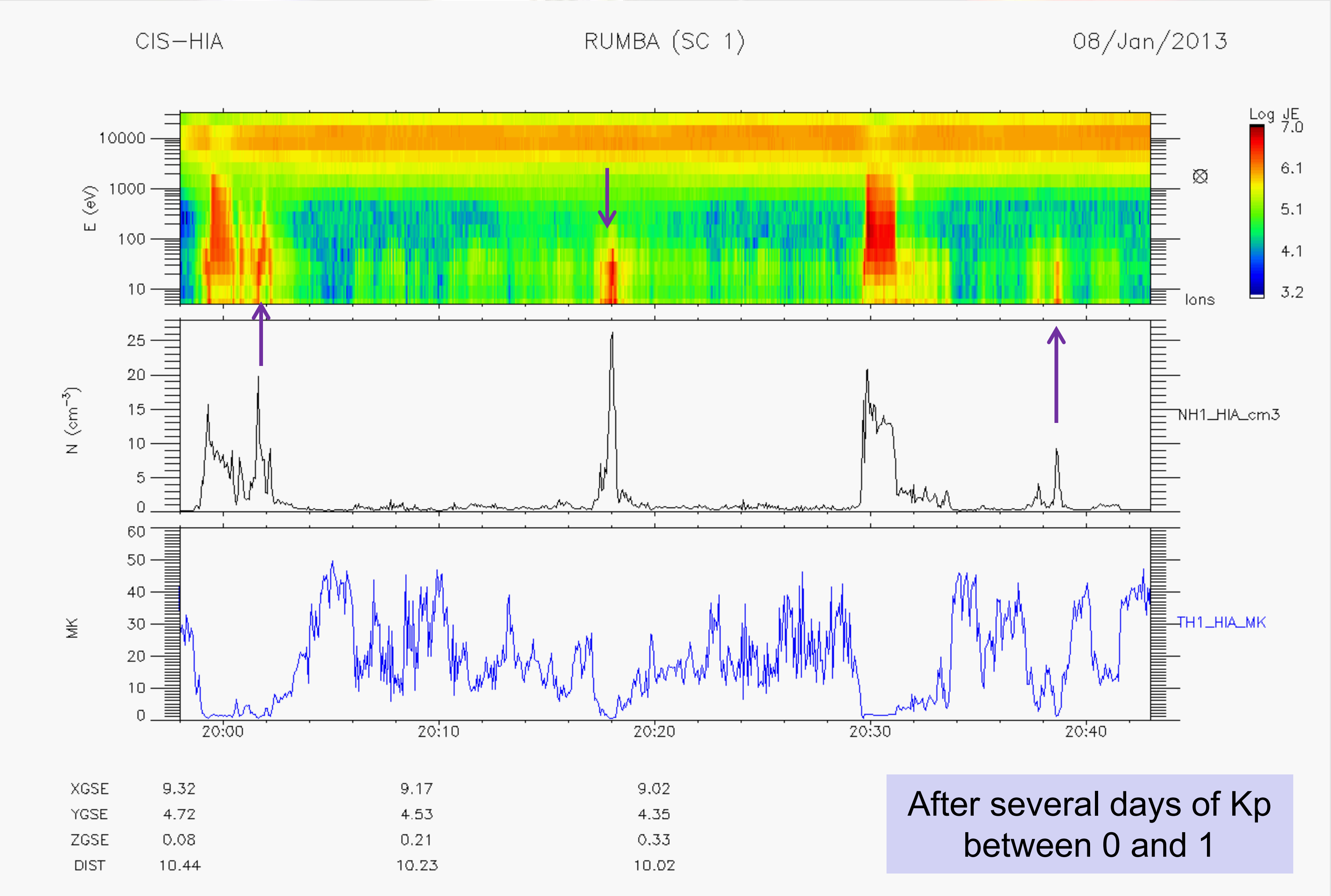
Using a Spacecraft Wake to Detect Low-Energy Ions:
- Wake behind a positively charged Cluster spacecraft, caused by a supersonic flow of cold ions
- Non-sinusoidal electric field measured with a spin period of 4 s, in a cold plasma

Statistics of low-energy ions inside the magnetopause:

Histogram of density in drainage region and other regions

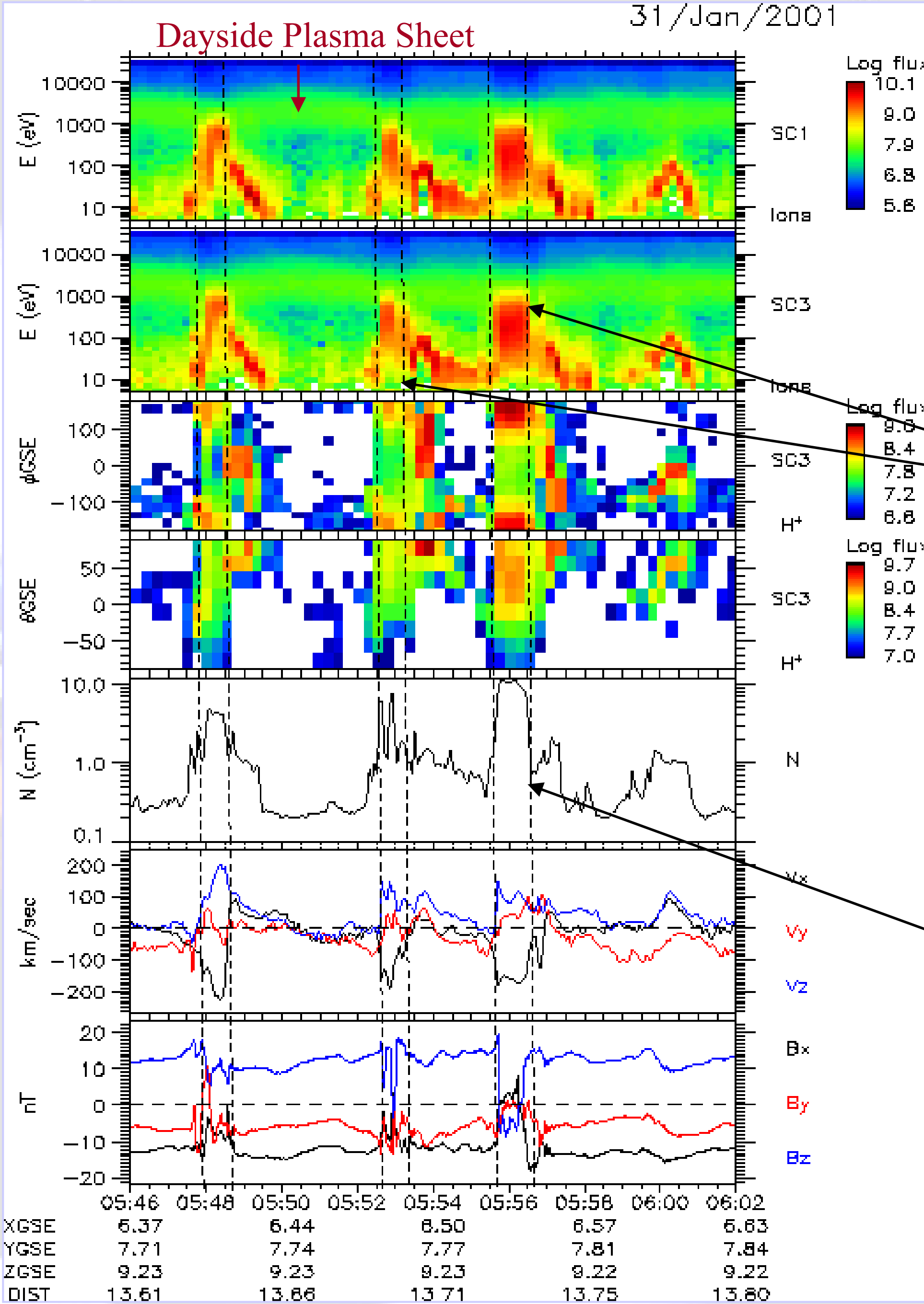
M. André and C. M. Cully, *Geophys. Res. Lett., 2012*

Plasmaspheric Wind Contribution to the Magnetosphere: Where does it go?



After several days of Kp between 0 and 1

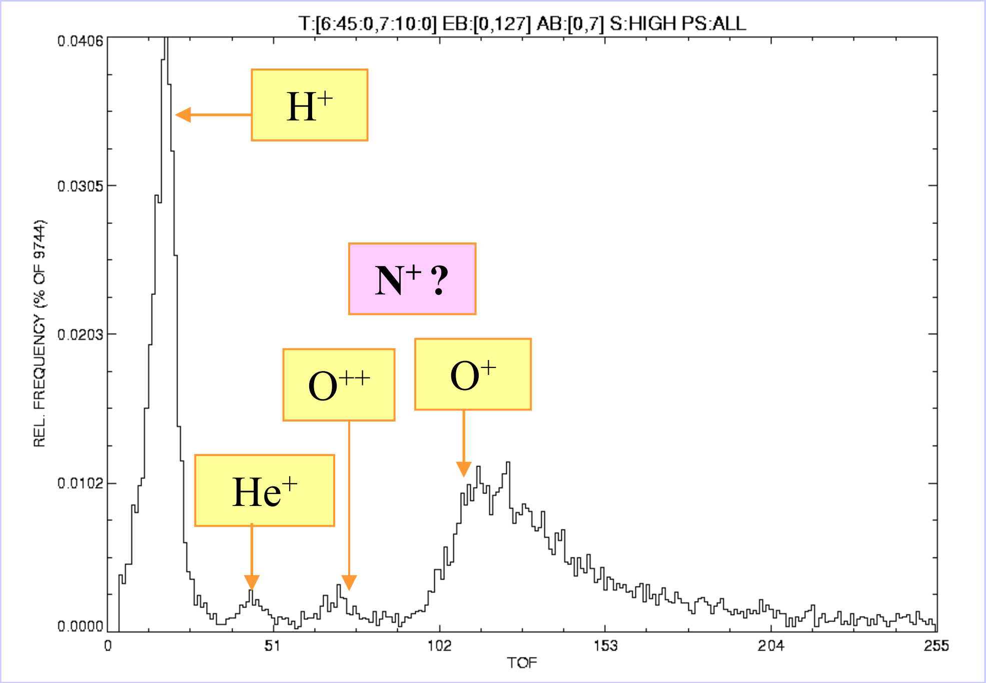
Intermittently accelerated cold plasma, adjacent to the magnetopause and on its magnetospheric side



- First observations with Cluster of a very dense population of locally accelerated thermal ionospheric ions (H^+, He^+, O^+) in a region just adjacent to the magnetopause and on its magnetospheric side.
- The observation follows a long period of very weak activity. Recurrent motions of the magnetopause (>100 km/s) are associated with the appearance, inside closed field lines, of recurrent energy structures of ionospheric ions.
- The heaviest ions are detected with the highest energies.
- The ion behavior is interpreted as resulting from local electric field enhancements / decreases which adiabatically enhance / lower the bulk energy of a local dense thermal ion population.
- When fast flowing, i.e. when detectable, the density (~ 1 cm^{-3}) of these ions from terrestrial origin is largely higher than the density of ions from magnetospheric/plasma sheet origin, which poses again the question of the relative importance of solar and ionospheric sources for the magnetospheric plasma during very quiet magnetic conditions.

Sauvaud et al., Ann. Geophys., 2001

What Cluster-CIS Cannot Answer?



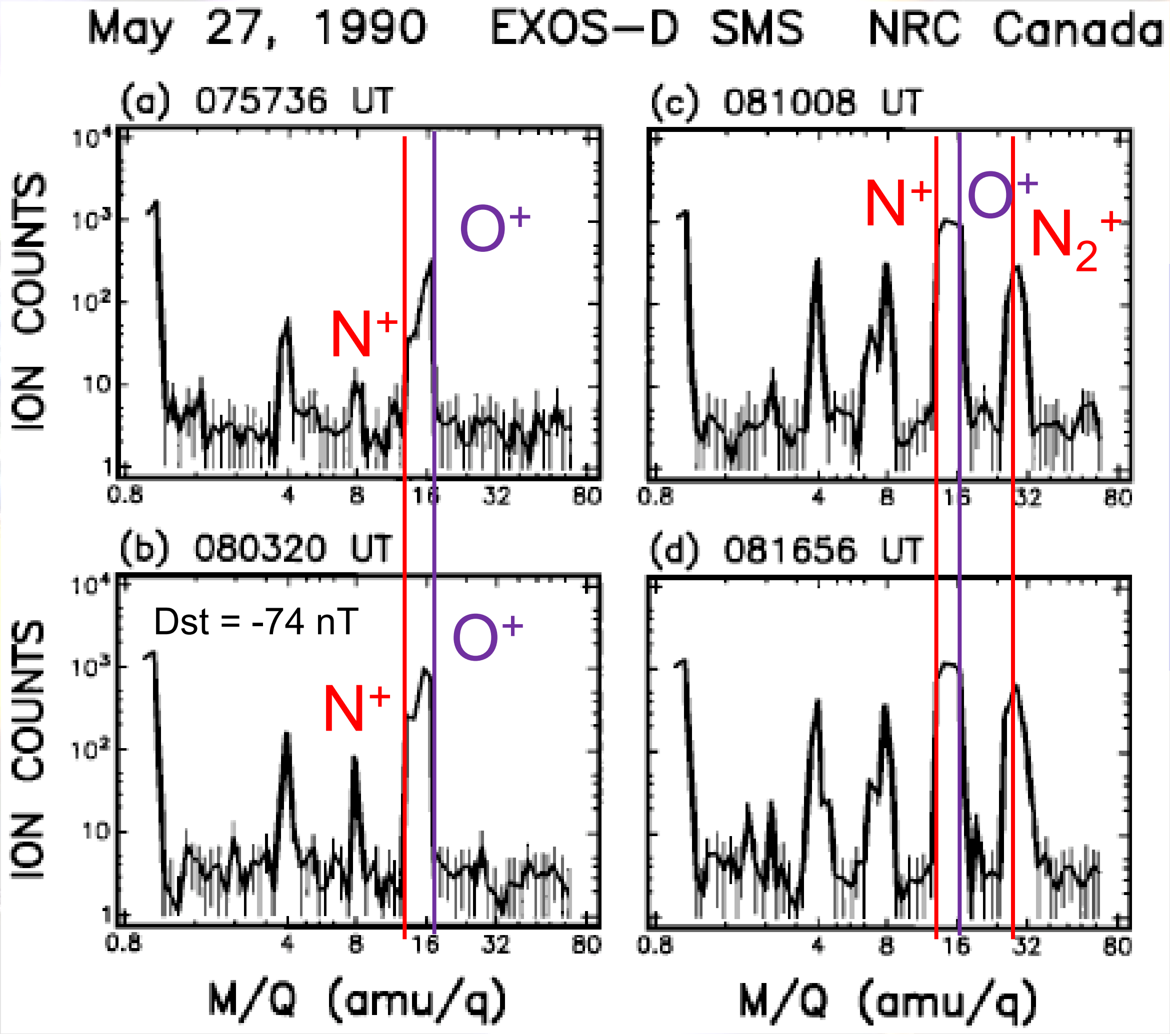
CIS: $M / \Delta M \sim 4 - 6$

To separate N^+ and O^+ :

$M / \Delta M > 7$ needed

Present knowledge on N^+ escape

More drastic changes for N^+ than for O^+, E < 50 eV



N^+ / O^+ escape ratio

Varies from:

< 0.1 (quiet conditions)

to **~1 (intense storms)**

But destination and acceleration is not clear

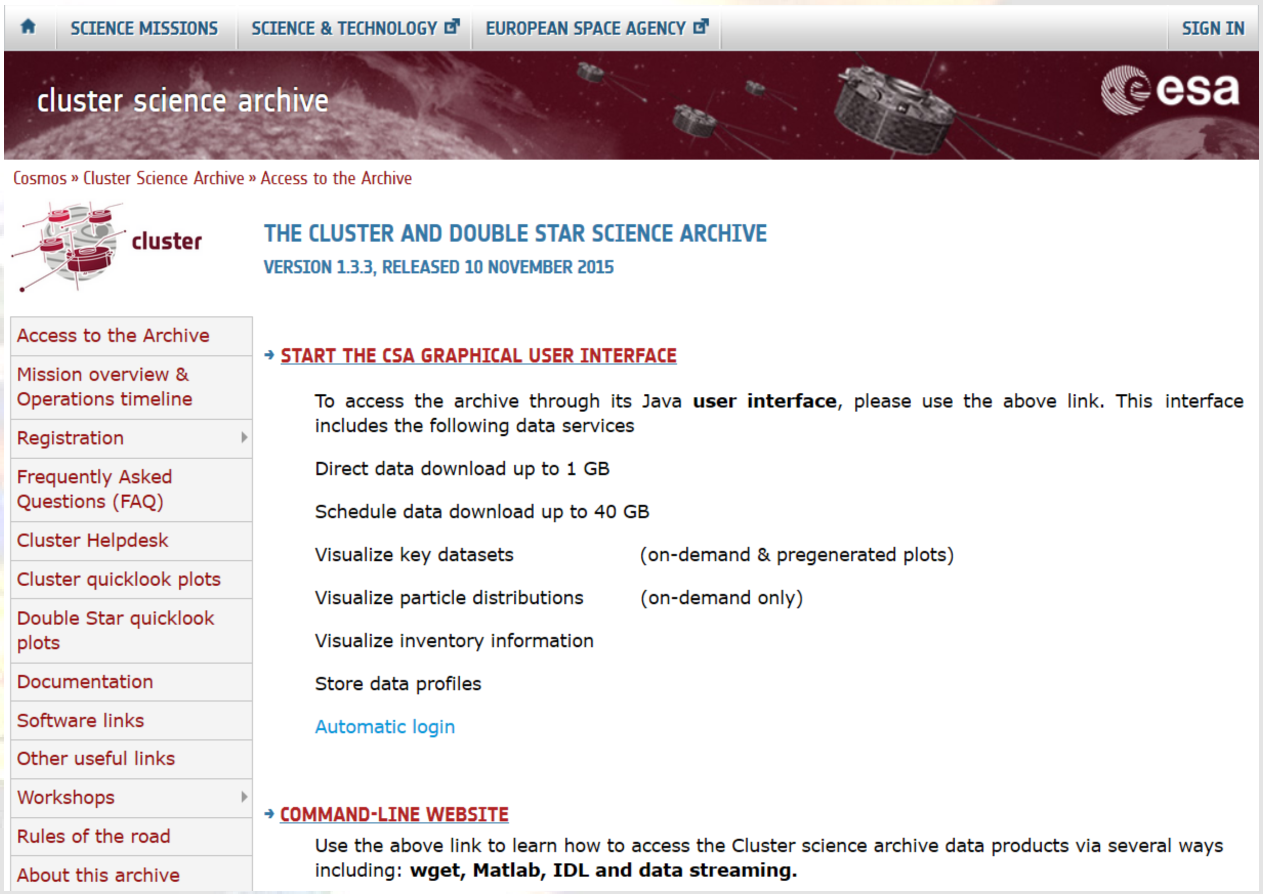
Cluster - CIS Data Availability

Cluster Data Archiving at the CSA

Cluster Science Archive

http://www.cosmos.esa.int/web/csa

and at the CDPP

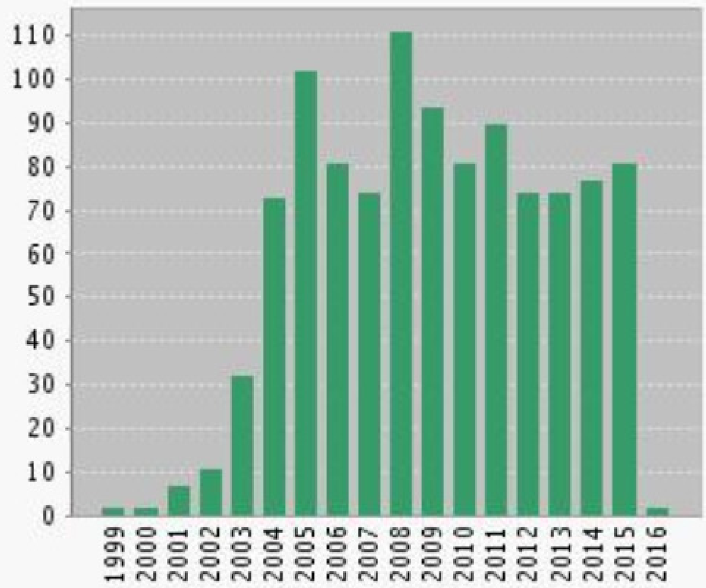


All **calibrated, high resolution data, together with associated documentation and data caveats. Publicly available data**.

CIS Publications

- ~1100 science papers published in refereed journals,
  based on the analysis of CIS (Cluster) and HIA (Double Star) data.
- List of representative CIS publications at :
  http://cluster.irap.omp.eu/public/publications/CIS_publications_list.htm

Citations in Each Year



The latest 20 years are displayed.

References to:
Rème et al., 1997, 2001, 2005

Results found: 3

Sum of the Times Cited [?] : 1068

Sum of Times Cited without self-citations [?] : 1066

Citing Articles [?] : 1007

Citing Articles without self-citations [?] : 1005

Average Citations per Item [?] : 356.00

h-index [?] : 3

Recent review paper:

Welling et al., The Earth: Plasma Sources, Losses, and Transport Processes, Sp. Sci Rev., 2015

CONCLUSIONS

Two main plasma sources for the Earth's magnetosphere:

- ❖ The **solar wind**, which provides mostly hydrogen (~10^{27} ions s^{-1})
- ❖ The Earth's **ionosphere** (and **plasmasphere**), which in addition to hydrogen is capable of delivering considerable amounts of **heavier ions**

- ❑ The **Polar ionosphere source** (~10^{26} ions s^{-1} varying by a factor of ~3 as a function of the activity level and dependent on the IMF orientation) :
  - ➢ **Cusp**: main source of energetic oxygen ion outflow
  - ➢ **Polar caps**: substantial contribution of upwelling ions, with solar, IMF and magnetospheric activity dependence
  - ➢ **"Hidden" cold ion populations** revealed streaming in the **lobes** and also present inside the **magnetopause**
- ❑ The **Plasmaspheric source**:
  - ➢ **Plumes**: mainly during active periods (~ $2x10^{26}$ ions)
  - ➢ **Plasmaspheric Wind**: steadily transporting cold plasma outwards and contributing to the Magnetospheric populations (~5 x 10^{26} ions s^{-1})
- ❑ **Cluster** calibrated high-resolution data available at the **CSA** and at the **CDPP**