Multipoint Observations of Ionic Structures in the Plasmasphere by CLUSTER - CIS and Comparisons with IMAGE - EUV Observations and with Model Simulations

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ABSTRACT

The 4 Cluster spacecraft orbit the Earth in a highly eccentric polar orbit at 4 R_E perigee, and this permits them to sample the ring current, the radiation belts and the outer plasmasphere. Data provided by the Cluster Ion Spectrometry (CIS) instruments are used to analyze Cluster crossings of the plasmasphere. CIS is capable of obtaining full three-dimensional ion distributions (about 0 to 40 keV/q) with a time resolution of one spacecraft spin (4 sec) and with mass-per-charge composition determination. In addition the CIS Retarding Potential Analyzer (RPA) allows more accurate measurements in the about 0 - 25 eV/q energy range, covering the plasmasphere energy domain.

The low-energy ion distribution functions, obtained by CIS-RPA during the perigee passes, allow to reconstruct statistically the plasmapause morphology and dynamics, but they also reveal new and interesting features. The ion discrimination capability of CIS reveals how the density profile is different for each of the main ion species (H^+, He^+, O^+): H^+ and He^+ present mostly similar profiles; O^+, however, is not observed as trapped plasmaspheric population at the Cluster orbit altitudes ($R \geq 4\ R_E$). Low-energy O^+ is observed mainly as upwelling ion, on auroral field lines.

Detached plasmasphere events, that are observed by CIS during some of the passes at about 0.5 to 1 R_E outside the plasmapause, are also present. The bi-directional distribution functions of these detached plasmaspheric populations allow us to distinguish them from upwelling ion populations.

The CIS-RPA observations of the plasmapause position have been simulated with an interchange instability numerical model for the plasmapause deformations, and the model reproduces in a very satisfactory way the CIS observations.

The CIS local ion measurements have also been correlated with global images of the plasmasphere, obtained by the EUV instrument onboard Image, for an event where the Cluster spacecraft were within the field-of-view of EUV. The EUV images show, for this event, that the difference observed between two Cluster spacecraft was temporal (boundary motion): the radial density profile of the plasmasphere varies with MLT, and a more extended radial profile “rotated” into between the two Cluster spacecraft perigee passes. They thus show the necessity for correlating local measurements with global images, and the complementarity of the two approaches; local measurements giving the “ground truth” (including plasma composition, distribution functions etc.) and global images allowing to put local measurements into a global context, and to deconvolve spatial from temporal effects.

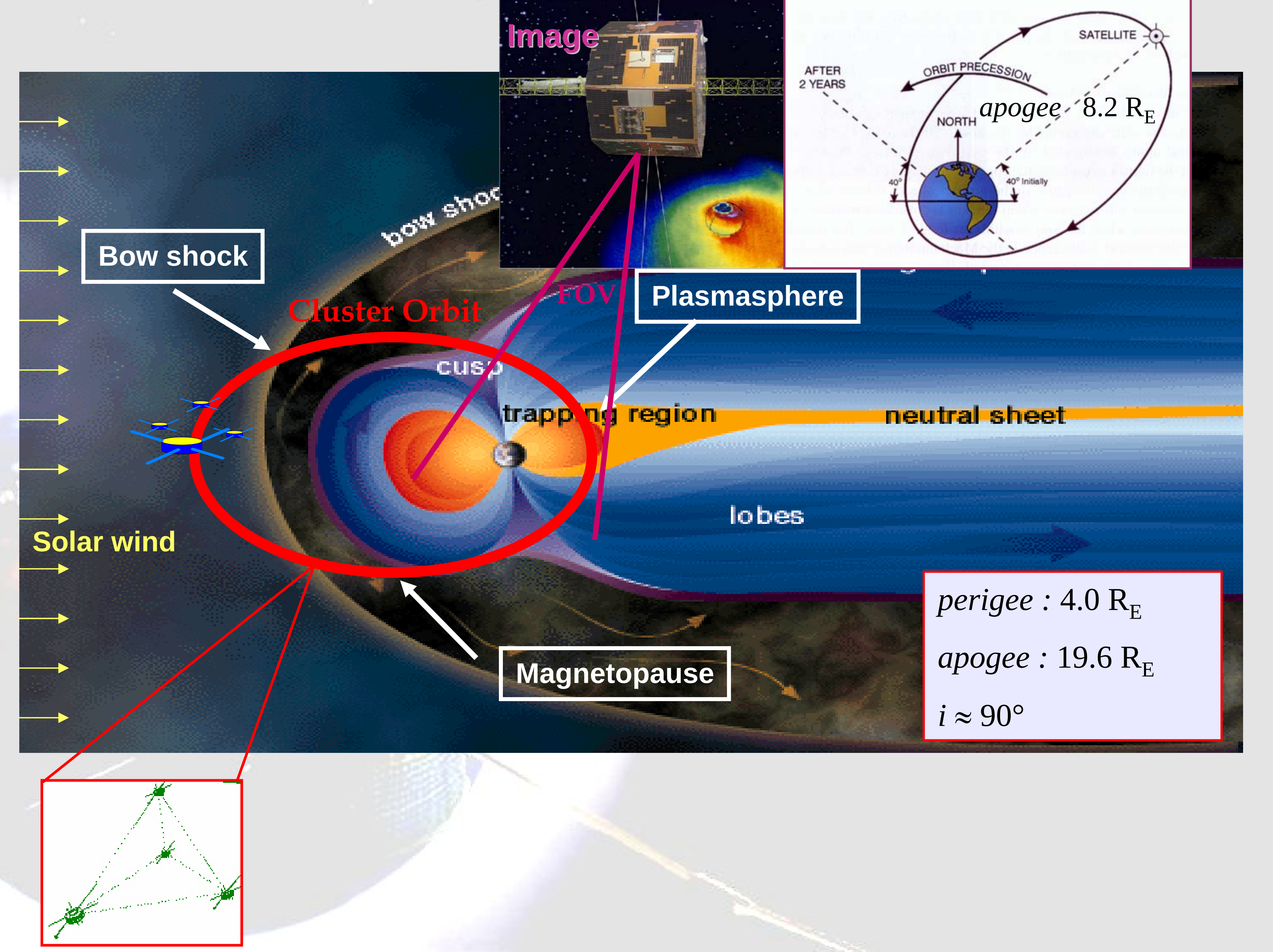
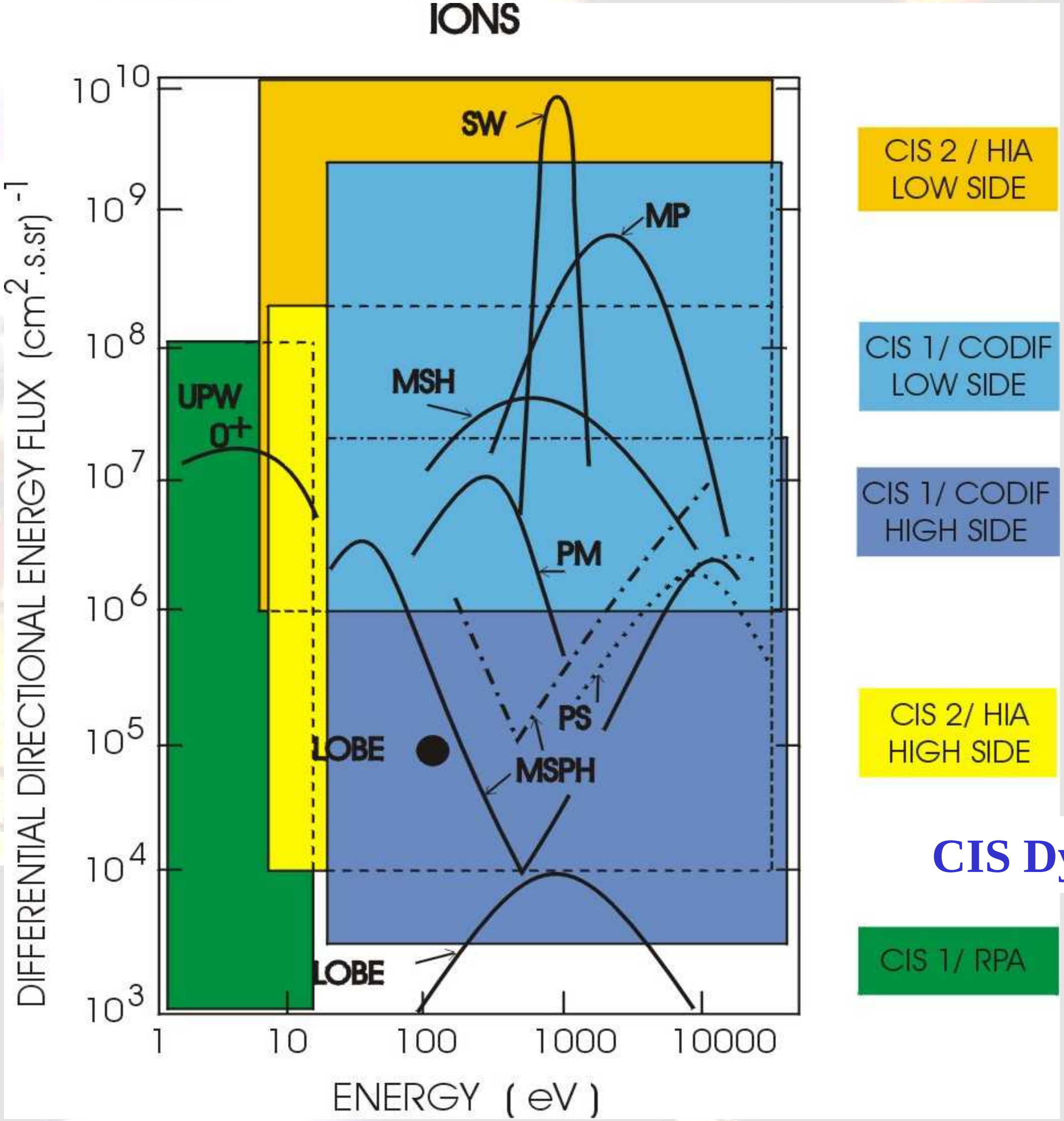


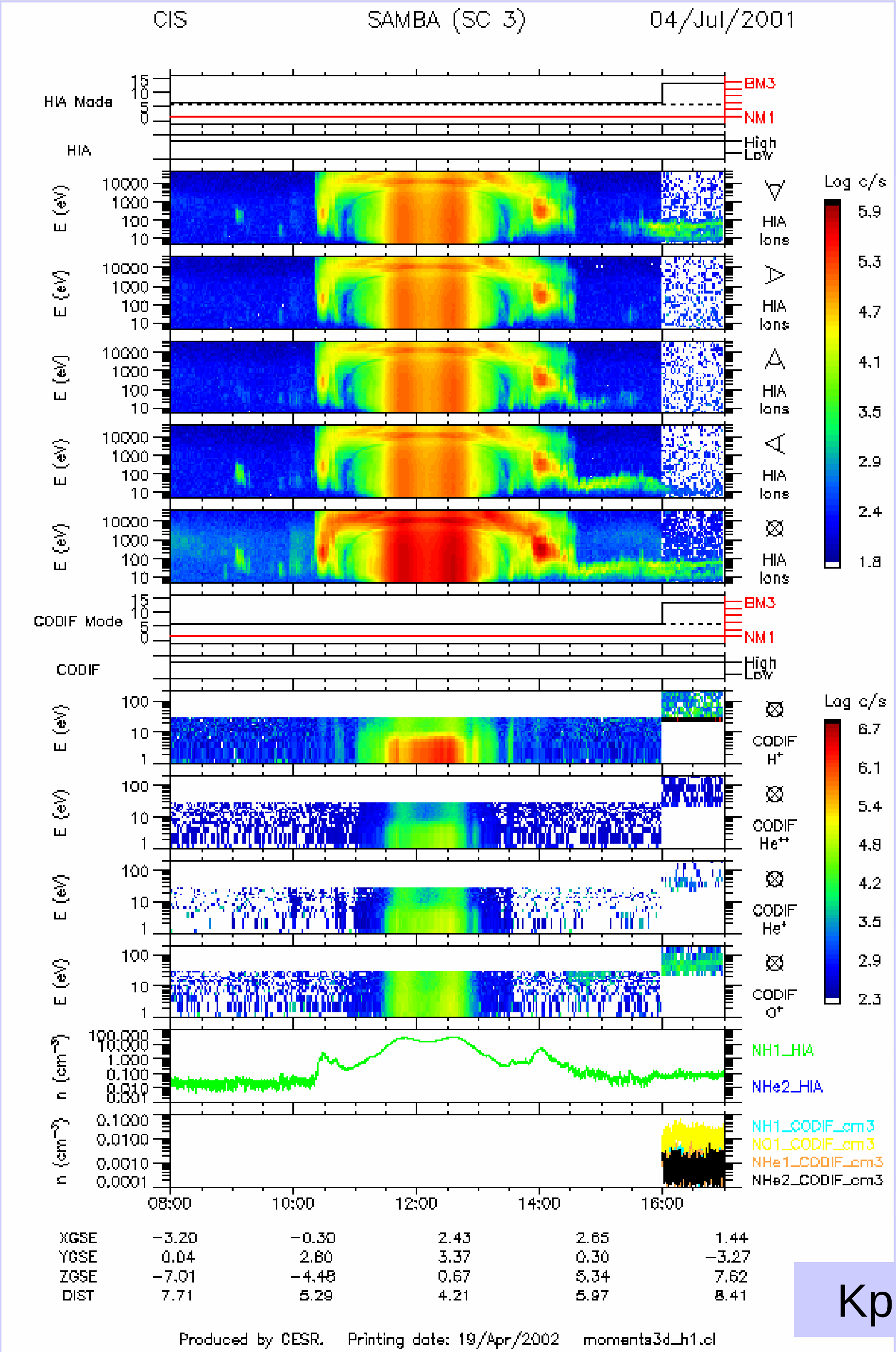
Image
AFTER 2 YEARS
ORBIT PRECESSION
SATELLITE
NORTH
apogee 8.2 R_E
40°
40° Initially
bow shock
Bow shock
Cluster Orbit
FOV
Plasmasphere
cusp
trapping region
neutral sheet
lobes
Solar wind
Magnetopause
perigee : 4.0 R_E
apogee : 19.6 R_E
$i \approx 90°$

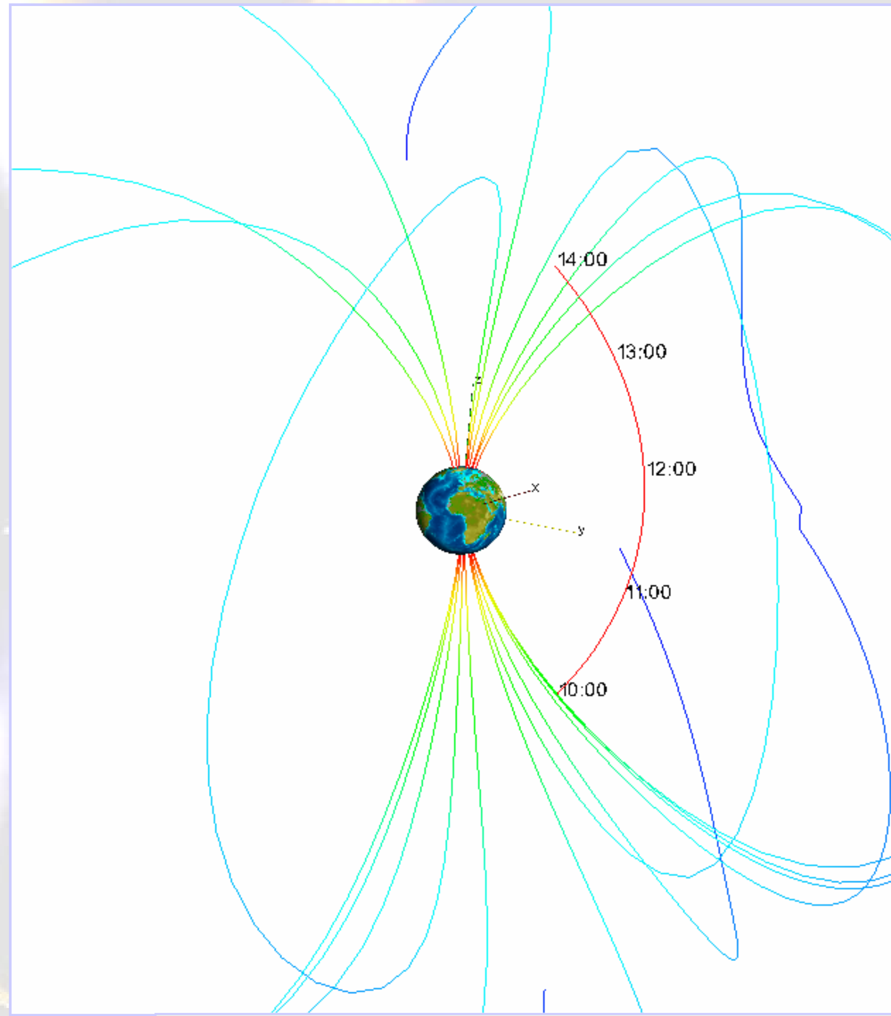
CIS
Cluster Ion Spectrometry



CIS Dynamic Range

Plasmasphere Cut : Context

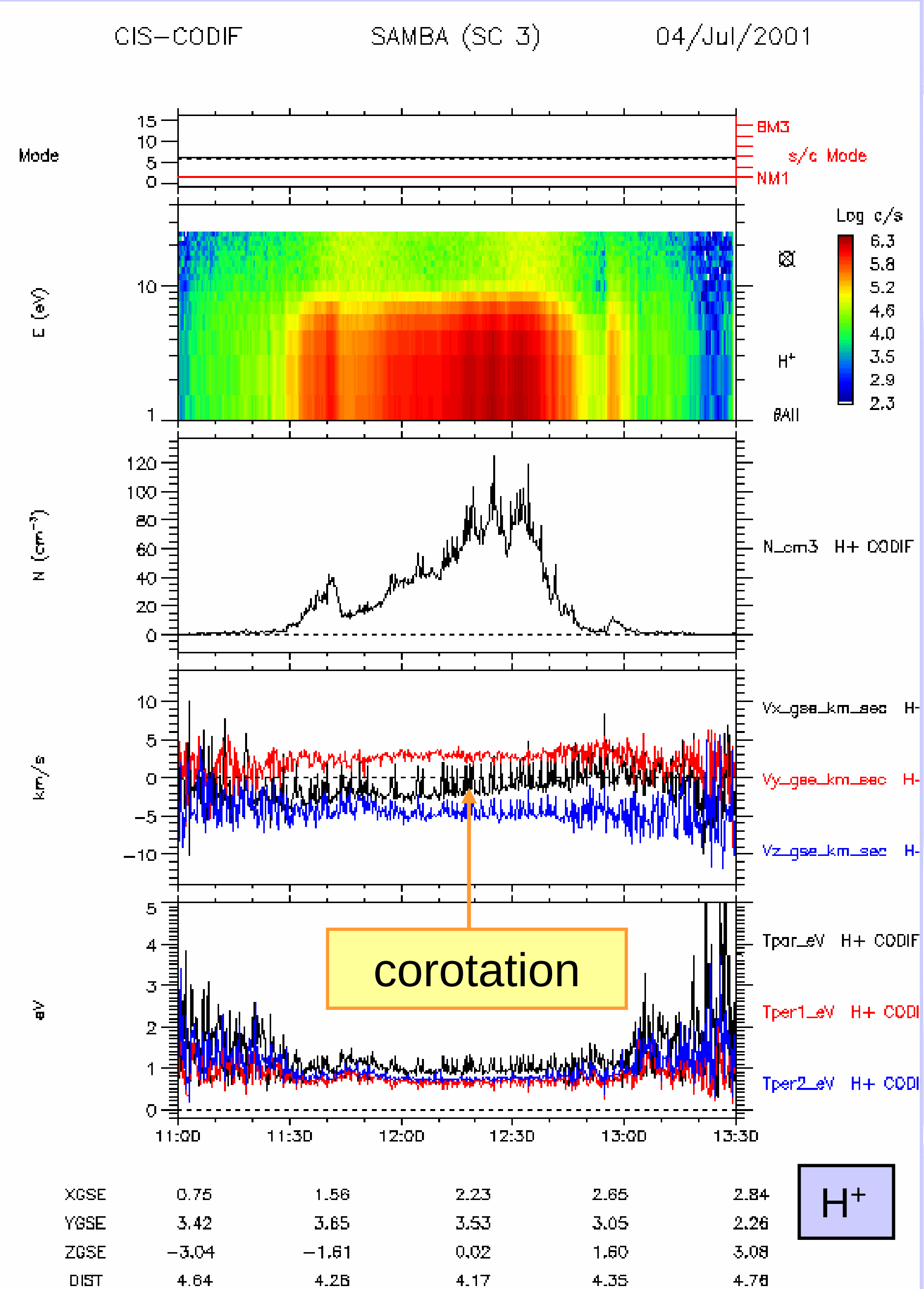


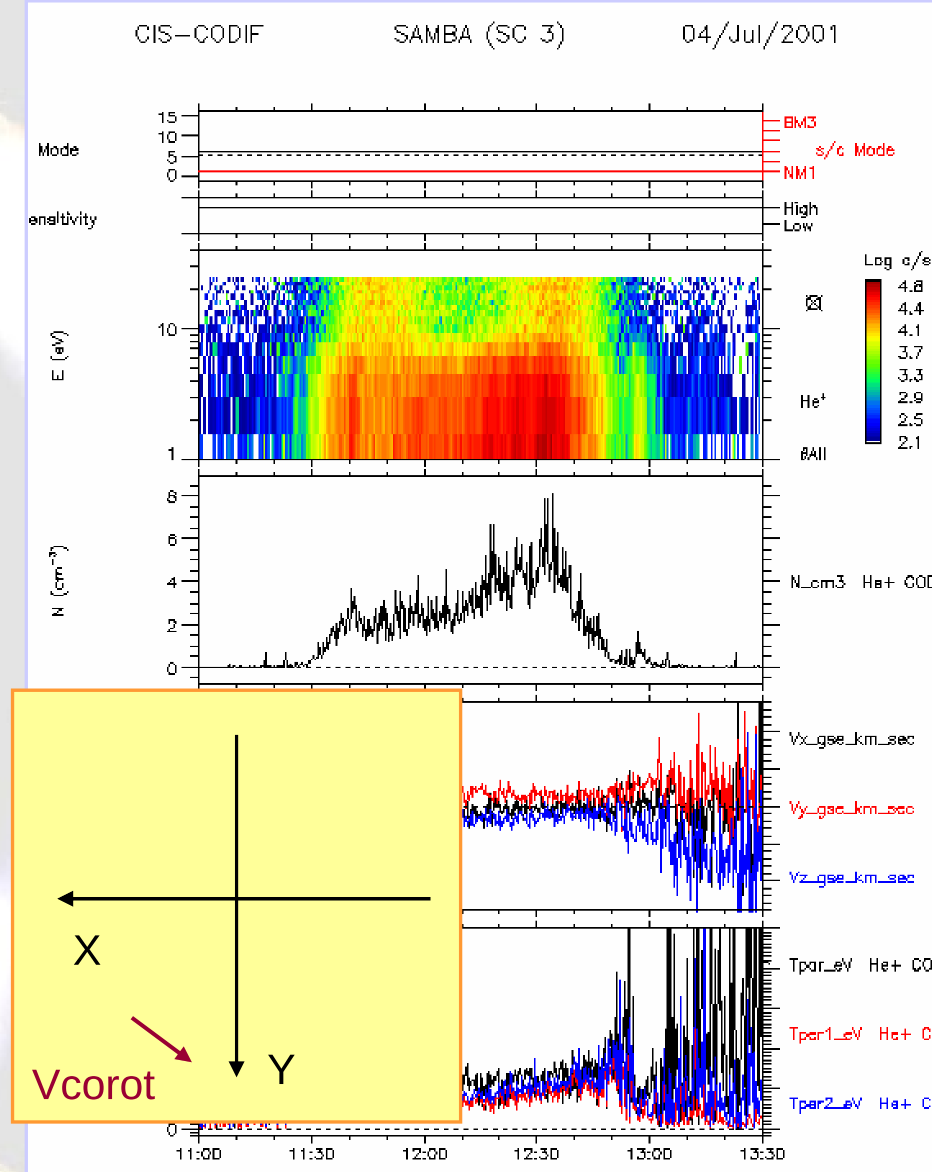


Orbit Visualization Tool plot, thanks to the OVT Team

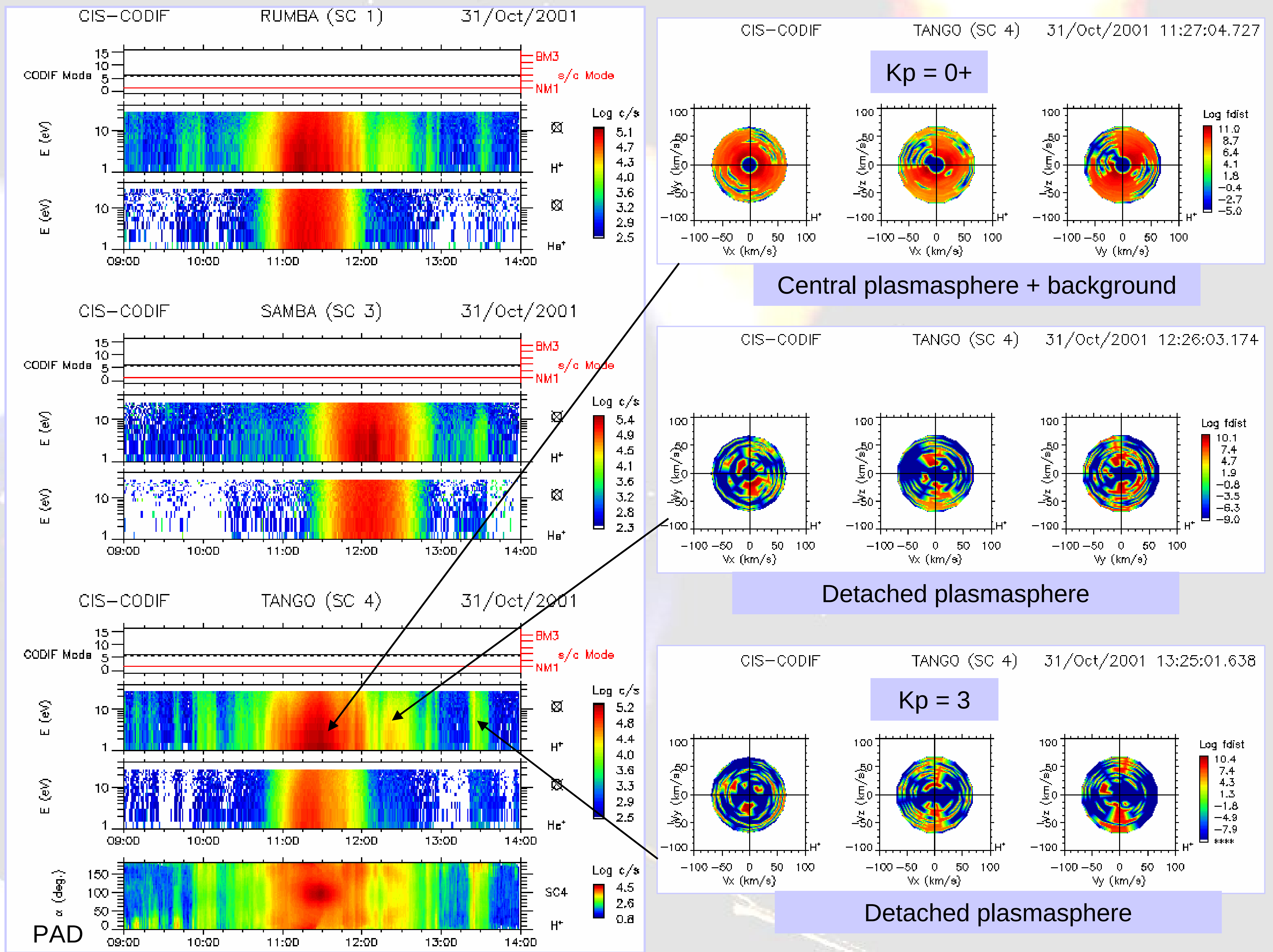
Kp = 1+

Plasmasphere Cut : H^+ and He^+ densities

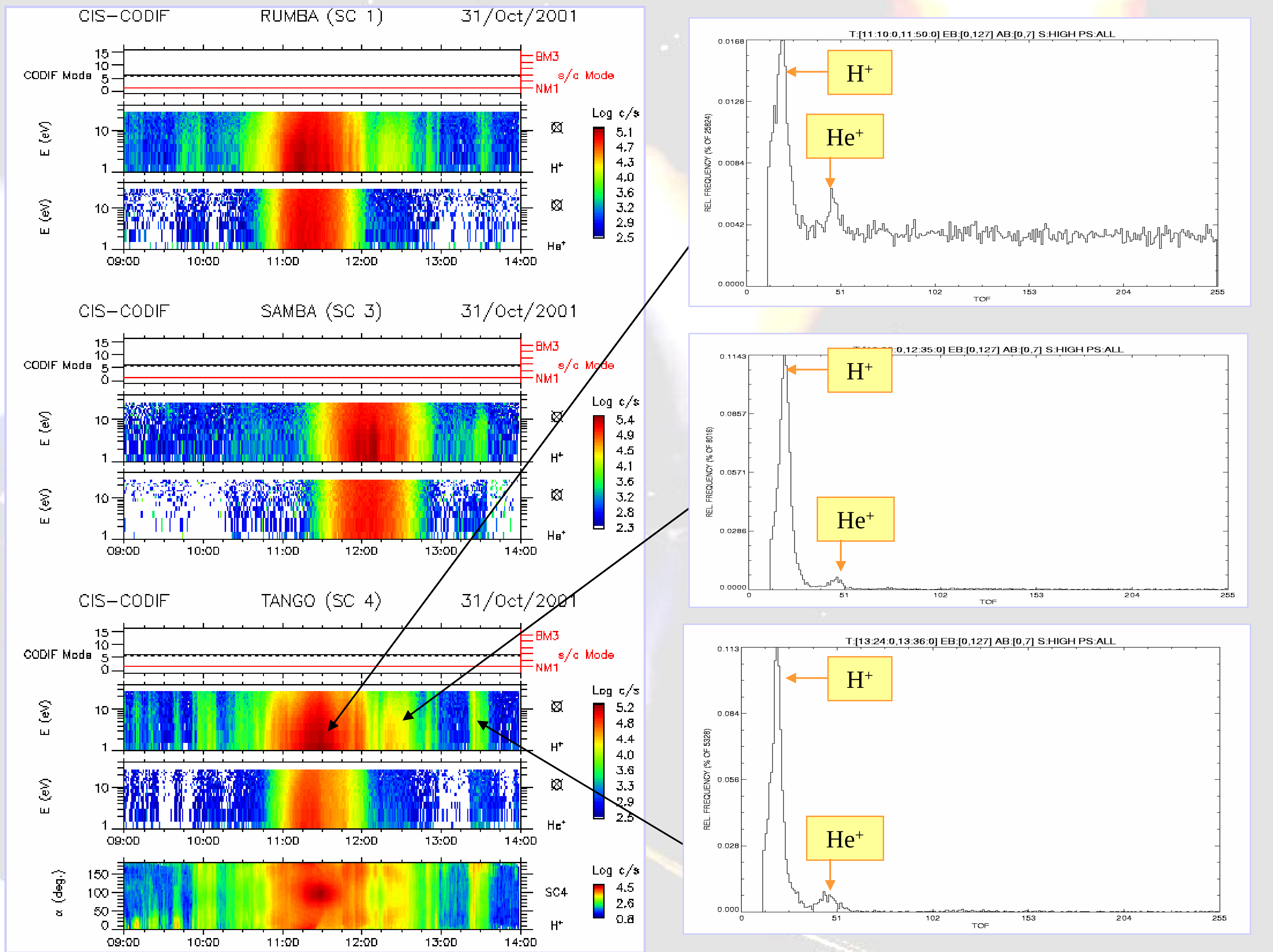




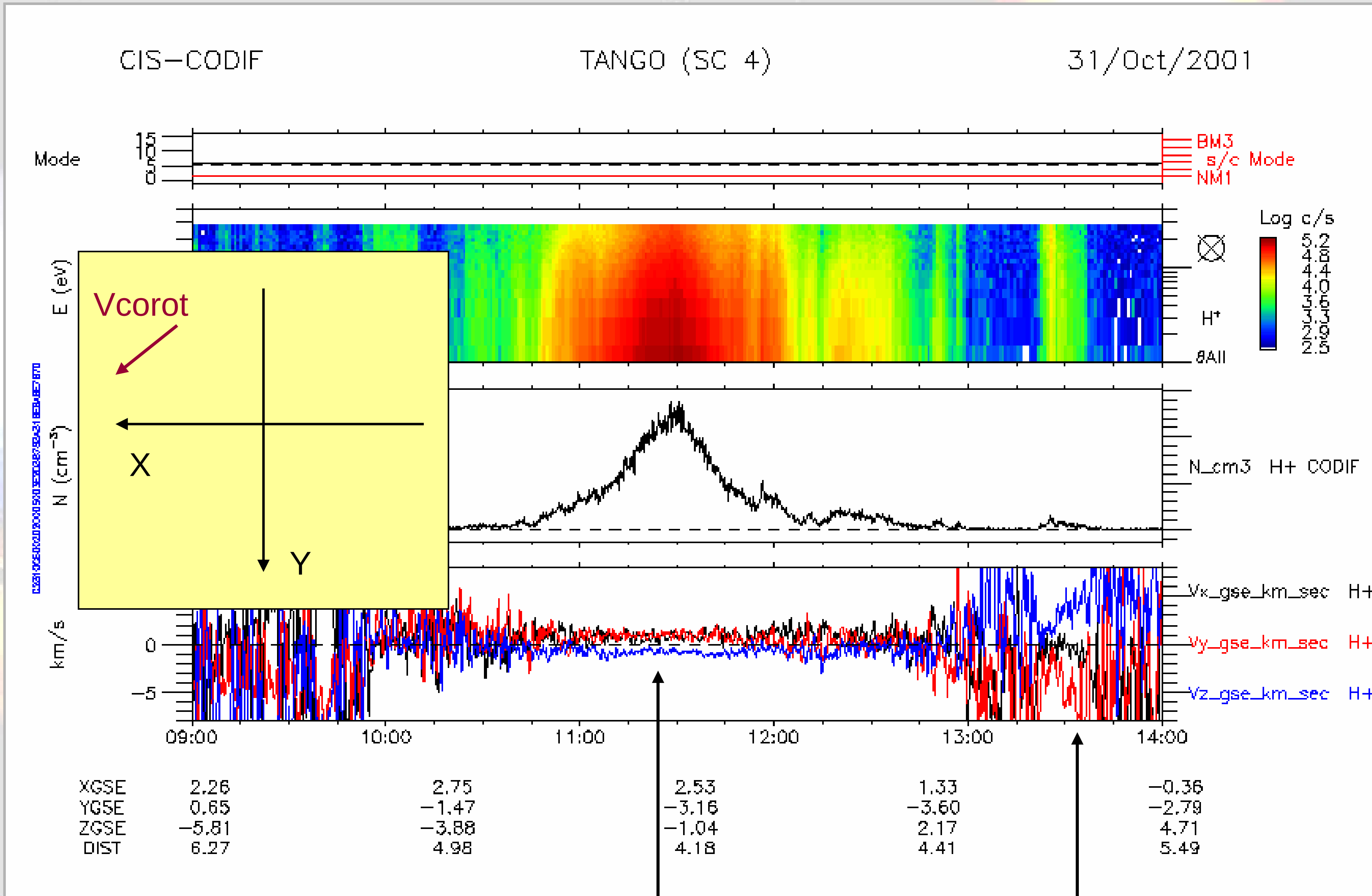
Dandouras et al., *AGU Monograph: Global Physics of the Coupled Inner Magnetosphere*, 2005



CIS−CODIF RUMBA (SC 1) 31/Oct/2001
CIS−CODIF SAMBA (SC 3) 31/Oct/2001
CIS−CODIF TANGO (SC 4) 31/Oct/2001
CODIF Mode
BM3
s/c Mode
NM1
E (eV)
Log c/s
H+
He+
α (deg.)
SC4
PAD
09:00 10:00 11:00 12:00 13:00 14:00
CIS−CODIF TANGO (SC 4) 31/Oct/2001 11:27:04.727
Kp = 0+
Vx (km/s)
Vy (km/s)
Vz (km/s)
Log fdist
Central plasmasphere + background
CIS−CODIF TANGO (SC 4) 31/Oct/2001 12:26:03.174
Detached plasmasphere
CIS−CODIF TANGO (SC 4) 31/Oct/2001 13:25:01.638
Kp = 3
Detached plasmasphere

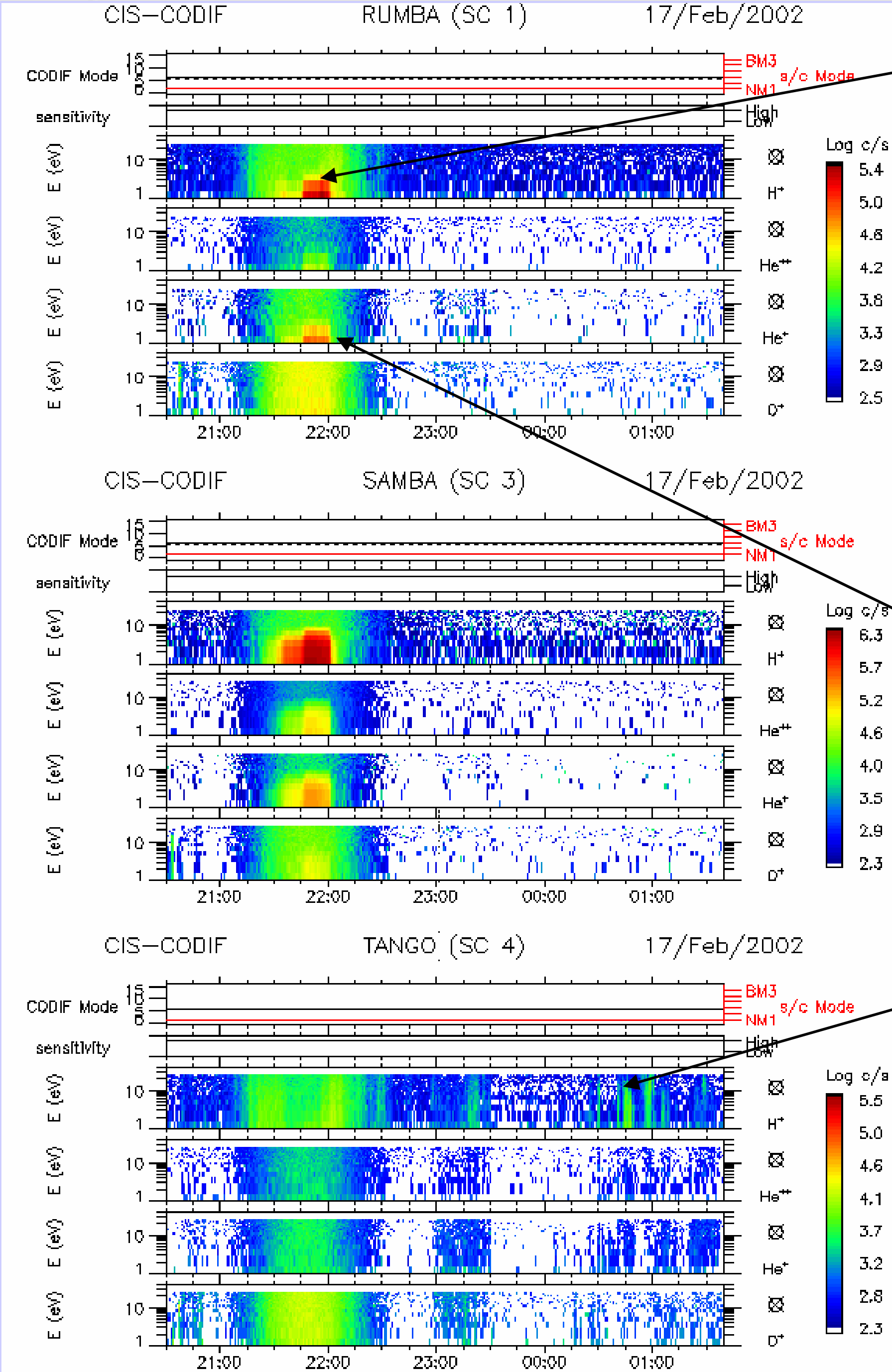


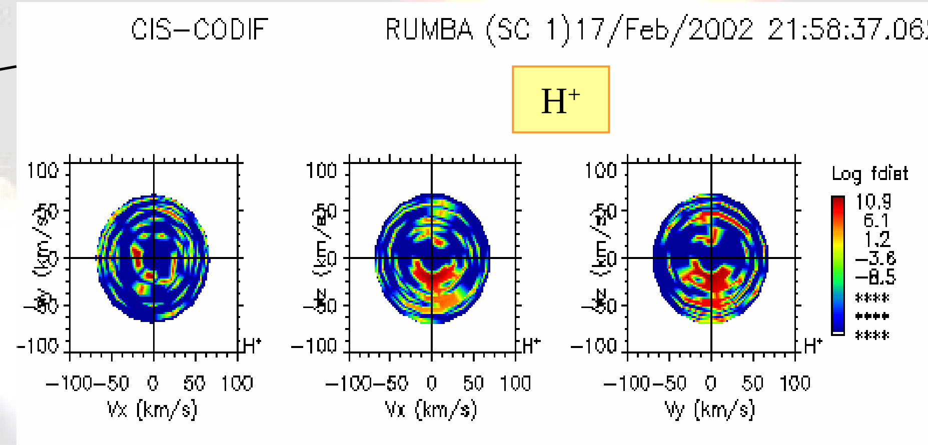
CIS–CODIF
RUMBA (SC 1)
31/Oct/2001
CODIF Mode
BM3
s/c Mode
NM1
E (eV)
Log c/s
5.1
4.7
4.3
4.0
3.6
3.2
2.9
2.5
H+
He+
09:00
10:00
11:00
12:00
13:00
14:00
CIS–CODIF
SAMBA (SC 3)
31/Oct/2001
Log c/s
5.4
4.9
4.5
4.1
3.6
3.2
2.8
2.3
CIS–CODIF
TANGO (SC 4)
31/Oct/2001
Log c/s
5.2
4.8
4.4
4.0
3.6
3.3
2.9
2.5
α (deg.)
SC4
Log c/s
4.5
2.6
0.8
T:[11:10:0,11:50:0] EB:[0,127] AB:[0,7] S:HIGH PS:ALL
REL. FREQUENCY (% OF 25824)
TOF
H+
He+
:0,12:35:0] EB:[0,127] AB:[0,7] S:HIGH PS:ALL
REL. FREQUENCY (% OF 8016)
T:[13:24:0,13:36:0] EB:[0,127] AB:[0,7] S:HIGH PS:ALL
REL. FREQUENCY (% OF 5328)



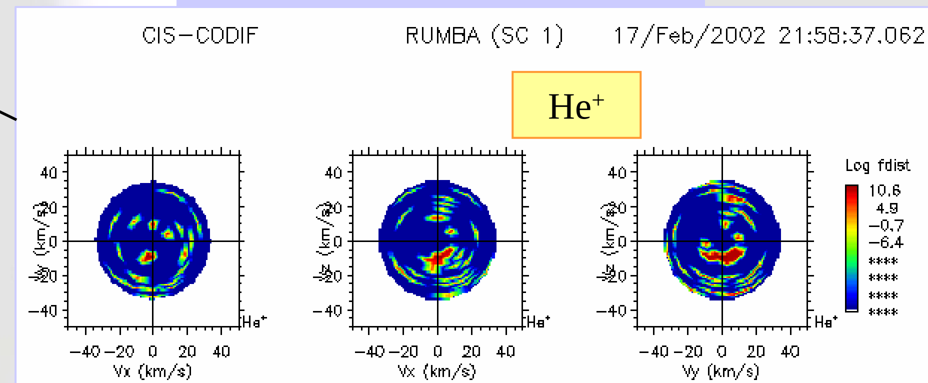
Central plasmasphere : corotation

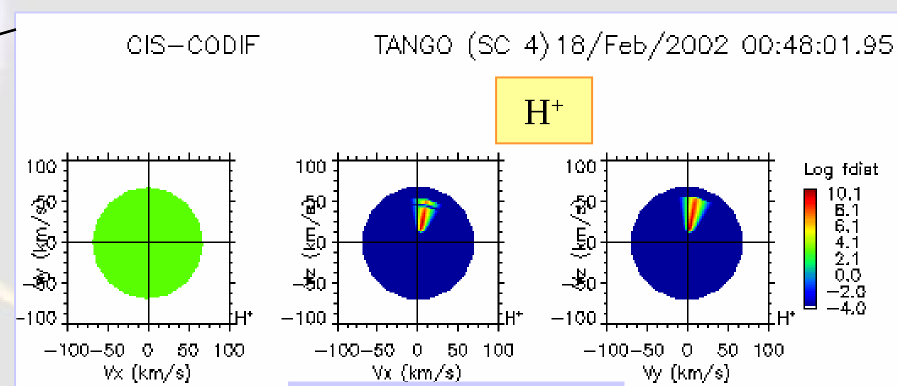
Detached plasmasphere : expansion



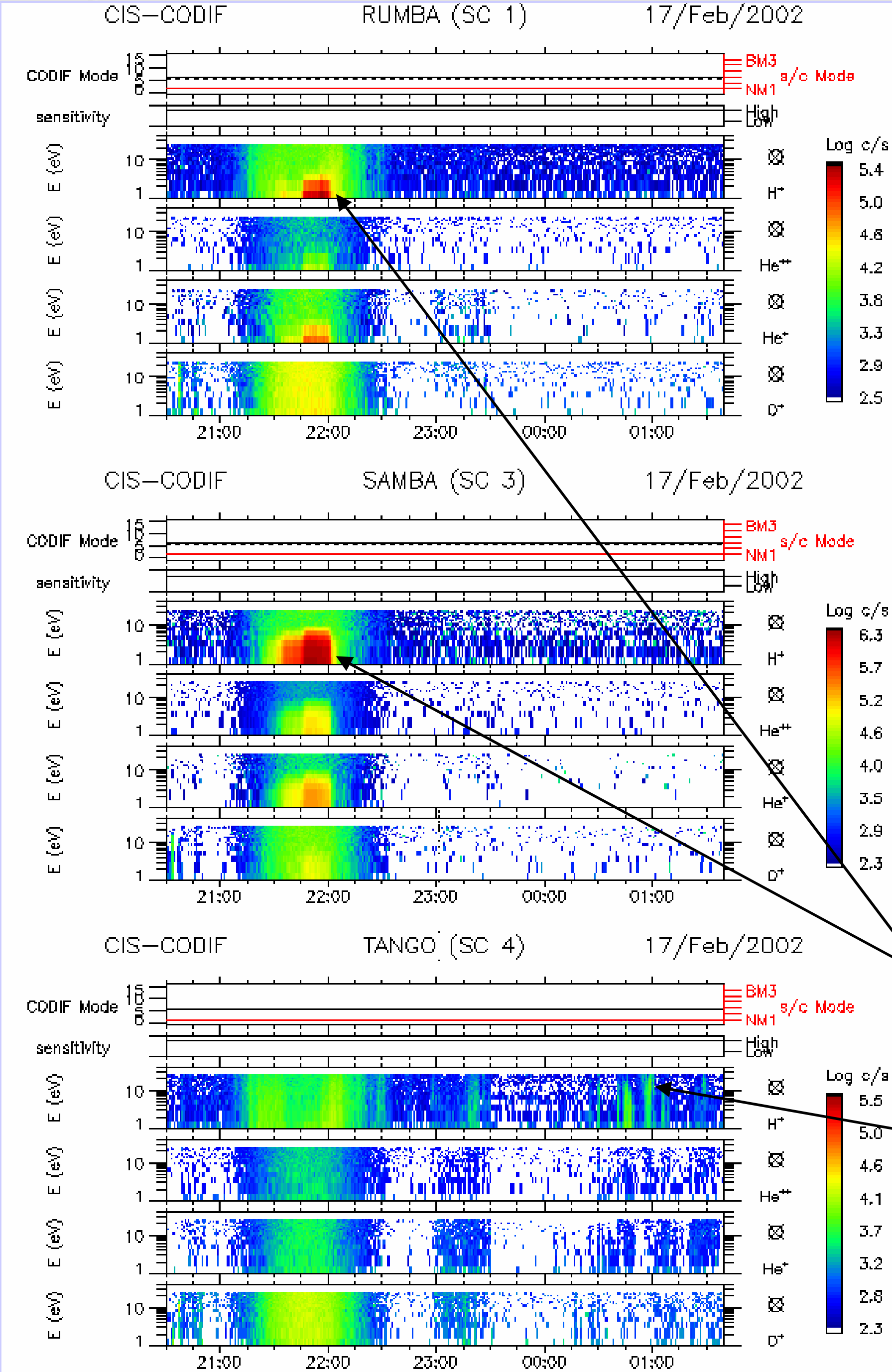


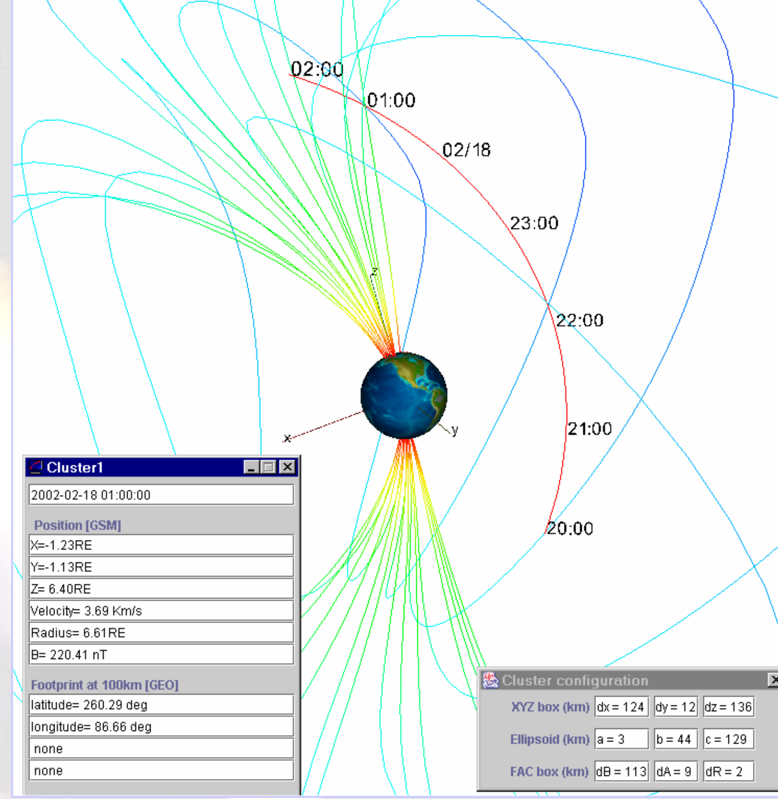
Central plasmasphere





Upwelling H+

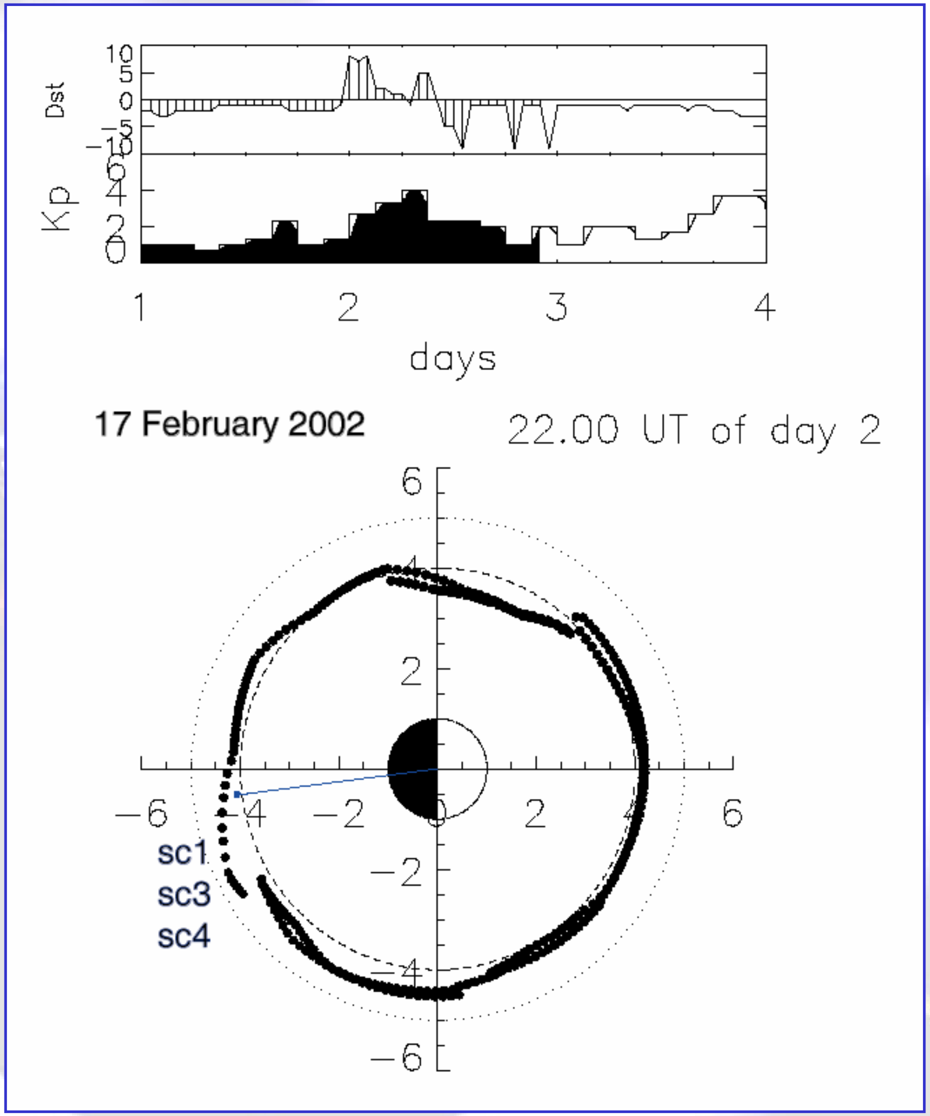


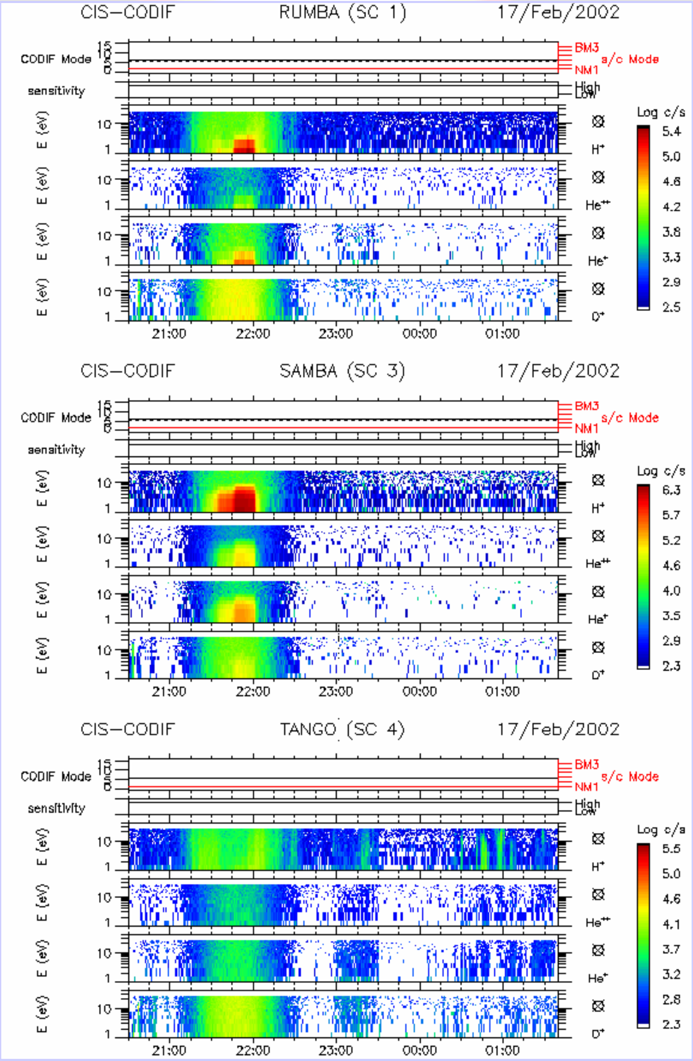


Different profiles observed in the plasmasphere by spacecraft 1-3 and 4:

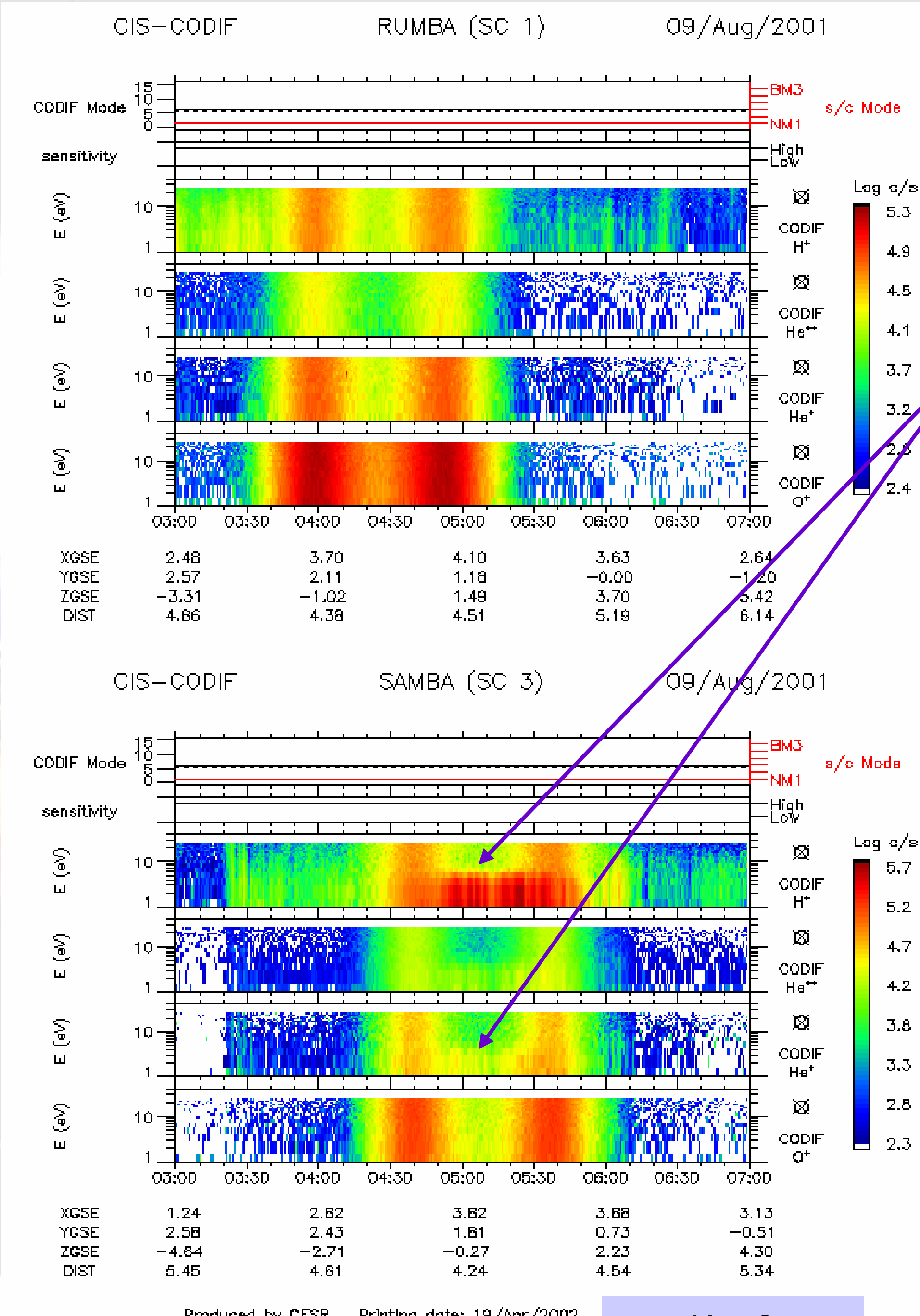
- **Spacecraft 1 and 3** observing a **very low energy (*E* < 10 eV) H^+ and He^+** population, **not observed by spacecraft 4** (plasmasphere observed during eclipse: 21:45 - 22:10 for all sc).
- **Upwelling H^+ (and He^+)** observed on auroral field lines **by sc 4** (ASPOC ion emitter operating on sc 3 and 4 during this observation).
- Spacecraft separation **less than 200 km**.

Interchange instability numerical model simulation for the plasmapause deformations
[*Pierrard and Lemaire,* 2004]





spacecraft 1, 3 and 4, separated by less than 200 km, are almost at the edge of a plasmapause bulge, formed by plasma brought by interchange instability, explaining why only some of the spacecraft (1 and 3) get into the plasmasphere



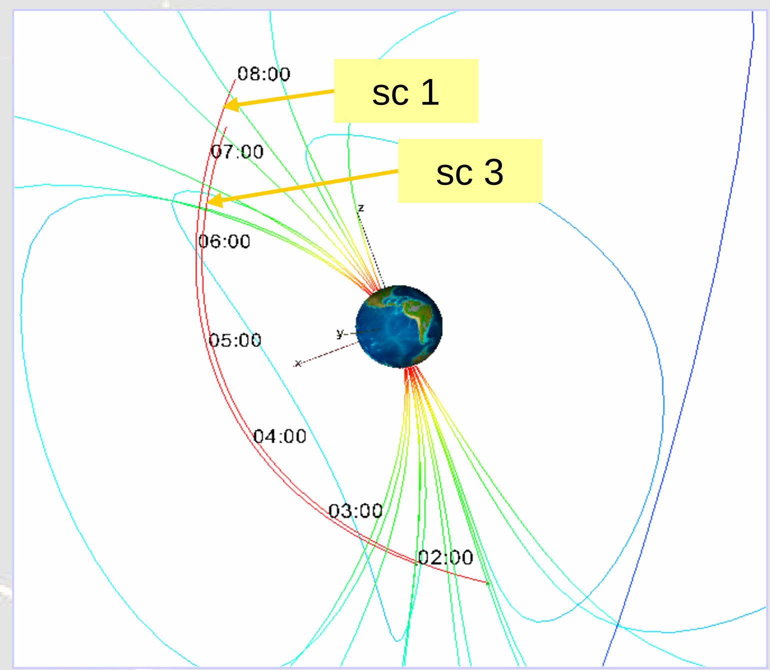
Kp=2

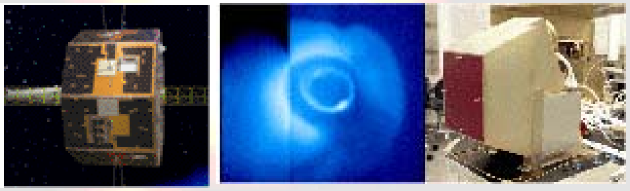
Different radial profiles observed in the plasmasphere by spacecraft 1 and 3:

Spacecraft 3 getting innermost (down to L=4.23 at ~05:10 UT, ≈13.5 MLT), and observing a **very low energy (*E* < 5 eV) H^+ and He^+** population between the two local maxima.

Spacecraft 1, however, whose orbit does not get below L=4.36, cannot detect such a population at its perigee.

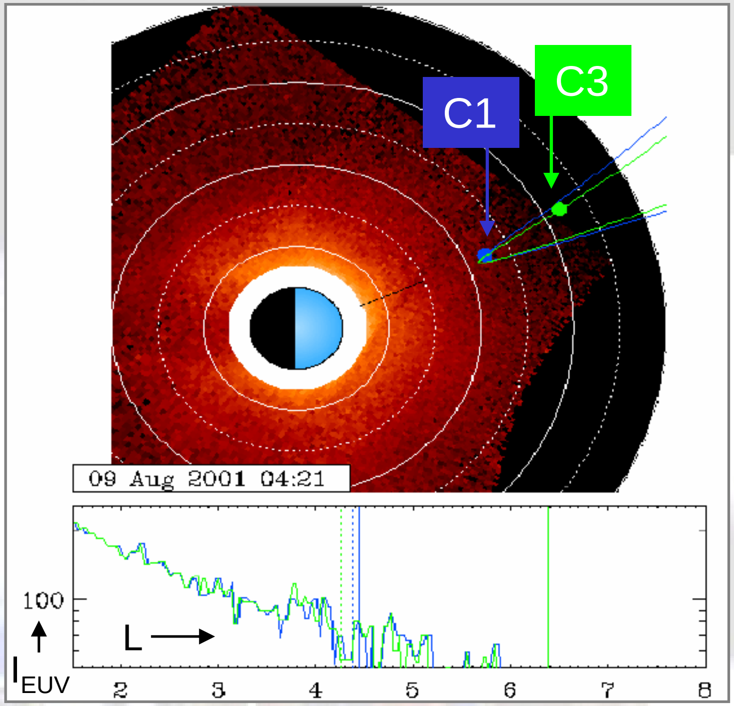
⇒ **boundary situated between sc 1 and sc 3**

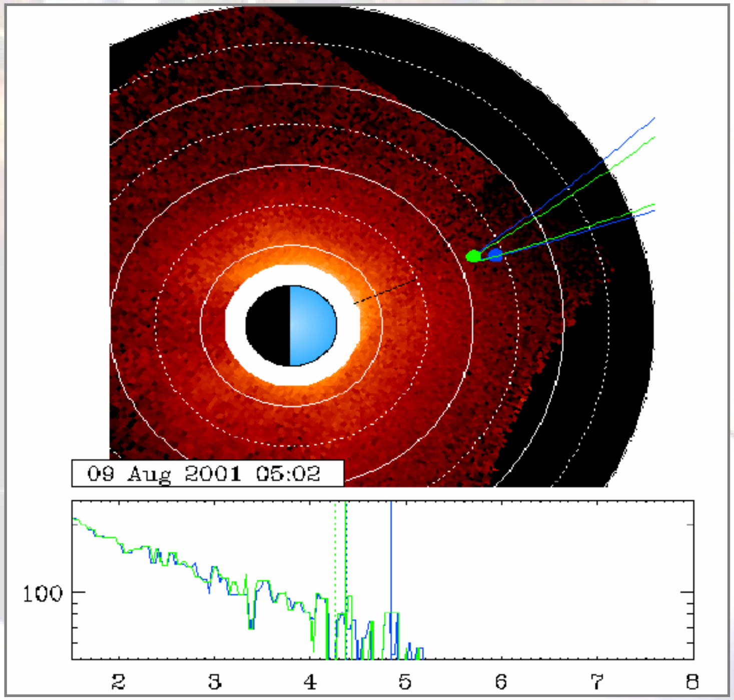


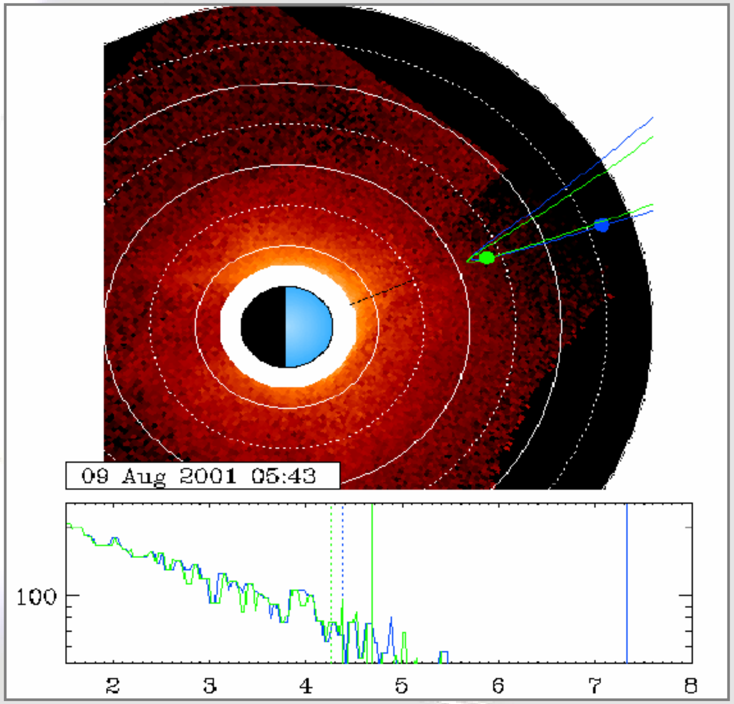


EUV - Image analysis of the 09 Aug 2001 event

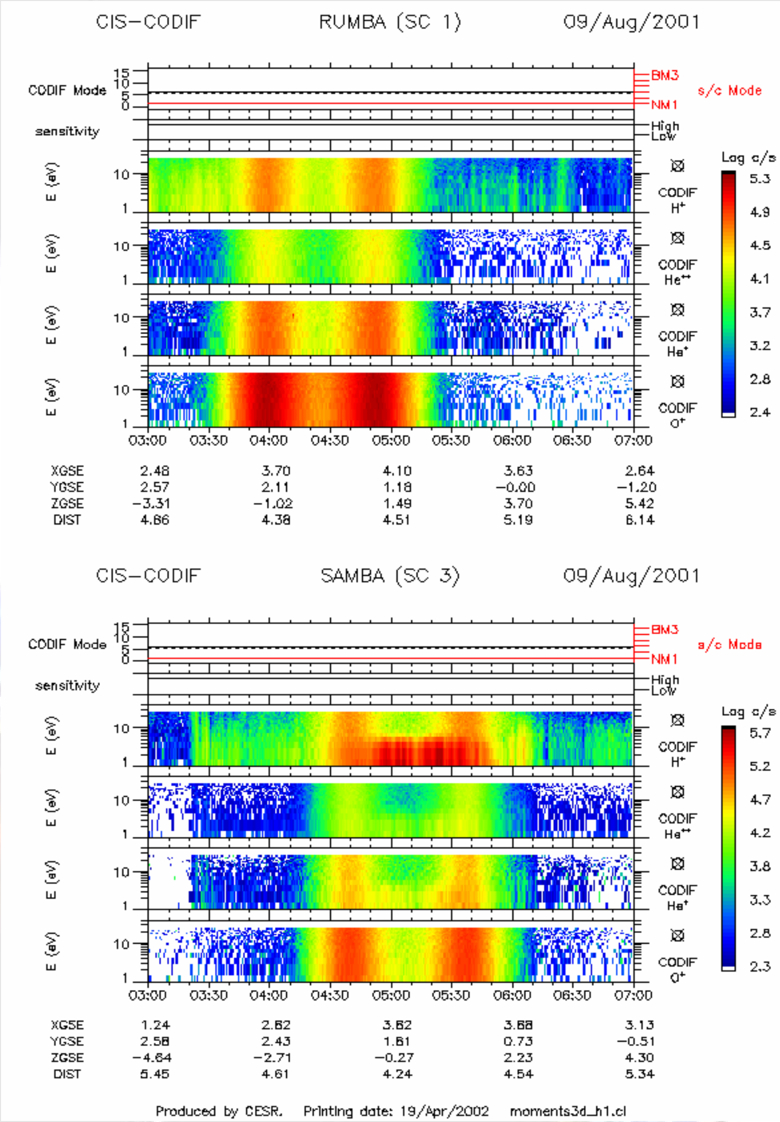
- Diffuse dayside plasmasphere, resulting from an extended period of quiet geomagnetic conditions
- Azimuthal structure in the plasmaspheric density

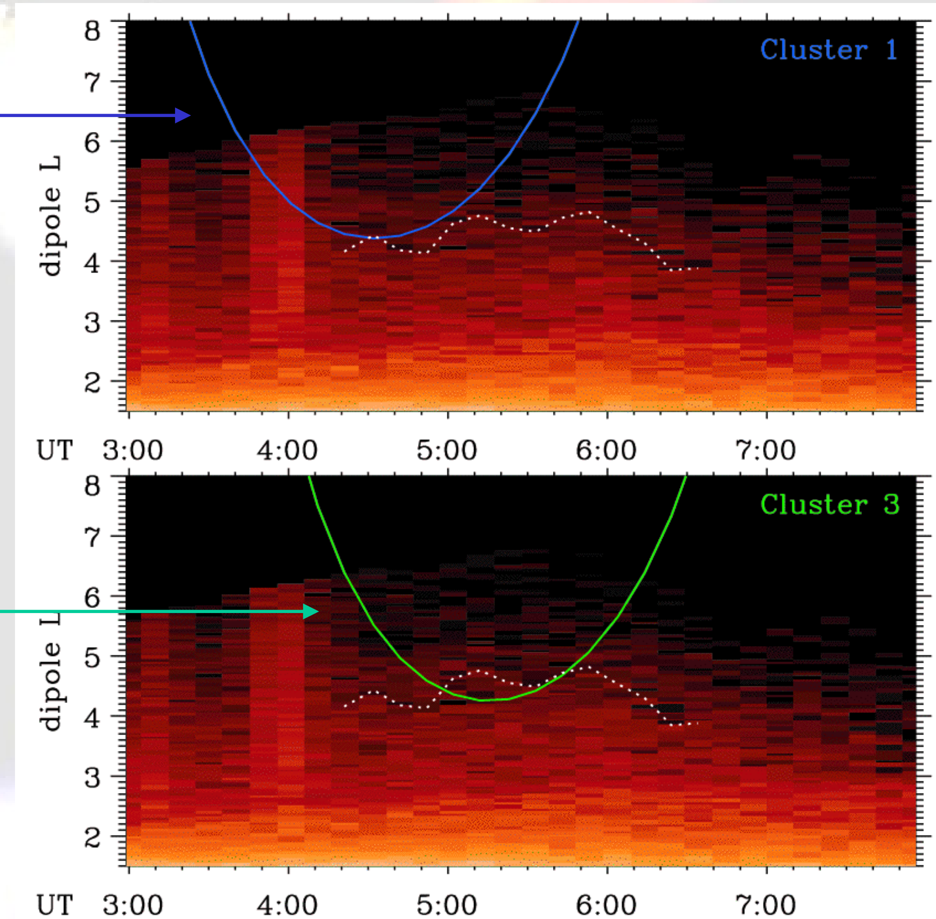






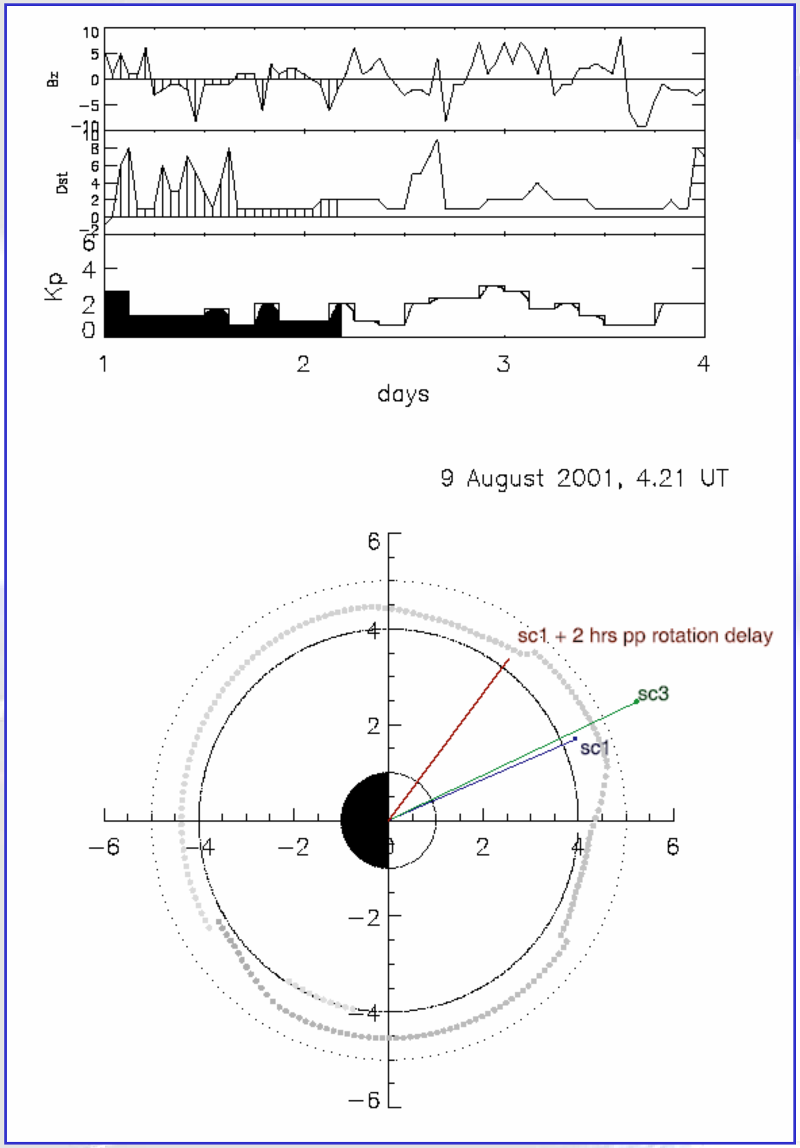
CLUSTER - IMAGE

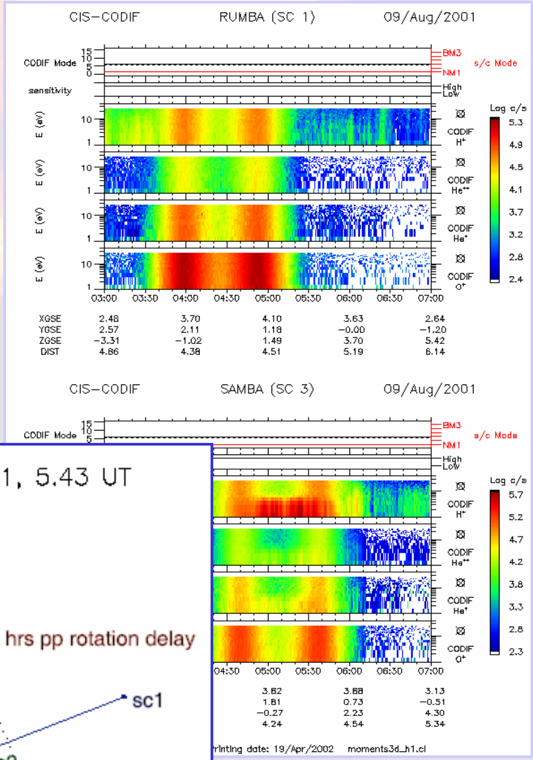


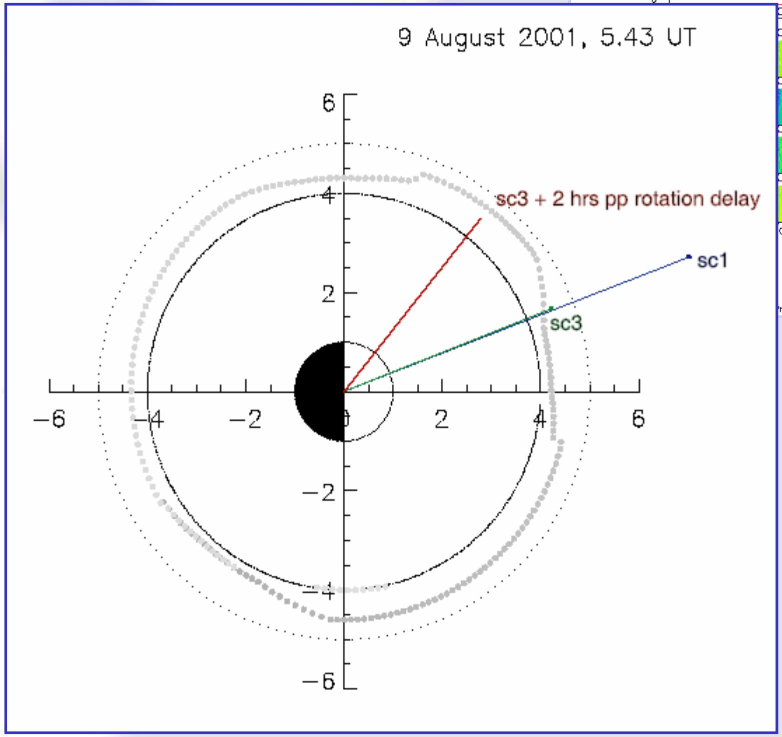


The EUV images show, for the 09 August 2001 event, that the difference observed between Cluster spacecraft 1 and 3 was temporal (boundary motion): the radial density profile of the plasmasphere varies with MLT, and a more extended radial profile "rotated" into 13.5 MLT in between the two Cluster spacecraft perigee passes

Interchange instability numerical model simulation for the plasmapause deformations [*Pierrard and Lemaire,* 2004]







By introducing a 2 hrs rotation delay on the plasmapause rotation (numerical simulation uses Kp as input: 3 hrs resolution), the interchange instability model reproduces the difference observed between Cluster sc 1 and 3, and shown also in the EUV images

CONCLUSIONS (1)

• The density profile is different for each of the main ion species (H^+, He^+, O^+) :

H^+ and He^+ present mostly similar profiles.

O^+ however, is not observed as part of the main plasmaspheric population at the Cluster orbit altitudes ($R \geq 4$ R_E).

• Detached plasmasphere events observed at ~0.5 R_E outside the plasmapause. The bi-directional distribution functions of these detached plasmaspheric populations allow to distinguish them from upwelling ion populations, which present very anisotropic distributions.

• The density values measured during the detached plasmasphere observations are by about an order of magnitude lower than the ones measured in the main plasmasphere.

• The plasmasphere co-rotation with the Earth is observed in the ion distribution functions, acquired within the main plasmasphere.

• In the detached plasmasphere observations, however, the plasma is not corotating, but has a strong outwards expansion velocity, which is increasing as a function of the L-shell value.

CONCLUSIONS (2)

• The CIS-RPA observations of the plasmapause position have been simulated with an interchange instability numerical model for the plasmapause deformations, and the model reproduces in a very satisfactory way the CIS observations.

• The CIS local ion measurements have also been correlated with global images of the plasmasphere, obtained by the EUV instrument onboard Image. The EUV images show, for this event, that the difference observed between two Cluster spacecraft was temporal (boundary motion): the radial density profile of the plasmasphere varies with MLT, and a more extended radial profile "rotated" into between the two Cluster spacecraft perigee passes. They thus show the necessity for correlating local measurements with global images, and the complementarity of the two approaches.