3D analysis of the ring current for the 20 April 2002 event using ENA image inversions (IMAGE/HENA) and the curlometer technique (Cluster/FGM data).

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Methodology

Goal: 3D Mapping of a well-developed ring current (20 April 2002) using in-situ and remote-sensing data.

1- In-situ: Cluster perigee pass inside the ring current (polar orbit)

⇒ 4 simultaneous points of measurement of B.

⇒ J estimate using Maxwell-Ampere's law (*curlometer technique*).

⇒ Provides the latitudinal evolution of the J vector (all along the Cluster orbit).

⇒ Local particle flux measurements.

2- Remote-sensing: IMAGE-HENA gives a global view of the ENA population issued from charge exchange processes

⇒ Provides a global picture of the equatorial ring current ions distribution (*inversion algorithm*).

⇒ Allows an estimate of the kinetic pressure distribution. (under study)

MHD theory

- MHD momentum equation:

$$\rho \frac{d\vec{U}}{dt} = -\nabla \cdot \vec{p} + \vec{J} \times \vec{B}$$

U: flow velocity.
P: pressure tensor.
J: current density.

- Solution in the plane perpendicular to **B** (static):

$$\vec{J}_\perp \approx \frac{\vec{B}}{B^2} \times \left[\nabla_\perp p_\perp + \frac{(p_{//} - p_\perp)}{B^2} \left[\left(\vec{B} \cdot \nabla \right) \cdot \vec{B} \right] \right]$$

Current due to
Pressure gradients

Current due to the
B curvature and anisotropy

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In situ Cluster data:

the curlometer technique

Curlometer technique

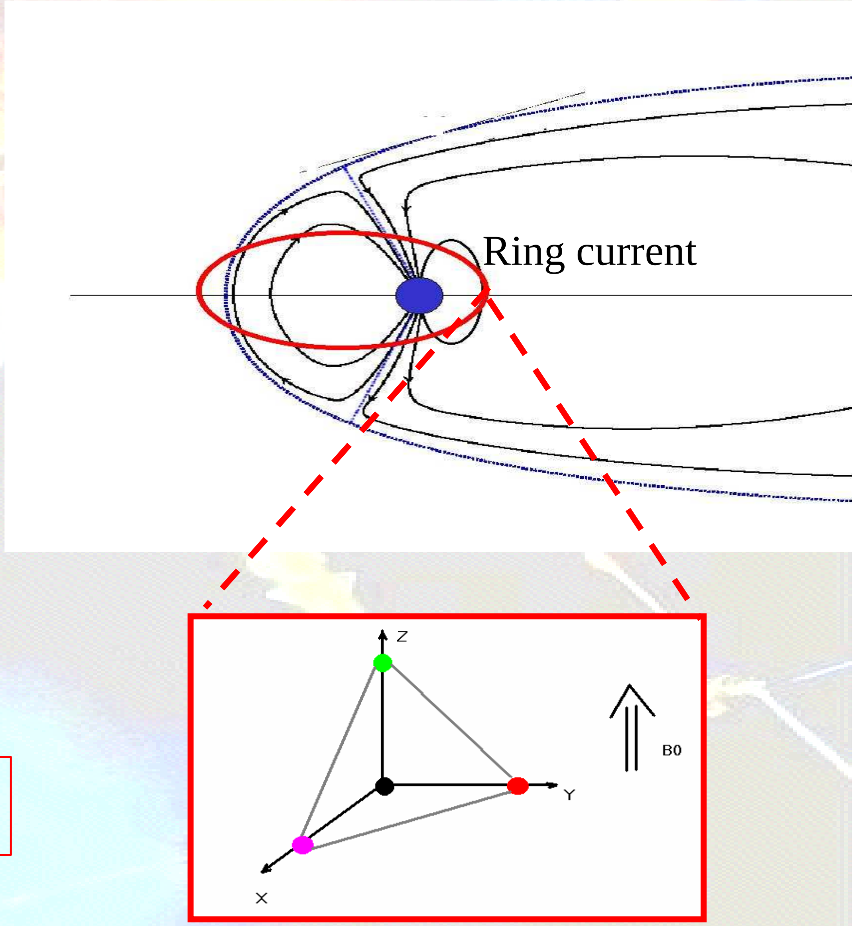
Maxwell-Ampère's law:

$$\nabla \times \vec{B} = \mu_0 \cdot \vec{J}$$

$$(\nabla \times B)_x = \frac{\Delta Bz}{\Delta y} - \frac{\Delta By}{\Delta z}$$

$$(\nabla \times B)y = \frac{\Delta Bx}{\Delta z} - \frac{\Delta Bz}{\Delta x}$$

$$(\nabla \times B)z = \frac{\Delta By}{\Delta x} - \frac{\Delta Bx}{\Delta y}$$



$$\mu_0 \vec{J}_{average} \, (\Delta \vec{r}_i \times \Delta \vec{r}_j) = \Delta \vec{B}_i . \Delta \vec{r}_j - \Delta \vec{B}_j . \Delta \vec{r}_i$$

$\Rightarrow$ **Curlometer technique**: Local current density estimate (strength and orientation) deduced from the 4 SC magnetic field data.

Curlometer technique limitations

- **Tetrahedron size and shape** (elongation and planarity of the tetrahedron).
- **Linear interpolations** (truncations errors and reference spacecraft).
- **Accuracy of the magnetic field measurement** (gain and offset).

Perigee passes of Cluster (ring current crossing) with a **100 km separation strategy (20 April 2002 event) :**

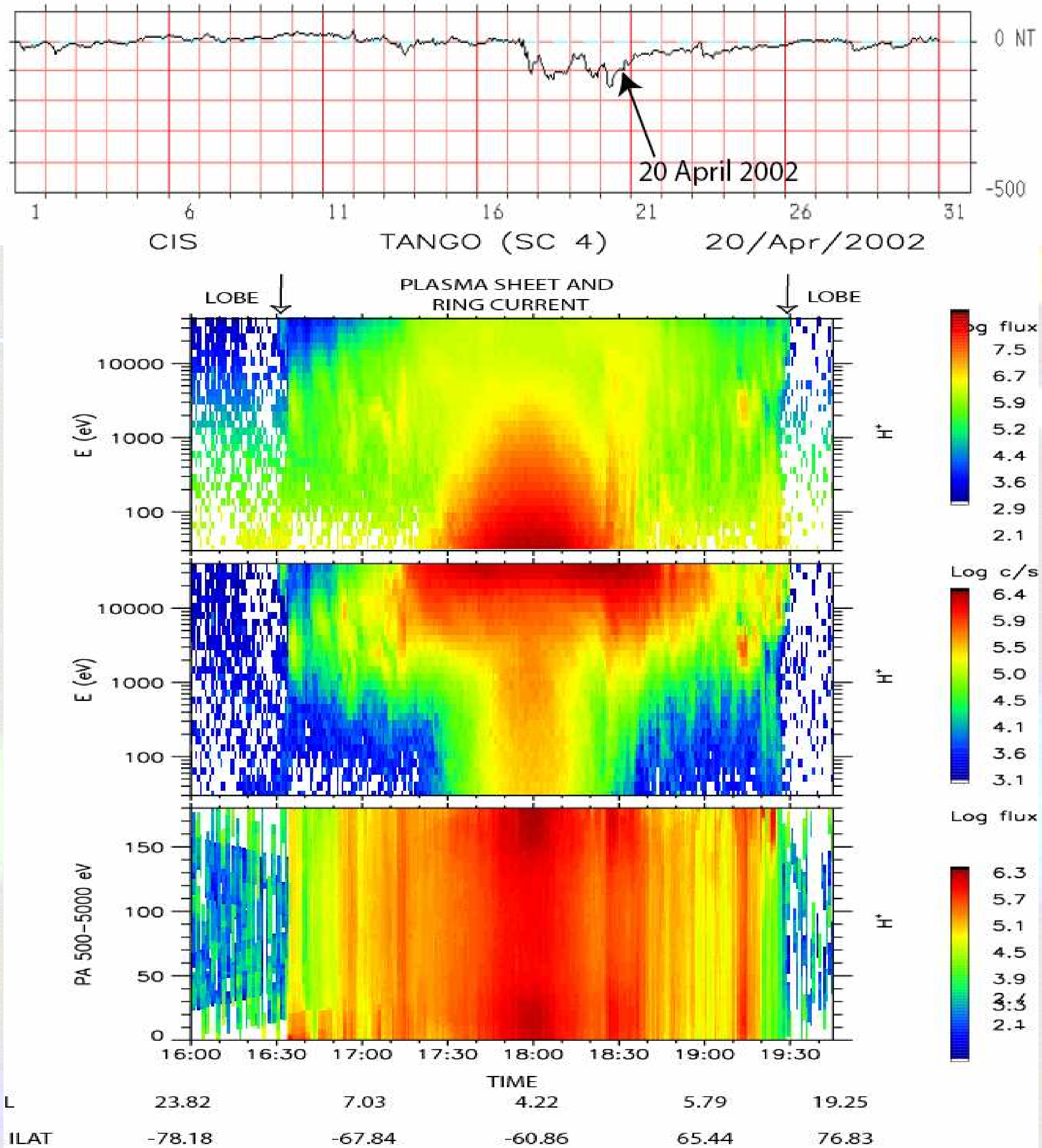
⇒ **Most of the error carried by Jz (up to 20%).**

⇒ **Good estimation of Jx and Jy** (accuracy of about **2% - 5%).**

[***Vallat et al.,*** *Ann. Geophysicae, 2005*]

1- In situ Cluster data

20 April 2002 (1)



- Storm conditions.
- Dst ~ -100 nT:
Well-developed ring current.

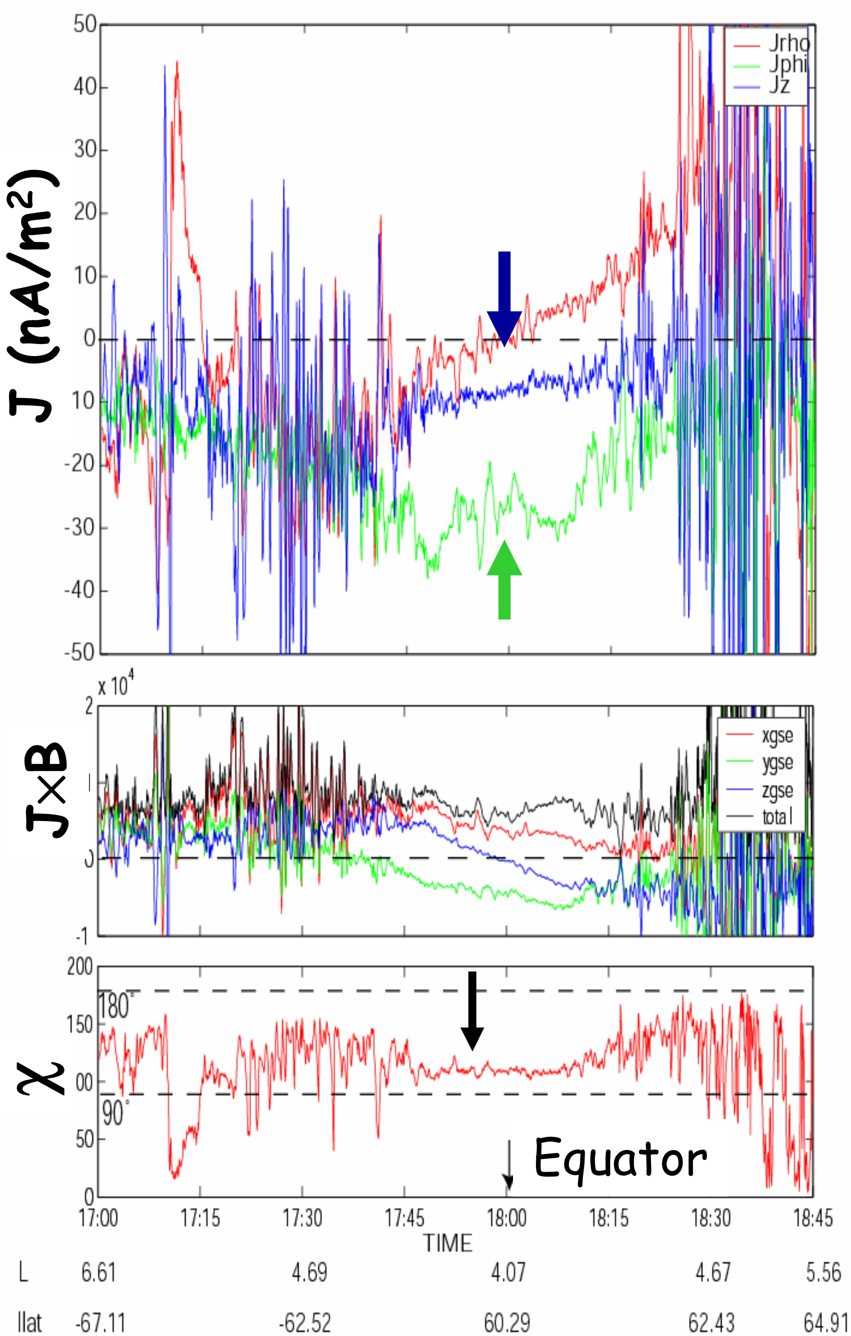
- Cluster perigee crossing:

MLT ~ 21

- CIS/Cluster ion data:

Gradual transition between the plasma sheet and the ring current.

20 April 2002 (2)



- Negative and constant **Jz** component all along the ring current traversal

- The largest component of J is azimuthal: $\langle J\varphi \rangle \sim -25 \pm 20\%$ nA/m^2 (westward current)

- **J×B** α ∇**P** (gives the position w.r.t the maximum pressure):

  => P_{max} situated dawnward (towards the tail axis) and slightly Earthward of the spacecraft location.

- Ring current is not fully azimuthal during disturbed periods:

  $\Rightarrow$ Existence of a small parallel component near the Equator.

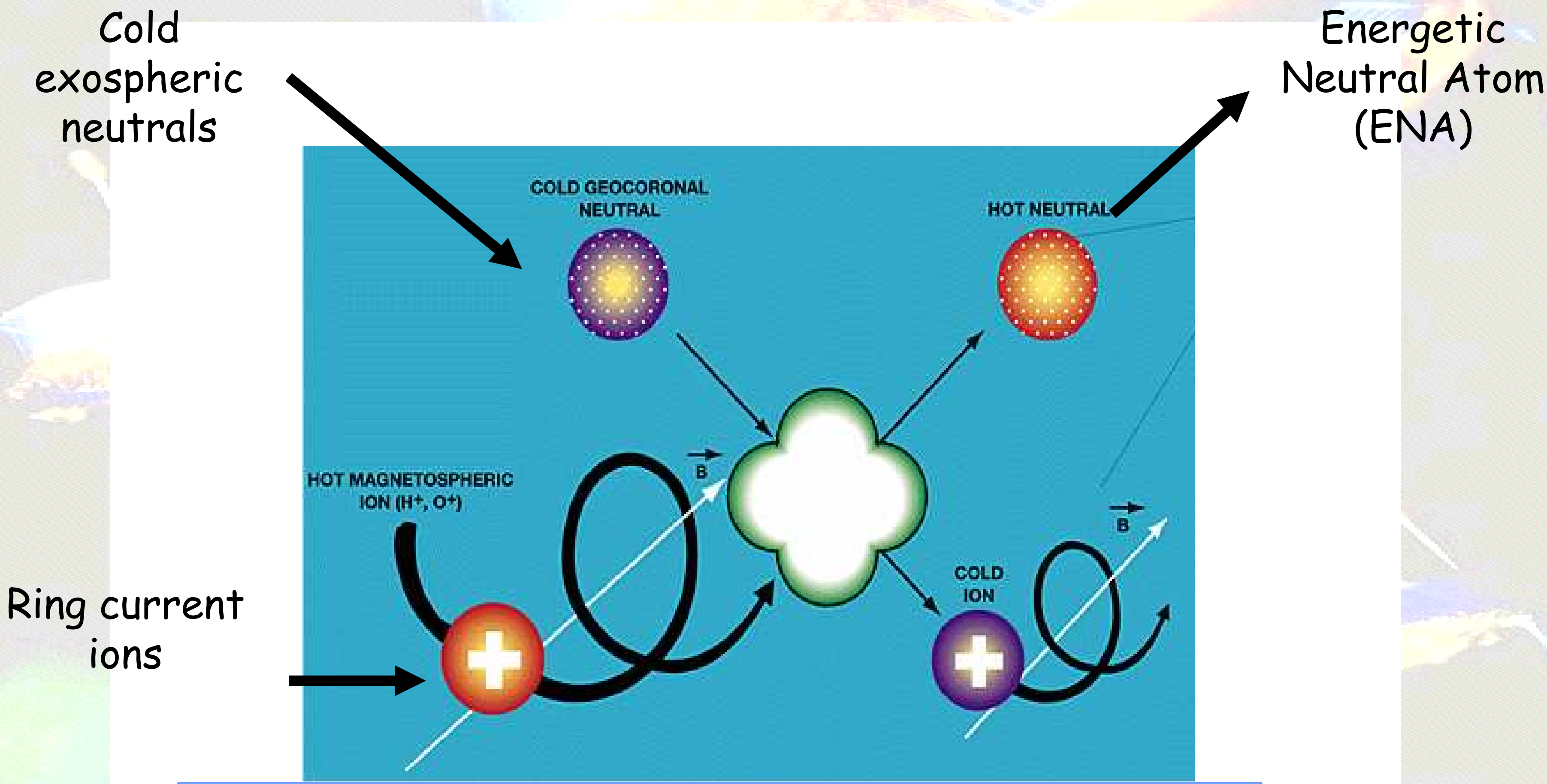
  (Seasonal effects due to the different ionospheric conductivities of the two hemispheres?)

2

IMAGE ENA imaging:

the image inversion technique

2- IMAGE-HENA imaging Charge exchange



$$j_{ena}(E) = \int_0^{Se} n^H(s)\sigma_H^{10}(E)\, j_{ion}(s,E)\,ds + j_{ena}^e(s_e)$$

[*Roelof*, 1989]

Energetic neutral atoms have the same direction and the same energy as the incoming ion.

=> ENA bring crucial information concerning the ring current ions.

Inversion method

1_ Number of counts received by the neutral imager (HENA)

$$C_i = \int_0^{\infty}\int_0^{\infty}\int_0^{2\pi}\int_0^{\pi} \sin\varepsilon A_i(\varepsilon,\beta,E,t)\, j_{ena}\, d\varepsilon\, d\beta\, dE\, dt$$

2_ Neutral intensity

$$j_{ena} = \int_0^{Se} n^H(s)\sigma_H^{10}(E)\, j_{ion}(s,E)\, ds + j_{ena}^e(s_e)$$

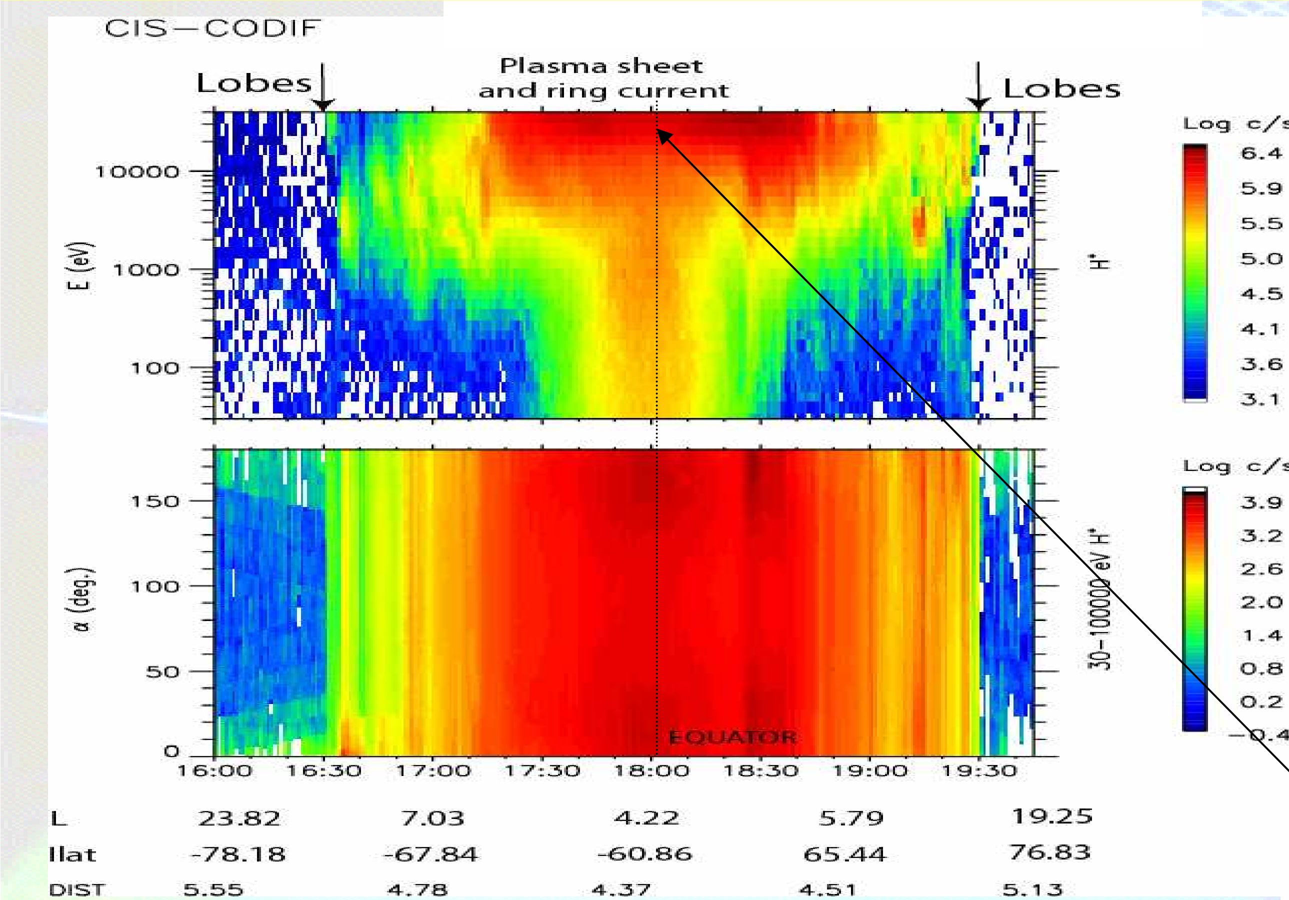
1 + 2: Linear inversion method.
Solution can be written as :

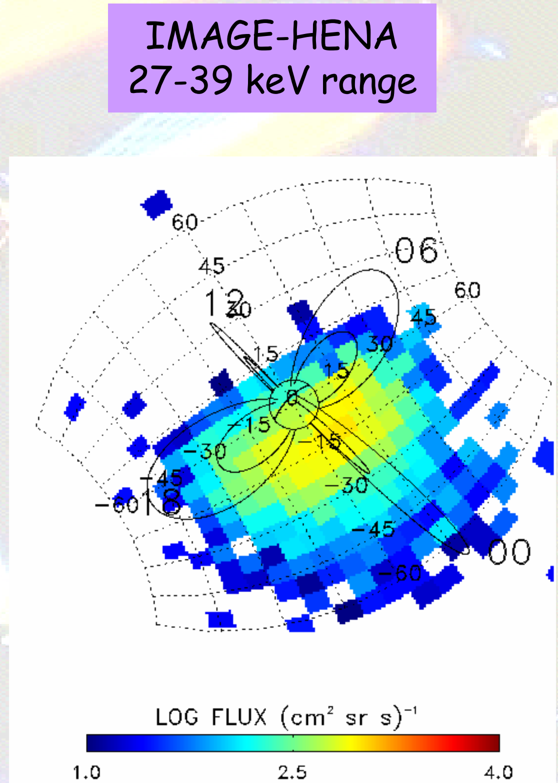
$$J_{ion} = (K^T\sigma_C^{-2}K + \gamma H)^{-1} K^T \sigma_C^{-2} C$$

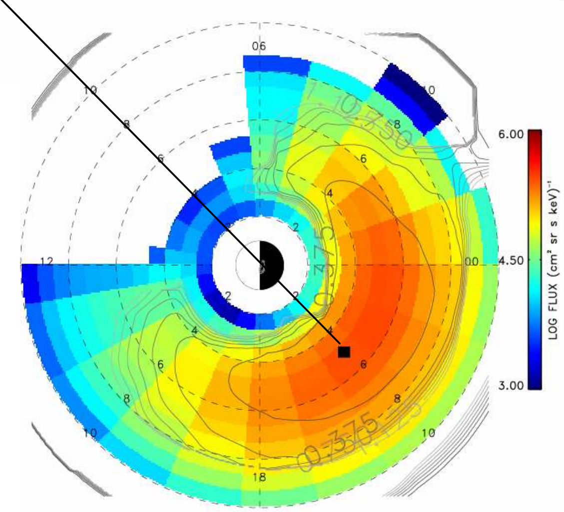
[*DeMajistre et al.*, JGR, 2004]

⇒ Using ENA imaging, we can access to the equatorial distribution of the parents ions (i.e. the current carriers) for the energy range considered.

2- IMAGE-HENA imaging   20 April 2002 (2)







• Quantitatively: consistent results (factor of ~ 1.3) between in-situ and ENA image inversion data *(H+, 27<E<39 keV):*

CIS: $f_i \approx 1.78 \times 10^5$ (cm^2 sr s keV)$^{-1}$.
HENA inversions: $f_i \approx 2.43 \times 10^5$ (cm^2 sr s keV)$^{-1}$.

• Morphology of the ring current (position of Cluster w.r.t the ring current bulk) is well reproduced by the image inversion [*Vallat et al.*, JGR, 2004].

Conclusions...

The curlometer technique:

* Latitudinal evolution of the J orientation :

- Filamentation of the current density components in the plasma sheet.

  ⇒ Consequence of non-linear gradients due to the small size of the current layers (< tetrahedron size).

- Shows the existence of a small parallel component near the Equator.

  ⇒ Seasonal effects due to the different ionospheric conductivity between the two hemispheres?

* Position of the maximum pressure is situated dawnward and Earthward of the spacecraft location for the event studied.

The energetic neutral atom image inversion:

* Position of the maximum pressure is situated dawnward (towards the tail axis) of the spacecraft location.

⇒ Consistent with the curlometer results.

* Possibility to calculate equatorial currents from the pressure distribution (under study).