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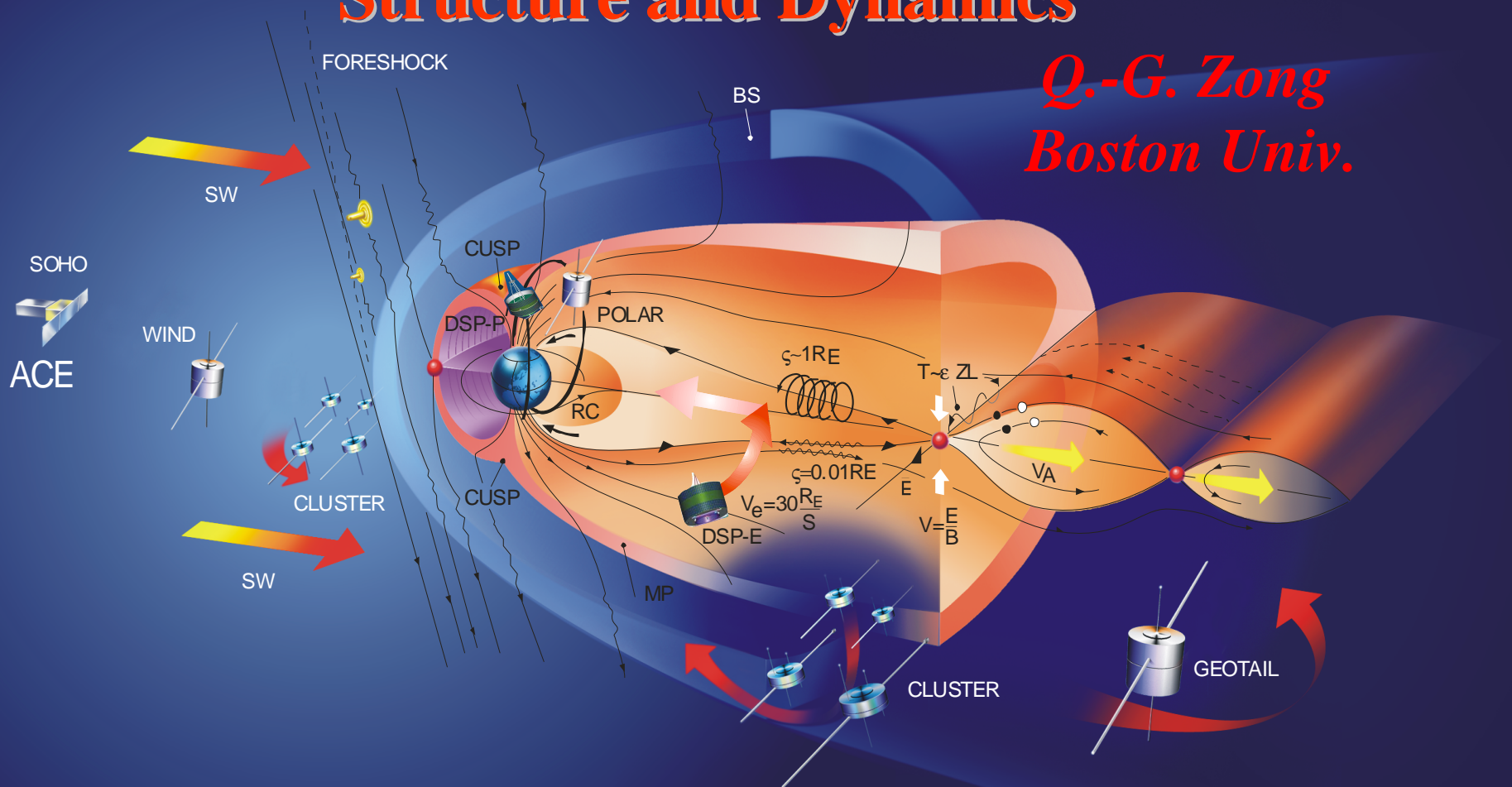
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The Magnetospheric Cusp: Structure and Dynamics

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Outline

- 1. Brief Introduction: Cusp**
- 2. Particle Aspect of the Cusp**
- 3. Boundary Layers**
- 4. Multiple and Dynamics Cusp**



Brief History

Brief introduction

- *~Qin dynasty (221-206 B.C.) Magnetic compass discovered in China.*

(The first person recorded to have used the compass as a navigational aid was Zheng He (1371-1435), from the Yunnan province in China, who made seven ocean voyages between 1405 and 1433)

- *1600 William Gilbert publishes in London "De Magnete" ("on the magnet"). His explanation of the compass: the Earth is a giant magnet.*
- *Maxwell (~1880) showed that a perfect conductor adjacent to a dipole formed an image dipole*
- *Chapman and Ferraro (1931) first induced the basic nature of the Earth's magnetosphere, its 2-D and 3-D topologies have indicated the existence of a dayside magnetic cusp.*
- *Spreiter and Summers (1962) predicted a stagnation flow in the cusp region by using a gas dynamics model*
- *Heikkila and Winningham (1971) and Frank (1971) showed a high-latitude band of low-energy particle precipitation with magnetosheath-like properties on the dayside at low altitudes which have accepted as the first evidence to discover the magnetospheric cusp.*



Cusp Definition:

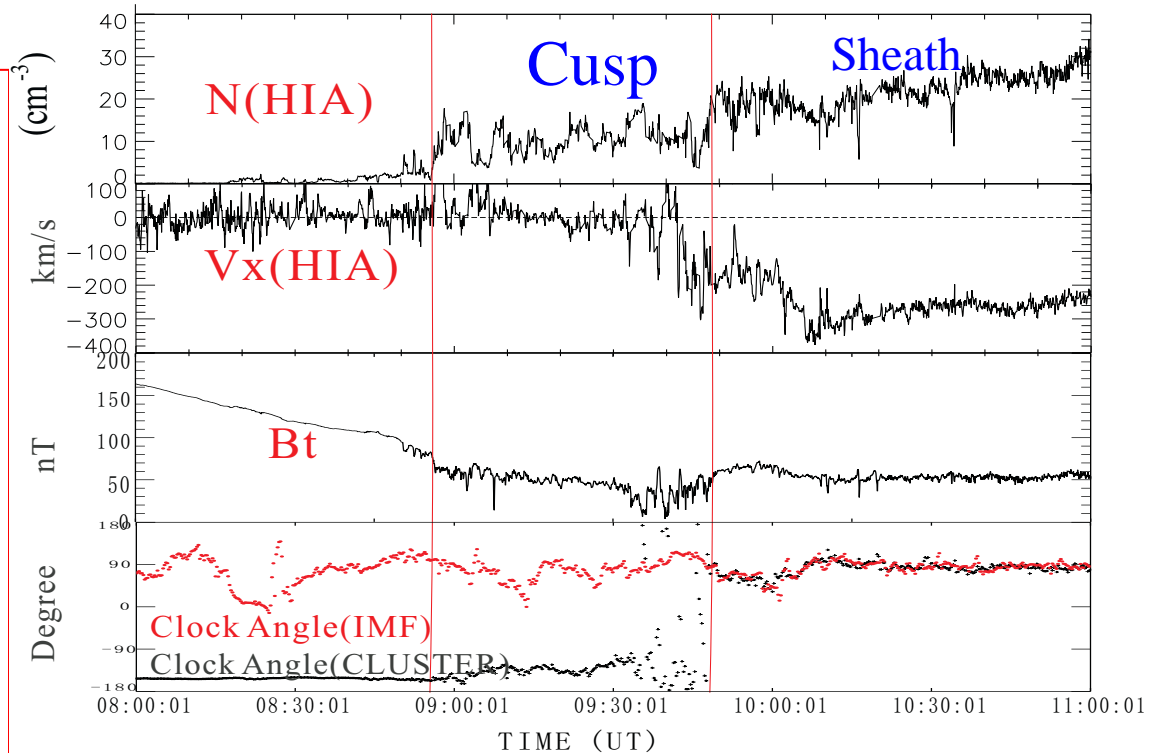
Funnel-shaped areas in the high latitude of both hemispheres with near zero magnetic field magnitude called the polar cusps. They provide a direct entry for the magnetosheath plasma into the magnetosphere (e.g., Reiff et al., 1977; Marklund et al., 1990)

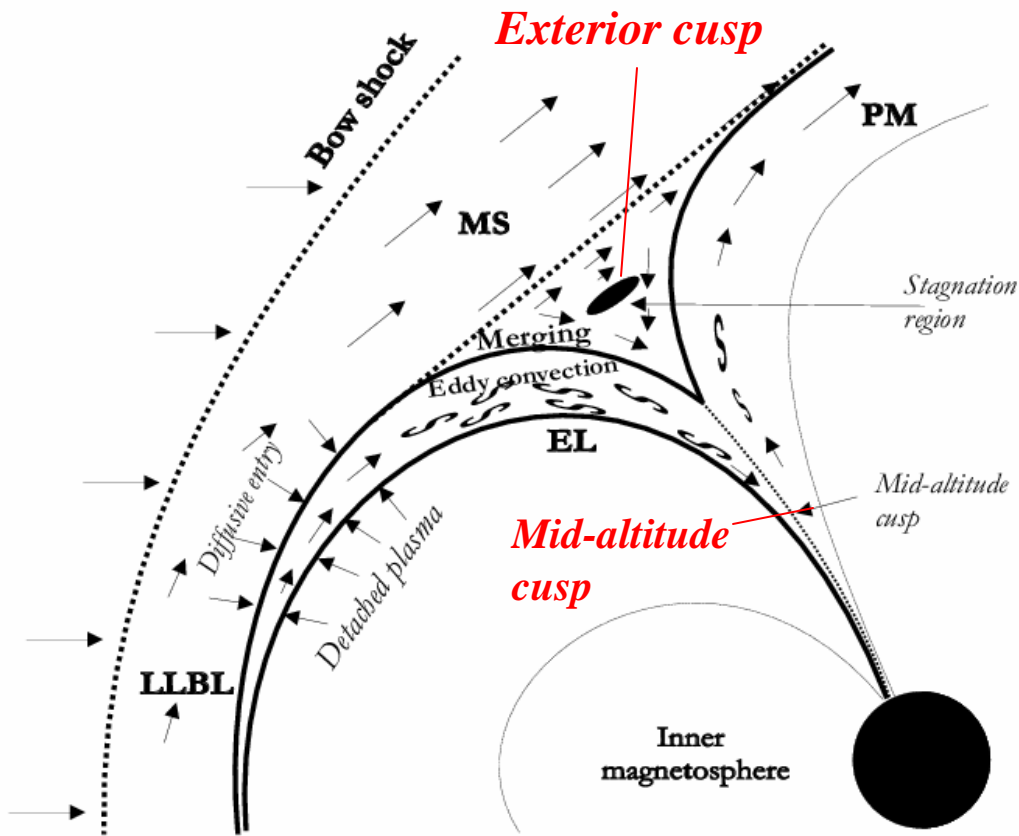
Cusp Definition (observational):

@ the high latitude region

- I. turbulent and depressed magnetic fields,
- II. high density plasma (\sim sheath level),
- III. stagnant plasma flow ($V_x \sim 0$),
- IV. clock angle criterion (the Cusp clock angle should be different with the IMF's).

Cluster/C1
Mar. 4, 2002





Sketch representing **connection** of the dayside **boundary regions** reconnection to the polar cusp field lines (after Haerendel, 1978)

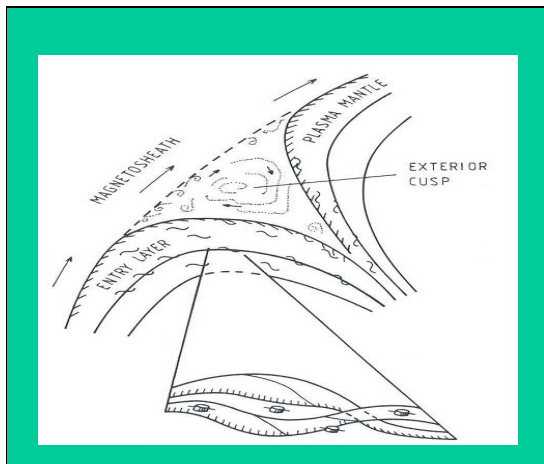
MS, magnetosheath;

PM, Plasma mantle (Rosenbauer, 1975)

LLBL, Low latitude boundary layer (after Haerendel, 1978)

EL, Entry layer (Paschmann et al., 1976)

The exterior cusp / stagnation region (Sckopke et al., 1976, Sckopke et al., 1981)



Sub-structures

Haerendel, 1982 in Cluster mission proposal

5th Cluster Anniversary and Double Star workshop, ESA, 2005



Observational features in the Cusp

- I. **Energy dispersion and reverse dispersion** (Reiff, 1977, Burch, 1982, Lockwood and Smith, 89, Iijima, 1984; Potemra et al 92, Phillips, 93), **pitch angle dispersion** [Woch and Lundin, 1992].
- II. **Energetic Particle present** (Aparicio et al., 1991; Kremser et al., 1995; Chen et al., 1997; Chang et al., 1998; Fritz et al., 1999; 2000; 2001; Trattner et al., 2001),
- III. **cusp ion steps** (Lockwood and Smith, 1992); ‘**staircase ion signatures**’
cusp structure (Escoubet et al. 1992) **and Step function** (Trattner et al., 2002, 2003)
- IV. **Trapped Electrons** (Sheldon, 1998) **and ions** (Zong et al, 2003)
- V. **$T_{\perp} > T_{\parallel}$** ---> **Mirror mode (slow mode)**, **ULF** (Lin et al., 2003),...
- VI. **Turbulent boundary layer** (Savin et al, 1998, 2003),
- VII. **Waves:** Alfvén, lower hybrid, electron and ion cyclotron waves as the most typical modes in this region of the magnetosphere (Pottelette et al., 1990, Blecki et al 1998, 1999, Menietti et al., 2002, Savin et al., 1999)
- VIII. **Cusp-Magnetosheath Interface** [Lavraud et al., 2002, Zong et al, 2004, Dunlop et al , 2004].
- XI. **Magnetosphere-Ionosphere Coupling** [Cowley, 82, Lockwood et al, 93]
- X. **FTE & Flux ropes** (Haerendel et al, 1978, Zong et al, 2003, Pu et al, 2004)
- XI. **Reverse Convection (Sunward flow)** (Gosling, 91; Lu et al, 1994, Kessel, 96, Phan et al, 03)
- XII. **Cusp proton aurora** (Fuselier 02, Frey 02, 03, Zong, et al, 04)
- XIII. **The location related to IMF B_y** (Gosling et al, 91; Cowley et al, 91 and many others) **and IMF B_x** (Cowley et al, 91), **Solar Wind Dynamic pressure** (Russell, 00), **Azimuthal flow** (Lundin et al, 01, Zong et al 04)
- XIV. **Cusp Field-aligned Current** (Iijima, 1984; Potemra et al., 1992; Vennerstrom et al, 2002)



Problems

- What's the **nature of the boundaries** between different regions?
- What's the **plasma transport mechanism** through the cusp and the boundary layers?
- Are the observed double or triple cusps **temporal or spatial effect**? How are they formed?
- What's the **role of the cusps in supplying plasma to the plasma sheet**?



1. Particle Aspect of the Cusp

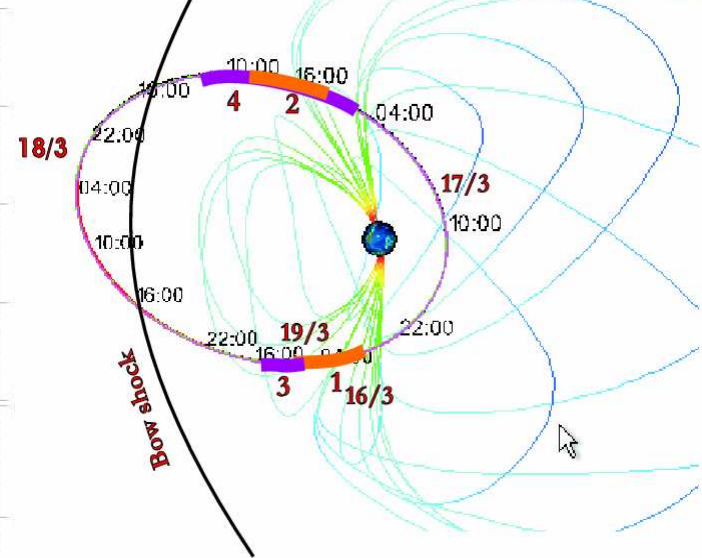
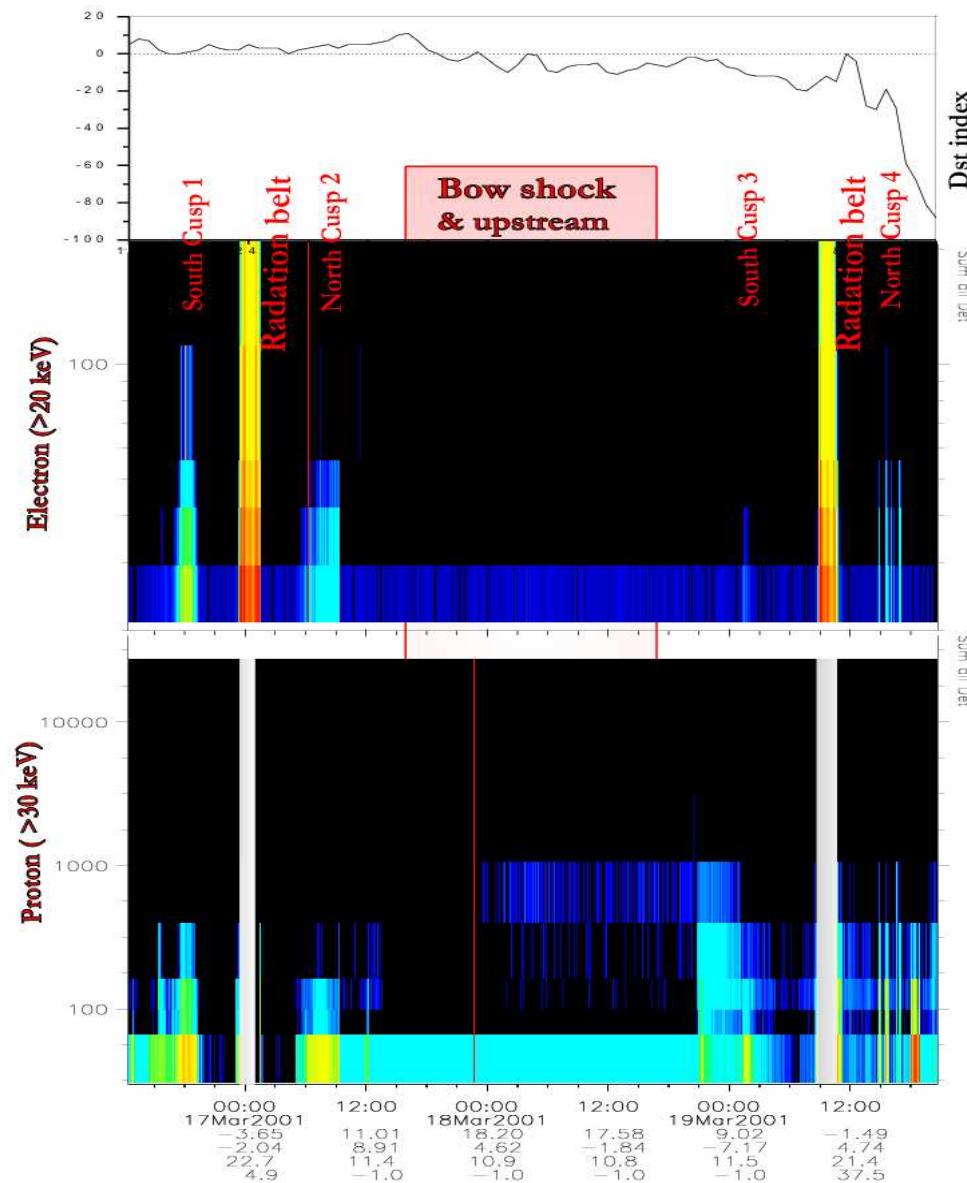
2. Interface between the Cusp and the MSH

3. Multiple-cusp Events



Cusp: Particle description

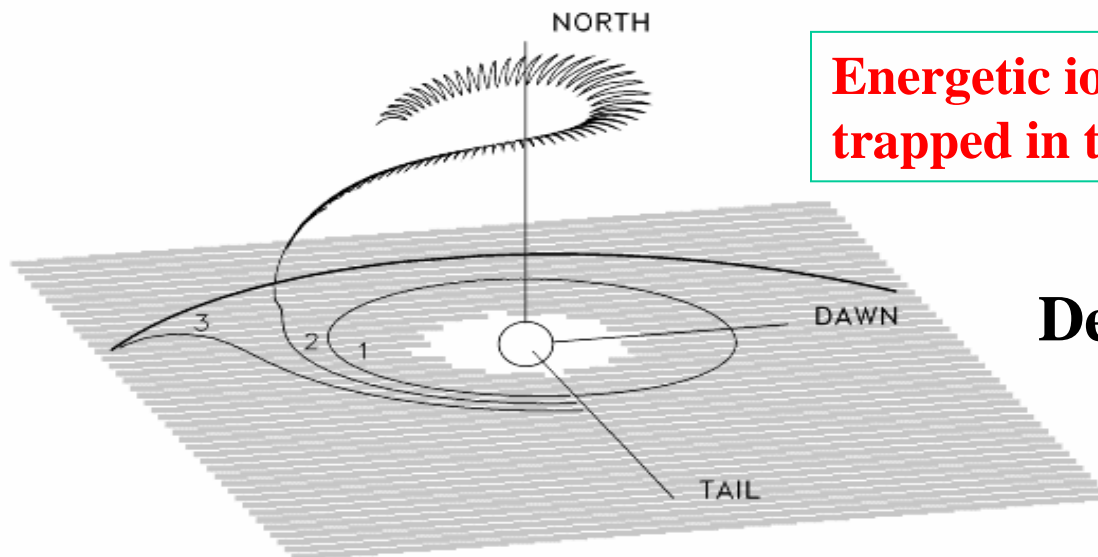
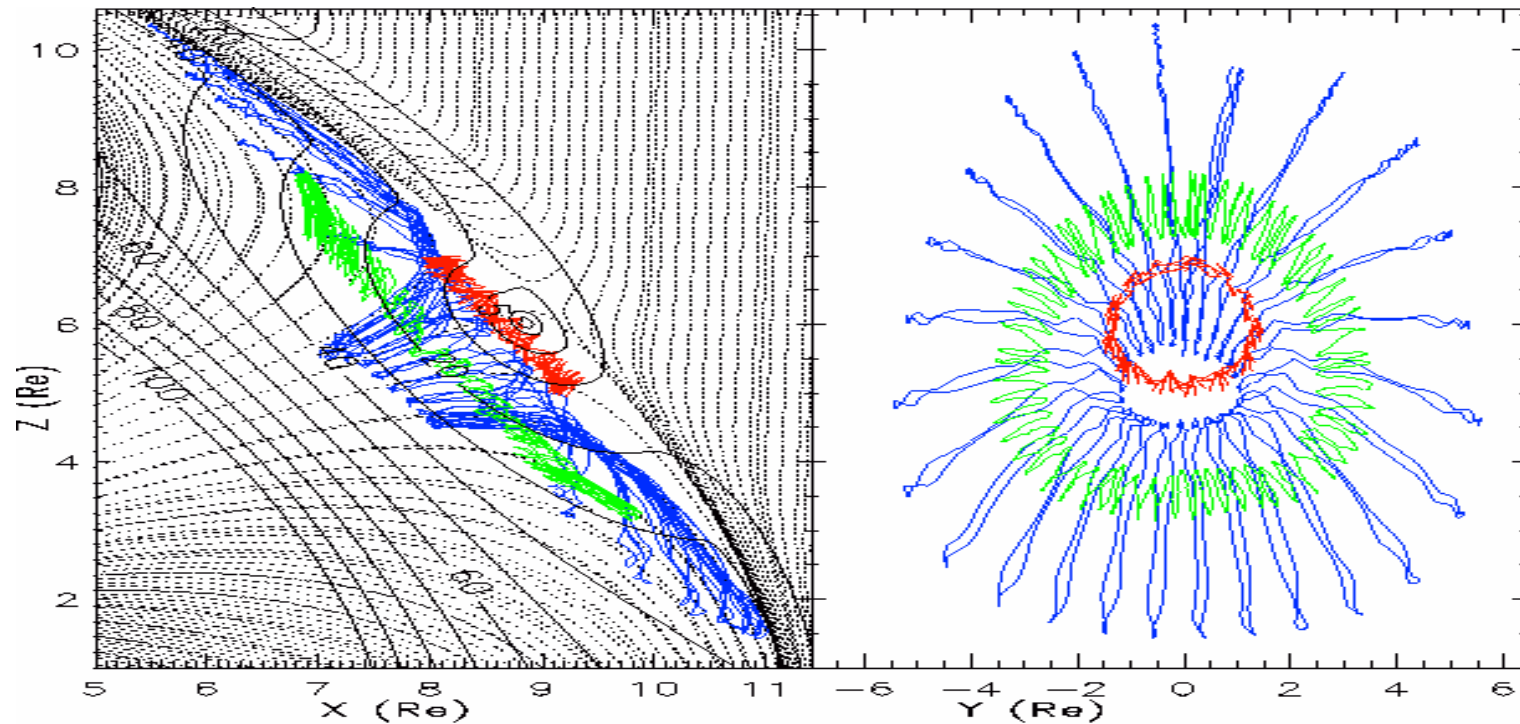
Energetic electron and ion measurements in two completed orbit



- | | | | |
|---|-------------------|-----------------|----------|
| 1 | 16/3 17h00-19h10m | South HLBL/Cusp | quiet |
| 2 | 17/3 06h00-09h20m | North HLBL/Cusp | quiet |
| 3 | 19/3 01h00-02h30m | South HLBL/Cusp | activity |
| 4 | 19/3 14h50-19h00m | North HLBL/Cusp | activity |



Cusp: Particle description



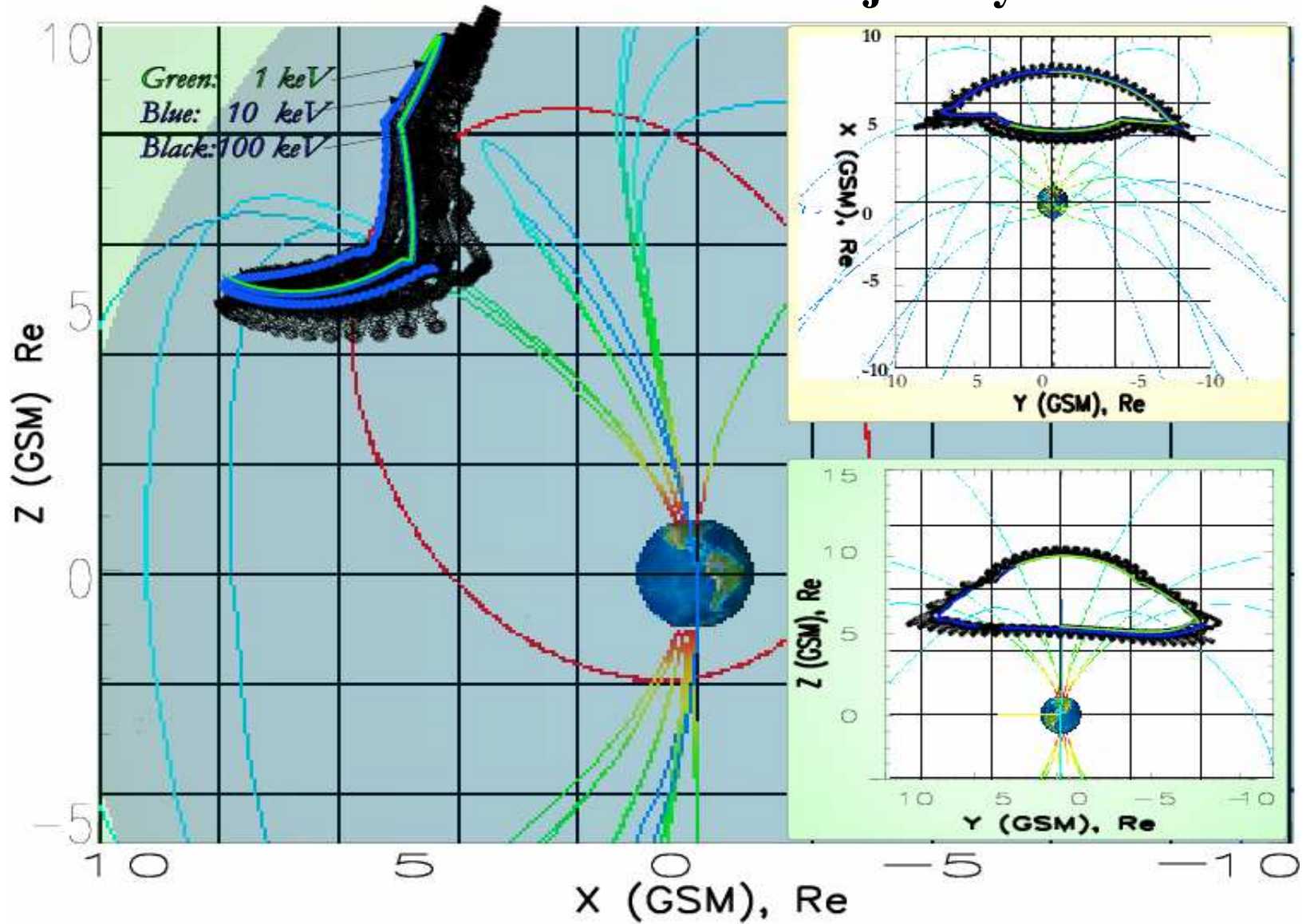
Energetic ions can be temporally trapped in the B-min region.

Delcout et al 98,99



Cusp: Particle description

Ion's trajectory



Zong et al, 2005
Survey in
Geophysics



5th Cluster Anniversary and Double Star workshop, ESA, 2005



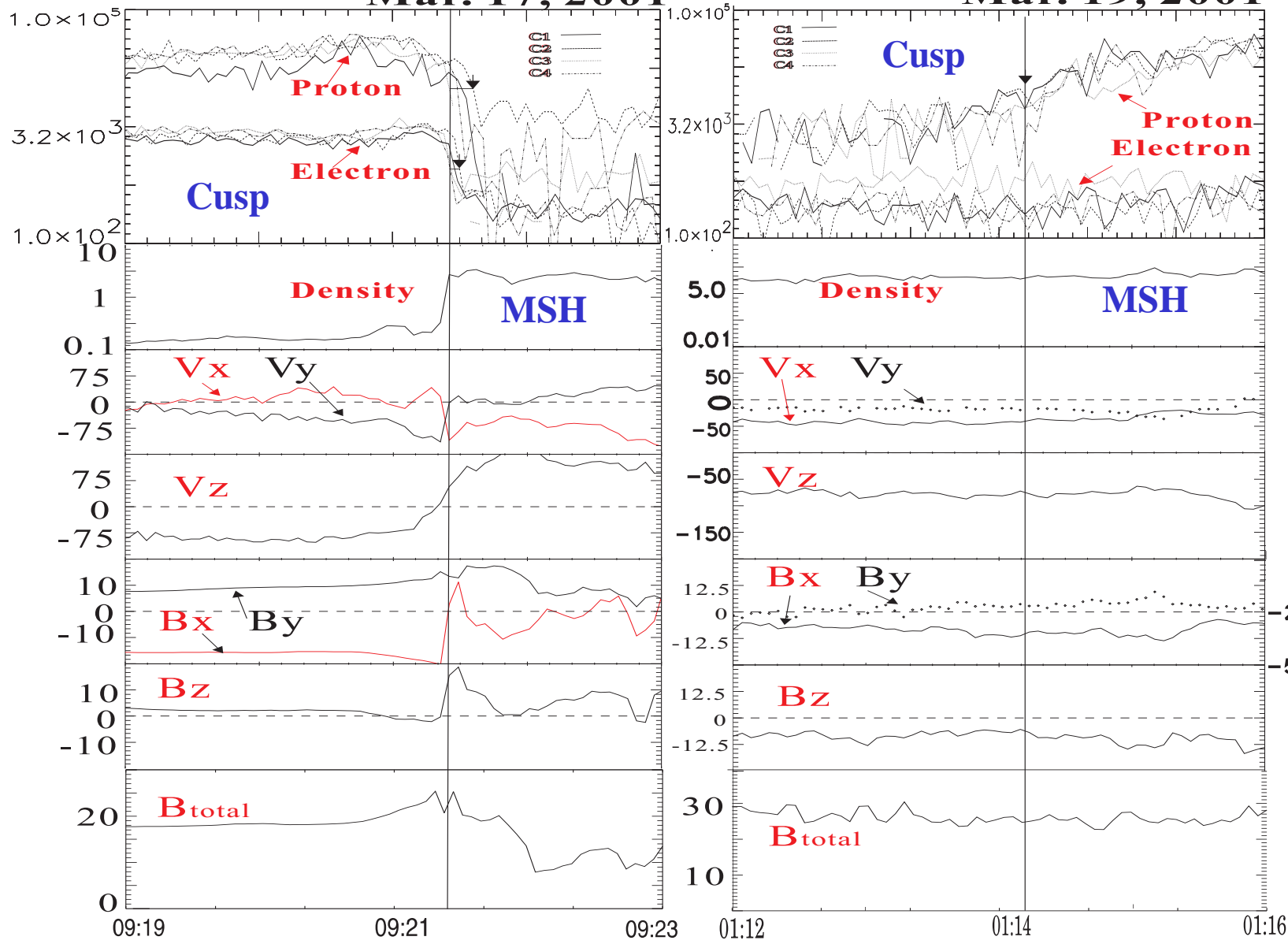
Clear

Interface between
the cusp and MSH.

Unclear

Mar. 17, 2001

Mar. 19, 2001

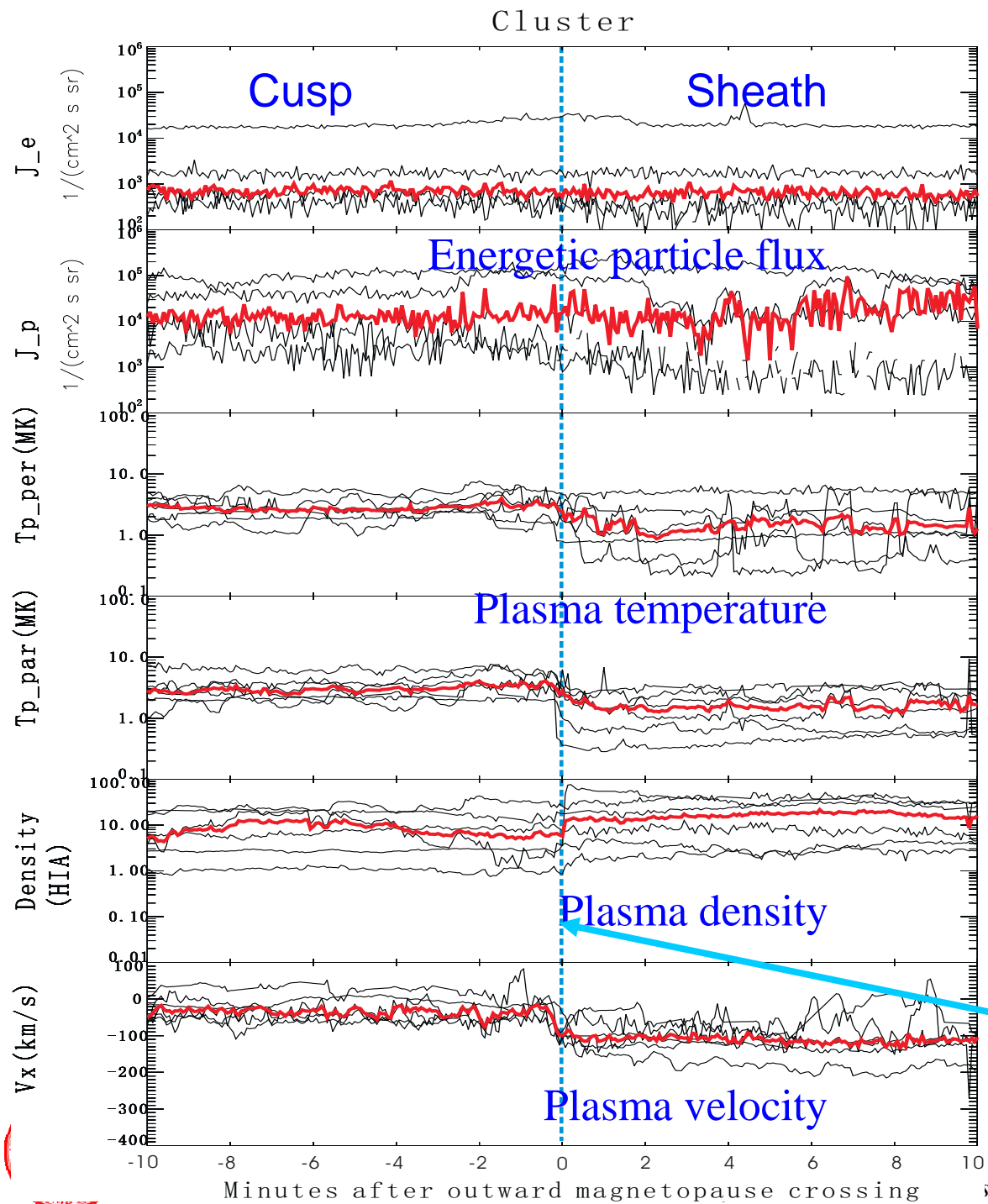


Zong et
al,
Survey in
Geophys.
2005

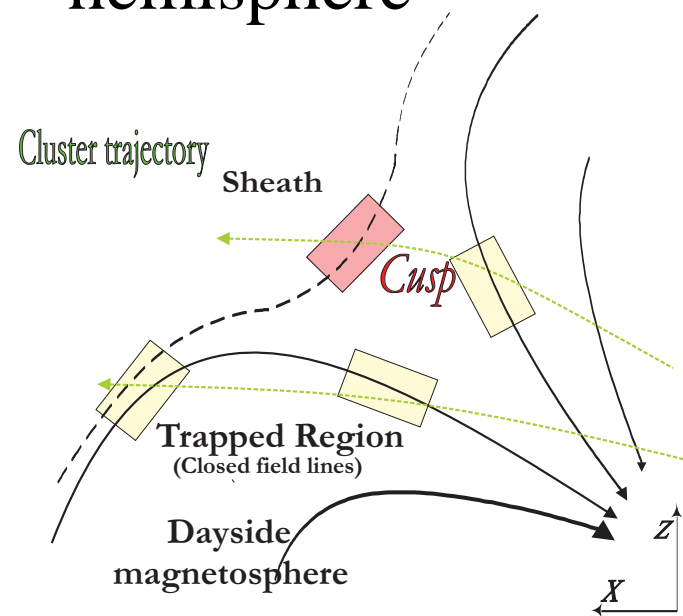
TIME (UT)

5th Cluster Anniversary and Double Star workshop, ESA, 2005





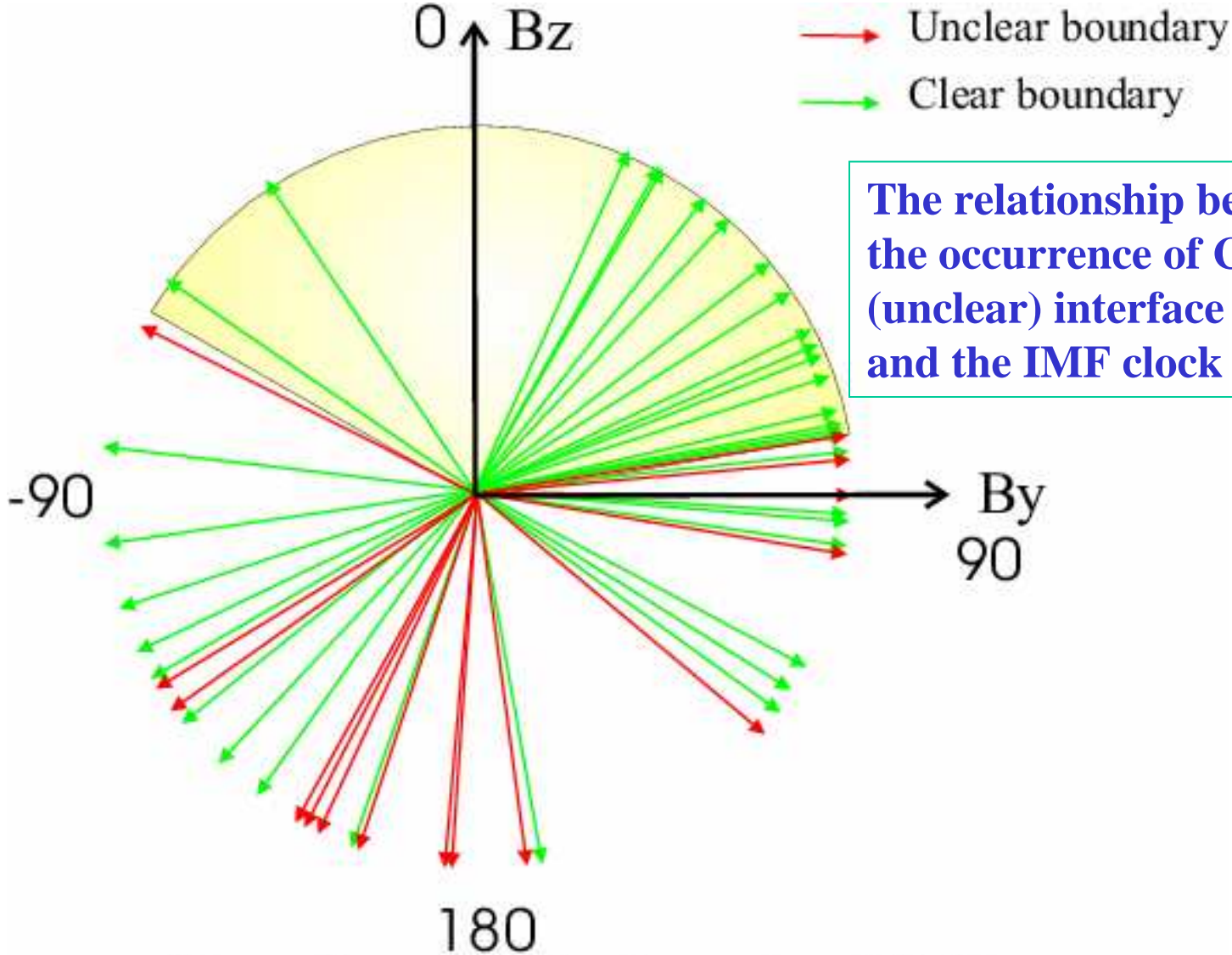
Superposed epoch analysis under northward IMF in northern hemisphere



Magnetopause

shop, ESA, 2005



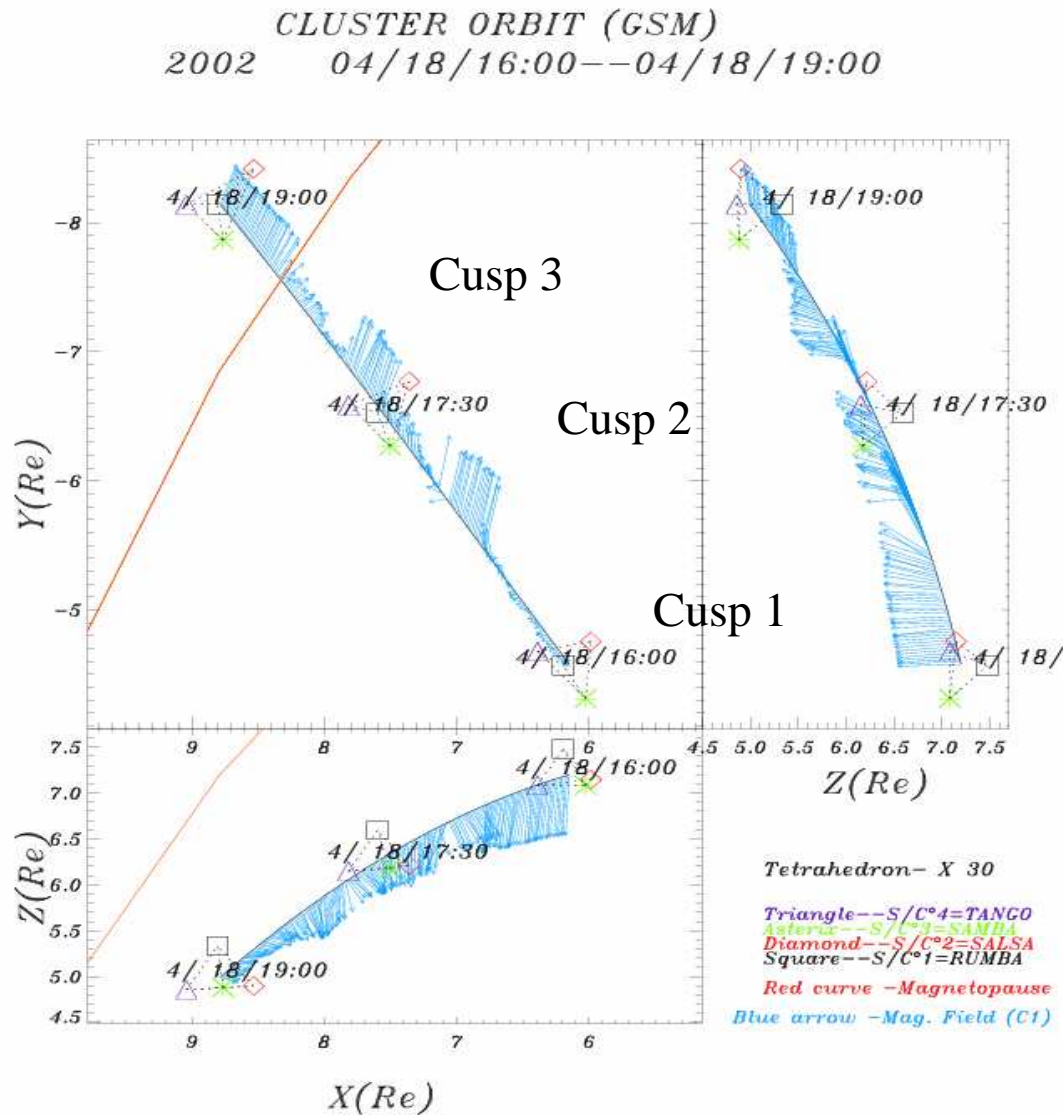


The relationship between the occurrence of Clear (unclear) interface and the IMF clock angle.

Boundary and clock angle of IMF



Triple cusps on April 18, 2002

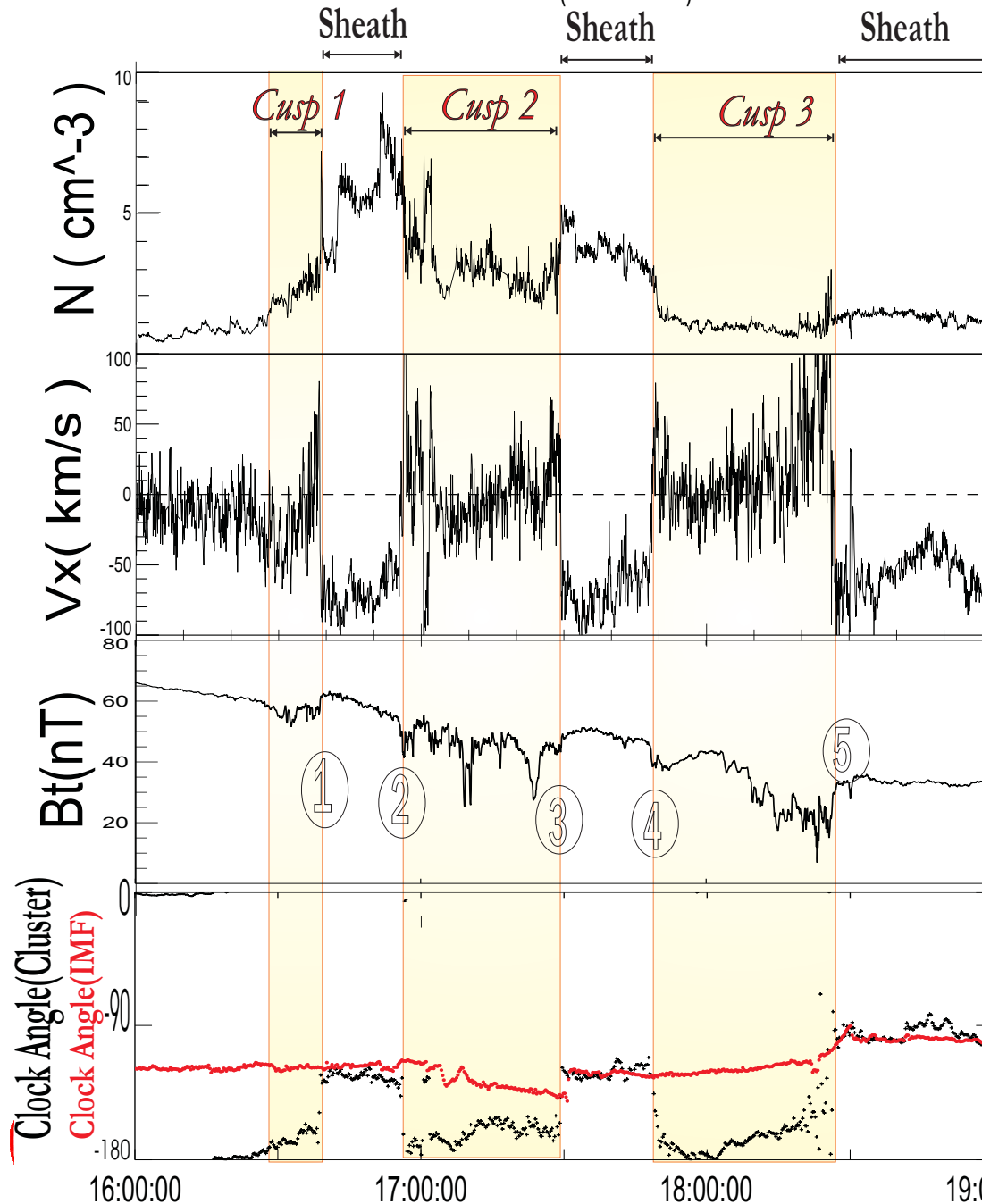


Magnetopause Crossing Order

| No. | Cluster Order | Comment |
|-----|-------------------|------------------------|
| 1 | C4-->C1-->C2-->C3 | Cusp to Sheath |
| 2 | C3-->C2-->C1-->C4 | Sheath to Cusp |
| 3 | C4-->C1-->C2-->C3 | into Sheath again |
| 4 | C3-->C2-->C1-->C4 | back to Cusp again |
| 5 | C4-->C1-->C2-->C3 | into Sheath third time |

Cluster C1

4/18/2002 (DOY : 108)



New Observations by Cluster

On April 18, 2002, the Cluster spacecraft were outbound in the northern journey towards the pole and entered the cusp.

1. The cusp-like region was observed consecutively three times from 1620 to 1830 UT by all four Cluster Spacecraft

2. the solar wind dynamic pressure was small and stable.

3. All three cusp encounters are characterized by

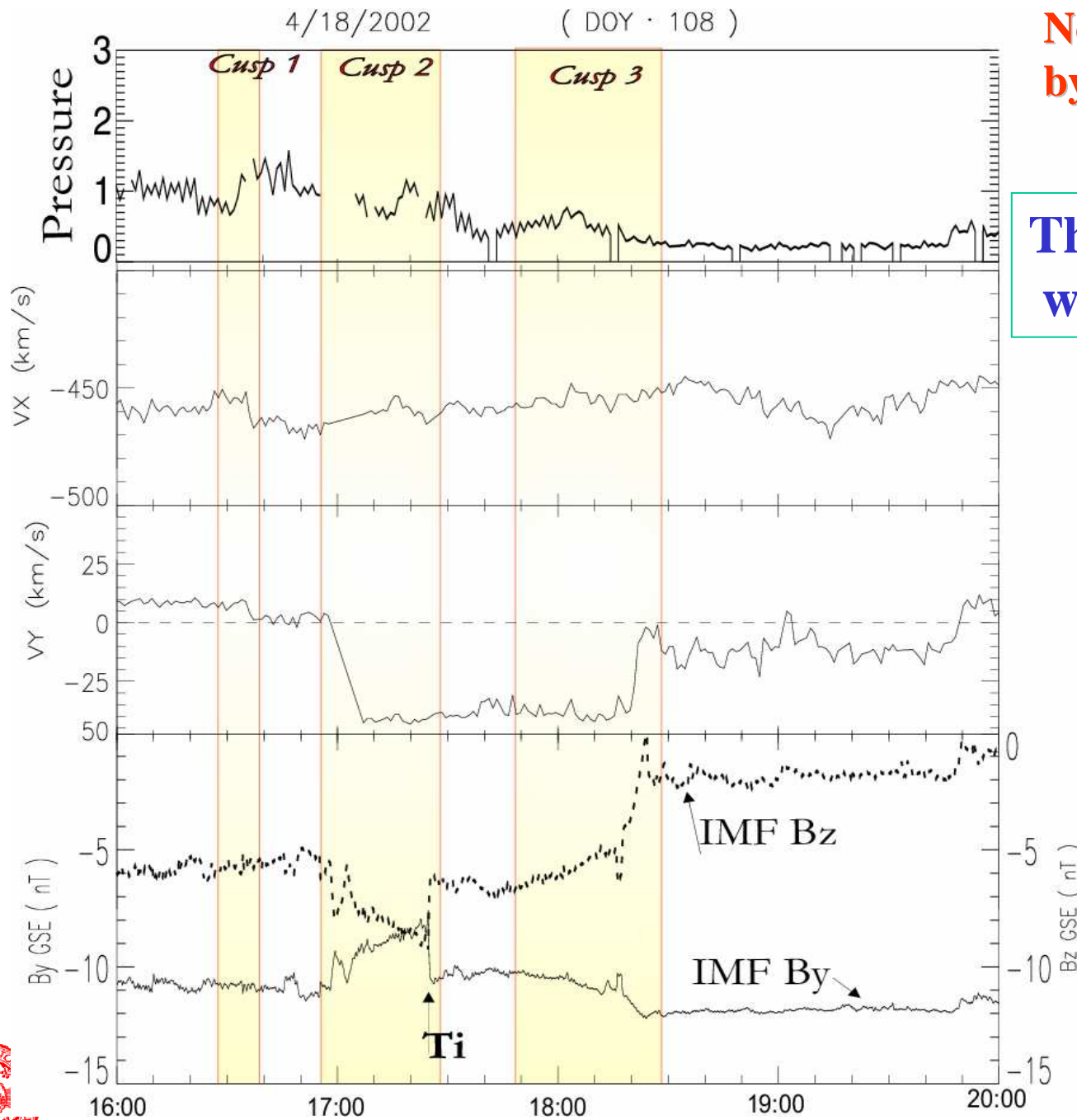
- I. turbulent magnetic fields,
- II. high density plasma
- III. stagnant plasma flow.
- IV. clock angle criterion.



New Observations by Cluster

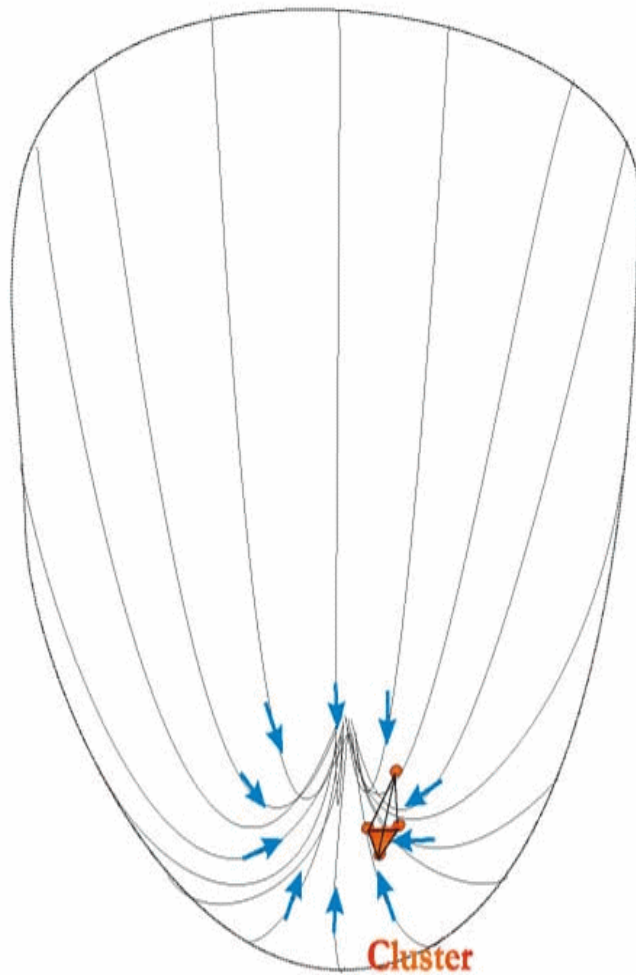
The related solar
wind conditions

Solar wind **driver**
of the
magnetospheric
wind-sock model
(Zong *et al*, 2004
GRL)



5th Cluster Anniversary and Double Star workshop, ESA, 2005



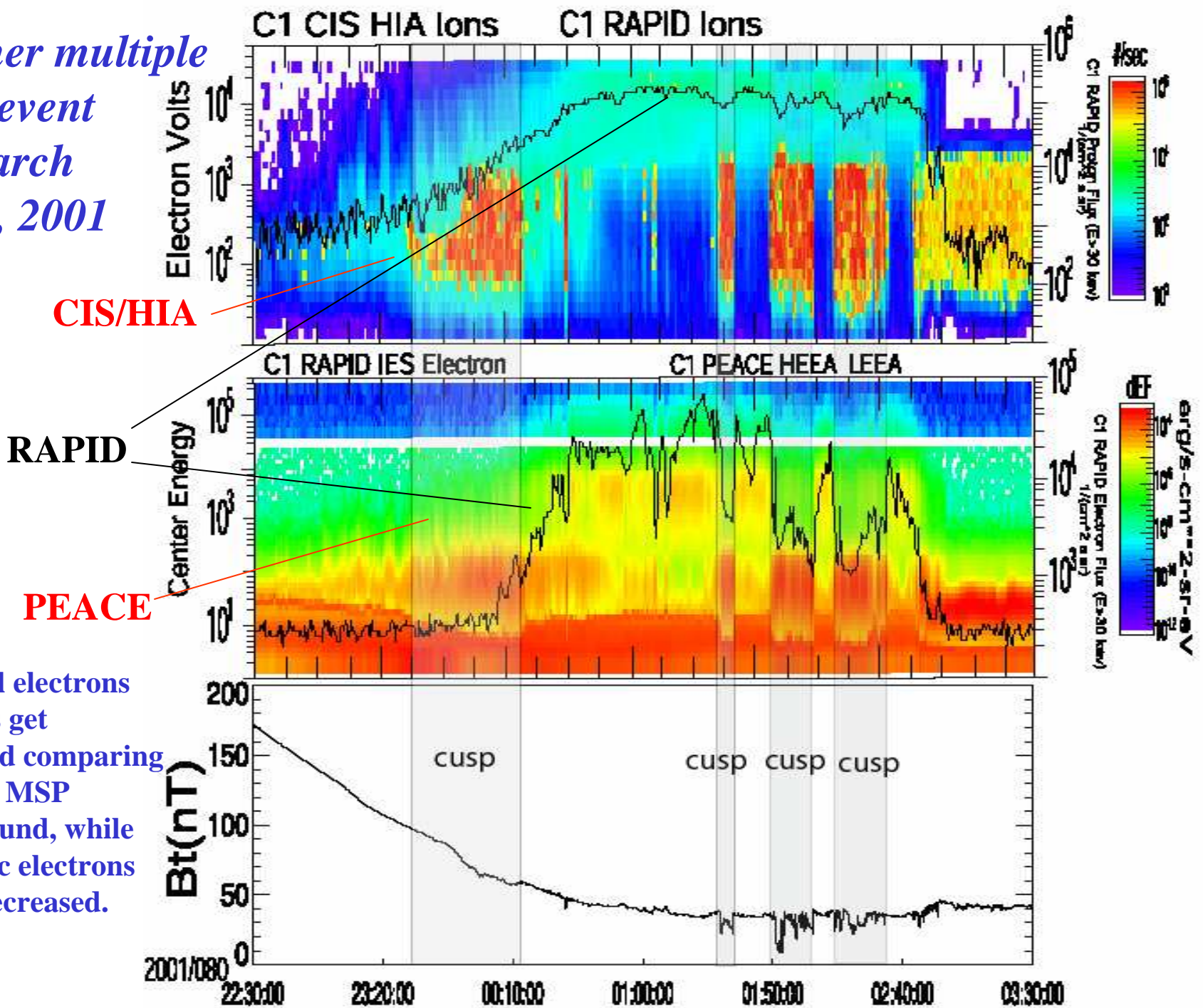


Solar wind V
 V_y V_x

| | $\Phi N(^{\circ})$ | $\theta N(^{\circ})$ | N |
|---|-------------------------|----------------------|-----------------------|
| | λ_2 / λ_3 | | |
| 1 | -28 | 1 | (0.89 -0.46 0.01) 2.5 |
| 2 | -28 | 1 | (0.88 -0.47 0.01) 5.4 |
| 3 | -28 | 6 | (0.87 -0.47 0.11) 5.8 |
| 4 | -20 | 4 | (0.94 -0.35 0.07) 1.8 |
| 5 | -26 | 6 | (0.89 -0.44 0.11) 5.5 |



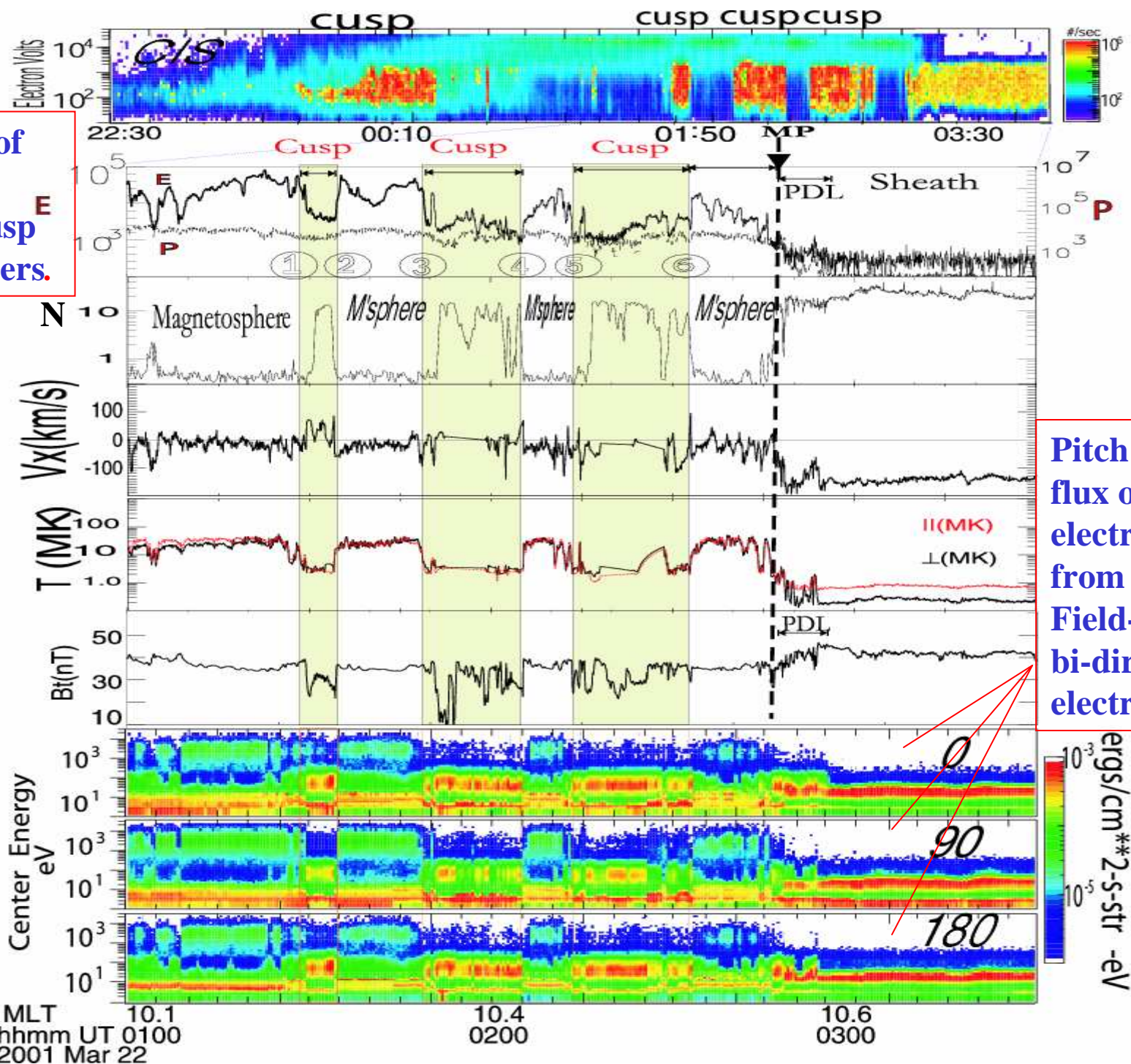
*Another multiple
Cusp event
on March
21-22, 2001*



Thermal electrons
and ions get
increased comparing
with the MSP
background, while
energetic electrons
(ions) decreased.



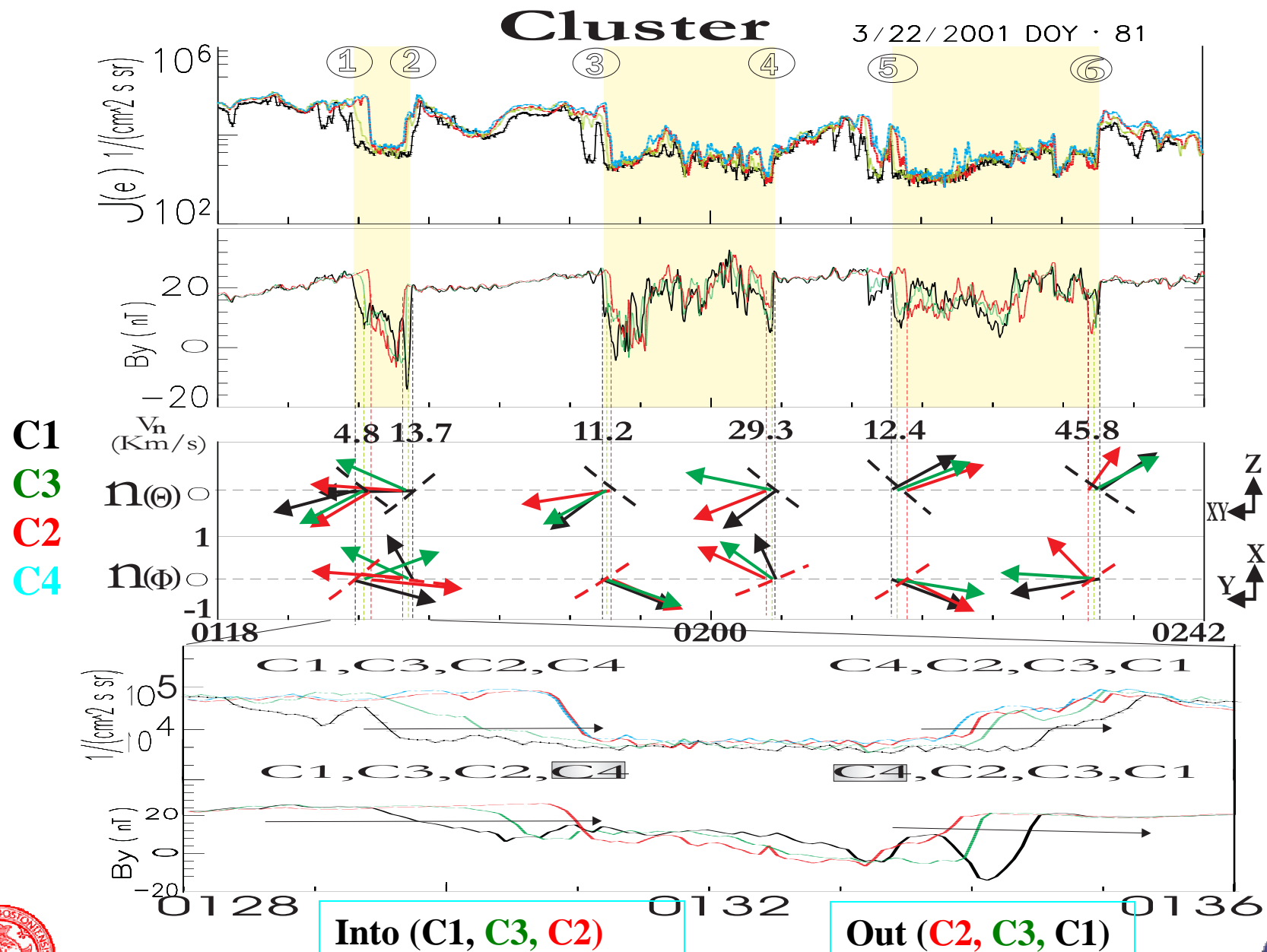
Details of
the last
three cusp
encounters.



Pitch angle
flux of
electrons
from PEACE.
Field-aligned
bi-directional
electrons.



The interface crossing of the last 3 cusp encounters

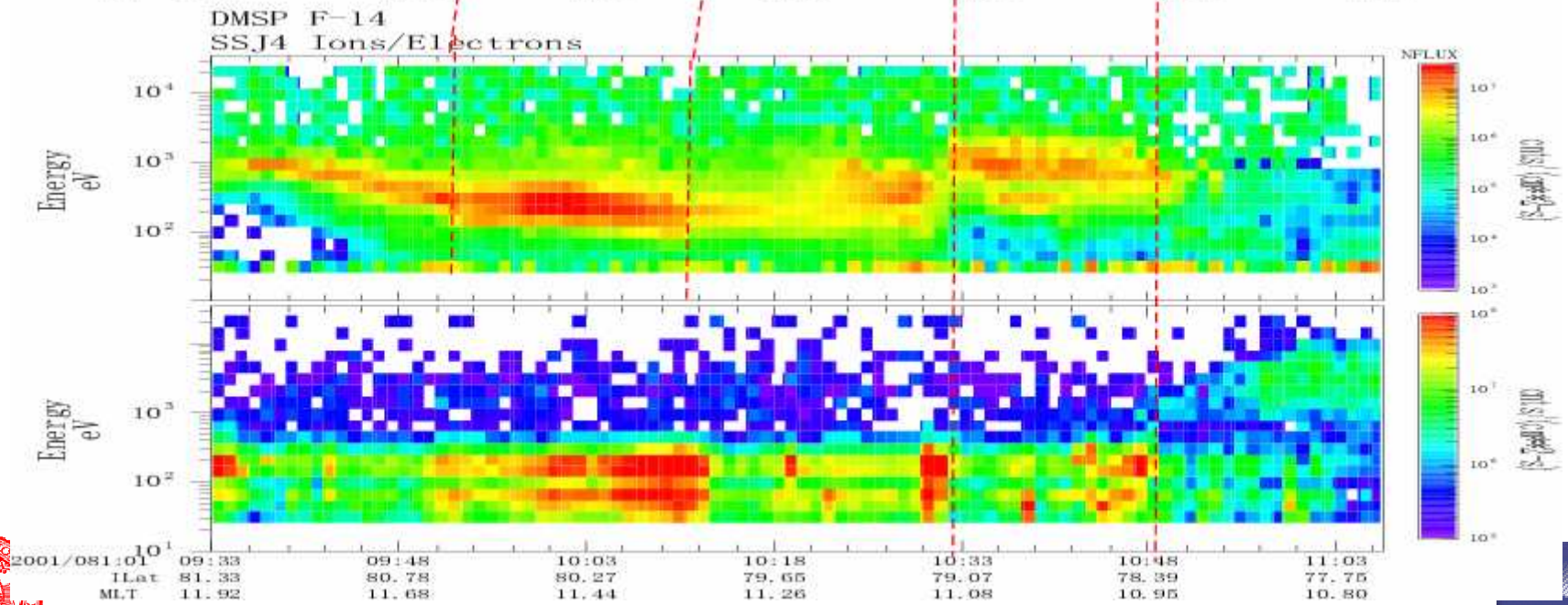
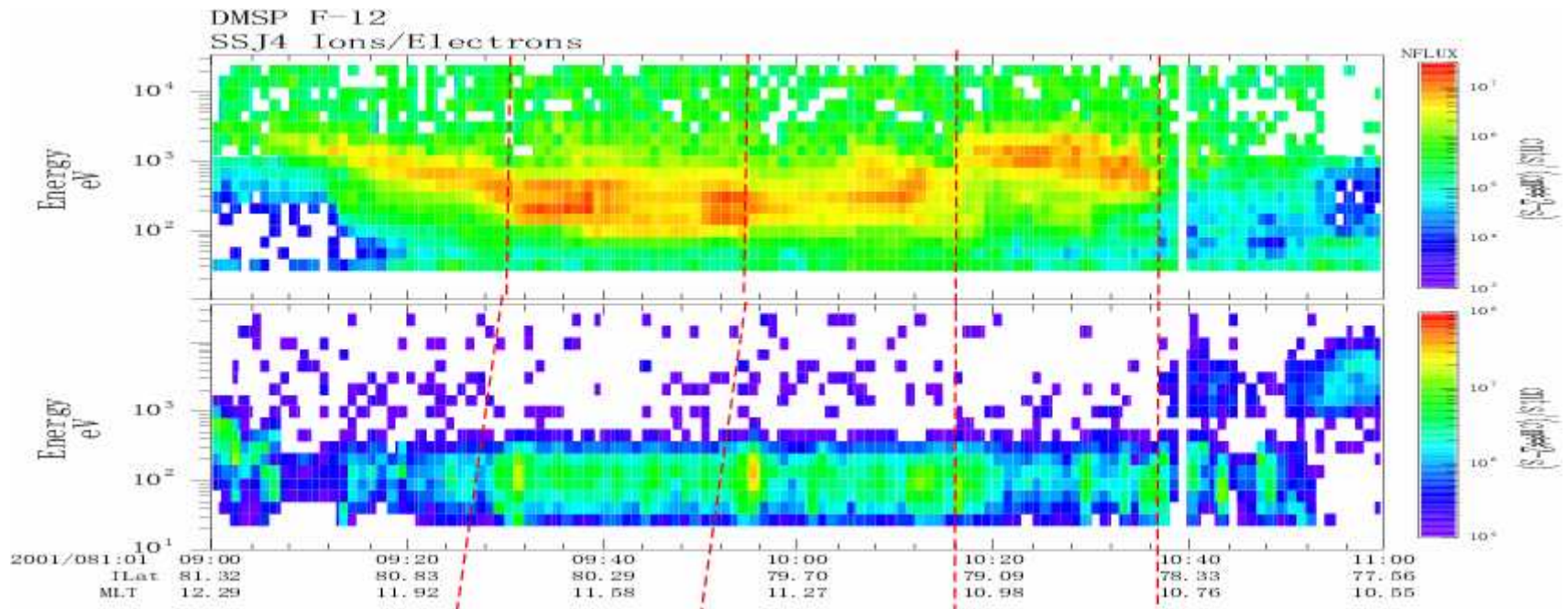


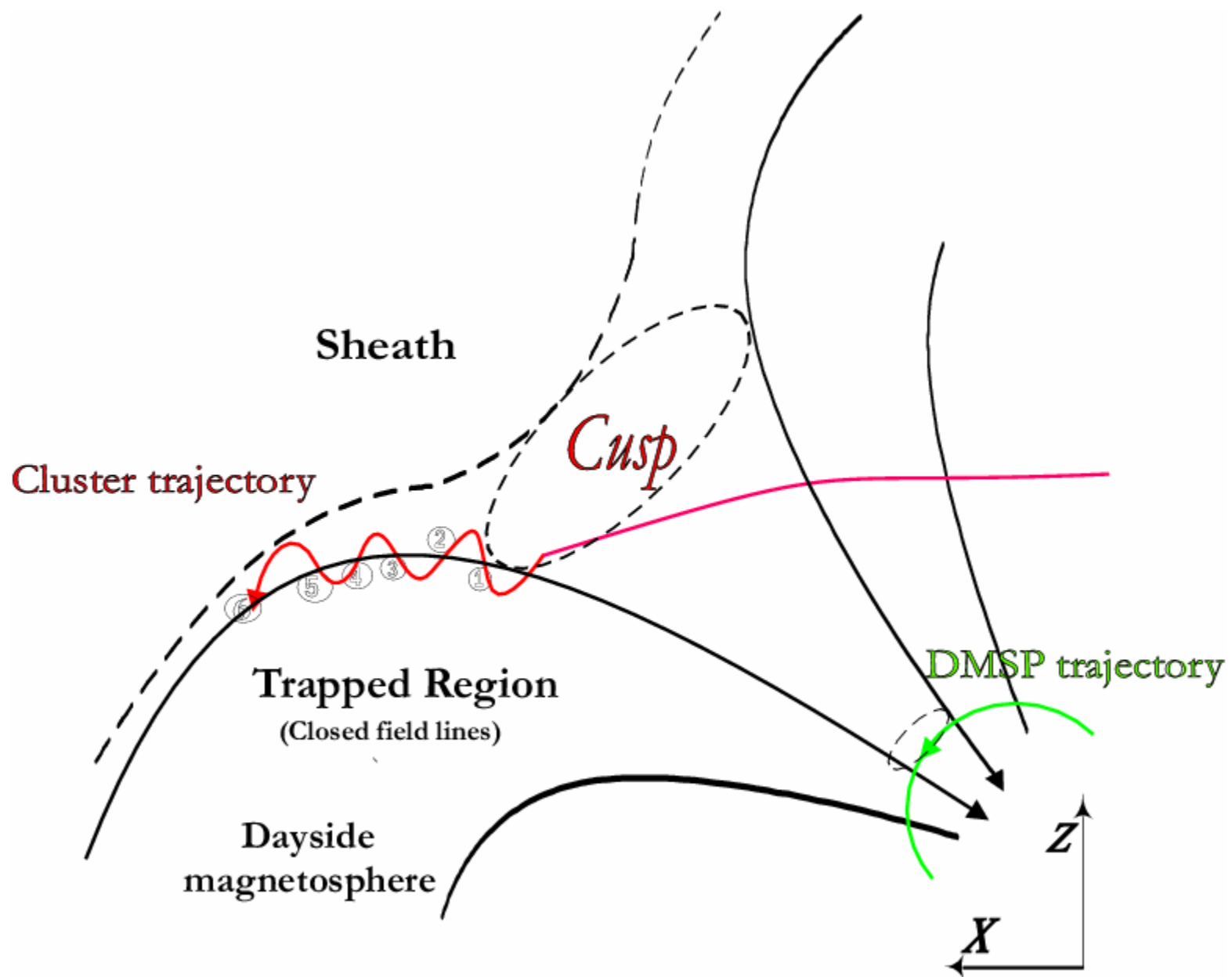
The spacecraft positions relative to the interface

C2 **C3** **C1** \Leftarrow **Cusp**
(Leading edge)

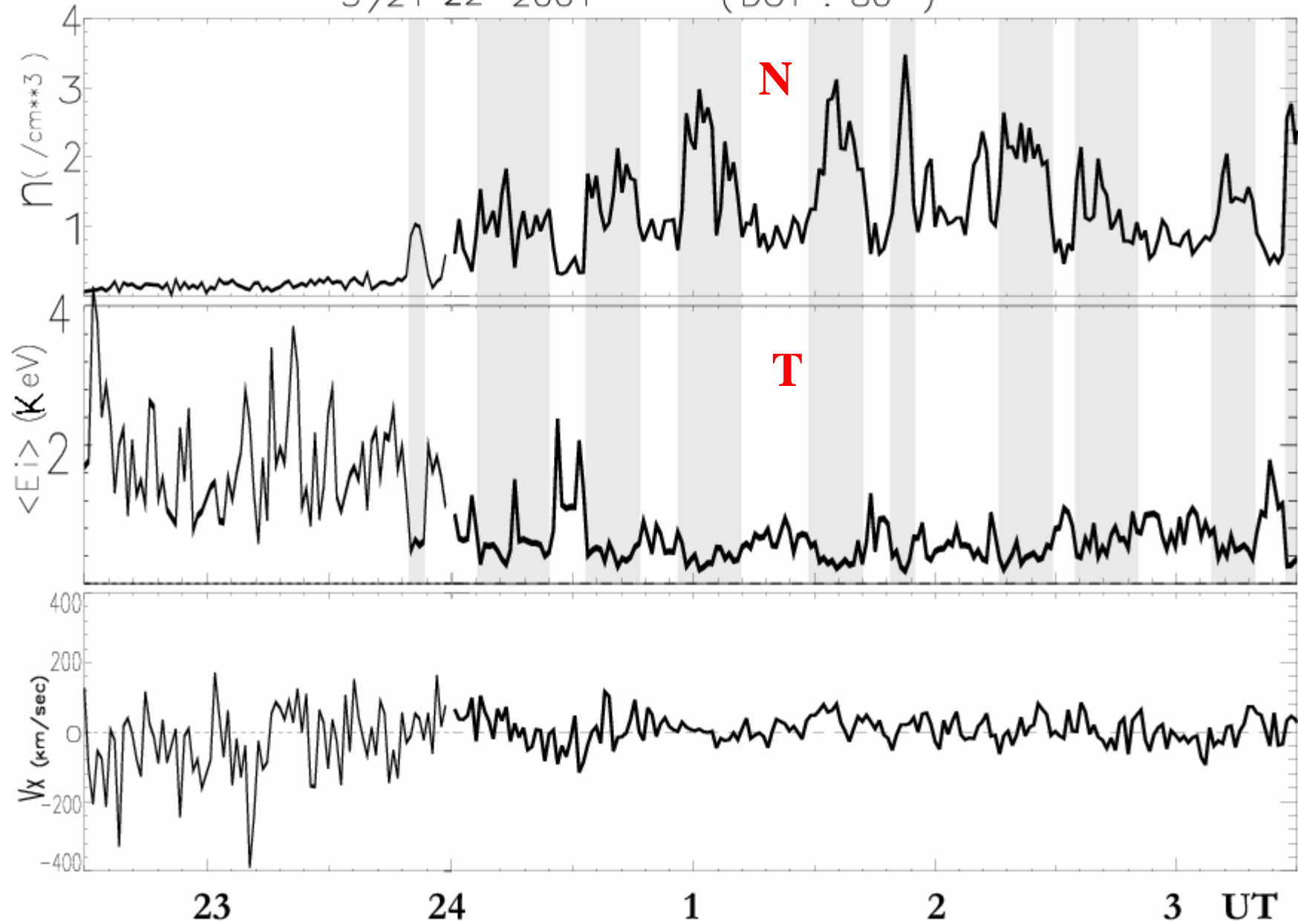
Cusp \Rightarrow **C2** **C3** **C1**
(Back edge)



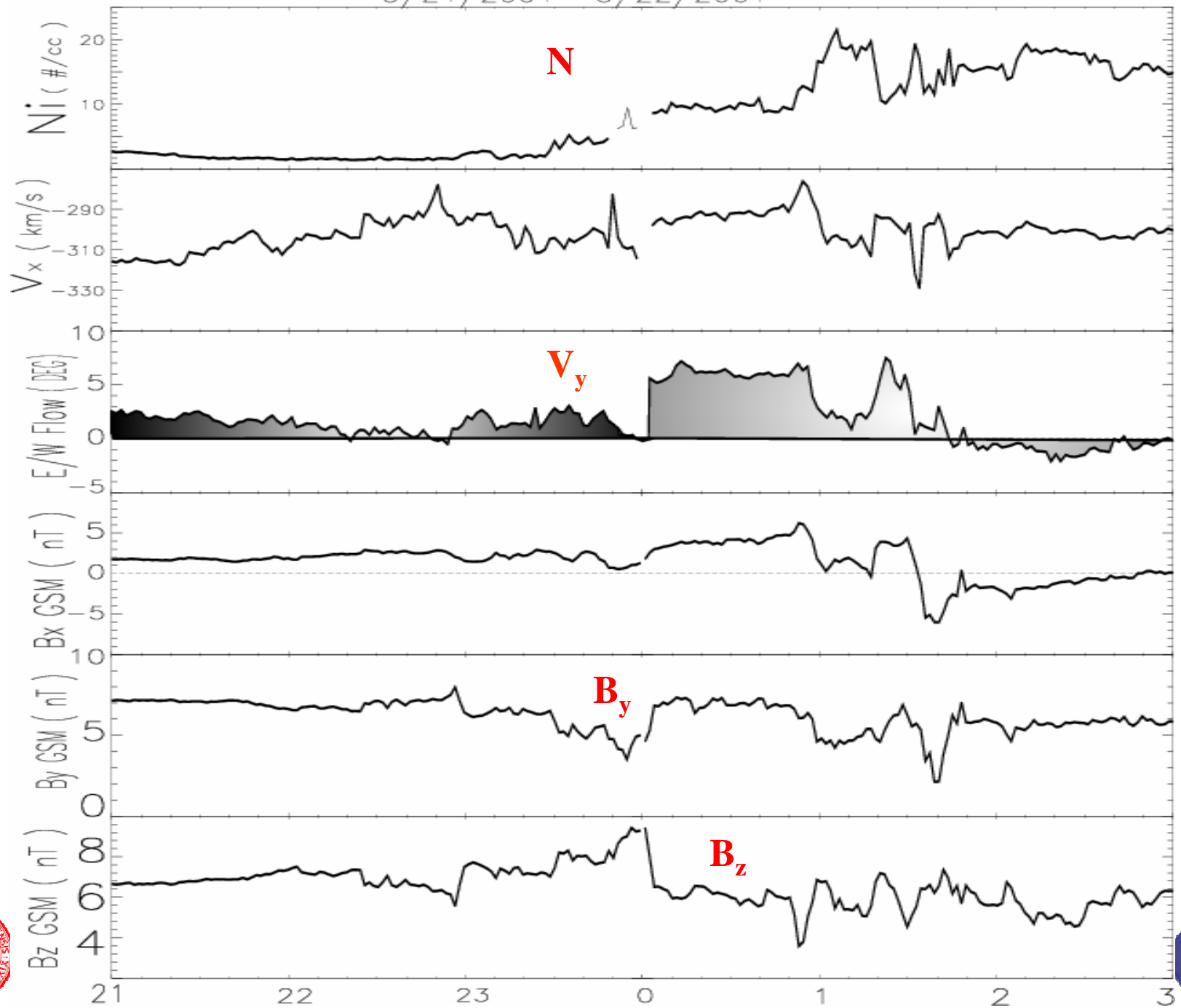




GEOTAIL / Comprehensive Plasma Instrumentation
3/21-22 2001 (DOY : 80)



WIND / Solar Wind Experiment
3/21/2001 – 3/22/2001



Conclusions(1)

- Energetic ion could be temporally trapped in the High Latitude/Cusp Region whereas electron could not be.
- In the 94 high latitude boundary crossings, 66% have clear boundaries, 16% have unclear boundaries and 18% have partly clear boundaries.
- When the **IMF is northward**, all the **boundaries are clear**.



Conclusions (2)

- The observed multiple cusps may be either explain as the funnel-shaped cusp bifurcated or swiveled into a complicated geometry in space or the cusp was shifted position back and forth three times in about two hours interval as if Cluster flew through the cusp three times.
- The observed triple cusps prefer a temporal sequence rather than a spatial effect.
- Further we suggest that the solar wind azimuthal flow is the controlling factor of the cusp position and is as strong as, potentially even stronger than, that of the IMF B_y/B_z component. The importance of the solar wind azimuthal and north/south flow as a dynamic driver of the cusp, and even the whole magnetosphere has been more or less neglected or underestimated.

