The Magnetospheric Cusp: Structure and Dynamics

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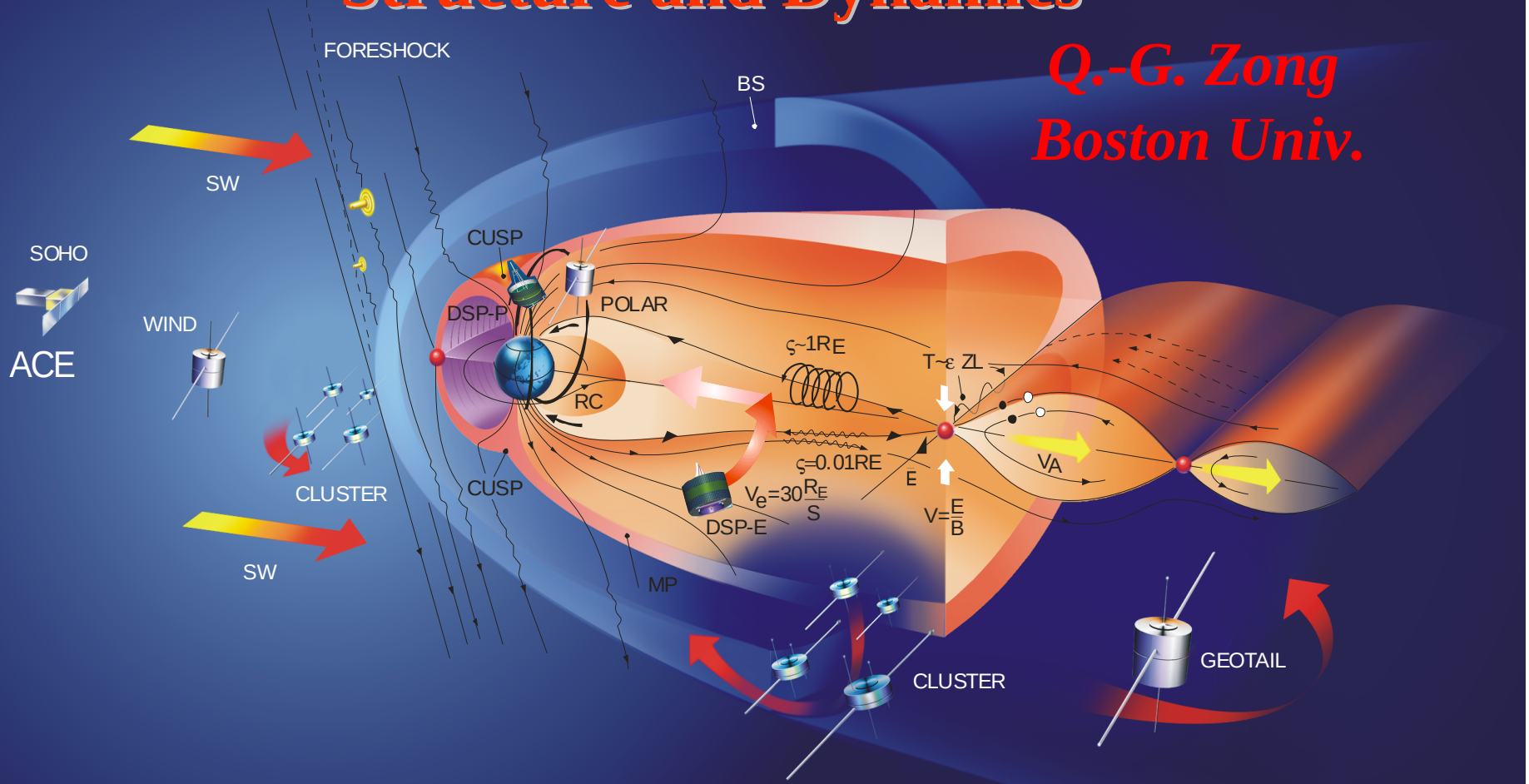


T. A. Fritz, Z.Y. PU, H. Zhang, S.Y. Fu, J.B Cao, M. Dunlop, A. Korth, M. Goldstein, D.Winningham, P. W. Daly, A. N. Fazakerley, H. Reme

Outline

1. Brief Introduction: Cusp

2. Particle Aspect of the Cusp

3. Boundary Layers

4. Multiple and Dynamics Cusp

Brief History

- ***~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 magnetitude 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):

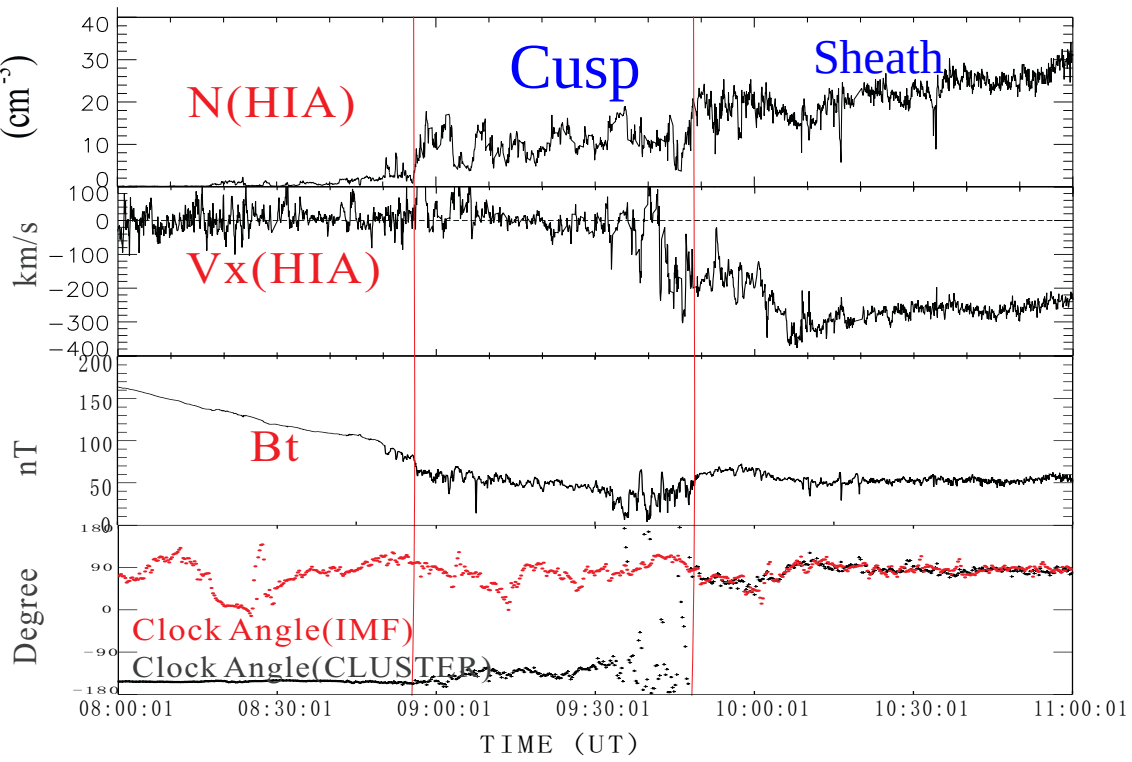
@ the high latitude region

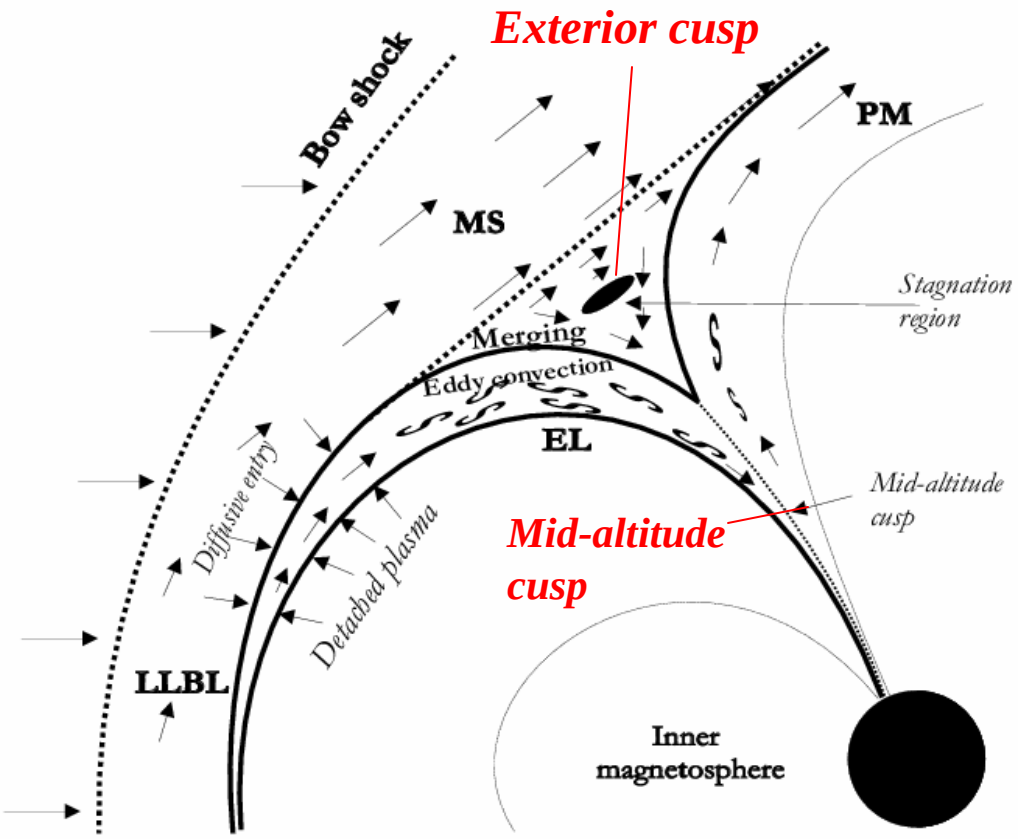
I. turbulent and depressed magnetic fields,

II. high density plasma (~ sheath level),

III. stagnant plasma flow (Vx ~ 0),

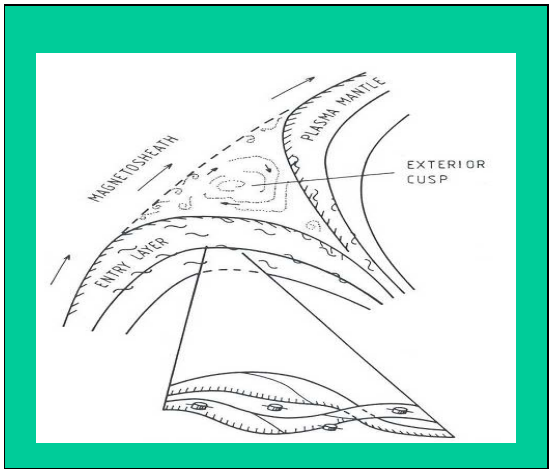
IV. clock angle criterion (the Cusp clock angle should be different with the IMF's).





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***

Observational features in the Cusp

I. ***Energy dispersion and reverse dispersion*** *(Reiff,1977, Burch,1982,Lockwood and Smith,89, Iijma,1984;Potemra et al 92,Phillips,93),* **pitch angle dispersion** *[Woch and Lundin, 1992].*

II. ***Energetic Particle present*** *(Aparcio 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. ***$T_{\perp} > T_{//}$ ---> Mirror mode (slow mode), ULF (****Lin et al.,, 2003****),…***

VI. ***Turbulent boundary layer*** ***(****Savin et al, 1998, 2003****) ,***

VII. ***Waves:*** **Alfven, 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, Frey02, 03, Zong, et al, 04)*

XIII. ***The location*** ***related to IMF By*** *(Gosling et al, 91; Cowley et al, 91 and many others)* ***and IMF Bx*** *(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*** ***(Iijma,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**?

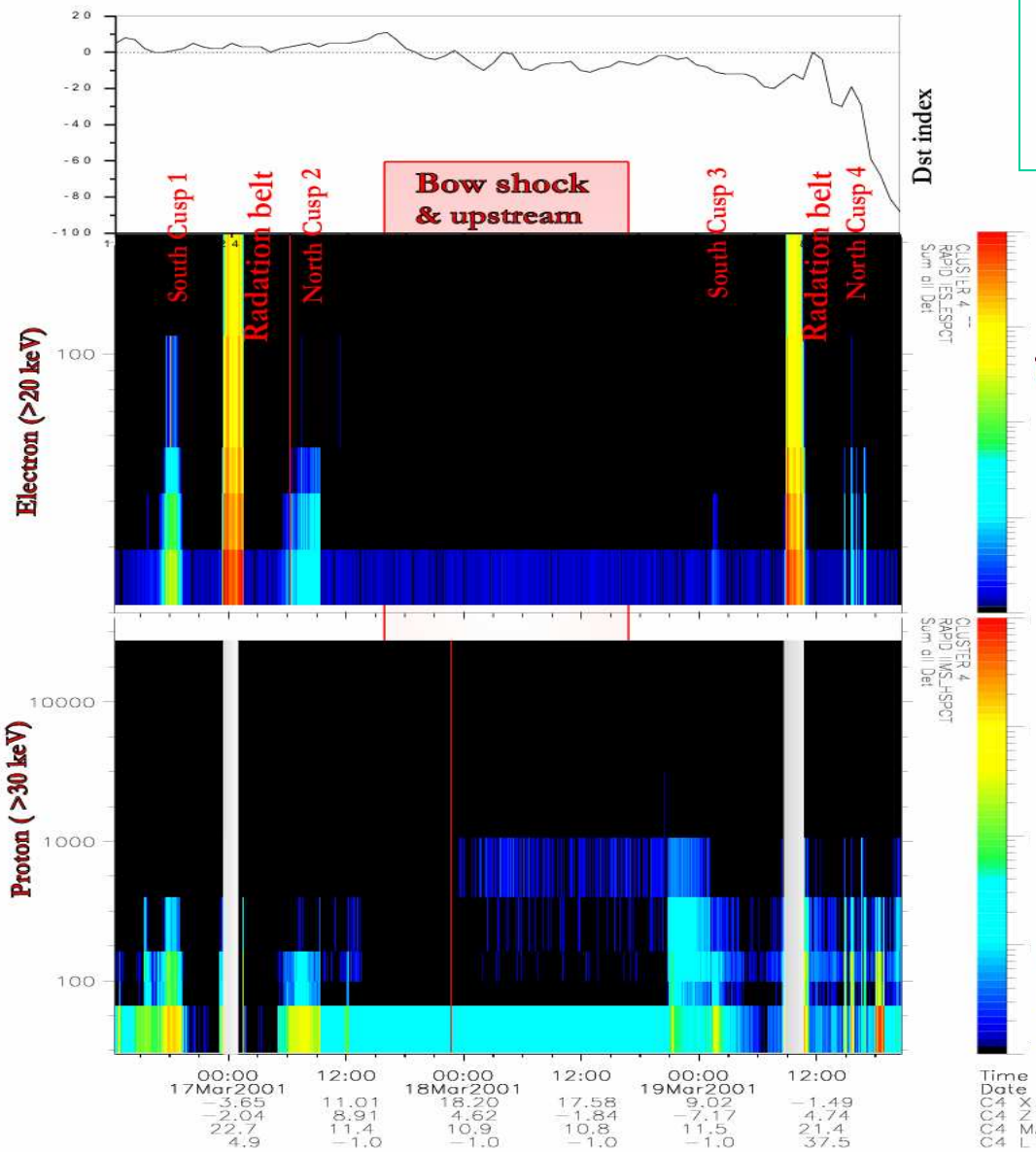
1. Particle Aspect of the Cusp

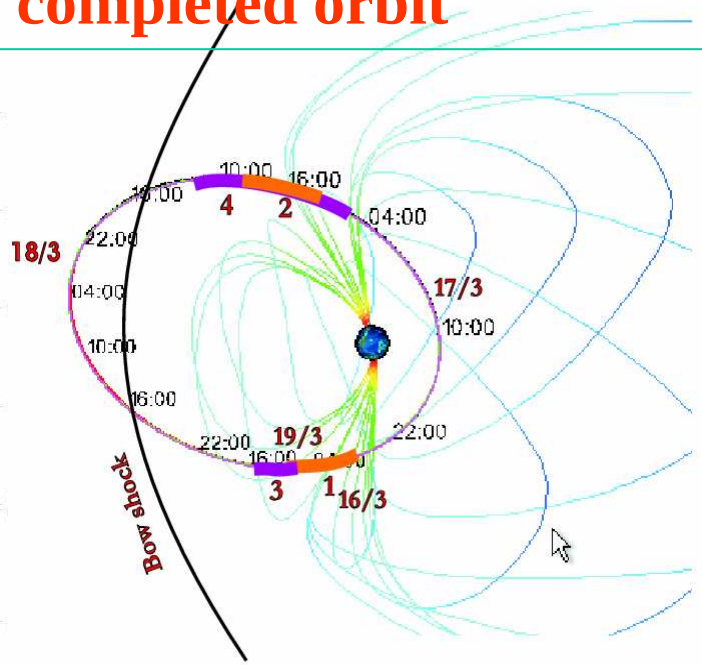
2. Interface between the Cusp and the MSH

3. Multiple-cusp Events

Cusp: Particle description

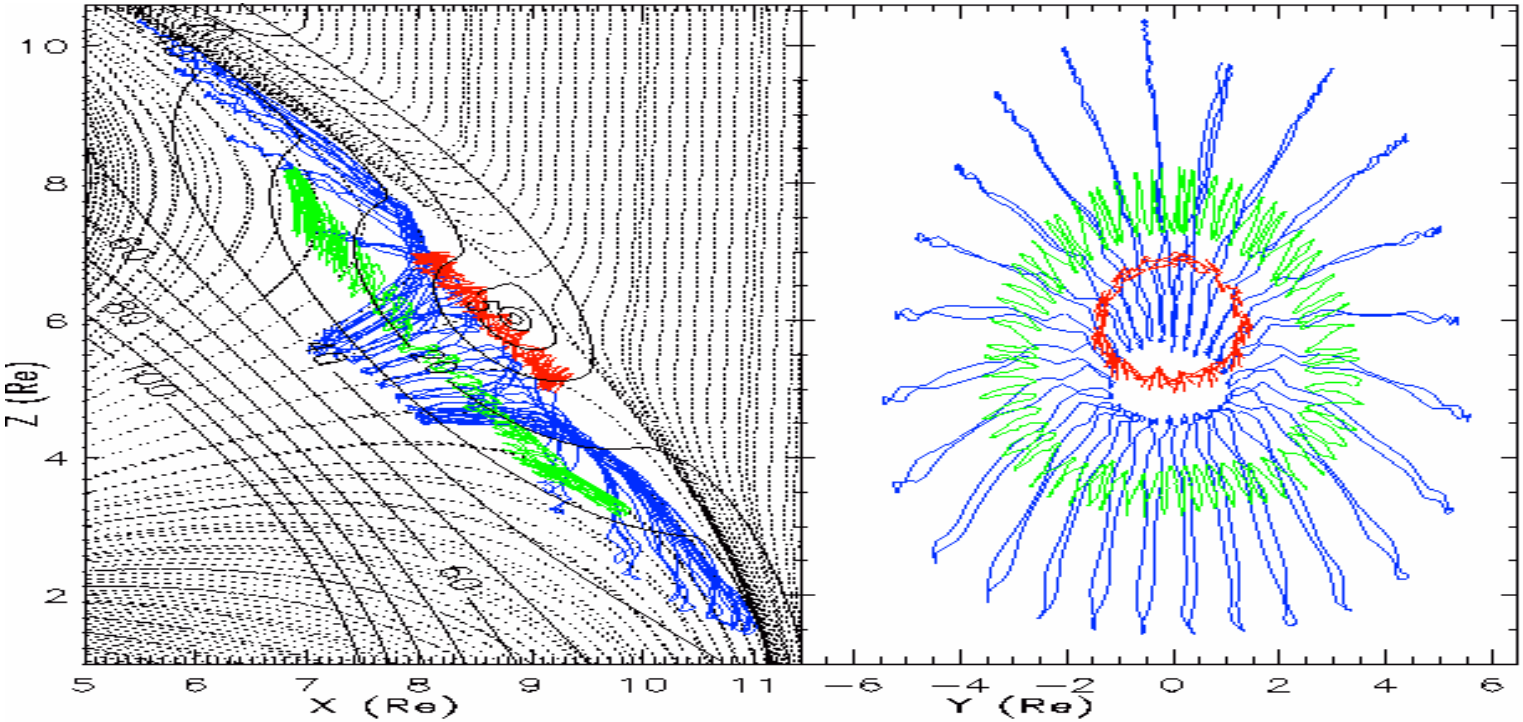
Energetic electron and ion measurements in two completed orbit

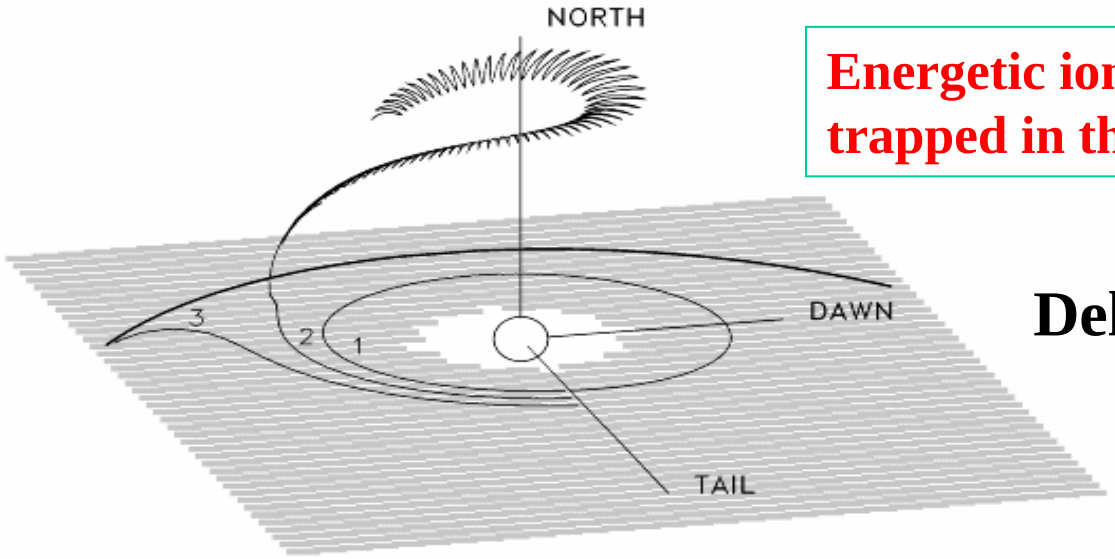




1	16/3	17h00-19h10m South HLBL/Cusp	quiet
2	17/3	06h00-09h20m North HLBL/Cusp	quiet
3	19/3	01h00-02h30m South HLBL/Cusp	activity
4	19/3	14h50-19h00m North HLBL/Cusp	activity

Cusp: Particle description



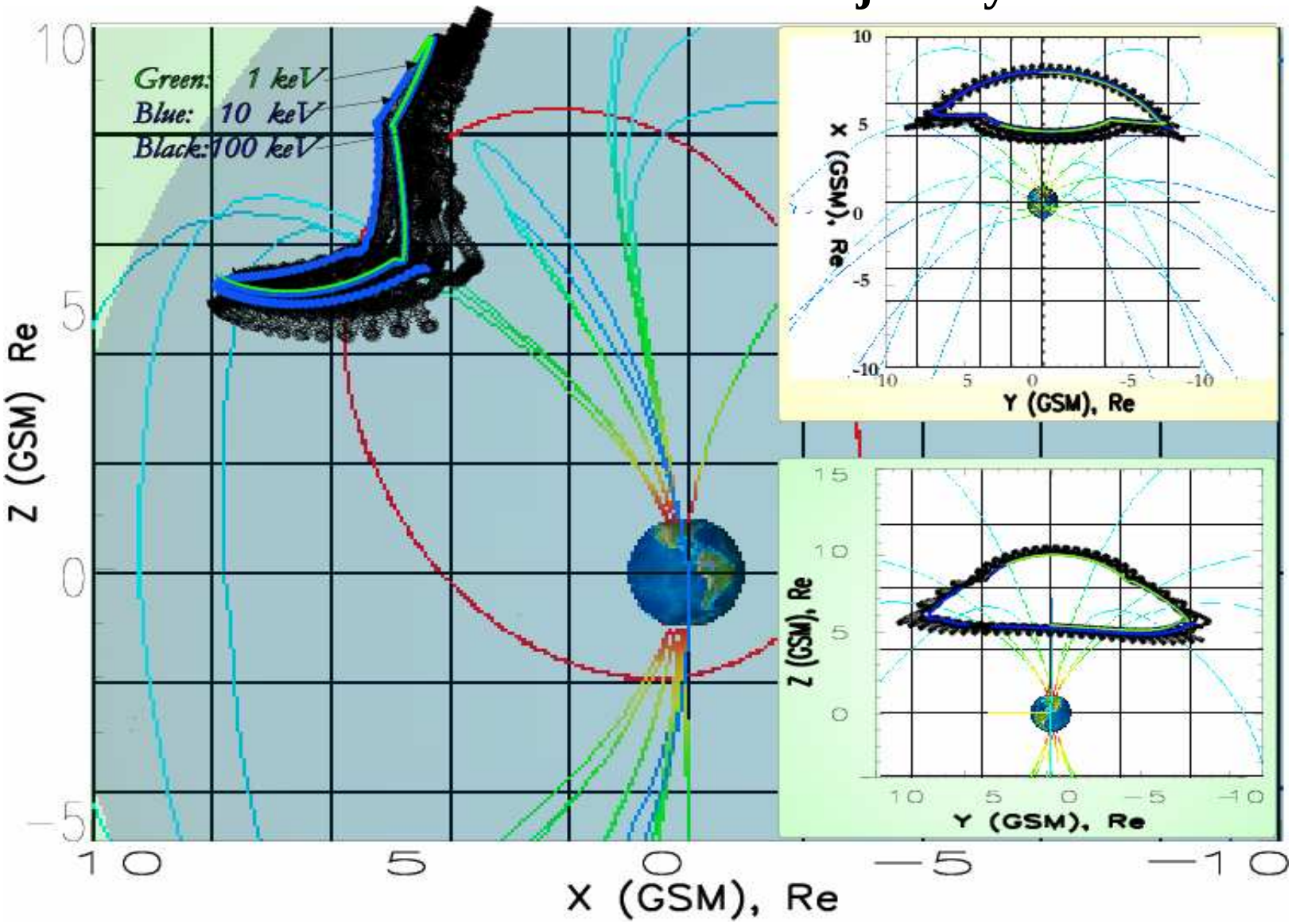


Energetic ions can be temporally trapped in the B-min region.

Delcout et al 98,99

Cusp: Particle description

Ion's trajectory

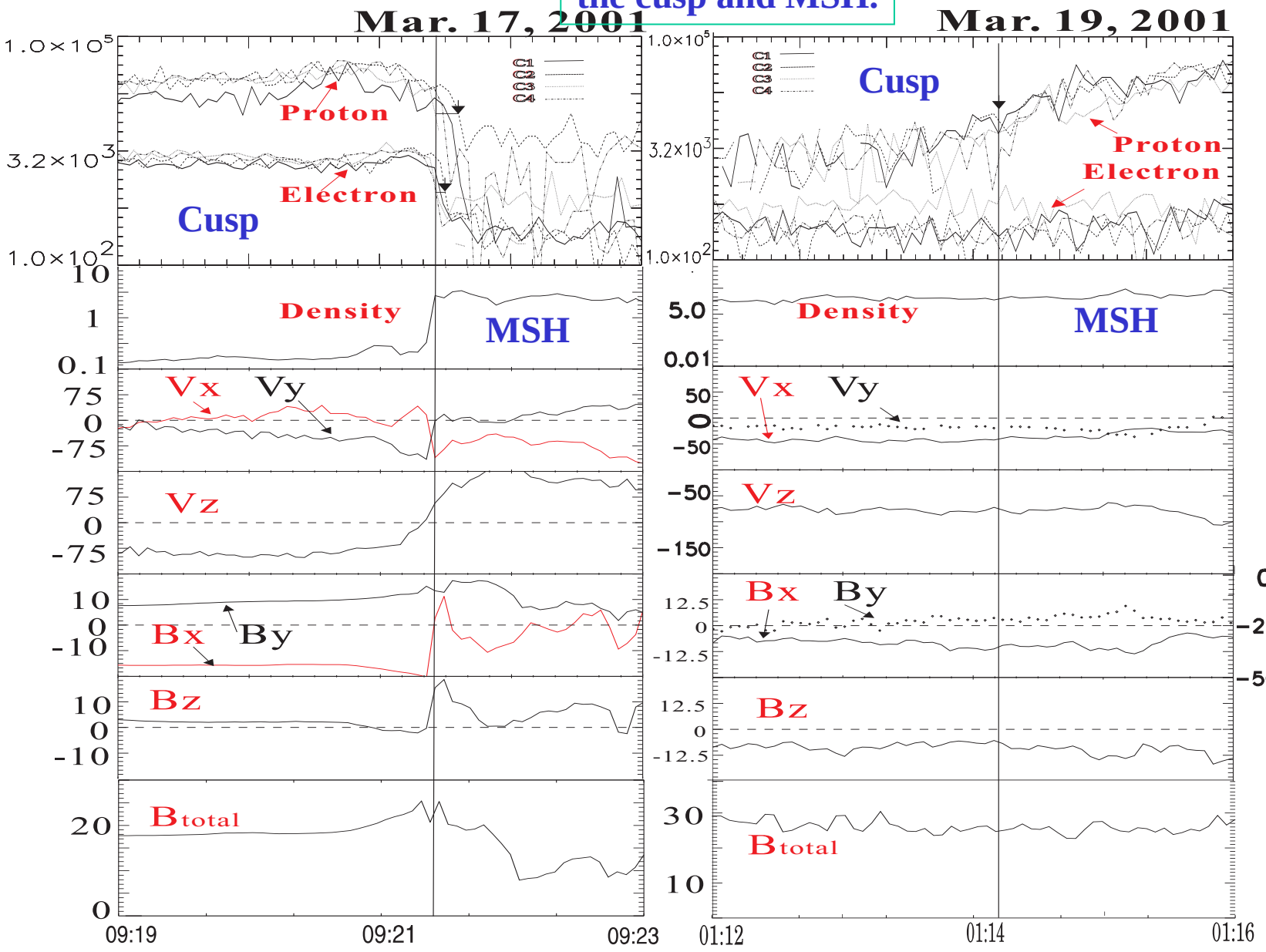


Zong et al, 2005
Survey in
Geophysics

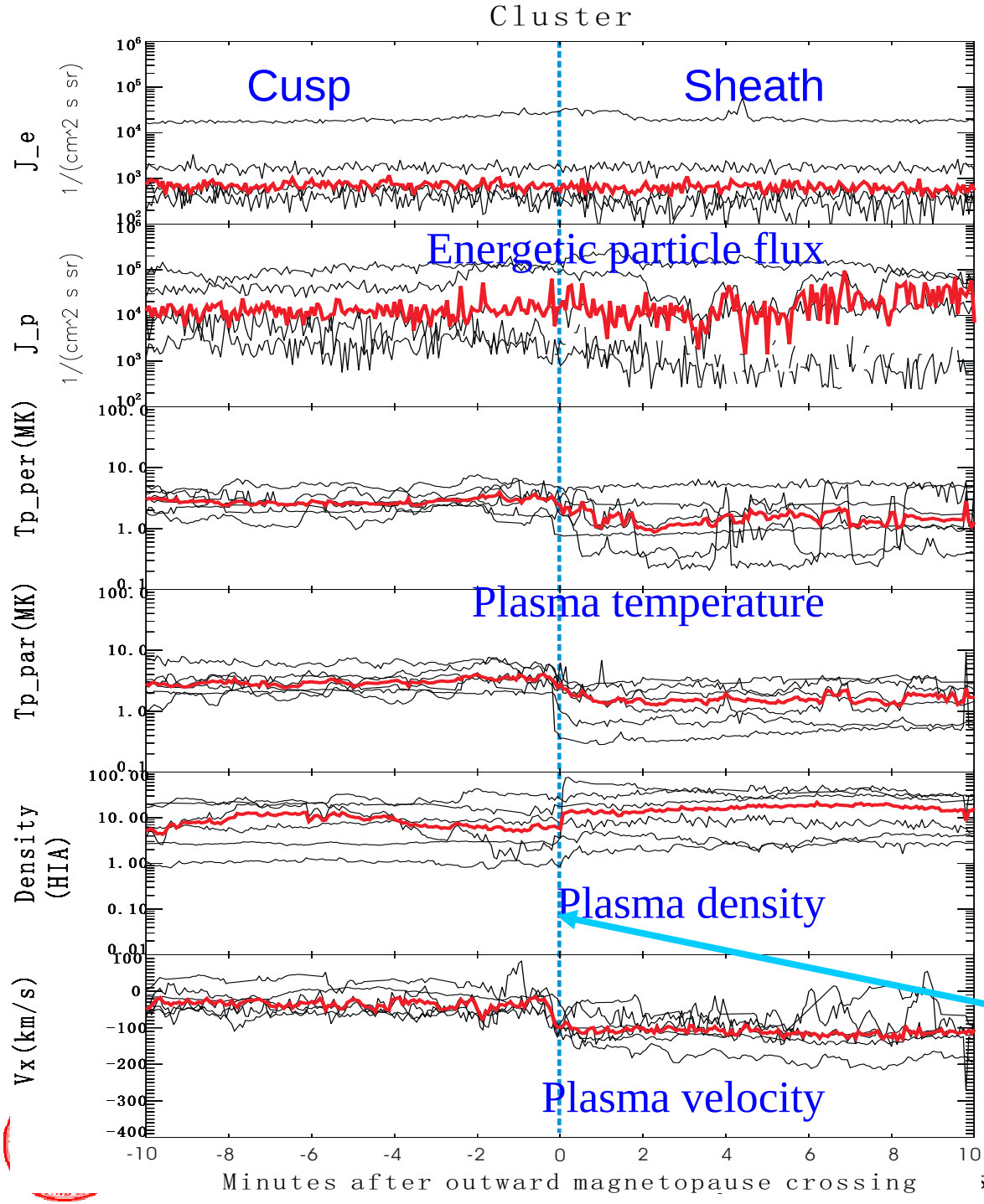
Clear

Interface between the cusp and MSH.

Unclear

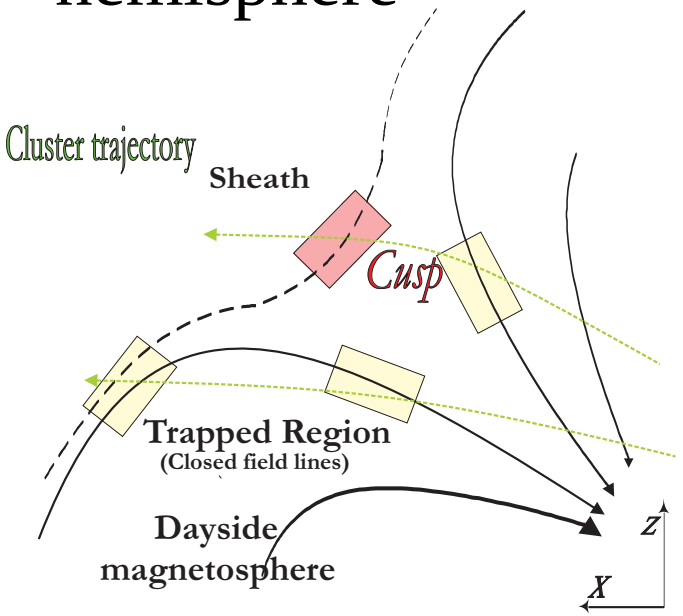


Zong et al, Survey in Geophys. 2005



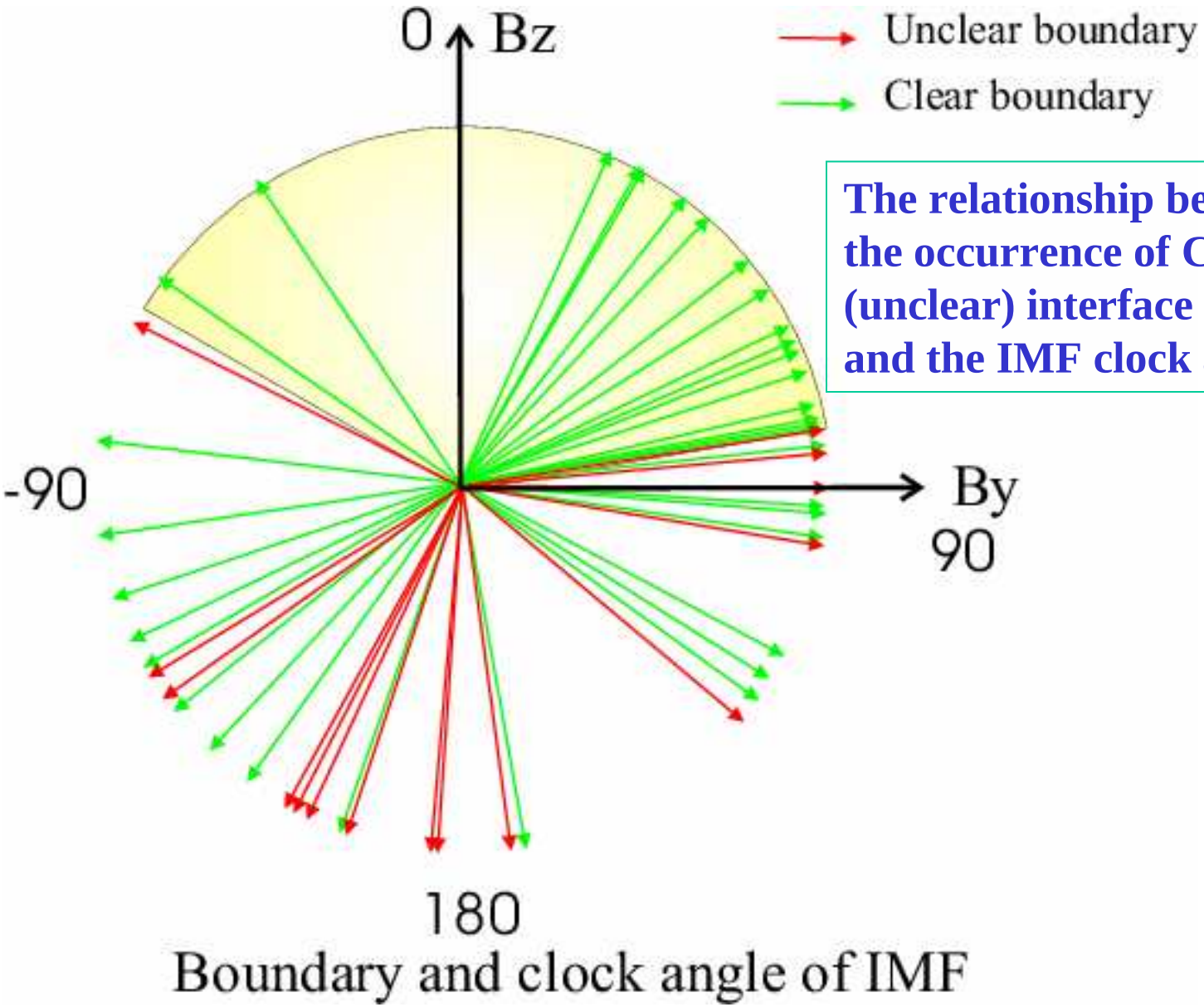
Superposed epoch analysis

under northward IMF in northern hemisphere



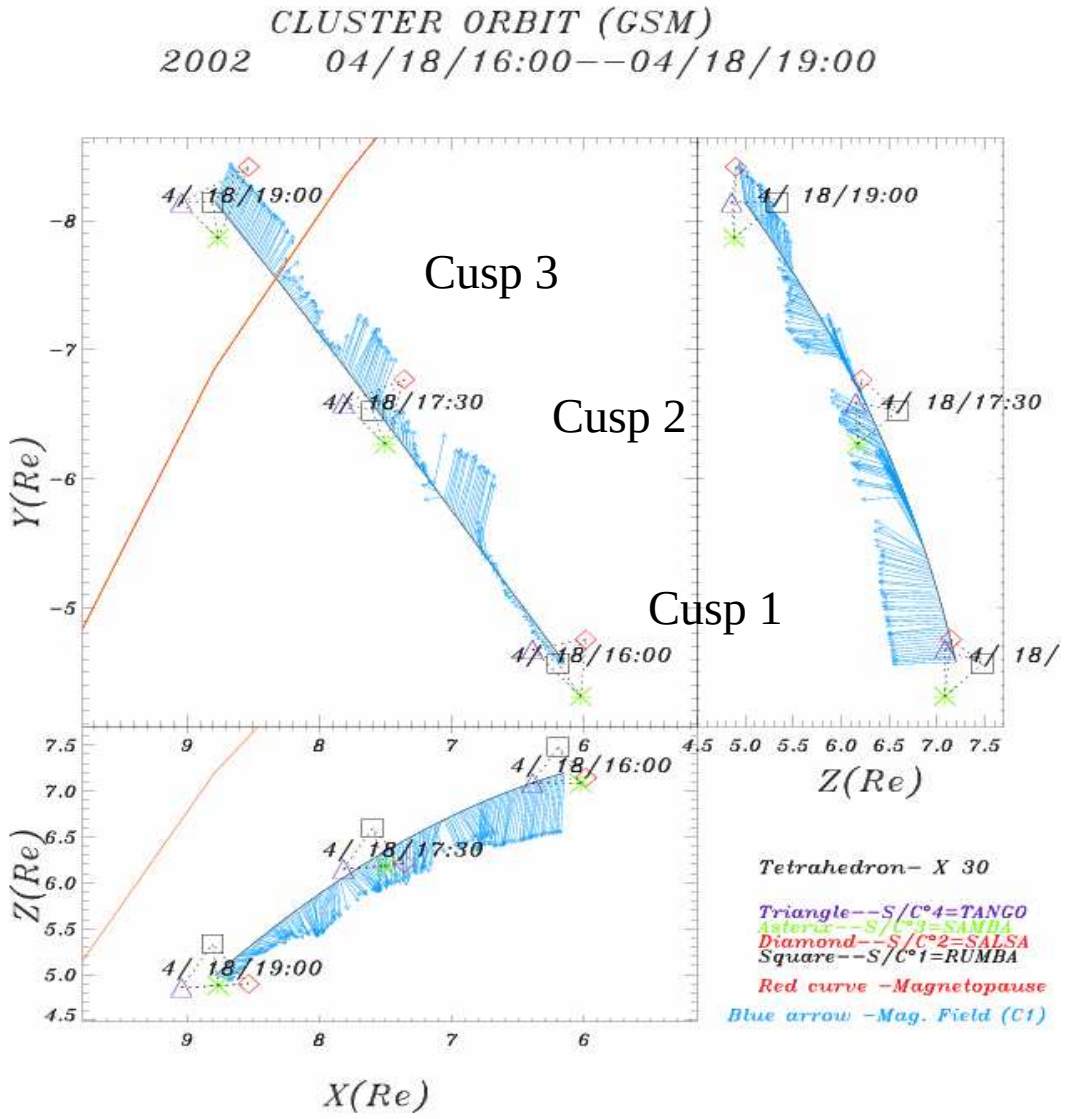
Magnetopause

shop, ESA, 2005



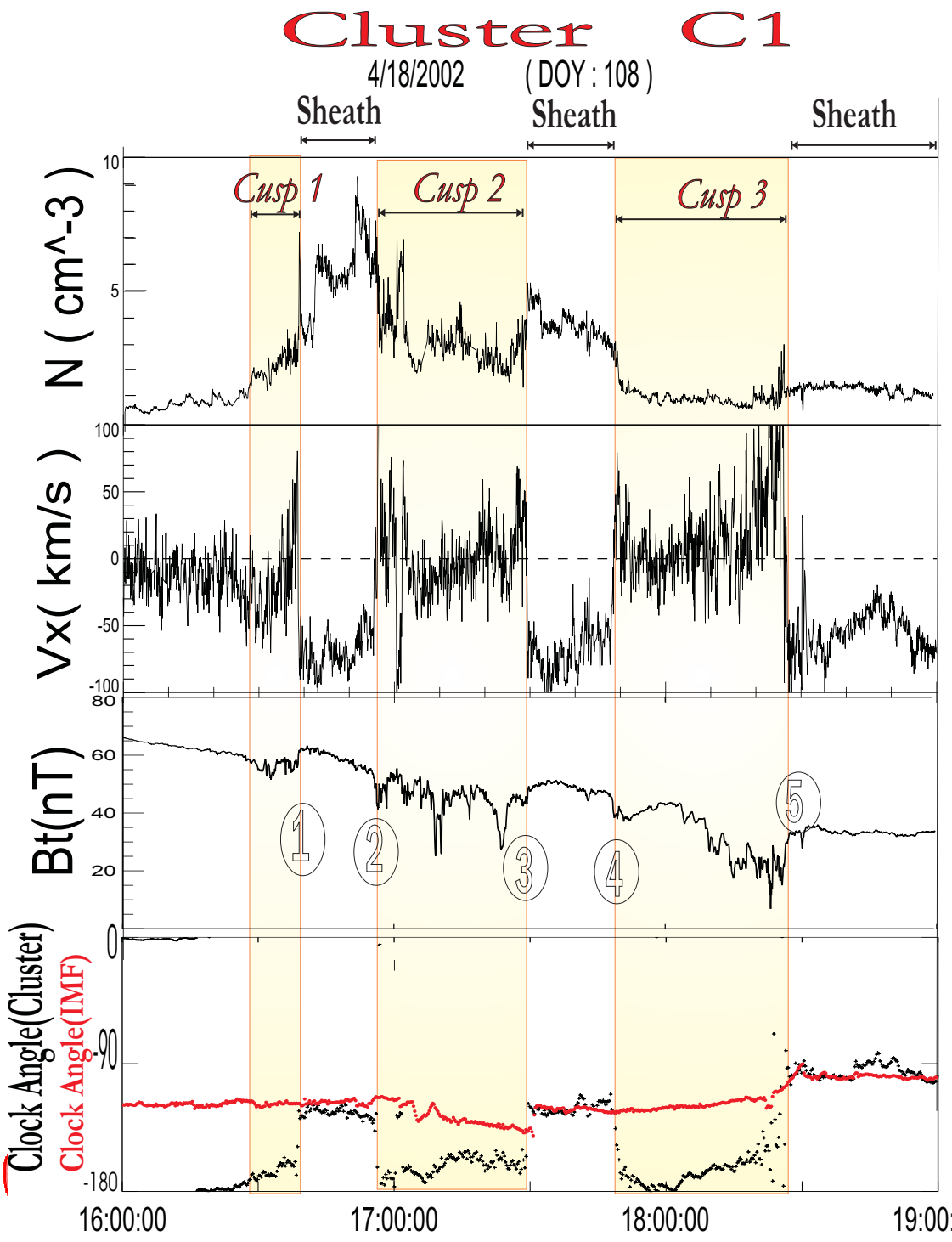
The relationship between the occurrence of Clear (unclear) interface and the IMF clock angle.

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



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**

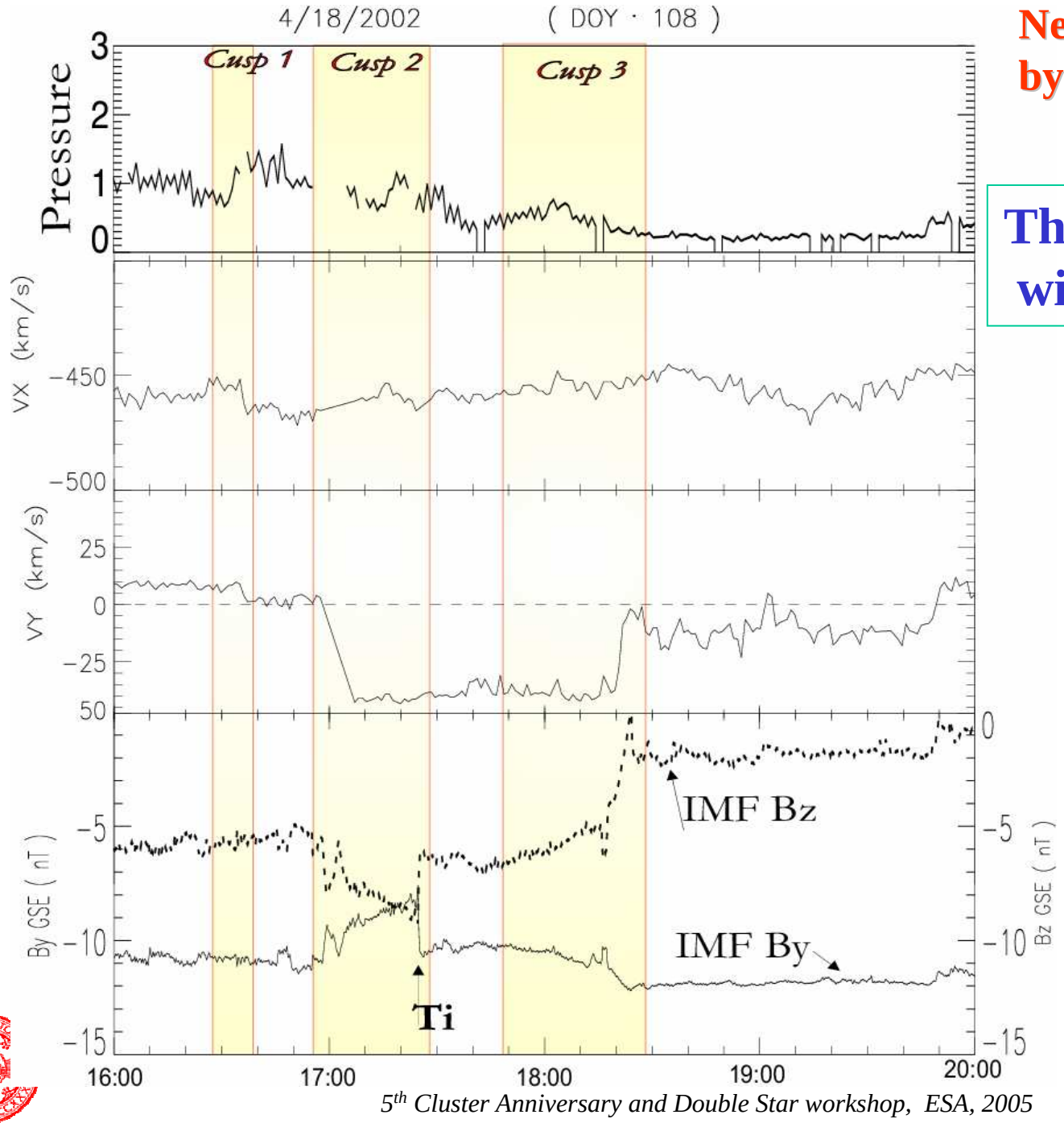
I. turbulent magnetic fields,

II. high density plasma

III. stagnant plasma flow.

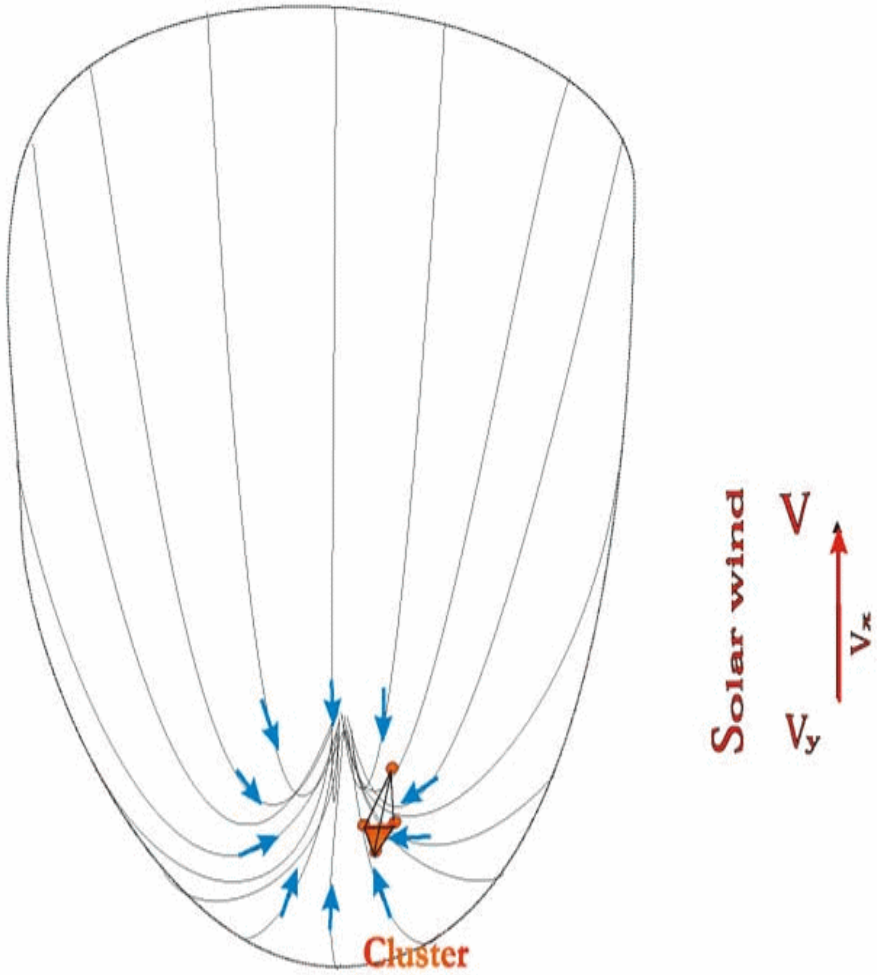
IV. clock angle criterion.

New Observations by Cluster



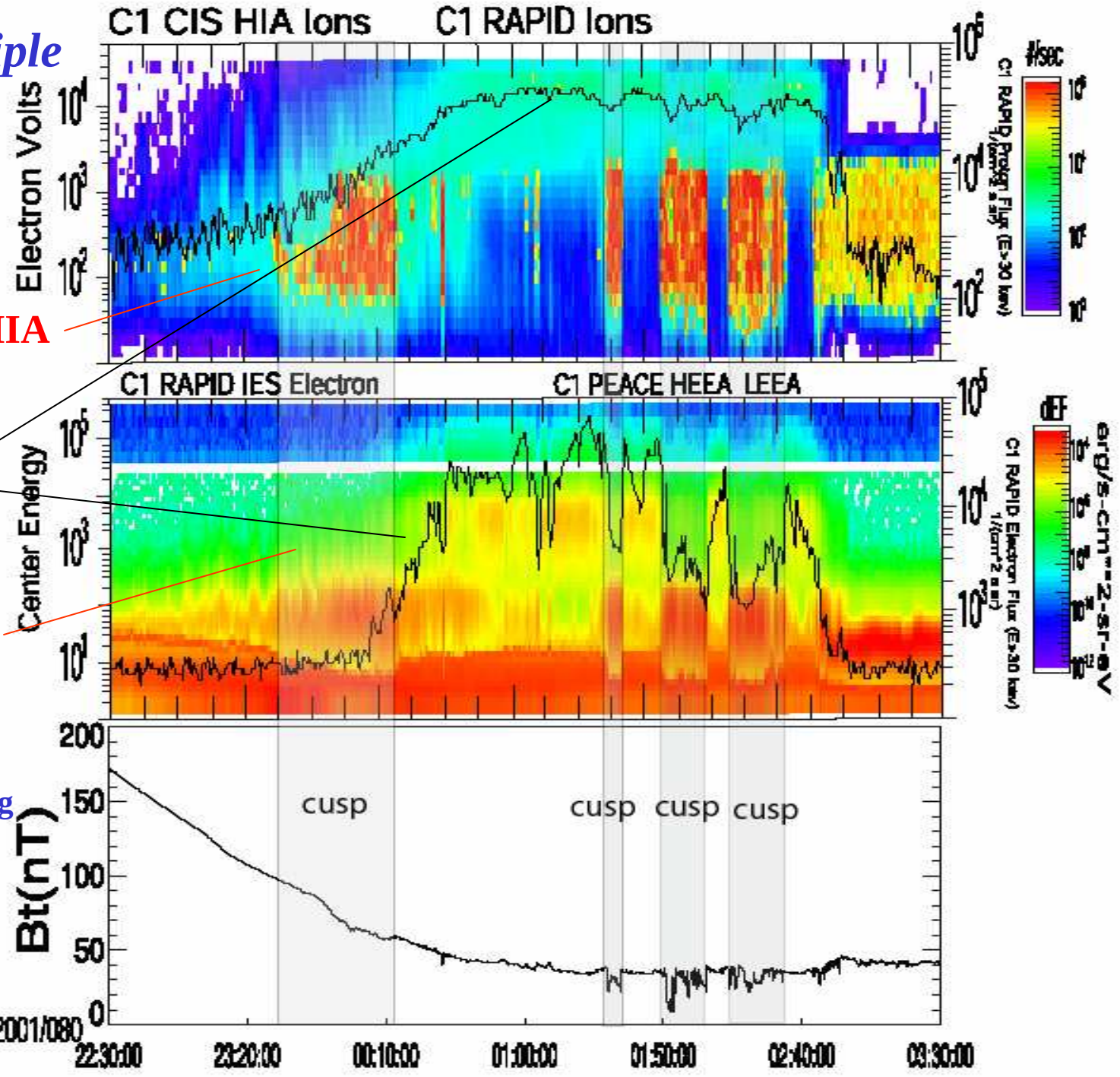
The related solar wind conditions

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



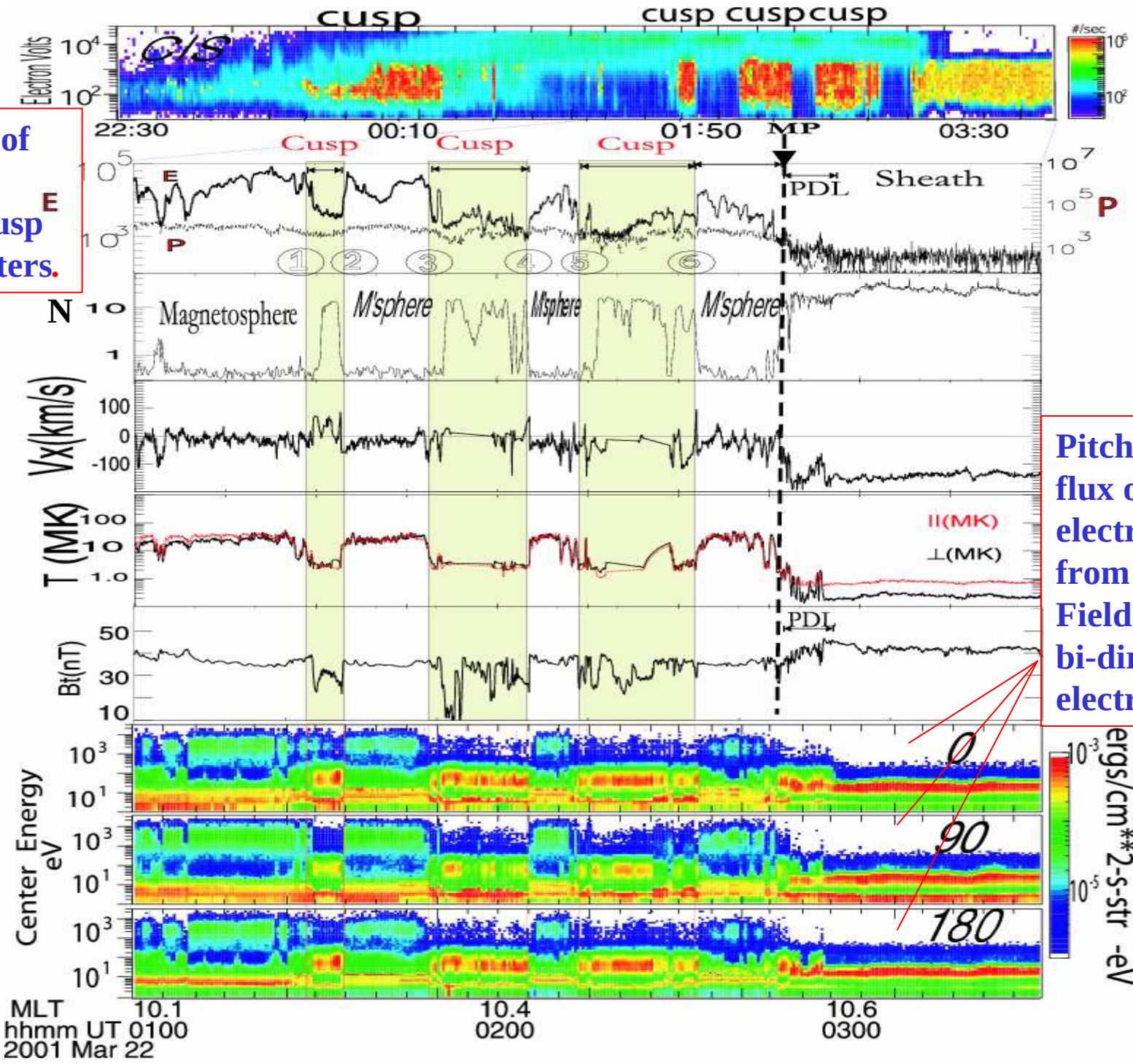
	ΦN (º)	θN (º)	N
		λ2/ λ3	
1	-28	1	(0.89 -0.46 0.01) 2.5
2	-28	1	(0.88 -0.47 0.01) 5.4
3	-28	6	(0.87 -0.47 0.11) 5.8
4	-20	4	(0.94 -0.35 0.07) 1.8
5	-26	6	(0.89 -0.44 0.11) 5.5

Another multiple Cusp event on March 21-22, 2001



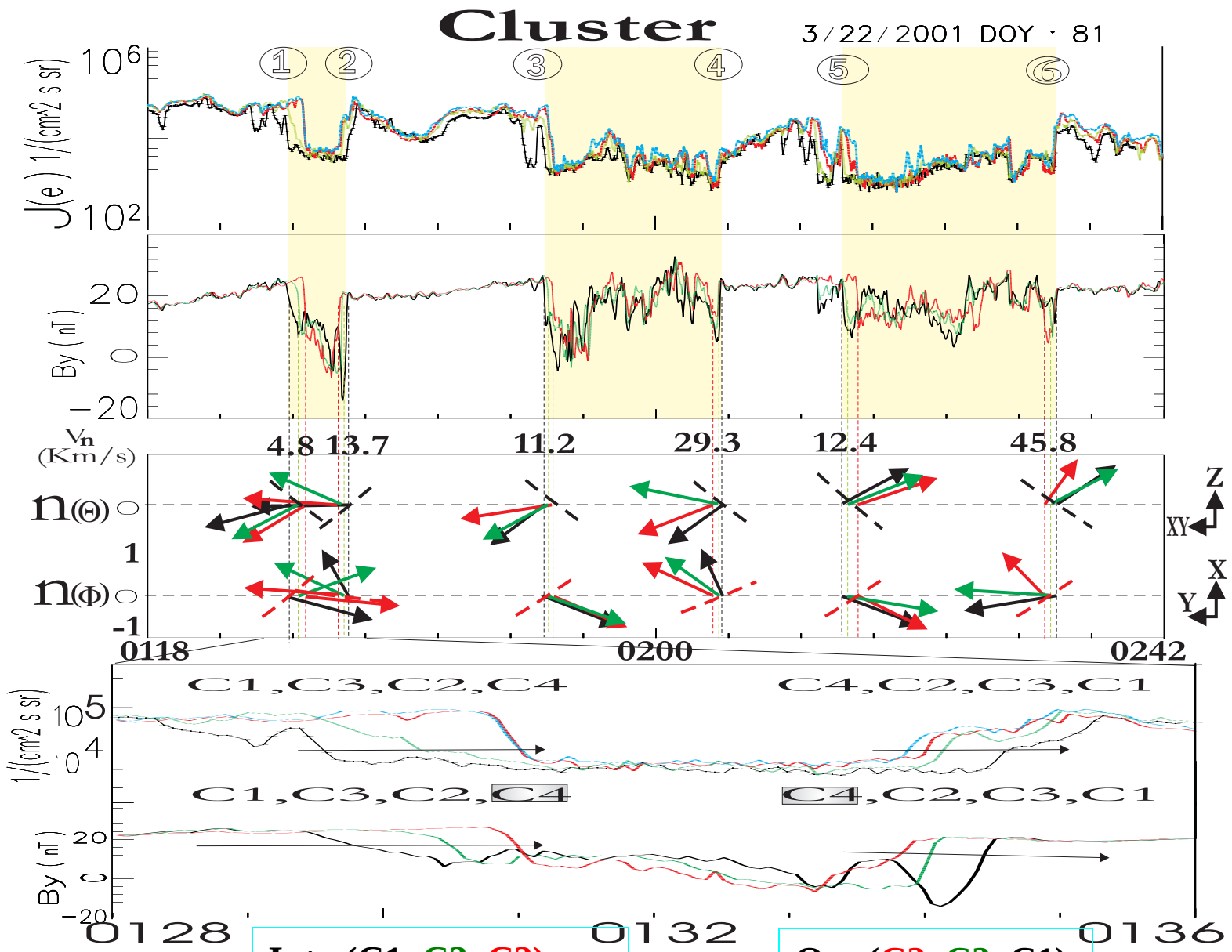
Thermal electrons and ions get increased comparing with the MSP background, while energetic electrons (ions) decreased.

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



Into (C1, C3, C2)

Out (C2, C3, C1)

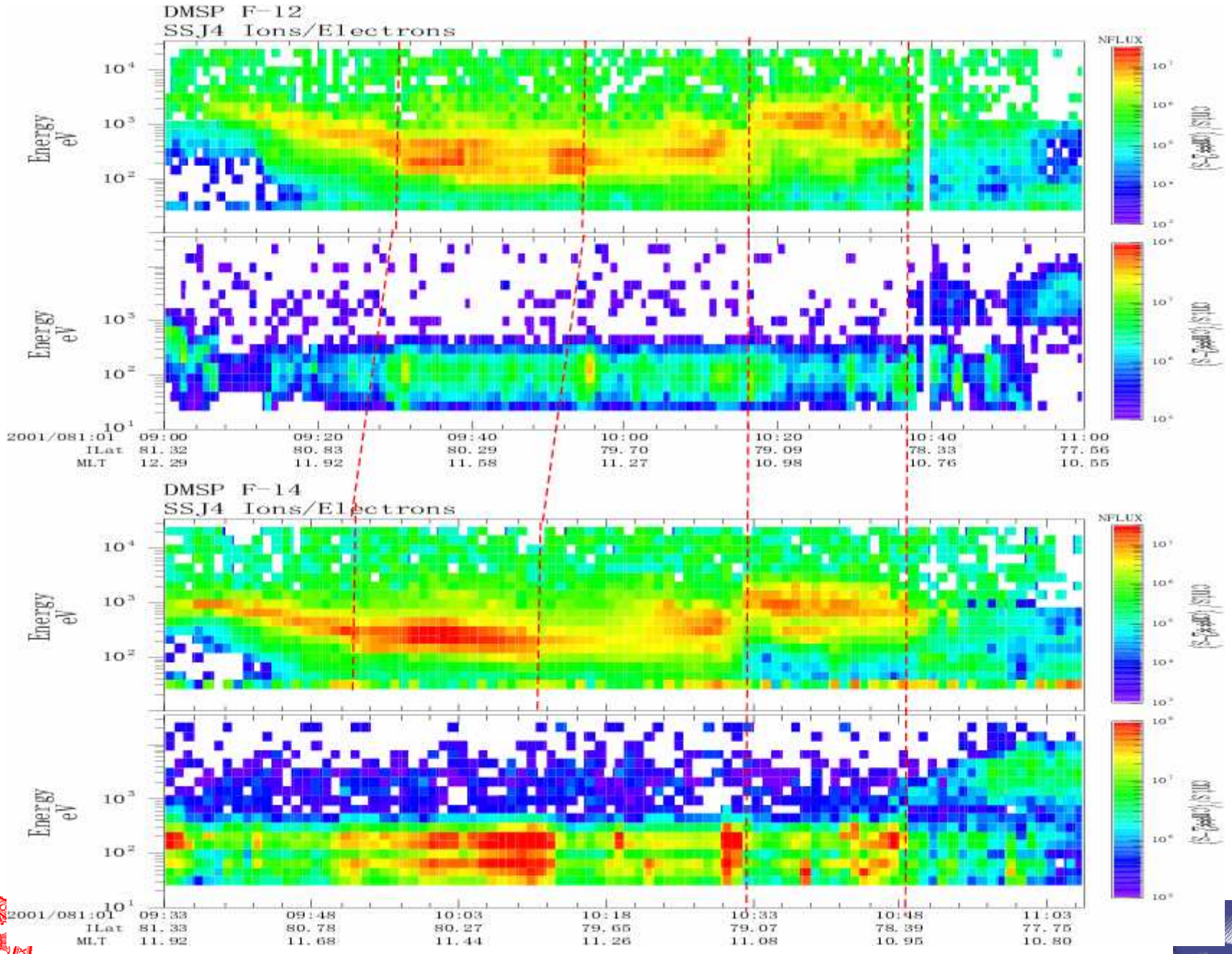
The spacecraft positions relative to the interface

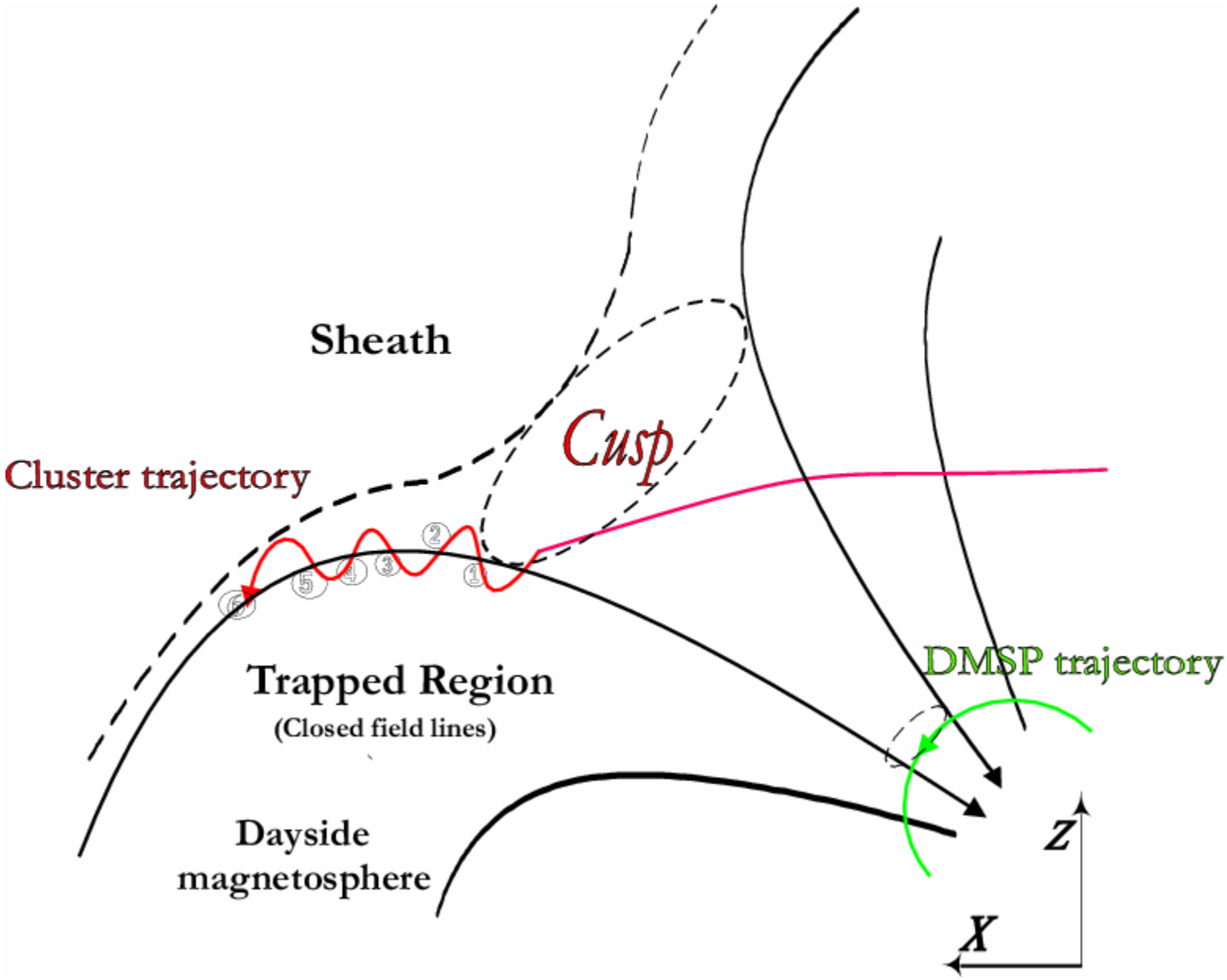
C2 C3 C1 ⇐ Cusp

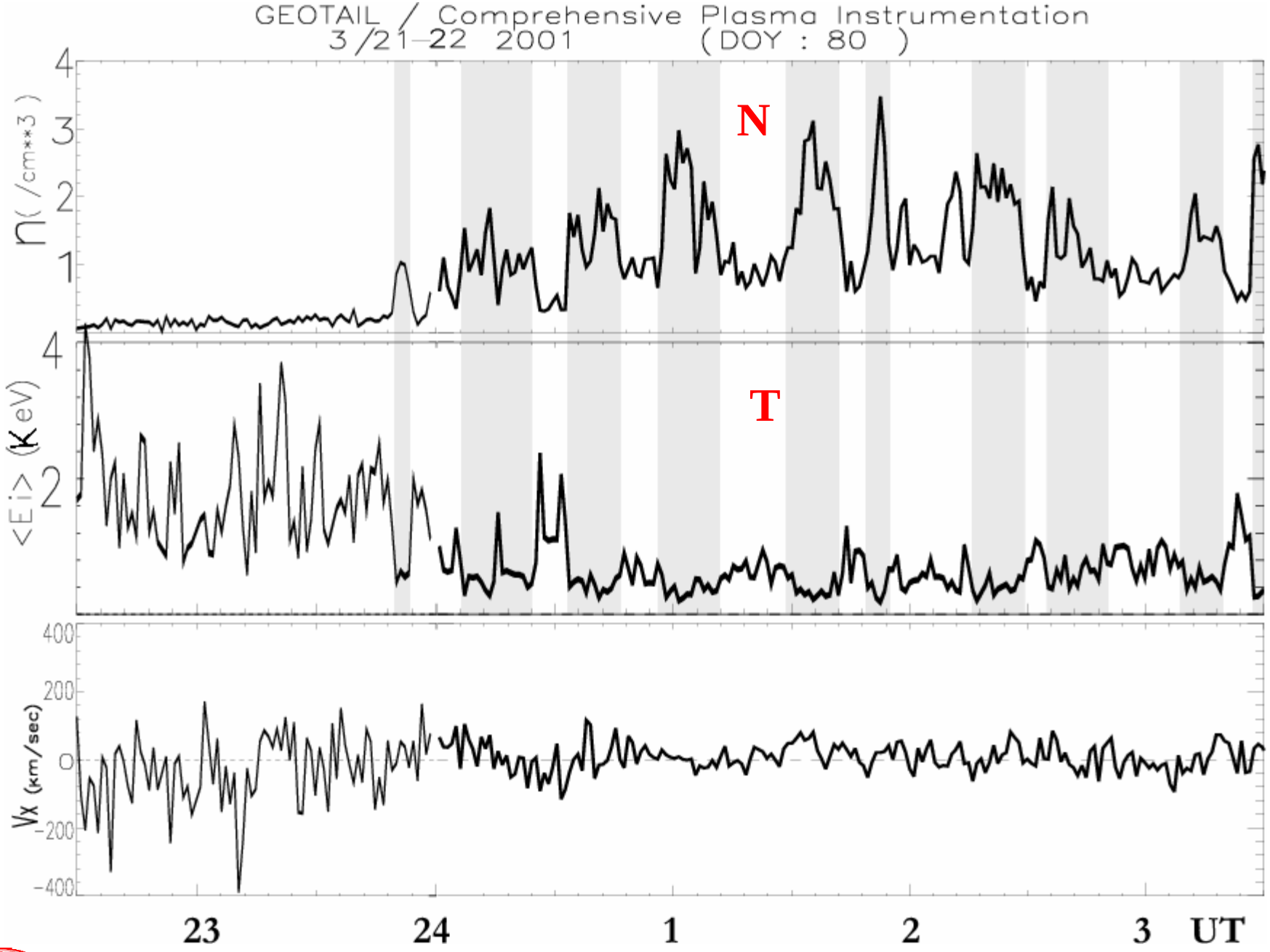
(Leading edge)

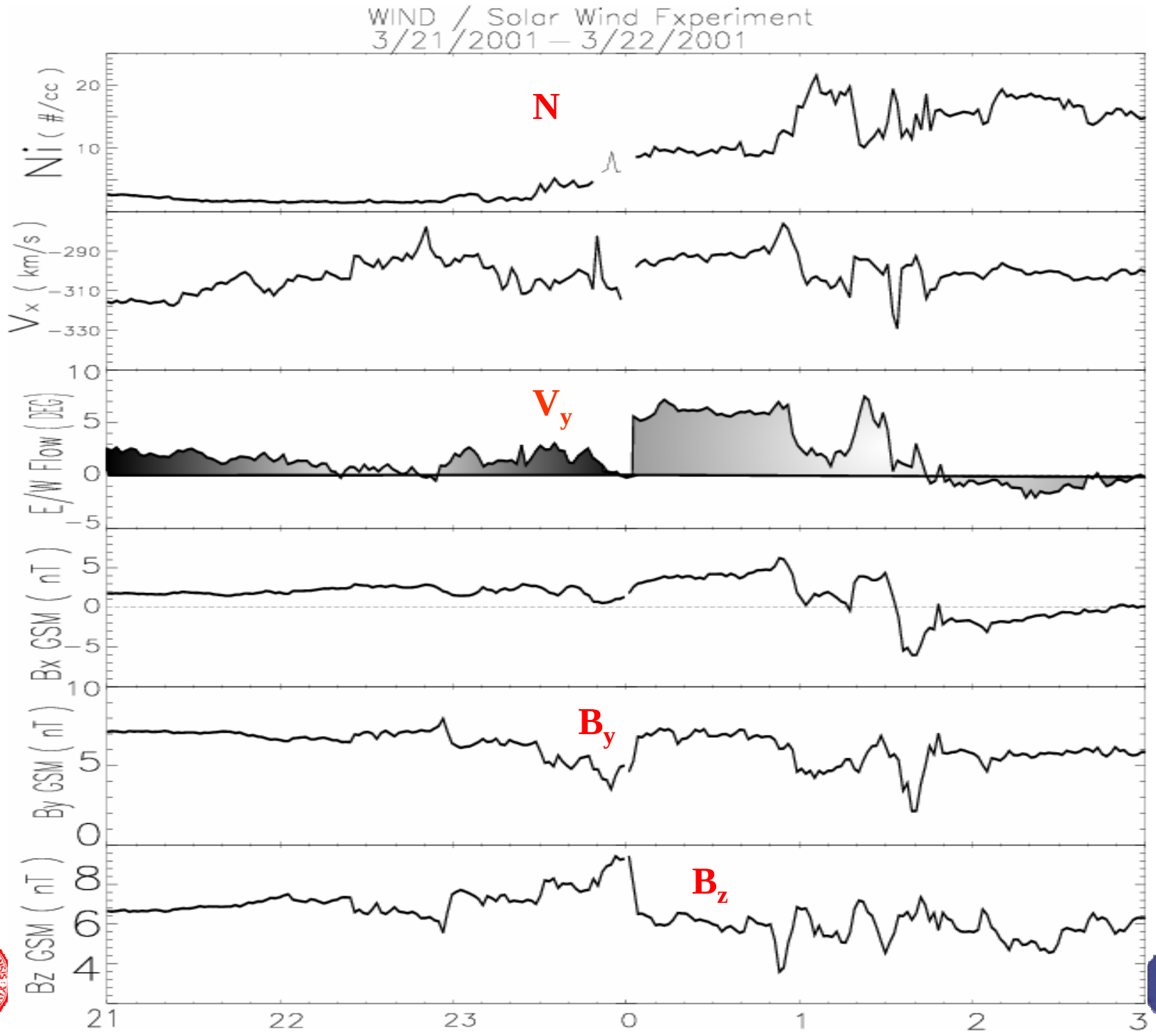
Cusp ⇒ C2 C3 C1

(Back edge)


DMSP F-12
SSJ4 Ions/Electrons
Energy eV
NFLUX
2001/081:01 09:00 09:20 09:40 10:00 10:20 10:40 11:00
ILat 81.32 80.83 80.29 79.70 79.09 78.33 77.56
MLT 12.29 11.92 11.58 11.27 10.98 10.76 10.55
DMSP F-14
SSJ4 Ions/Electrons
Energy eV
NFLUX
2001/081:01 09:33 09:48 10:03 10:18 10:33 10:48 11:03
ILat 81.33 80.78 80.27 79.65 79.07 78.39 77.75
MLT 11.92 11.68 11.44 11.26 11.08 10.95 10.80


Sheath
Cusp
Cluster trajectory
1
2
3
4
5
6
Trapped Region
(Closed field lines)
DMSP trajectory
Dayside
magnetosphere
Z
X


GEOTAIL / Comprehensive Plasma Instrumentation
3/21-22 2001 (DOY : 80)
n(/cm**3)
N
<Ei> (KeV)
T
Vx (km/sec)
23
24
1
2
3 UT


WIND / Solar Wind Fxperiment
3/21/2001 — 3/22/2001
Ni (#/cc)
20
10
N
Vx (km/s)
−290
−310
−330
E/W Flow (DEG)
10
5
0
−5
Vy
Bx GSM (nT)
5
0
−5
By GSM (nT)
10
5
0
By
Bz GSM (nT)
8
6
4
Bz
21
22
23
0
1
2
3

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 By/Bz 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.