The Cluster Mission to the Magnetosphere

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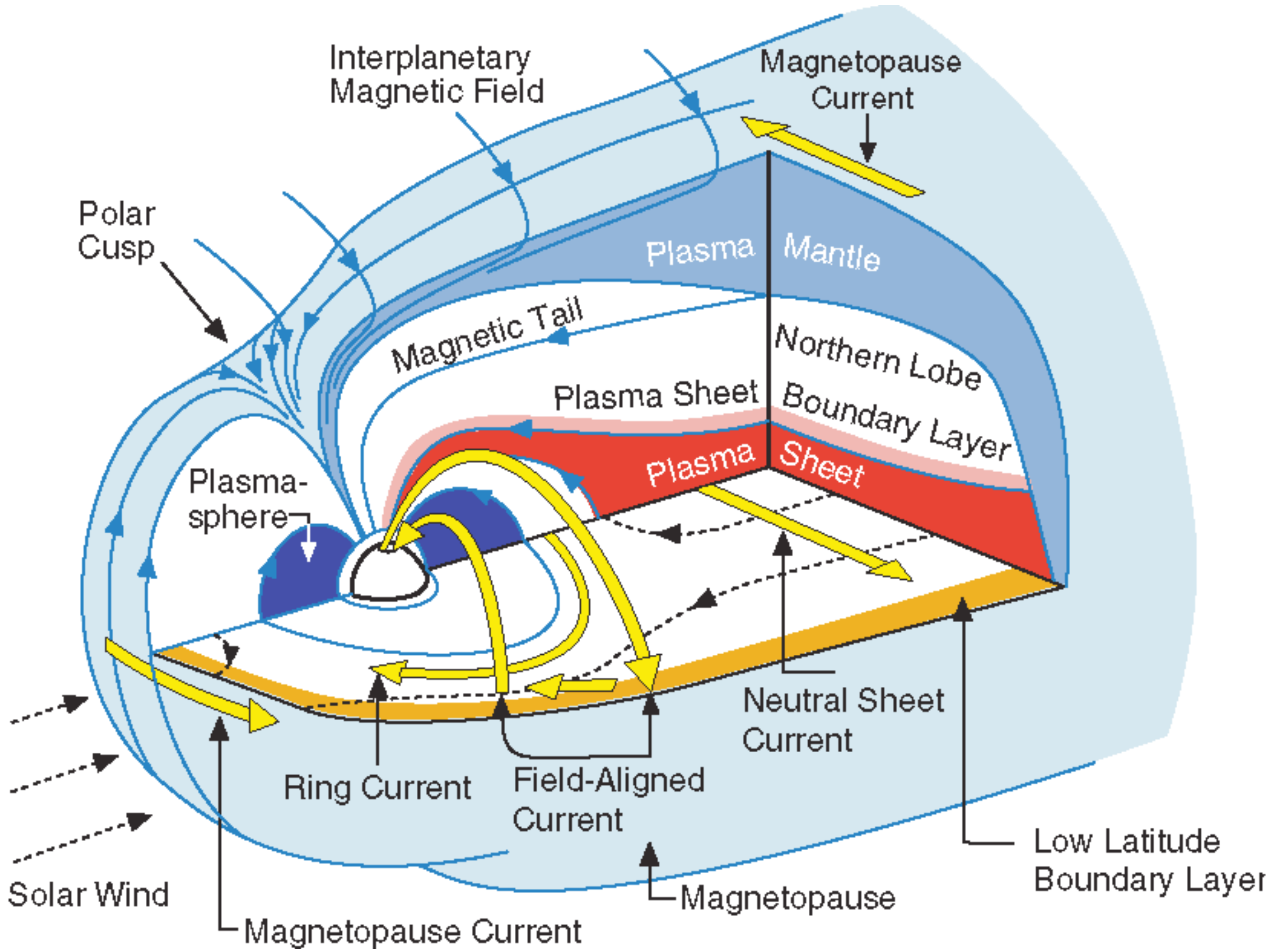
Sinaia, 5June 2007

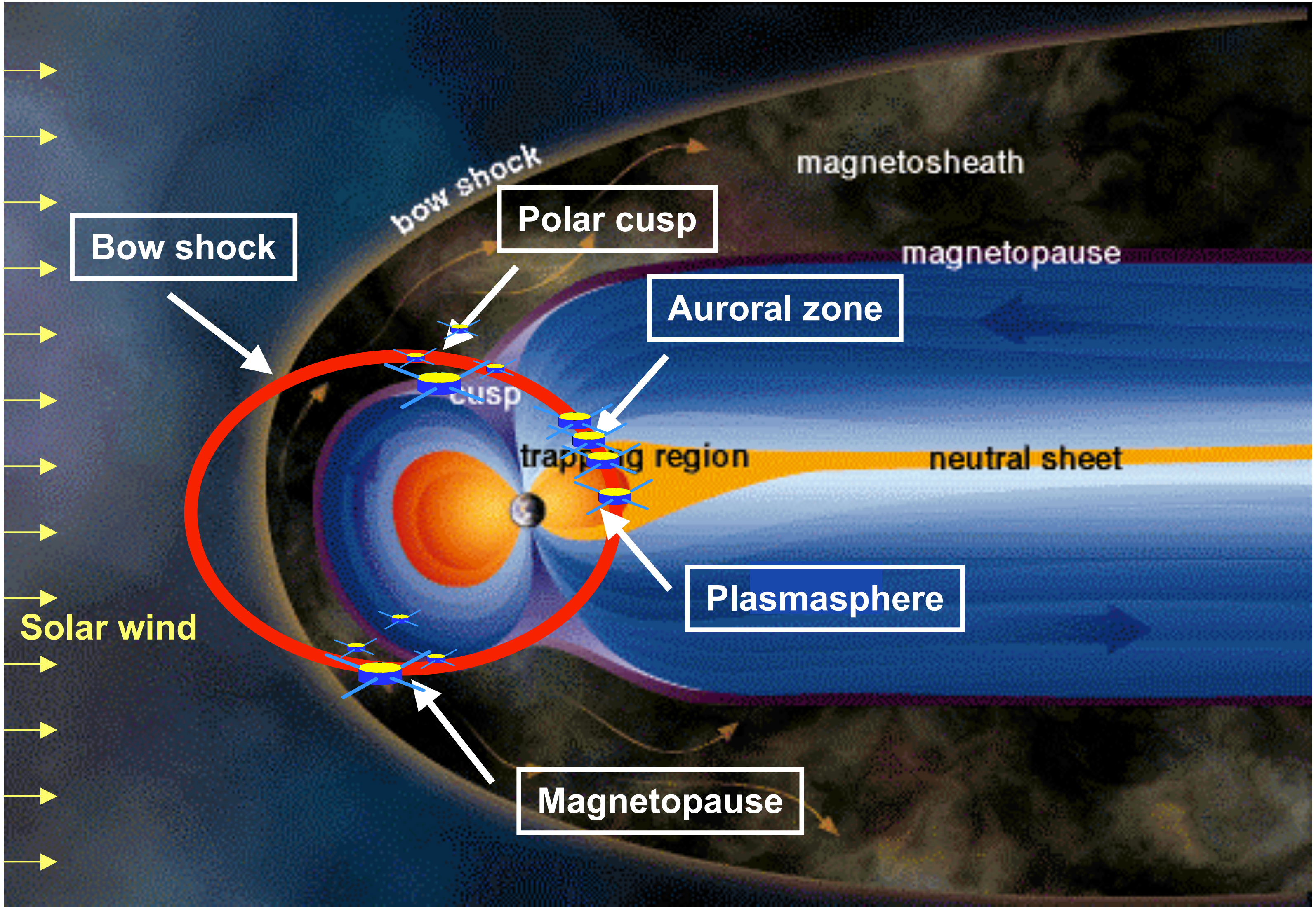
Short Cluster History

- 1982: Mission Proposal to ESA
- 1987; Instrument Proposals
- 1996: Launch Failure Ariane-V at Kourou
- 2000: Successful Launch with Soyuz at Baikonur
- 2009(?): End of Mission

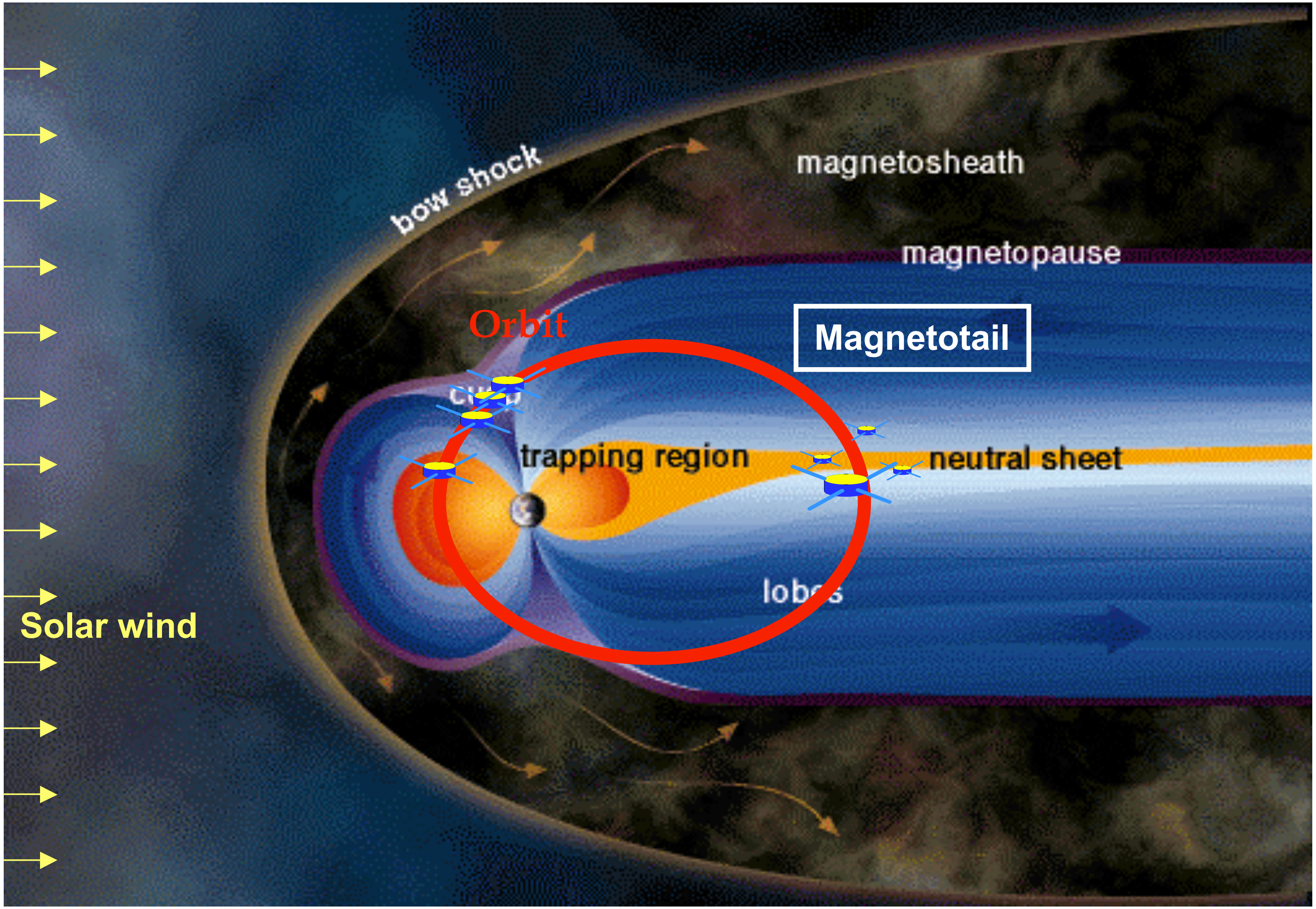
3D View of the Magnetosphere



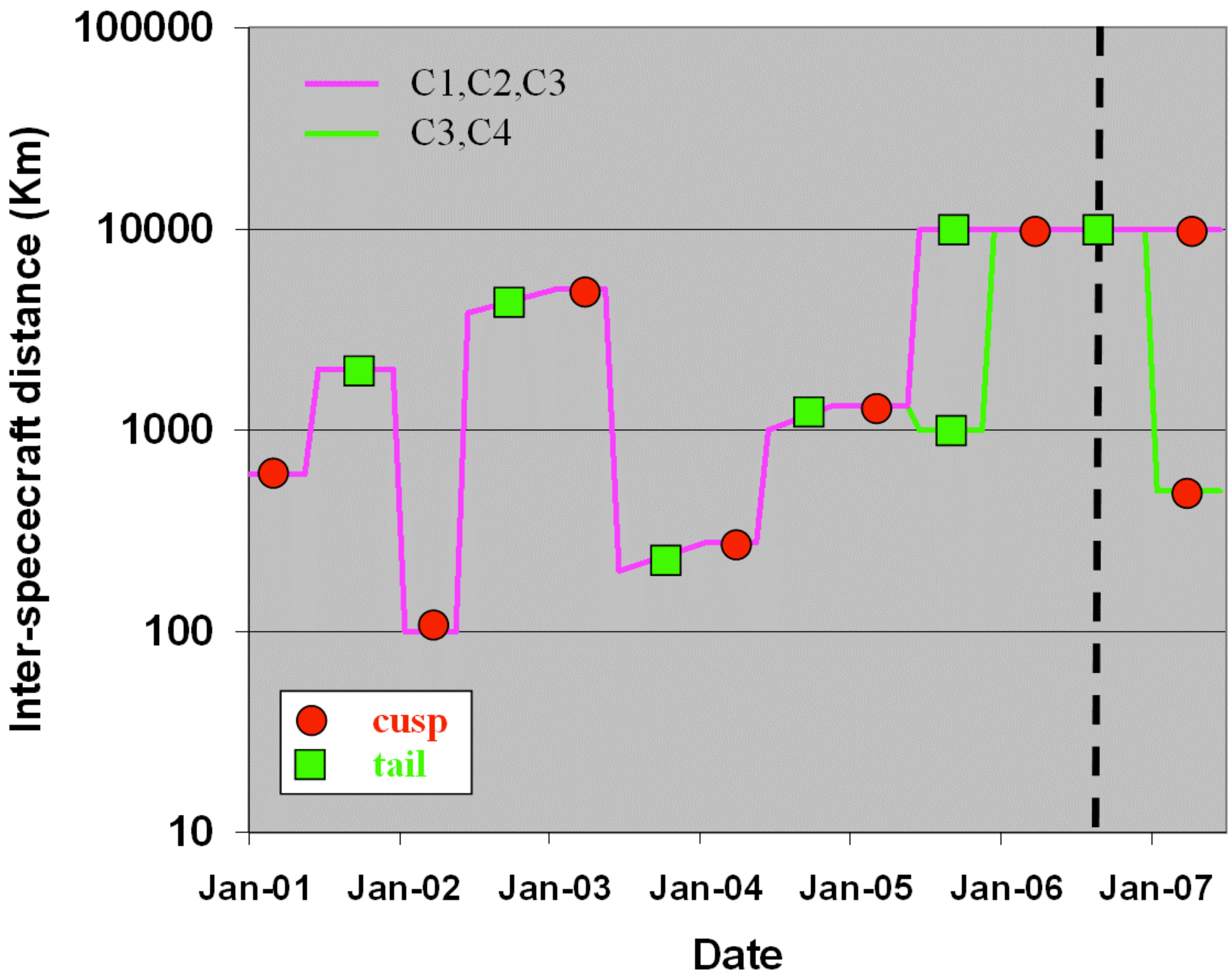
Regions visited by Cluster: Spring



Regions visited by Cluster: Fall

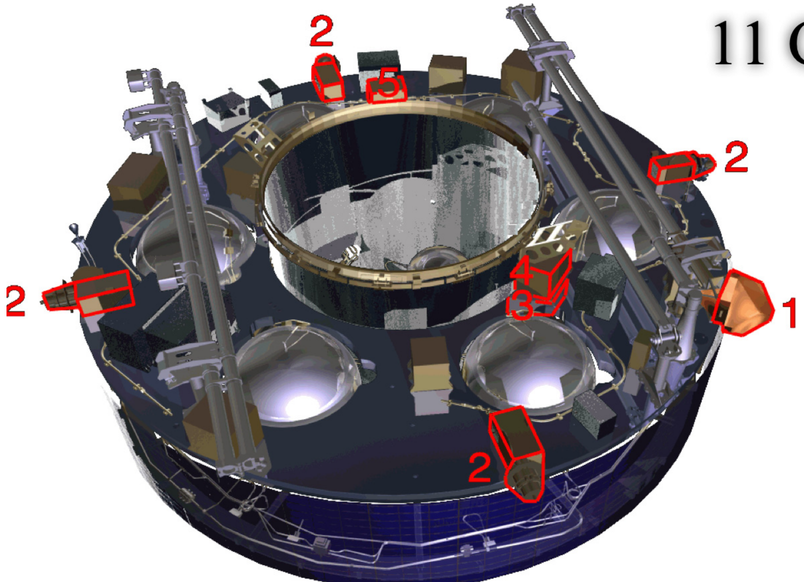


Cluster Separations



Payload

11 Cluster Instruments



1 **STAFF** (N. Cornilleau-Wehrlin, F)
Magnetic and electric fluctuations

2 **EFW** (M. Andre, S)
Electric fields and waves

3 **DWP** (H. Alleyne, UK)
Wave processor

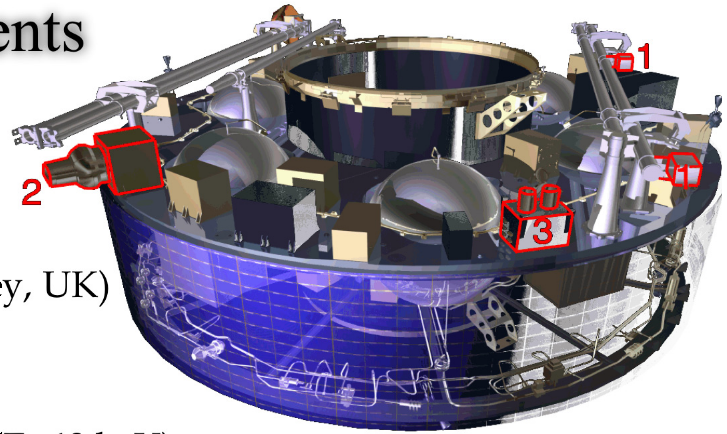
4 **WHISPER** (P. Decreau, F)
Electron density and plasma waves

5 **WBD** (D. Gurnett, USA)
Electric field wave-forms

1 **PEACE** (A. Fazakerley, UK)
Electrons (E<30 keV)

2 **CIS** (H. Reme, F)
Ions & Composition (E<40 keV)

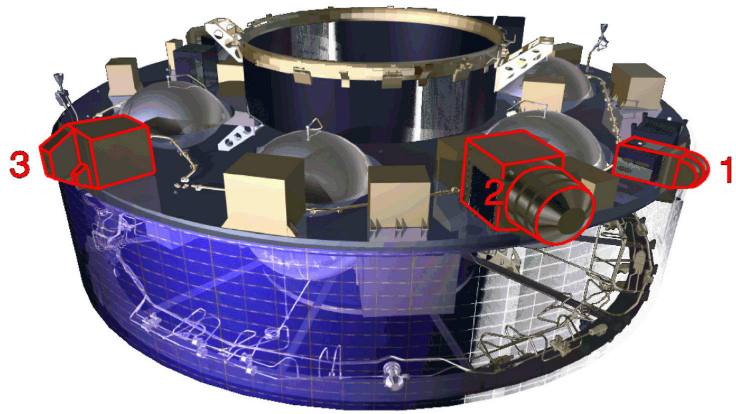
3 **RAPID** (P. Daly, D)
High energy electrons and ions



1 **FGM** (A. Balogh, UK)
Magnetic field

2 **EDI** (G. Paschmann, D)
Electron drift velocity

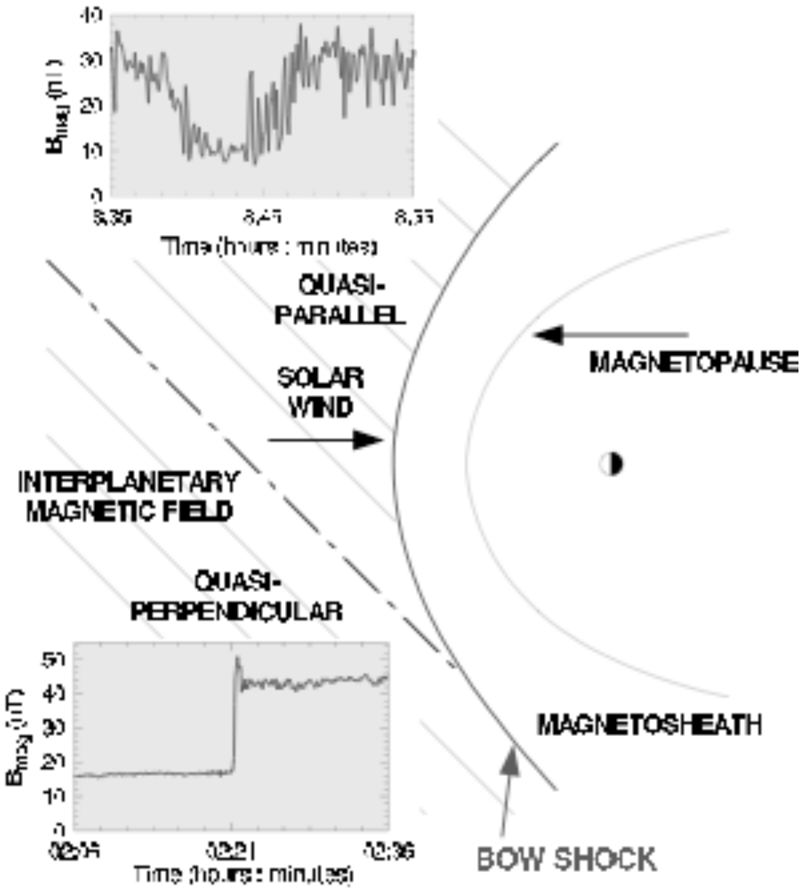
3 **ASPOC** (K. Torkar, A)
Spacecraft potential control



Bow Shock Topics

- Thickness Scaling
- SLAMS Scales
- Origin of Ion Beams

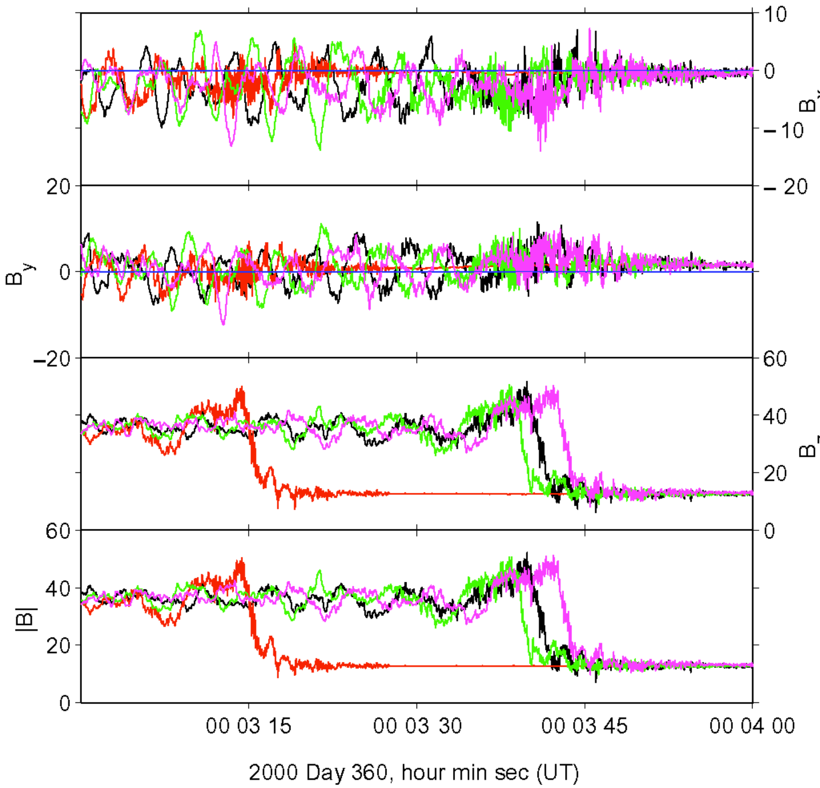
Bowshock & Foreshock



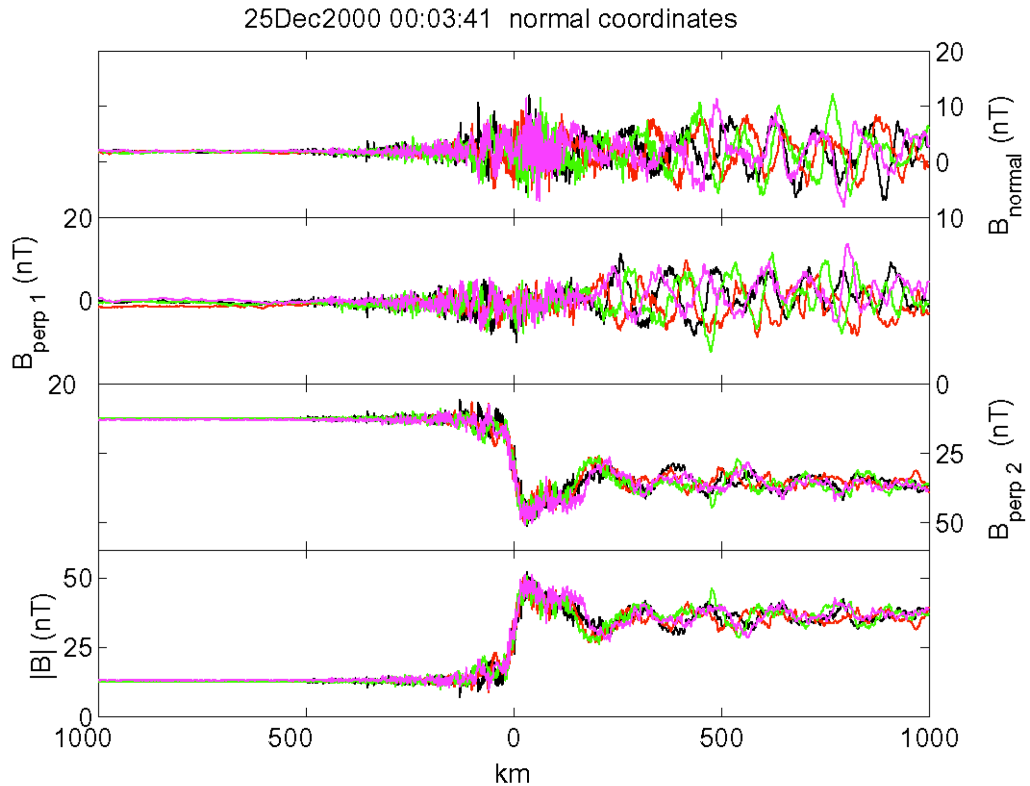
(from A. Balogh)

Bow Shock Magnetic Field Profiles

Temporal



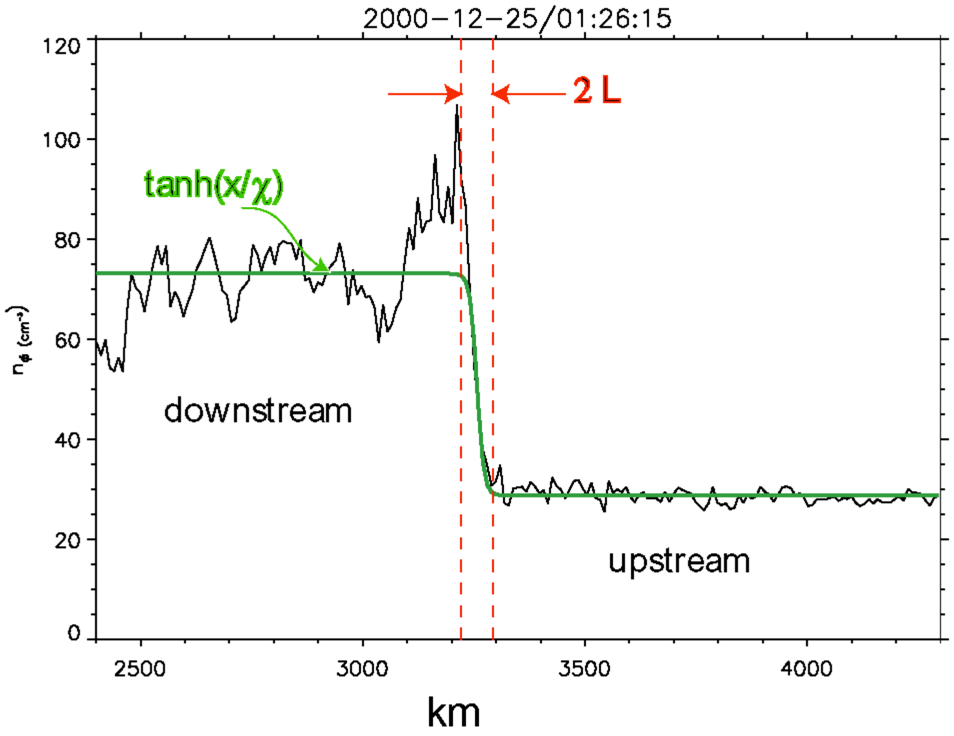
Spatial



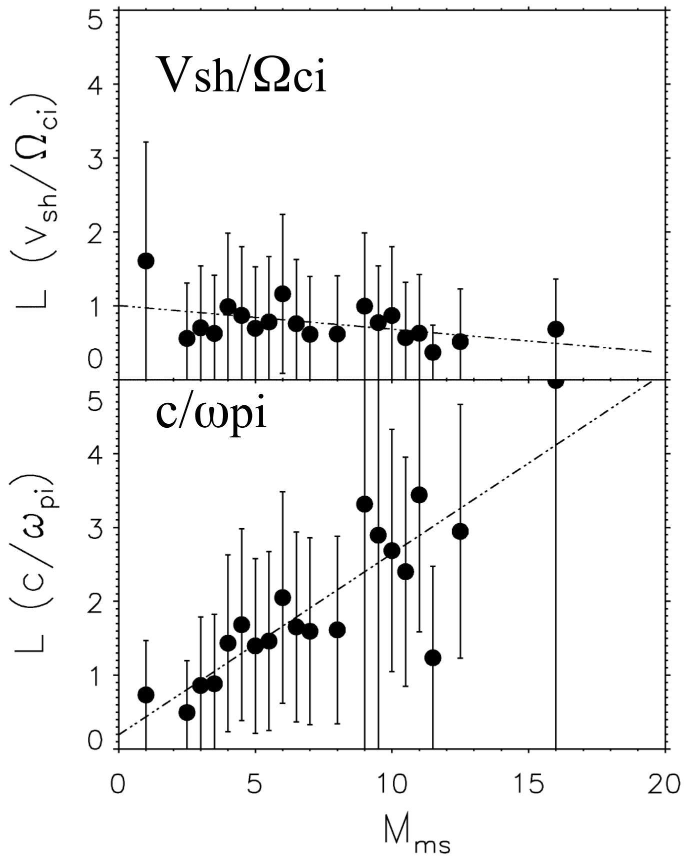
[Horbury et al., 2001]

Bow Shock Thickness

Example: Density vs. Distance



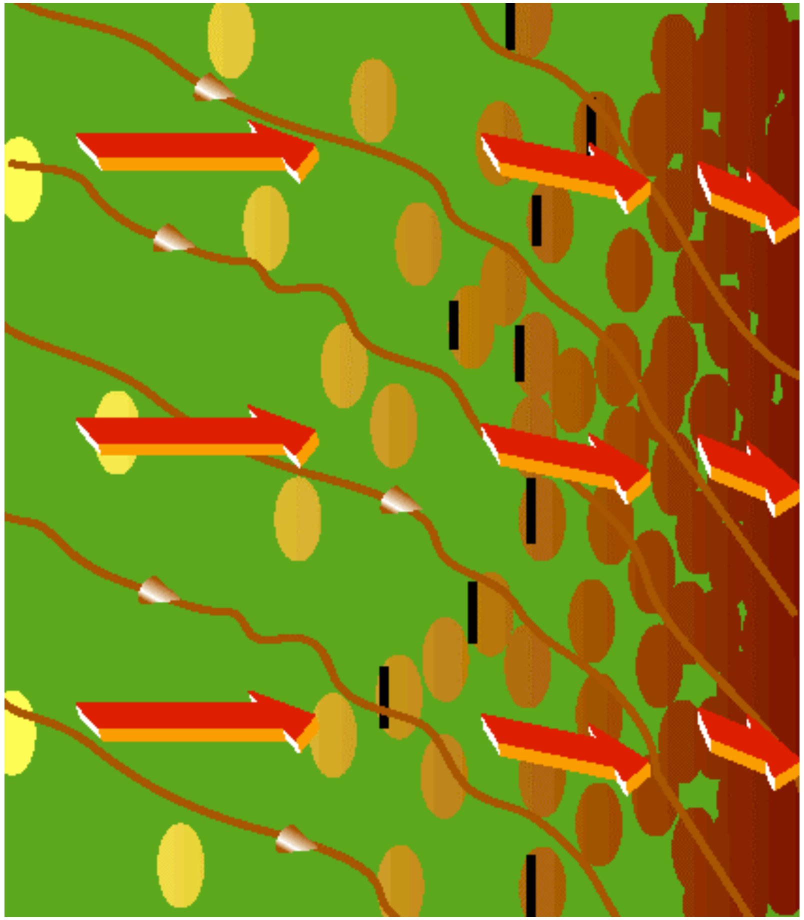
Thickness vs. Mach-Number



[Bale et al., 2003]

98 Crossings Mms bin size: 0.5

SLAMS: Building Blocks of Parallel Shocks

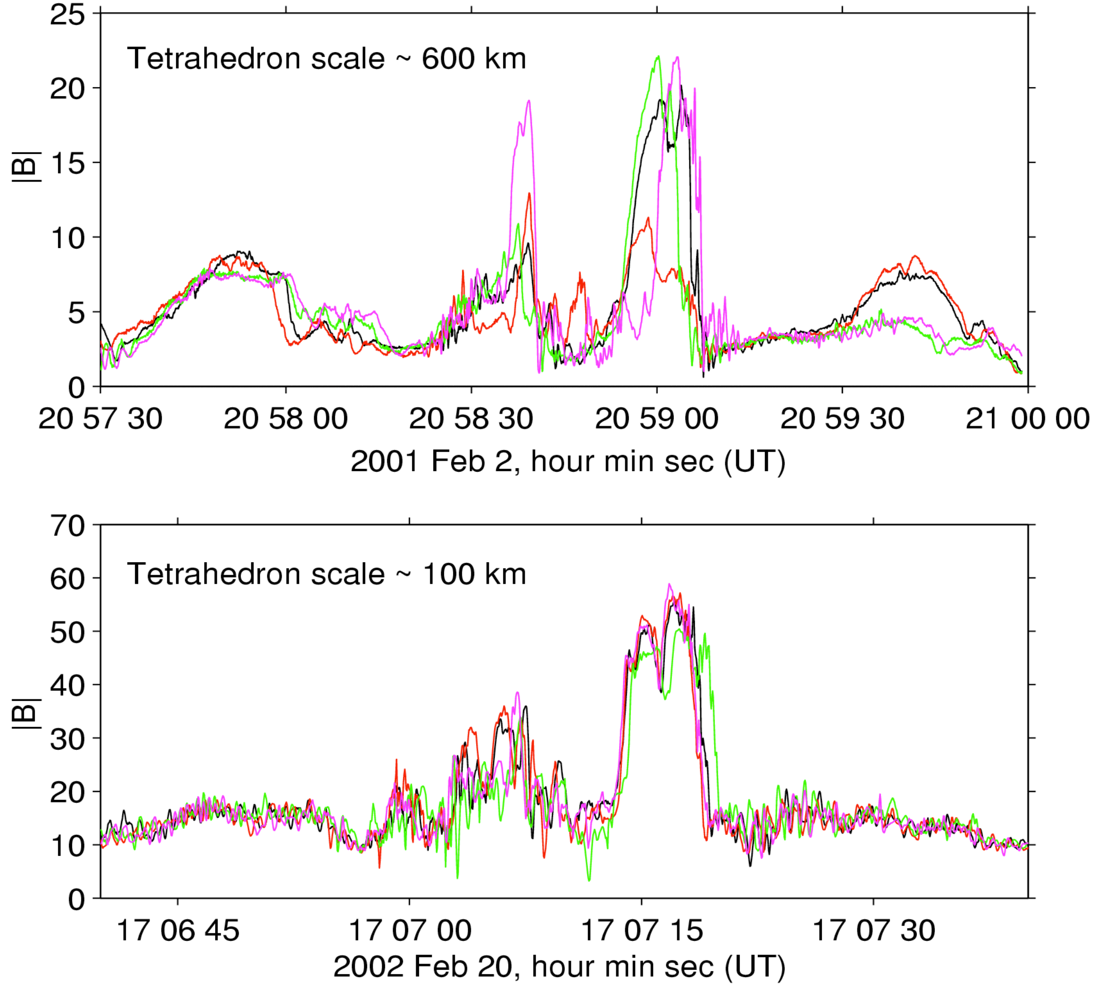


SLAMS = Short Large-Amplitude Magnetic Structures)

(from Schwartz & Burgess)

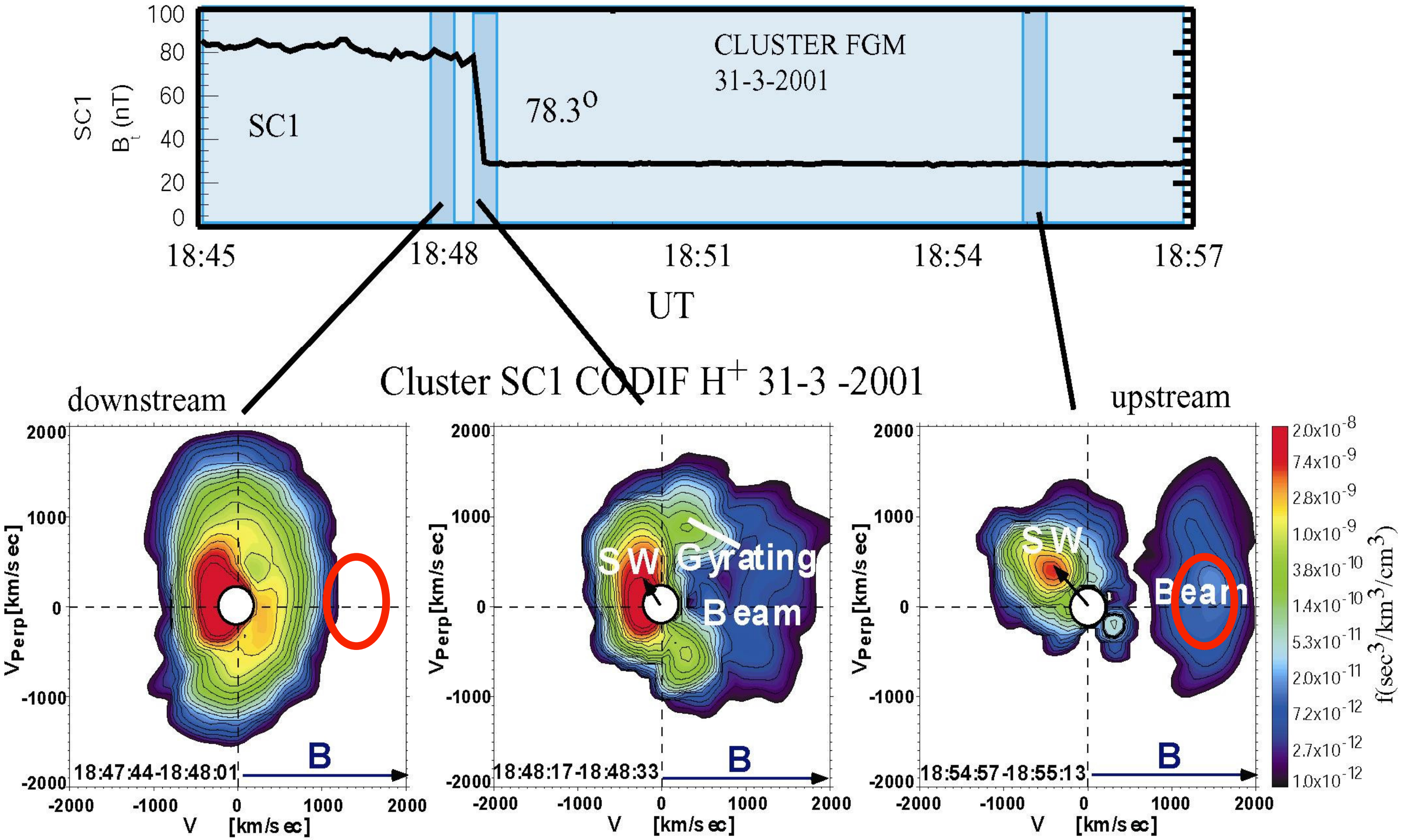
SLAMS – observations at different scales

- SLAMS are smaller than expected; internal structure



[Lucek et al., 2001]

Source of Upstreaming Beams: Reflection

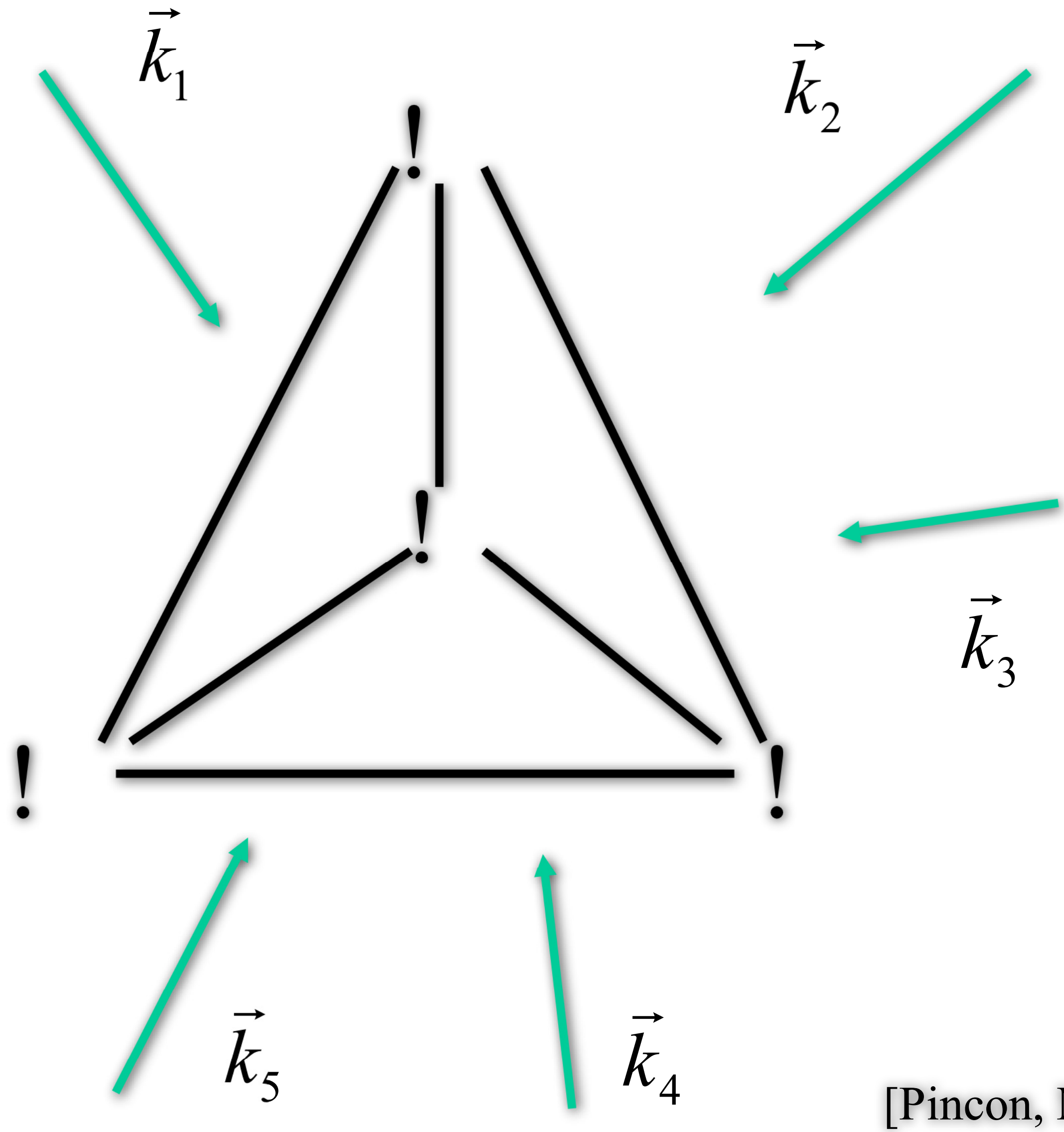


[Kucharek et al. 2003]

Magnetosheath Topics

- Waves in 4D (ω, **k**) Space
- Mirror Structure Scales

Wave Telescope / k-Filtering



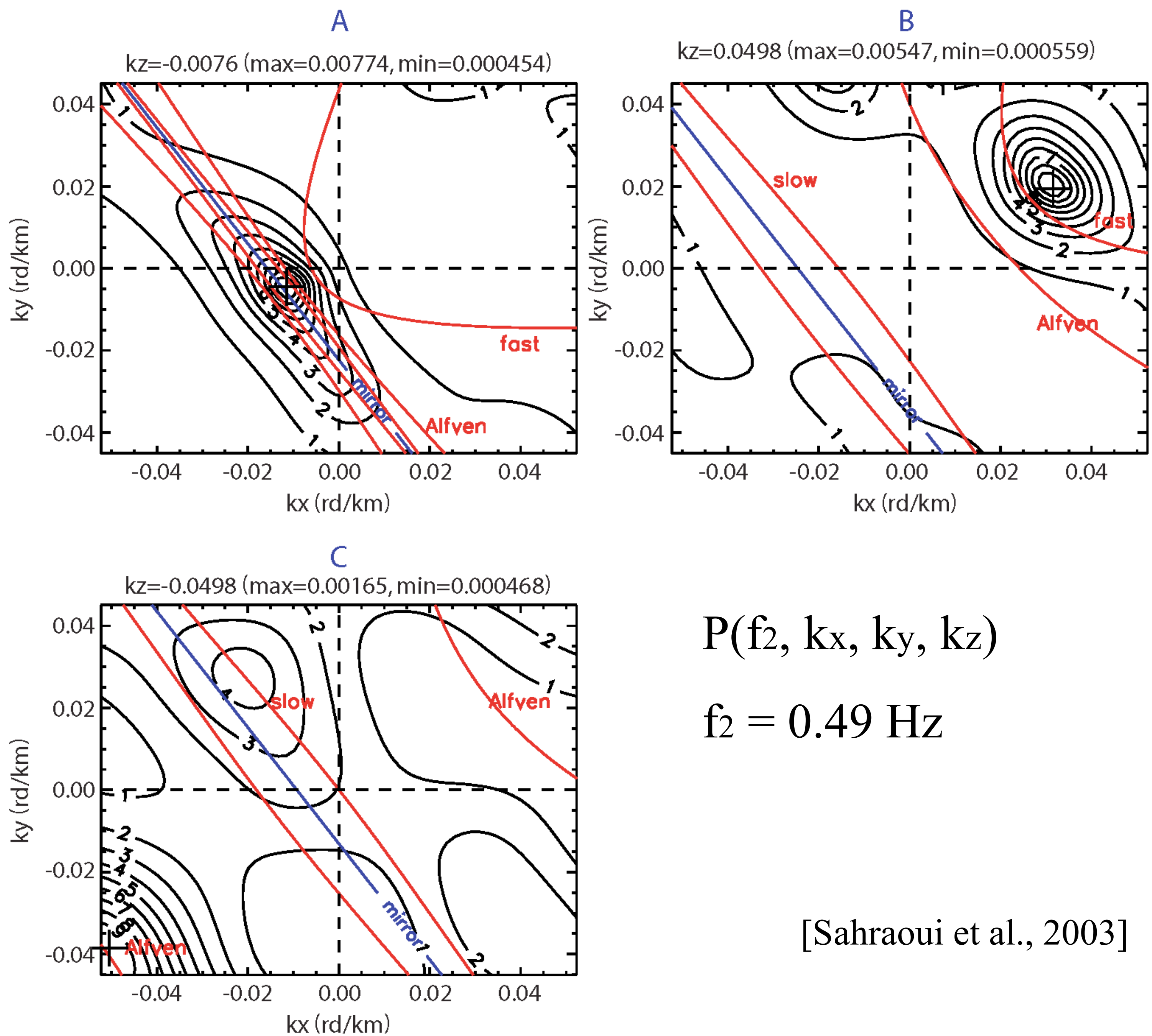
The measured signals at the spacecraft are superpositions of the different waves passing the CLUSTER configurations and cause phase differences according to $\vec{k}_i \cdot \vec{r}_j$

The wave telescope output is a weighted version of the input signal.

Beam forming or phased array techniques are used to determine weights.

[Pincon, Motschmann, Glassmeier 1998]

Wave Telescope / k-Filtering: Example



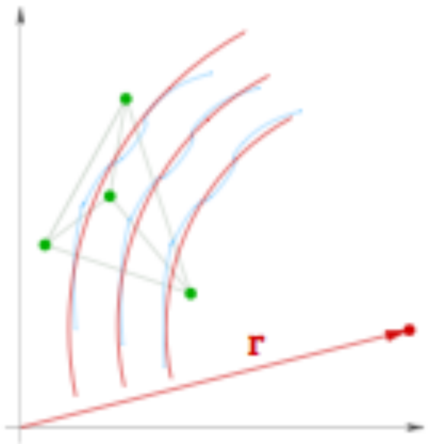
$P(f_2, k_x, k_y, k_z)$

$f_2 = 0.49$ Hz

[Sahraoui et al., 2003]

Source Location

Spherical waves representation



- measurements: $\mathcal{B}$
  - $\mathcal{B}_{ij} = B_i B_j$
- representation: $\boldsymbol{w}(k', \boldsymbol{r}')$
  - $w_s \propto \rho_s'^{-1} \exp\{ik'\rho_s'\}$

Source locator

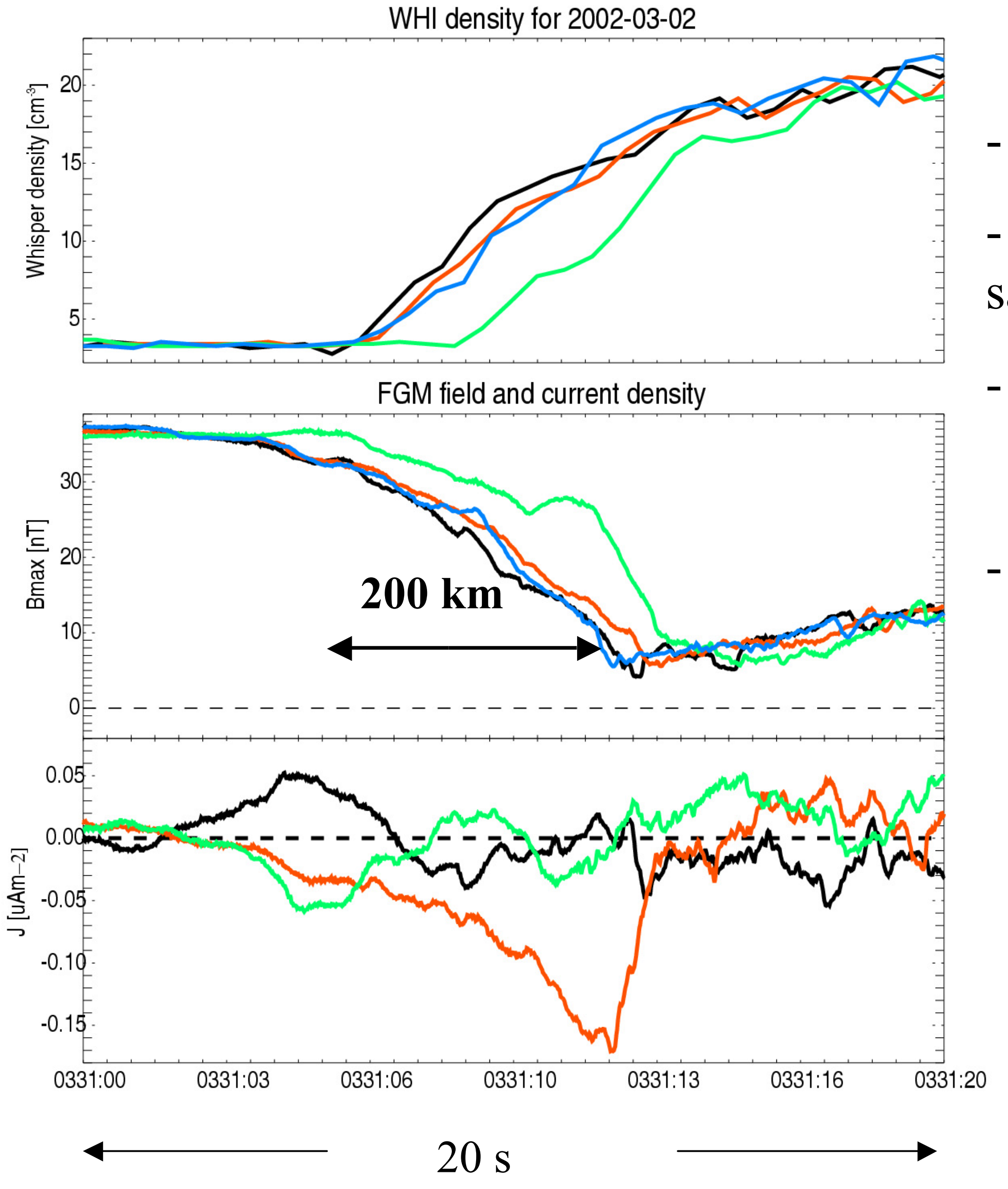
$$P(k', \boldsymbol{r}') = [\boldsymbol{w}^{\dagger}(k', \boldsymbol{r}')\mathcal{B}^{-1}(\omega)\boldsymbol{w}(k', \boldsymbol{r}')]^{-1}$$

(Constantinescu et al., 2007

Magnetopause Topics

- Thickness & Currents

Magnetopause: Thickness & Currents



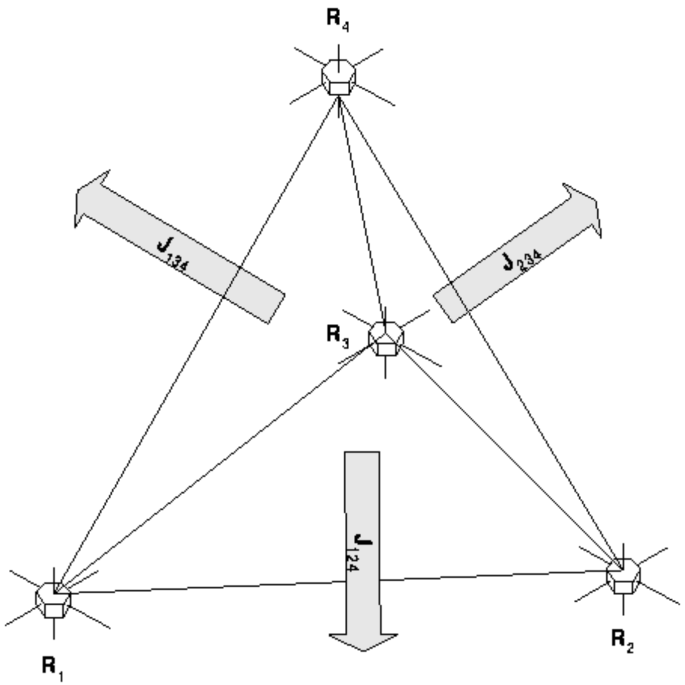
- Spacecraft separation: 100 km
- All 4 S/Cs in current layer at the same time
- currents from Ampere's law

$$\mathbf{j} = (\nabla \times \mathbf{B})/\mu_0$$

- No Boundary Layer

[Haaland et al., 2004]

The Curlometer



♦Uses Ampère's law to calculate the current density through the tetrahedron:

$$\boldsymbol{J}\cdot(\Delta\boldsymbol{R}_i\times\Delta\boldsymbol{R}_j)=\Delta\boldsymbol{B}_i\cdot\Delta\boldsymbol{R}_j-\Delta\boldsymbol{B}_j\cdot\Delta\boldsymbol{R}_i$$

Also we have:

$$div(\boldsymbol{B})|\Delta\boldsymbol{R}_i\cdot\Delta\boldsymbol{R}_j\times\Delta\boldsymbol{R}_k|=|\sum_{cyclic}\Delta\boldsymbol{B}_i\cdot\Delta\boldsymbol{R}_j\times\Delta\boldsymbol{R}_k|$$

♦This estimates ***J*** normal to the face 1ij of the tetrahedron.

♦Assumption: linear field variation between spacecraft.

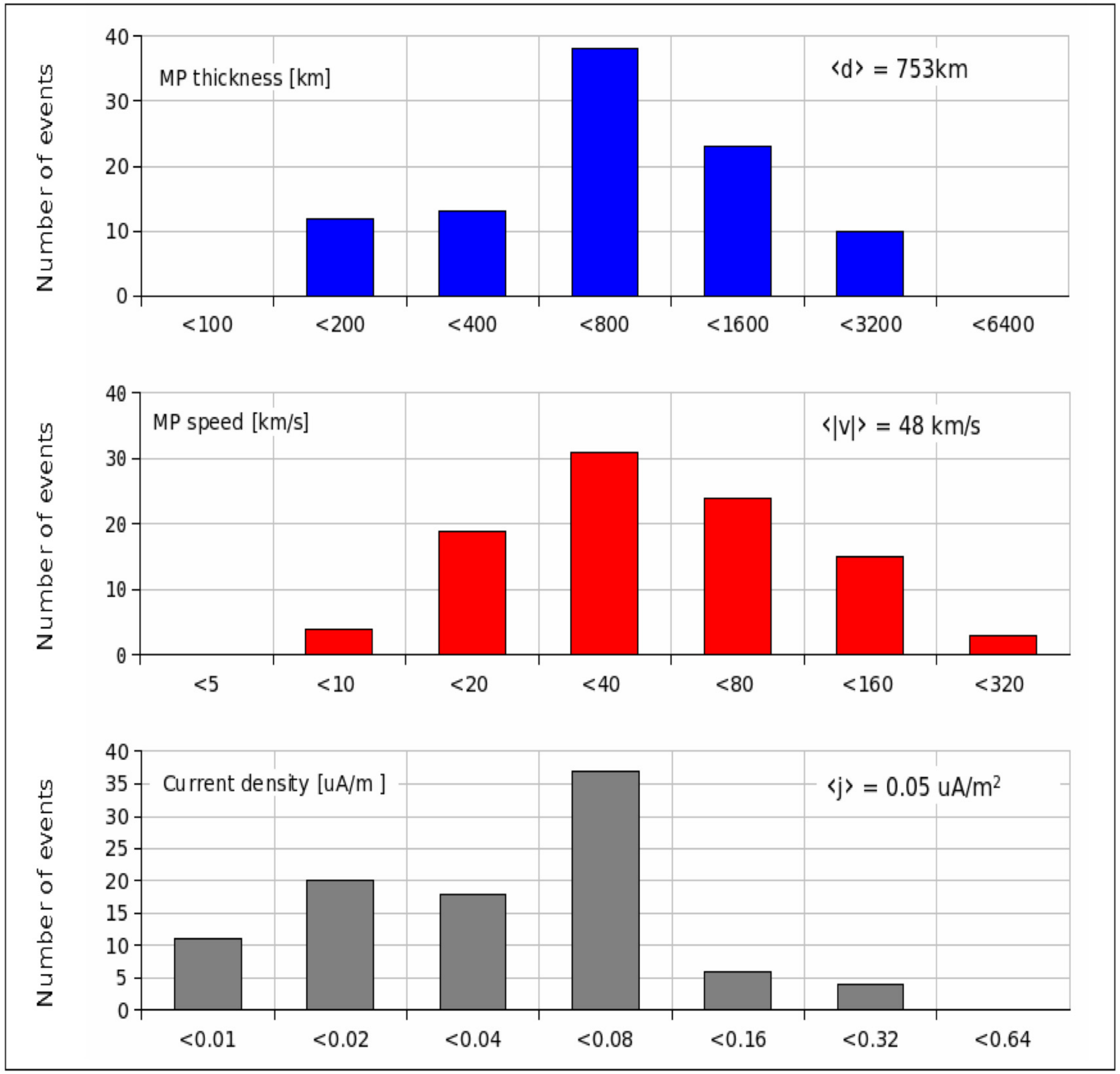
•The calculation of *div(**B**)* can provide a quality estimate for the calculated value of ***J***.

•The orientation of ***J*** to the s/c configuration, as well as to the magnetic field, also affects the application.

•Temporal variations have different effects on the estimates of ***J*** and *div(**B**)* at different time resolutions.

(from Dunlop et al., 2002)

Magnetopause Statistics



Thickness

Speed

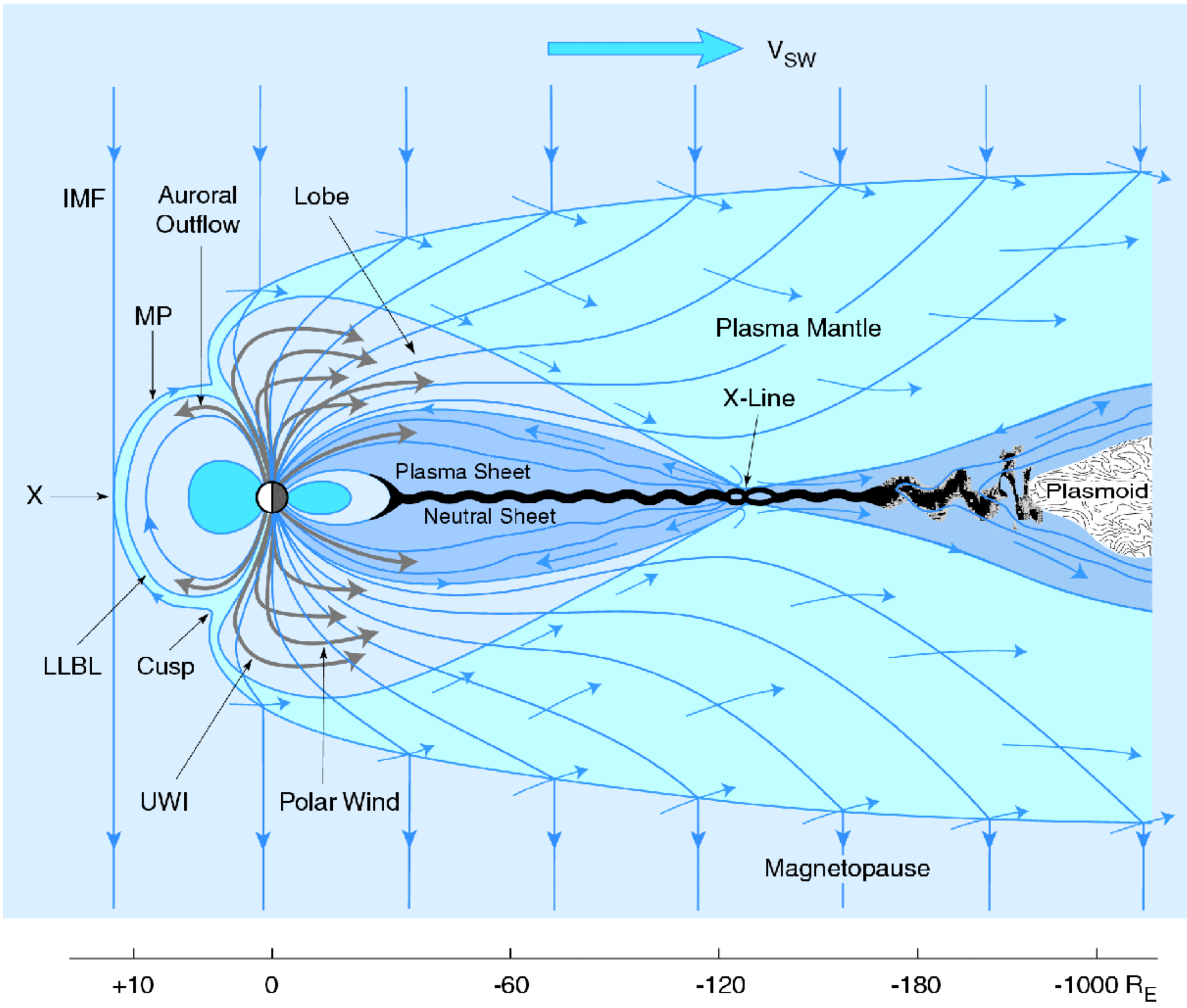
Current Density

[Paschmann et al., 2005]

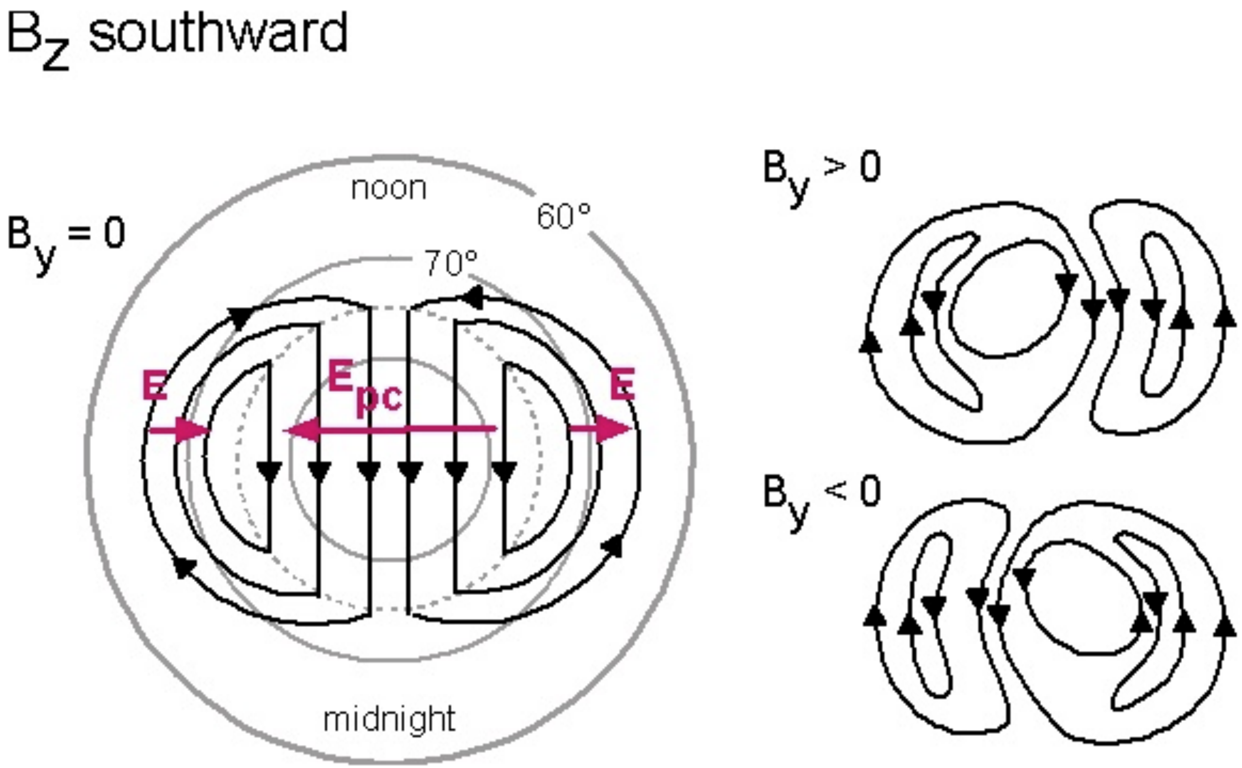
Magnetosphere Topics

- Convection
- Neutral Sheet Oscillations
- Fast Flow Scales
- Dipolarization Fronts
- Continuum Radiation
- Black Aurora
- Auroral Kilometric Radiation

Magnetosphere Topology & Flows



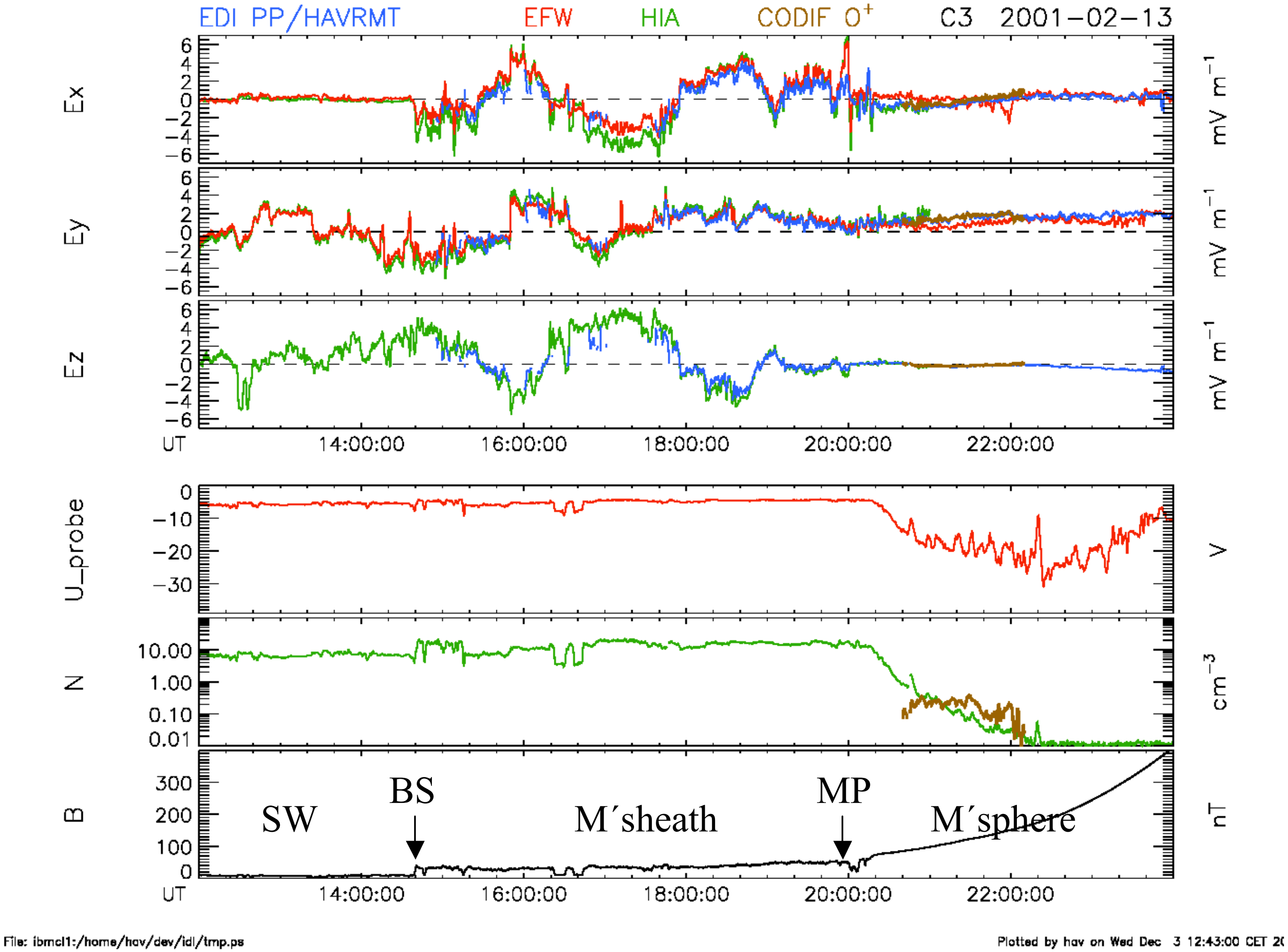
Two-Cell Pattern in the Ionosphere



Digression: Electric Field Measurements on Cluster

- Electric Field Instrument (EFW): **E** = Voltage / Distance
- Electron Drift Instrument (EDI): $\mathbf{E} = -\mathbf{V}_e \times \mathbf{B}$
- Ion Spectrometer (CIS) $\mathbf{E} = -\mathbf{V}_i \times \mathbf{B}$

Electric Fields from EFW, EDI & CIS

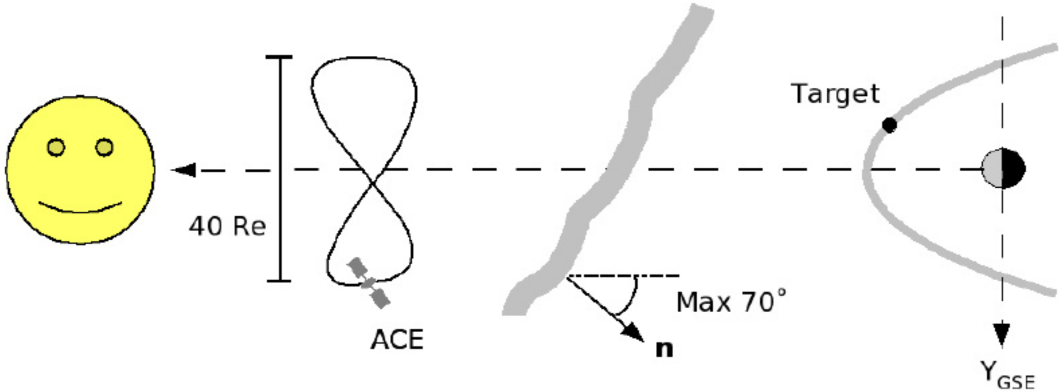


[Eriksson et al., 2003]

Procedure for Convection Statistics

- Start with 5 years of 1-min averages of EDI velocities
- Propagate IMF conditions measured by ACE at L1
- Remove intervals with ‘unstable’ IMF by bias vector filtering
- Map EDI velocity measurements into ionosphere
- Transform into potential distributions
- Sort according to IMF and other parameters

Upstream IMF conditions :
SW propagation – Weimer method



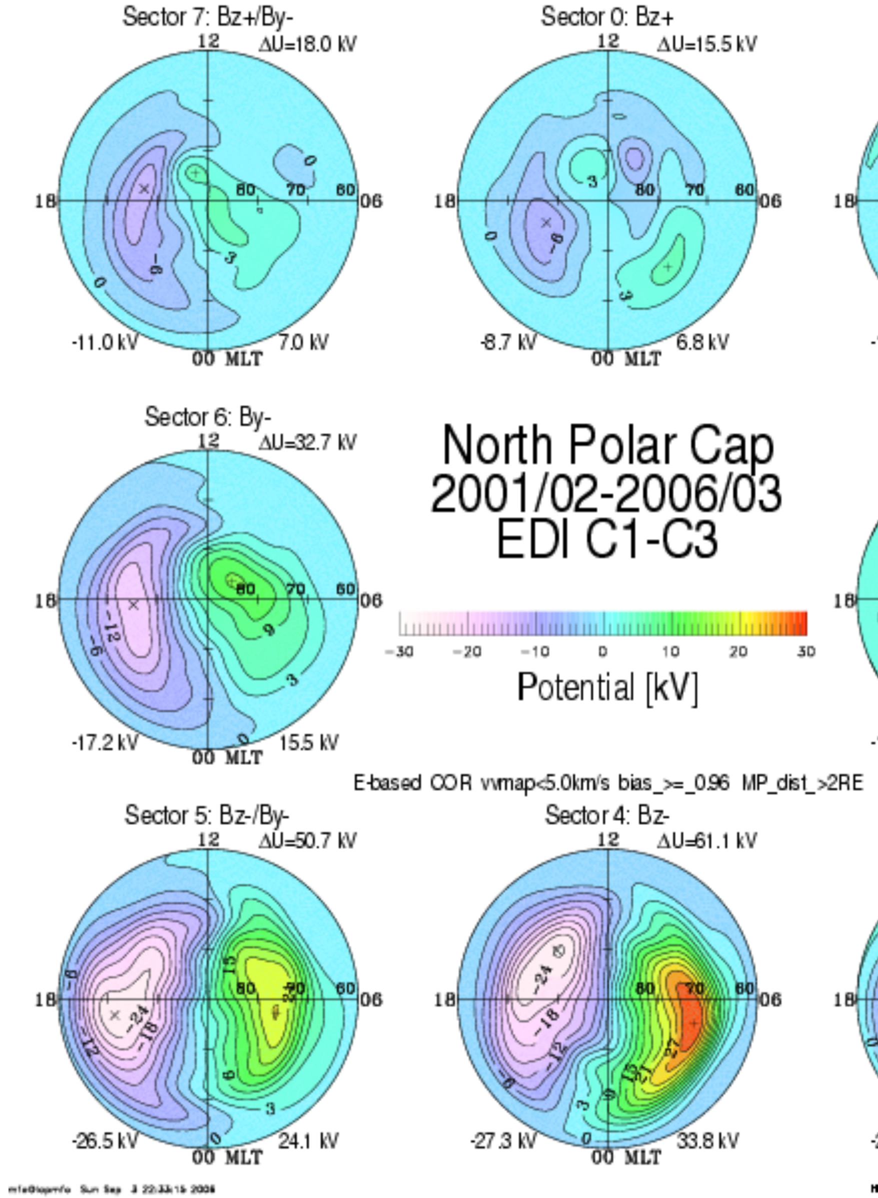
$$\Delta t = \frac{(\mathbf{r}_{ACE} - \mathbf{r}_{TARGET}) \cdot \mathbf{n}}{\mathbf{V}_{ACE} \cdot \mathbf{n}}$$

n from constrained MVAB!!

Weimer et al., *J. Geophys. Res.* Vol. **108**, doi: 10.1029/2002JA009405, 2003; with Correction Dec 2004

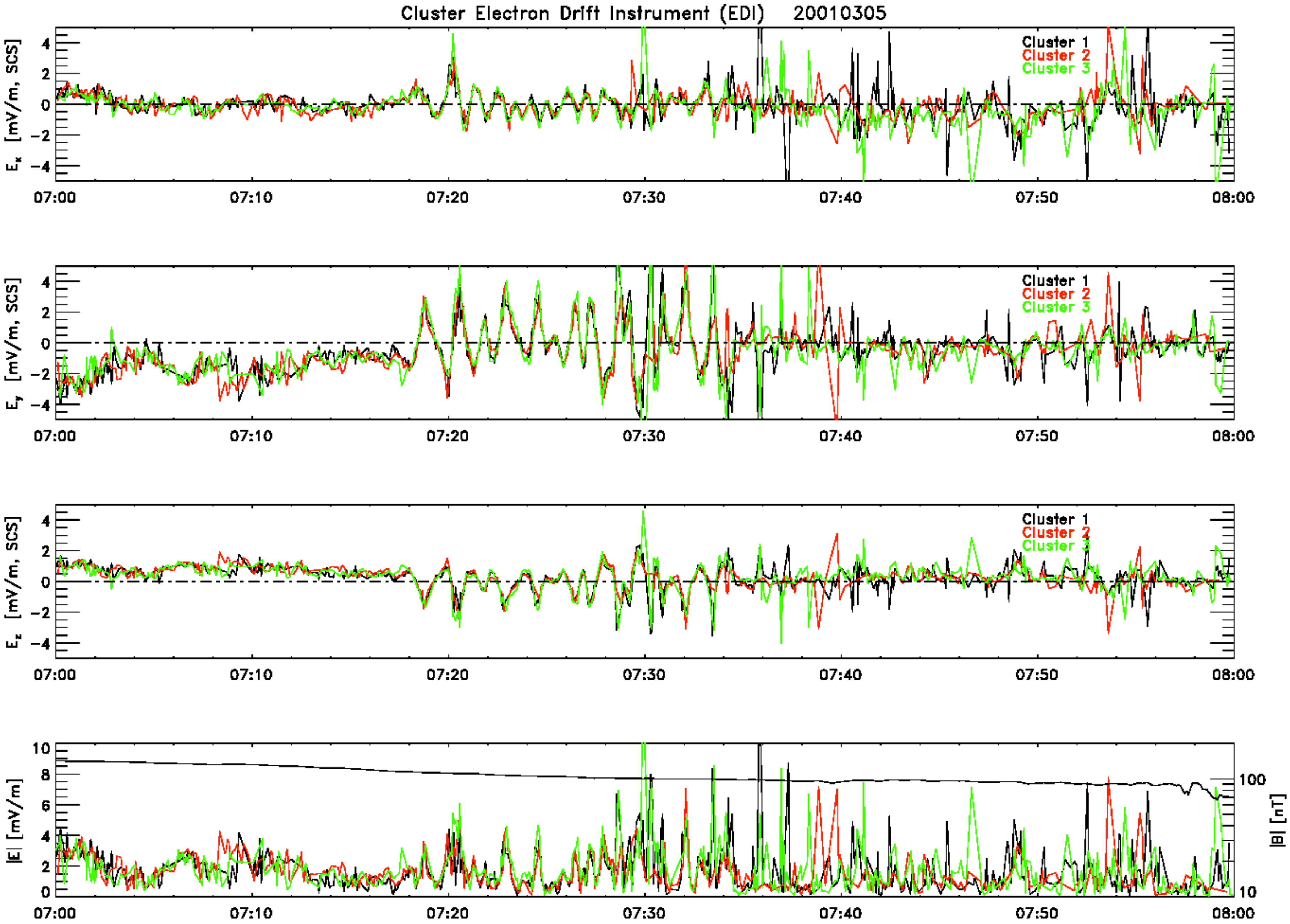
Haaland, S., G. Paschmann, and B.U.Ö. Sonnerup, *J. Geophys. Res.*, Vol. **111**, doi: 10.1029/2005JA011376, 2006

Potential Patterns for 8 IMF Sectors



(Haaland et al., 2007)

Convection Time Series from EDI



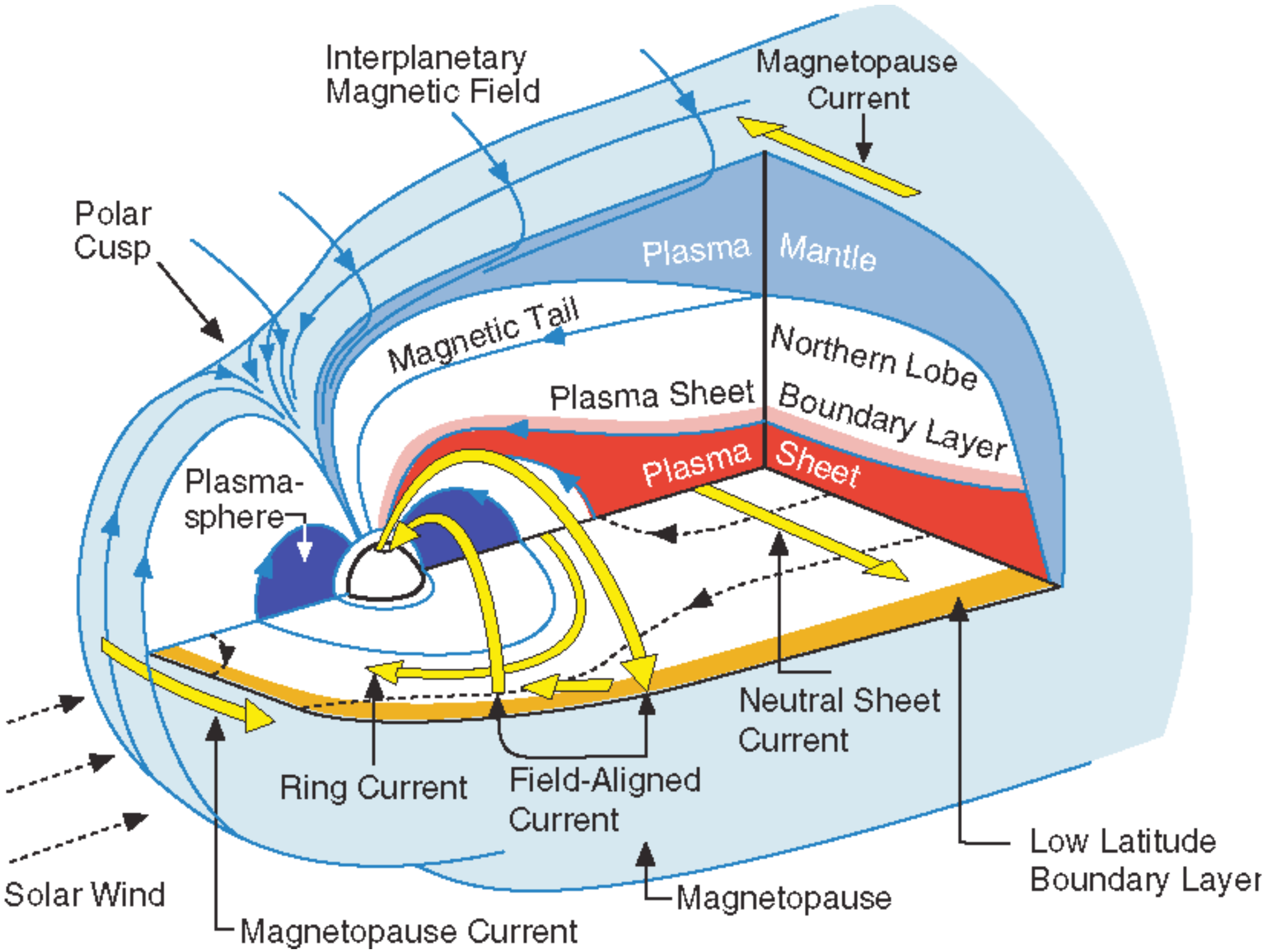
plotted : Thu Mar 22 17:24:08 2001

Cluster Magnetic Reconnection Obervations

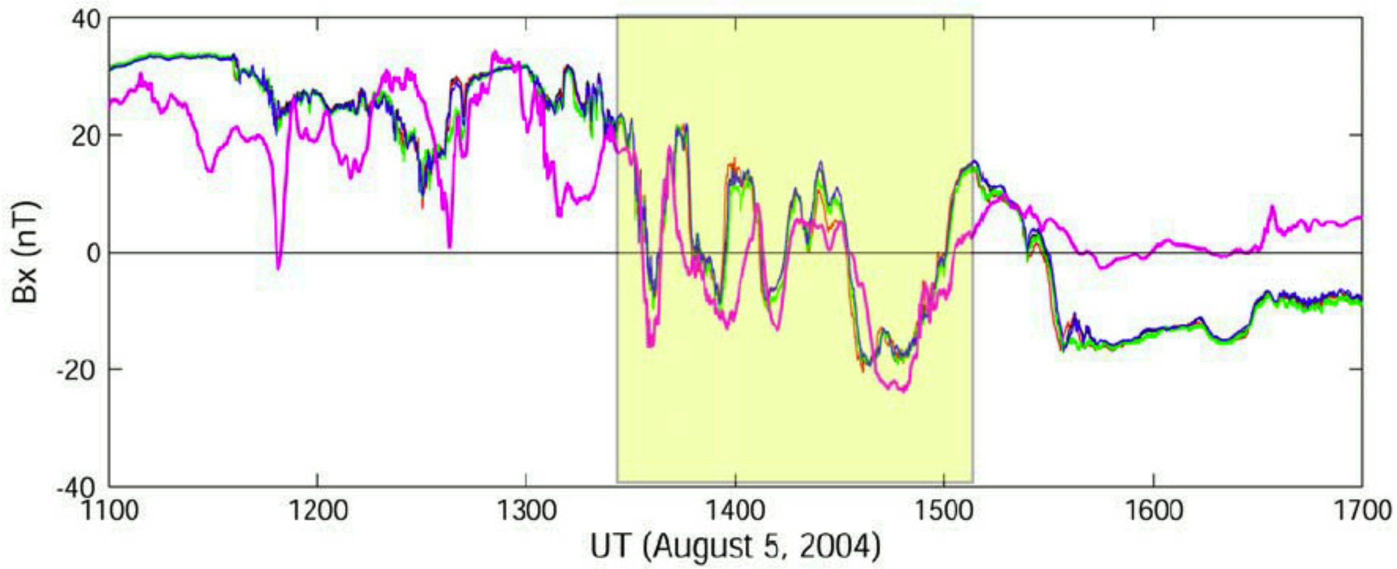
- Solar Wind
- Magnetosheath
- Magnetopause
- Magnetotail

More on Friday!

3D View of the Magnetosphere

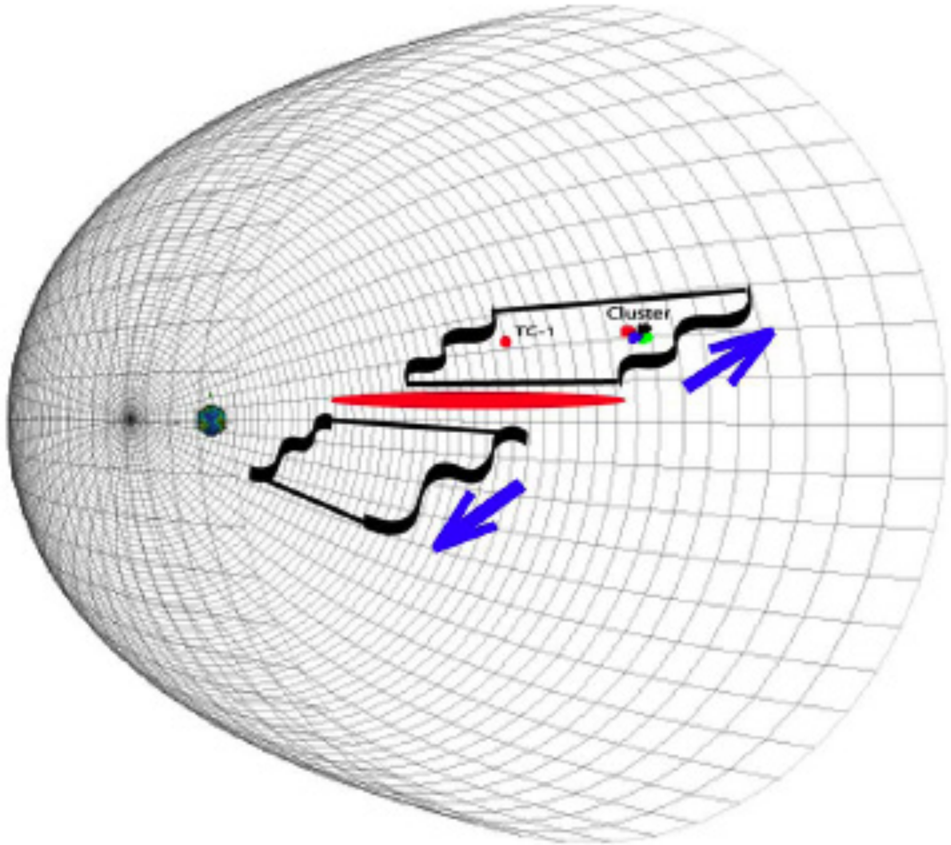


Neutral Sheet Oscillations: Cluster & DoubleStar



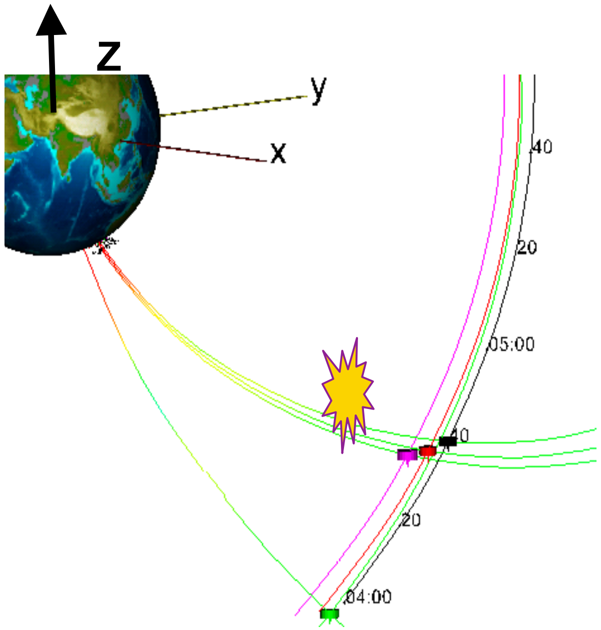
(From Zhang et al., 2005)

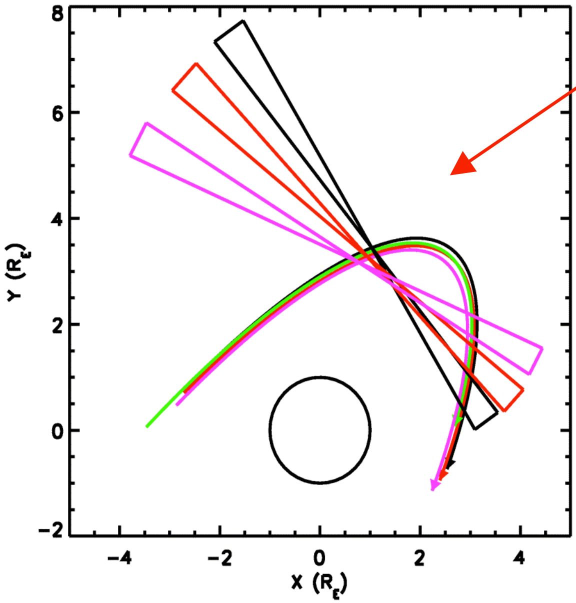
Neutral Sheet Oscillations: Interpretation

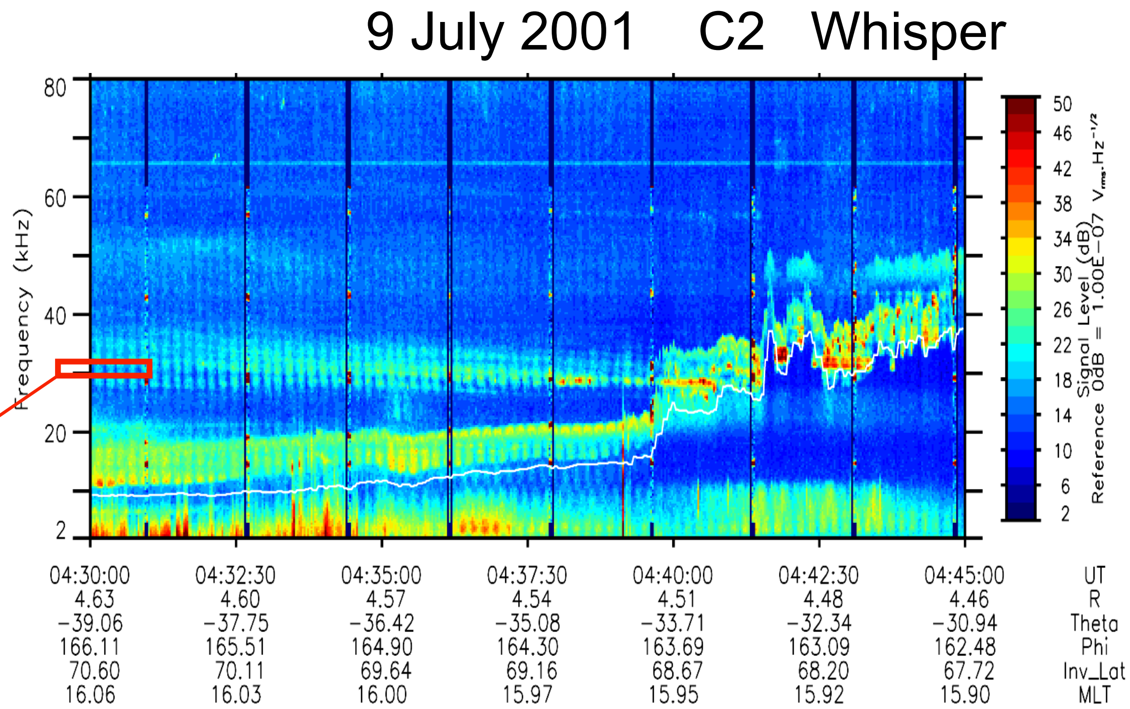


(Runov et al., 2004; Zhang et al., 2005)

Localization of terrestrial continuum radiation

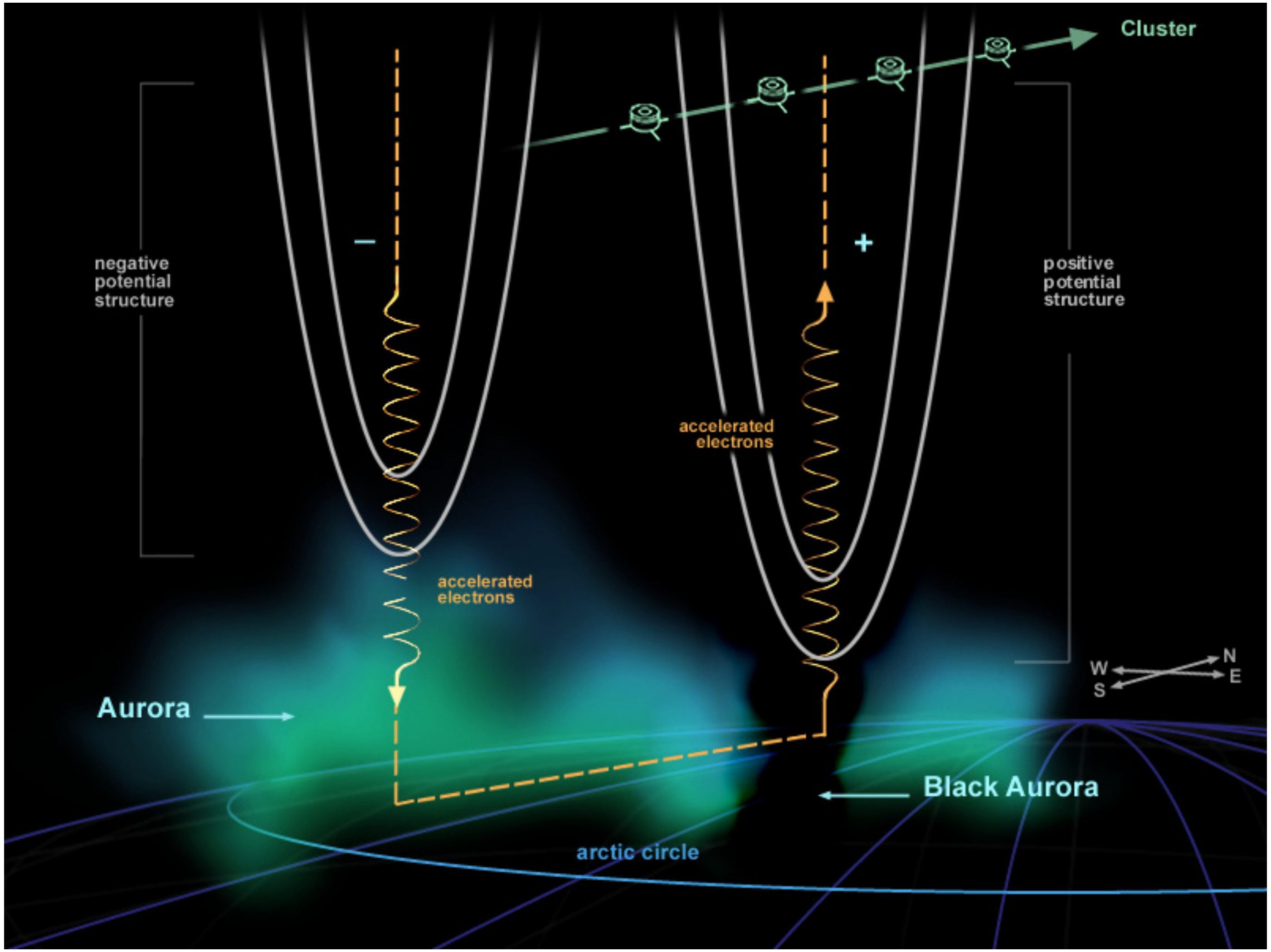






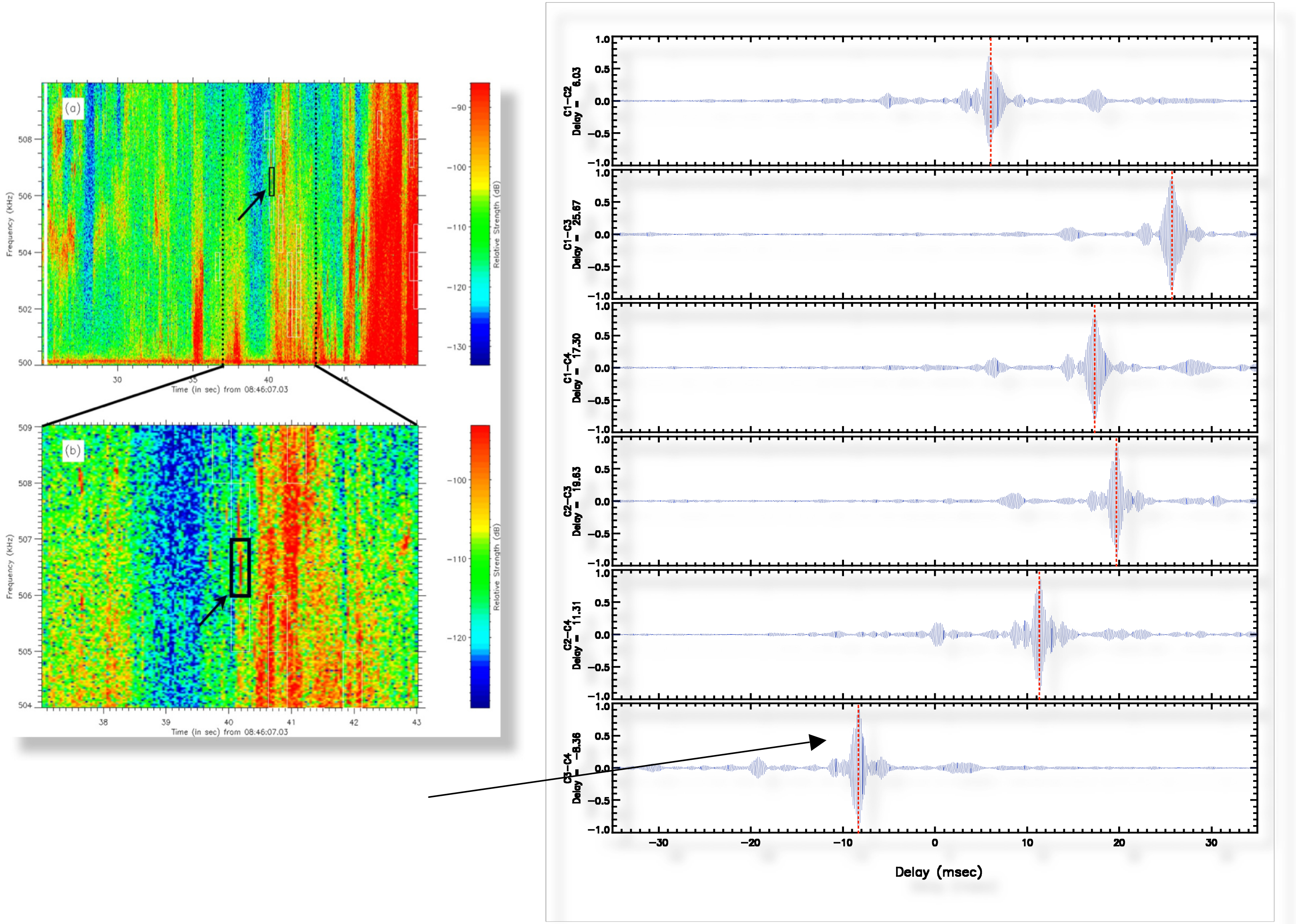
[Decreau et al., 2003]

Aurora & Black Aurora



(from Marklund et al., 2001)

Auroral Kilometric Radiation: VLBI with Cluster WBD



(Mutel et al., 2003)

The End