Formation of the high-altitude cusps and dayside boundary layers: CLUSTER results

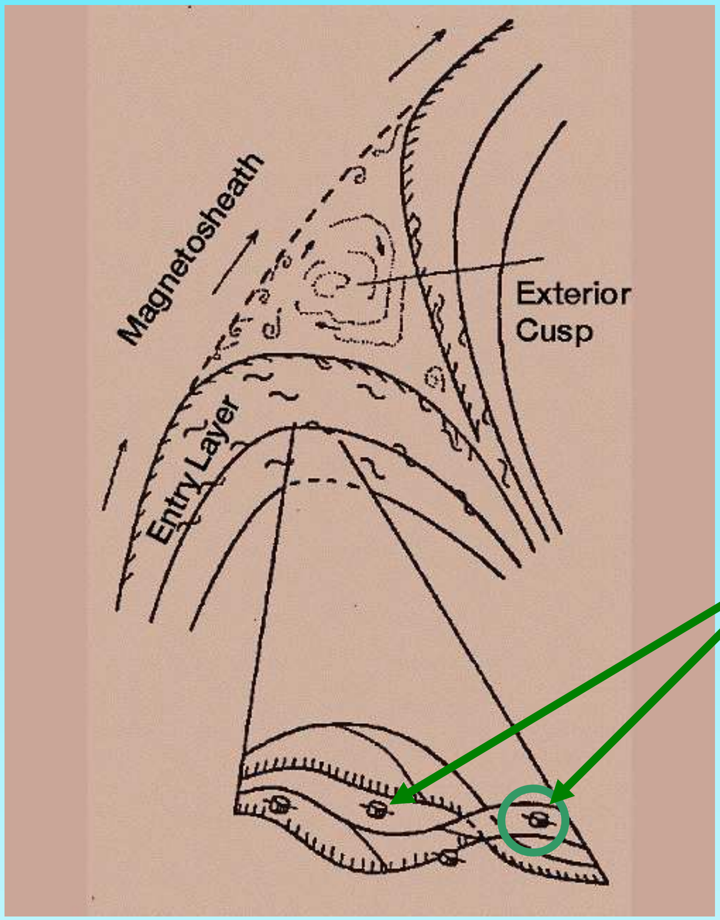
Benoit LAVRAUD
Space Science and Applications, Los Alamos National Laboratory, USA

Michelle THOMSEN (LANL, Los Alamos, USA)
Peter CARGILL (Imperial College, London, UK)
Elena BUDNIK (CESR/CNRS, Toulouse, France)
Steve SCHWARTZ (Imperial College, London, UK)
Bertrand LEFEBVRE (Imperial College, London, UK)
Tai PHAN (SSL, UC Berkeley, CA, USA)
Andrei FEDOROV (CESR/CNRS, Toulouse, France)
Malcolm DUNLOP (RAL, Didcot, UK)
Matthew TAYLOR (MSSL, Surrey, UK)
Henri REME (CESR/CNRS, Toulouse, France)
Andre BALOGH (Imperial College, London, UK)
Andrew FAZAKERLEY (MSSL, Surrey, UK)
and the CLUSTER Teams.

Outline

- Introduction to the magnetospheric cusps
- Results from case studies:
  → Northward IMF
  → Southward IMF
- Results from statistical studies:
  → Global properties for all IMF conditions
  → Flows characteristics for selected IMF
- Conclusions: structure and role of the cusps

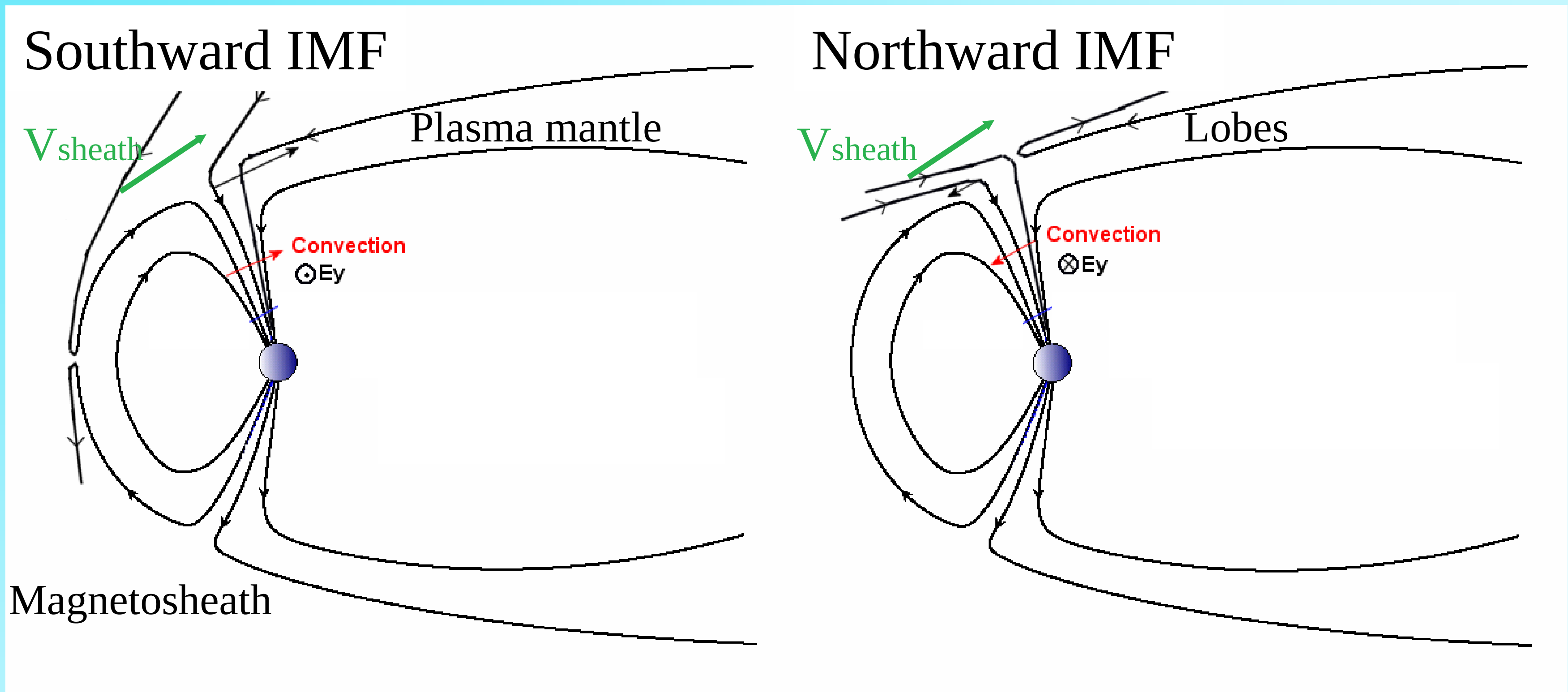
Introduction: the magnetospheric cusps



- Original picture from Cluster mission proposal
- Cluster orbit was designed to encounter the high-altitude cusp

- The exterior cusp region may be characterized by large-scale turbulence and flow eddies [e.g. Haerendel et al., 1978]
- The exterior cusp / magnetosheath boundary may be a shock [e.g. Walters, 1966; Cargill, 1999]

Introduction: reconnection and the magnetospheric cusps

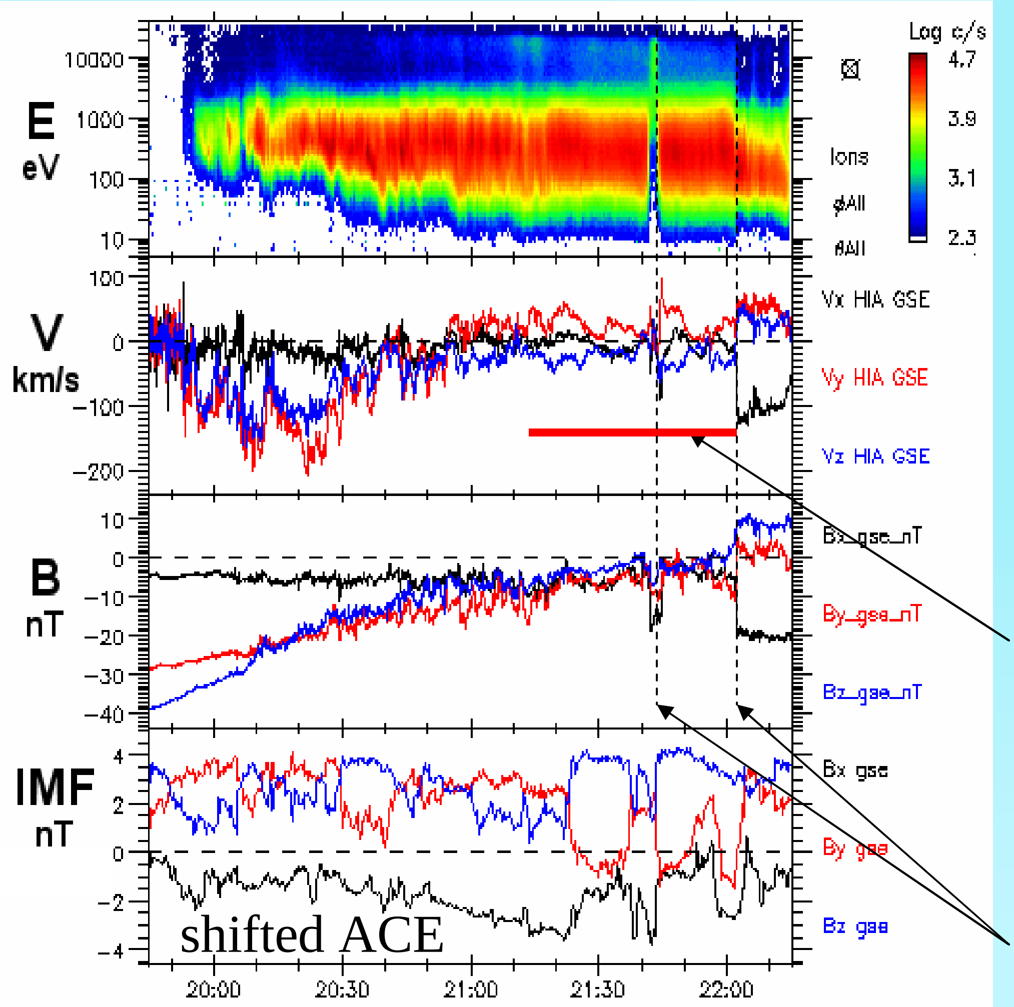


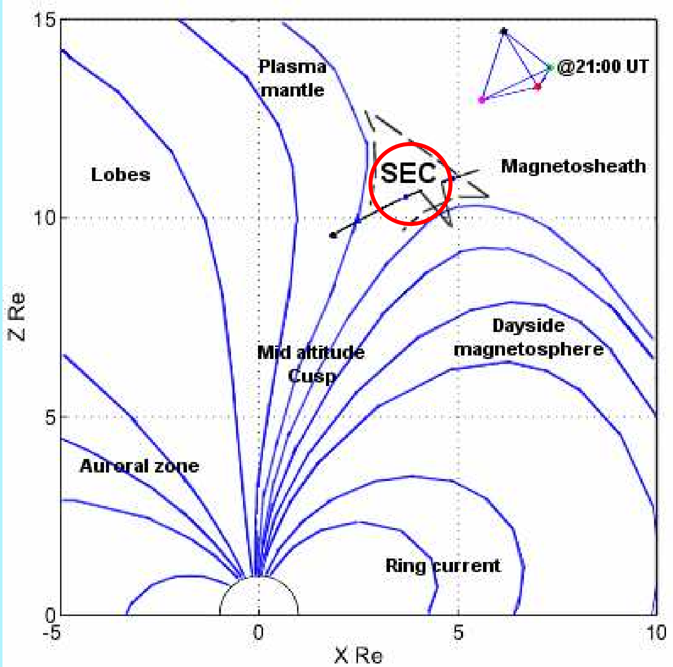
- Reconnection may occur at the low-latitude magnetopause for southward IMF, but in the lobes for northward IMF
- The outer cusp boundary may be a rotational discontinuity (RD)
- Presence/absence of a plasma mantle for southward/northward IMF
- Super-Alfvenic flows in the magnetosheath would prevent sunward convection in the cusps under northward IMF

Case studies of the exterior cusp structure: Northward and Southward IMF

Northward IMF case: February 04, 2001

Stagnant exterior cusp and surrounding boundaries

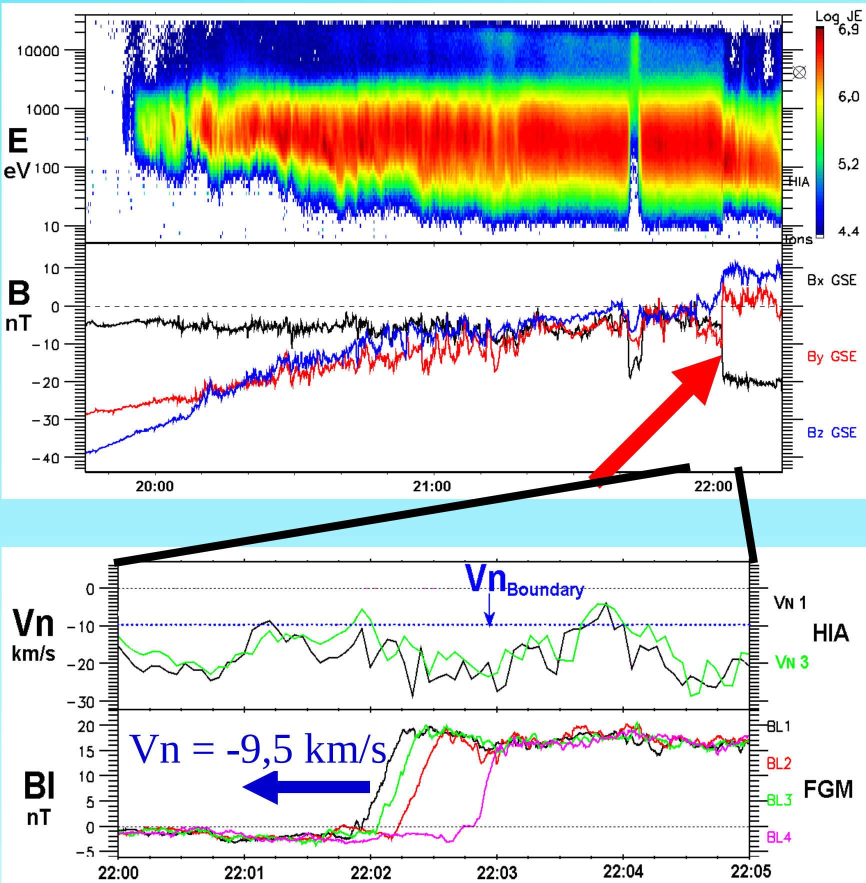




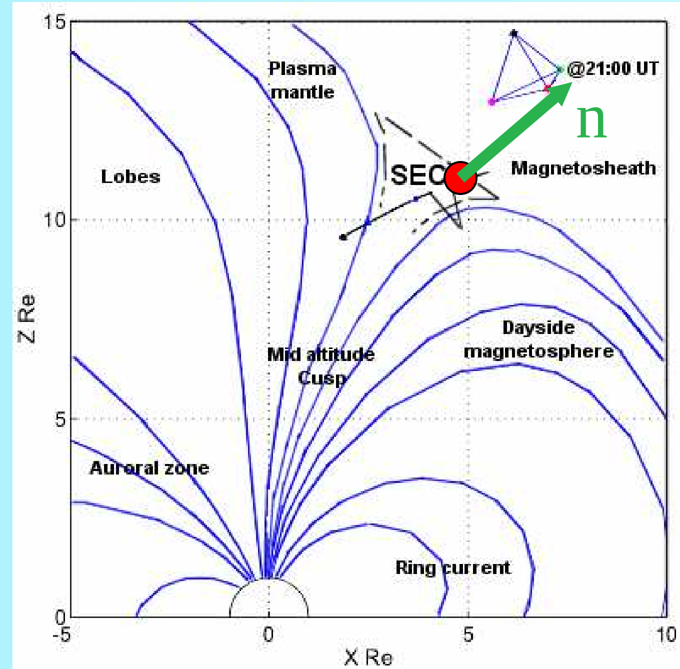
- The exterior cusp is stagnant and surrounded by:
- High-speed downward flows but no plasma mantle
- Two distinct boundaries with the plasma sheet and sheath

→ The exterior cusp is bounded by three distinct boundaries

Boundary with the magnetosheath (1)



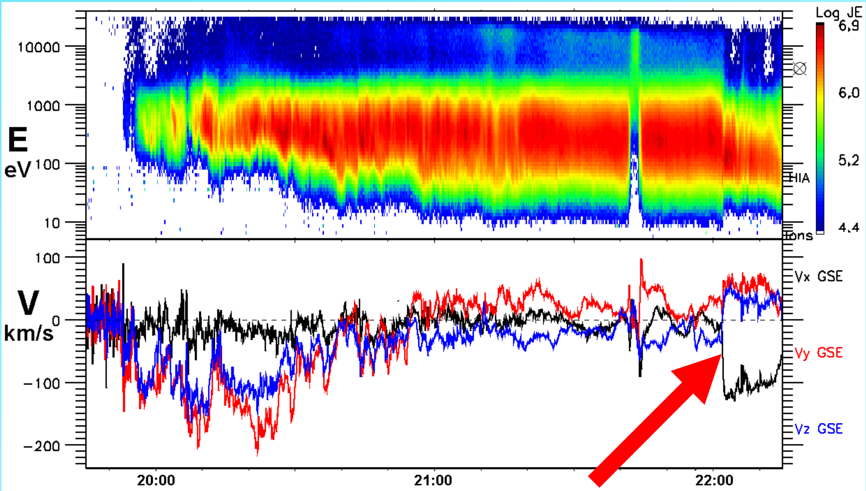
→ Magnetosheath plasma flows through an "open" boundary

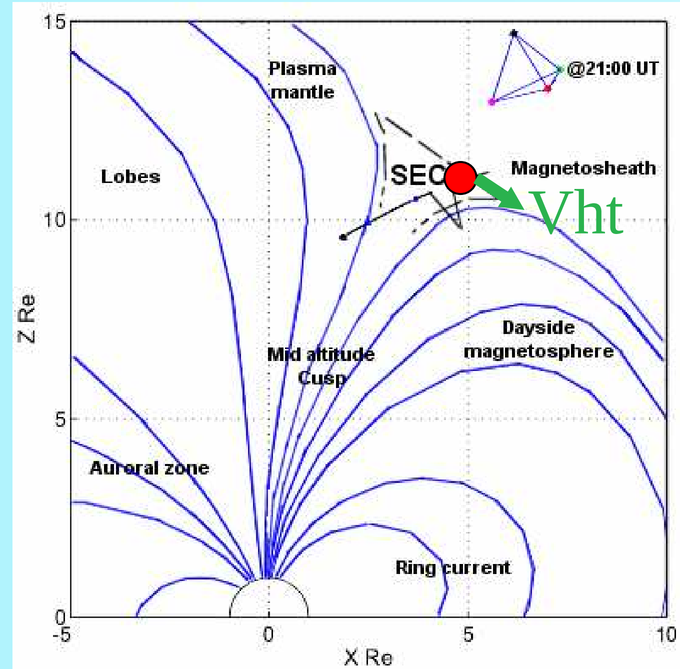


Minimum variance and planar discontinuity analyses yield:

- Outward boundary normal
- Inward normal magnetic component
- Inward boundary speed
- Inward, additional plasma flow

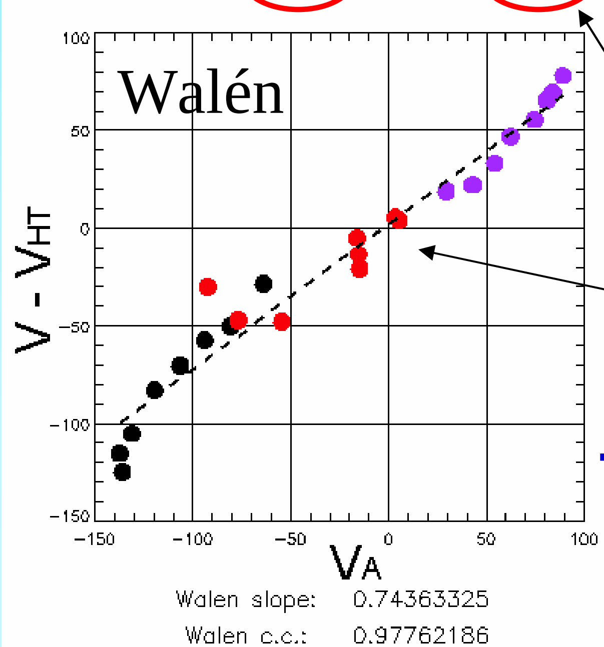
Boundary with the magnetosheath (2)





V_{HT} = 10,39 41,29 −18,41

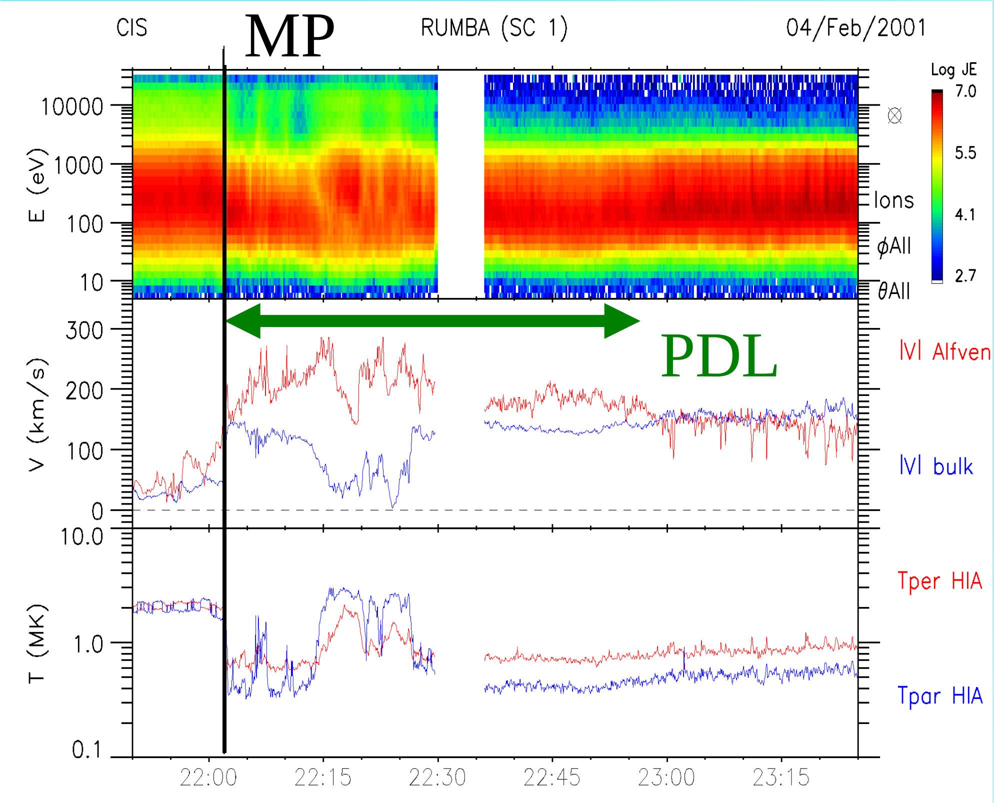
$V_{SHEATH} - V_{HT} = V_A$



- Slow deHoffmann – Teller velocity, directed sunward and downward
- Walén test satisfied consistent with $B_n \neq 0$

→ The boundary is possibly a rotational discontinuity (RD) originating from lobe reconnection

Sub-Alfvenic plasma depletion layer



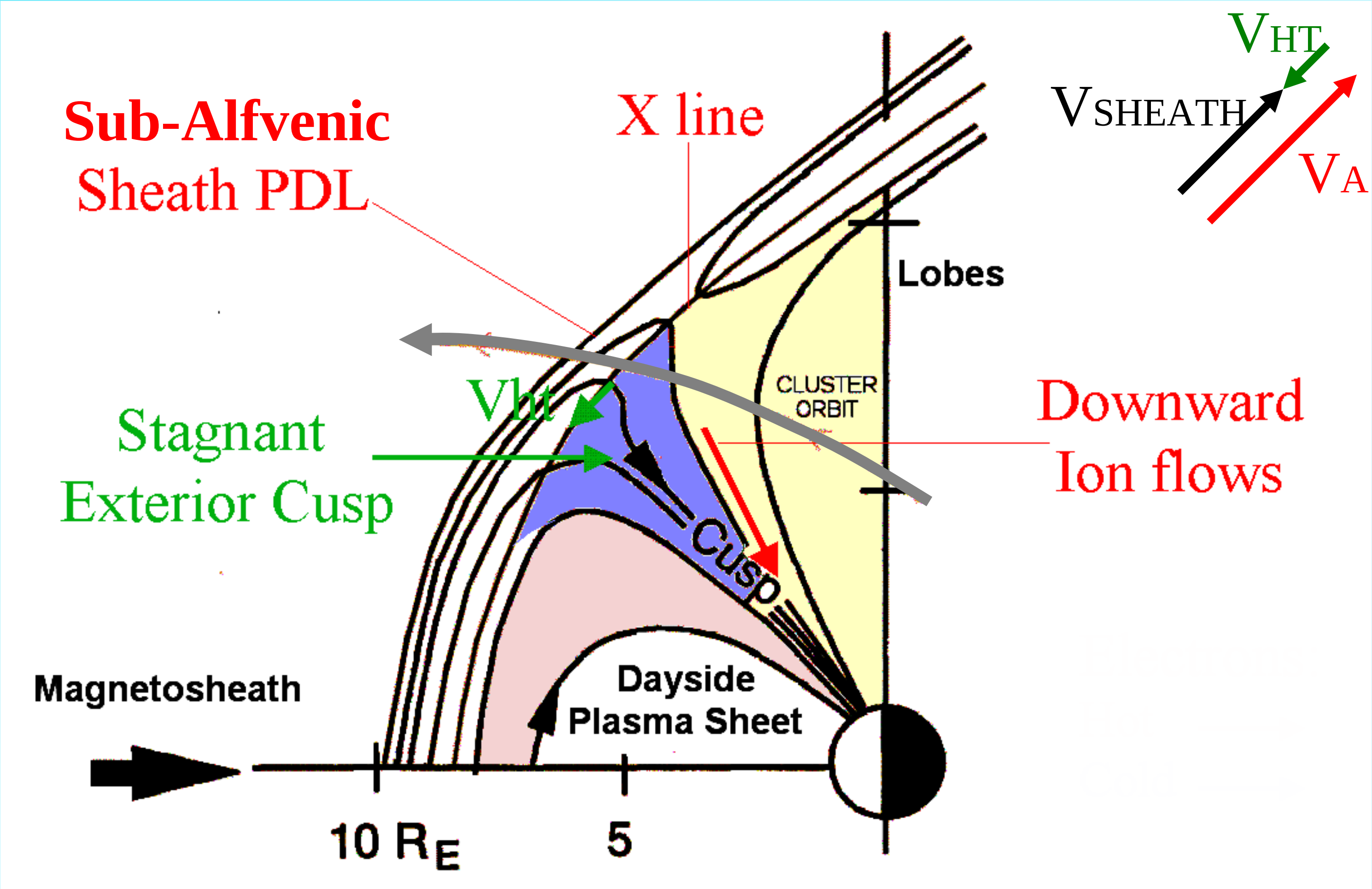
- Magnetic field pile-up at the dayside magnetopause
  → Plasma depletion layer **(PDL)**

- Density decreases and magnetic field increases
  → Alfvén speed increases
  → Sub-Alfvénic flows close to the magnetopause

→ The sub-Alfvénic PDL allows the sunward convection **(V_{HT})** and propagation of the reconnected field lines

→ It may allow the stability of the lobe reconnection site

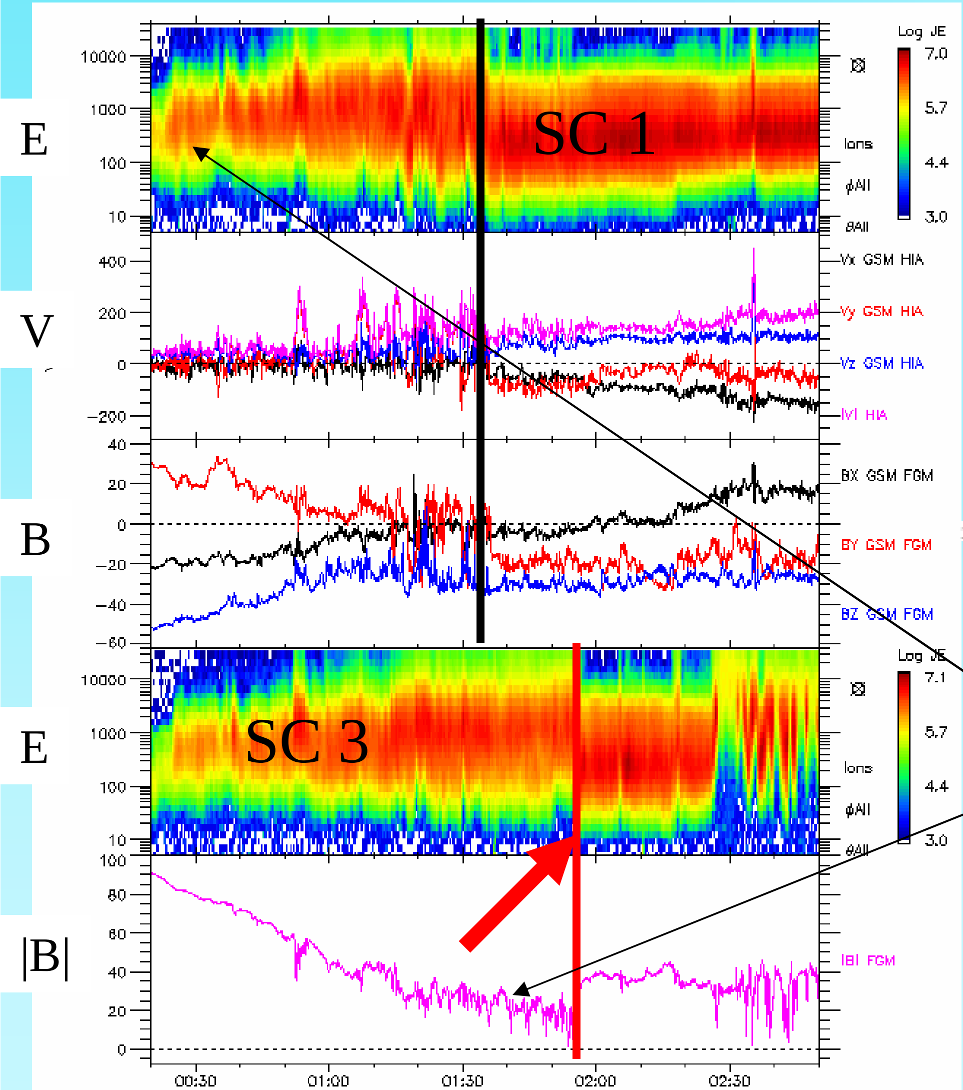
The exterior cusp under northward IMF: Overall structure

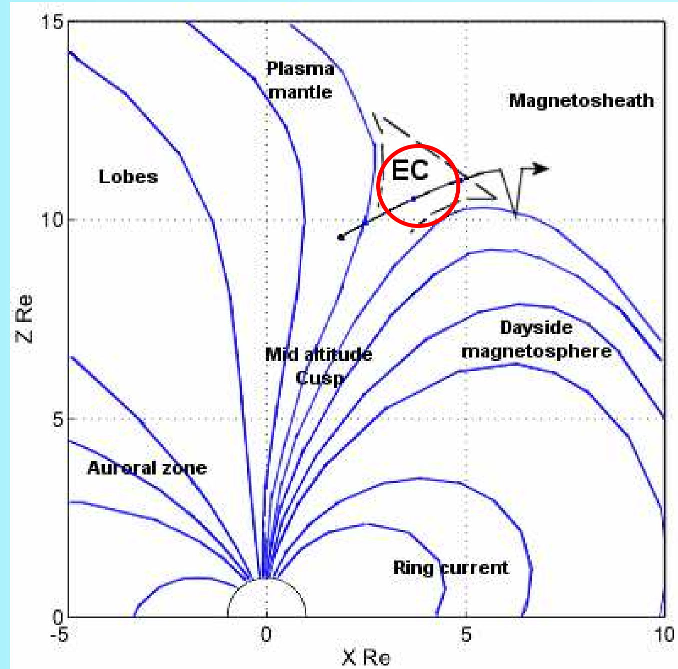


→ The exterior cusp structure is consistent, at large scales, with the occurrence of lobe reconnection

Southward IMF case: April 01, 2003

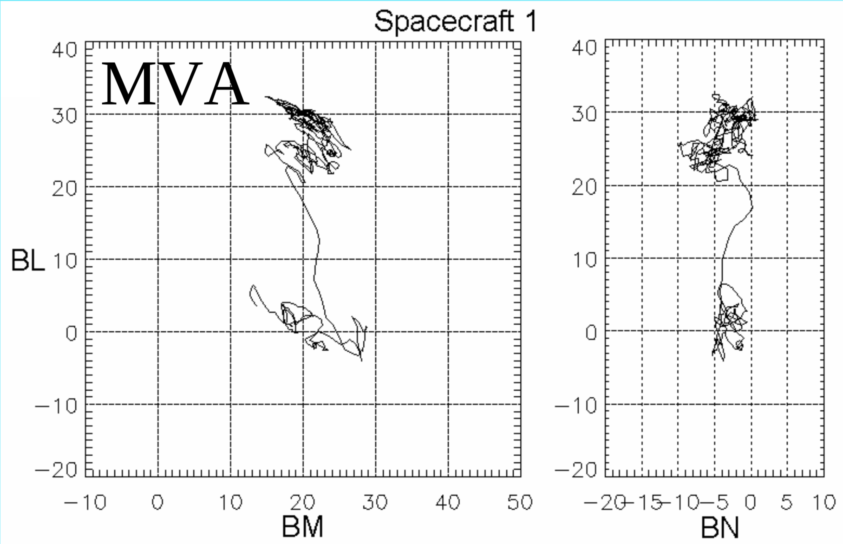
Large plasma flows in the high-altitude cusp

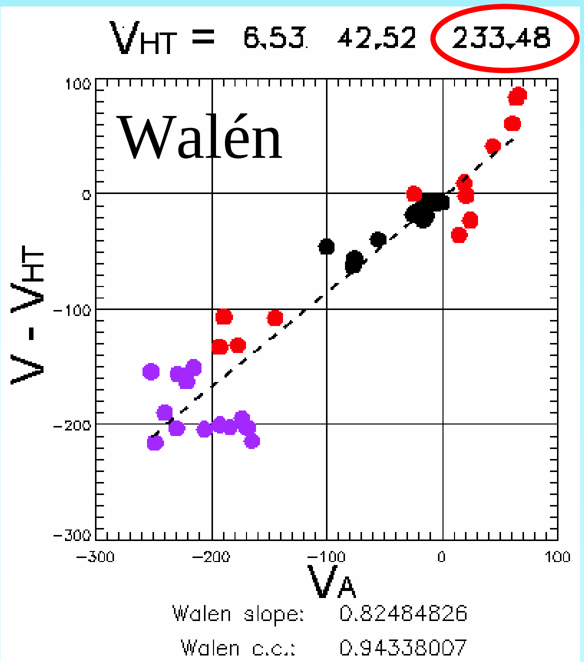


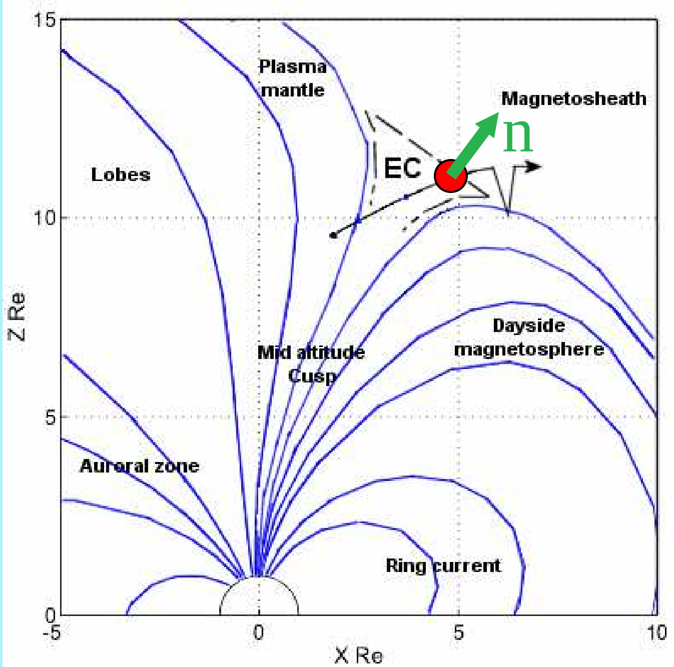


- Presence of a plasma mantle
- Low magnetic field and large flows in the exterior cusp simultaneously at two S/C
- S/C 1 monitors a southward IMF when S/C 3 crosses MP

Boundary with the magnetosheath



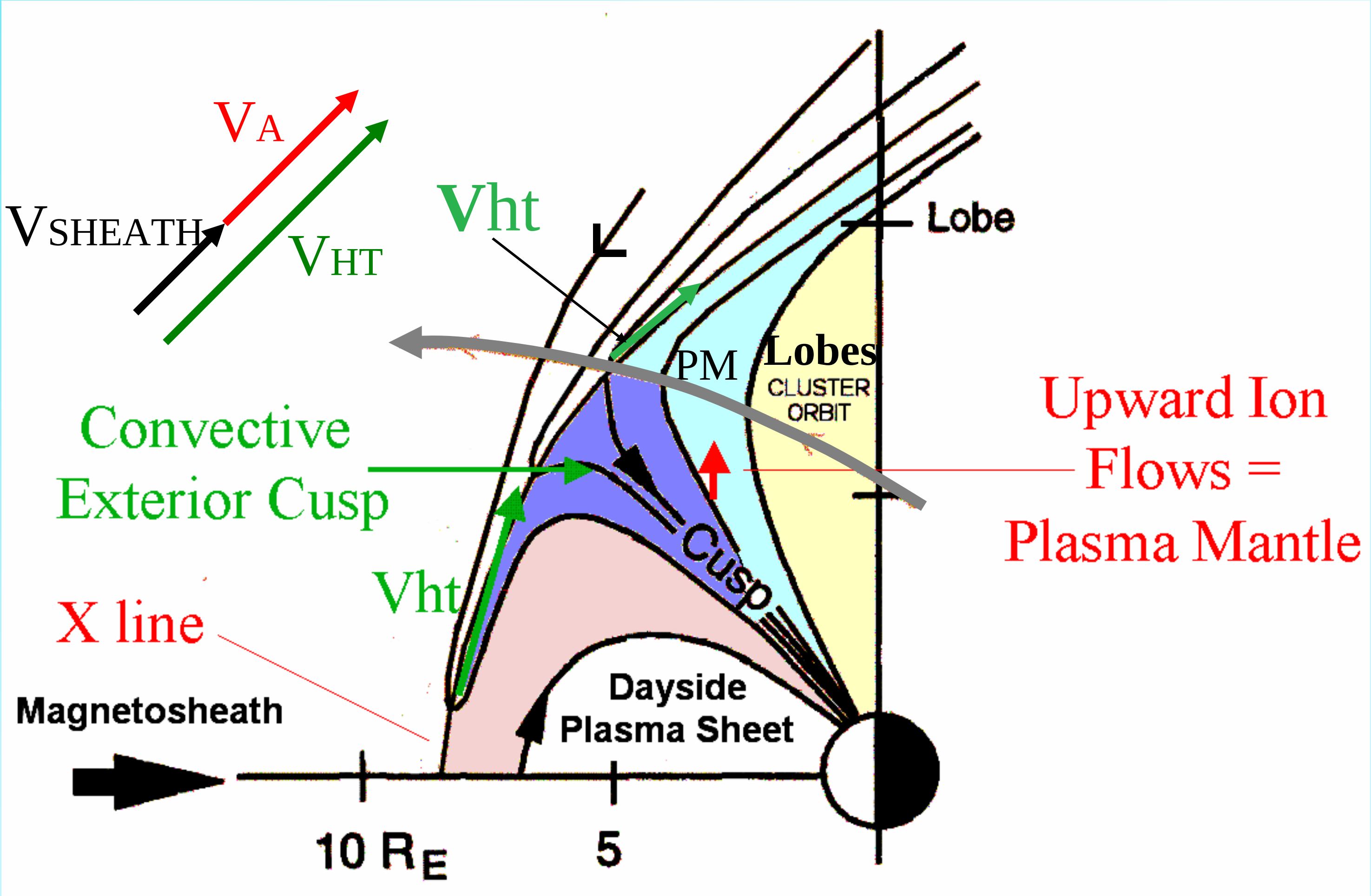




- Large deHoffmann – Teller velocity, directed upward
- Normal magnetic component $B_n \neq 0$
- Walén test satisfactory

→ The boundary is possibly a rotational discontinuity (RD) originating from low-latitude reconnection

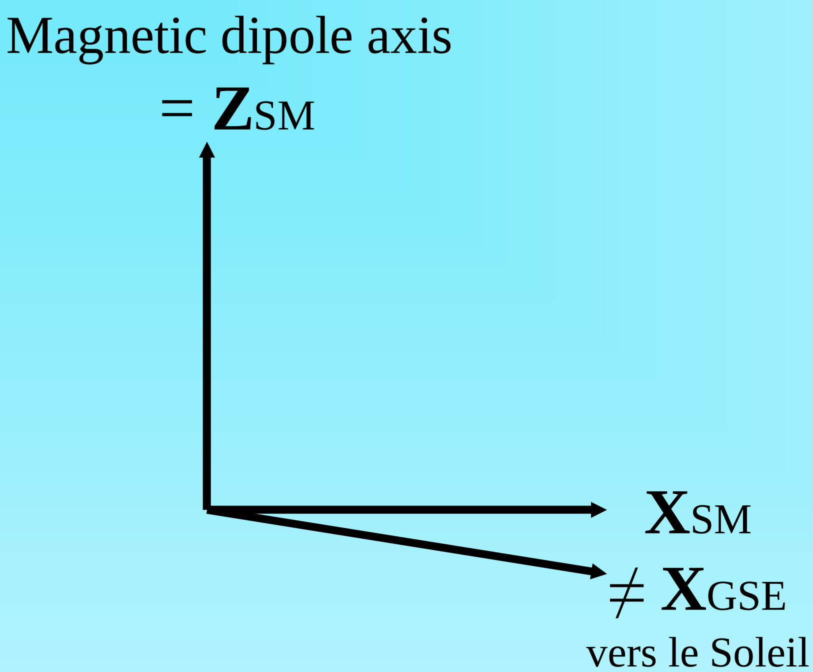
The exterior cusp under southward IMF: Overall structure

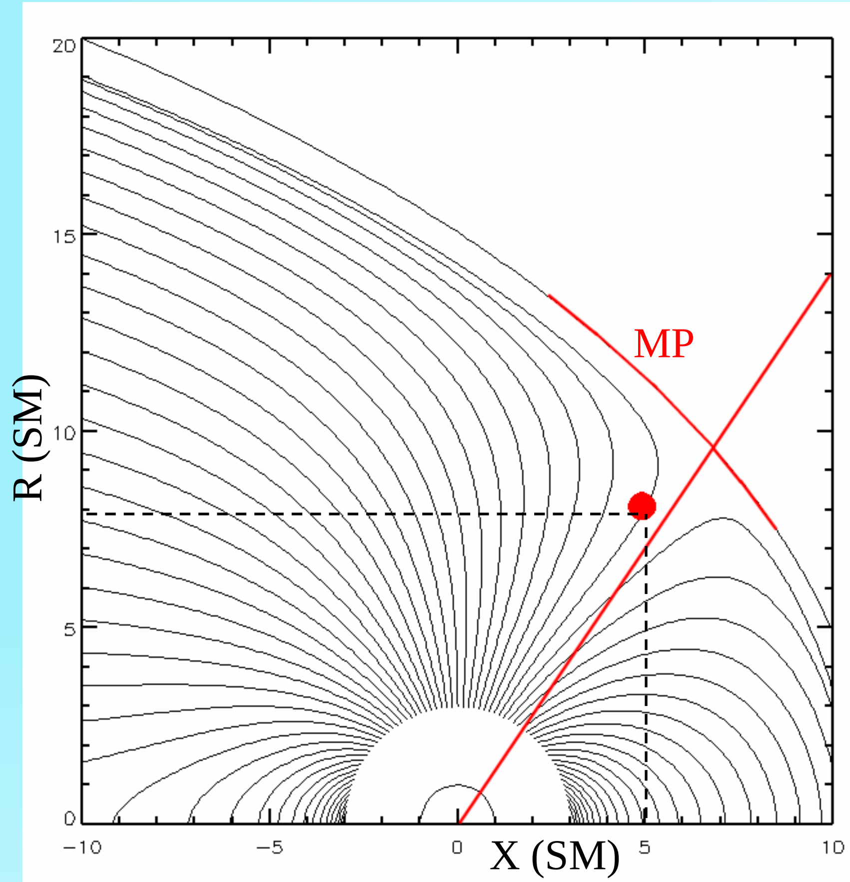


→ The exterior cusp structure is consistent, at large scales, with the occurrence of low-latitude reconnection

Statistical study of the exterior cusp structure: Three years of Cluster data

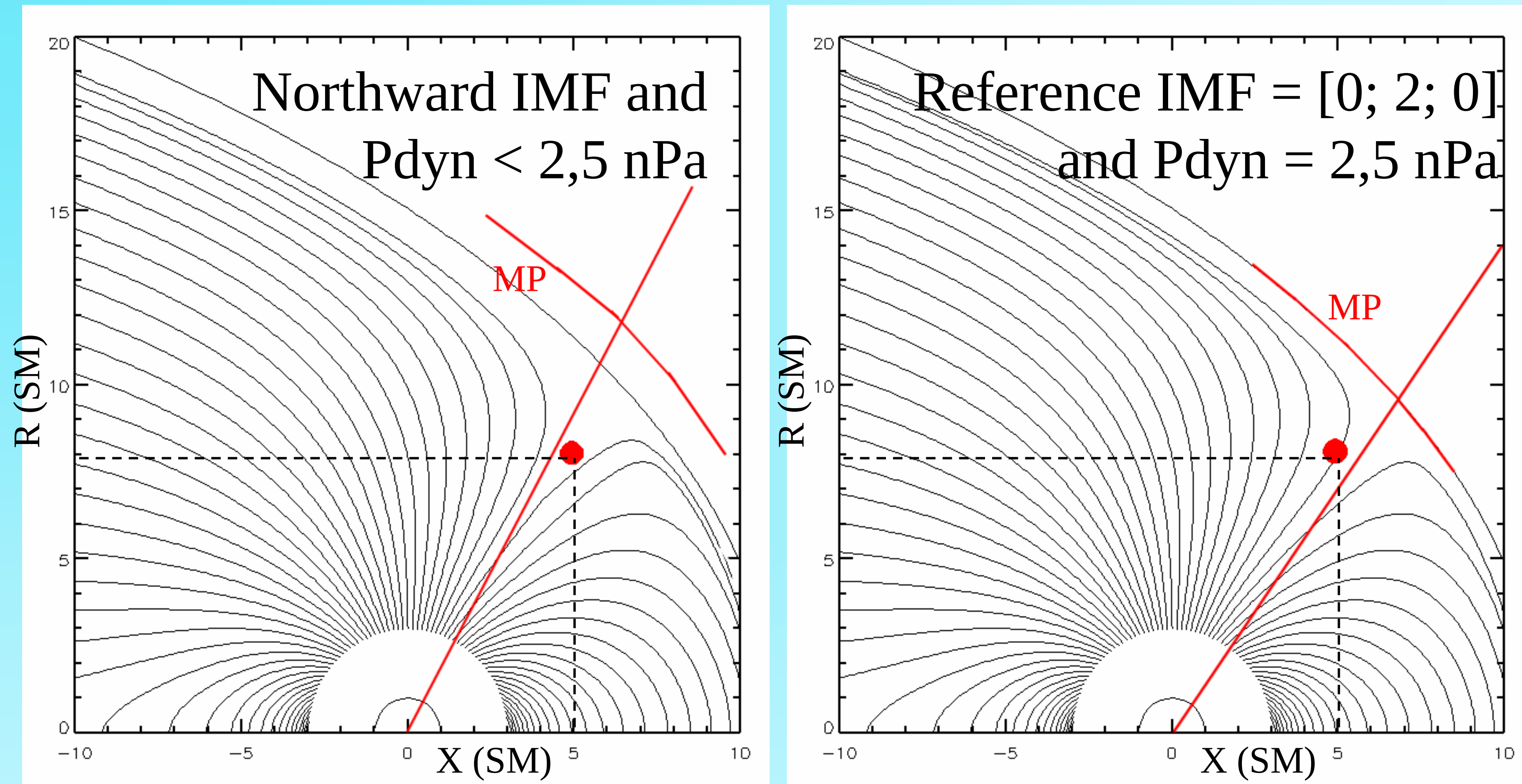
Superposed epoch analysis: methodology(1)





- Solar wind conditions are sampled at intervals of 10 minutes (ACE) and Cluster data every 2 minutes (163 crossings)
- We make use of SC3 data on 2001 et 2002 (~600 and 100 km separation), data from satellites 1 and 3 are used for 2003 (~1Re).

Superposed epoch analysis: methodology(2)



- The orbit points are brought back to the $(X,Z)_{SM}$ plane
- The variations in cusp latitudinal location are taken into account by use of a model field [Tsyganenko, 1996]
- The variations in radial magnetopause location are taken into account by use of a model magnetopause [Shue et al., 1997]

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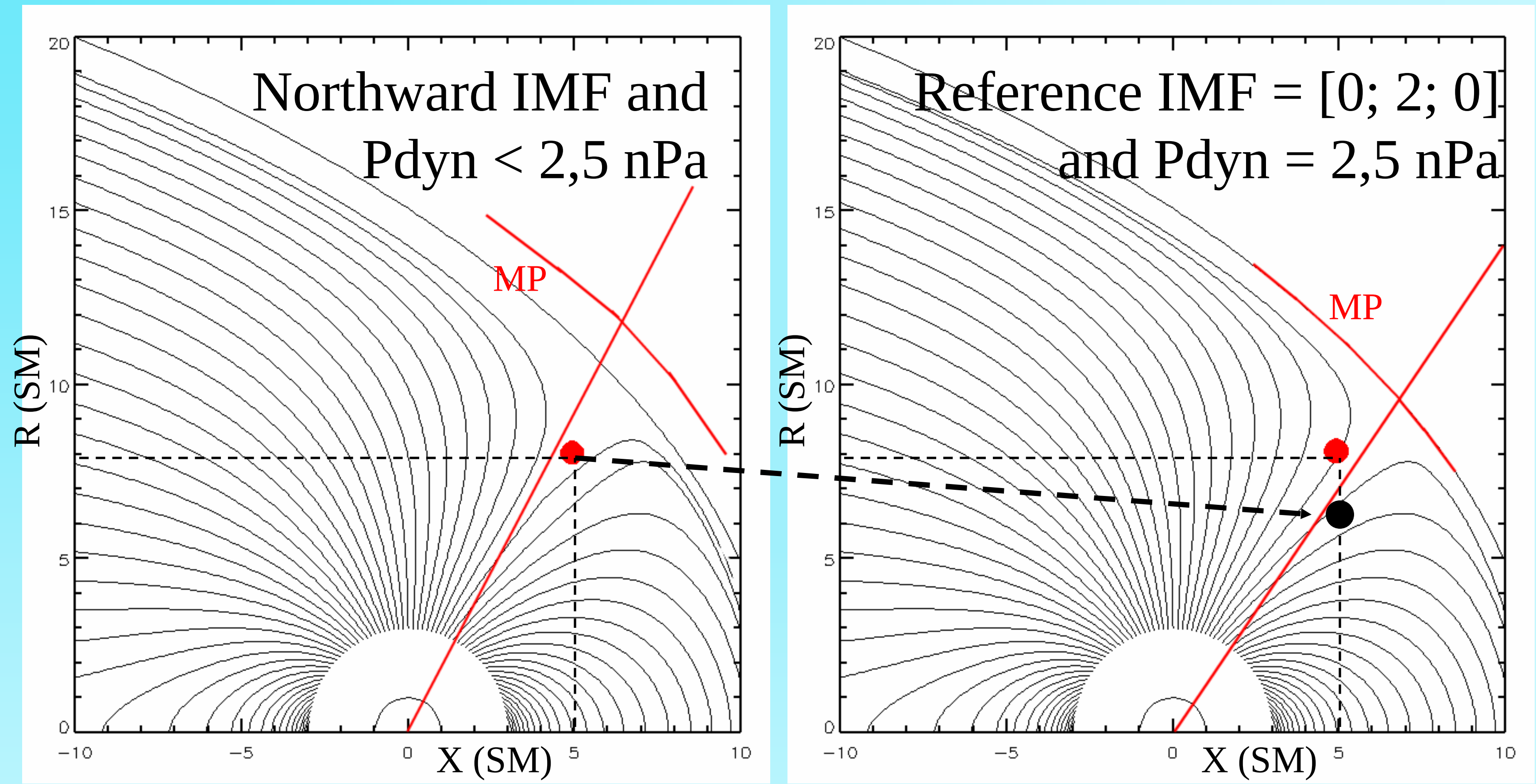

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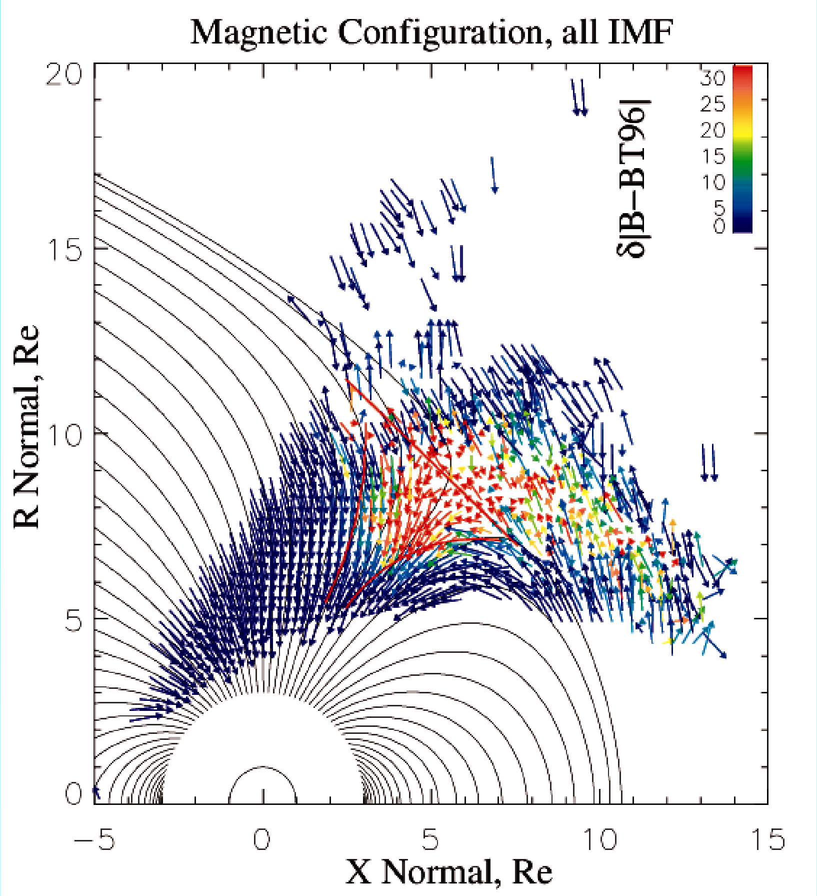
Global properties for all IMF conditions

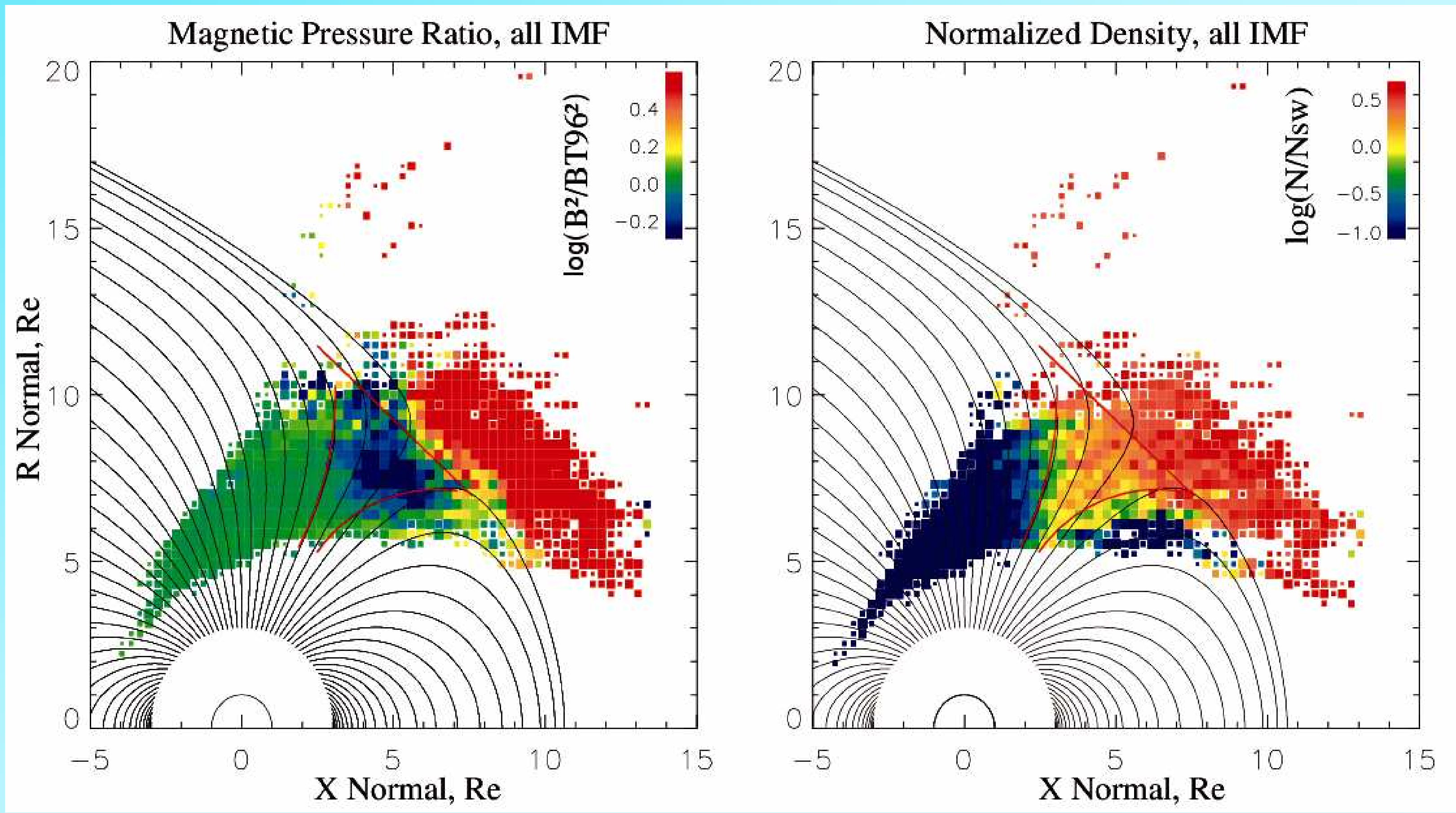
Magnetic configuration



- The magnetic configuration follows that expected in the lobes and dayside plasma sheet
- The variations in $<|B_{meas} - B_{T96}|>$ shows the existence of a transition region:

"The Exterior Cusp"

The exterior cusp: a diamagnetic cavity

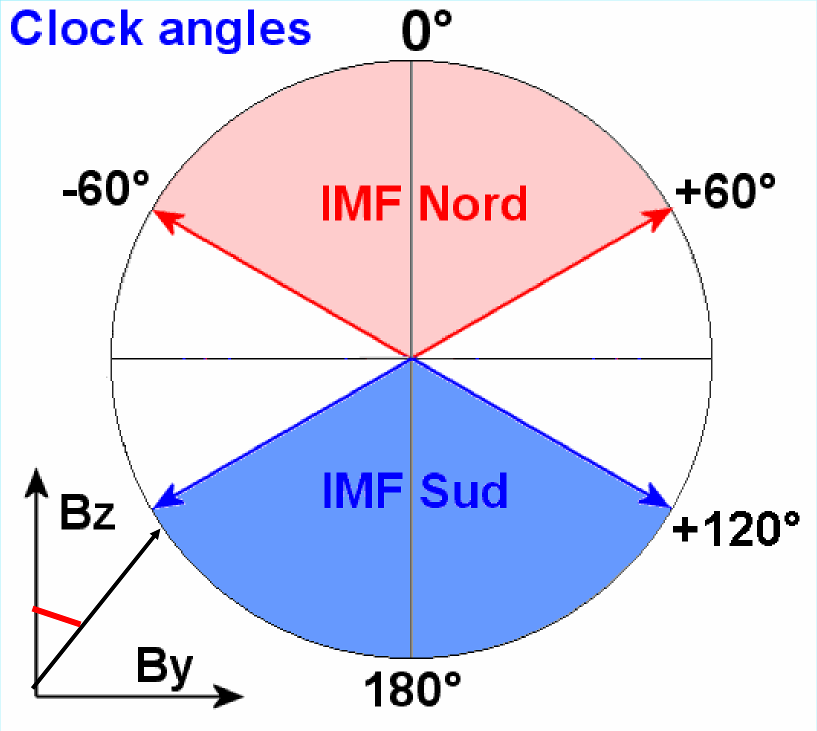


- The magnetic pressure difference observed with the T96 model field shows the diamagnetic nature of the exterior cusp
- Three distinct boundaries are found with the lobes, the dayside plasma sheet and the magnetosheath

Flow characteristics for selected IMF directions

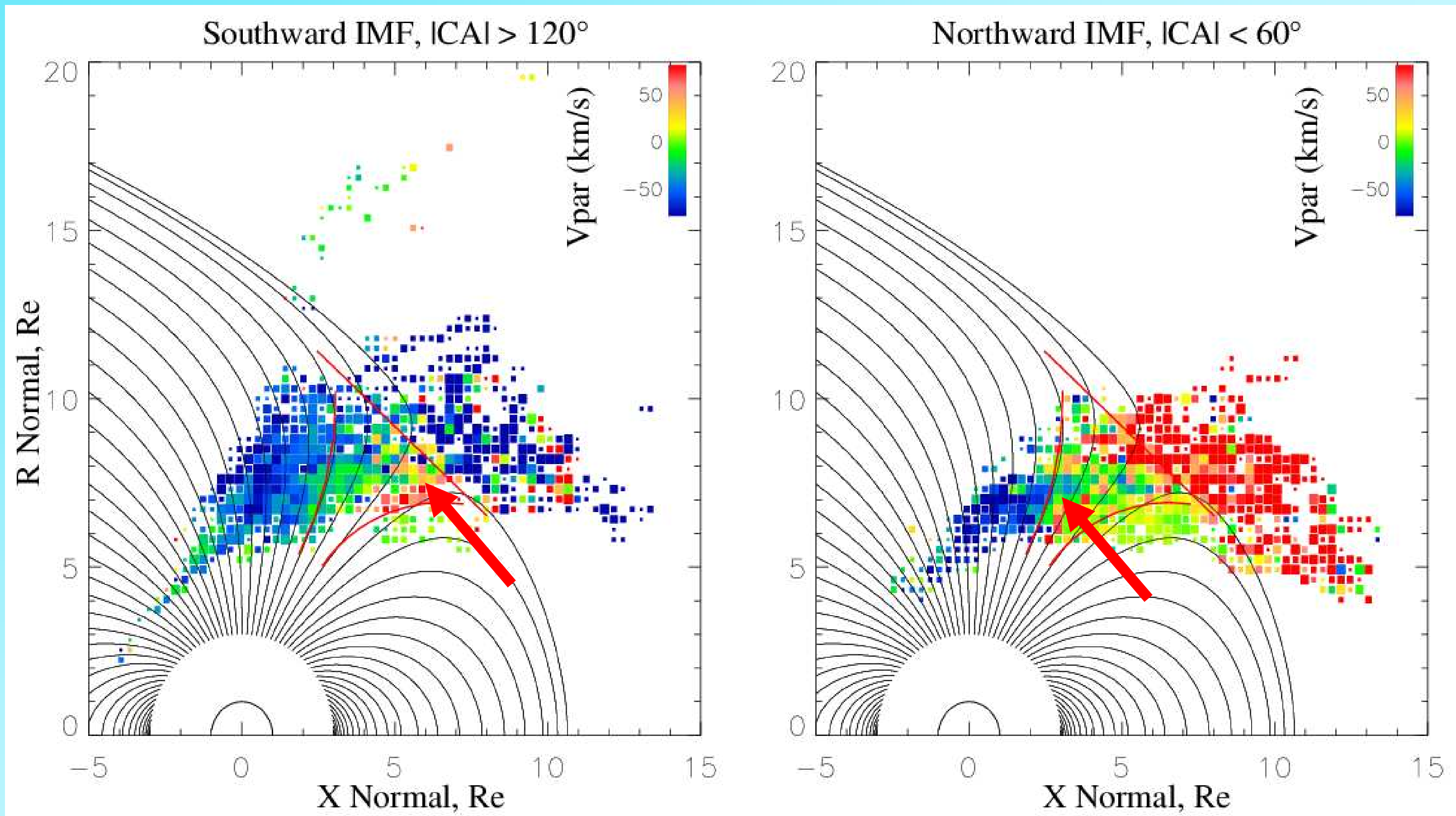
IMF restrictions

Clock angle



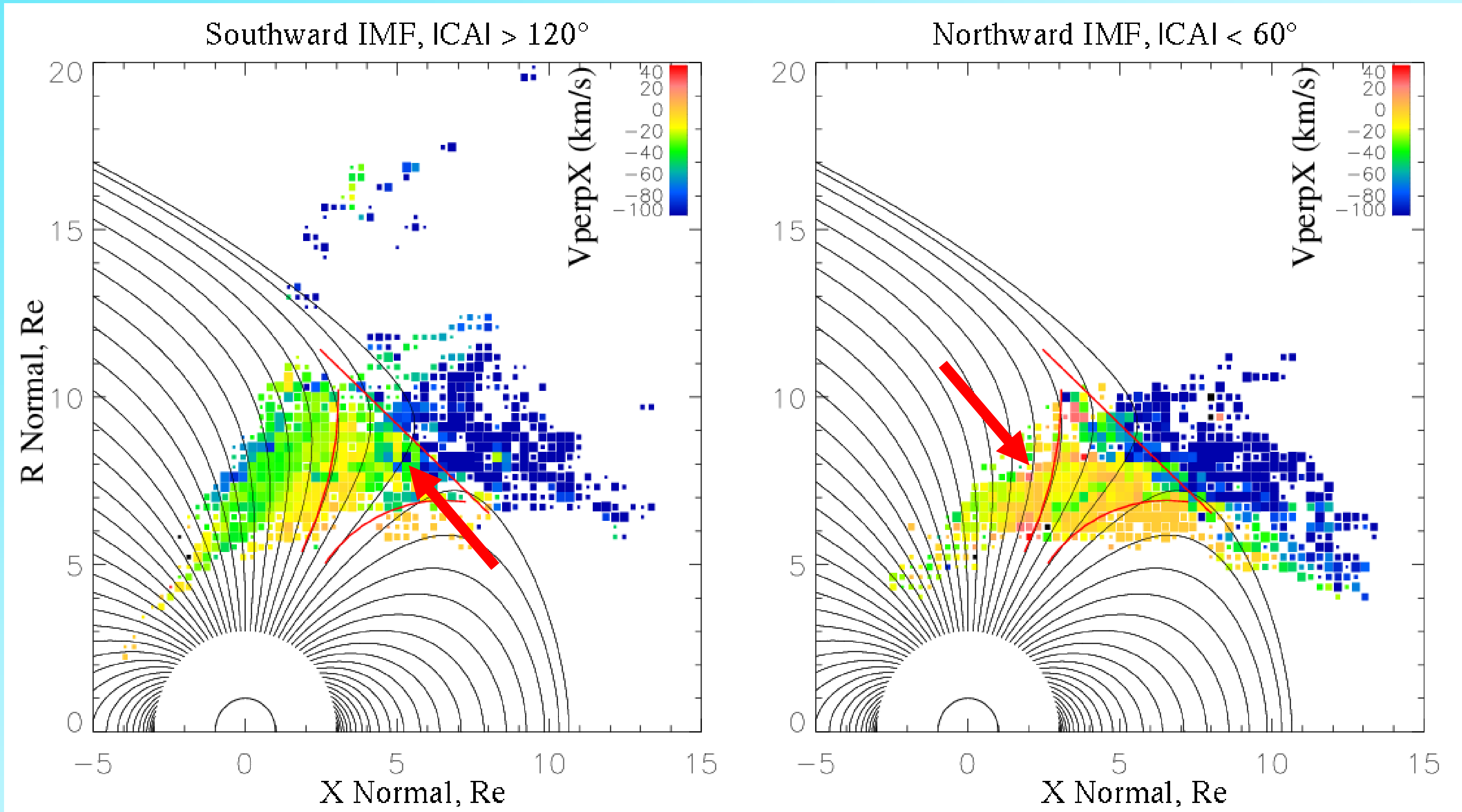
- Clock angle (CA) = arctan (IMF By / IMF Bz)
- Northward IMF defined as |CA| < 60°
- Southward IMF defined as |CA| > 120°

Parallel flows: precipitation location



- Precipitation occurs at the equatorward edge of the cusp for southward IMF, at the boundary with the dayside plasma sheet
- It occurs at higher latitudes for northward IMF, at the boundary with the lobes

Perpendicular flows: plasma convection (X direction)



- Plasma convection is clearly tailward at the equatorward edge, and throughout, the cusp for southward IMF
- The exterior cusp is rather stagnant for northward IMF, slight sunward convection is observed near the boundary with the lobes

Conclusions: the structure of the cusp

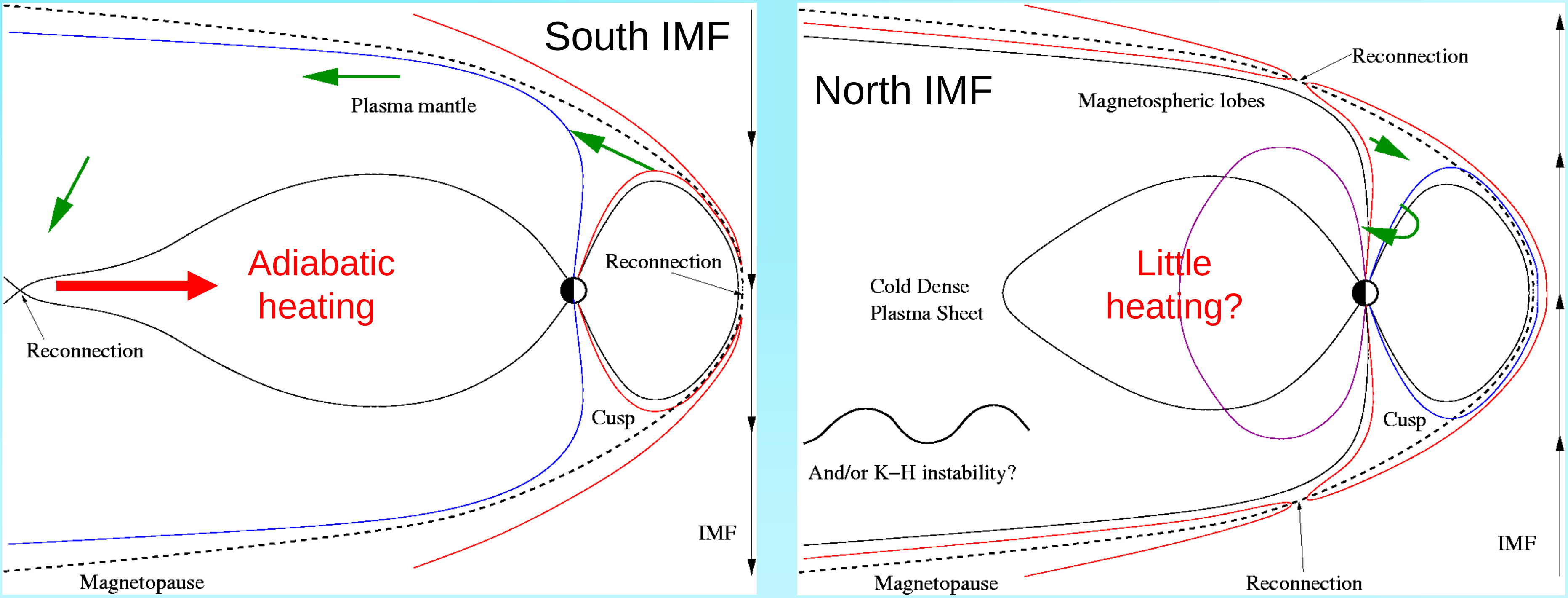
- The Exterior Cusp is a diamagnetic cavity forming a transition region between the magnetosheath and the magnetosphere
- Three distinct boundaries surround the exterior cusp with the lobes, the dayside plasma sheet and the magnetosheath
- The outer boundary may be defined as the magnetopause
- It is seen as a sharp transition in most parameters, may be rotational in nature, and allows for permanent plasma entry into the cusps

Conclusions: the role of reconnection

- Plasma precipitation occurs at low (high) latitudes for southward (northward) IMF
- Plasma convection is tailward for southward IMF, the exterior cusp is stagnant for northward IMF
- Sunward convection is observed near the boundary with lobes under northward IMF
- Under northward IMF, the presence of a PDL renders the magnetosheath flow sub-Alfvenic, possibly allowing lobe reconnection to be stable
- Such findings are consistent with the high-altitude cusp being structured, at large scales, by reconnection

Perspectives/ongoing work

- What are the mechanisms leading to the formation of the low-latitude boundary layers and plasma sheet (cold and dense) under northward IMF?



- Candidate mechanisms:
  - Diffusion by wave particle interactions
  - Transport through Kelvin-Helmholtz instability
  - Double high-latitude reconnection (see next talk by J. McFadden)