Formation of the Low-Latitude Boundary Layer and cusp under the northward IMF: simultaneous observations by Cluster and Double Star

Y.V. Bogdanova[1, 2], C.J. Owen[2], M.W. Dunlop[3], J.A. Wild[4], J.A. Davies[3], A.D. Lahiff[2], M.G.G.T. Taylor[5], A.N. Fazakerley[2], I. Dandouras[6], C.M. Carr[7], E.A. Lucek[7], H. Rème[6]

(1) Department Physics, La Trobe University, Victoria, Australia;
(2) Mullard Space Science Laboratory, UCL, UK;
(3) Rutherford Appleton Laboratory, Didcot, UK;
(4) Lancaster University, UK;
(5) European Space Agency, The Netherlands;
(6) Centre d'Etude Spatiale des Rayonnements, France;
(7) Imperial College London, UK

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Aim

- To investigate the main mechanism of plasma transport from the solar wind into the magnetosphere for the long period of the northward IMF.

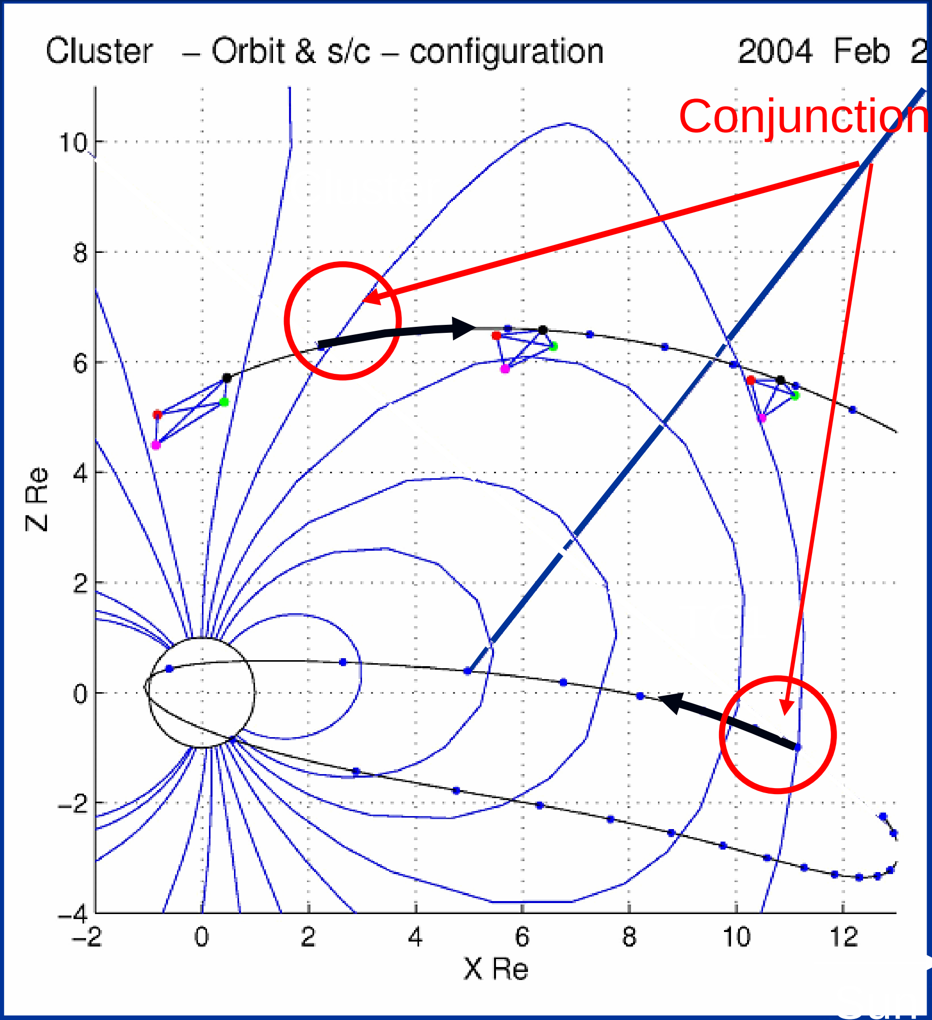
- To identify definitive plasma parameters inside plasma regions which are formed due to dual or single lobe reconnection and by diffusion process.

- To check if the Low-Latitude Boundary Layer (LLBL) observed at the dayside maps into the cusp region during northward IMF.

Data analysis

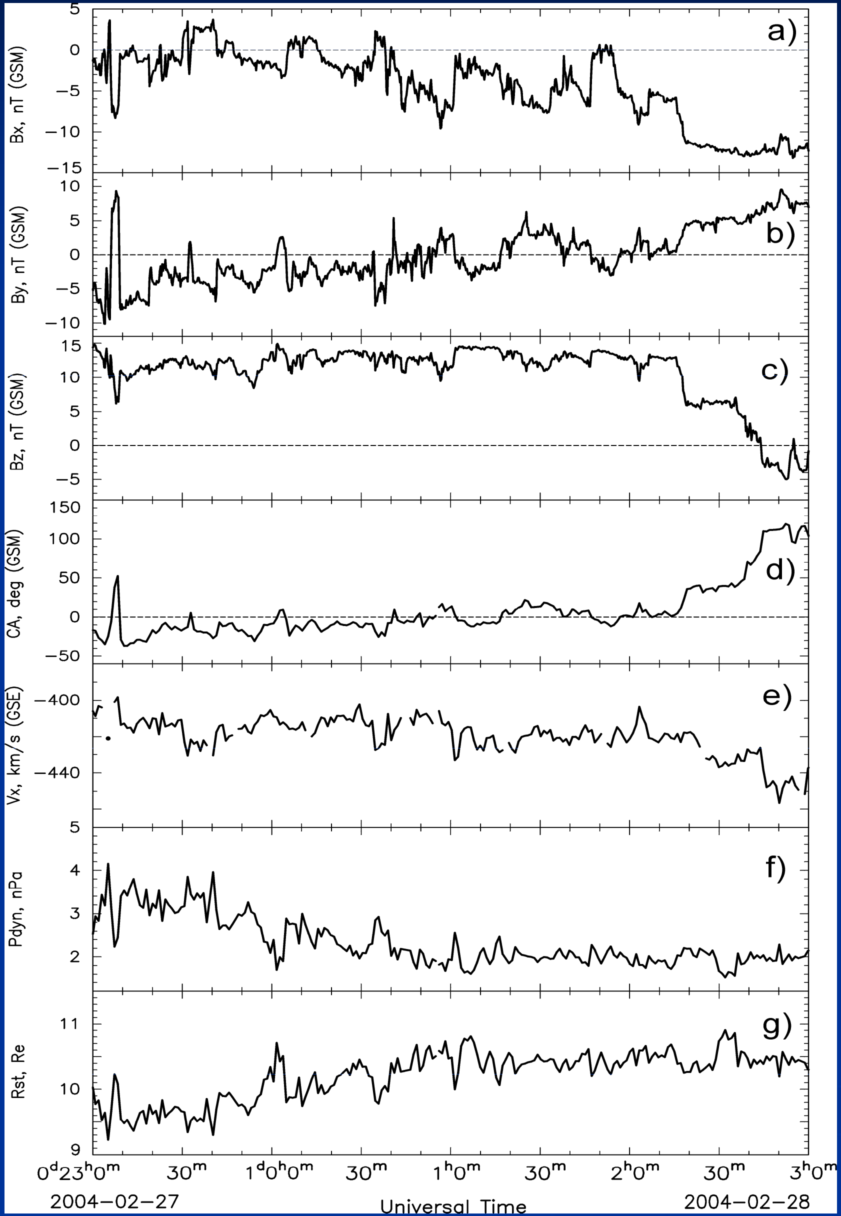
- SuperDARN data from the both hemispheres.
- Cluster and Double Star satellites' magnetic field and electron data.
- Time resolution = 4 seconds.
- Analysis of electron spectra, density, temperature, velocity, pitch-angles, and distribution functions.
- To remove time variations and emphasize spatial variations the transition parameter technique has been used. This technique is based on the anti-correlation in the electron density and temperature across the LLBL and allows to re-order data according to transition parameter which is 0 in the magnetosheath and 100 in the dayside plasma sheet.
- Cross-comparison between multipoint satellite measurements.

The event



- 28 February 2004, 0100-0300 UT.
- Conjunction between Cluster and Double Star satellites.
- Cluster is the cusp, TC1 is crossing the sub-solar magnetopause
- Cluster and TC1 at similar MLT sector, around 12 MLT.

IMF and solar wind conditions

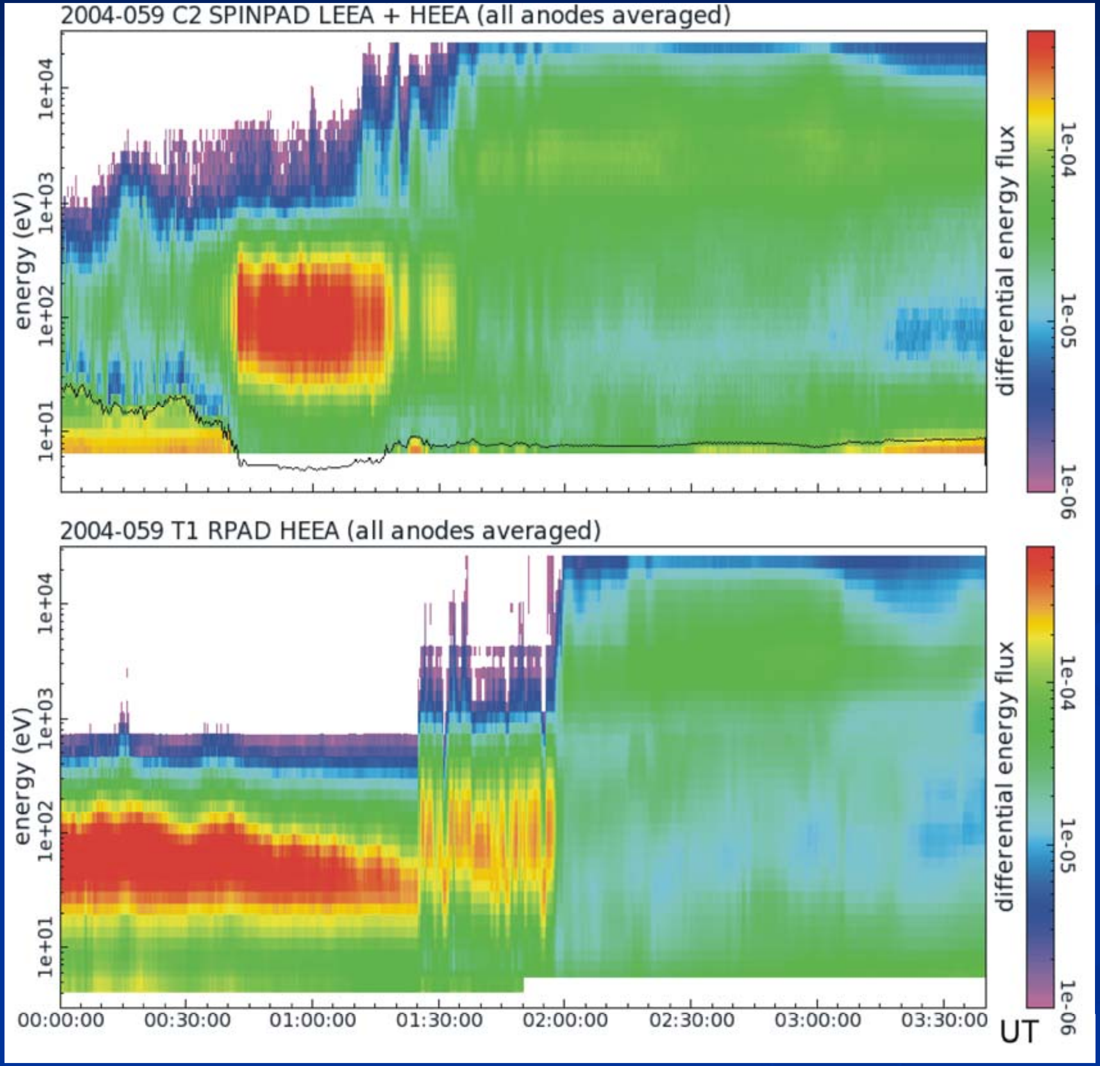


Period with strong and stable northward IMF.

- B_x=-5 nT
- B_y=0-(-5) nT
- B_z=13 nT
- V_x ~ 420 km/s
- P_{dyn}= 2-3 nPa
- MP dist =9.8-10.6Re

(from Walker & Russell, 1995)

Overview of conjunction

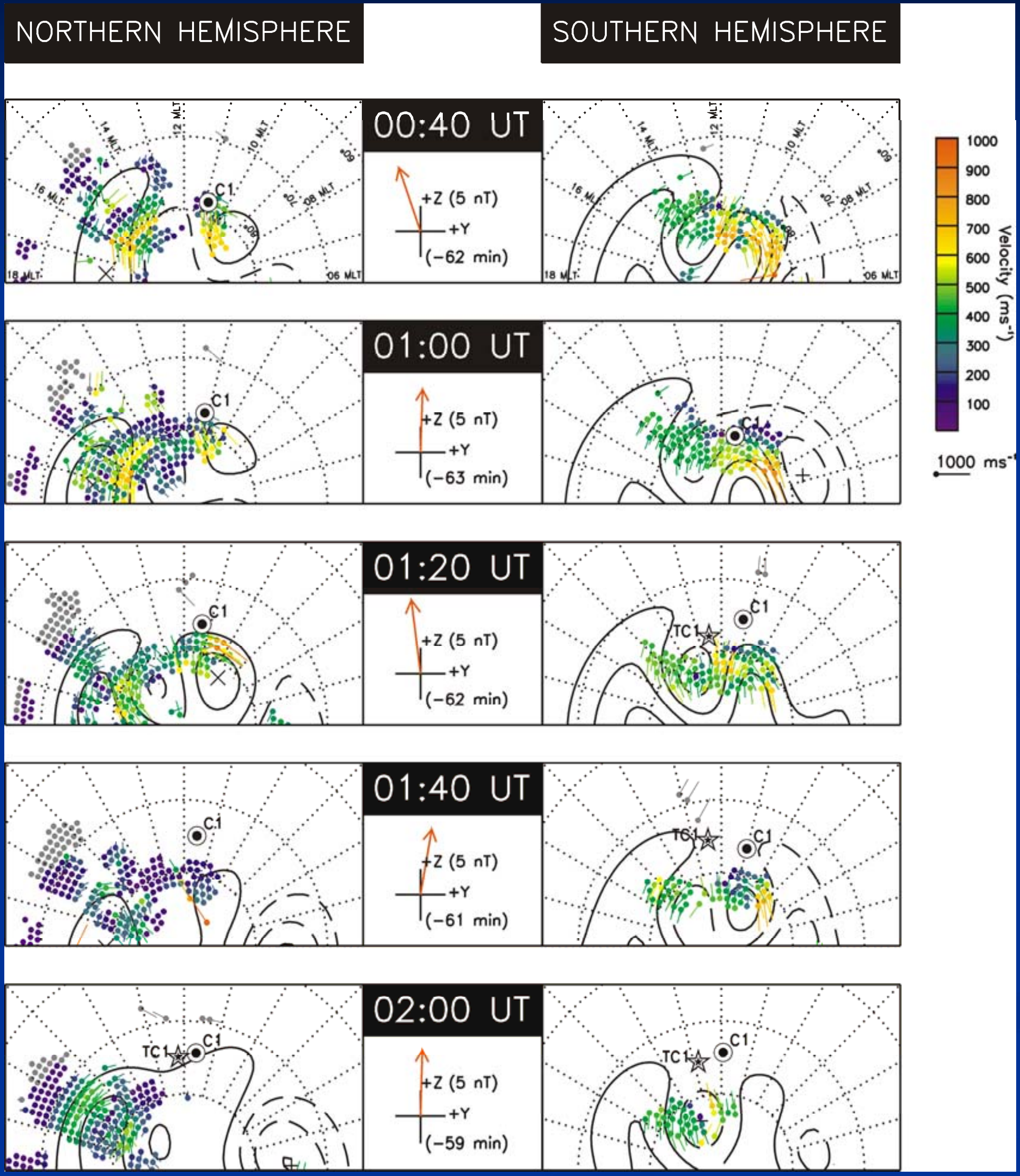


- Cluster: cusp proper is surrounded by boundary layers.

- TC1: multiple crossing into the Low-Latitude Boundary Layer with lots of substructure.

- Electron omnidirectional spectrograms from Cluster and TC1 are shown.

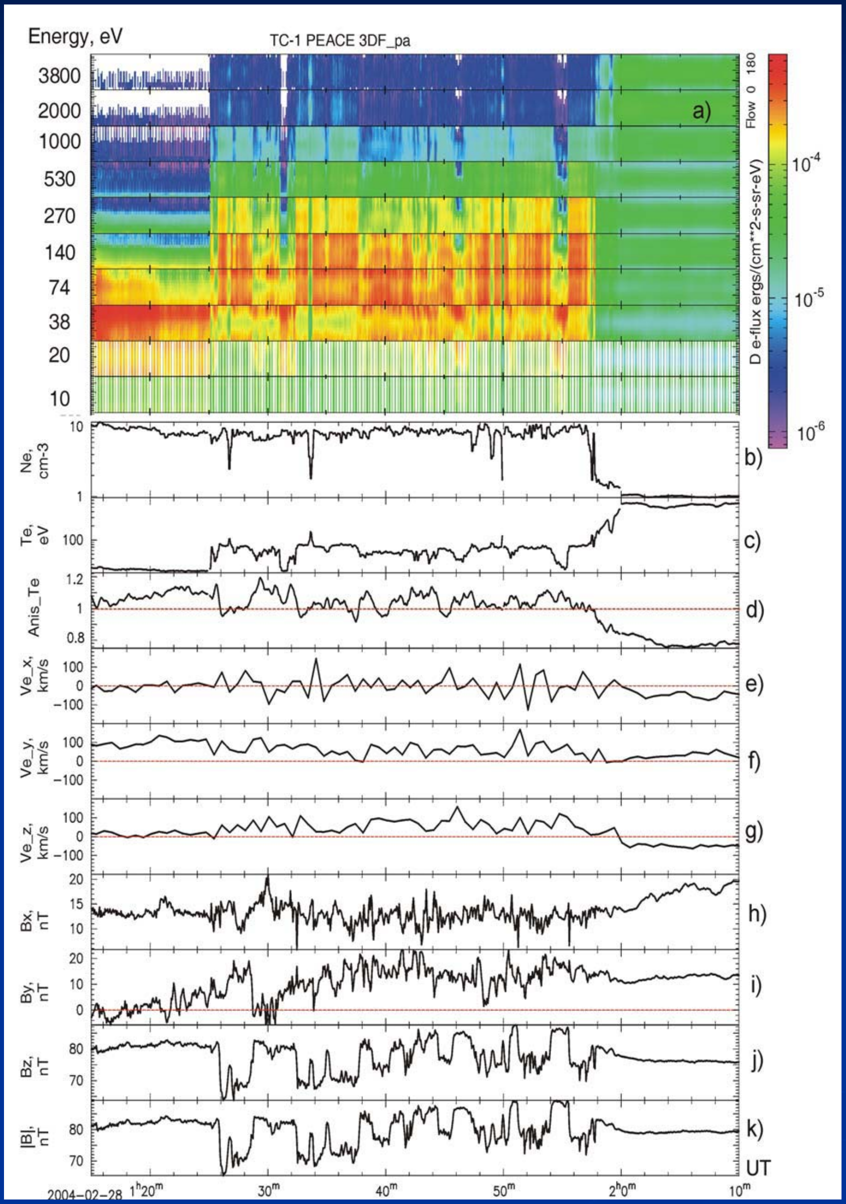
Convection in the ionosphere



- During the entire time of interest, SuperDARN radars in both hemispheres detect sunward flow in the noon sector.

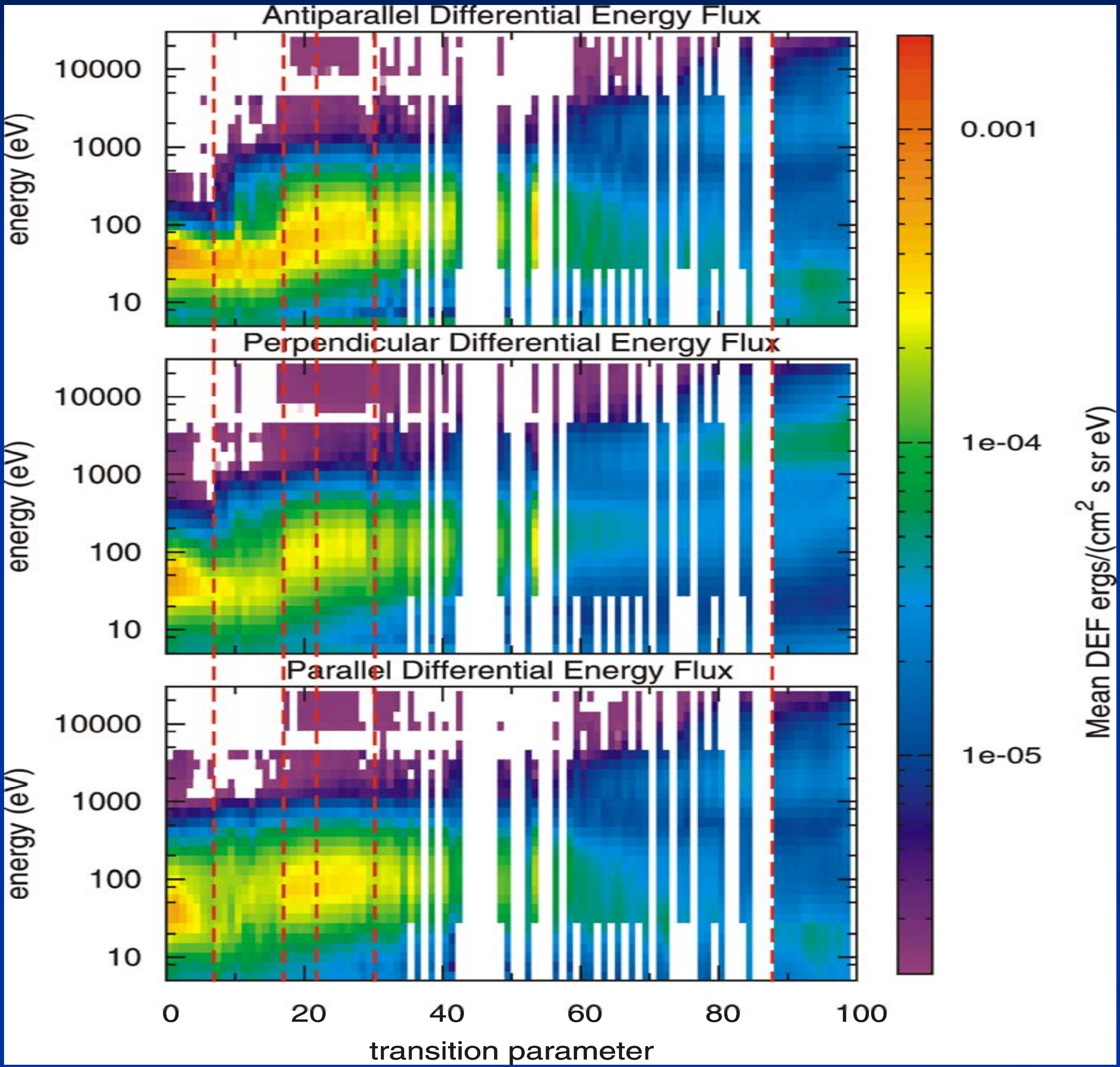
- This suggests a possibility of dual lobe reconnection.

TC1 LLBL crossing overview



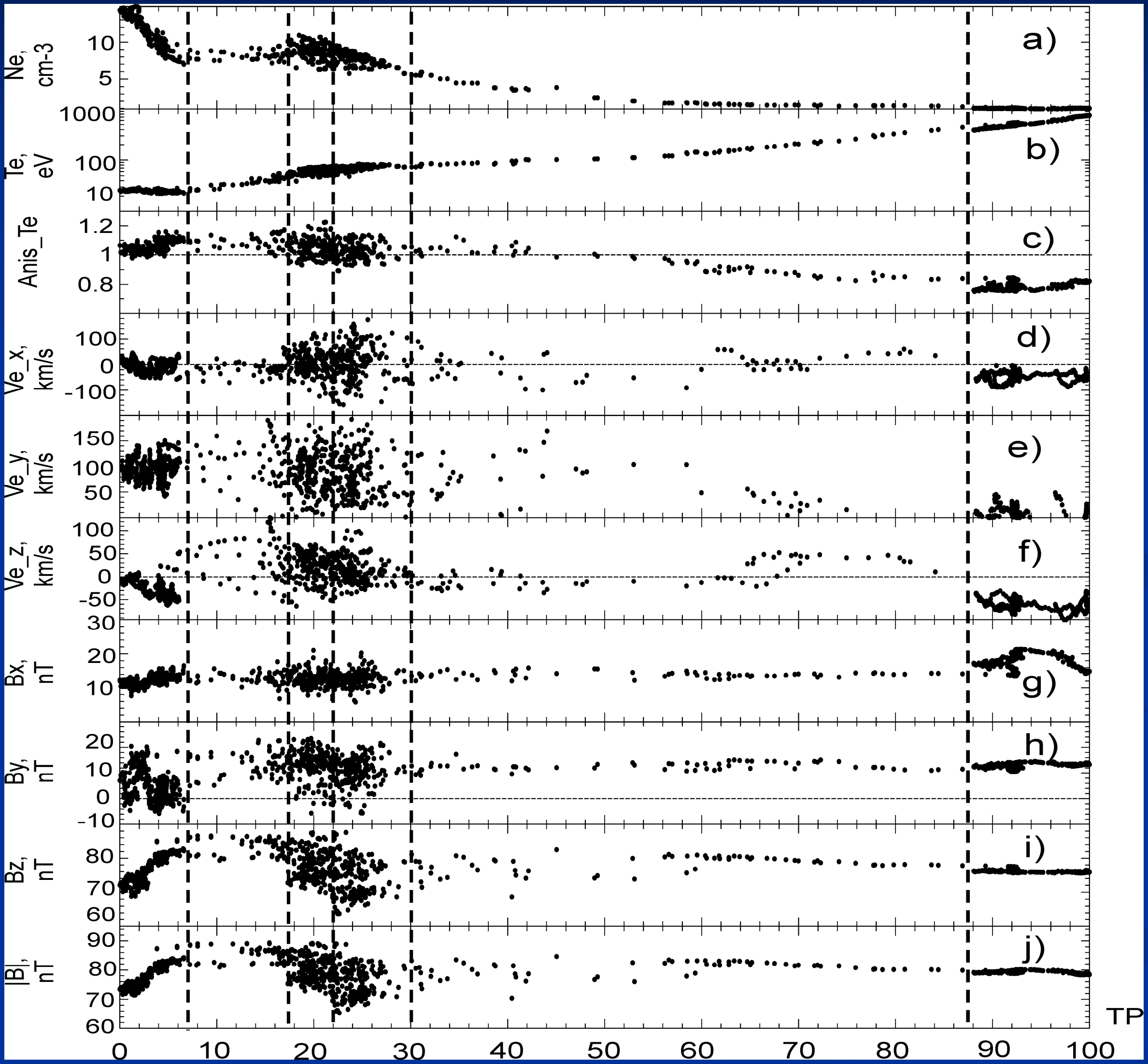
- Two sharp boundaries: at 01:25 UT and 01:57 UT.
- 3 excursions in the PDL.
- Mixture of anti-parallel heated uni-directional msh (magnetosheath) electrons and bi-directional msh heated electrons.
- Another layer with a mixture of low-dense trapped msh and plasma sheet populations.

Re-ordered LLBL crossing by TC1



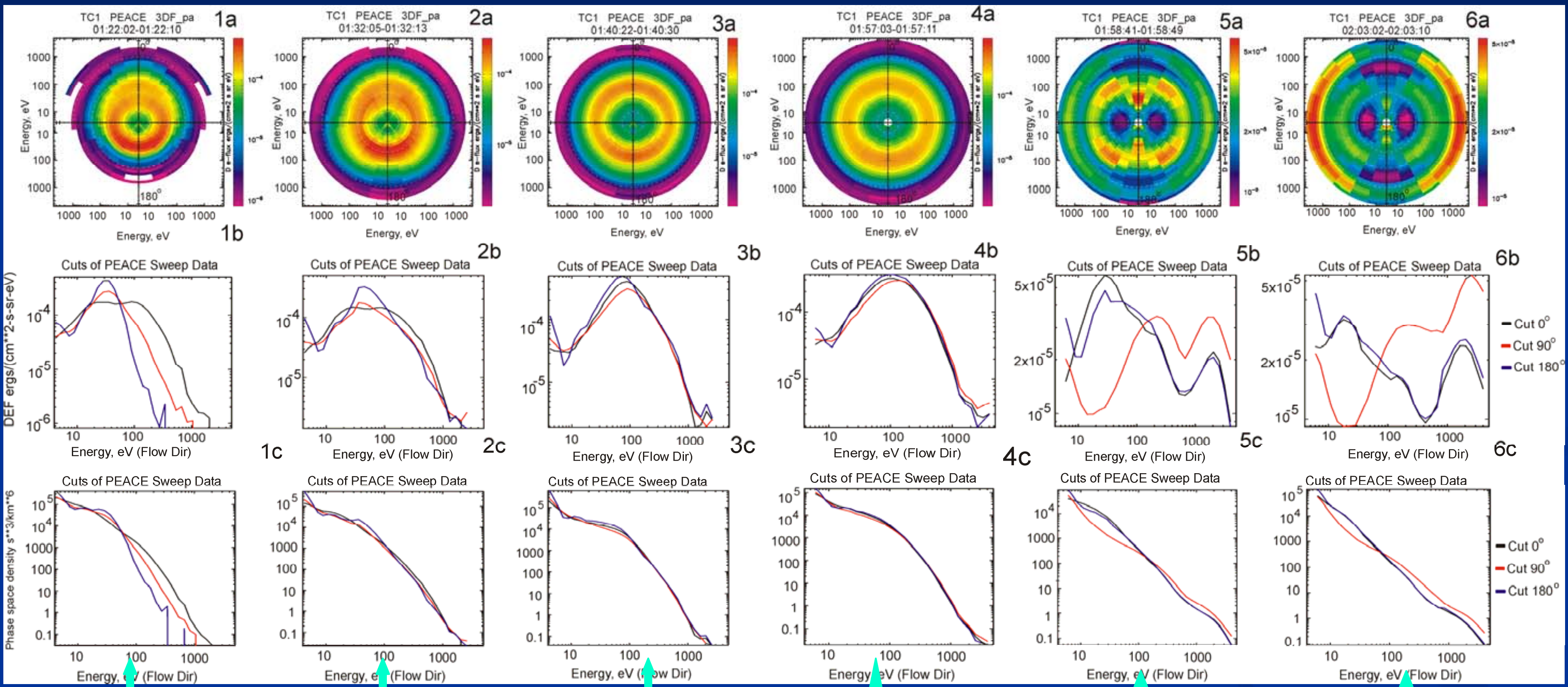
- TC1 electron energy versus transition parameter spectrogram
- Six different plasma regions with different properties are separated by vertical red lines.

Re-ordered LLBL crossing by TC1



- Plasma parameters and magnetic field variations inside the 6 regions identified above.
- The main rotation in the magnetic field at TP = 18-23, then SC crosses a kink in the magnetic field. At this TP: transition from uni-directional electron layer to bi-directional.

TC1: electron spectra in different sub-layers



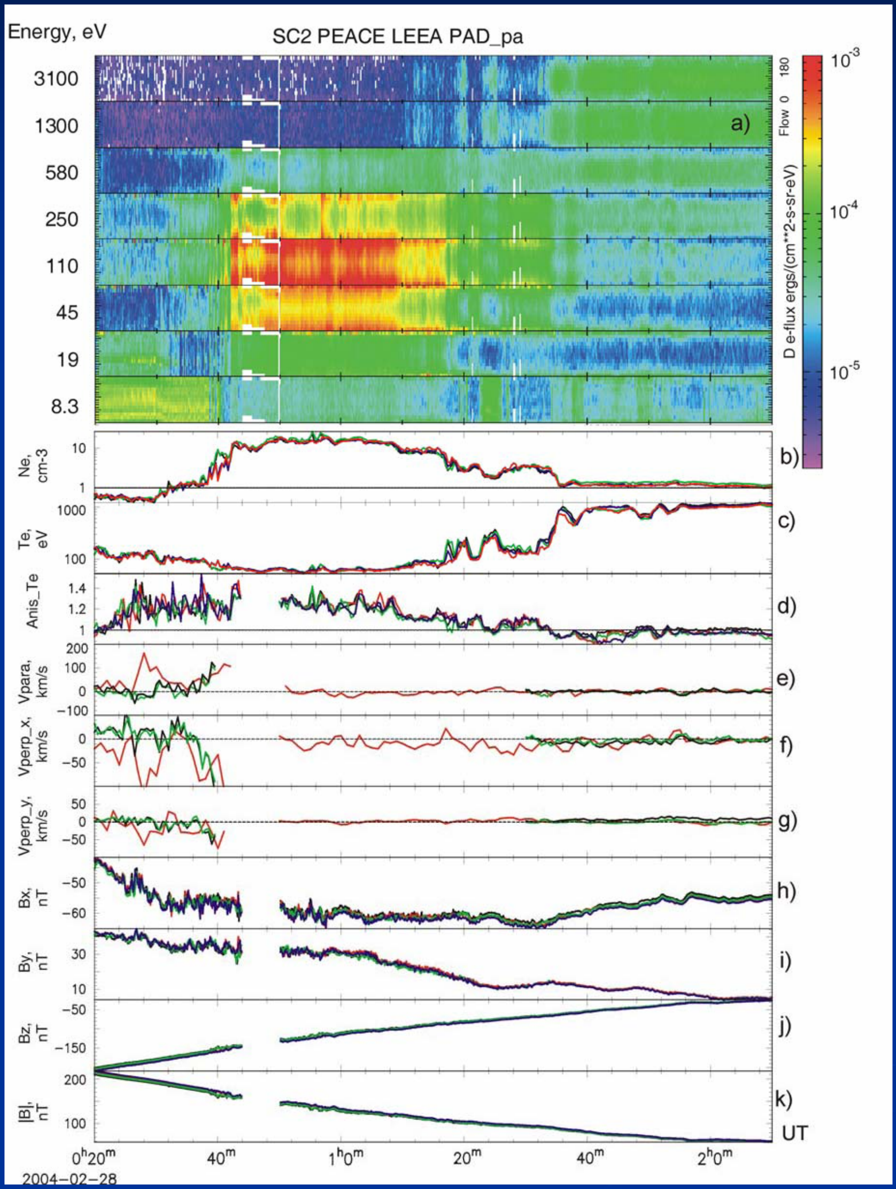
Plasma Depletion Layer

Uni-directional, bi-directional with non-equal fluxes, and bi-directional with equal e_s fluxes layers.

Transition layer

LLBL on the closed field lines

Cluster cusp crossing overview

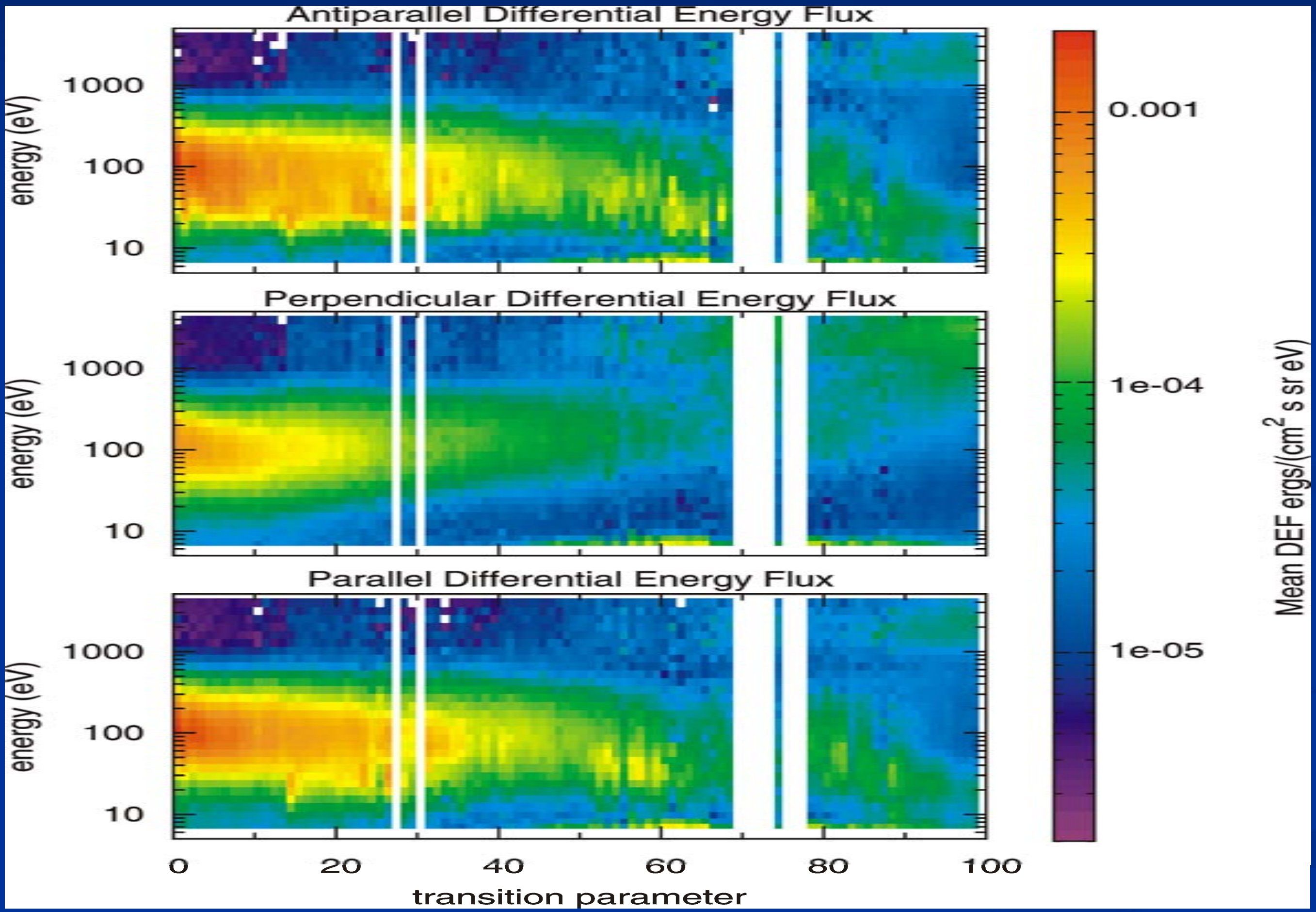


Injections of plasma at the polar boundary.

6 distinctive regions are crossed:

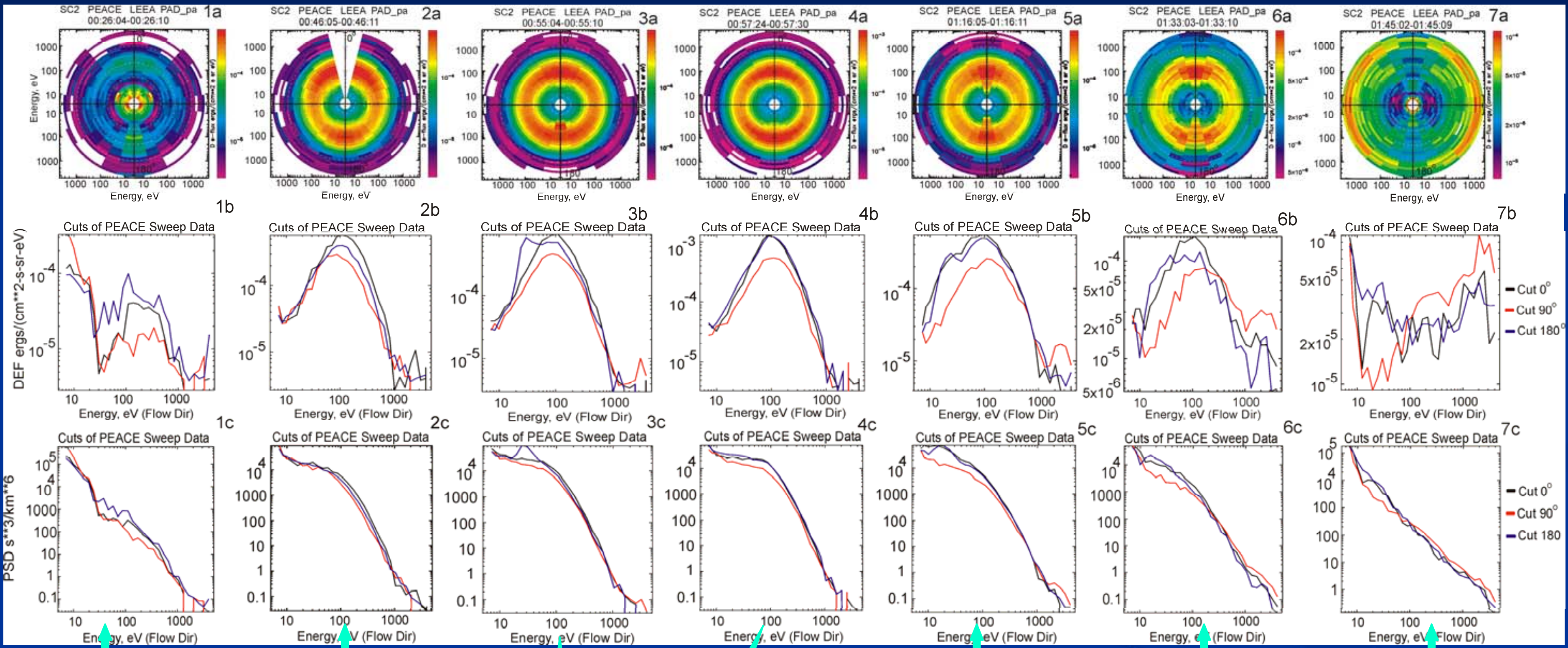
- boundary layer near the poleward boundary
- region with bi-directional electrons inside the cusp, cusp proper with more isotropic population
- 3 boundary layers near the equatorward boundary of the cusp with step changes in plasma density and temperature.

Re-ordered cusp crossing by Cluster



- Cluster electron energy versus transition parameter spectrogram (starting from the cusp proper as TP=0)
- Changes in the electron energies / fluxes can be seen.

Cluster - electron spectra



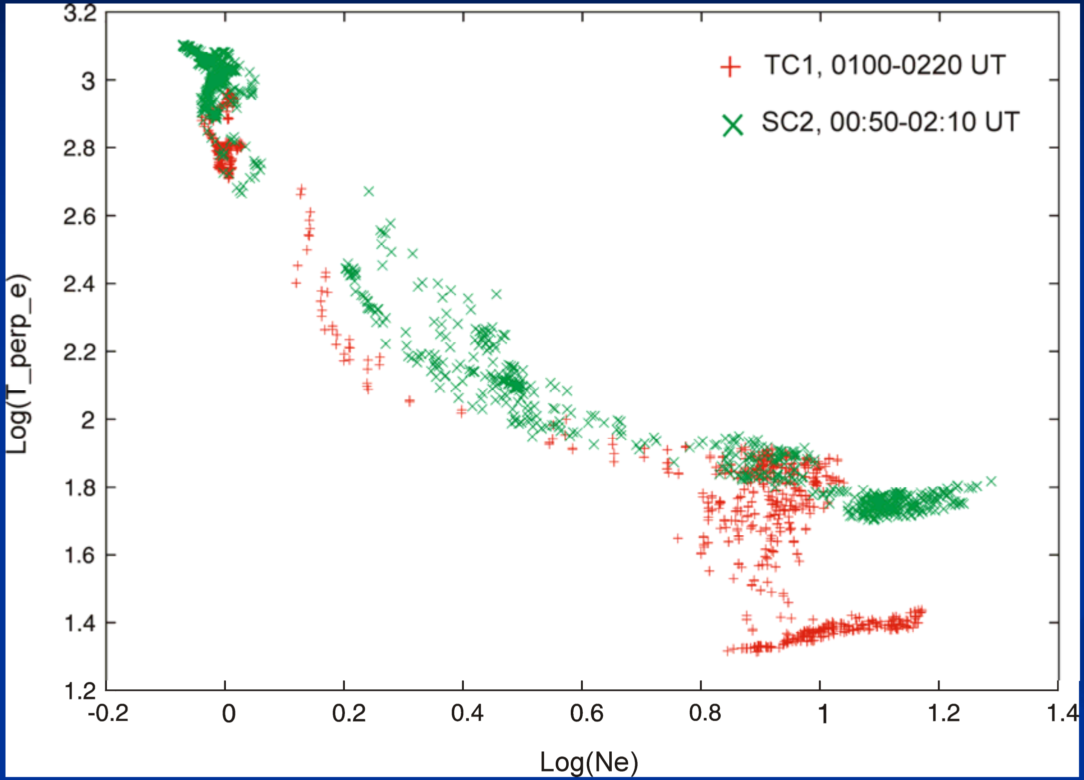
Electron edge of the LLBL

Boundary layer with bi-directional beams

Cusp proper with more isotropic unbalanced and balanced electron populations.

Three equatorward boundary layers with mixed plasma sheet and magnetosheath populations.

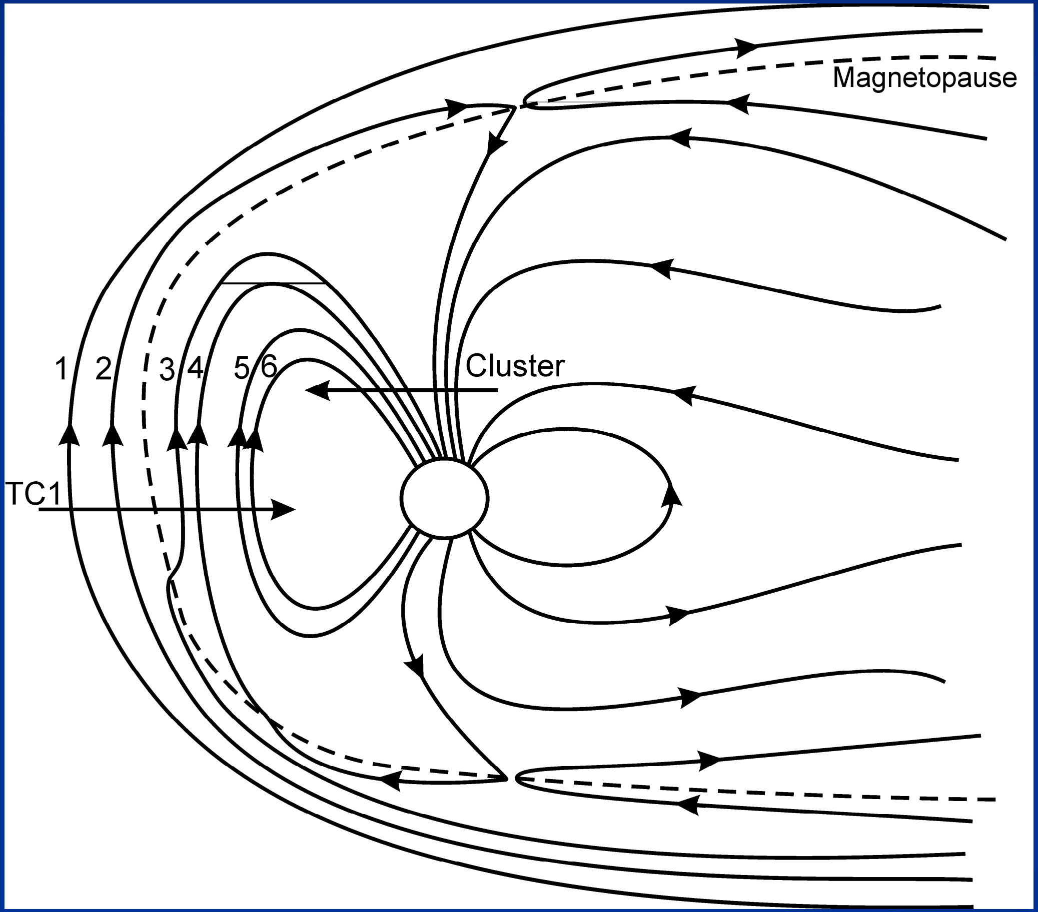
TC1-Cluster cross-comparison



- Log of electron temperature versus log of electron density for Cluster and TC1.
- These curves have been used for Transition parameter estimation.

Good agreement between plasma populations observed by Cluster inside the cusp and surrounding boundary layers and those observed by TC1 while crossing a complicated LLBL structure near the sub-solar point.

Formation of the different sub-layers inside the LLBL and cusp



Large scale reconnection geometry and magnetic topology inside the different sub-layers inside the LLBL and cusp.

Conclusions-1

• Excellent conjunction between Cluster and TC1 during strong northward IMF, supported by a good coverage of the ionospheric convection by SuperDARN.

• Dual lobe reconnection can partially explain the complex substructure of the LLBL. There are three different sub-layers which are formed by single or dual lobe reconnection process:

→ on open field lines outside the magnetopause which are reconnected in the northern hemisphere lobe sector;

→ on open field lines inside the magnetosphere which are reconnected in the northern hemisphere lobe sector and sink inside the magnetosphere;

→ on re-closed field lines, which undergo a second reconnection in the southern hemisphere lobe sector.

Conclusions-2

- Another part of the LLBL, characterised by equal fluxes of magnetosheath-like and plasma sheet populations, is formed by diffusion processes as strong pitch-angle diffusion and formation of a loss cone is observed inside this region.

- Plasma (electron) properties inside different sub-layers have been identified.

- The LLBL with the complex sub-structure observed at the dayside magnetopause maps very well into the cusp and surrounding boundary layers observed at mid-altitudes.

- TP technique can be successfully used for cusp crossings (with caution).