Energy Conversion Features Observed by Cluster in the Plasma Sheet

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ST11: Sources and Sinks of Energy in the Substorm Cycle

A Intro A

The substorm cycle consists of:

- Energy conversion:
  - Source of mechanical / elmag energy = sink of elmag / mechanical energy.
  - $E \cdot J > 0$ => Load => conversion electromagnetic → mechanical energy, e.g. associated with source regions of bursty bulk flows.
  - $E \cdot J < 0$ => Generator => conversion mechanical → electromagnetic energy, e.g. associated with source regions of auroral arcs.
- Energy transfer:
  - Electromagnetic transfer => like the Poynting flux in the auroral magnetosphere, from generator regions in the plasma sheet to the acceleration region and ionosphere.
  - Mechanical transfer => like the bursty bulk flows in the plasma sheet (which can be braked, e.g. Cluster / Double Star example by Martin Volwerk et al., ST8 poster, and possibly generate Poynting flux)

Here we focus on energy conversion, in particular on loads in the plasma sheet.

A Intro A

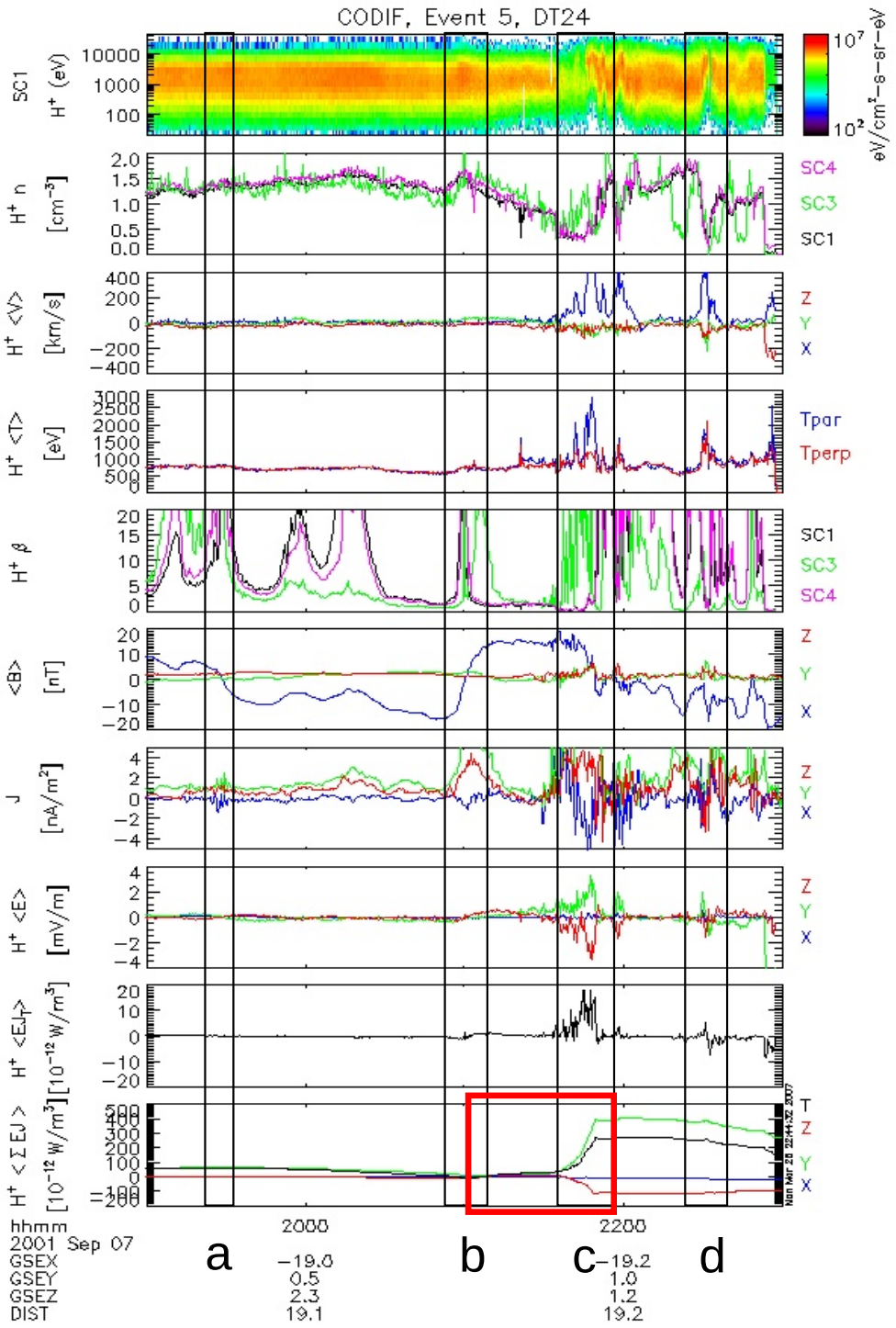
- With Cluster one can investigate local energy conversion, by computation of **E·J.** The sources and sinks of energy can be identified and examined by *in-situ* data.
- In the plasma sheet:
  - **E** can be inferred from two different experiments: CIS and EFW. Only CIS can provide estimates for the full electric field vector. Because **B** is almost parallel to the spin plane, EFW provides just the spin plane components. The duskward component, Ey, is used to cross-check CIS.
  - **J** can be computed by the Curlometer method from the magnetic field measured on the four satellites.
  - Reference system GSE => no coordinates transformation needed for EFW data (booms plane nearly the same with $(x, y)_{GSE}$).

A Intro A

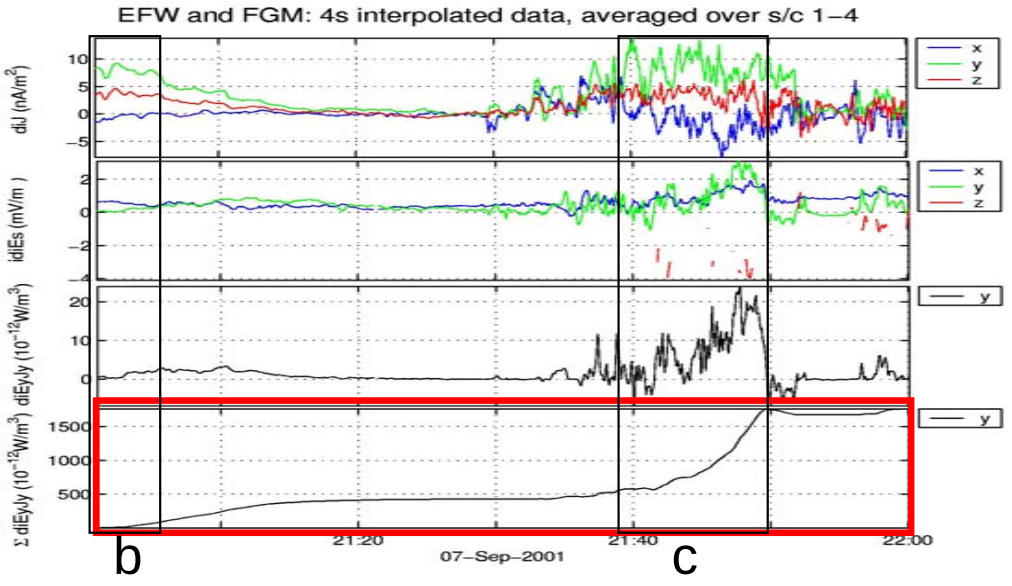
- We searched for energy conversion events between the end of August and the beginning of November, 2001. During this time the apogee of Cluster, at 19 R_E, was in the plasma sheet, moving from midnight to the dusk.
- Near Cluster apogee, the conversion of magnetic energy into mechanical energy, mostly by reversible ('motor') processes, is dominant, and the plasma sheet behaves, on average, as a load. The loads are rather concentrated (at least in z direction).
- The fact that plasma sheet behaves as a load is not a surprise. However, we do not know very well what is the structure of this load.
- Concentrated generator regions are also observed in the data – less frequent than the load regions and with lower power densities.
- For illustration we present two load events and a generator event:
  - L1 from Sep. 7, 2001,
  - L2 from Aug. 29, 2001,
  - G1 from Sep. 19–20, 2001,

  with focus on L1.

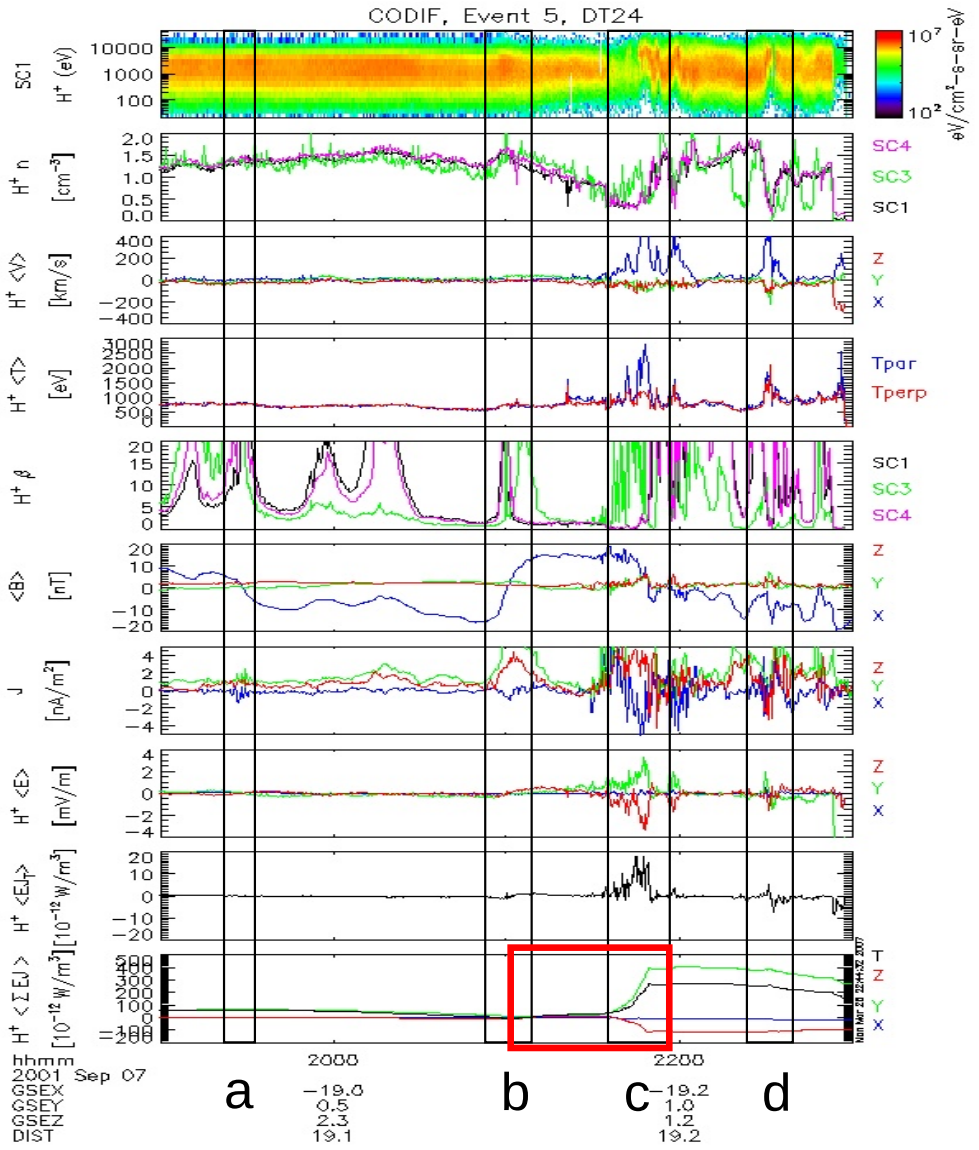
B Load Event L1: Data B

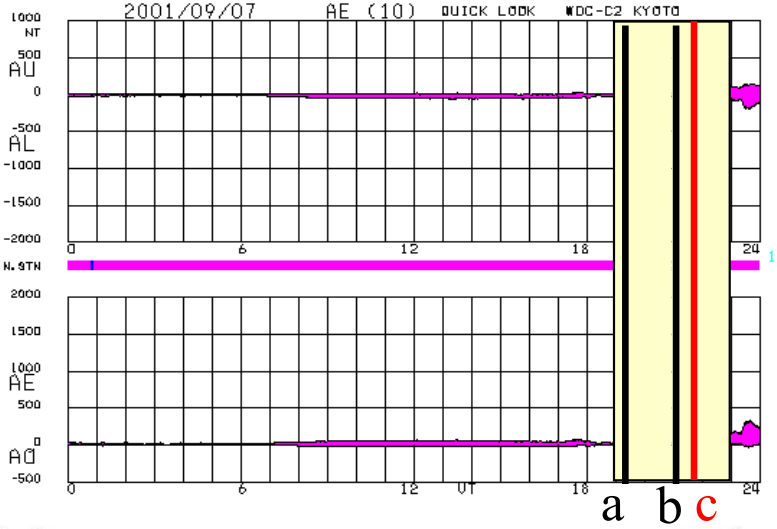


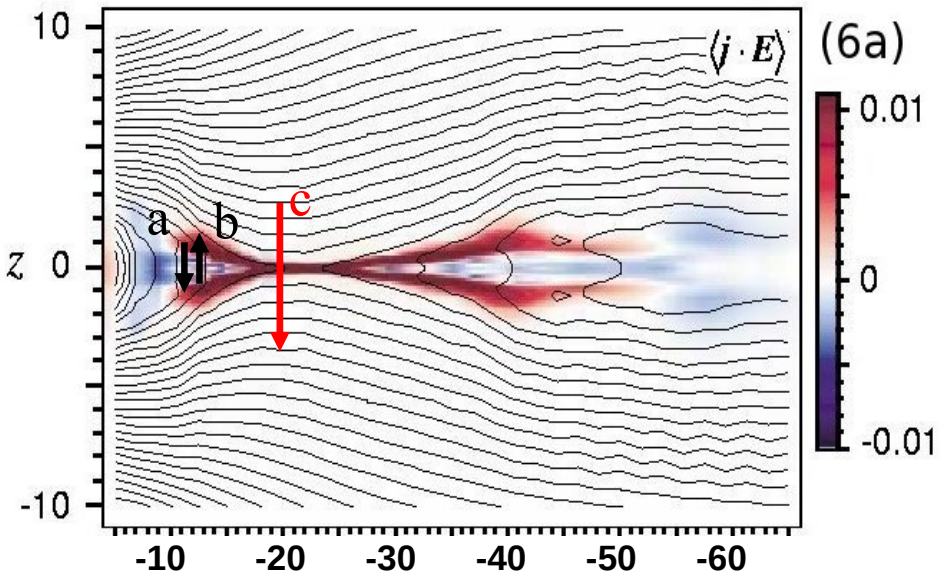
- Big load (L1c) close to the neutral sheet (high β) and midnight. L1c associated with bulk flow (mainly field aligned) and temperature anisotropy ($T_{||} > T_{\perp}$).
- No significant load is observed near the neutral sheet when the bulk flow is missing (L1a, L1b).
- Bulk flow not necessarily assoc. with a load (L1d).
- Good qualit. agreement between the (c) jump in the integ. EyJy seen by CODIF and EFW, but a factor of 2 missing: CODIF=400 for tres=24 s, EFW=1200 for tres=4 s (6 times more points).



Load Event L1: Interpretation



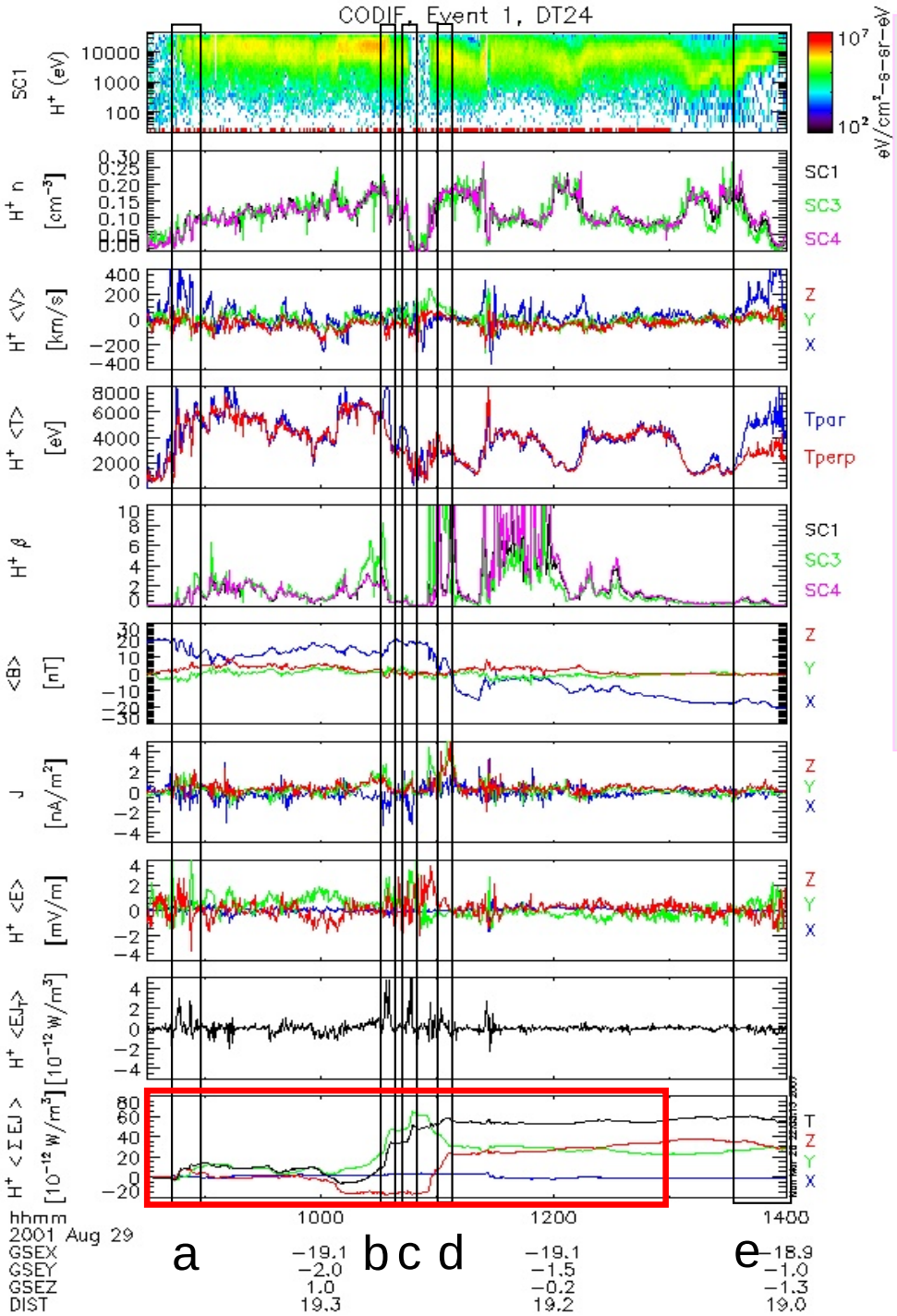




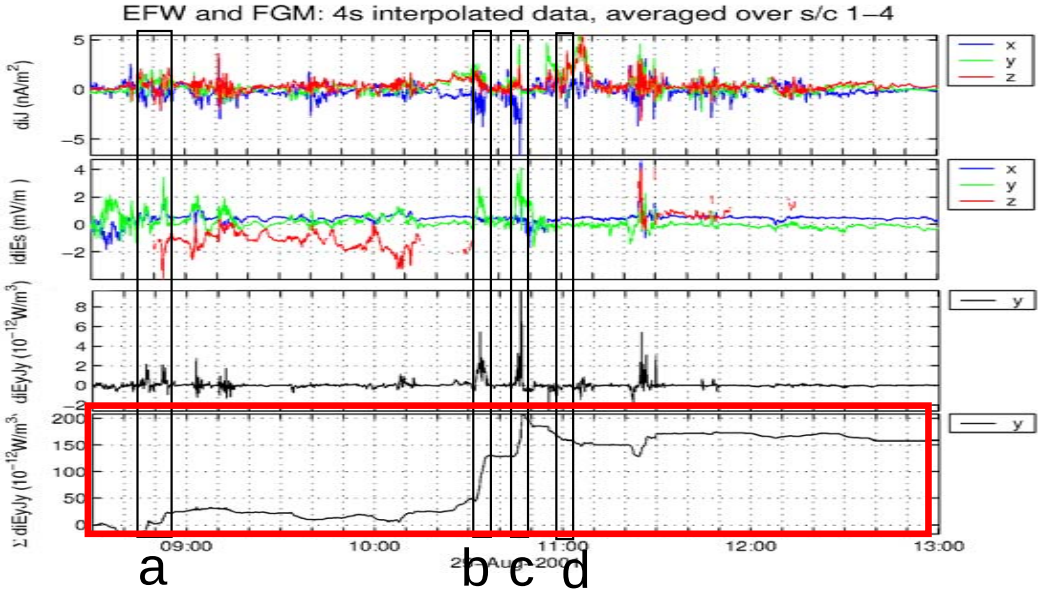
Birn and Hesse, Annales, 2005.

- Substantial change between (b) and (c), possibly related to the substorm development.
- If there is indeed a relation to the substorm, then the motion of the reconnection site to the Earth is surprising for the growth phase. Fast tailward motion after the Cluster pass?

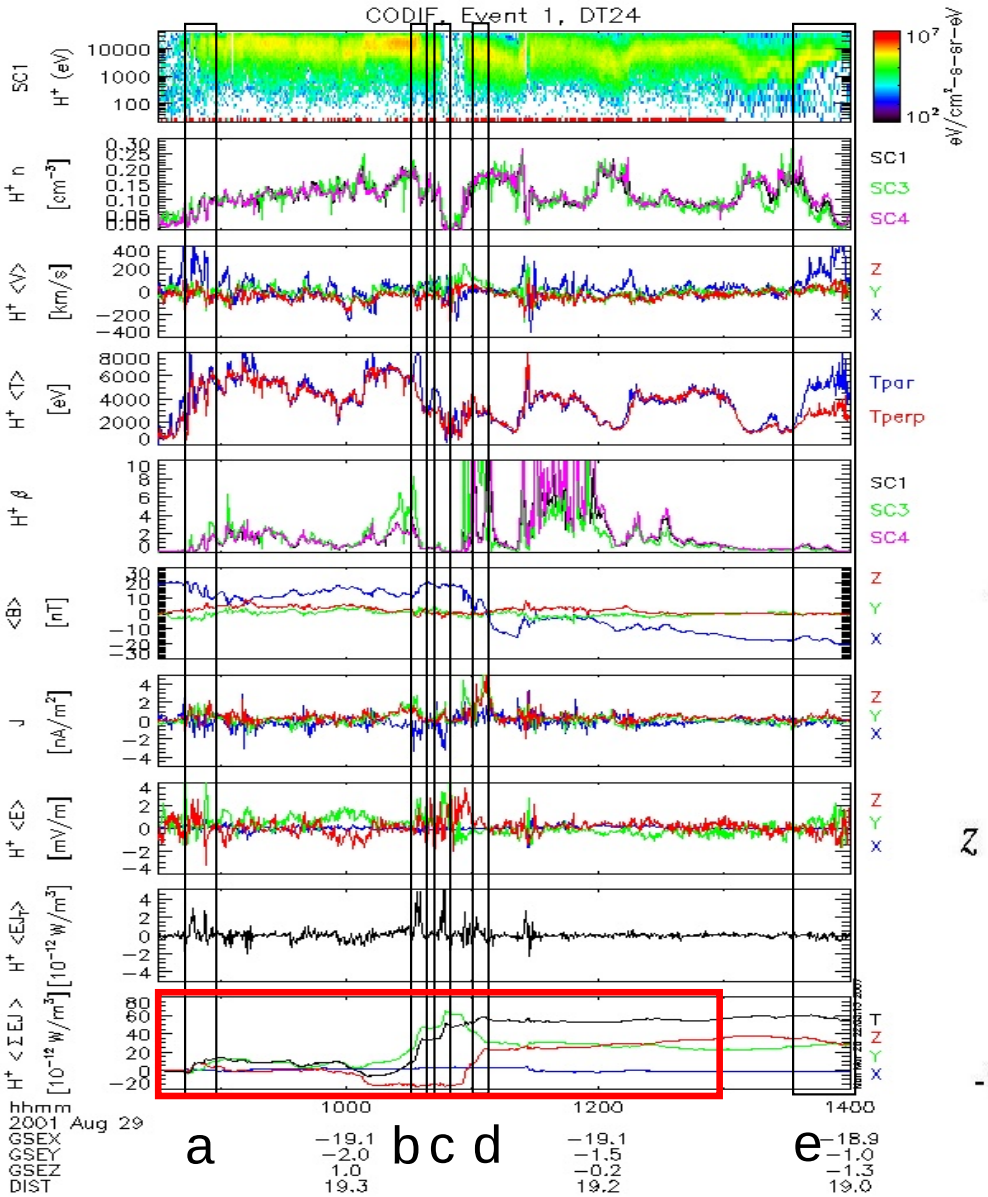
Load Event L2: Data

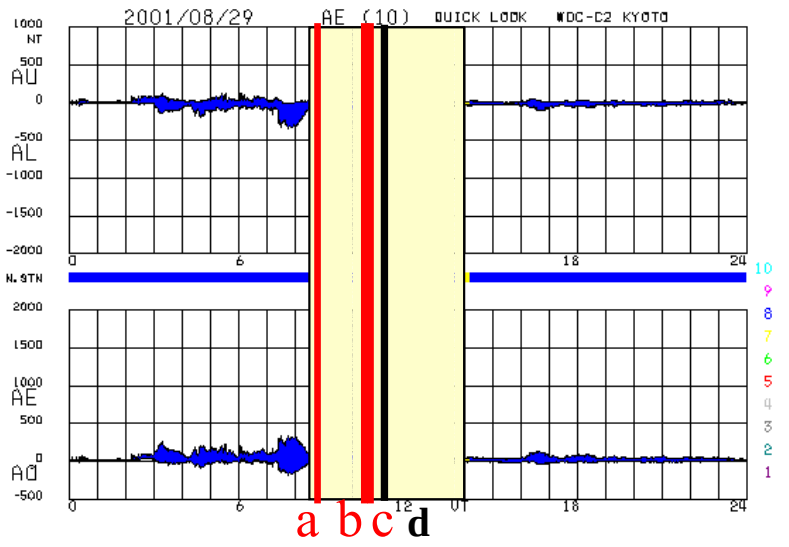


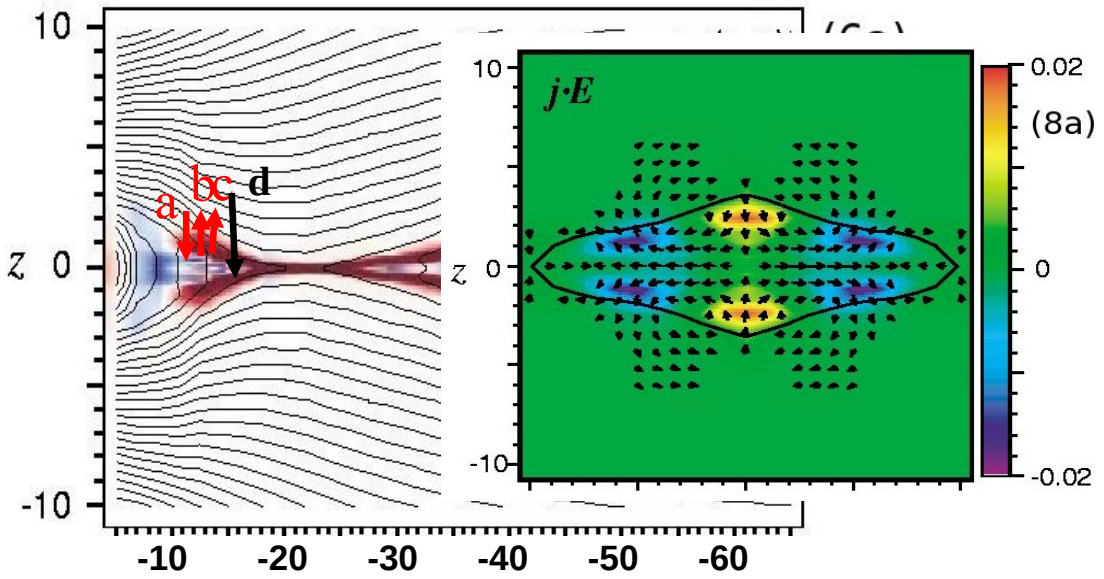
- Small and moderate loads (L2a, L2b, L2c) near the plasma sheet boundary (low/moderate beta).
- L2a assoc. with field aligned flow. L2b assoc. with Z bulk flow (untypical). L2c at the edge of field aligned flow. L2b, L2c assoc. with temp. anis. ($T_{||} > T_{\perp}$).
- No load when crossing the neutral sheet (L2d).
- Neither bulk flow nor temperature anisotropy are necessarily associated with a load (L2e).
- Qualitative agreement again good, but we miss a factor of 2.5: L2b+L2c ~60 (CODIF) vs ~150 (EFW).



B Load Event L2: Interpretation B

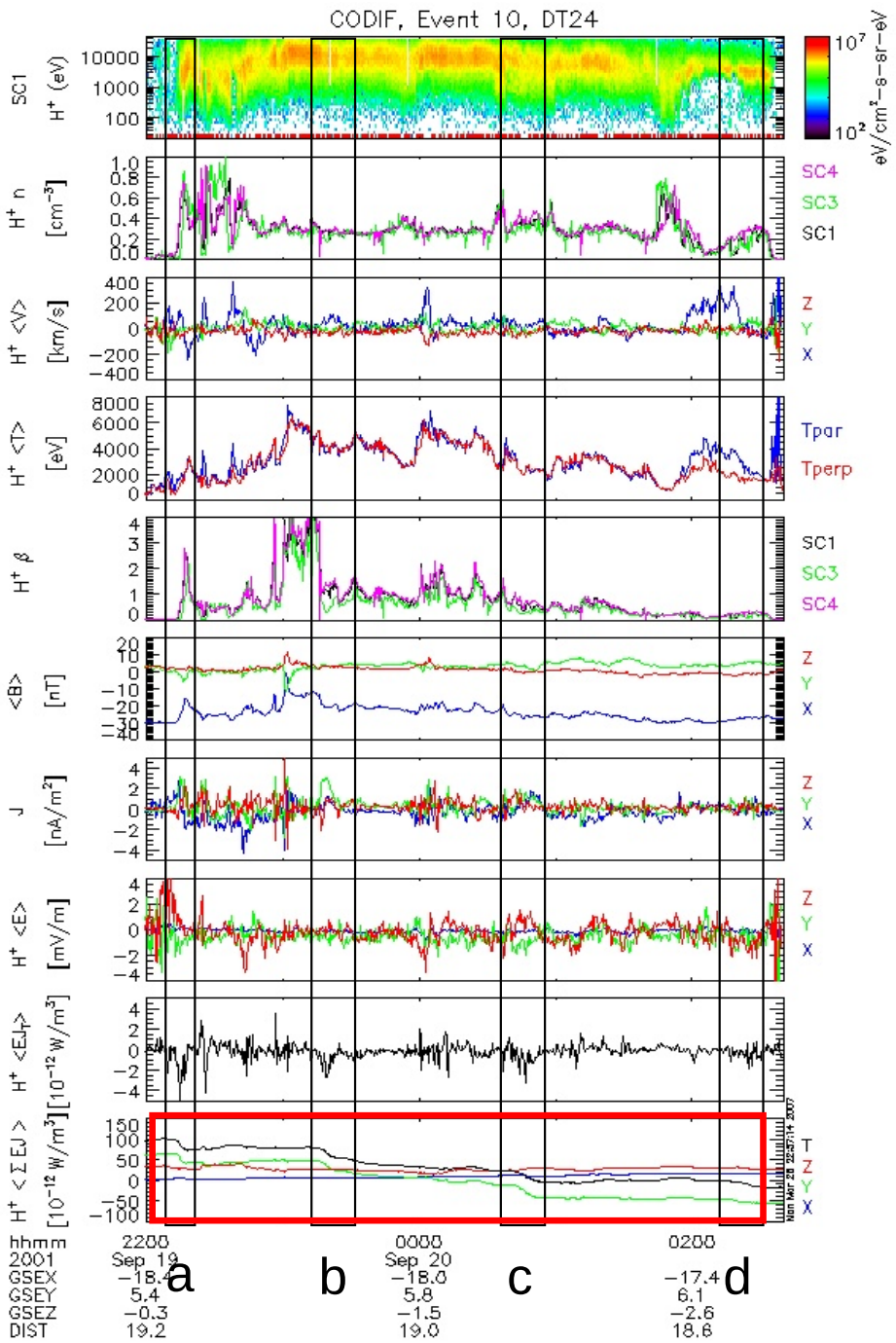




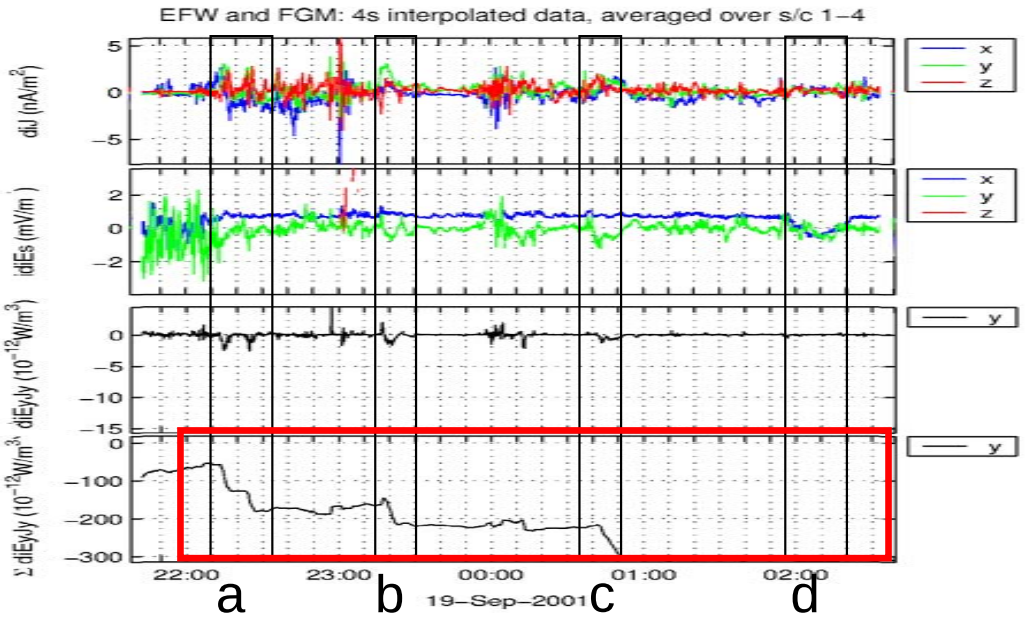


- Possibly the reconnection site comes closer to the Earth during the substorm expansion phase, but not close enough, so that eventually Cluster crosses the neutral sheet without encountering a load.
- E.J in the [x, z] panel is integrated along y. Even if on average E.J>0, locally one can have E.J=0 (L2d), or even E.J<0 (next slide).

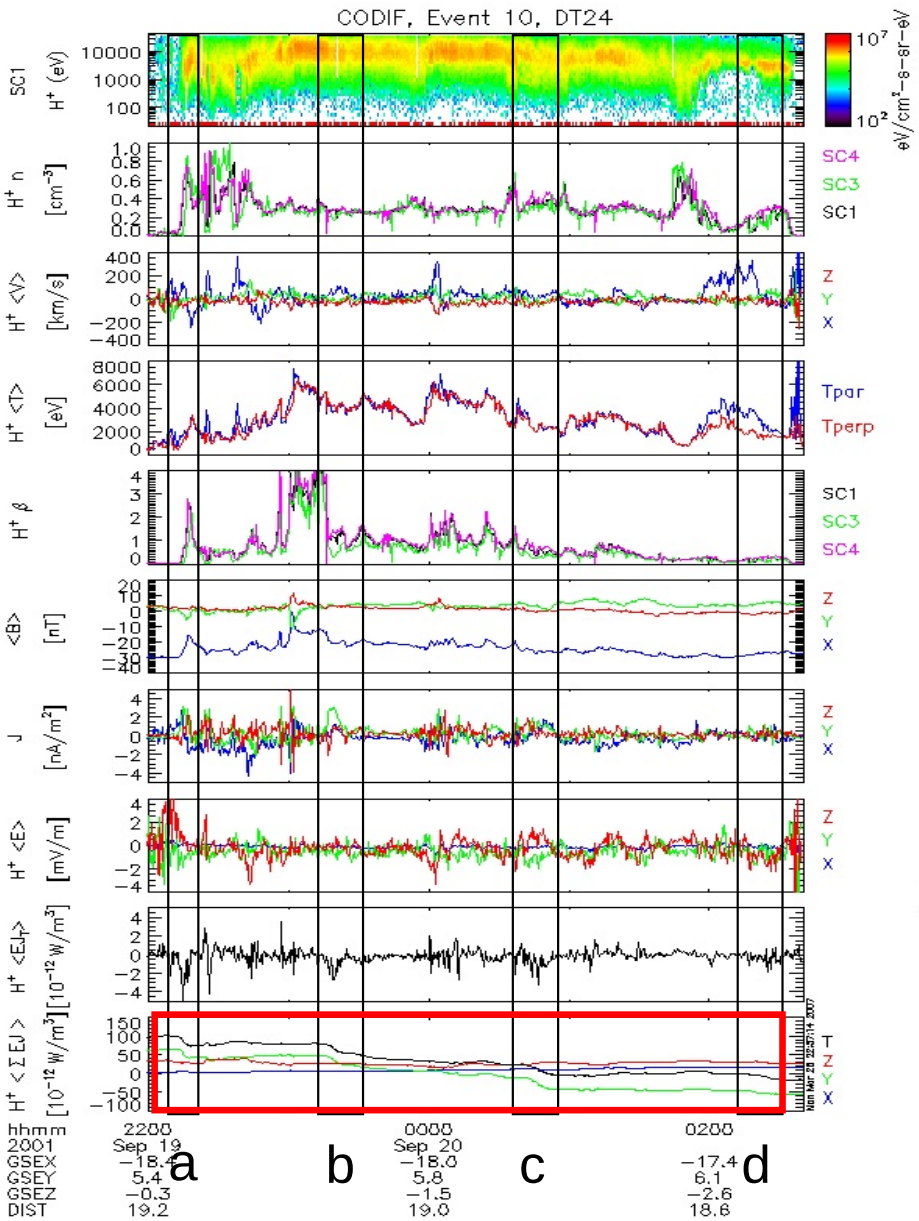
C Generator Event G1: Data C

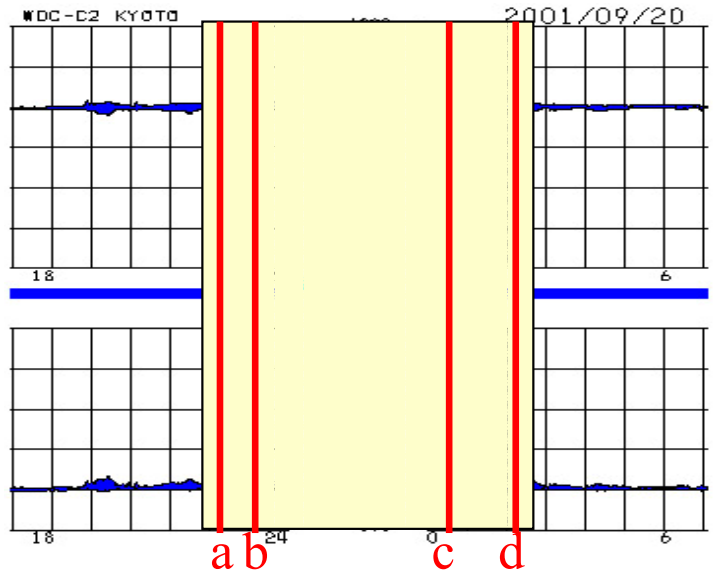


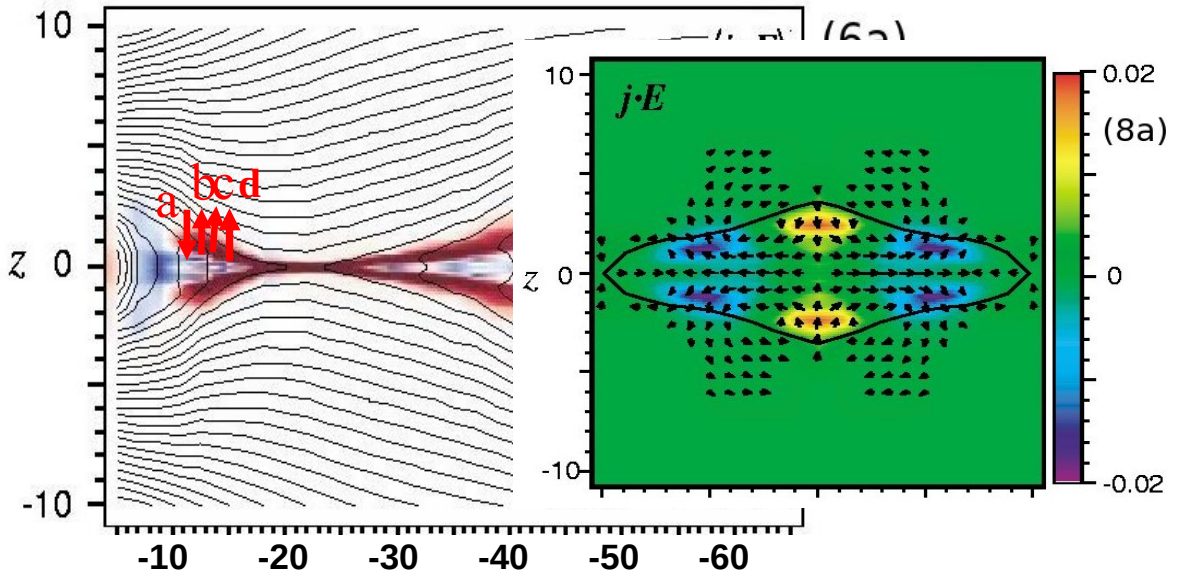
- Concentrated Generator Regions (CGRs) in the PSBL, discussed by Marghitu et al. (2006) and Hamrin et al. (2006), Ann. Geophys.
- Four CGRs of moderate (G1a, G1b, G1c) or small (G1d) power density.
- G1, G2, and G4 associated with field aligned flow. No field aligned flow for G3.
- G4 assoc. with temp. anis. No temp. anis. for G1–3.



C Generator Event G1: Interpretation C







➢ Although the average E.J shows load character [(x, z) panel], the local signature can still indicate a generator [(y, z) panel].

Summary

- Location of the energy conversion regions (ECRs):
  - High power density loads close to the neutral sheet, in high β plasma.
  - Low/moderate power density loads, as well as generators, near the PSBL, in low β plasma.
- Relation to plasma flow and temperature anisotropy, in particular for loads:
  - EC usually related to plasma flow, dominantly along the magnetic field. The reverse is not true, plasma flow can be observed without EC.
  - Temperature anisotropy often observed, with $T_{||} > T_{\perp}$.
- Possible scenario: Local plasma acceleration (load) naturally associated with bulk flow, which is thermalized faster in parallel direction ($T_{||} > T_{\perp}$). If the satellite path is far from the acceleration site, one observes just the bulk flow and the temperature anisotropy. If the path is very far => just the bulk flow.
- The observations are in decent agreement with simulation results, which can help to understand the context.

D Prospects D

- Closer look at the micro-physics:
  - Is the plasma flow associated with local acceleration by parallel electric fields, or the Lorentz force is enough?
  - Is the anisotropy indeed related to faster thermalization in parallel direction?
  - Reversible versus irreversible processes – entropy calculation?
- Improvement of the event statistics:
  - Completing the 2001 dawn–dusk survey with Cluster plasma sheet crossings in June – August 2001.
  - Cluster plasma sheet crossings in 2002 – 2004.
- Extension to other regions and missions:
  - Energy conversion at the magnetospheric flanks => better electric field from EFW, as well as EDI.
  - Energy conversion close to the subsolar point (coming soon).
  - Extension to future multi-spacecraft missions, like THEMIS (the current disruption region), MMS (reconnection sites), Cross-Scale (reconnection sites and shocks).