Local Energy Conversion in the Plasma Sheet and its Relationship to Aurora as Observed by Cluster and FAST

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Outline

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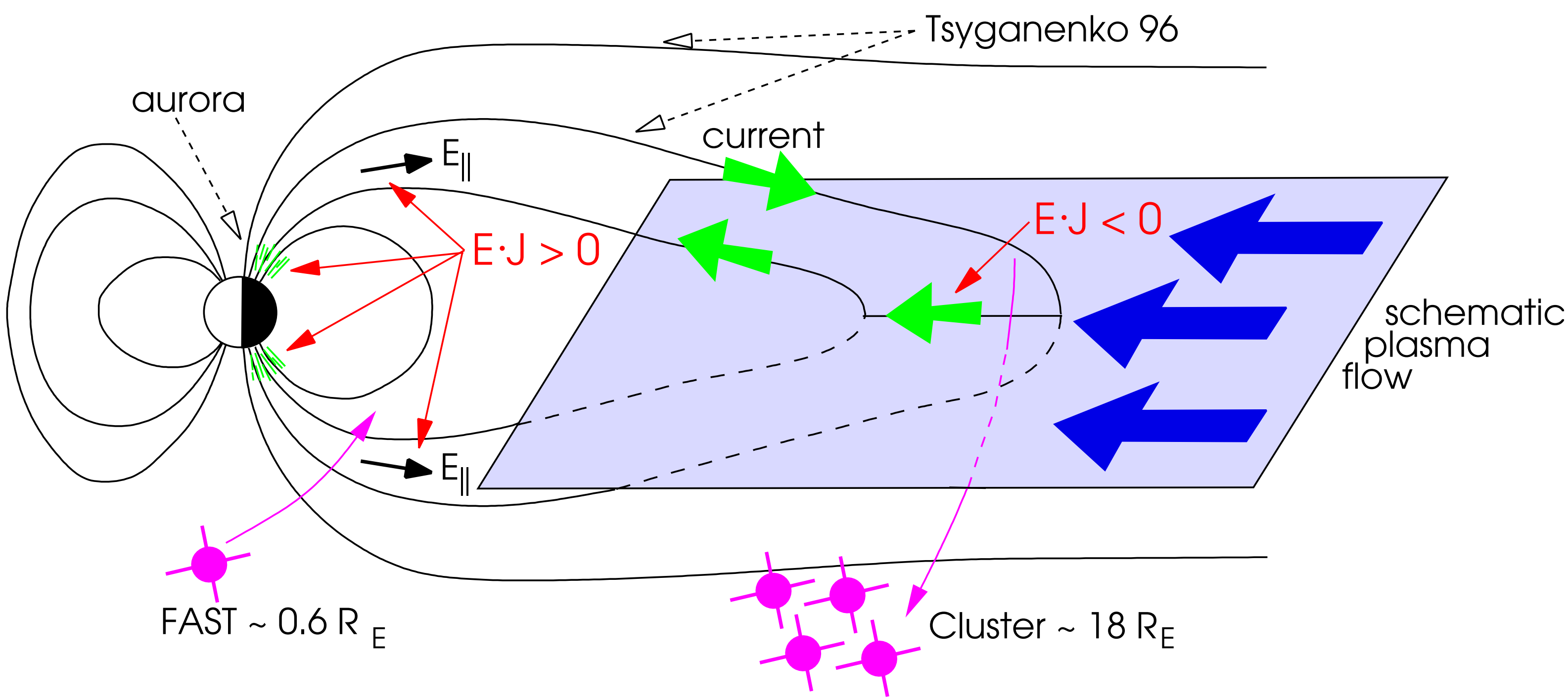
Background

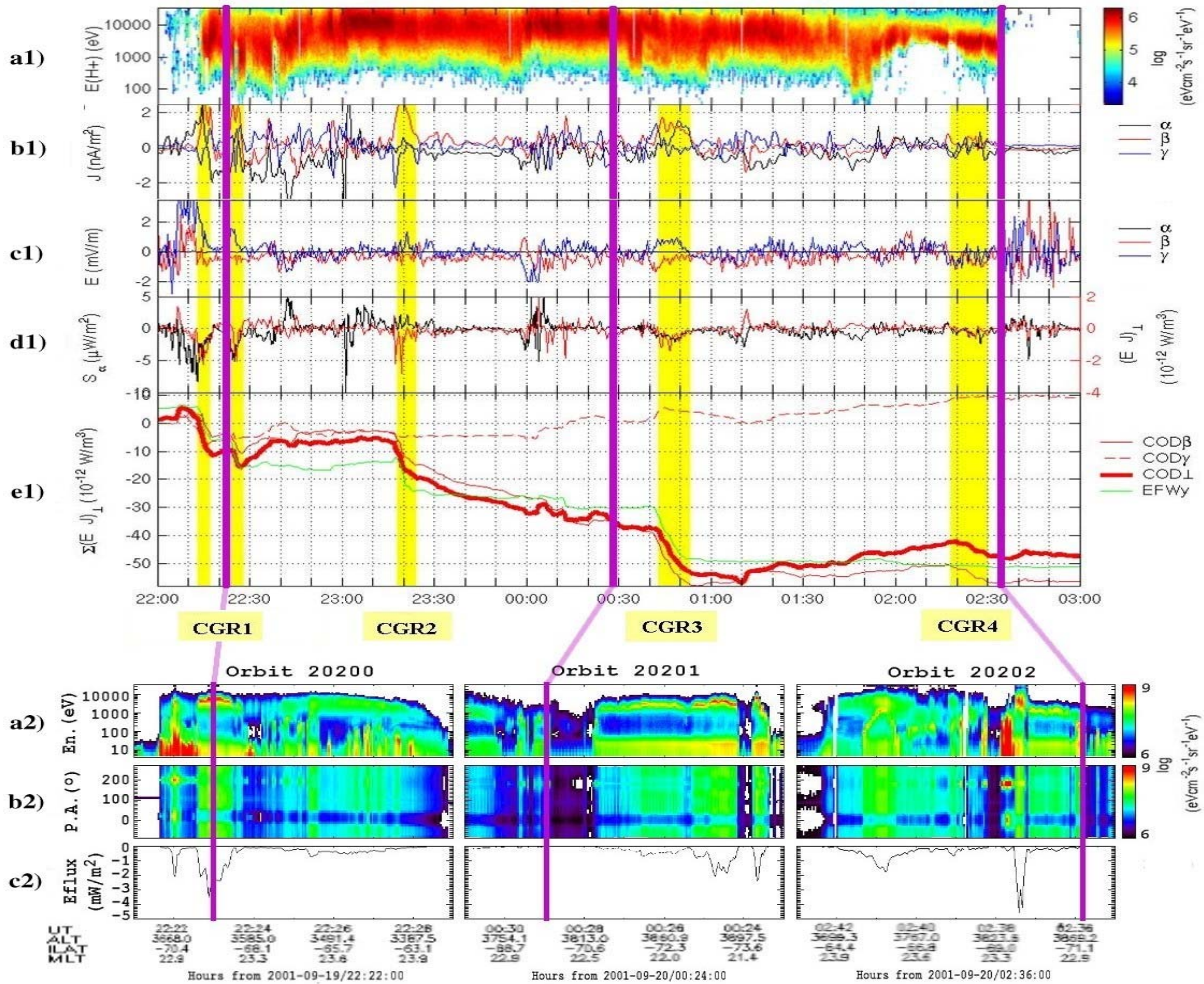
- With Cluster one can investigate local energy conversion, by computation of **E·J**
- **E·J** < 0 => Generator => conversion mechanical → electromagnetic energy
- **E·J** > 0 => Load => conversion electromagnetic → mechanical energy
- In the plasma sheet:
  - **E** can be inferred from two different 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, which are used to cross-check CIS
- **J** can be computed by the Curlometer method from the magnetic field measured on the four satellites
- The reference system is GSE.

B Generator Regions: Intro B



- A magnetospheric generator (**E·J**<0) powers loads (**E·J**>0) in the auroral acceleration region and ionosphere.
- The energy flux of a moderate aurora, $\sim 10^{-2}$ W/m^2, maps to $\sim 10^{-5}$ W/m^2 in the tail (mapping factor ~1000). If the generator region extends 10^7–10^8m (1.5–15R_E) along the field line, the power density is $\sim 10^{-13}$–10^{-12} W/m^3, close to the detection limit of the instruments.
- Still, Cluster provides the means to identify generator regions, even if not the accurate magnitude of **E·J.**

B Generator Regions: Cluster versus FAST data B



$\mathcal{B}$ Generator Regions: Consistency Checks $\mathcal{B}$

$\Sigma E_Y J_Y$

E_Y

J_Y

P_K

P_B

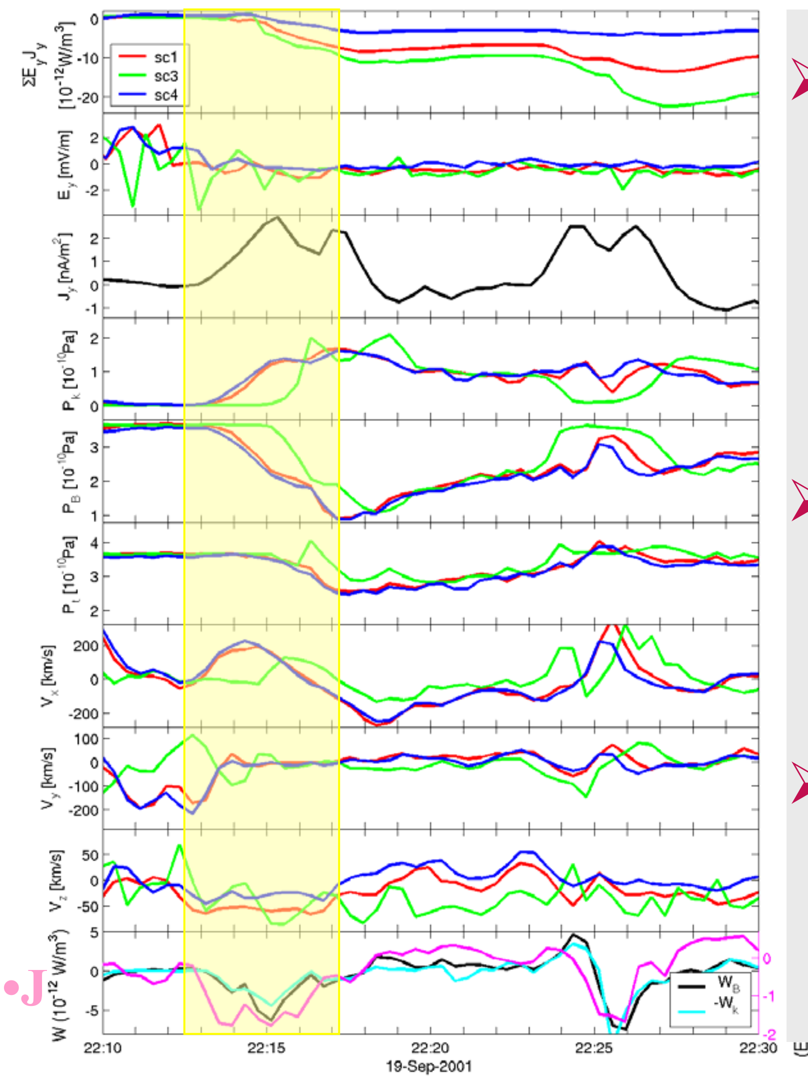
P_T

V_X

V_Y

V_Z

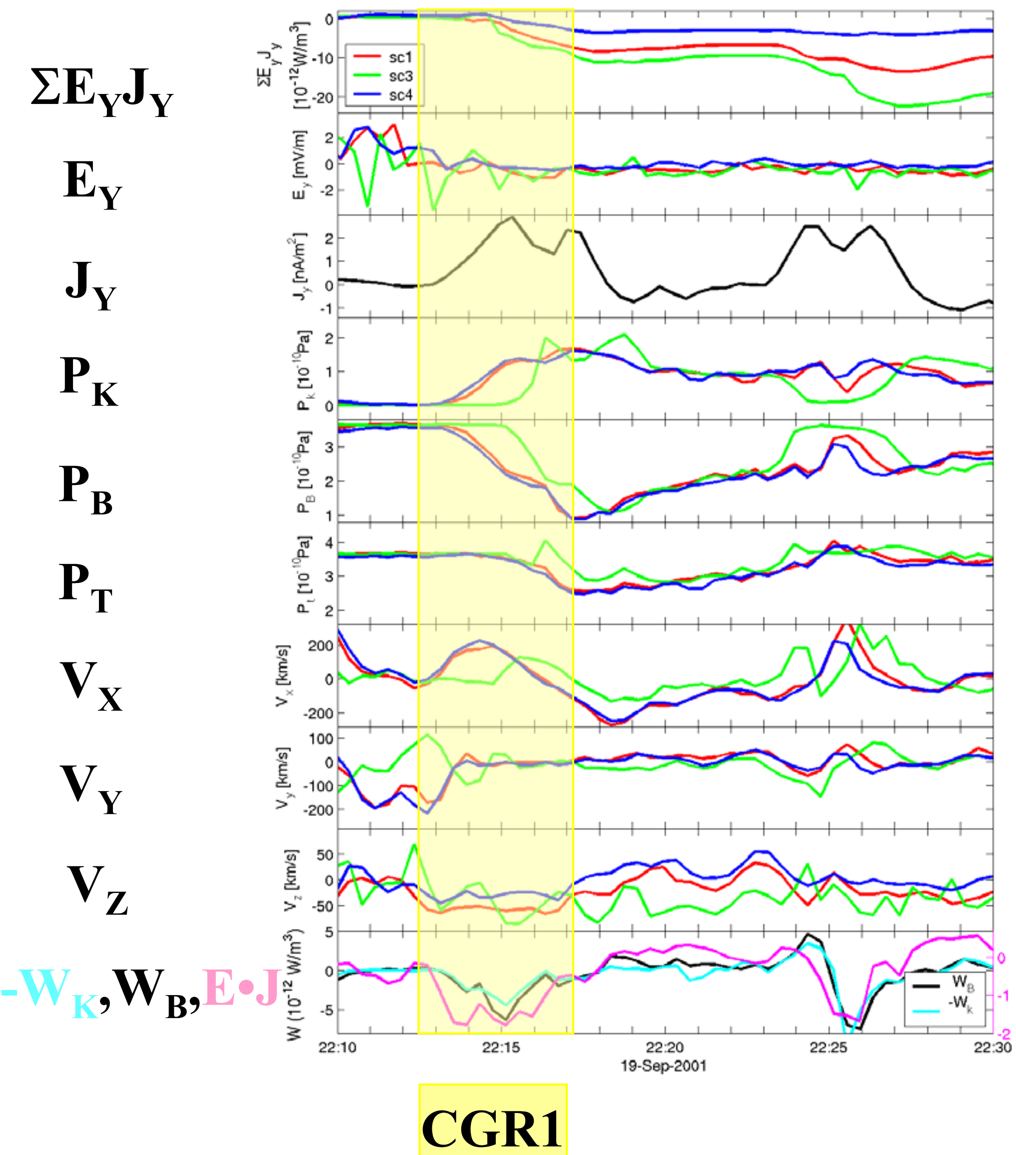
$-W_K$, W_B, $E \bullet J$



CGR1

- $\partial \mathcal{E}/\partial t = -\nabla \bullet (\mathcal{E}\ \mathbf{V}) + \mathbf{W_K} + \mathbf{W_L}$
  - $n < 1 cm^{-3}$, $V < 100 km/s \Rightarrow \mathcal{E} < 10^{-11} J$
    $W_K + W_L \cong 10^{-13} - 10^{-12}$
  - $\mathcal{E}/T \cong W_K + W_L \Rightarrow T \cong 10 - 100$ s
  - $\mathcal{E}V/L \cong W_K + W_L \Rightarrow L \cong 10^3 - 10^4$ km
- $W_L = W_B + W_T \cong \mathbf{E \bullet J}$
  - $\mathbf{E \bullet J} \cong -2\ 10^{-12}$, $W_B \cong -6\ 10^{-12}$
    $\Rightarrow W_T \cong 4\ 10^{-12}\ W/m^3$
- $W_T = \mathbf{V} \bullet (\nabla \bullet \mathcal{T}_B) \cong VB^2/\mu_0 L$
  - B=30 nT, V=50 km/s
    => $L \cong 10{,}000$ km

$\mathcal{B}$ Generator Regions: Consistency Checks $\mathcal{B}$



- The Poynting theorem (PT):

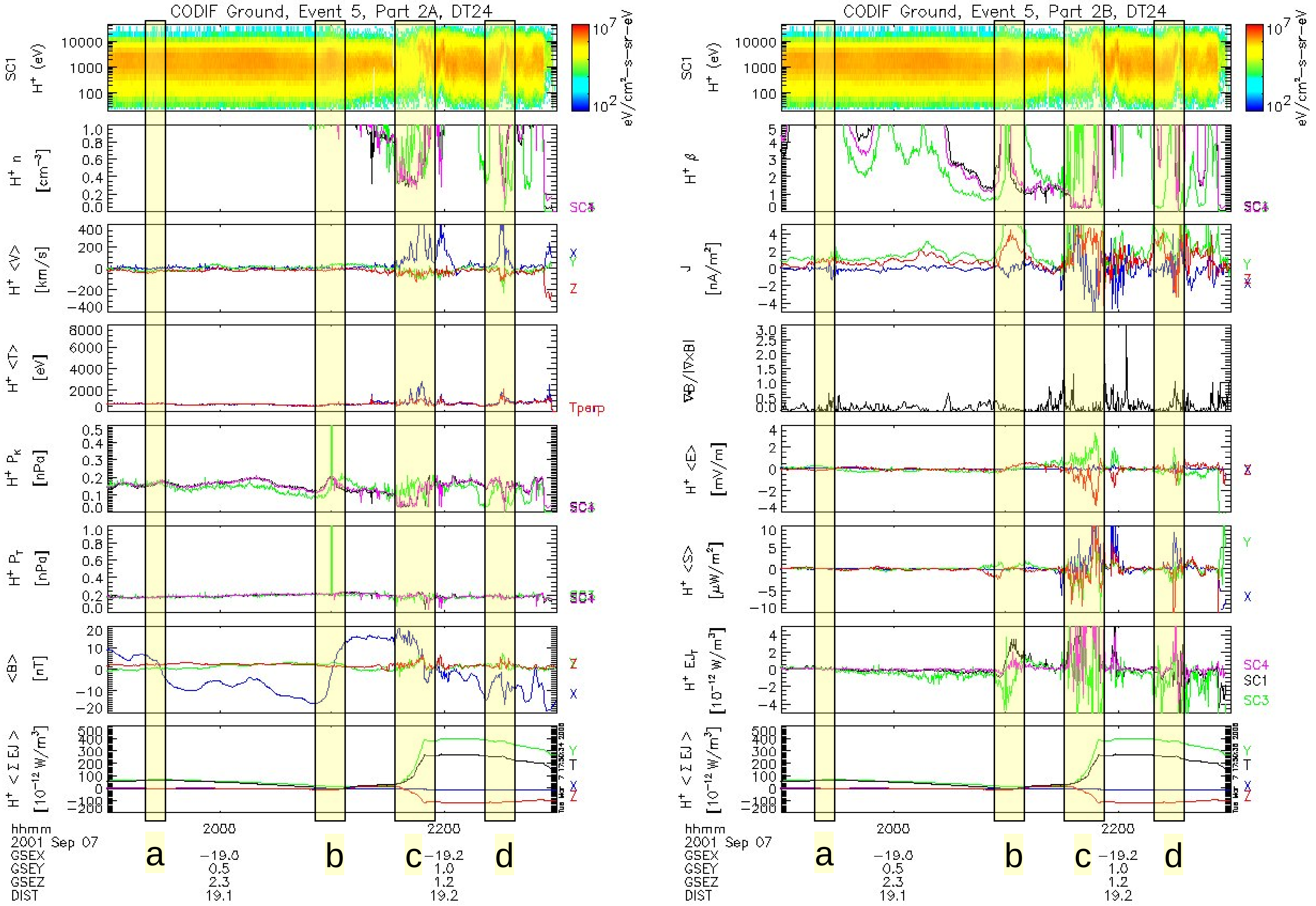
  $\nabla \cdot \mathbf{S} = -\,\partial W/\,\partial t - \mathbf{E \cdot J}$

  with $W \cong W_B = B^2/2\mu_0 \equiv P_B$.
- $\partial/\partial t \cong d/dt$ in the s/c system, because $V_{sat} << V_{plasma}$. In the P_B panel =>regions where $-dP_B/dt > 0$.
- Both terms on the r.h.s. of PT positive => elmag. energy carried away from the CGR.
- $-\,\partial P_B/\,\partial t \cong 0.2\text{nPa}/200\text{s} = 10^{-12}\text{W/m}^3$, comparable to $-\mathbf{E \cdot J}$.
- $\nabla \cdot \mathbf{S} \cong S/L$. $S \approx 4 \cdot 10^{-6}\ \text{W/m}^2$, $\nabla \cdot \mathbf{S} \approx 2 \cdot 10^{-12}\ \text{W/m}^3 \Rightarrow L \approx 2000$ km

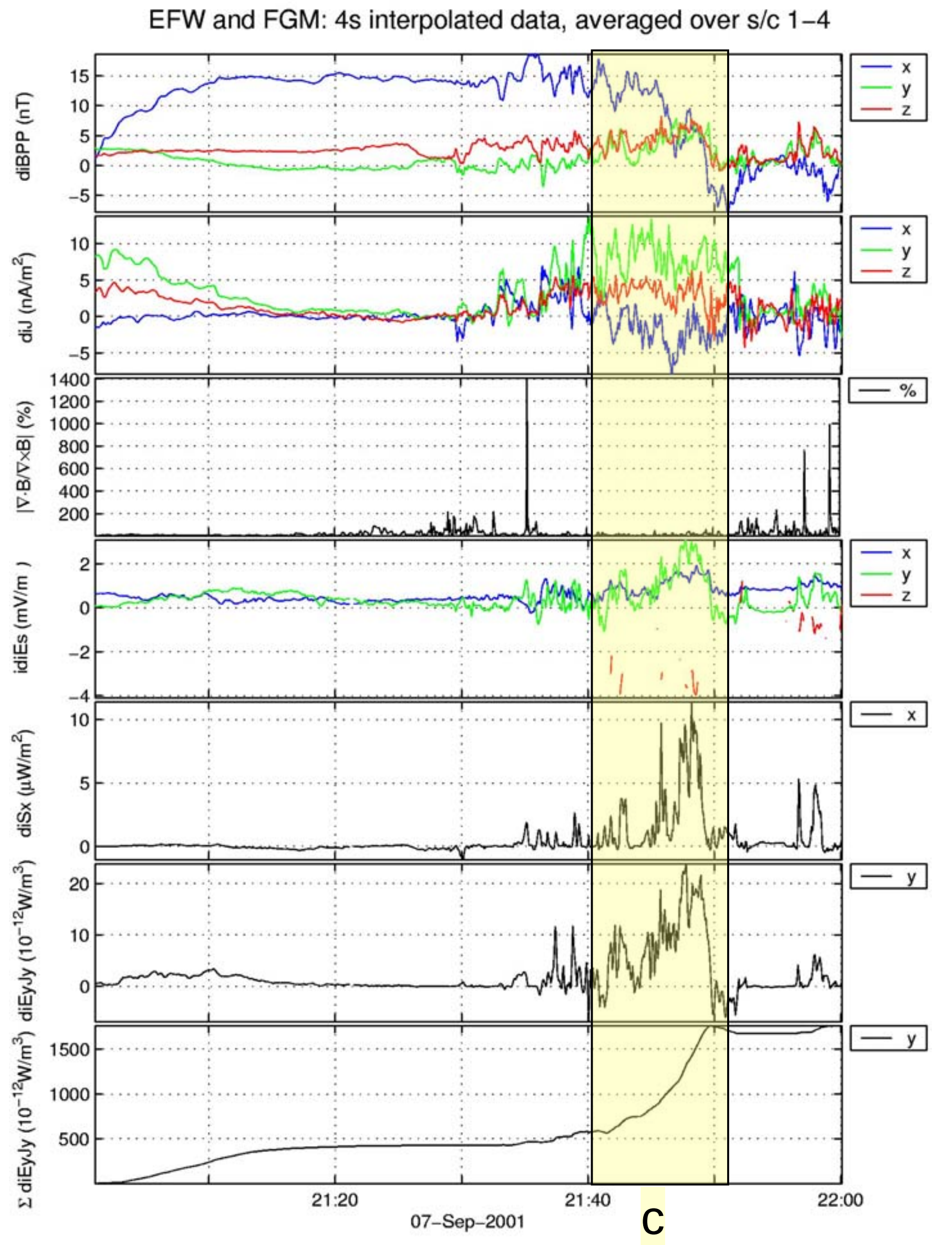
C Load Regions: Intro C

- In order to extend the search for (auroral) generator regions we selected a time interval between the end of August and the beginning of November, 2001, with increased conjunction rate between the two spacecraft. During this time the apogee of Cluster, at 19 R_E, was in the plasma sheet, moving from midnight to the dusk.
- With the progress of the work it became clear that Cluster data can be used for a broader investigation of the energy conversion, not restricted to generator regions. Consequently, we started to build a database of CIS and EFW quantities (so far 28 intervals, between 4 and 24 h), useful for the study of local energy conversion.
- The main observation, illustrated by one example, is that near the Cluster apogee the conversion magnetic → mechanical energy is dominant (we believe mostly by reversible, 'motor' processes), and the plasma sheet behaves, on average, as a load.

C Load Region Example: CODIF / FGM Data C



C Load Region Example: EFW /FGM Data C



Ɗ ECRs in the Plasma Sheet : Summary Ɗ

- Starting from the examination of generator regions, we developed a method that allows for a systematic investigation of the energy conversion regions (ECRs).
- Cluster North–South crossings of the plasma sheet show, on large scales, mostly load character, with a substantial fraction of the load near the neutral sheet.
- The magnitude of the integrated load seems to decrease from midnight to the dusk. Away from the midnight one can even encounter integrated generator regions, in good agreement with simulation results (Birn and Hesse, 2005).
- The CGRs seem to develop in the PSBL, as inferred from the plasma β – consistent, again, with the simulations. One example was shown, where the CGRs observed by Cluster correlate with electron precipitation observed by FAST.
- High power density CLRs are located not far from the neutral sheet, in high β plasma, while for the low/moderate power density CLRs a clear dependence on β it is not obvious so far.
- The energy conversion seems to be related to bulk plasma flow, dominantly along the magnetic field. Temperature anisotropy is observed as well, with $T_{\parallel} > T_{\perp}$.

Ɗ ECRs in the Plasma Sheet : Prospects Ɗ

- Further investigation of the generator events presented:
  - Computation of W_T by direct evaluation of $\nabla \bullet \mathcal{T}_B$.
  - Direct evaluation of $\nabla \bullet \mathbf{S}$.
  - CGR geometry – curvature radius, etc.
- Completing the dawn–dusk survey with the Cluster plasma sheet crossings in June – August 2001. Closer look at the local energy budget – work of the pressure forces, Poynting theorem, etc.
- Is the plasma flow associated with local acceleration and parallel electric fields? Is the anisotropy related to thermalization, achieved faster in parallel direction ?
- Cluster plasma sheet crossings in 2002 – 2004.
- Energy conversion at the magnetospheric flanks => better electric field from EFW, as well as EDI.
- Energy conversion close to the subsolar point (later in the mission).
- Extension possible to future multi-spacecraft missions, like THEMIS and MMS.