Investigation of the auroral current–voltage relationship in upward current regions with FAST and Cluster spacecraft

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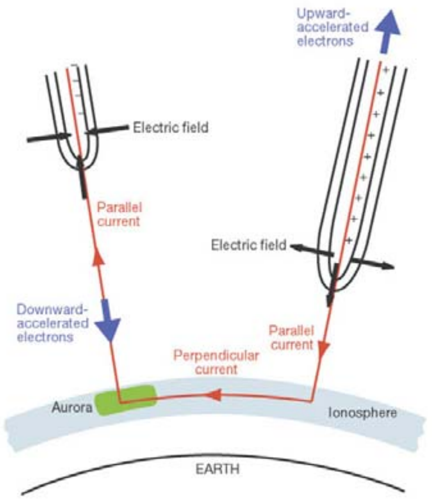
Abstract

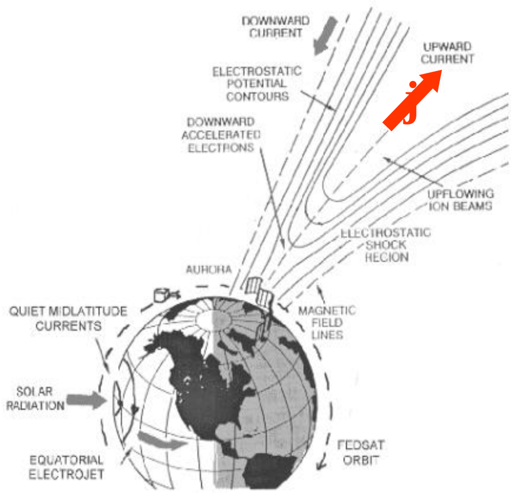
A key element for the physics of the magnetosphere–ionosphere coupling is the current–voltage relationship (CVR) within the auroral acceleration region (AAR). In upward current regions the CVR can be often approximated with a linear dependence, J=KU (with J the current density and U the field-aligned potential drop), where K may vary between roughly 10-12 and 10-9 S/m2.

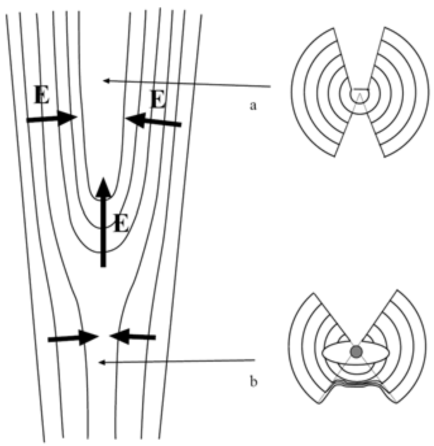
The Cluster and FAST spacecraft provide a good platform to study the CVR at two locations that encompass the AAR. When near perigee, Cluster may pass close to the top boundary of the AAR, while FAST near apogee may skim the bottom side of the AAR. For both spacecraft, J can be derived from the magnetic field data, assuming the current sheet approximation. On Cluster, U can be estimated by using both electric field and ion data, and the association between bipolar signatures in the electric field and the occurrence of ion beams provides a double-check for the AAR crossing. On FAST, U can be inferred from the electron and ion data (with the ion data needed only when the satellite crosses the AAR).

In this paper we analyze two sets of AAR events, acquired by Cluster in 2001-2003 and by FAST in 1996-1998. For each event we check whether the CVR is linear, and for the linear cases we concentrate on the dependence of K on altitude. We also investigate the dependence of K on the MLT sector and AE index. For some of the FAST events conjugate optical data are available, which allow the examination of the CVR in relation with the auroral morphology.

Introduction: Auroral acceleration region

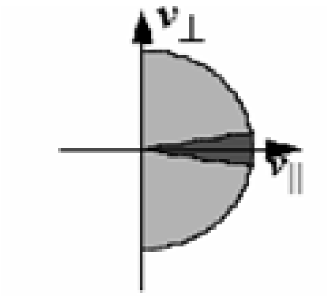


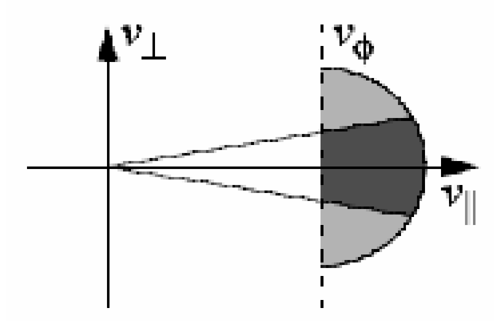


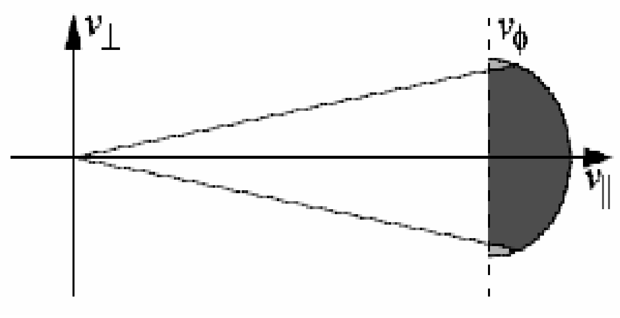


- The magnetosphere often acts as a current generator
- Electrons are accelerated downwards by upward E-field.
- This increases the pitch-angle of the electrons, and more electrons can reach the ionosphere, where the current is closed.

Introduction: Auroral currents – Knight relation







Thermal flow $\frac{e\Phi_\parallel}{kT_e} << 1$

Linear regime $1 << \frac{e\Phi_\parallel}{kT_e} << R_M$

Saturation $R_M << \frac{e\Phi_\parallel}{kT_e}$

Fraction of particles in the loss cone:

$$f = \frac{\pi\theta_{lc}^{\ 2}}{2\pi} \approx \frac{B_M}{B_I} \approx 10^{-2}$$

Apply a parallel potential drop:

$$j_{\parallel,ion} = n_0 e v_{th} f \frac{B_{ion}}{B_{ms}} \left[1 - \frac{e^{-xe\Phi_P/T_e}}{1+x} \right] \quad x = \frac{1}{B_I / B_M - 1} \quad v_{th} = \sqrt{T_e / 2\pi m_e}$$

Thermal current:

$$j_{\parallel,ion} = n_0 e v_{th} f \frac{B_{ion}}{B_{ms}} =$$

$$n_0 e v_{th} \frac{B_{ms}}{B_{ion}} \frac{B_{ion}}{B_{ms}} = n_0 e v_{th} \approx$$

$$[n_e = 0.1 cm^{-3}, T_e = 1 keV] \approx 1 \mu A / m^2$$

Linear regime :

$$j_{\parallel,ion} \approx n_0 e v_{th} \frac{e\Phi_\parallel}{k_B T_e} = K\Phi_\parallel$$

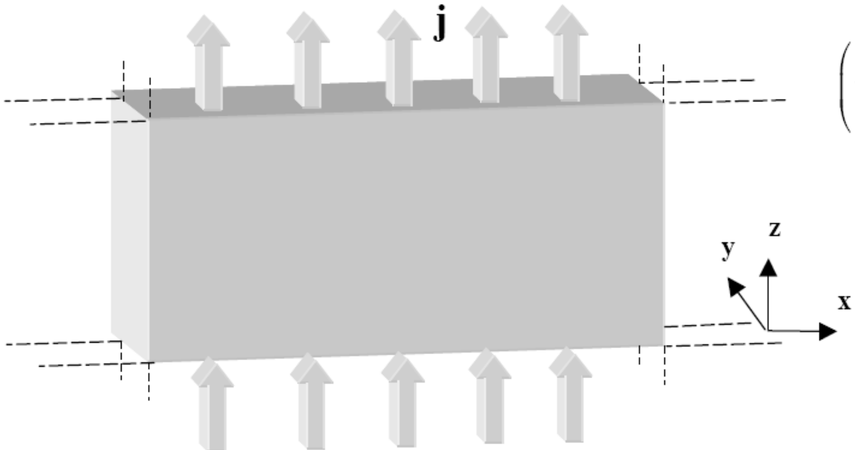
$$K = \frac{e^2 n_0}{\sqrt{2\pi m_e k_B T_e}} : 10^{-9} S / m^2$$

Saturation :

$$j_{\parallel,ion} = R_M j_{th} \quad R_M = \frac{B_I}{B_M}$$

$$R_M = 100 \rightarrow j_{\parallel,ion} \approx 100 \mu A / m^2$$

Method: Current sheet approximation



$$\left(\frac{\Delta B_z}{\Delta y} - \frac{\Delta B_y}{\Delta z},\ \frac{\Delta B_x}{\Delta z} - \frac{\Delta B_z}{\Delta x},\ \frac{\Delta B_y}{\Delta x} - \frac{\Delta B_x}{\Delta y} \right) = \mu_0 \left(j_x,\ j_y,\ j_z \right)$$

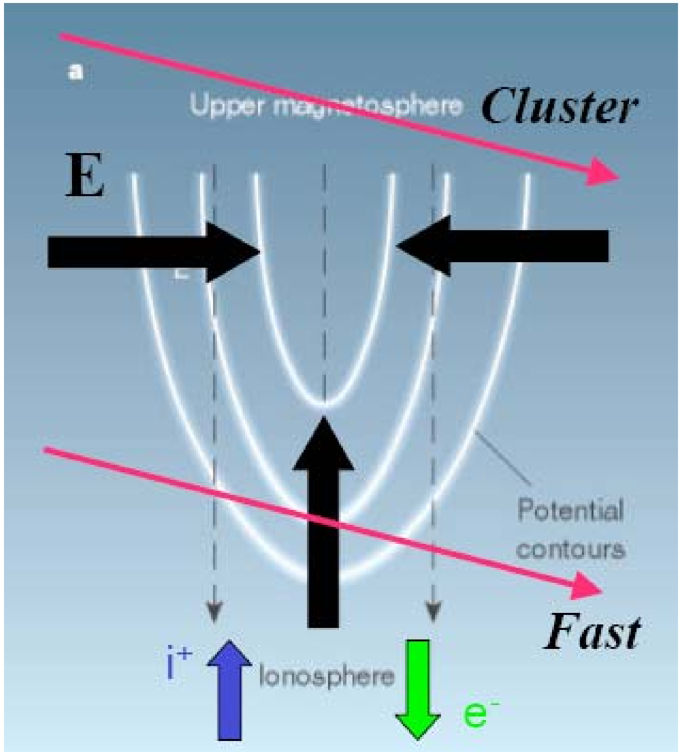
$$\frac{\Delta}{\Delta x} = 0 \qquad \frac{\Delta}{\Delta z} = 0$$

$$\left(\frac{\Delta B_z}{\Delta y},\ 0,\ -\frac{\Delta B_x}{\Delta y} \right) = \mu_0 \left(0,\ 0,\ j_z \right)$$

or

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{j} \quad \Longrightarrow \quad j_z = -\frac{1}{\mu_0} \frac{\Delta B_x}{\Delta y}$$

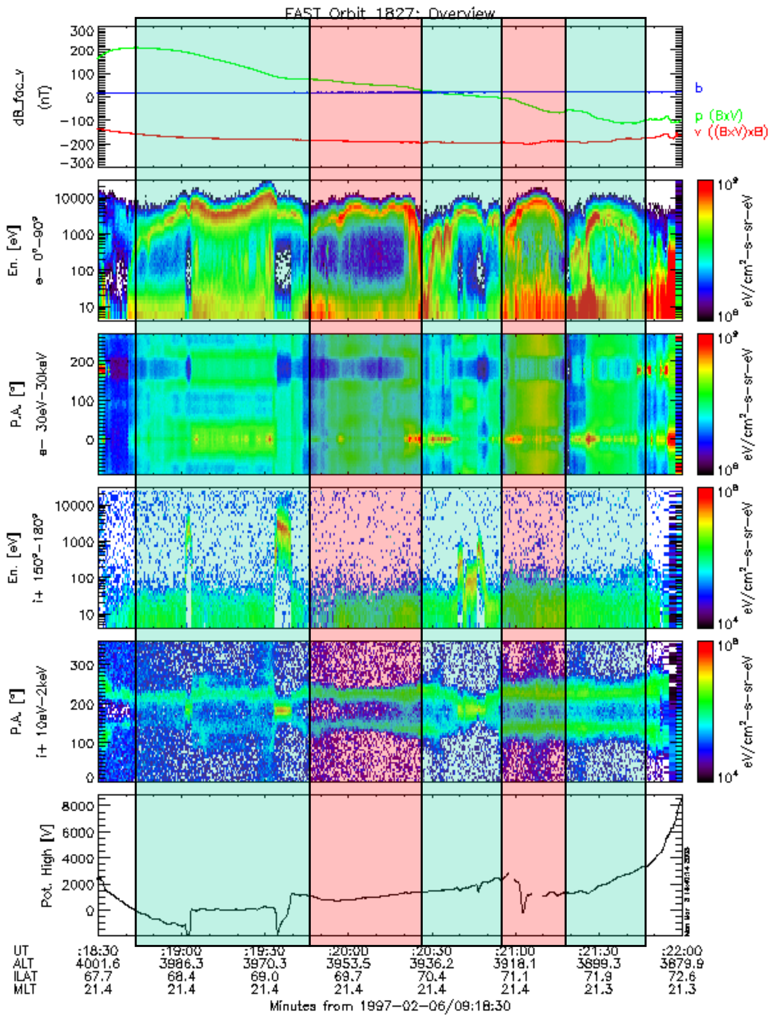
Method: Potential drop estimation

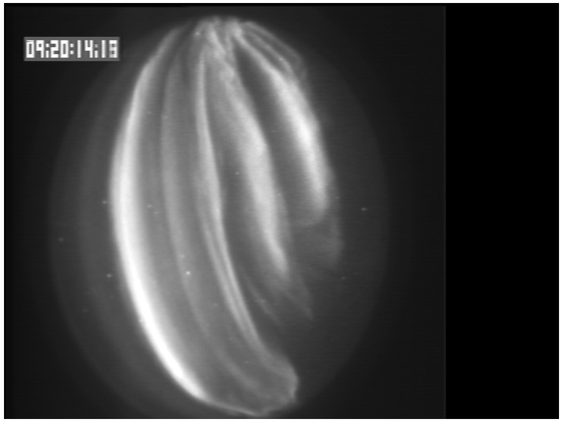


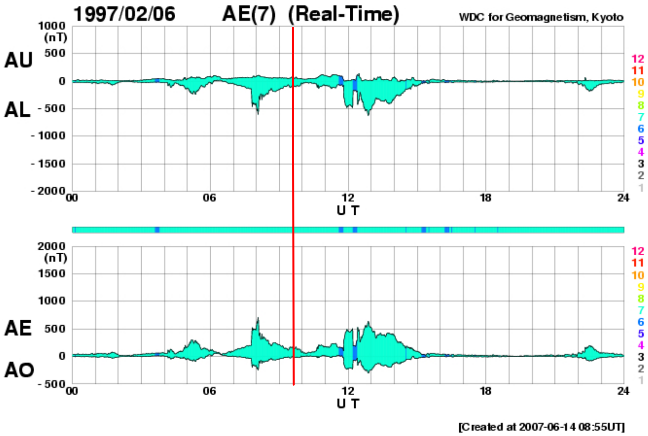
FAST
- Energy of the precipitating electrons plus the energy of the upgoing ion beam when FAST crosses the AAR

Cluster
- Integrate E along the satellite path
- Energy of the upgoing ion beam

FAST case study: orbit 1827

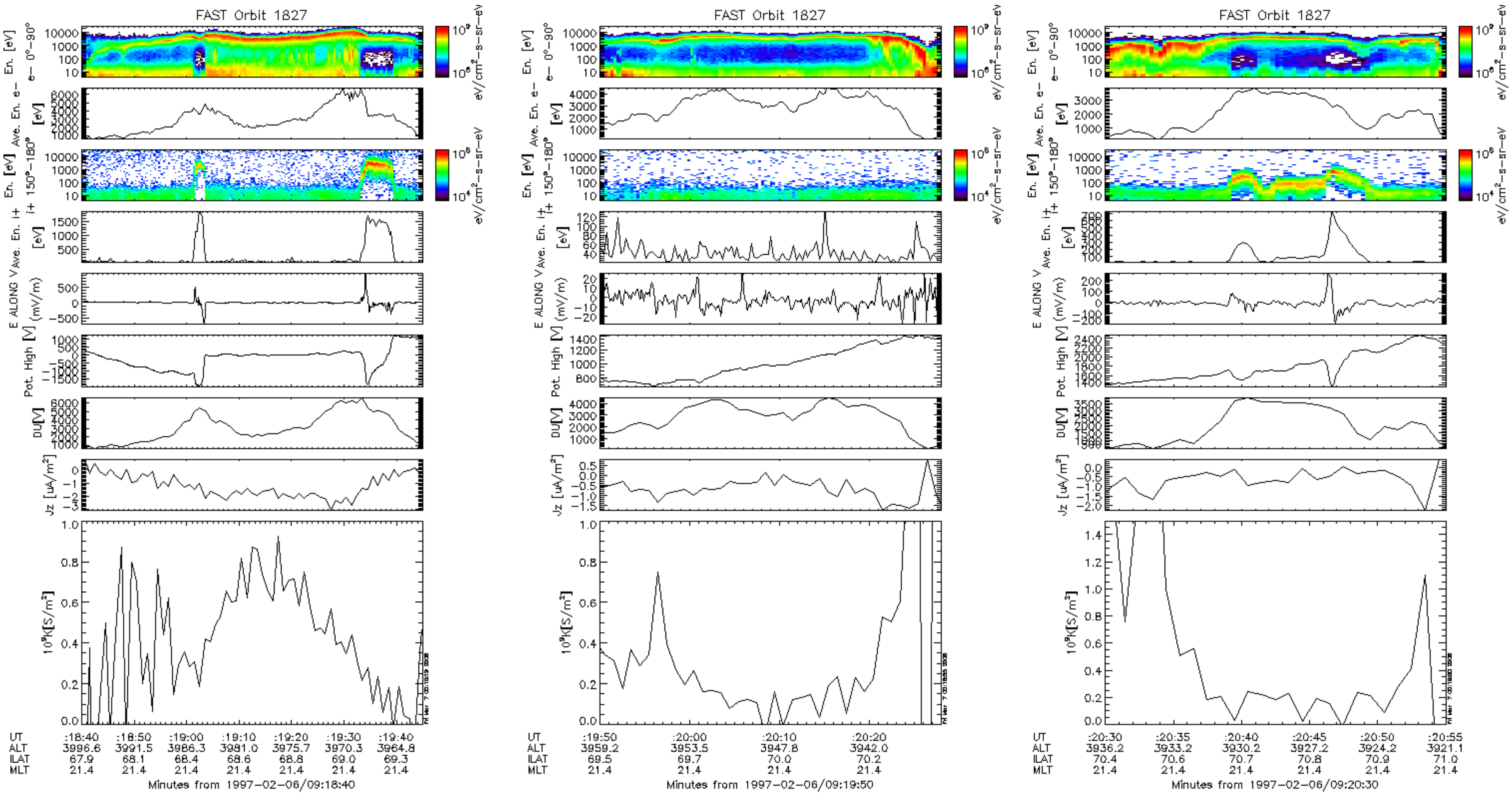




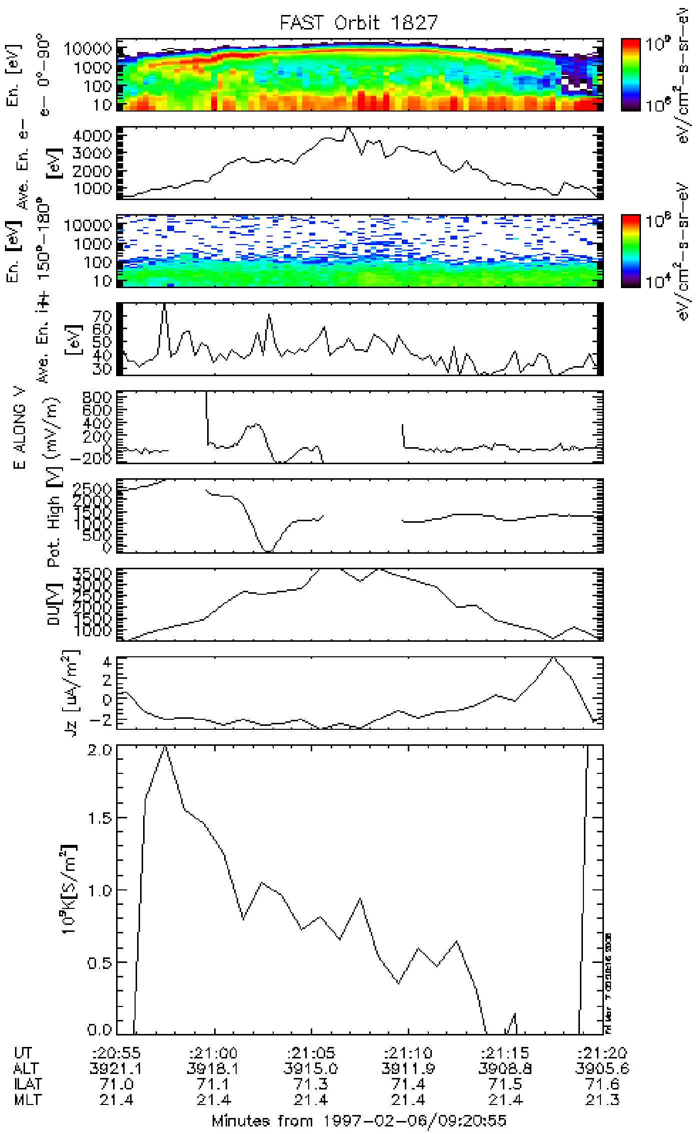


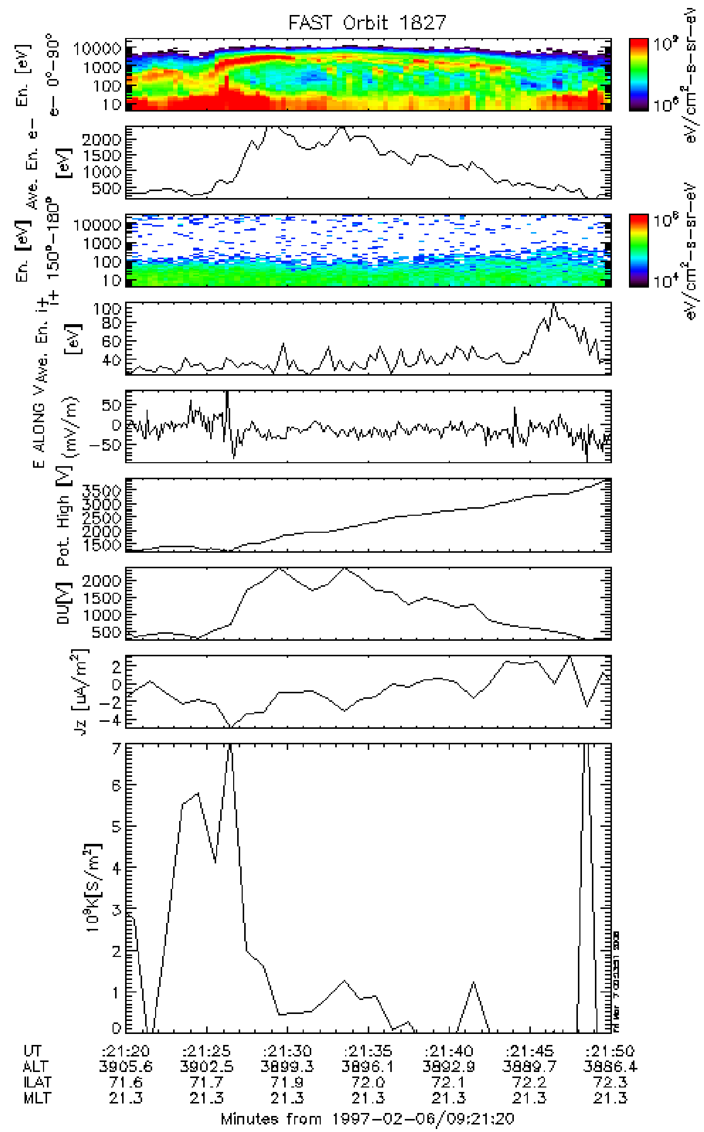
Stenbaek-Nielsen et al., GRL, 25, 2073, 1998

FAST case study: orbit 1827

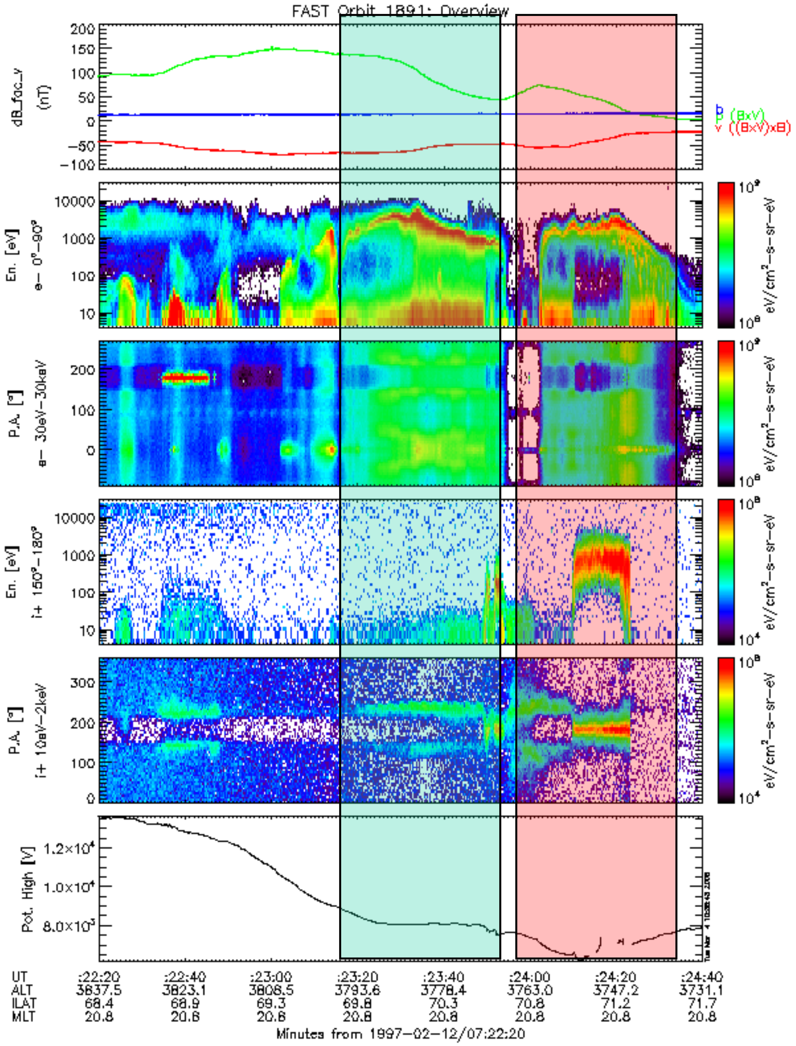


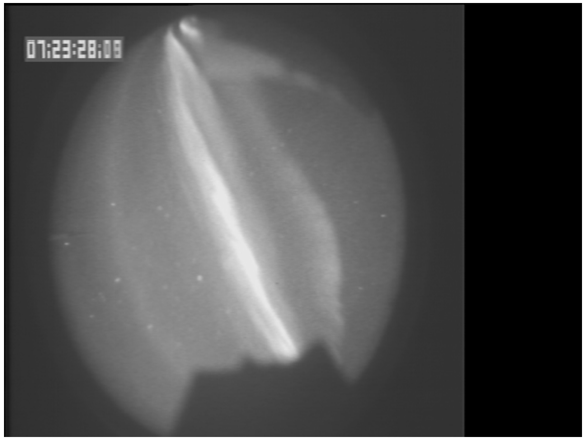
FAST case study: orbit 1827

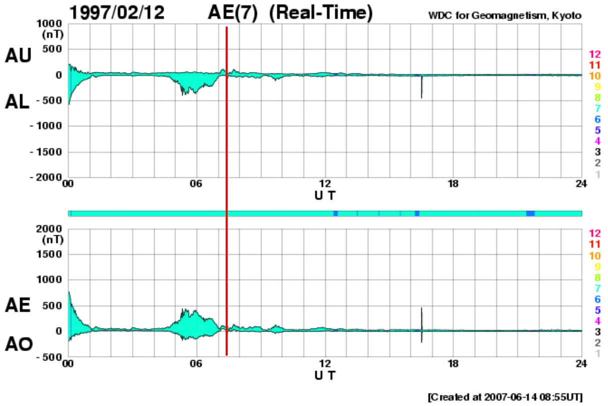




FAST case study: orbit 1891

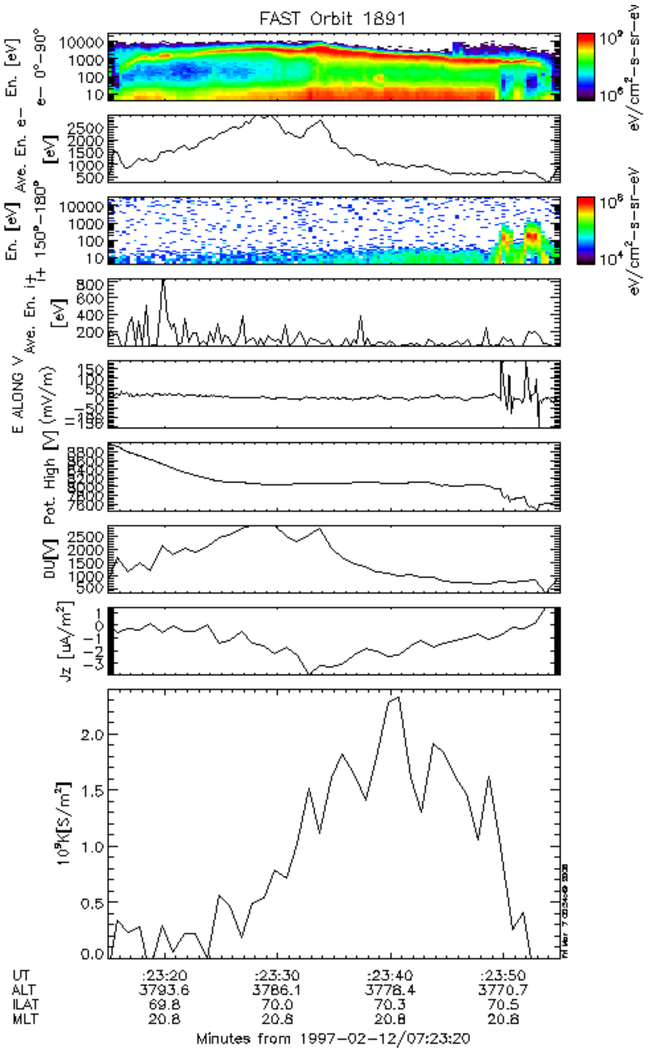


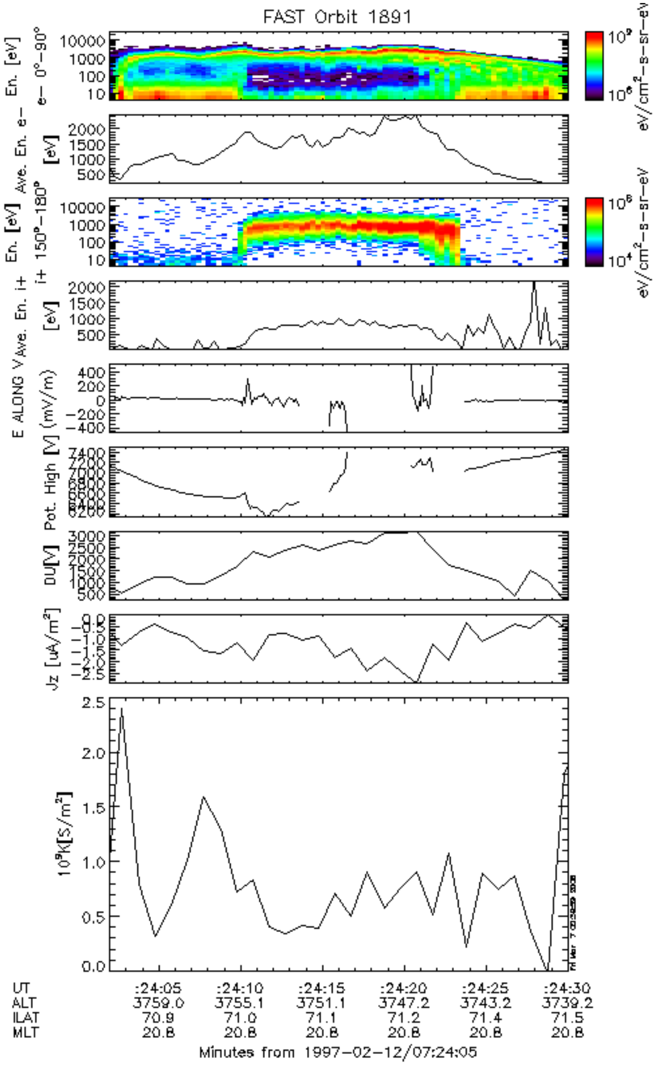




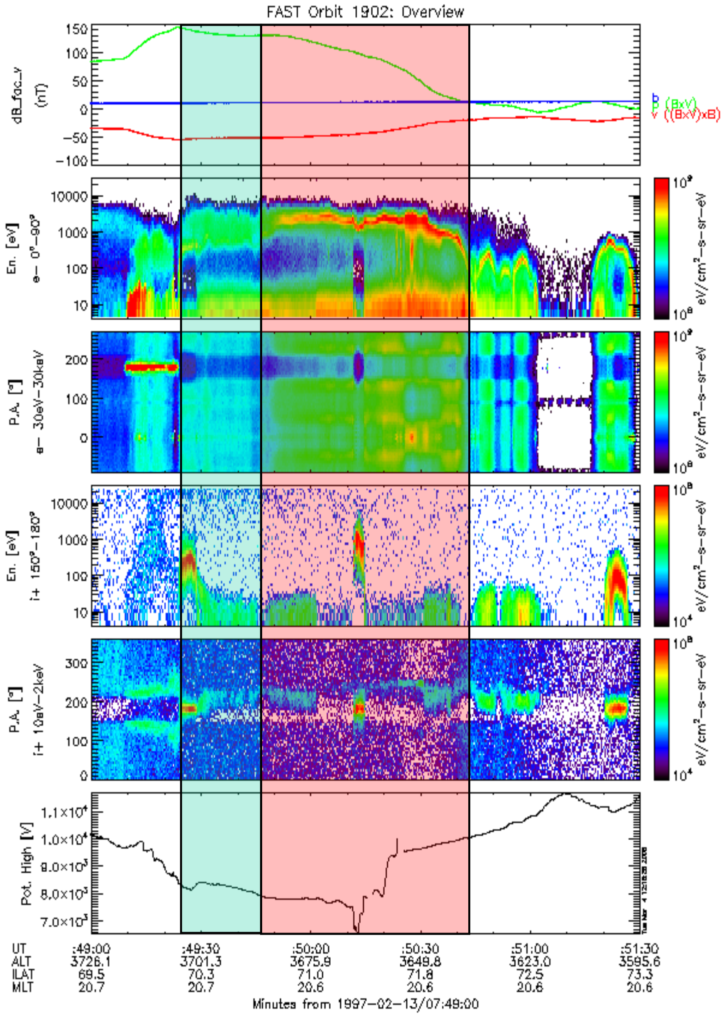
FAST Conjunctive Studies
http://sprg.ssl.berkeley.edu/fast/scienceprod/conjunctive

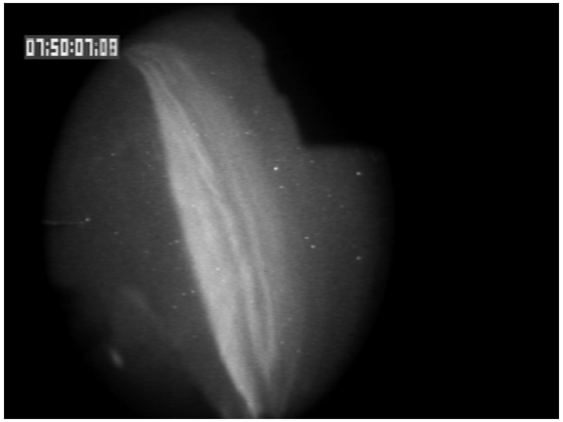
FAST Case study: orbit 1891

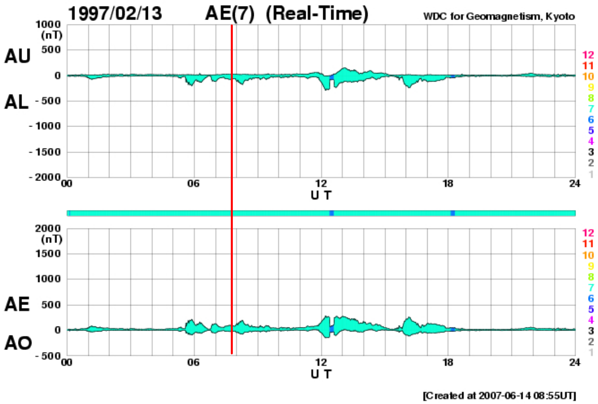




FAST case study: orbit 1902







FAST Conjunctive Studies
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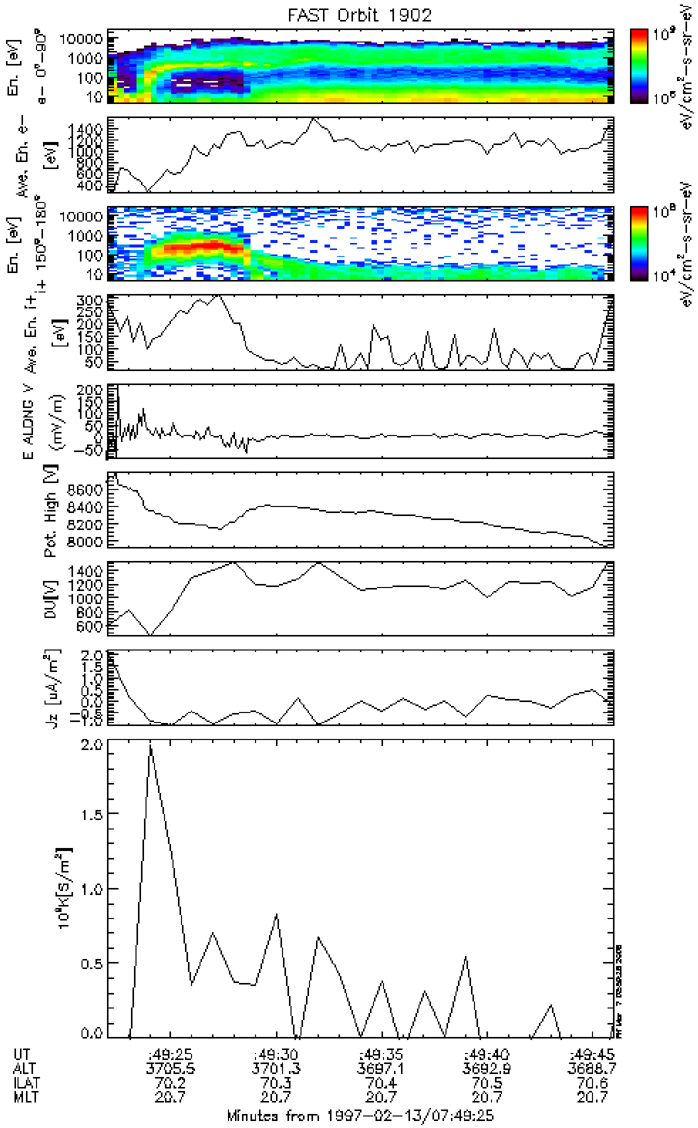
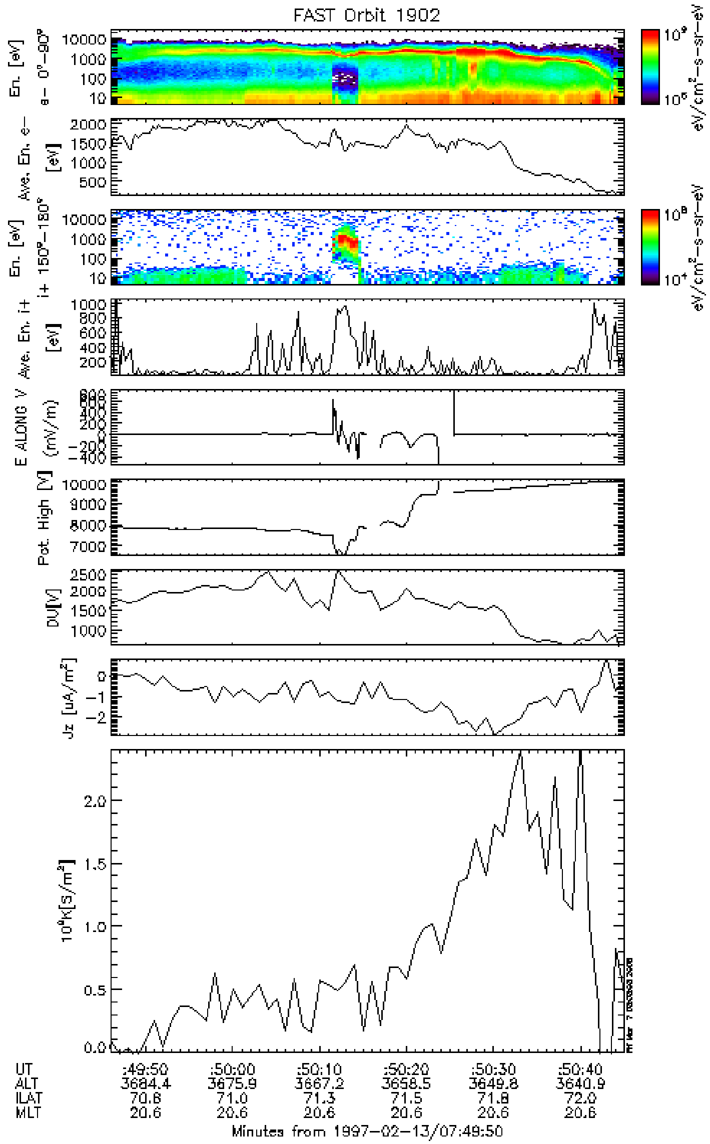
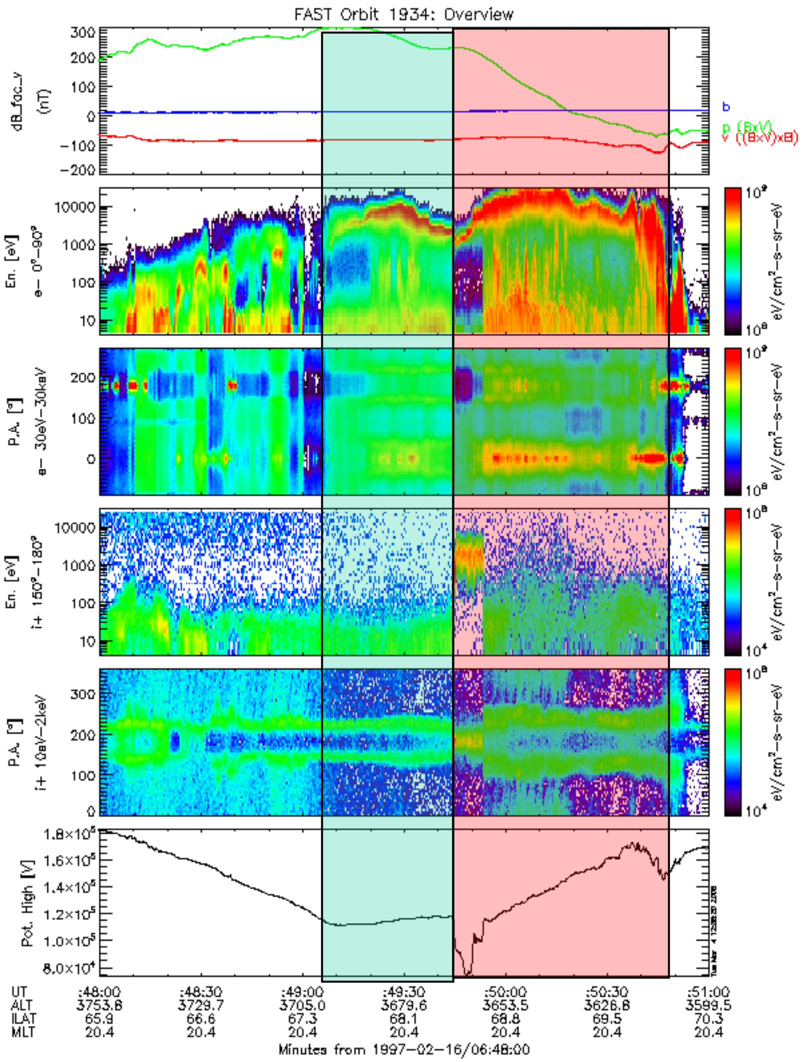
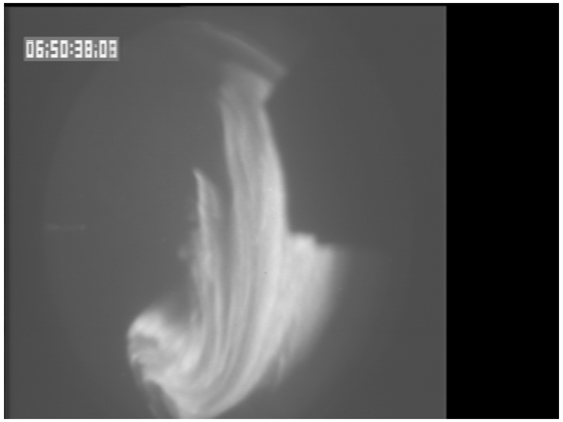
FAST case study: orbit 1902

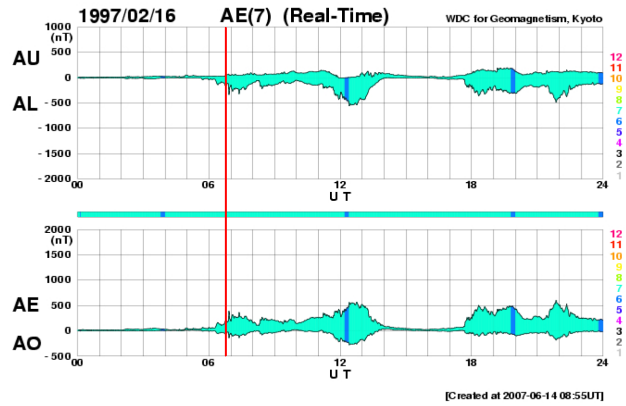




FAST case study: orbit 1934







FAST Conjunctive Studies
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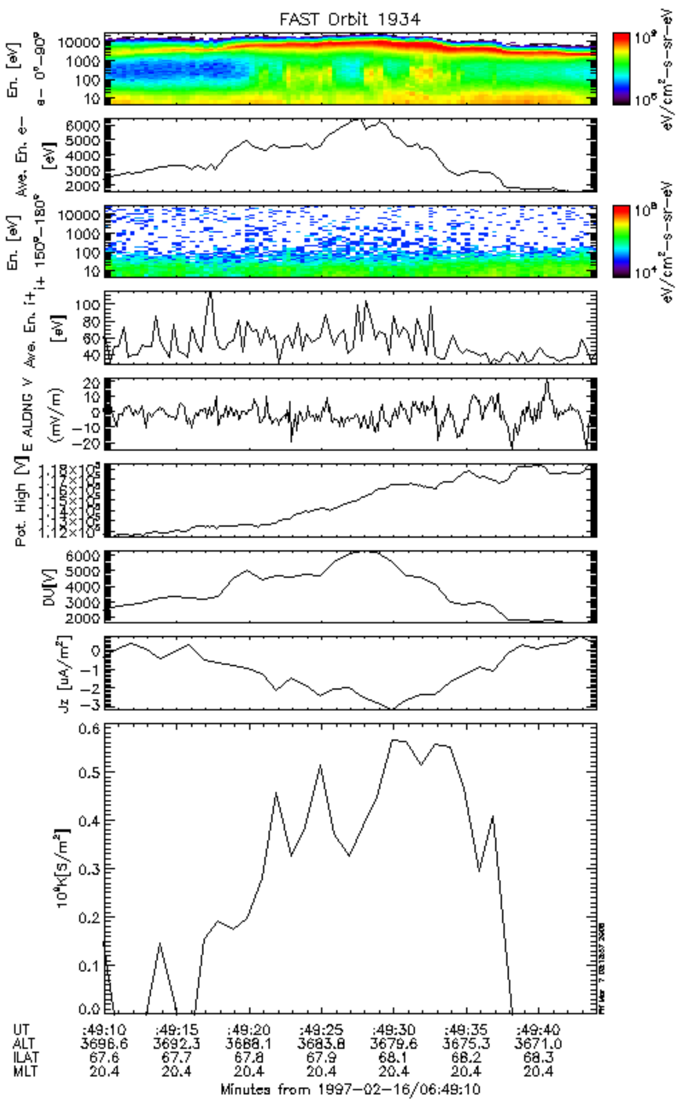
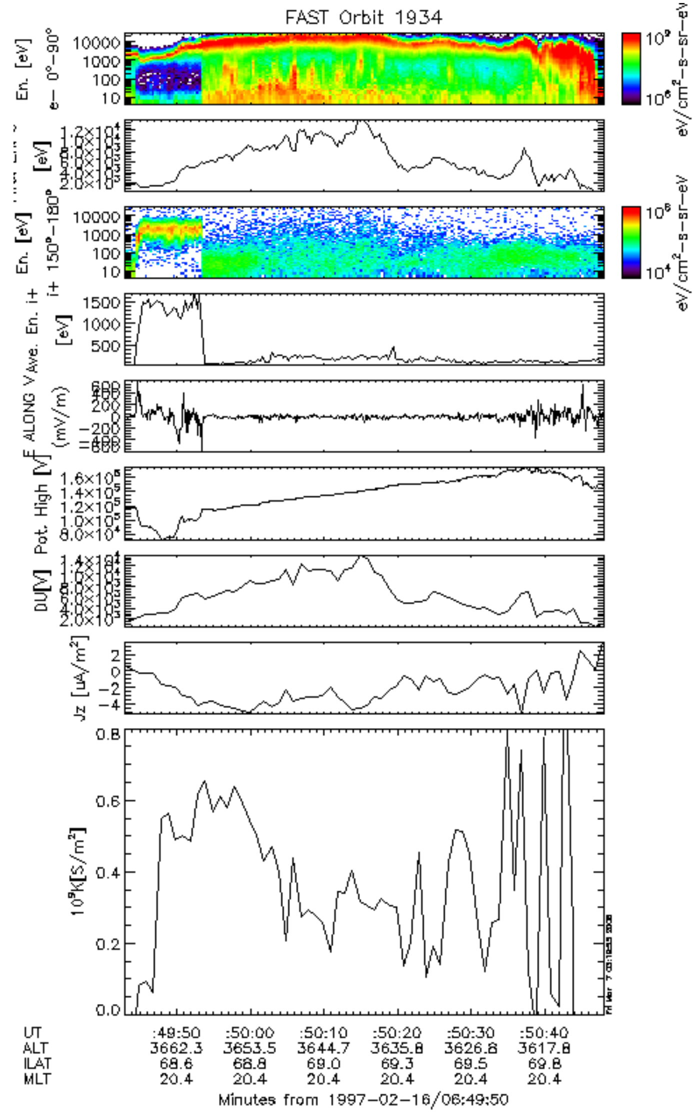
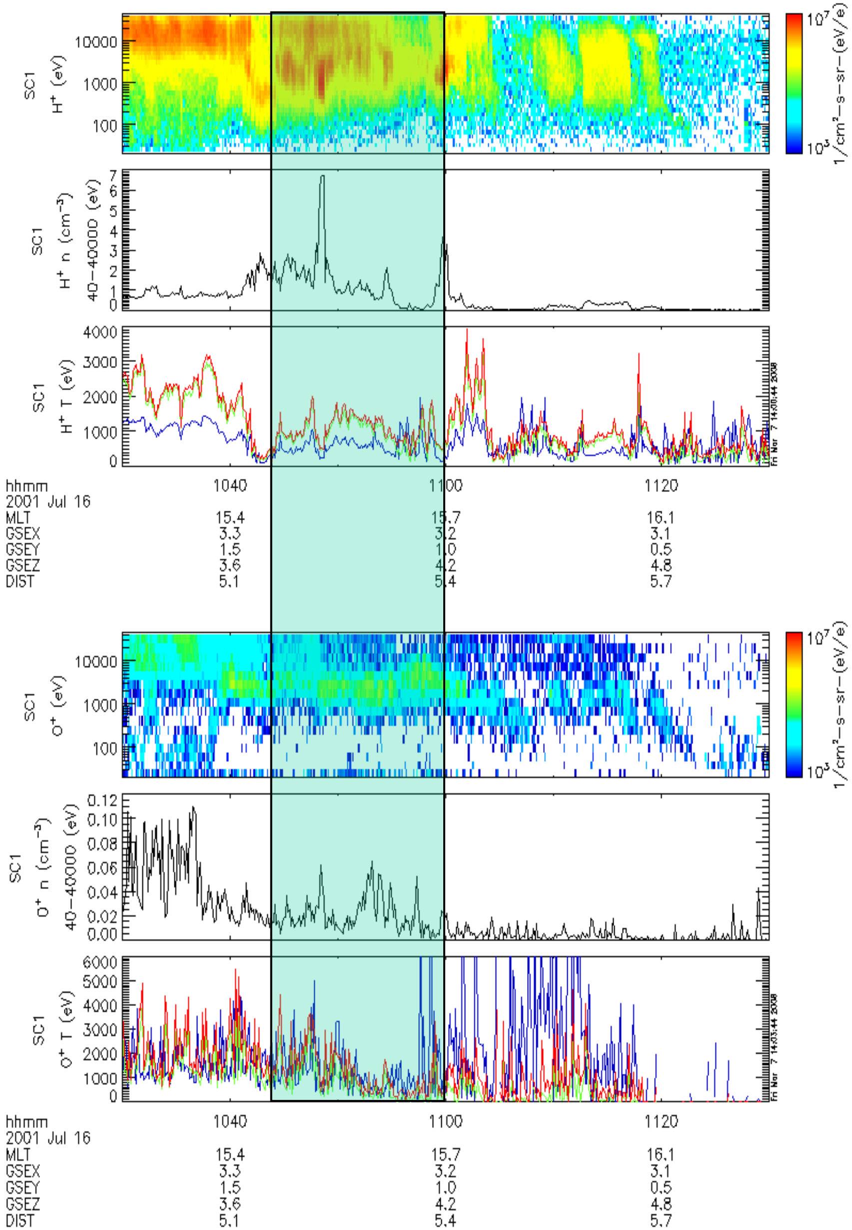
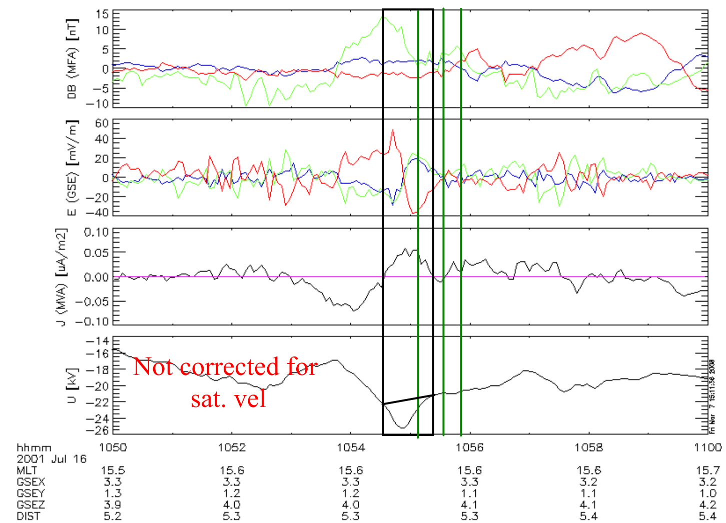
FAST case study: orbit 1934

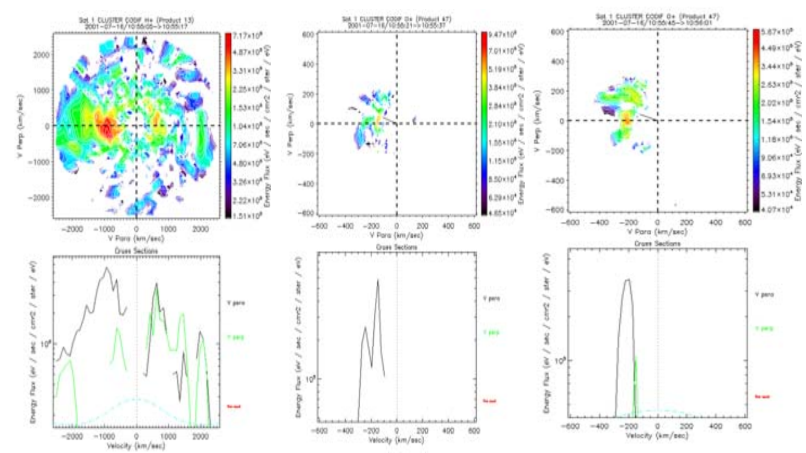




Cluster case study: 2001-07-16







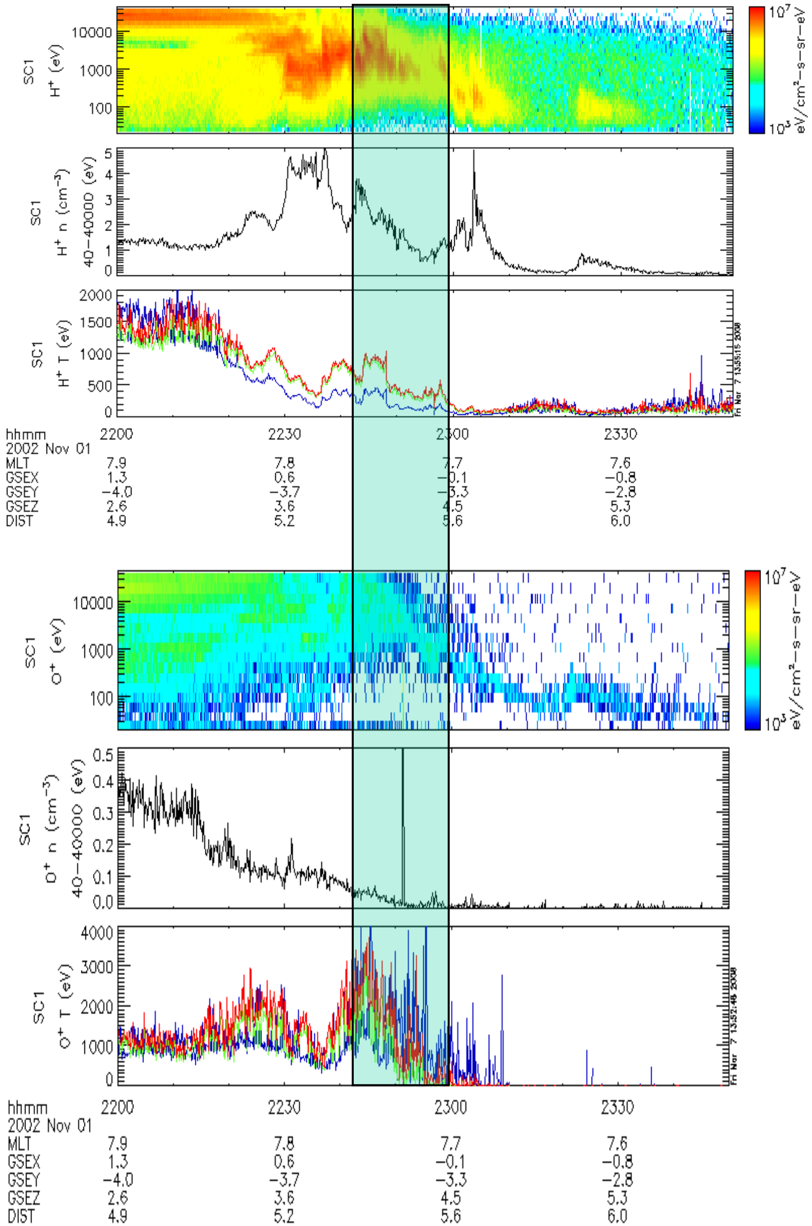
$j = 0.05\ \mu A/m^2$

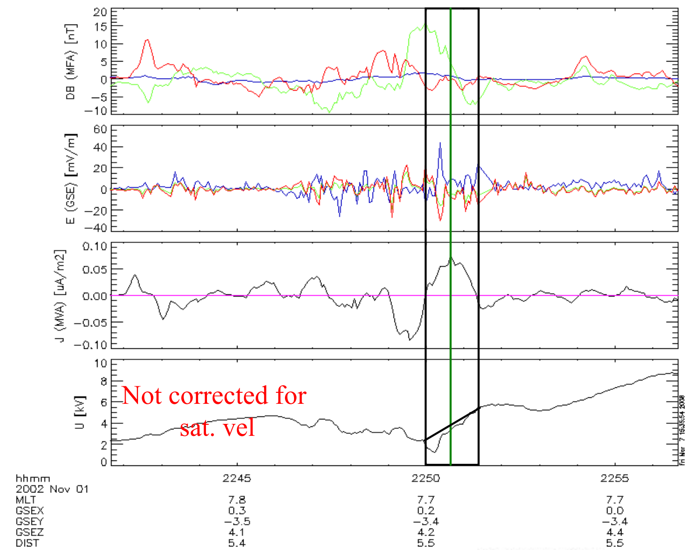
$\Delta U^E \approx 1.5$ kV; $\Delta U^I \approx 4$ kV

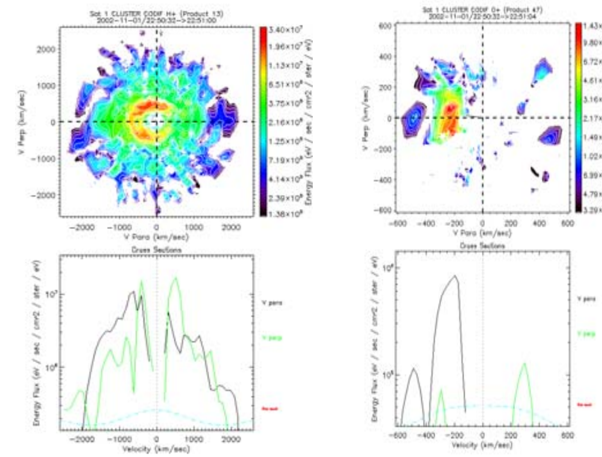
$K = j * R_M / \Delta U$

$K^E \approx 5.3\ 10^{-9}$; $K^I \approx 2\ 10^{-9}$

Cluster case study: 2002-11-01







$j = 0.07\ \mu A/m^2$

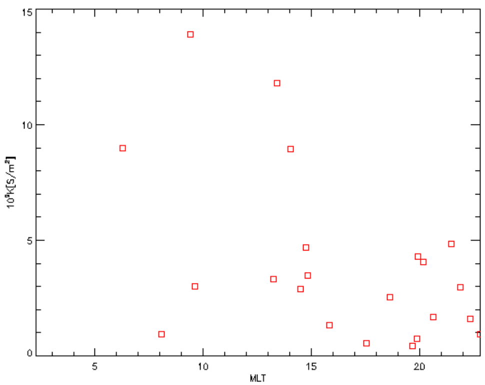
$\Delta U^E \approx 0.5$ kV; $\Delta U^I \approx 4$ kV

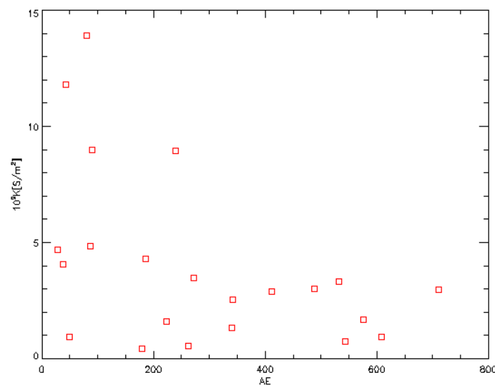
$K = j * R_M / \Delta U$

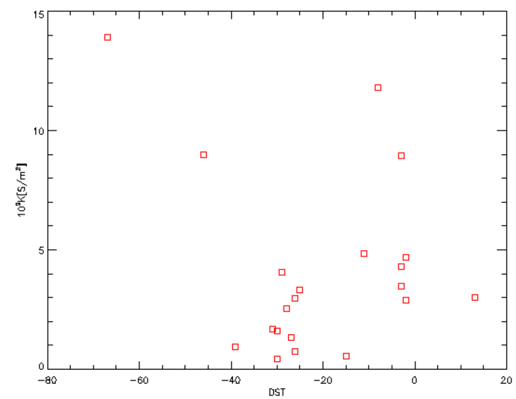
$K^E \approx 2.4\ 10^{-8}$; $K^I \approx 3\ 10^{-9}$

Statistical study – Cluster events

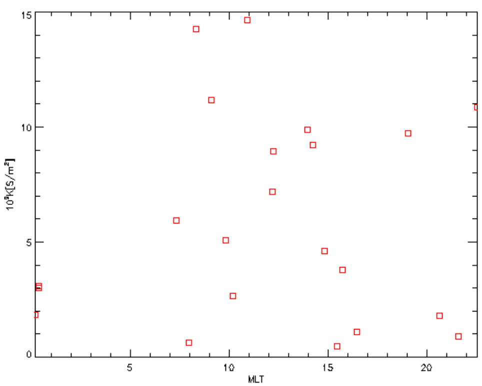
Winter

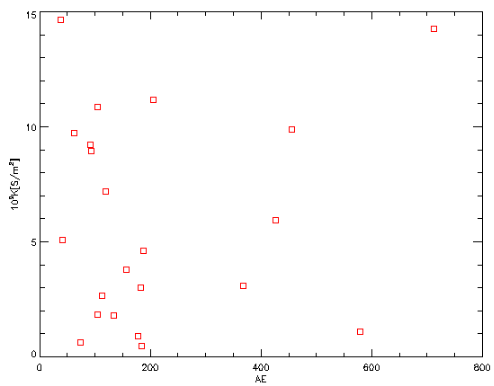


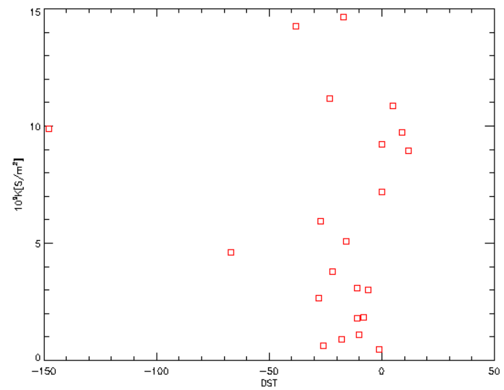




Summer







Summary

- With one exception, FAST data shows higher K values near the edges of the inverted-V structures, consistent with earlier studies (e.g. Marshall et al., 1991, DE data; Sakanoi et al., 1995, Akebono data).
- K is highly uncertain for the exception case (orbit 1934), because of the complicated auroral geometry, which makes the infinite current sheet assumption questionable.
- More often K has a symmetric profile when crossing an inverted-V structure, but sometimes the profile is not symmetric (e.g. the last two time intervals from orbit 1827).
- The K values inferred from Cluster data are in order of magnitude agreement with those derived at FAST level.
- Preliminary results of the Cluster statistical study indicate a positive correlation between K and the ionospheric conductance.
- However, the potential drop below Cluster as derived from electric field data is different from that provided by ion data. This may indicate non-stationary processes and / or non-adiabatic effects.

Prospects

- Refinements of the data processing techniques (e.g. electric field correction for satellite velocity at Cluster).
- Increase the number of FAST cases up to a statistical study (e.g. the “Conjunctive studies” database).
- Deriving the complete set of K values for each Cluster event.
- Add more events to the Cluster statistical study.
- Evaluation of K based on the electron density and temperature as measured on Cluster, by using data from the Cluster Active Archive. Comparison with K=J/U.
- Evaluation of K based on the electron density and temperature inferred from FAST data, by fit with accelerated maxwellian functions. Comparison with K=J/U.
- Selection of a few FAST / Cluster conjunctions and comparison of the FAST and Cluster results.