Cluster/FAST conjunctions as a tool to investigate auroral acceleration

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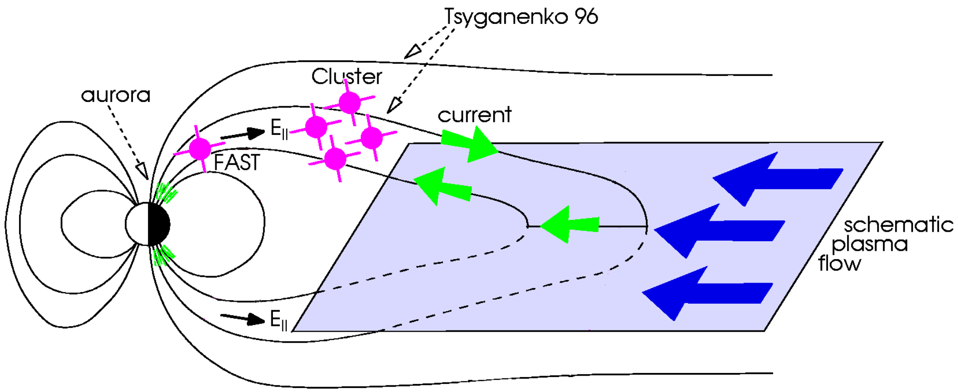
Cluster/FAST conjunctions provide a powerful tool to investigate auroral phenomena, in particular the auroral acceleration region (AAR). We present results of a systematic search through almost 6 years of data, acquired by the two spacecraft since January 2001, when Cluster became operational. We started by looking for time intervals when Cluster is close to perigee (at ~20,000 km) and FAST close to apogee (at ~4,000 km), with both satellites above the winter, nightside auroral oval. Such a setup offers two measuring platforms that encompass the AAR – with Cluster closely above it and FAST occasionally skimming its bottom side – an optimal configuration for further investigations. After the selection stage based just on orbit information, we were left with slightly above 100 conjunctions, out of more than 1500. The manual examination of the data resulted in another reduction, down to a few events, including three conjunctions when FAST crosses the AAR – as proved by the detection of ion beams. For these final events we derive the fieldaligned potential drop by using FAST electron data, when the satellite is below the AAR, to which we add ion data within the AAR, and compare it with the value inferred from Cluster ion data. The results are discussed with respect to the geophysical conditions, the proximity of the conjunctions, and the oxygen content of the upflowing ions. Given their scarcity and the quality of the data, the events to be presented are rather unique. They are now subject to a thorough analysis and offer good prospects for comparison with simulations.



A schematic sketch of the auroral current circuit (adapted after Hamrin et al., 2006). Above auroral arcs, at about 1-2 RE altitude, the electrons are accelerated to keV energies by the parallel electric field inside the auroral acceleration region (AAR). Conjugated data from the Cluster and FAST spacecraft may be used to cross-check simulation results and probe the processes that lead to aurora.

• Here we look for conjunctions between Cluster and FAST, with Cluster near the perigee (and near the top boundary of the AAR) and FAST close to apogee (and to the bottom of the AAR).

• We focus on the evening-midnight sector of the auroral oval, where the arc generation mechanism has a good chance to fulfill the assumptions in the simulation code [Vedin and Rönnmark, 2006].

• This condition emphasizes the winter time as main search interval, roughly November to March, when the Cluster perigee is properly located.

• We check ion data on Cluster to identify ion beams which match the field aligned potential drop seen by FAST and also the travel time required for that potential.

In order to find the time intervals when Cluster and FAST are in the appropriate configuration we performed a thorough examination of all FAST orbits, by plotting the altitude as a function of latitude and local time for every set of 1000 orbits (about 3 months).

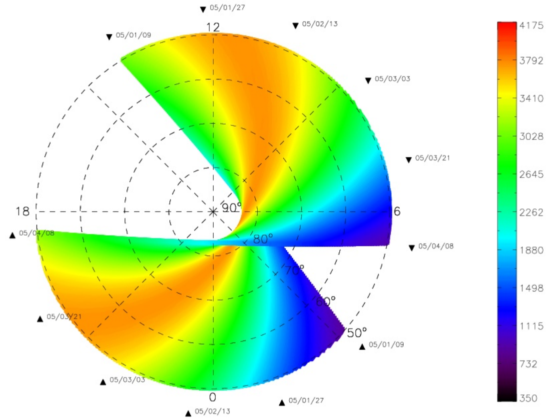
Right plots: FAST altitude (color) as function of latitude and local time. The orbit rotation in local time is indicated by printing the date for a few orbits. The motion along the orbit is from the upward triangle to the downward triangle.

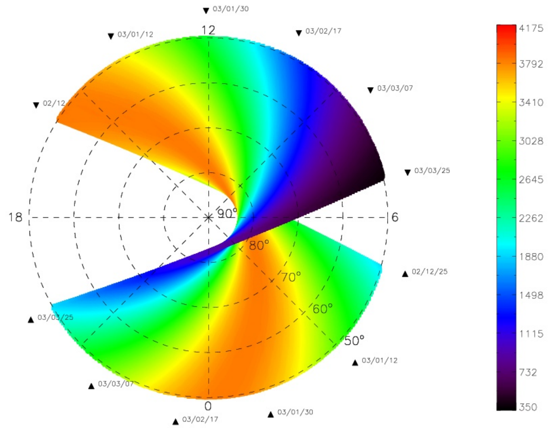
The obtained plots provide a convenient selection tool. The most promising time intervals for double conjunctions, under the conditions described above, are:

northern hemisphere: Jan – Feb 2003, Jan – Feb 2004, Feb – Mar 2005, Feb – Mar 2006
southern hemisphere: Jan – Feb 2001

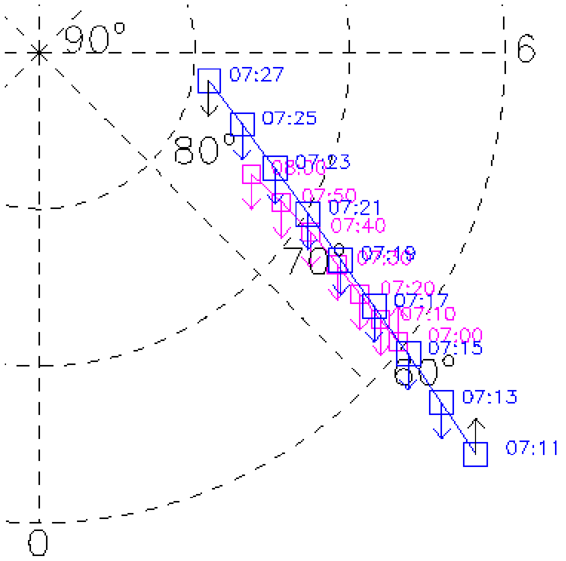
Out of the 105 conjunctions explored during these intervals, we were able to select only 6 promising events, which are summarized below. The events cover different geo-magnetic conditions, from quiet to quite active intervals, as seen in the AE and DST indices.

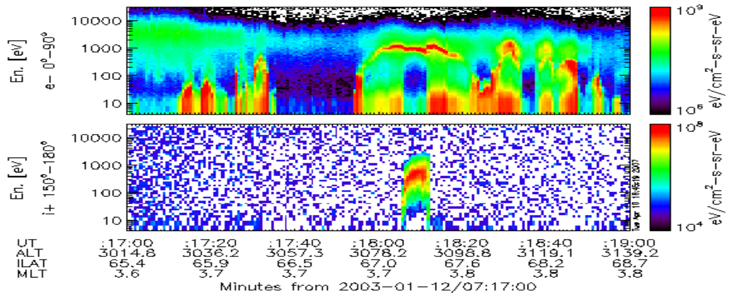
Following the summary of the events we present a detailed analysis for three of them, mainly by comparing the ion data on the two spacecraft.

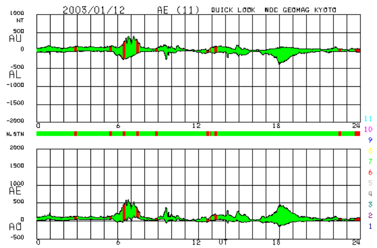


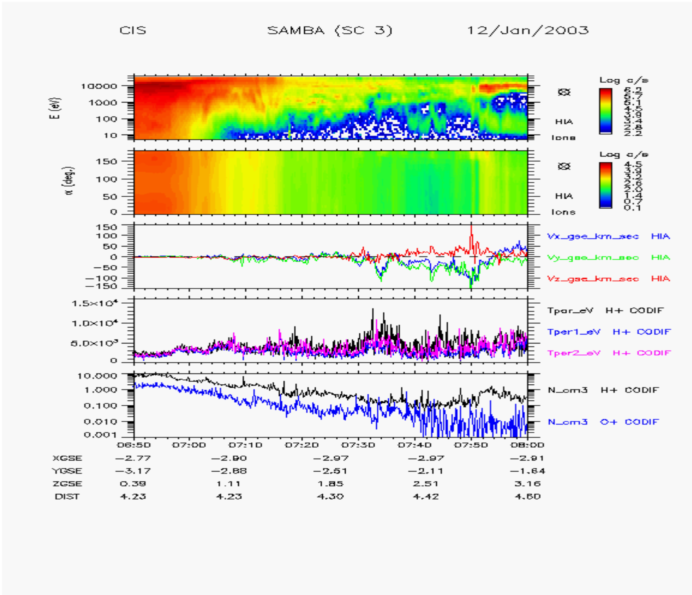


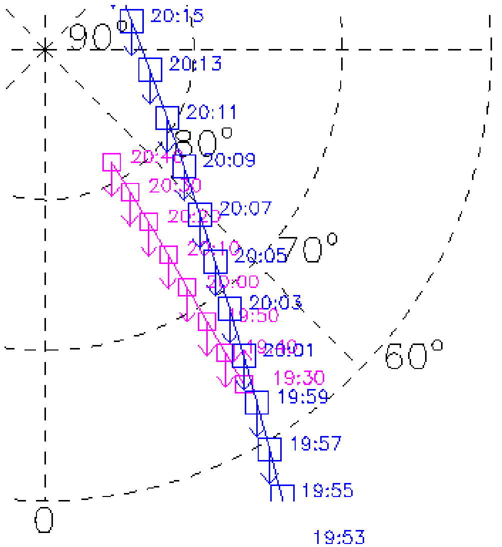
Cluster/FAST conjunctions - Events summary

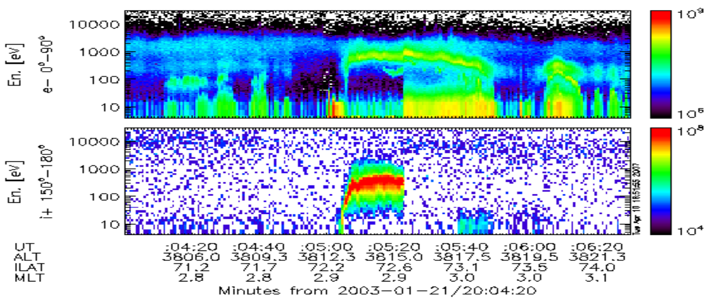


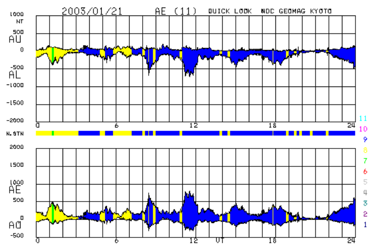


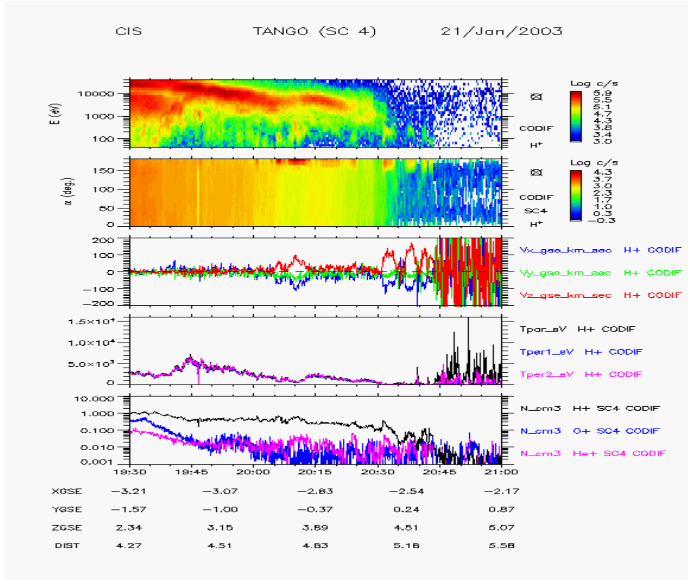




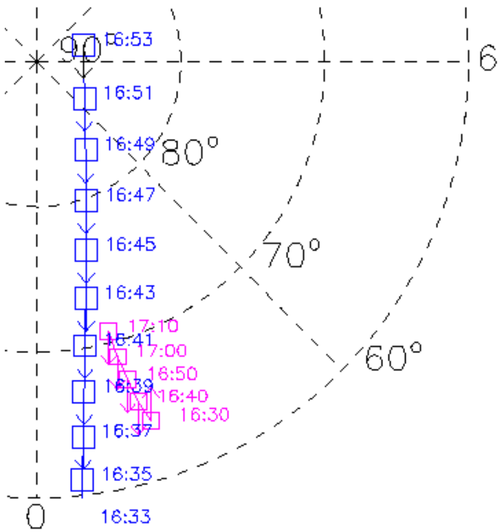


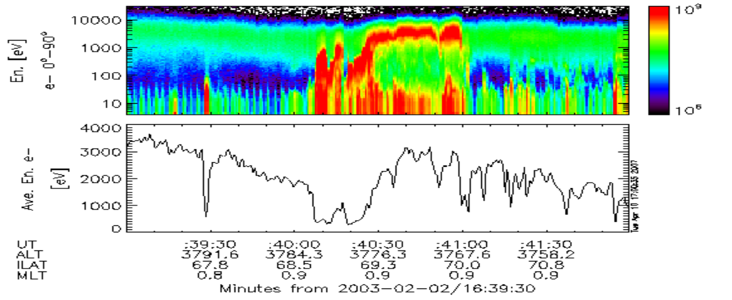


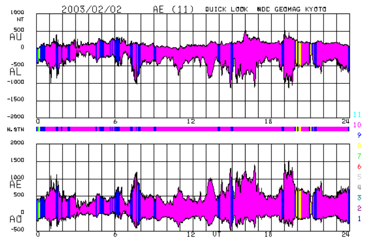


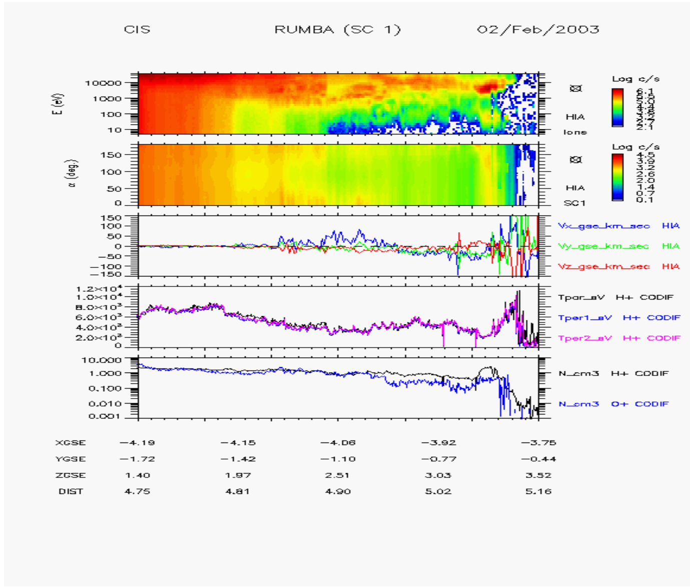


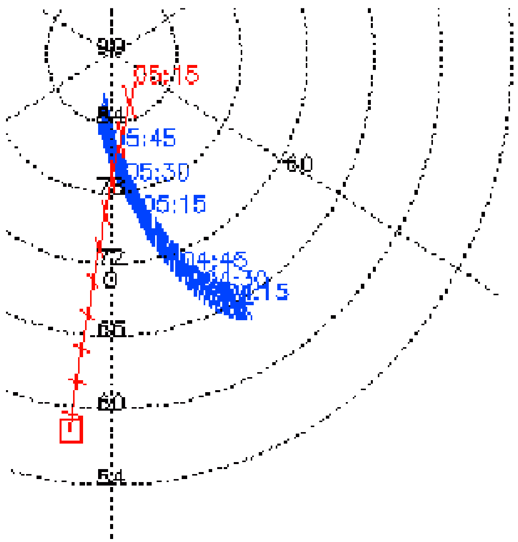
Cluster/FAST conjunctions - Events summary

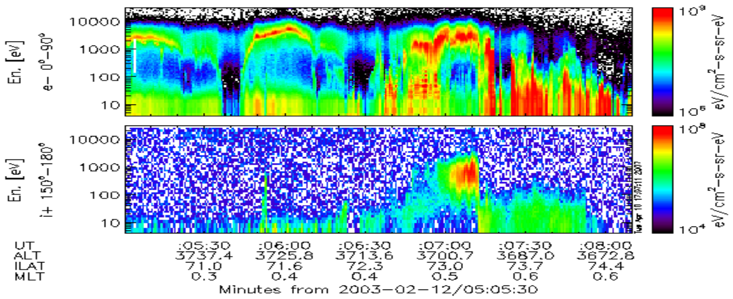


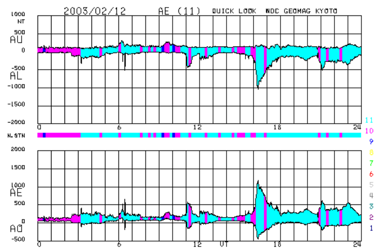


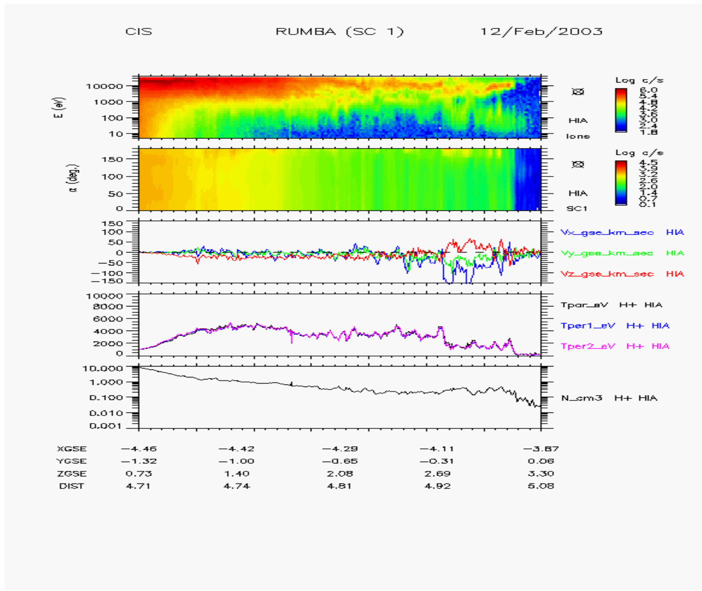




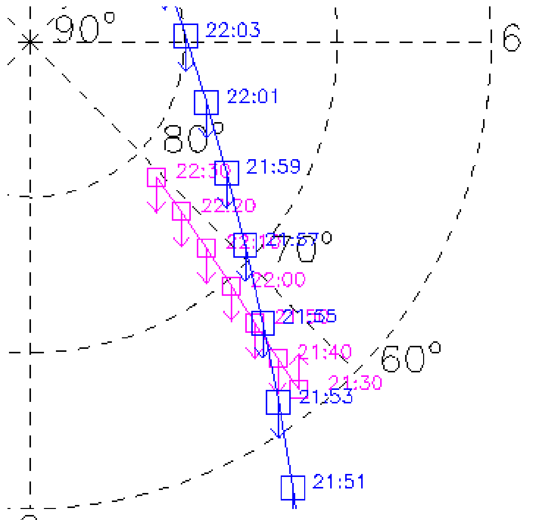


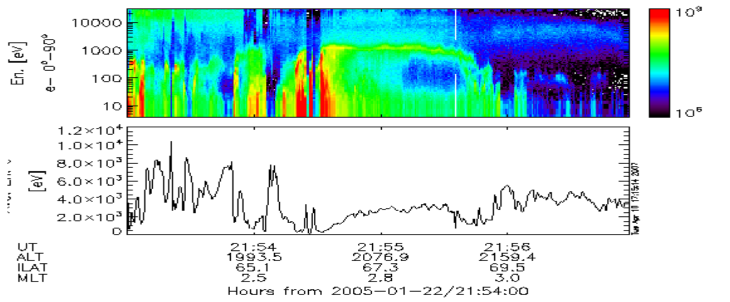


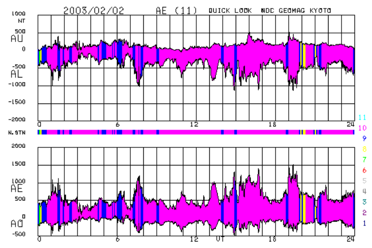


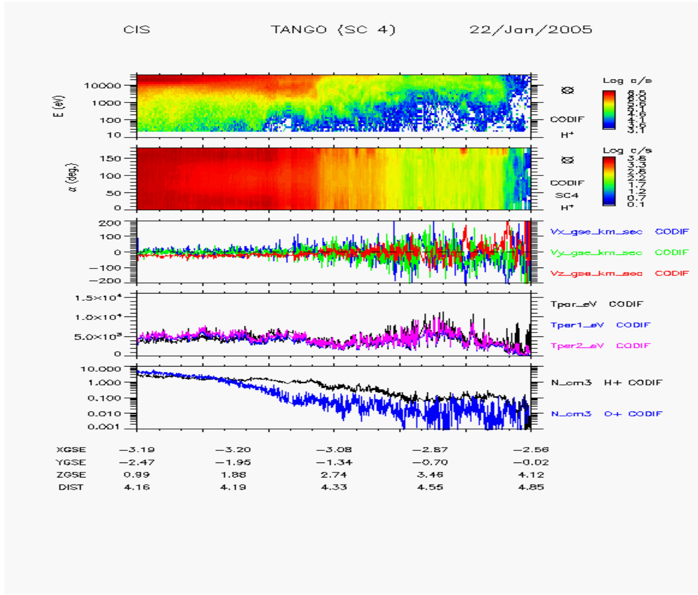


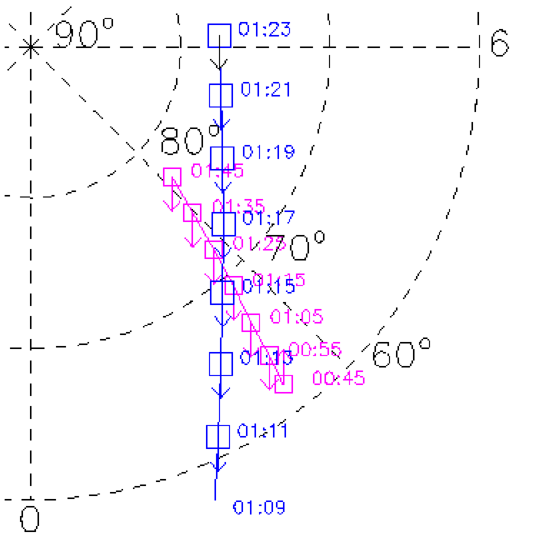
Cluster/FAST conjunction - Events summary

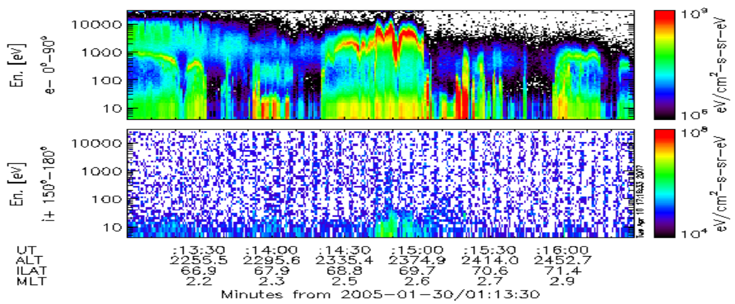


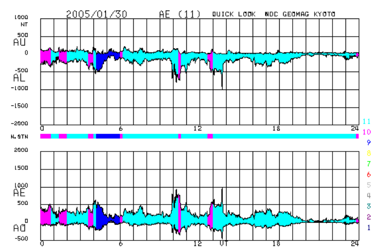


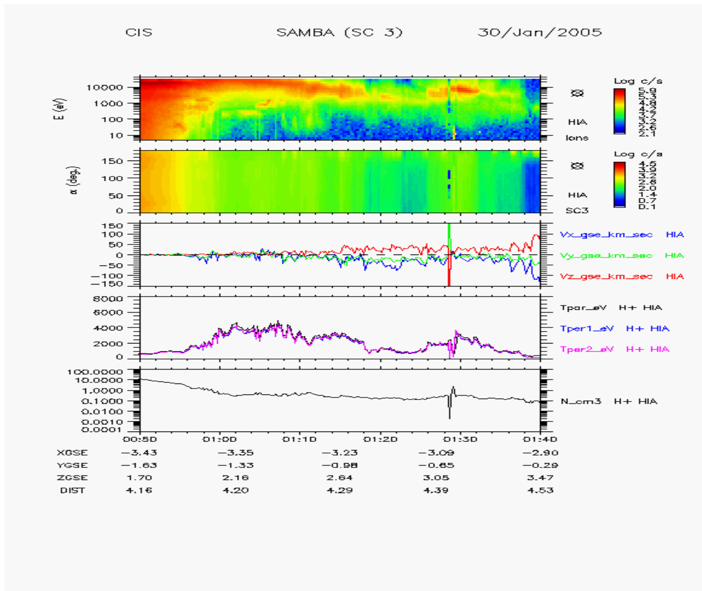




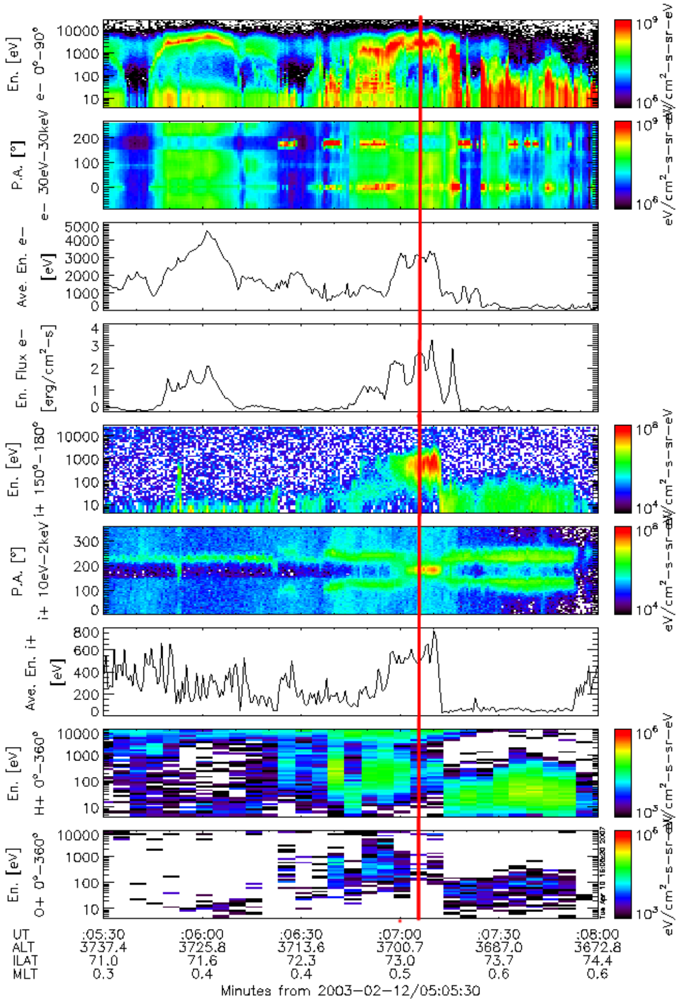


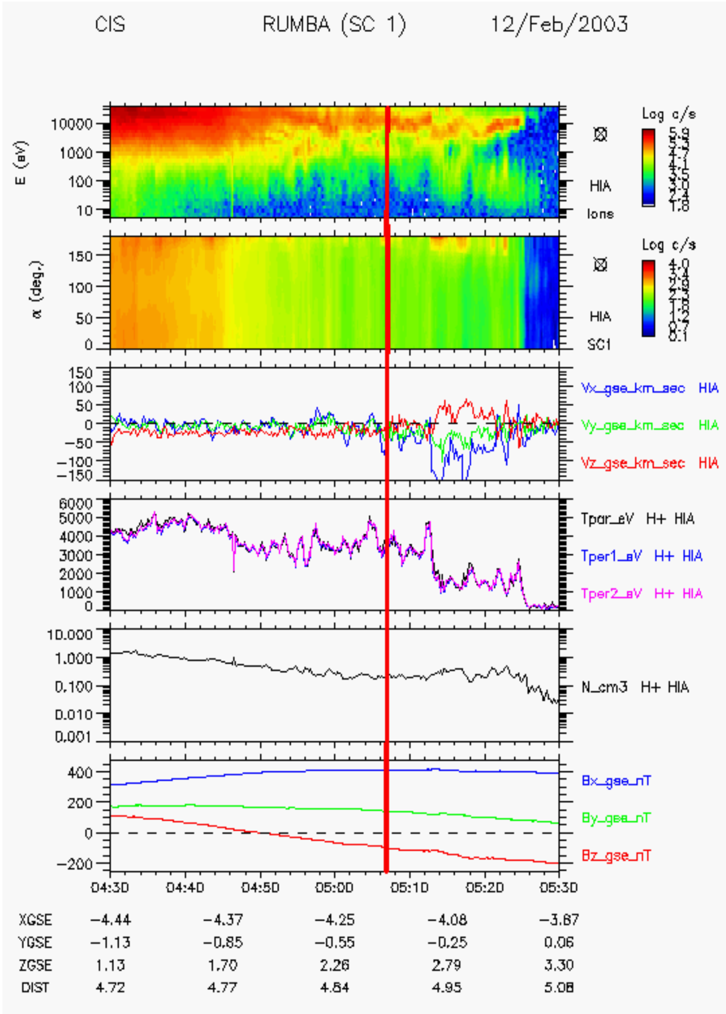






Cluster/FAST conjunction - Case study 1

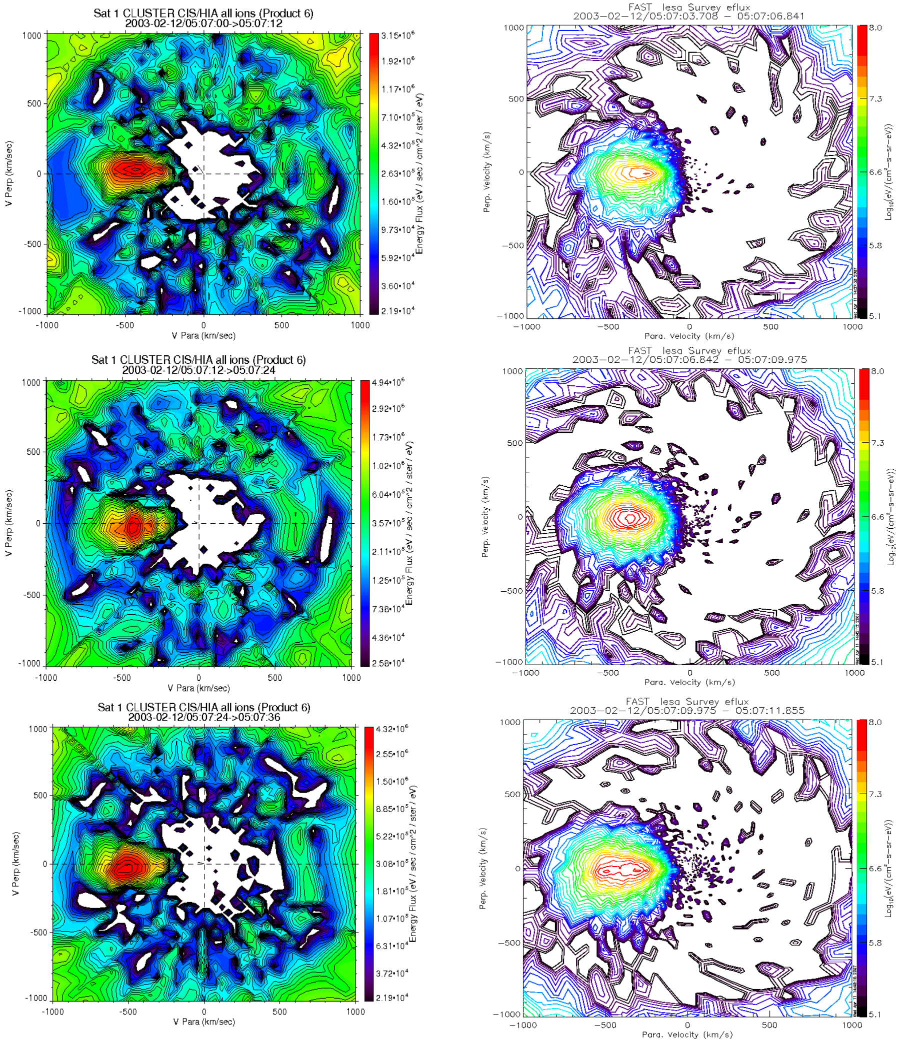


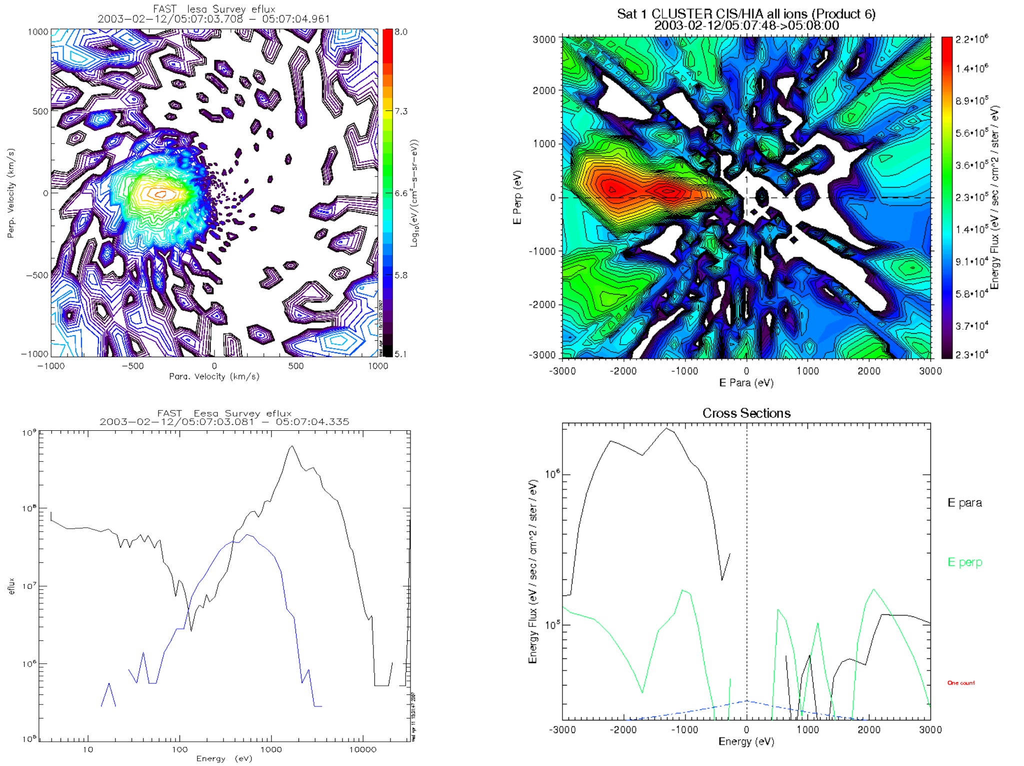


Left: FAST electron and ion data. Right: Cluster/HIA data. In both plots the red line indicates the conjunction time.

Around the conjunction time we observe energetic electron precipitation and an outflowing ion beam in the FAST data. The mass composition, TEAMS data, show that the beam consists of protons and some oxygen. On Cluster 3 we see two populations, one at high enery coming from the plasma sheet and one at lower energy, probably coming from the bottom of the AAR. These two distinct populations are better seen in the distribution functions.

As shown next slide, in this case we find a resonably good agreement between the data on the two spacecraft, which is a bit surprising given the separation of ~10 degree in longitude between Cluster and FAST.

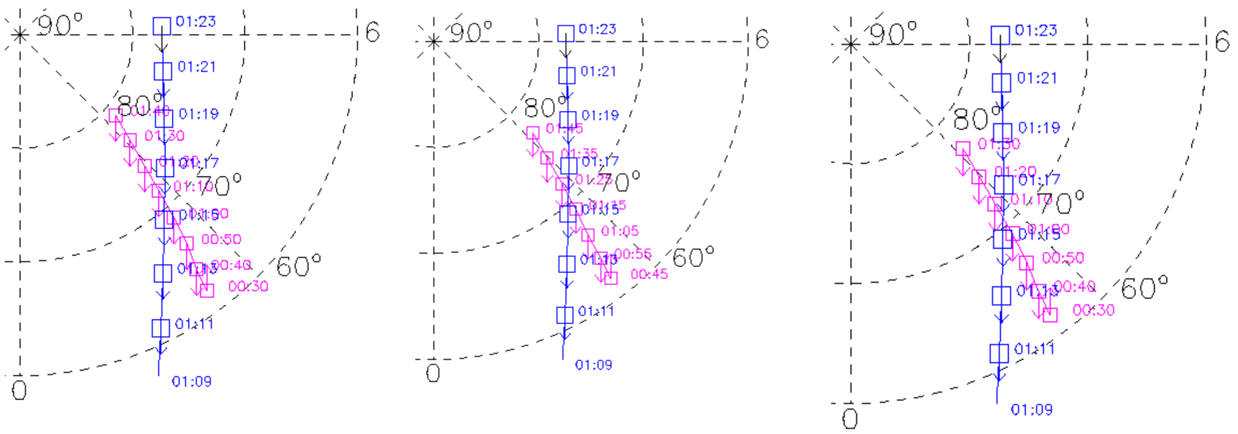




Left: CLuster/HIA distributions showing an ion beam coming from the bottom of the AAR. Right: FAST distributions which show possibly the same ion beam. The matching between the two ion beams is illustrated in the plots nearby.

Left: FAST ion distribution (top) and electron energy spectrum (botom) from 05:07:03, when the spacecraft starts to detect the ion beam. The total potential drop is ~2.2 keV, out of which ~1.7 keV above the satellite and ~0.5 keV below.

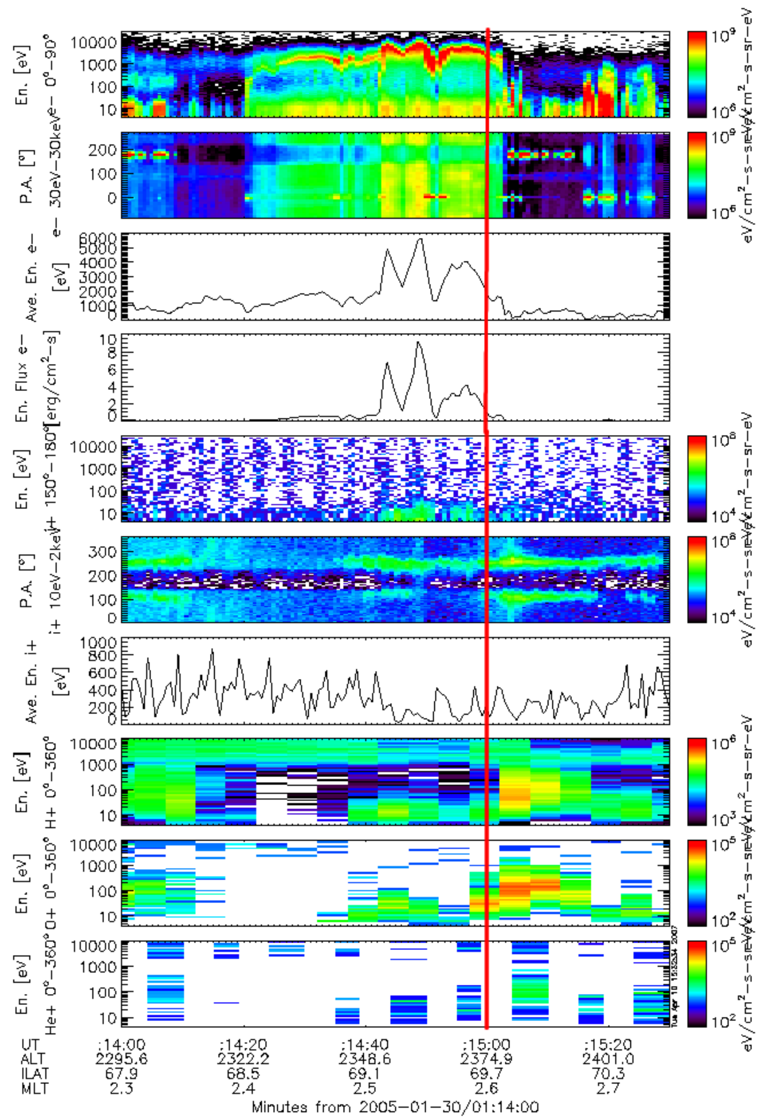
Right: Cluster/HIA distribution measured ~40s later, which corresponds to the travel time needed by the beam ions to reach Cluster3 altitude (assuming protons). One can see two peaks, at ~1.3 keV and ~2.2 keV. The higher energy peak matches quite well the total potential drop inferred from FAST data.

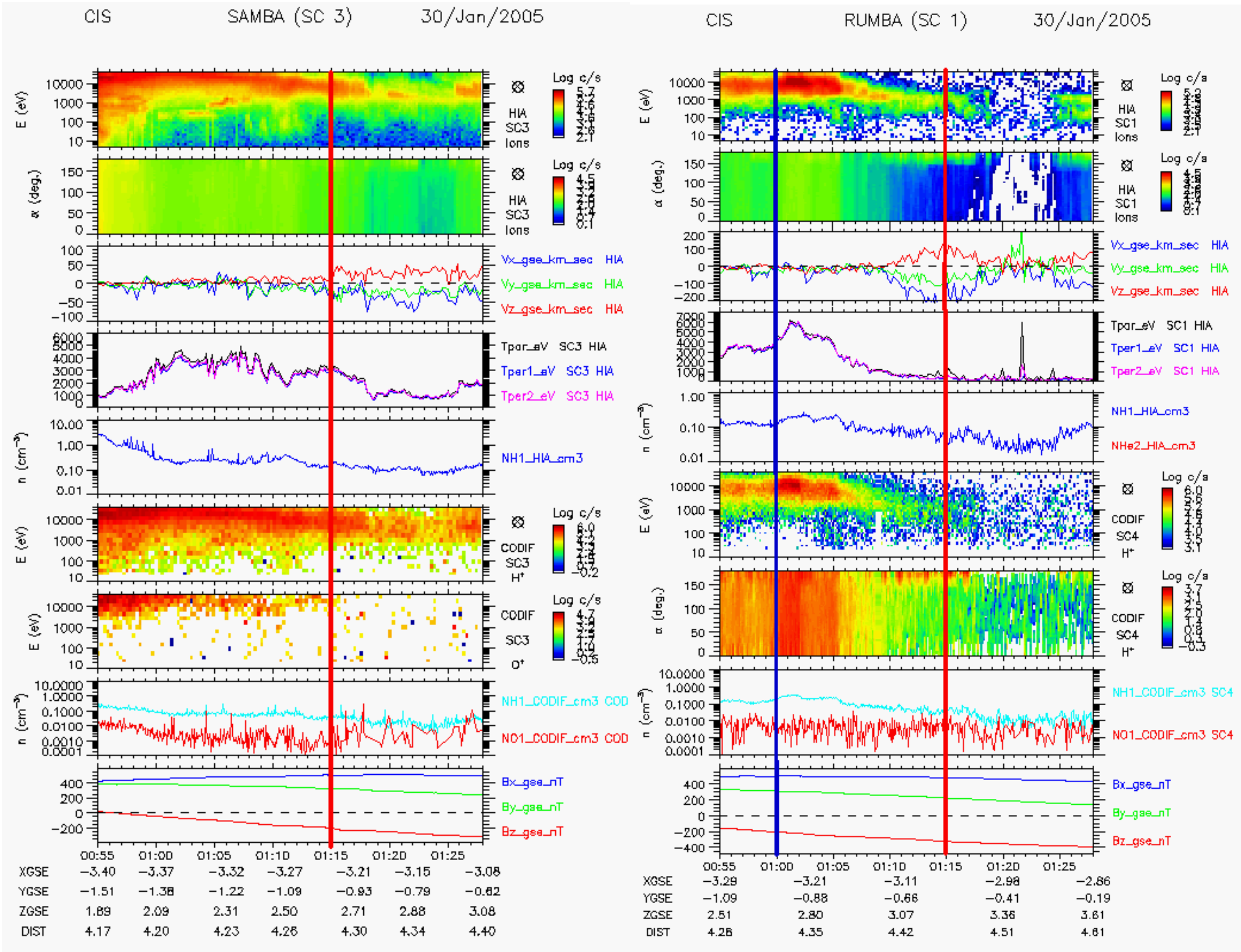


FAST and Cluster footprints at ionospheric level. The best conjunction is realized with C3 around 01:15:00. C1 and C4 have the footprints close to the conjunction point 15 min earlier, around 01:00:00. For this event C1 and C4 help to check the beam variation in space and time.

During FAST crossing, between 01:14:32 and 01:15:00, the potential drop above the satellite, as derived from electron data, has large variations from 0.7 keV to 9keV. The variations are associated with narrow inverted-V structures, centered at 01:14.43, 01:14:48, and 01:14:56.

The O+ content on FAST is quite substantial, in good agreement with the active geomagnetic context.

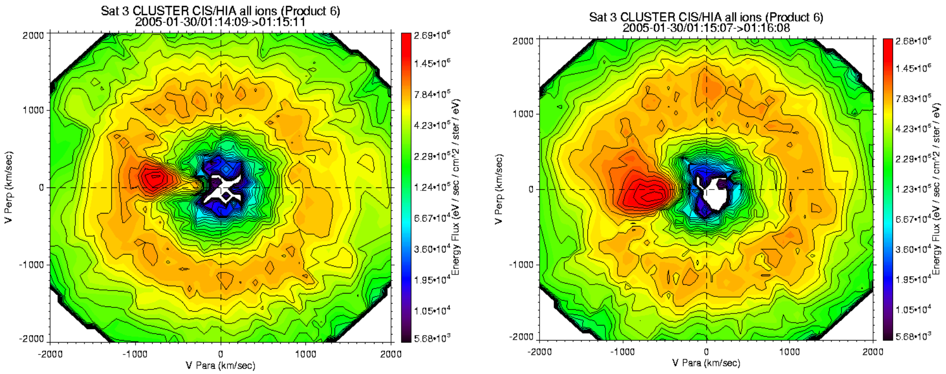




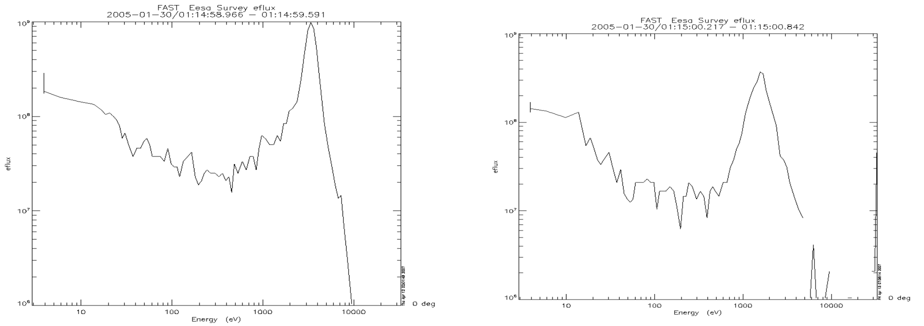
Left: CODIF and HIA data on C3. Right: HIA data on C1 and CODIF data on C4.

The conjunction between FAST and C3, at 01:15:00, is indicated by the red line. The time when C1 and C4 have the footprint around the conjunction point, 01:00:00, is shown by the blue line. In the energy spectrograms we see that at the conjunction site both C3 and C1/C4 encounter a higher energy population, while the (beam) ions measured by C1/C4 at the conjunction time have lower energy. This is better visible in the distribution functions presented the next two slides.

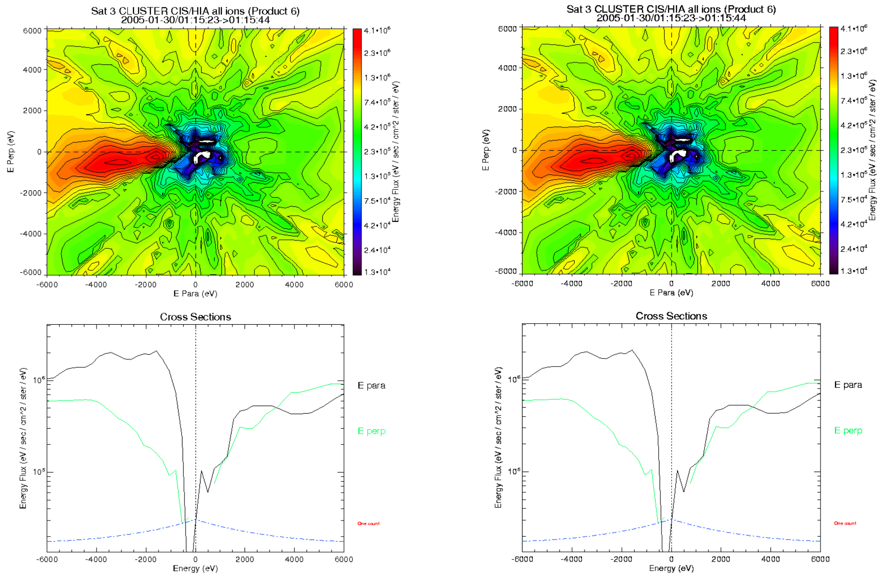
Cluster/FAST conjunctions - Case study 2



C3/HIA distributions which show that the beam is quite stady for about 2 min, during the C3 crossing above the conjunction site.

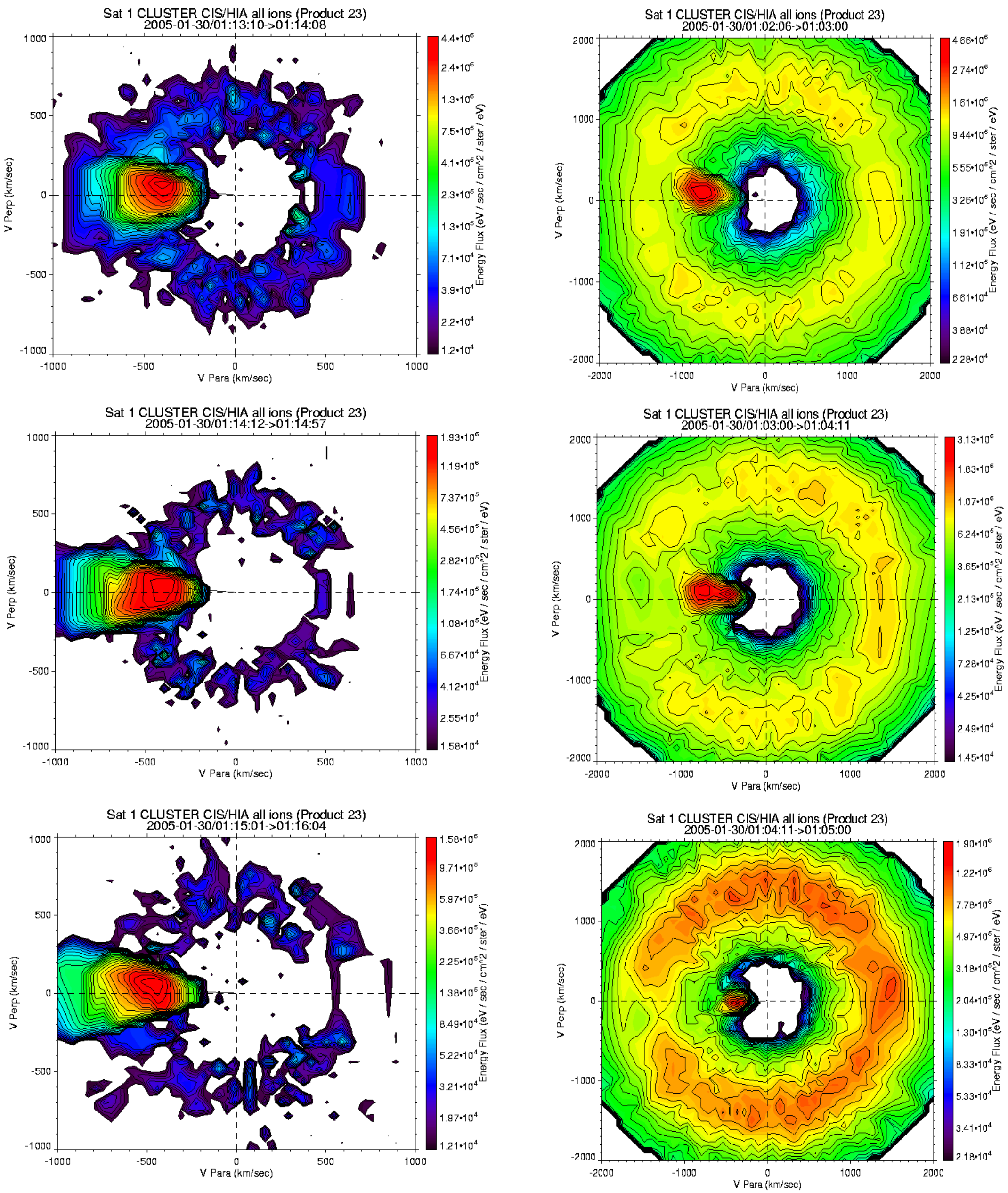


FAST electron spectra around 01:15:00, which show the variation of the potential drop from above 3 keV to below 2 keV. The travel time needed for an H+ ion to reach C3 altitude is about 30 s.



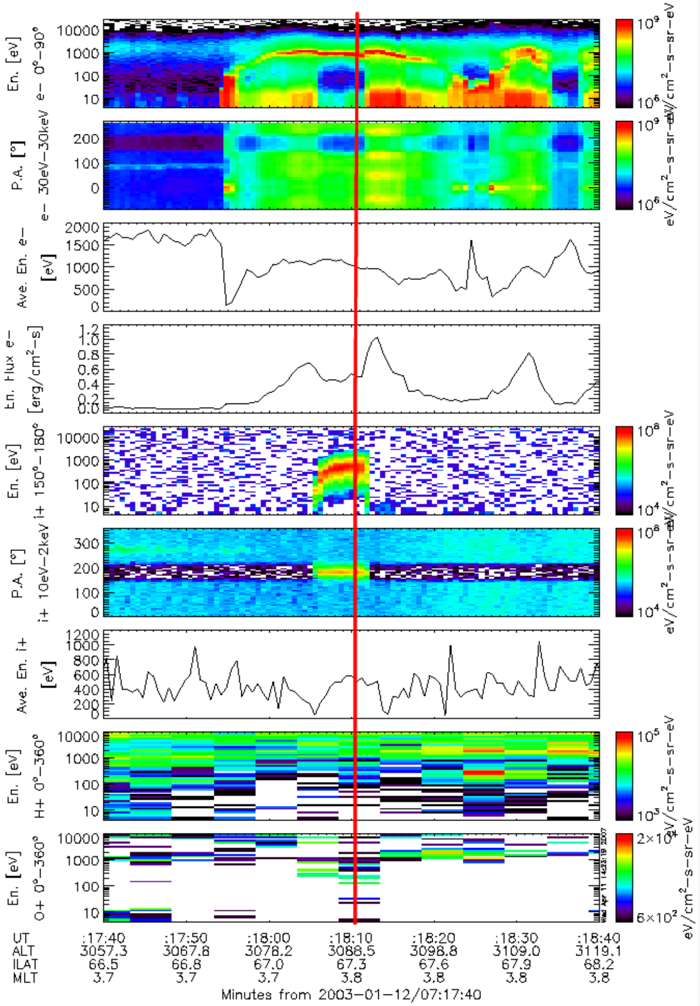
The HIA distribution measured between 01:15:23 and 01:15:35 (left) shows a relatively good agreement with the FAST data, since we see a beam population elongated along Vpara, which peaks around 3 keV.

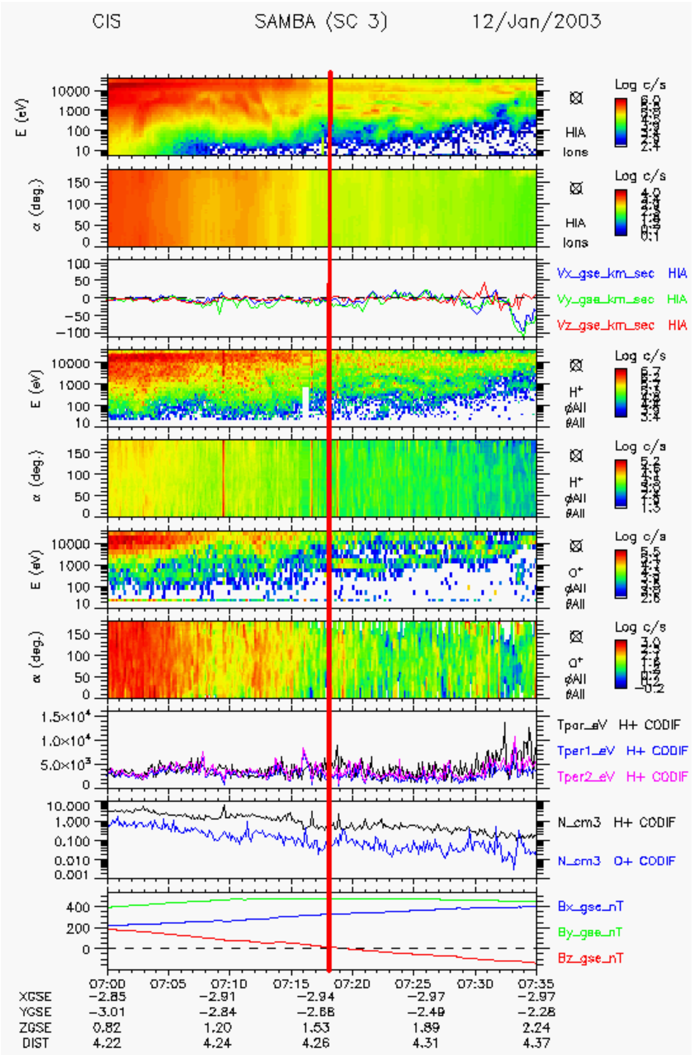
The second distribution (right), averaged over a bit longer time, is also elongated along Vpara, from below 2 keV to above 3 keV, which is consistent with FAST data.



Left: C1 HIA distributions measured around the conjunction time of C3 with FAST, when C1 is a few latitude degrees away from the conjunction site. The distributions show a ~1 keV ion beam.

Right: C1 HIA distributions measured from 01:02 to 01:05. In the first two distributions one can see a ~3 keV ion beam.

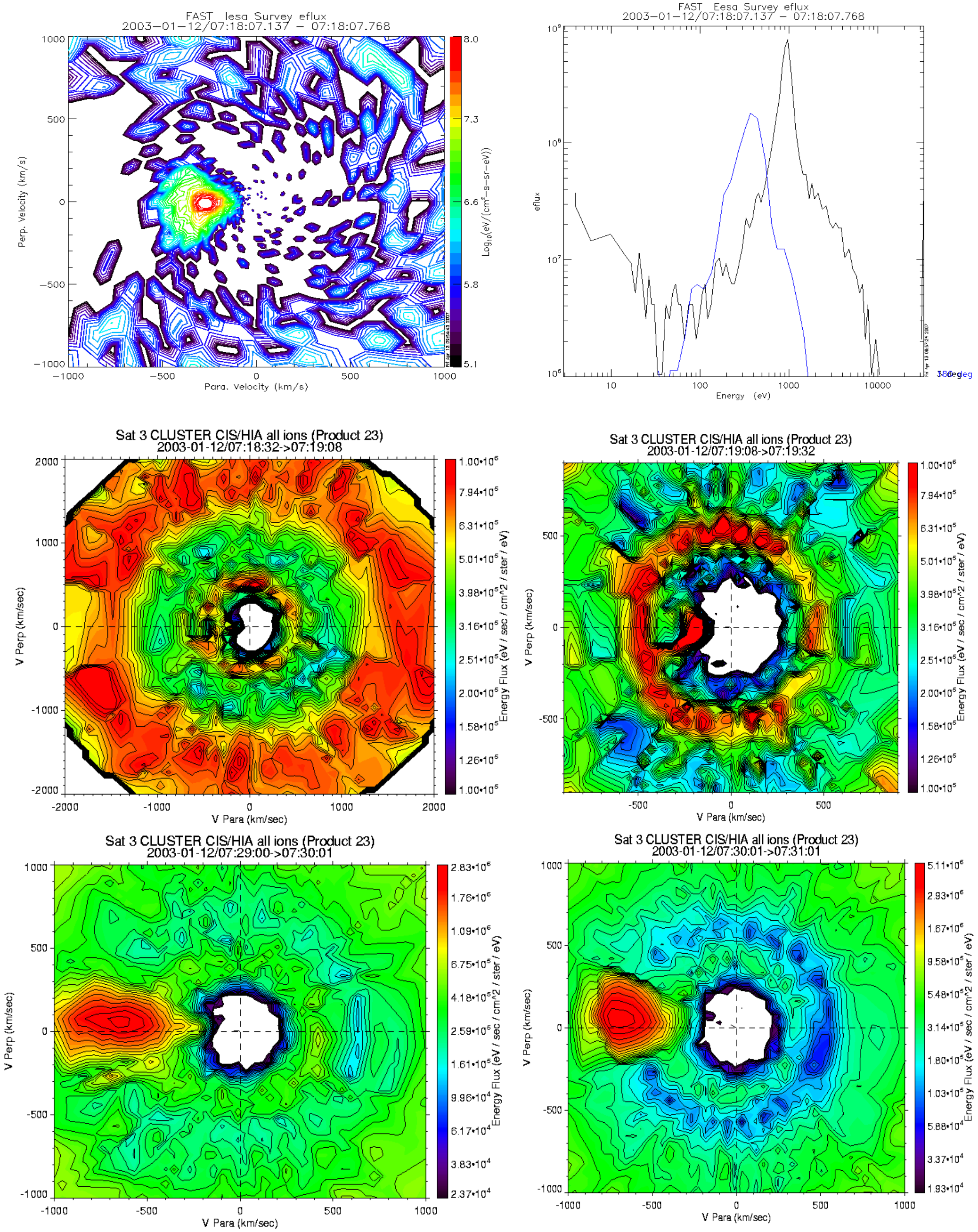




Left: FAST electron and ion data. Right: Cluster HIA data. In both plots the red line indicates the conjunction time.

Around the conjunction time the FAST data show ~1 keV electron precipitation and an ion beam. TEAMS data indicate a beam composed mainly by protons, with traces of oxygen. On Cluster 3 we see two populations, one at high enery of plasma sheet origin, and one at lower energy possibly coming from the ionosphere. These two populations are better visible in the distribution functions.

Cluster/FAST conjunctions - Case study 3



Line 1: FAST ion distribution (left) and electron/ion spectra (right). The data indicate a potential drop above the satellite of about 1 keV, and below the satellite of about 0.4 keV, providing a total of ~1.4 keV.

Line 2: HIA distributions measured ~50 s later (to include the ion travel time between FAST and C3). A low energy isotropic population is visible around 1.4 keV.

Line 3: 10 min later, when C3 is still very close to the conjunction site, HIA observes a well shaped ion beam, steady for ~2 min, at an energy slowly increasing from 2.2 keV to 2.5 keV.

Cluster/FAST conjunctions with interesting data sets seem to be extremly rare, although the five years database is quite substantial.

We have identified a few conjunction events with promising data on both spacecraft.

The Cluster and FAST data were found to be in pretty good agreement for two of these events.

More work is needed to clarify the less good or lack of agreement for the other four events, one of which has also been presented here.

The first event, where both Cluster and FASTdetect an ion beam, allows the check of the Liouville theorem. This can provide additional evidence on the conjugacy of the low and high altitude observations.

The first and second event, where particle information support the conjugacy of the data, may offer optimum conditions to cross-check simulation results on the auroral acceleration.

References:

J. Vedin and K. Rönnmark, *Particle-fluid simulation of the auroral current circuit*, J. Geophys. Res., 111, A12201, doi:10.1029/2006JA011826, 2006.

M. Hamrin, O. Marghitu, K. Rönnmark, B. Klecker, M. André, S. Buchert, L. M. Kistler, J. McFadden, H. Rème, A. Vaivads, *Observations of concentrated generator regions in the nightside magnetosphere by Cluster/FAST conjunctions*, Ann. Geophys., 24, 637 – 649, 2006.