Auroral acceleration region

The work on the auroral acceleration region (AAR) was carried on by Costel Bunescu, who holds a Master degree in Physics from the University of Bucharest. Initially, this work concentrated on comparing AAR observational findings based on Cluster and FAST data with simulation results obtained at Umeå University by Prof. Kjell Rönnmark and Dr. Jörgen Vedin (e. g. *Vedin and Rönnmark, J. Geophhys. Res., 2006*). Specific issues addressed at this stage were the altitudinal distribution of the field-aligned potential drop, as inferred from electron distribution functions, and the current–voltage relationship (CVR). Later on, the work developed towards a more comprehensive examination of the M–I coupling and in March 2011 Costel visited the University of California at Berkeley / Space Sciences Laboratory, where he benefited from discussions with lead experts in the field. In May 2011, Costel was accepted as external PhD student at Jacobs University Bremen (JUB), and in September 2011 he defended his PhD proposal, *Investigation of magnetosphere–ionosphere coupling by multi-point satellite and ground data*. Costel's PhD work, guided by Prof. Joachim Vogt from JUB and by Dr. Octav Marghitu from ISS, is expected to make a significant contribution to the collaboration between ISS and JUB. This work is also relevant for the POLARIS project, where Costel's participation is supported by ISSI under the Young Scientist program, and for the M–ICAR project, selected for a grant of the Romanian National Authority for Scientific Research in September 2011.

The Cluster and FAST spacecraft provided an optimum platform to study the AAR, by combined information from two locations that encompass this key region. However, the selection of suitable Cluster/FAST conjugate events proved to be rather challenging, and it was discussed in a poster presented at the EGU General Assembly (*Bunescu et al., 2007*). Among the few events that were eventually identified, the most promising ones were observed on January 30, 2005 (Event 1), and on January 12, 2003 (Event 2). For these events two electron distribution functions measured by FAST inside the AAR were found to agree rather well with simulated distribution functions obtained by the colleagues at Umeå University, who used Cluster input for the electron density and temperature above the AAR.

In a different study, the simulated distribution functions were compared to FAST observations in order to diagnose a concentrated parallel potential drop located closely above the satellite. The specific signature is presented in Figure 1, as derived numerically from simulations (panel a), and as observed in the FAST data (panels b and c). The results of this study, relevant for both ECSTRA and ALEGRO, were published in *Vedin et al. (2007)*. For the particular cases illustrated by Figure 1, it can be shown that in panel b some 8% of the potential drop above the satellite is located within 75 km, while in panel c about 20% of the potential drop is located within 200 km.

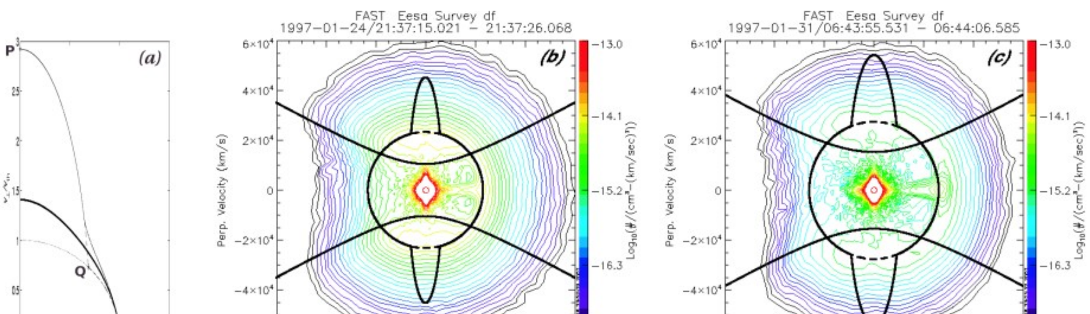

Figure 1: Simulated and observed distribution functions, indicating a concentrated parallel potential drop closely above the satellite. After *Vedin et al. (2007)*. **(a)** A concentrated electric field (CEF) above the satellite yields a specific signature in the velocity space, corresponding to the particles trapped below the CEF. Numerical simulations show that if e. g. 0.5 kV out of a total parallel potential drop of 1 kV are produced by a CEF, the trapping boundary extends from the dotted circle (or the bold oval, depending on the altitudinal distribution of the rest 0.5 kV), to include the PQ line. **(b, c)** Electron distribution functions observed by the FAST satellite inside the AAR, integrated over 11 s. The particle populations in the velocity space are separated by boundaries indicated with bold lines. One can recognize the signature of the CEF above the satellite in the elongated vertical 'hats', resembling the PQ line from the left panel (together with its mirror with respect to the $v_\perp$ axis).

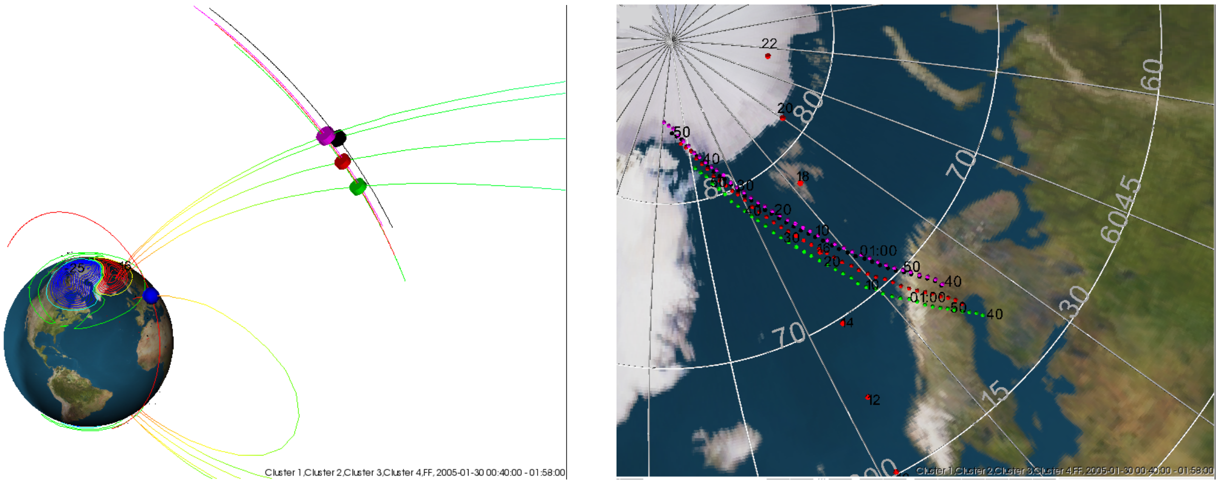

Figure 2: Spacecraft tracks (left) and their ionospheric footprints at 100 km altitude (right).

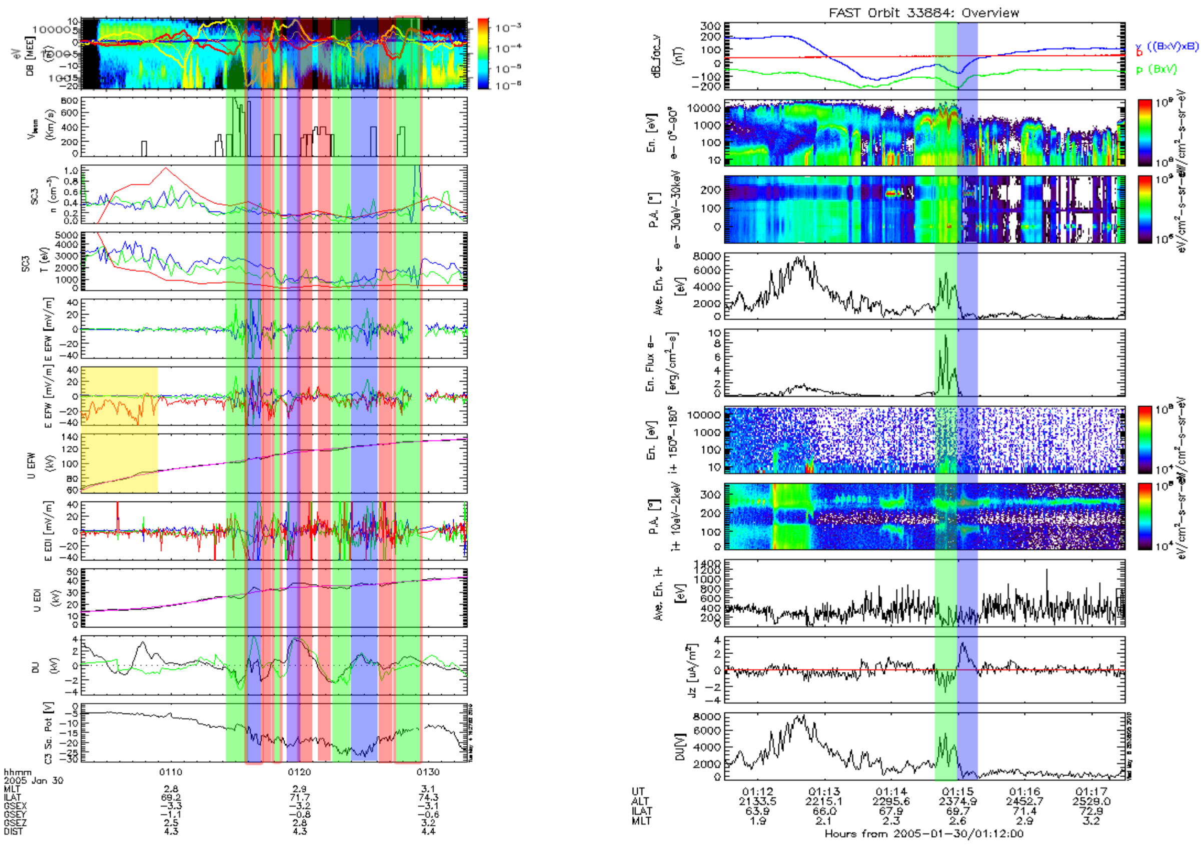

Figure 3: *Left:* Cluster data. Electron spectrograms of upward electrons and superposed magnetic field perturbation; electron (red) / ion (CODIF green, HIA blue) density and temperature; EFW/EDI electric field, potential along the satellite track, and field-aligned potential; spacecraft potential. The green / blue vertical bars indicate upward / downward FAC regions where the various data signatures are consistent with each other. The red bars indicate ambiguous intervals, where the various data are not consistent with a stationary situation, possibly because of Alfvénic activity near the polar cap boundary. In the yellow regions the magnetic field vector is within 10 deg from the satellite spin plane, which prevents a reliable determination of the vector electric field and of the electric potential.
Right: FAST data. Magnetic field perturbation; electron and ion energy / pitch-angle spectrograms, average energy, and energy flux; current density (Jz, positive downward); field-aligned potential drop (DU). The green / blue vertical bars indicate upward / downward FACs likely to be the low altitude match of the first Cluster FAC pair.

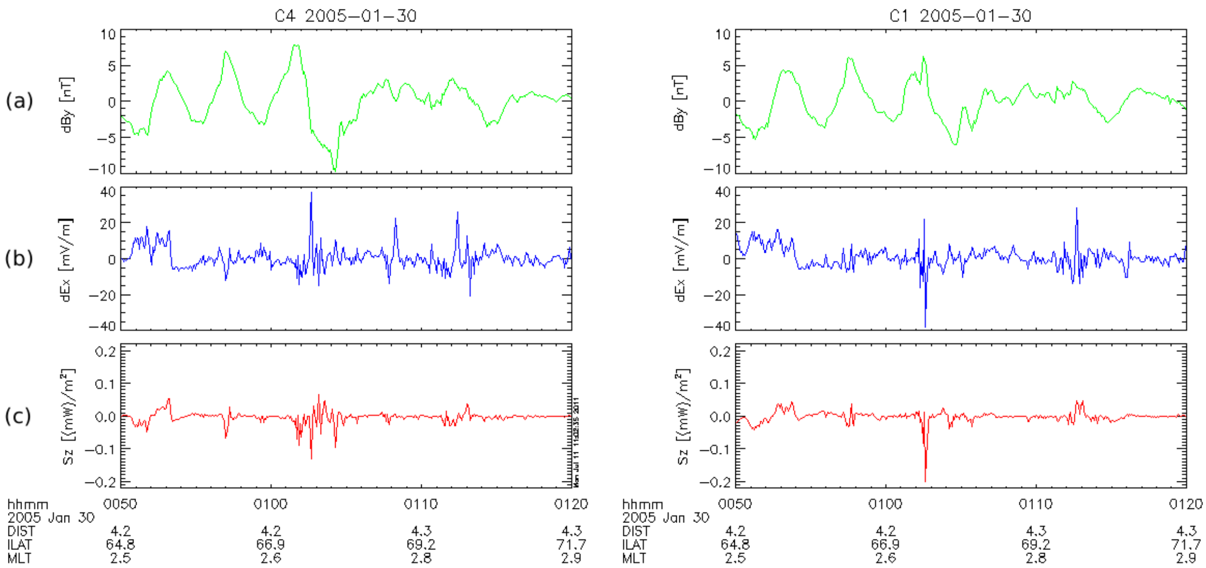

Figure 4: Magnetic field (a), electric field (b), and Poynting flux (c) measured by Cluster 4 (left) and Cluster 1 (right) above the auroral oval, on two neighboring paths. The data illustrate the complementarity of quasi-stationary and time-dependent M–I coupling, as well as the importance of the scale (see text).

The examination of the CVR, based on both Cluster and FAST data, was initiated at the STIINTE workshop, with the project *Auroral Knight relation using electric field and particle data*. Later on, Costel Bunescu was selected by ESA for one of the five scholarships offered to PhD students at the 15th Cluster workshop, where he presented results that added to the work started at STIINTE (*Bunescu et al., 2008*). The value of the so-called Knight constant, $K_{JU} \equiv J/U$ (with J the current density and U the field-aligned potential drop), as derived for a set of FAST events, was shown to be larger near the edges of inverted-V structures, consistent with earlier studies. The K_{JU} values inferred for a few Cluster events were found to be in order of magnitude agreement with the FAST data, or larger, depending on the data used to compute U. Thus, U^E, derived from electric field data, was significantly smaller than U^I, derived from ion data, and K^E_{JU} larger than K^I_{JU}, with K^I_{JU} found, in turn, comparable to the FAST based estimates. Preliminary results of a statistical study based on Cluster data suggested also a positive correlation between K_{JU} and the ionospheric conductance, with somewhat higher K_{JU} values observed during summer.

Further work concentrated on Event 1, observed in the early morning sector, during the late recovery phase of a substorm. Figure 2 presents the spatial configuration of the spacecraft, with Cluster crossing the auroral field lines in pearl-on-string configuration at about 3.5 R_E altitude and FAST probing the topside ionosphere at about 0.4 R_E altitude. The ionospheric footpoints indicate the proximity of Cluster 1 and Cluster 4 mapped trajectories, as well as a close conjunction between Cluster 3 and FAST around 01:15 UT. Figure 3 shows a selection of Cluster 3 and FAST data for this event. The green/blue vertical bars in the Cluster plot show time intervals with upward/downward FAC when the various data signatures are consistent with each other. The red vertical bars indicate intervals of poor consistency, possibly because of spatial and/or temporal variability. The green/blue vertical bars in the FAST plot show as well a meso-scale upward/downward FAC pair, whose latitudinal extent and magnetic perturbation appears to match the mapped characteristics of the first green/blue FAC pair observed in the Cluster data. The small-scale structures visible in the FAST electron data and the Alfvénic oscillations mapped from the Cluster altitude (see below) appear to have similar sizes as well.

After the initial comparison of simulation and observed distribution functions, the investigation of this event continued with a careful examination of the CVR. Preliminary results in this respect were presented at the IPELS conference (*Bunescu et al., 2009*) and at the ISSS-9 School on Space Simulations (*Bunescu and Marghitu, 2009*). When using Cluster data, K_{JU} (with U based on electric field data) was found to be 2–3 times larger as compared to the values derived from FAST data, possibly because of neglecting the current sheet motion at Cluster and/or the influence of non-stationarity on the CVR. K_{JU} at Cluster was also compared to the theoretical value, K_{NT}, which depends on the electron density, N, and temperature,

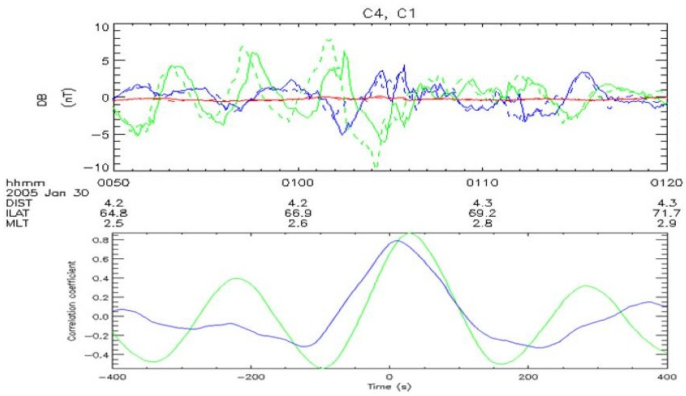

Figure 5: *Top:* Magnetic field perturbation observed on Cluster 4 (dashes) and Cluster 1 (solid). The x, y, and z components are indicated by blue, green, and red. *Bottom:* Cross-correlation coefficient for ΔB_x (blue) and ΔB_y (green) depending on time lag. Maximum values of ~0.8 for ΔB_x and ~0.9 for ΔB_y are obtained for time lags of 12 s and 28 s, respectively.

T. Consistent with older results, K_{JU} was systematically larger than K_{NT}, which may be related also to violations of the adiabatic conditions.

Further work, partially reported at the 19th Cluster workshop (*Bunescu and Marghitu, 2010*), included also Event 2, which showed several similarities to Event 1 in the magnetic field, electric field, and particle signatures. Among these, all the Cluster satellites observe an oscillating magnetic field perturbation with about 5 min period and 5–10 nT amplitude, tentatively interpreted in terms of back and forth motion of FAC sheets that close in the ionosphere. The temporal sequence of upflowing ion and electron beams suggest a pair of upward/downward FAC sheets, with embedded field-aligned potential structures. Higher frequency oscillations, identified as (dispersive) Alfvén waves, are visible in the electric and magnetic field.

Figure 4 shows 30 min of Cluster 4 and Cluster 1 data from Event 1, with low frequency magnetic field and high frequency electric field oscillations. The second ones contribute to wave Poynting flux, most prominent around 01:03 UT when the electric field is large. The scale of the magnetic field oscillation is significantly larger than the distance between the two spacecraft, and thus the magnetic field measured by Cluster 4 and Cluster 1 is strongly correlated. At the same time, the electric field and Poynting flux profiles show significant differences around 01:03 UT, suggesting that the scale of the Alfvénic activity is smaller than the distance between spacecraft. This is consistent with the fact that small scale auroral structures are often of Alfvénic nature.

The strong correlation between the magnetic field perturbations on Cluster 1 and Cluster 4 is emphasized by Figure 5. The difference in the time lags that maximize the correlation coefficients for ΔB_x and ΔB_y may indicate that the observed $\Delta\mathbf{B}$ is obtained from the superposition of a larger scale FAC sheet pair and smaller scale FACs with less advanced symmetry. The relative speed of the spacecraft with respect to the larger scale FAC sheet pair was estimated to be in the range 5–15 km/s, to be compared with ~5 km/s, the spacecraft velocity in GSE. If the FAC sheets are considered at rest, the estimate of the sheets' width can be underestimated by up to a factor of 3, resulting in a likewise overestimate of the current density and of K_{JU}. This result is consistent, qualitatively, with the conclusion based on the CVR examination. However, the exact value of the relative velocity to be used in computing the width, and further on the current density, depends on the orientation of the FAC sheets, which is still under investigation.

By exploring a set of 14 more Cluster events, 7 in 2003 and 7 in 2005, similar magnetic field oscillations were observed in most of these events. Recent simulations by *Wolf et al., J. Geophys. Res., 2012* suggest that such oscillations can be related to BBFs' braking in the inner magnetosphere. A THEMIS–Cluster conjunction event, identified in the framework of the POLARIS project, provides experimental evidence along this line which is now under close scrutiny. The inspection of the events in 2005, when the distance between neighboring satellites was smaller (800–900 km, as compared to about three times more in 2003), and the correlation of the respective magnetic perturbations was better, is now in progress (*Bunescu et al., manuscript in preparation*), and may contribute to a better understanding of the BBFs' coupling to ionosphere.