ECR statistical investigations

The statistical investigations of energy conversion started with a few ECRs, identified in the plasma sheet data measured by Cluster in 2001, at 16–20 R_E geocentric distance. Several interesting features observed in the data were presented at the EGU General Assembly, at the STIMM-2 workshop, and at one of the CIS team meetings. (*Marghitu et al., 2007a, b, c*). Among these features, the location of the ECRs with respect to the neutral sheet appeared to depend on ECR properties (like the magnitude of energy conversion), the ECRs were in general associated with plasma flow (while plasma flow was not always associated with ECRs), and the temperature was often anisotropic, with $T_{\parallel} > T_{\perp}$.

The next stage of exploring the energy conversion relied on a manual database 43 ECR events observed by Cluster in the plasma sheet. A preliminary evaluation of these events was presented at the 4th Alfvén Conference (*Marghitu et al., 2007d*), while a detailed analysis was performed for the 15th Cluster workshop (*Marghitu et al., 2008*) and published later on in the Proceedings of this workshop (*Marghitu et al., 2010a*). These results were also communicated at a joint Cluster–THEMIS workshop (*Marghitu et al., 2008b*) and at an invited seminar at Southwest Research Institute (*Marghitu et al., 2008c*).

As judged from the manual database, the energy conversion in the plasma sheet appeared to be rather structured, with concentrated load regions (CLRs) and concentrated generator regions (CGRs), the crossing of which took typically of the order of 10 min. The database consisted of 26 CLR and 17 CGR events. Two examples, one CLR and one CGR, are presented in Figure 1. The results of the investigation performed on all the 43 ECR events are summarized in Figure 2. A cross-check of the data based on electric field

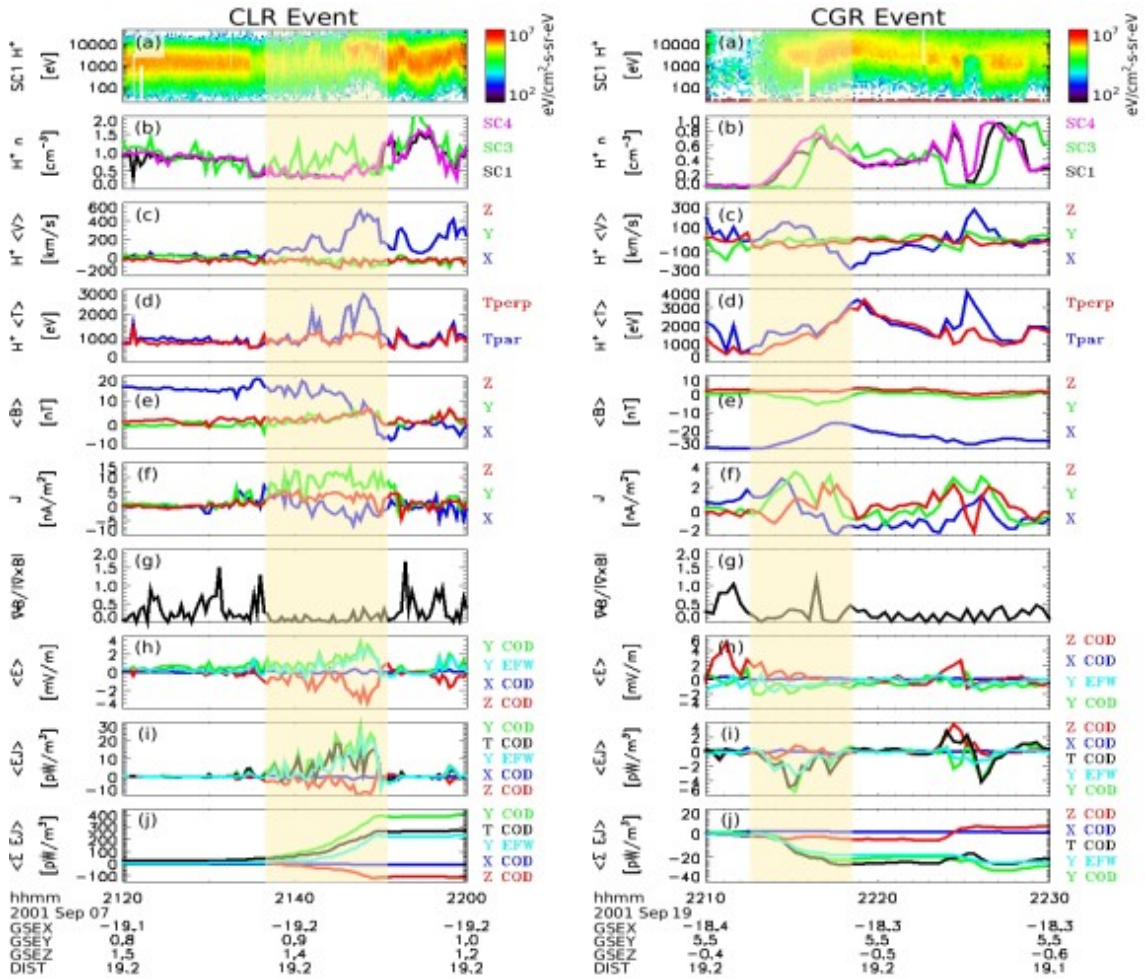

Figure 1: Examples of a concentrated load region (left) and a concentrated generator region (right). After Figure 1 of *Marghitu et al., 2010a*. From top to bottom, the panels in each plot show: (a) proton energy spectrogram, (b) density, (c) velocity, (d) temperature, (e) magnetic field, (f) current density, (g) ratio $\nabla \cdot \mathbf{B}/|\nabla \times \mathbf{B}|$, (h) electric field, (i) power density, and (j) the cumulative sum of the power density. The vertical bands indicate the ECRs.

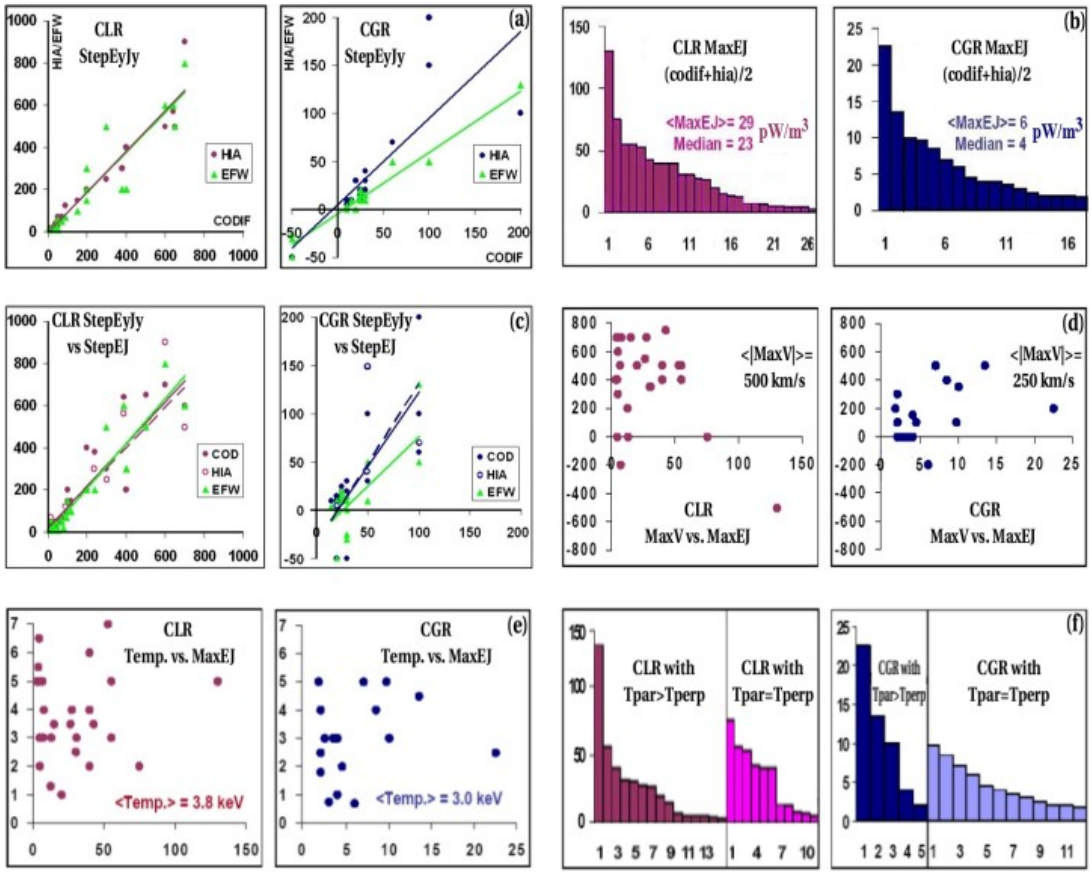

Figure 2: CLR and CGR features (left and right, respectively, in each panel). After Figure 2 of *Marghitu et al., 2010a*. (a) Step variation in the cumulative sum (SVCS) of $E_y J_y$, as derived from EFW and HIA data, versus CODIF. (b) Maximum $\mathbf{E} \cdot \mathbf{J}$ for each event. (c) Contribution of $E_y J_y$ to $\mathbf{E} \cdot \mathbf{J}$. (d, e) Maximum velocity and temperature versus maximum $\mathbf{E} \cdot \mathbf{J}$. (f) Association with $T_{\|} > T_{\perp}$. $\mathbf{E} \cdot \mathbf{J}$, $E_y J_y$, and the respective SVCS are given in pW/m3. In the two histogram type panels, (b) and (f), each event is represented by a vertical bar, of height equal to the maximum $\mathbf{E} \cdot \mathbf{J}$, while the horizontal axis shows the event count, in decreasing $\mathbf{E} \cdot \mathbf{J}$ order.

inferred from three different instruments, CIS/CODIF, CIS/HIA, and EFW (panel a), indicates reasonable agreement (better for CLRs) and suggests that the results are relevant within the error margin. As expected in the tail, at about 19 Earth radii (R_E) geocentric distance, the energy conversion is more intense for CLRs, on average some 25 pW/m^3, compared to some 5 pW/m^3 for CGRs (panel b). The CLRs are located closer to the neutral sheet and dominated by E and J in the GSE y direction, unlike the CGRs, that prefer locations towards the plasma sheet boundary layer, where the deviations of E and J from the GSE y direction can be significant (panel c). The ECRs are often associated with high speed plasma flows, on average faster and hotter for CLRs (panels d, e). The CLRs appear to be associated also with density drop (not shown) and sometimes with temperature anisotropy, $T_{\|} > T_{\perp}$ (panel f), features observed less frequently for CGRs.

Table 1: Summary of ECR events included in the automatically selected database, from *Hamrin et al. (2010)*. The data correspond to the years 2001, 2002, 2004, and to the three years together. Columns 2–3 show the number of plasma sheet passes and plasma sheet hours, columns 4–8 provide ECR statistics, columns 9–11 show information on random events, and column 12 indicate the scale size of the Cluster tetrahedron.

Year	Pass.	PS[h]	ECR	ECR/h	CLR	CGR	CLR/CGR	RAND-L	RAND-G	RAND-L/G	~L [km]
2001	85	660	134	0.20	110	24	4.6	577	464	1.2	1500
2002	68	1000	233	0.23	173	60	2.9	450	275	1.6	4000
2004	67	1070	188	0.18	145	43	3.4	440	258	1.7	1000
2001+ 2002+ 2004	220	2730	555	0.20	428	127	3.4	1467	997	1.5	–

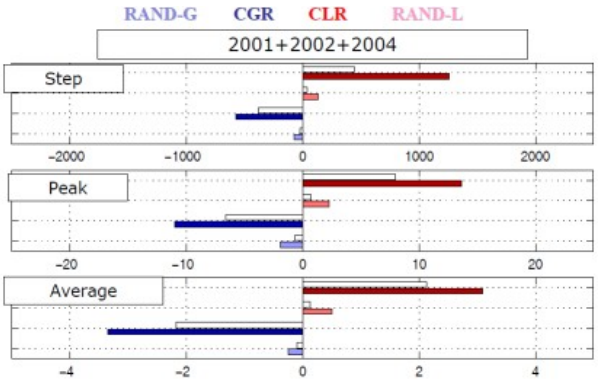

Figure 3: Magnitude of the automatically selected ECRs, from *Hamrin et al. (2010)*. The magnitude is measured in three different ways, by the 'step', 'peak', and 'average' values, where 'step' is the integral of $\mathbf{E} \cdot \mathbf{J}$ over the ECR event, 'peak' is the maximum $\mathbf{E} \cdot \mathbf{J}$, and 'average' is equal to 'step' divided by the duration of the event. Red / blue corresponds to CLRs / CGRs and light red / light blue to RAND-Ls / RAND-Gs. The colored / white bars indicate mean / median values.

A comprehensive examination of the ECRs observed by Cluster in the plasma sheet was made possible later on by a streamlined data processing and by a semi-automated ECR selection procedure developed by Dr. Maria Hamrin and Dr. Patrik Norqvist at Umeå University, Sweden. Results on the occurrence, location, lifetime, and scale size of the ECRs were published by *Hamrin et al. (2009a, b)*, followed by an investigation regarding geomagnetic activity effects on the ECRs (*Hamrin et al., 2010b*). An invited presentation at the APPW workshop (*Hamrin et al, 2010a*), materialized later in a review paper on energy conversion and transport in the plasma sheet (*Hamrin et al, 2011*). One more paper, on the role of inner to mid tail plasma sheet in channeling the solar wind power to the ionosphere, is presently under review (*Hamrin et al., 2012*).

A brief summary of the ECRs identified in 2001, 2002, and 2004, including both CLRs and CGRs, is given in Table 1, while Figure 3 provides information on the magnitude of these ECRs. Table 1 and Figure 3 include also random energy conversion events, RAND-L ($\mathbf{E} \cdot \mathbf{J} > 0$) and RAND-G ($\mathbf{E} \cdot \mathbf{J} < 0$), intended to capture the average behavior of the plasma sheet and to provide thus a reference level. The ECRs were shown by *Hamrin et al., 2009b* to be in general temporal structures, with lifetime of the order of 1 to 10 minutes and scale size of a few R_E. CLRs were found to be somewhat larger and live somewhat longer than CGRs. The dependence of the CLR to CGR occurrence rate on plasma β (Figure 4) indicates that CLRs are located more often close to the neutral sheet than CGRs, consistent with the earlier findings based on the manual database. Figure 5 shows that the occurrence rate of CLRs and CGRs scales with geomagnetic activity. Energy conversion strength inside both CLRs and CGRs, as well as the lifetime of CLRs, were also observed by *Hamrin et al. (2010b)* to scale with geomagnetic activity.

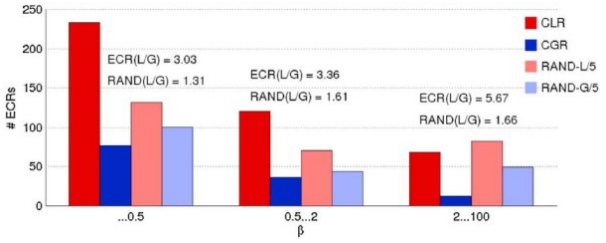

Figure 4: Dependence of the ECR occurrence rate on plasma β, as derived from Cluster plasma sheet data observed in 2001, 2002, and 2004 (from *Hamrin et al., 2011*). The CLR to CGR ratio (indicated as ECR(L/G)) is seen to increase towards high plasma β, that is towards the neutral sheet.

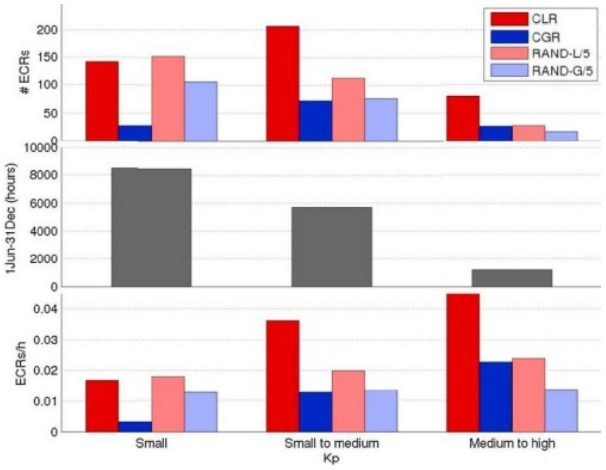

Figure 5: Statistical results on the influence of geomagnetic activity, as expressed by the Kp index, on energy conversion (from *Hamrin et al., 2010b*). The top, middle, and bottom panel show the number of ECR and RAND events, the number of available observation hours, and the occurrence rate in events per hour. The results are based on Cluster plasma sheet data from 2001, 2002, and 2004.

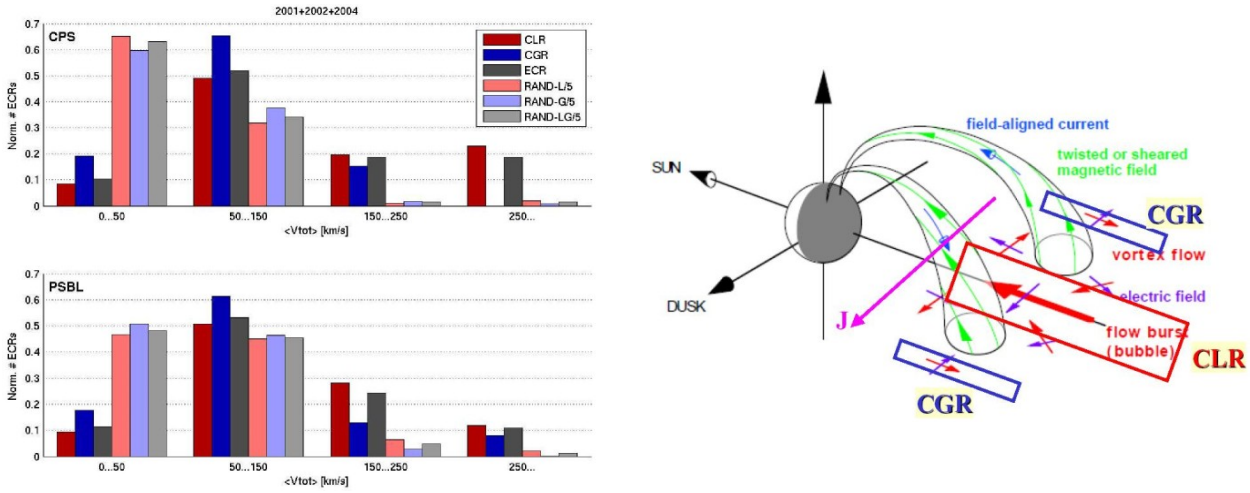

Figure 6: Statistical results on the association between ECRs and BBFs, based on Cluster plasma sheet data from 2001, 2002, and 2004. *Left:* Normalized numbers of ECR and RAND events depending on total plasma flow velocity (from *Marghitu et al., 2010e*). Each set of histograms (CLR, CGR, ECR, RAND-L, RAND-G, RAND-LG) is normalized by the total number of events in the respective set. The CPS (top) and PSBL (bottom) panels correspond to plasma $\beta > 1$ and < 1, respectively. *Right:* Cartoon suggesting a possible interpretation of the ECR–BBF association (adapted after *Birn et al. (2004), Ann. Geophys., 22, 1773–1786*).

Energy conversion and energy transport are closely related, as indicated by the association between ECRs and bursty bulk flows (BBFs) — known to make a major contribution to the energy (as well as mass and magnetic field) transport in the plasma sheet. Statistical evidence on this association, consistent as well with the observations in the early stages of the research, was presented at the 10th anniversary Cluster workshop (*Marghitu et al., 2010e*), and in an invited seminar at University of New Hampshire / Space Science Center (*Marghitu, 2011a*). The left plot of Figure 6 illustrates the ECR dependence on the total plasma flow velocity, V_{tot}, in the central plasma sheet (CPS) and plasma sheet boundary layer (PSBL). The comparison of the ECR features with the average behavior of the plasma sheet, as indicated by the RAND database, makes clear the correlation between ECRs and high speed plasma flows. While 50%–60% of the RAND events are associated with slow flow ($V_{tot} < 50$ km/s), only about 10% of the ECR events fall in this category. A possible interpretation of the relationship between ECRs and BBFs is provided in the right plot of Figure 6, showing that the CLRs are likely to be observed inside the BBF flow channel, while the CGRs might be located at the flanks of the BBF, where return flows are expected to occur. The work on the association between ECRs and BBFs will be reported in an upcoming publication (*Marghitu et al., manuscript in preparation*).