Waves in the energy conversion regions

By being able to transport energy in and out ECRs, waves can strongly affect the energy balance and the physical phenomena taking place inside these regions. One of the important parameters needed to determine their contribution is the propagation direction. Another is the local or transient character. Both can be determined by the source locator technique (described by *Constantinescu et al., J. Geophys. Res., 2006*) applied to magnetic field data. We used this technique to determine how the plasma properties inside ECRs differed from the surrounding plasma, in particular to determine if wave instability conditions were more likely to be found inside or outside ECRs. We investigated as well whether there was any difference between CLRs and CGRs regarding the plasma wave generation or damping.

The source locator is a wave analyzing method which combines three dimensional multi point measurements to determine the wave vector and the curvature of the wave front for a selected wave in the wave field. To be truly three dimensional, the measurements must satisfy two geometrical criteria: the number of measuring points (at a given time) should be at least four and the points should not be in the same plane. The four Cluster spacecraft provide an excellent platform to sample such data. The first criterion is always satisfied (if data are available from all spacecraft) and the second criterion is satisfied as well if the spacecraft configuration is close to a regular tetrahedron. In order to estimate how close is the configuration at a certain time to the ideal shape of a regular tetrahedron, one can use the "quality factor", which compares the actual volume and surface of the configuration with those of the ideal tetrahedron.

Additional requirements refer to the scale of the tetrahedron and to the properties of the wave field. The scale of the tetrahedron has to match the targeted wave: If the tetrahedron scale is larger than the wave length, spatial aliasing occurs and the source locator cannot be used. On the other hand, if the tetrahedron scale is significantly larger than the wave length (in practice 10 to 20 times), the resolution becomes too low, both in direction and wave length. The wave field has to be stationary during the measurements and homogeneous on the tetrahedron scale.

All these constraints have to be taken into account when an event is chosen to be analyzed or a statistical study performed. Such an event was observed during a plasma sheet crossing from July 29, 2003. At this time the Cluster formation was close to a regular tetrahedron, with the satellites separated by about 200 km. The plasma sheet was traversed from North to South, at a geocentric distance of about 18 R_E, and Cluster encountered a number of ECRs, as illustrated in Figure 1. Two of the intervals analyzed by the source locator technique are discussed in more detail below.

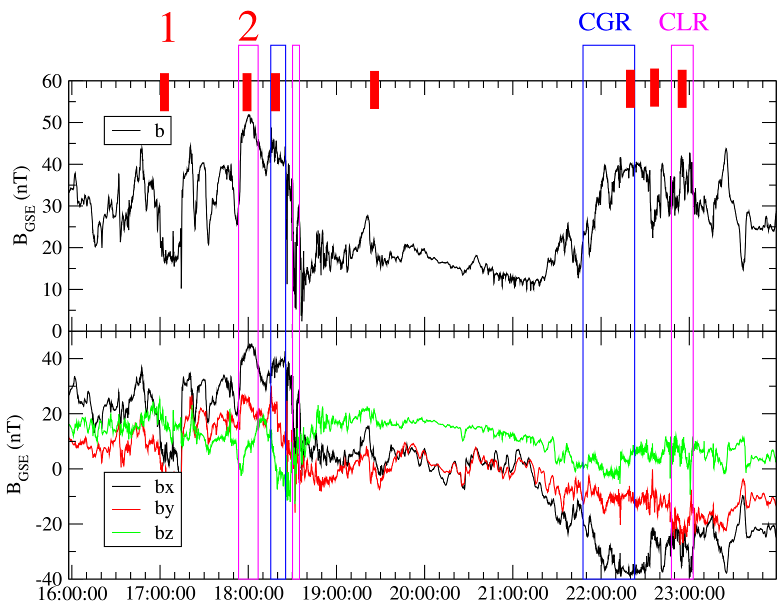

Figure 1: Magnetic field magnitude and GSE components during the Cluster plasma sheet crossing from July 29, 2003, selected for a closer investigation of the wave activity associated with ECRs. The pink and blue boxes indicate CLRs and CGRs, respectively. The red marks indicate analyzed intervals, out of which "1" and "2" are discussed in more detail.

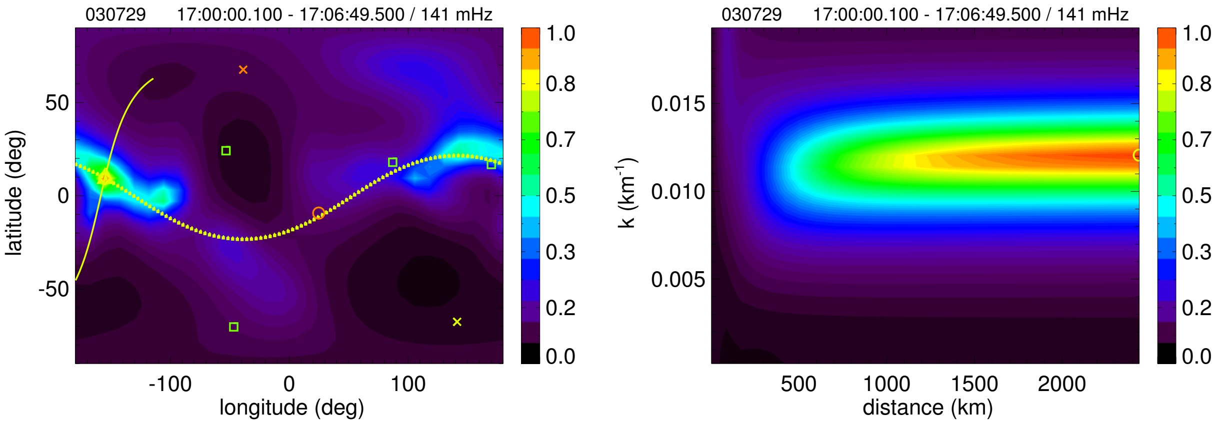

Figure 2: Wave detected outside ECR. It propagates orthogonal to the mean magnetic field, coming from the tail inside the equatorial plane. The wavefront is plane, indicating that the wave comes from a distant source. The frequency is 141 mHz and the wavelength 540 km. This wavelength is more than twice larger than the mean spacecraft separation, which ensures that no aliasing is present.

The results for the data interval identified as number "1" in Figure 1 are shown in Figure 2. This interval is outside the observed ECRs and the results are representative for all the investigated intervals outside ECRs. The left panel in Figure 2 shows the normalized spectral power (color) as a function of direction in a reference system obtained by translating the GSE system origin to the center of mass of the Cluster formation. This plot indicates that most of the wave power comes from a layer close to the equatorial plane and propagates sunward. Moreover, the angle between the mean magnetic field and the propagation direction of the wave is 88°, consistent with the field direction near the neutral sheet around 17:00 UT (see Figure 1). The right panel of Figure 2 shows the distribution of the wave power depending on the other two parameters that can be explored with the source locator: the wave number, k, and the curvature radius of the wave front, which is an indicator for the distance to the wave source. The power distribution in this plot is consistent with a wave generated at a distance larger than 2000 km, whose wavelength is $\sim$500 km.

We move now to the interval inside a CLR, identified as number "2" in Figure 1. The results of the source locator analysis are shown in Figure 3. In the left panel we see that the wave comes from the dawn flank of the magnetosphere and from outside the equatorial plane, at an angle of 82° to the mean magnetic field. Analysis of the other intervals inside ECRs showed no preferred direction for the detected waves. The right panel indicates that the wavelength is close to 500 km, similar to the wave length in Event 1, but now the wave comes from a distance of just 500 km from the formation center. We cannot say, for the time being, whether the wavelength of 500 km is in any way remarkable, or it occurred just by chance.

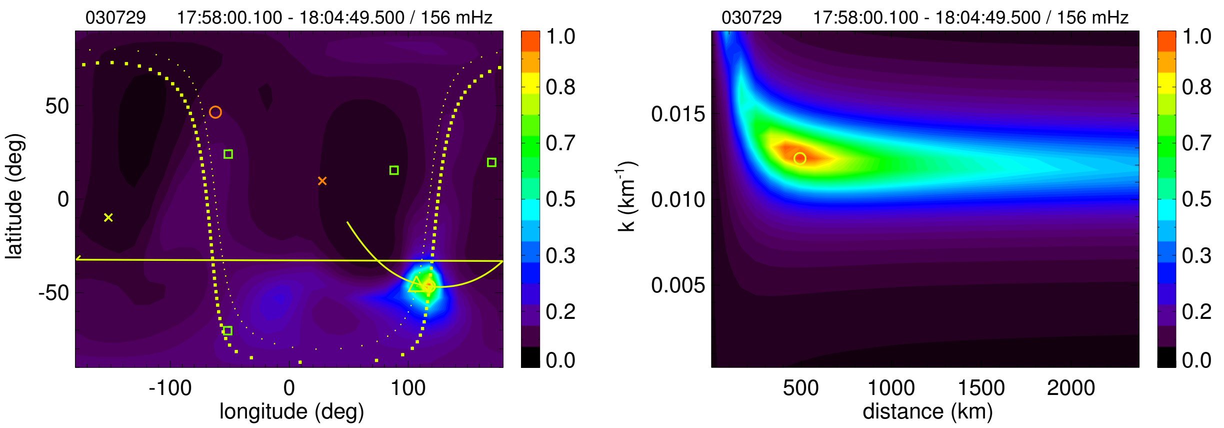

Figure 3: Wave detected inside a CLR. This wave propagates as well orthogonal to the magnetic field. However, the source locator detected a curved wavefront, corresponding to an origin of the wave at only about 500 km from the tetrahedron center. The frequency is 156 mHz and the wavelength 507 km.

The results suggest that conditions inside ECRs lead to generation of low frequency waves while plasma conditions are much more stable outside these regions. Although in the case studied we detected waves originating from both types of ECRs, the CLRs seem to be much more active than the CGRs. Preliminary results from these case studies were presented at the AGU Meeting of the Americas in August 2010 *Constantinescu et al., 2010b*. During the analyzed time intervals, the Cluster tetrahedron was located in the magnetospheric tail, within the plasma sheet. Both inside and outside of the ECRs the propagation direction of the detected waves was orthogonal to the mean magnetic field. This information is useful to determine the wave mode, suggesting magnetosonic waves. However, further study is necessary in order to determine which instability is responsible with the excitation of these waves.

In order to see if the features observed above represent general properties of the ECRs, a statistical investigation has to be carried out and a conversion of the available software is under way. The goal is to minimize the required CPU time and to allow for a more efficient scanning of the data. The new software can then be applied to a selection of ECRs, identified by neural networks or by other more conventional means. The conditions required for the selection will take into account both physical parameters and criteria specific to multi-point measurements, like the tetrahedron configuration. A complication which has to be considered is the rather short wavelengths (hundreds of kilometers) that seem to be characteristic for the waves inside and around ECRs. This may result in spatial aliasing for a significant number of the selected events, therefore a large database with candidate events might be necessary.