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Relevance of Cluster observations near the diffusion region

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Abstract. The ESA Cluster mission comprises 4 satellites on very similar orbits and is equipped with 11 scientific instruments cloned on each satellite providing high quality measurements of particles and fields. It was launched in 2000 to investigate the small-scale three dimensional structure of the Earth's plasma environment, separating unambiguously spatial from temporal variations. Here, some of the relevant results of the analysis of Cluster observations near the diffusion region are reported.

Key words. Magnetic Reconnection – Diffusion Region

1. Introduction

The occurrence of magnetic reconnection at the Earth magnetopause (MP) is rather well established but this process is far from being completely understood. Its comprehension, besides being extremely relevant for the understanding of the global magnetospheric dynamics, has an intrinsic importance, since reconnection, at the origin of explosive conversion of magnetic energy in internal and kinetic energy of the plasma, is ubiquitous in the universe. All the reconnection models presume the existence of a diffusion region where the frozen-in condition breaks down and magnetic field reconfigures. The reconnection rate depends on the specific model of reconnection and its value is a crucial validity test for the model itself. The aspect ratio of the diffusion region is an important factor for reconnection: an elongated diffusion region gives rise to reconnection rates much lower than the observed ones. According to the Petschek (1964) model, the diffusion region is vanishingly small, two slow mode shock waves, connected to the diffusion region, accomplish the rotation of the magnetic field and most of the plasma is accelerated out through these shock waves, without entering the diffusion region, allowing the reconnection rate to be comparable to the observations. It is unknown which is the structure of the diffusion region. If collisionless effects are dominating with respect to resistivity, the relative motion between electrons and ions gives rise to a quadrupolar out of plane Hall magnetic field in the ion diffusion region (Sonnerup 1979). Moreover, full particle simulations in large simulation domains have recently shown that the electron dissipation region should develop a two scale structure: a stationary localised out of plane current layer connected to an elongated super-Alfvénic electron jet that extends up to several 10's ion inertial length (λ_i) (Shay et al. 2007; Karimabadi et al. 2007).

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The principal aim of the Cluster mission is to provide high quality three dimensional in situ measurements to reveal the physics of reconnection and others fundamental plasma processes. Here, a brief description of some Cluster observations of the diffusion region will be given.

2. Cluster observations of the diffusion region

2.1. Cluster measurements near the diffusion region

On 3 December 2001 the Cluster spacecraft skimmed the southern high-latitude duskside MP during a period of about four hours. This period was extensively studied by Retinò et al. (2005) which gave fluid evidence of quasi continuous reconnection occurring tailward of the southern cusp. A characteristic of this long lasting reconnection event is the abundance of secondary populations related to reconnection. During reconnection particles enter the boundary layer along magnetic field lines. Because of the flux-tube motion along the magnetopause imposed by reconnection, only those particles with velocities greater than the flux-tube velocity will be able to enter the boundary layer. This results in the so called D-shaped distribution functions (Cowley 1982; Fuselier et al. 1991). Also the presence, just outside the magnetopause, of reflected ions displaced with respect to the incident population by $2 \cdot V_A$, where V_A is the Alfvén velocity, along the convected magnetic field direction is an indication of reconnection (Fuselier 1995).

The detailed study of the kinetic aspect of the 3 December event by Bavassano-Cattaneo et al. (2006) showed the excellent agreement of the observed secondary populations with theoretical expectation for reconnection and evidenced that, at a certain time, the diffusion region was between Cluster SC3 and Cluster SC4, which were 3000 km ($50\lambda_i$) apart. In Fig. 1 the sketch of this event is shown: Cluster SC3 observed a D-shaped distribution in the boundary layer (BL) and simultaneously SC4 observed, in the magnetosheath boundary layer (MSBL), the incident magnetosheath population plus the reflected population flowing antiparallel to the magnetic field at about 400 km/s. The reflected population appears as an enlargement, in the antiparallel direction, of the principal population. The distribution functions observed in the magnetosheath proper and in the magnetosphere are also shown. The vicinity to the X-line allowed to study in detail the structure of the separatrix region on the magnetospheric side, evidencing that it is highly structured down to Debye length scales (Retinò et al. 2006).

2.2. Cluster observation of the Hall magnetic field

The Hall magnetic field in the vicinity of the X-line has been revealed by single satellite measurements (e.g. Oieroset et al. 2001; Mozer et al. 2002; Nagai et al. 2001), but such observations suffer for the ambiguity in distinguishing spatial from temporal structures. On February 20, 2002 Cluster crossed many times the MP tailward and duskward of the northern cusp. The study of the high time resolution observations during one of the crossings lead Vaivads et al. (2004) to confirm the importance of the Hall physics in the diffusion region. These observations show for the first time that the Hall fields are a stable spatial feature of the diffusion region rather than some temporal variation, since all four spacecraft, crossing the MP consecutively, observe the large amplitude Hall fields. In particular, Cluster SC4 observes a positive out of plane magnetic field while simultaneously Cluster SC3 observes a negative out of plane magnetic field.

2.3. Cluster observation of the complexity of the diffusion region

Regarding the structure of the electron diffusion region, recently Phan et al. (2007) have reported on Cluster observations of a reconnection exhaust during a current sheet crossing in the magnetosheath. Cluster SC1 observed the bipolar out of plane Hall magnetic field indicative of the crossing of the ion dif-

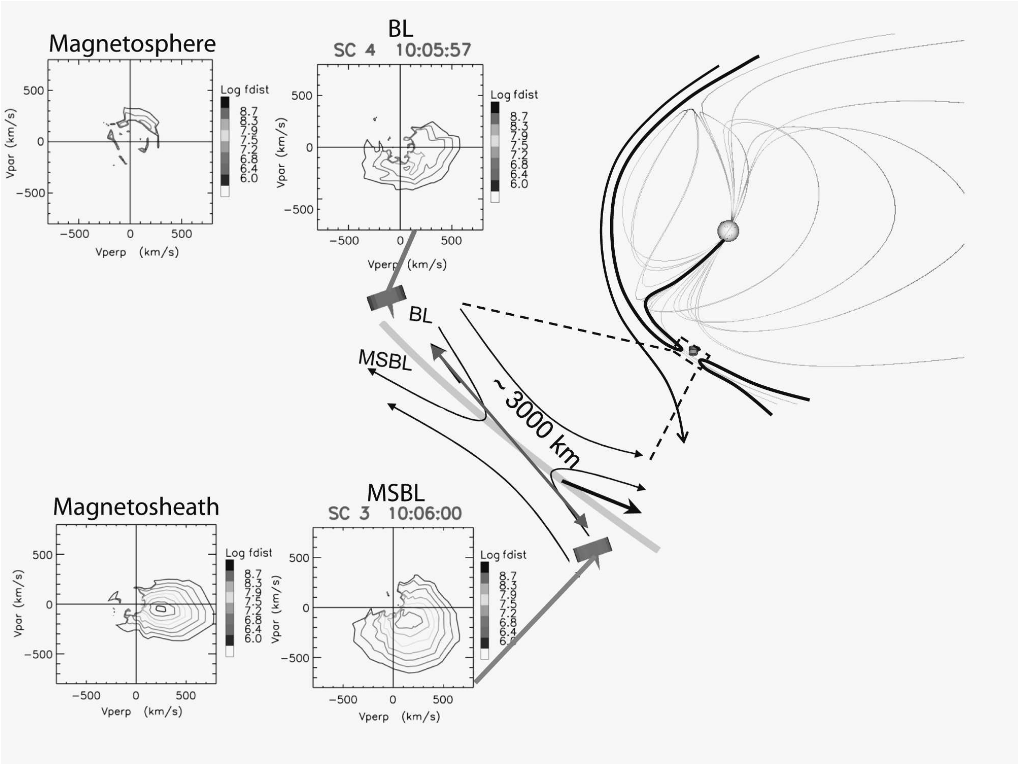

Fig. 1. Ion distribution functions observed by Cluster SC3 and Cluster SC4 in the magnetosphere, in the magnetosheath, and in the MSBL (BL) upstream (downstream) of the diffusion region.

fusion region. Moreover, Cluster SC1 detected a broad current layer with an embedded collimated and unfrozen super-Alfvénic electron jet. In the broader region a frozen-in electron outflow enables reconnection to be fast. The electron jet was detected at a distance of 3400 km (63 λ_i) from the X-line. These observations confirm that an elongated, super-Alfvénic, and unfrozen electron jet is produced during fast reconnection. The comparison of the Cluster SC1 plasma and magnetic field measurements show remarkable agreement with recent full particle simulation of Shay et al. (2007).

3. Conclusions

Here some valued Cluster observations concerning reconnection have been reported. These are only few among the important Cluster results concerning fundamental plasma processes and have been only briefly described, but hopefully it has been shown the high potentiality of multi point observations. In spite of Cluster's achievements, many question remain unanswered regarding reconnection. With this regard, the Cluster mission is now extended until 2009. Moreover, it has to be noted that the physics of reconnection, as of other fundamental plasma processes like turbulence and shocks, implies a complex and time dependent nonlinear coupling between scales and it cannot be ultimately understood without simultaneous in situ measurements at all the three fundamental plasma scales: the fluid, ion and electron scale. With the Cross-Scale mission it will be possible to do such multi-scale measurements positioning spacecraft such that some have separations comparable to each of these three scales (Schwartz 2008). Cross Scale has been selected for the Assessment Phase of the ESA Cosmic Vision program..

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