ION KINETIC FEATURES AROUND A LOBE RECONNECTION SITE

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ABSTRACT

During a period of mainly northward interplanetary magnetic field (IMF), the Cluster spacecraft are skimming the high latitude southern dusk magnetopause (MP) tailward of the cusp and have frequent encounters with the MP where they detect reconnected flows for which the Walen test has been successfully verified by Retinò et al. in [12]. In the present study we discuss the kinetic signatures of reconnection which appear in the ion data in the magnetosheath boundary layer (MSBL) and in the magnetospheric boundary layer (BL). Inspection of the distribution functions allows to infer whether the spacecraft are sunward or tailward of the reconnection site and shows that frequently, even on short time scales, the reconnection site moves from sunward to tailward (or viceversa) with respect to the spacecraft, indicating that the spacecraft are usually close to the reconnection site. The reflected and transmitted magnetosheath ions, observed by CIS experiment in the MSBL and in the BL respectively, show good agreement with the predictions by kinematical considerations.

Key words: space plasmas; magnetopause; magnetic reconnection; kinetic signatures of reconnection.

1. INTRODUCTION

Magnetic reconnection at the magnetopause (MP) is believed to be an efficient process to transfer mass, energy and momentum from the solar wind to the magnetosphere. Crucial questions regard the duration of the reconnection process and its large scale configuration. For southward interplanetary magnetic field (IMF) reconnection occurs on the dayside MP, whereas for northward IMF it occurs at high latitude, tailward of the cusp (the so called ”lobe reconnection”). There have been a number of observations of lobe reconnection, which include also the kinetic aspects: Gosling et al. ([6],[7]) observe lobe reconnection on the flanks of the MP, in the case of antiparallel magnetosheath and magnetospheric magnetic fields (not necessarily for northward IMF) and discuss kinetic signatures as well as field line convection. Long lasting reconnection events have been observed both at low (e.g. [5],[9],[8]) and at high latitude (e.g. [10],[12]). When reconnection occurs, particles of magnetosheath/magnetospheric origin are reflected at the MP or transmitted across it and travel along reconnected field lines: their distribution functions have characteristic signatures which have been predicted theoretically by Cowley ([3],[4]). The interest of these signatures is that they allow to infer important information on the reconnection topology. The present study concerns the ion kinetic signatures observed during a quasi-continuous lobe reconnection event occurring during a period of mainly northward IMF.

2. OBSERVATIONS

The event under study occurs on december 3, 2001 between 7:30-12:00 UT. The data used are from the Cluster Ion Spectrometer (CIS) onboard the Cluster spacecraft. The CIS experiment consists of two instruments: HIA, which provides the ion three-dimensional (3D) distribution functions in the energy range 5-32000 eV, and CODIF which provides the 3D distribution functions in

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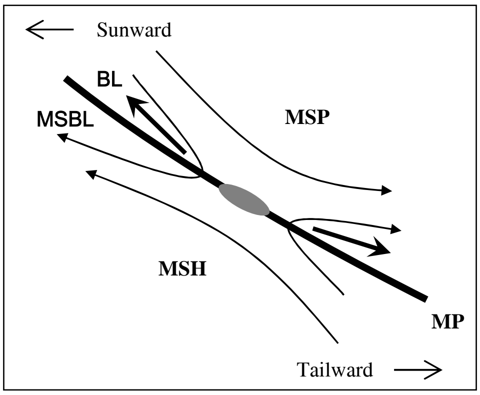

Figure 1. Sketch of the reconnection topology for the present event. The MSBL, BL, and MP are indicated.

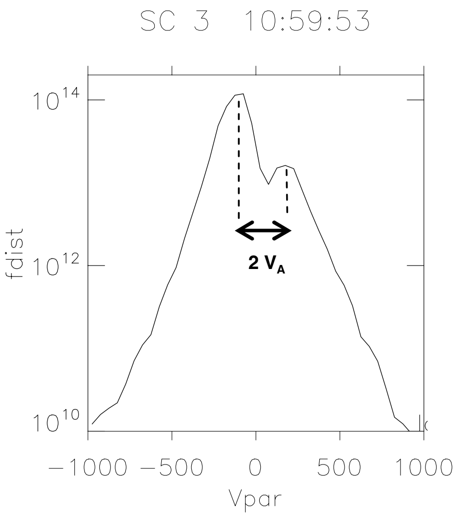

Figure 2. Profile of the ion distribution function along the magnetic field in the MSBL: the two populations are the incident and reflected magnetosheath ions.

the energy range 20-40000 eV for four ion species. For the present study moments and 3D distribution functions are available with the maximum time resolution, i.e. 4 s, and this allows to follow the changes of the distribution functions on short time scales. Spin averaged magnetic field data from the FGM experiment onboard the Cluster spacecraft have also been used. The CIS and FGM experiments have been described respectively in [11] and [1].

During this period the Cluster orbit lies in the Y_{GSM} Z_{GSM} plane. The spacecraft are skimming the southern high latitude dusk magnetopause, tailward of the cusp during a period of mainly northward IMF and of sub-alfvenic magnetosheath flow and have frequent encounters with the MP. In the magnetospheric boundary layer (BL) they detect signatures of reconnection for about four hours: these consist of accelerated tailward flows or sunward flows, depending on whether the spacecraft are located tailward or sunward of the reconnection site, respectively. For these reconnection signatures the tangential stress balance has been successfully verified in [12]. A few reconnected flow reversals, namely reconnected flows directed in opposite directions within short time intervals, were detected in the BL suggesting that, at least in a few cases, the spacecraft are close to the reconnection site. A sketch of the reconnection topology, as derived in [12], is shown in Fig. 1. The plane of the figure is roughly the Y_{GSM} Z_{GSM} plane, but the dawnward side is tilted sunward and the duskward side is tilted tailward, as the IMF is directed northward and sunward.

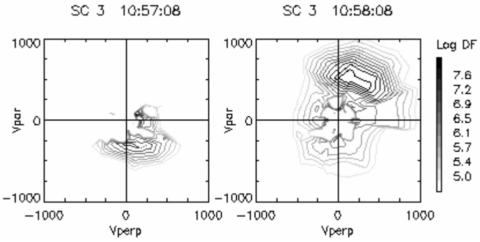

Figure 3. Two distribution functions obtained in the BL represented in the $V_{\|}$, $V_{\perp}$ plane.

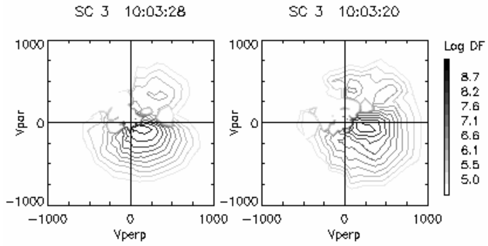

Figure 4. The same as Fig. 3 but in the MSBL.

One characteristic of this event is the large number of secondary ions related to reconnection: almost all MP crossings have reflected and/or transmitted magnetosheath ions. Kinetic signatures related to reconnection have been repeatedly reported in the literature, but these signatures are not present in all reconnection events. A possible interpretation of the large number of secondary ions in this event will be given below. Fig. 2 shows the profile of the distribution function in the magnetic field direction during a MSBL crossing. It consists of two peaks: the main peak, which flows antiparallel to $\mathbf{B}$, is the incident magnetosheath population and the secondary peak, which flows parallel to $\mathbf{B}$, is the reflected magnetosheath population. The two peaks are separated by $2{*}V_A$ (V_A being the local Alfven speed) as predicted by kinematical considerations ([3]), and the fact that the reflected ions travel parallel to $\mathbf{B}$ means that the spacecraft is located sunward of the reconnection site. Two examples of transmitted magnetosheath populations in the BL (already shown in [12]) are shown in Fig. 3. The two distribution functions are taken only one minute apart: they both have the characteristic D-shape ([4]): the one on the left flows antiparallel to $\mathbf{B}$, indicating that the spacecraft is located sunward of the reconnection site; the one on the right flows parallel to $\mathbf{B}$, indicating that the spacecraft is now tailward of the reconnection site. This means that in this crossing the spacecraft enters the BL sunward of the reconnection site and then the reconnection site moves sunward, so that shortly after the spacecraft is located tailward of it. Similarly in Fig. 4 two distribution functions taken in the MSBL only a few seconds apart are shown: they are the main population (incident magnetosheath ions) and a secondary population (reflected magnetosheath ions): in the left panel the reflected population flows parallel to the convected magnetic field, so that the spacecraft is located sunward of the reconnection site, whereas in the right panel the reflected population appears as a deformation of the contours in the antiparallel direction. In the latter case the spacecraft is tailward of the reconnection site.

Cases similar to the ones depicted in Figs. 3 and 4 are quite frequent in the present event and indicate that the reconnection site moves from sunward to tailward (or viceversa) with respect to the spacecraft on short time scales. This indicates that the reconnection site is close to the spacecraft.

It is clear that for these cases it is not possible to obtain a reliable De Hoffmann-Teller velocity ($\mathbf{V_{HT}}$), as this would require a time stationary discontinuity. There are however a number of crossings for which inspection of the distribution functions shows that indeed the discontinuity is time stationary and for these cases a good $\mathbf{V_{HT}}$ can be obtained. The velocity of the reflected and transmitted ions can then be predicted using $\mathbf{V_{HT}}$ and the local magnetic field geometry, according to the following equations derived by Cowley ([4]):

$$\mathbf{V}_R = (2\mathbf{V}_{HT}\cdot\mathbf{b}_1 - V_{i\|})\mathbf{b}_1 + \mathbf{V}_{HT\perp_1} \quad (1)$$

$$\mathbf{V}_T = (\mathbf{V}_{HT}\cdot(\mathbf{b}_2 - \mathbf{b}_1) + V_{i\|})\mathbf{b}_2 + \mathbf{V}_{HT\perp_2} \quad (2)$$

where $\mathbf{V}_i$, $\mathbf{V}_R$, $\mathbf{V}_T$ are the velocity of the incident, reflected and transmitted ions, $\mathbf{b}$ is the magnetic field unit vector, and labels 1 and 2 refer to the magnetosheath and magnetospheric side, respectively. In Figs. 5 and 6 three cuts of the distribution function along three orthogonal planes and in the $V_\|$, $V_\perp$ plane are shown in the MSBL and in the BL respectively. In Fig. 5 the predicted velocity of the reflected component, as predicted by Eq. 1, is indicated by black dots. The predicted separation between incident and reflected ions is roughly the $V_\|$ axis as in this case $V_{HT\|}$ is 10 km/s. In Fig. 6 the predicted position in velocity space of the transmitted component is indicated (black dots) together with the predicted low energy cutoff of the D-shaped distribution function (horizontal thick line), as derived by Eq. 2. In both cases the agreement between observations and predictions is very good.

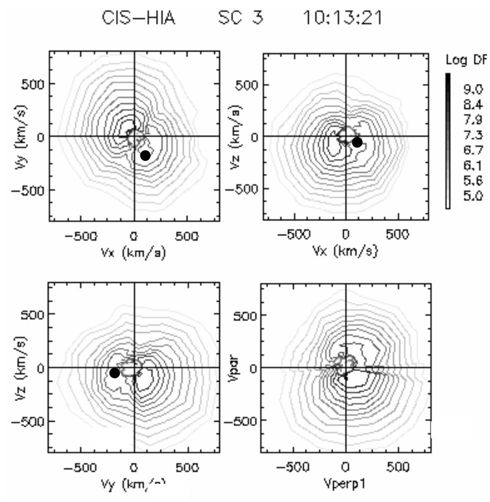

Figure 5. MSBL observations: cuts of the distribution function on three orthogonal planes and in the $V_\|$, $V_\perp$ plane.

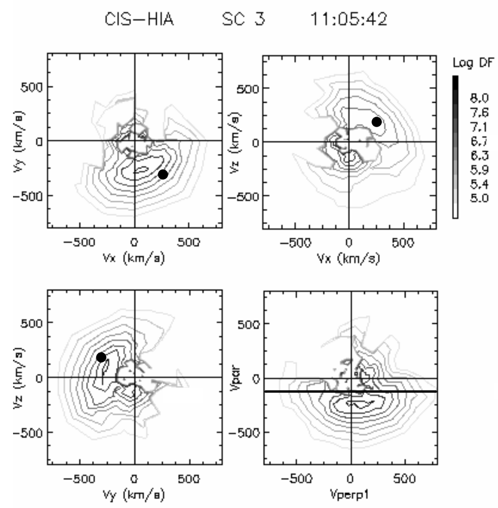

Figure 6. The same as Fig.5, but in the BL.

3. CONCLUSIONS

During a long lasting reconnection event tailward of the cusp CIS detected kinetic signatures of reconnection at almost all MP crossings. The characteristization of the distribution function of the reflected and transmitted magnetosheath ions sunward and tailward of the reconnection site allows to infer that the spacecraft is often close to the reconnection site and that it is sometimes located sunward and sometimes tailward of the reconnection site. The vicinity to the reconnection site is probably the reason of the large number of reflected and transmitted ions, which are not present in all the reconnection events reported in the literature (as suggested in [10]).

When a reliable De Hoffmann Teller velocity could be determined, the characteristic of the secondary populations in the MSBL and in the BL are in very good agreement with predictions by kinematical considerations.

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