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Results from the Cluster Close Separation Campaigns

Key Points:
- First direct evidence of magnetic reconnection in the front of a BBF
- The observation consistent with the generation process of dipolarization front
- Ions and electrons are both accelerated in this process

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In situ observation of magnetic reconnection in the front of bursty bulk flow

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Abstract Using the Cluster observation in the magnetotail, we investigate the dynamic processes associated with a bursty bulk flow (BBF) event. The BBF is inferred to be caused by magnetic reconnection proceeding to the lobe region in its tail, called "primary reconnection." On the BBF front, another reconnection was directly encountered by one of the four Cluster satellites, and no signatures of this reconnection were simultaneously measured by the satellite at the plasma sheet boundary. It indicates that this reconnection on the BBF front remained within the plasma sheet, called "secondary reconnection." The secondary reconnection moved earthward and was followed by a magnetic island. A few earthward moving pulses of B_z were detected between the island and the primary reconnection site. These B_z pulses, propagating faster than the island ahead of it, would lead to a more compressed B_z magnetic field in the wake of the island. The observational scenario is in accordance to the model proposed to explain the generation of dipolarization front in simulations. Furthermore, both electrons and ions were significantly accelerated in this process. The mechanism is discussed also.

1. Introduction

Magnetic reconnection is an important physical process in astrophysical, space, and laboratory plasma, by which magnetic energy is explosively released and converted into plasma energy and magnetic topology is rearranged. Specifically, it plays the key role in energy conversion and magnetic flux as well as mass transport in the Earth's magnetotail. In general, magnetic reconnection is thought to make the major contribution to the creation of the bursty bulk flow (BBF) in the plasma sheet.

The BBF in the plasma sheet is a fast earthward plasma flow with average time duration of approximately 10 min [e.g., *Angelopoulos et al.*, 1994; *Baumjohann et al.*, 1989, 1990]. It is responsible for the major earthward transport of energy and magnetic fluxes in the plasma sheet [*Angelopoulos et al.*, 1996; *Baumjohann et al.*, 1990; *Cao et al.*, 2013]. The BBF is frequently observed between −40 and −10 R_E and bounced at ~−10 R_E due to the Earth's dipolar magnetic field and the Lorentz force [*Baumjohann*, 2002; *Panov et al.*, 2010; *Nakamura et al.*, 2013]. While it is propagating earthward, some kinds of special magnetic structures are frequently detected in the front of and/or within the BBF, e.g., magnetic island/magnetic flux rope/dipolarization front [e.g., *Baumjohann et al.*, 1990; *Nakamura et al.*, 2002; *Slavin et al.*, 2003; *Ohtani et al.*, 2004; *sharma et al.*, 2008]. It means that there should be some dynamic processes associated with BBFs as they propagate earthward. Using multiple-spacecraft observations, the plausible evidence of transient reconnection occurring within a BBF event was presented recently [*Wang et al.*, 2014]. In this paper, we present in situ evidence of magnetic reconnection on the BBF front for the first time. The secondary reconnection site was moving earthward, and the Hall quadrupolar structure developed very well around the site.

2. Observation and Analysis

The data from several instruments onboard Cluster are used in this paper. The magnetic field and ion plasma data are taken from the fluxgate magnetometer (FGM) [*Balogh et al.*, 2001] and the Cluster Ion Spectrometry/Composition and Distribution Function (CIS/CODIF) [*Rème et al.*, 2001] instruments, respectively. The data of electron energy spectrum between 80 eV and 22 keV are taken from the Plasma Electron and Current Experiment (PEACE) [*Johnstone et al.*, 1997] instrument. The data of high-energy electrons and ions

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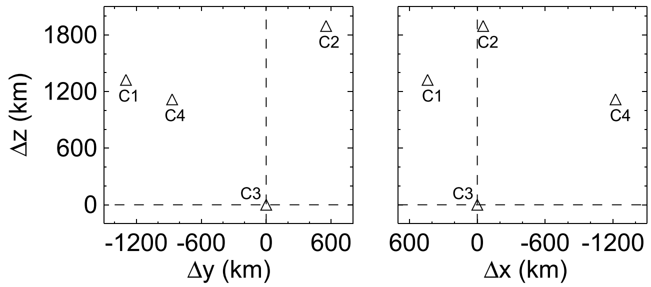

Figure 1. The relative position of the four satellites at 00:22 UT. The left figure is the profile in the $y-z$ plane, while the right figure represents the profile in the $x-z$ plane.

are obtained from the Research with Adaptive Particle Imaging Detectors (RAPID) instrument [*Wilken et al.*, 2001]. The magnetic field data in high resolution (1/22 s) is used. All the other data are sampled at 0.25 s^{-1}. Between 00:20 and 00:28 UT on 15 September 2001, Cluster was located at −19, 3, and 2 R_E in the GSM coordinates. Figure 1 shows the relative positions of the four satellites at ~00:22 UT. The satellite C3 was situated in the southmost, and the distance between C3 and the neighboring C4 in the *z* direction was about 1117 km. Figure 1 shows the Cluster measurements during this interval. It can be seen from Figure 1b that the order of the B_x values at the four satellites is $B_{x,C2} \geq B_{x,C1} \geq B_{x,C4} > B_{x,C3}$ in the most time except a short span from 00:23:50 to 00:24:10 UT when C1 observed the strongest B_x value. This order is the same to the spatial position of the four satellites in the *z* direction. That indicates that the current sheet was primarily lying in the $x-y$ plane of the GSM coordinates in the most time. So the GSM coordinates is used throughout this paper to avoid any uncertainty due to the coordinate transformation.

In Figure 1j, the plasma beta β_i evolved from 0.0001 in the beginning to about 5 at ~00:24 UT and then returned to 0.0001 again in the end. B_x displayed the similar evolution. It gradually decreased from 40 nT to about 0 nT at ~00:24 UT and then returned to 40 nT again (Figure 1b). Therefore, the four satellites passed through the center of the plasma sheet from the northern lobe region and then returned to the lobe region again. The electron energy spectrum (Figure 1a) further confirmed this process. In this interval, there was a background magnetic field in the *y* direction (horizontal dashed line in Figure 1c), i.e., the so-called guide field $B_g \approx -8$ nT (Figure 1c). This guide field was observed for about 1 h prior to this interval and persisted for at least 4 h after this interval (not shown). It means that the guide field was basically stable during the interval. In this event, Cluster was located in the premidnight sector ($y \approx 3$ R_E); the flaring effect should be considered as what *Runov et al.* [2008] have done. However, during our reconnection event, the Polar spacecraft was located at −6.3, 0.4, and 1.8 R_E, where the flaring effect is negligible, and it observed the background guide field also (not shown). Thus, the guide field in our event did not come from the flaring effect. At the same time, the Wind spacecraft was located in the solar wind at ~52 R_E and measured a background magnetic field along the *y* direction as well. The observation implies that the guide field observed by Cluster could come from the solar wind. This event is earlier than the extensively studied reconnection event on the same day [e.g., *Xiao et al.*, 2007].

The fast flow was observed between 00:20:40 and 00:26:20 UT while the spacecraft was approaching the central plasma sheet from the lobe region (Figures 1b–1f). The fast flows exceeding 300 km/s lasted for approximately 5 min, and the maximum value reached 1200 km/s. The proton number density (Figure 1i) within the fast flows changed from 0.01 to 0.4 cm^{-3}, sometimes lower than the normal value in the plasma sheet of 0.3 cm^{-3}, which is derived from a statistical work [*Baumjohann et al.*, 1989]. We interpret the fast flow as the BBF. While the BBF was observed, B_y at the four satellites was positive relative to the guide field except for a short span (00:21:10~00:21:50 UT) when the negative B_y variation was detected at C3 (Figure 1c). This short span will be analyzed in more detail in the next section. The positive B_y was primarily observed in the northern hemisphere of the earthward flow, which is consistent with the Hall magnetic field in the left upper quadrant of the Hall quadrupolar structure. It indicates that Cluster could pass through the left upper quadrant of the ion diffusion region, as the red and green curves in Figure 4a. The occasional low density (≤0.05 cm^{-3} between 00:22 and 00:24 and after 00:26 UT) within the BBF suggests that the reconnection proceeded to the open magnetic field flux of the lobe region in the magnetotail [e.g., *Birn et al.*, 2011]. This reconnection *x* line in the tailward of the BBF is called "primary reconnection" here.

In the leading part of the BBF, the satellite C3 in the southmost crossed the central plasma sheet quickly from 00:20:40 to 00:22:20 UT (Figure 1b), while the other three satellites (C1, C2, and C4) kept staying in the northern hemisphere. During the plasma sheet crossing, C3 measured a clear reversal of high-speed flow

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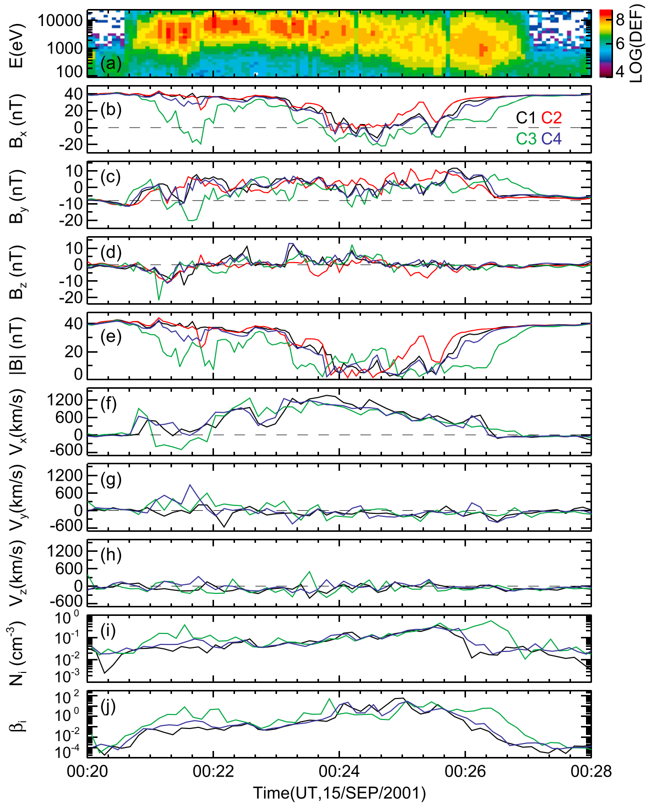

Figure 2. Overview of the BBF. (a) Electron energy time spectrum at C3. (b–e) Three components and magnitude of magnetic field at four satellites. (f–h) Three components of proton bulk flows. (i) Ion number density. (j) Plasma beta, the ratio between plasma pressure and magnetic field pressure. The curves with black, red, green, and blue represent C1–C4, respectively. The horizontal dashed line in Figure 2c represents the guide field.

from earthward to tailward at about 00:21:00 UT (Figure 1f). The high-speed flow reversed from ~800 km/s to ~−500 km/s. In this process, the magnetic field component B_z changed sign at about 00:20:50 UT from positive (2 nT) to negative (−20 nT) as well. The positive B_z was very weak (2 nT) and lasted a short time (3~5 s) before 00:20:50 UT. The negative B_z variation was much stronger than the positive, and this asymmetric B_z variation will be discussed later. According to the observations, it seems that C3 encountered another reconnection site from earthward to tailward. In order to further confirm the flow data during the crossing, the proton distribution function at C3 was examined in detail. The distribution function clearly shows that C3 measured the high-speed earthward flow first and then the tailward flow. The distributions captured at 00:20:56.220 UT in the earthward flow and at 00:21:28.293 UT in the tailward flow are shown in Figure 2b, respectively. Moreover, a clear duskward streaming component was observed at C3 in both earthward and tailward flows. This duskward flow around the reconnection site has been confirmed by the Geotail [e.g., *Nagai et al.*, 2011] and by the Time History of Events and Macroscale Interactions during Substorms observations [e.g., *Zhou et al.*, 2009] and was supposed to be caused by the reconnection electric field [*Nagai et al.*, 2011].

In addition, the B_y variation at C3 exhibited a localized structure during the flow reversal. It was positive while C3 observed the fast earthward flow in the northern hemisphere and became negative while C3 entered into the tailward flow in the northern hemisphere. This evolution of the B_y variation is consistent with the Hall quadrupolar structure during reconnection. Afterward, C3 shortly crossed the central plasma sheet twice at about 00:21:30 and 00:21:52 UT within the tailward flow. However, B_y did not change sign accordingly as expected in the antiparallel reconnection (without a guide field) and always remained negative even if C3 got into the southern hemisphere ($B_x \approx -17$ nT). Figure 3 shows the evolution of B_y as B_x changed at C3 between 00:20 and 00:22 UT. The strongest dawn-dusk magnetic field ($B_y - B_g$) was measured from $B_x \approx -5$ to $B_x \approx -17$ nT. As C3 got into the more south region ($B_x \approx -20$ nT), this field ($B_y - B_g$) sharply decreased to −5 nT. It indicates that the spacecraft approached the transition region of this strong dawn-dusk magnetic field region. Later, C3 returned to the northern hemisphere and observed the positive B_y variation again.

As discussed earlier, there was a guide field during this reconnection. The guide field can distort the Hall quadrupolar structure and results in asymmetric distribution of the Hall magnetic field [e.g., *Hesse*, 2006]. In the case of the tail reconnection with a negative guide field, the upper right quadrant of the Hall magnetic field is expanded into the southern hemisphere, while the lower right quadrant is shrunk and deflected into the more southern hemisphere [*Eastwood et al.*, 2005, 2010; *Wang et al.*, 2012, 2013]. Therefore, the B_y variation was consistent with the Hall quadrupolar magnetic field in the guide field reconnection. The strongest negative B_y was observed in the southern hemisphere (-17 nT $< B_x < -5$ nT) rather than near the neutral sheet; this deflection toward the south could be caused by the guide field and the compression of the

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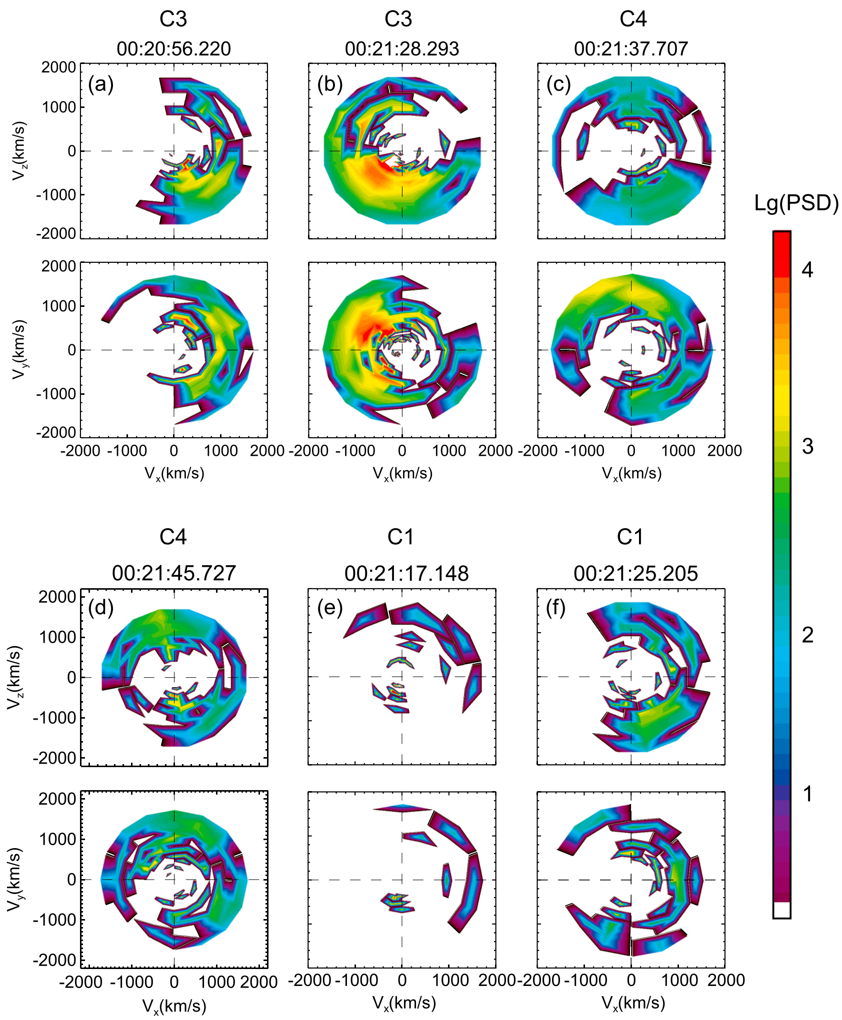

Figure 3. The ion distribution function from the CODIF/CIS of (a and b) C3, (c and d) C4, and (e and f) C1 in the $v_x - v_z$ and $v_x - v_y$ planes was shown.

reconnected magnetic fluxes from the primary reconnection. The trajectory of the C3 traversing the ion diffusion region from earthward to tailward is displayed in Figure 4b (green curve). In the guide field reconnection, the guide field can distort the ion flow in the reconnection plane ($x - z$ plane) but makes little effect on the magnetic field in that plane [*Hesse*, 2006]. Thus, this distortion will lead to the detected time delay between the reversals of B_z and V_x while the satellite passes through the ion diffusion region away from the neutral sheet, as verified by *Wang et al.* [2012]. The time delay between the reversals of B_z (at about 00:20:50 UT) and V_x (at ~00:21:00 UT) was indeed observed in this event.

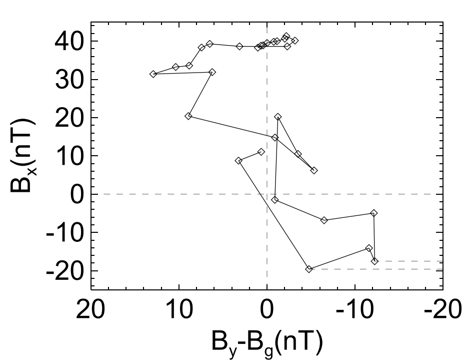

Figure 4. B_x versus $B_y - B_g$ at C3 during 00:20–00:22 UT.

As the tailward high-speed flow was observed at C3 from 00:21 to 00:22 UT, the moment data show that the earthward high-speed flows at C1 and C4 dropped to a low level, even close to zero from 0021:20 to 0021:50 UT (Figure 1f). In order to confirm whether the high-speed flow disappeared then, we examined the proton distribution function at C1 and C4. During this interval, the plasma beta and number density at C1 were ~0.03 and 0.02 cm^{-3}, respectively. The electron energy spectrum at C1 was shown in Figure 5f, and the thermal

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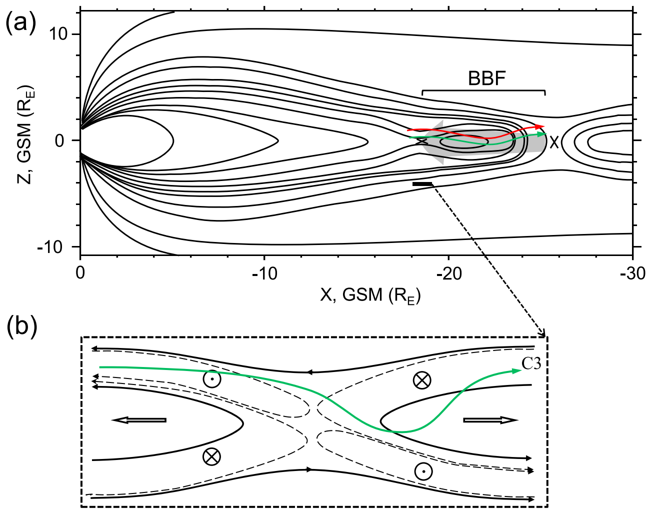

Figure 5. (a) Illustration of the magnetotail. The shadow arrow means the BBF, and the two crosses denote the reconnection *x* lines. The green arrow corresponds to the trajectory of C3, while the red means the trajectories of the other three satellites. (b) Illustration of reconnection ion diffusion region with a guide field.

energy was about 1~2 keV. Therefore, C1 was at the plasma sheet boundary, close to the side of the lobe region. The ion distribution function at C1 shows that there was a persistent earthward flow between 00:21 and 00:22 UT. Two plots at the selected times when $v_x \approx 0$ km/s were presented in Figure 2f. There was no continuous duskward flow at C1. In addition, there were counterstreaming flows in the *z* direction at C1 between 0021:25 and 0021:57 UT, and one selected plot is shown in Figure 2f.

At C4, the plasma beta (Figure 1j) and number density (Figure 1i) were ~0.1 and ~0.05 cm^{-3}, respectively, as the v_x drop. The electron energy spectrum at C4 (Figure 5f) exhibited that the thermal energy was about 4~5 keV. It indicates that C4 was located in the plasma sheet, close to the side of the plasma sheet boundary. There was a continuous duskward flow at C4, as at C3. The ion distribution function shows that the earthward flows at C4 were close to zero during 00:21:21–00:21:45 UT. Simultaneously, counterstreaming flows in the *z* direction with a rather high $\pm v_z$ (up to 1000 km/s) were observed, as shown in Figure 2d. Based on the ion distributions at C1 and C4, this type of counterstreaming flows in the *z* direction was mainly detected in the tailward outflow region of the secondary reconnection. The similar counterstreaming flows in the *z* direction were observed also at C3 when it entered into the same region. This type of counterstreaming flows could be caused by the mixture of the BBF earthward flows and the tailward outflow of the secondary reconnection.

Due to the secondary reconnection on the BBF front, the magnetic field lines below and above this *x* line would be bent toward the middle plane. Then, the BBF was deflected to the middle plane in the tailward flow region of the secondary reconnection from the straight propagation in the *x* direction. So the propagation direction of the BBF was changed from the *x* direction to the *z* direction in that region. This caused the v_x drop at C1 and C4 between 00:21 and 00:22 UT. On the other hand, the tailward outflow of the secondary reconnection would diverge due to the compression of the continuous accumulation of the reconnected fluxes from the primary reconnection. As a result, the counterstreaming flows in the *z* direction were detected in the tailward outflow region of the secondary reconnection.

Based on the analysis above, the high-speed earthward flow was continuously detected at C1. The continuous earthward bulk flow indicates that the primary reconnection was uninterruptedly occurring in the tailward of the spacecraft between 00:20:40 and 00:26:20 UT. The satellite C1 near the lobe region continuously observed this earthward flow, which indicates that this primary reconnection proceeded to the lobe region. In contrast, the ion diffusion region of the reconnection on the BBF front was only encountered directly by C3. At C4, although the Hall magnetic field was not observed, the duskward flow that resulted from the reconnection electric field was clear. It means that C4 passed the vicinity of the reconnection site, while C1, situated near the lobe region, measured neither Hall magnetic field nor associated duskward flow. In other words, this reconnection in the front of the BBF remained in the plasma sheet, called secondary reconnection. To our knowledge, in situ evidence of magnetic reconnection in the front of the BBF has never been reported before.

Since the secondary reconnection was localized within the plasma sheet, the reconnected magnetic flux earthward of this *x* line would be detected only in the plasma sheet. It can be used to explain why no strong positive B_z was observed in the beginning of the earthward flow (before 00:20:50 UT) when Cluster was still in the lobe region. In the tailward flow of the secondary reconnection, B_x at C3 changed sign twice; i.e., C3 was

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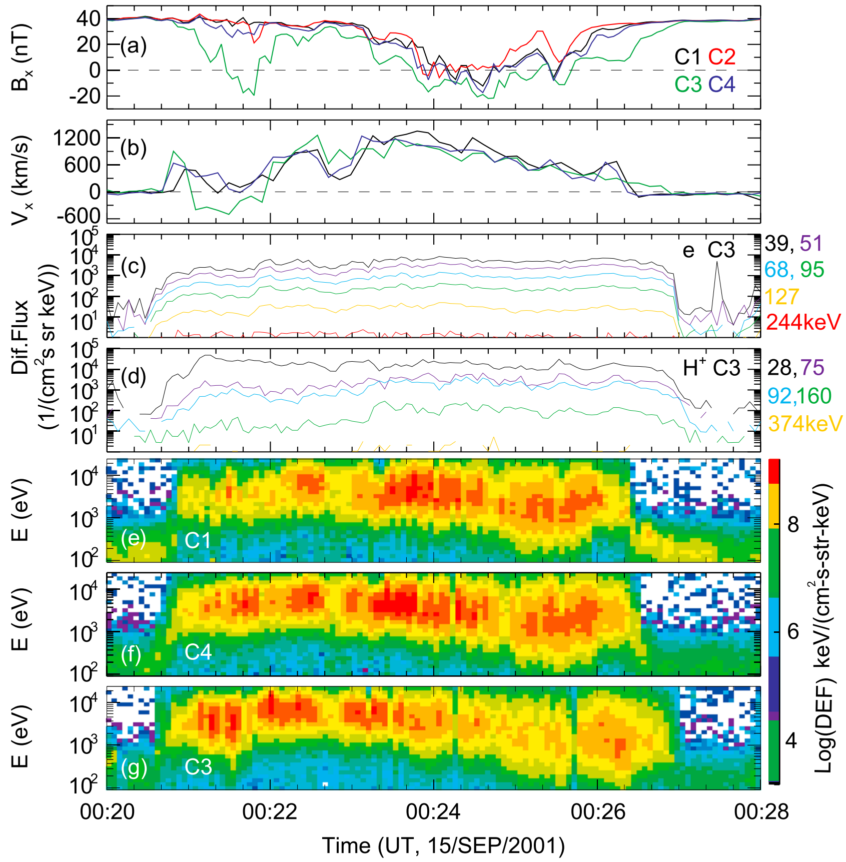

Figure 6. Energetic ion and electron data during the BBF. (a) B_x, (b) v_x, and (c and d) differential fluxes of electron and proton, respectively. The color denotes the energy level. (e–g) Electron energy spectra observed by C1, C4, and C3, respectively.

situated around the central plasma sheet. Then, the strong B_z was detected. As a result, the asymmetric B_z between the earthward and tailward flows was observed during the secondary reconnection.

Figure 5 shows *x* components of magnetic field and high-speed flows at the four satellites (no-flow data from C2), and differential electron (≥39 keV) and proton (≥27 keV) fluxes at C3, and electron energy spectra at C1, C4, and C3 from top to bottom. The time interval is the same to Figure 1. Both electron and ion fluxes significantly enhanced within the fast flows (Figures 5c and 5d). These enhancements should be related to the magnetic reconnection. Before this BBF event, the spacecraft passed through the central plasma sheet also at about 23:50 UT on 14 September 2001, when the magnetotail was quiet (not shown). Figure 6 shows the phase space density (PSD) for the electrons (≥39 keV) and protons (≥27 keV) observed within the central plasma sheet during the BBF (at about 00:24 UT on 15 September) and during the quiet magnetotail (at about 23:50 UT on 14 September), respectively. The PSD is obtained from the differential particle flux by the equation PSD $(\varepsilon) = \frac{m_e^2}{2\varepsilon}\text{diff. flux}(\varepsilon)$ (m_e: electron mass and ε: energy level) [e.g., *Retinò et al.*, 2008]. It is obvious that the fluxes of energetic electrons and protons within the BBF are much higher than those in the quiet tail. Therefore, the significant enhancements of electron and proton fluxes indicate that both electrons and ions were accelerated during magnetic reconnection.

3. Discussion

By using multipoint simultaneous observations in the near-Earth tail, we provide the direct evidence of one reconnection event on the BBF front. The fast flow of the BBF was continuously measured for about 5 min, and the density within it occasionally (≤0.05 cm^{-3} between 00:22 and 00:24 and after 00:26 UT) decreased to the lobe level. It indicates that magnetic reconnection resulting in the observed BBF (referred to as primary

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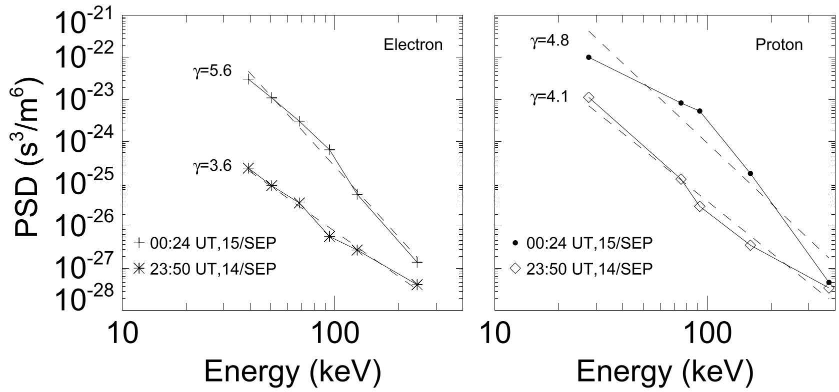

Figure 7. Electron and ion phase space density versus energy at 00:24 UT on 15 September and at 23:50 UT on 14 September. The dashed line represents the power law distribution with an index γ.

reconnection) proceeded to the lobe region. Reconnection observed on the BBF's front ("secondary reconnection"), however, was localized in the plasma sheet. Immediately after the secondary reconnection *x* line, a clear bipolar B_z variation from negative to positive was observed between 00:21:00 and 00:22:40 UT (Figure 1d). Although a stable guide field existed in this event, no clear core field was measured inside the magnetic loop structure. Furthermore, the B_z reversal lasted at least 100 s, longer than the typical duration of magnetic flux rope of about 30 s [*Slavin et al.*, 2003].

The scenario of this observation bears a close analogy to the model proposed by *Schindler* [1974]. In the model, one *x* line will have the highest reconnection rate and thereby first reconnect open magnetic field lines in the lobe region. This primary *x* line will produce the fast flows in the earthward and tailward directions. The magnetic island/magnetic flux rope will be naturally created between any two *x* lines (primary-secondary *x* lines or secondary-secondary *x* lines) and embedded in the fast earthward/tailward flows [e.g., *Slavin et al.*, 2003; *Deng et al.*, 2004; *Zhong et al.*, 2013]. Using the Cluster observations in the magnetotail, *Eastwood et al.* [2005] reported one earthward moving flux rope flanked by converging bidirectional plasma jets toward the center of the flux rope. The similar event has been observed also at the magnetopause [*Hasegawa et al.*, 2010]. In their events, however, no difference between the two *x* lines bounding the observed flux rope is deduced. In our event, the magnetic reconnection in the trailing of the BBF has proceeded into the lobe region while the reconnection on the BBF front remains within the plasma sheet.

After the magnetic island, at least two positive B_z pulses were observed at about 00:23:10 and 00:24:10 UT (Figure 1d and Figure 7). The amplitudes of the pulses were about 10 nT. The two satellites C1 and C4 were very close in *z* and *y* directions (~300 km) while were widely separated in *x* direction (~1660 km), as shown in Figure 1. Thus, the time delay between these two satellites mainly reflects the propagation of the observed structure in *x* direction. The satellite C4, farther away from Earth, encountered the pulses first. It indicates that the observed B_z pulses were propagating earthward. By the timing method, the propagating velocity of the B_z pulses can be estimated. The result shows that the first one at ~00:23:13 UT had a velocity of about 800 km/s and the second at ~00:24:09 UT had a velocity of about 1000 km/s in the *x* direction. In the same way, we can estimate the velocity of the magnetic island. The negative B_z peak of the island was observed by C4 at ~00:21:17 UT and then measured by C1 at ~00:21:31 UT. The positive B_z peak was detected by C4 at ~00:24:09 UT and observed by C1 at ~00:24:11 UT. Therefore, the average velocity of the island was about 220 km/s. These B_z pulses were moving faster than the island ahead of them. Consequently, the pulses would result in the formation of a more compressed magnetic field region in the wake of the island. This process is similar to the formation of the dipolarization front as suggested by simulations [*Divin et al.*, 2007; *Sitnov et al.*, 2009].

The dipolarization front (DF) or the nighside flux transfer event has been extensively observed in the near-Earth tail and is generally embedded within the earthward fast flows. It is characterized by a sharp increase of magnetic field B_z preceded by a smaller negative B_z variation [*Nakamura et al.*, 2002; *Ohtani et al.*, 2004; *Sormakov and Sergeev*, 2008; *Sharma et al.*, 2008; *Runov et al.*, 2009, 2011; *Schmid et al.*, 2011]. In other

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words, a profound asymmetry between its northern magnetic field ($B_z > 0$) and southern magnetic field ($B_z < 0$) perturbations is observed in most of the DF events. Numerical simulations suggest that spontaneous and transient reconnection, called secondary reconnection, can happen in the outflow region of the magnetotail-like configuration produced by the initial primary reconnection [*Divin et al*., 2007; *Sitnov et al*., 2009]. The primary reconnection will create a strong pileup region of B_z in the outflow region. The occurrence of secondary reconnection in the outflow region will result in an island ahead of the pileup region, which eventually leads to the generation of the DF [*Sitnov et al*., 2009]. However, the secondary/transient reconnection in the reconnection outflow region has never been observed so far. By multiple-point observations, *Wang et al*. [2014] speculated that the transient reconnection should endure only several seconds, and no clear Hall quadrupolar structure is generated around it. In this paper, the direct evidence of secondary reconnection pushed by a few B_z pulses within the BBF has been shown for the first time. The secondary reconnection continued for at least 1 min, and the Hall quadrupolar structure developed very well. The observation is consistent with the formation process of the DF, as predicted by simulations [*Sitnov et al*., 2009]. In our event, the B_z pulses were only measured in the earthward outflow of the primary reconnection site. In the earthward outflow of the secondary reconnection, no such pulses were observed. The reason is still unclear.

The increase of energetic electron flux suggests that electrons were accelerated in the process. The electron acceleration mechanisms in reconnection [*Hoshino et al*., 2001; *Øieroset et al*., 2002; *Fu et al*., 2006; *Huang et al*., 2010; *Birn et al*., 2012, and references therein] and in the DF [e.g., *Ashour-Abdalla et al*., 2011; *Birn et al*., 2012; *Wu et al*., 2013, and references therein] have been extensively studied. The significant enhancement of ion fluxes was detected also in this event. The spacecraft observation has showed that ions cannot be directly accelerated to high energy by magnetic reconnection itself [*Øieroset et al*., 2002]. Thus, the ion acceleration in this event could be related to other processes, e.g., reflection from the DF [*Zhou et al*., 2010; *Wu and Shay*, 2012] and/or resonance interaction with the DF [*Artemyev et al*., 2012]. Ions can obtain energy of a few keV due to the reflection from the DF. In contrast, the resonance interaction of ions with the DF can accelerate ions to 100–200 keV. These two mechanisms, however, can only accelerate ions in the localized region. In our event, the energetic ions can be observed in the whole plasma sheet. Another candidate for ion acceleration is the contracting magnetic island. The ions can get kinetic energy by reflecting from the two ends of the contracting island, similar to the mechanism used to explain the production of energetic electrons [*Drake et al*., 2006] and then are trapped within the island.

4. Summary

In conclusion, the direct evidence of magnetic reconnection occurring on the BBF front is presented. This reconnection site propagated earthward and naturally led to the generation of a magnetic island between the primary reconnection site and itself. The magnetic island expelled earthward by a few B_z pulses which moved earthward faster than the island. This observation is in accordance to the prediction of recent simulations where transient reconnection can happen in the outflow of primary reconnection and leads to the generation of dipolarization front. Ions and electrons were both accelerated in this process.

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