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Key Points:

- MMS provides direct observational evidence of a high-speed jet driving magnetic reconnection within the magnetosheath
- The jet interacted with the sunward ambient flow, strongly compressing the local plasma to form an intense, reconnecting current sheet
- HSJ-driven plasma compression overcomes theoretical suppression conditions, facilitating the occurrence of reconnection

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Magnetic Reconnection Driven by the Impact of a Magnetosheath High-Speed Jet

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Abstract High-speed jets (HSJs) are transient structures in the magnetosheath characterized by enhanced dynamic pressure. While recent studies report that HSJs trigger magnetic reconnection at the magnetopause, whether they can directly drive reconnection within the magnetosheath remains an open question. Using Magnetospheric Multiscale (MMS) observations, we provide direct evidence of an HSJ driving magnetic reconnection within the magnetosheath. We show that as an earthward-moving HSJ interacted with sunward ambient flows, it strongly compressed the local plasma, thereby forming an intense current sheet with a guide field. Within this current sheet, MMS detected clear reconnection signatures, including Hall electromagnetic fields, super-Alfvénic electron jets, and electron demagnetization near the electron diffusion region. Evaluating diamagnetic drift criteria reveals that this compression overcame theoretical suppression conditions, facilitating the occurrence of reconnection. These results establish HSJs as key drivers of magnetic reconnection in the turbulent magnetosheath.

Plain Language Summary The magnetosheath, located between the bow shock and the magnetopause, is formed primarily by decelerated and deflected solar wind. Within this highly turbulent region, transient structures known as magnetosheath high-speed jets (HSJs) are frequently observed. While recent studies suggest that HSJs can trigger magnetic reconnection at the magnetopause, whether they can directly drive this process within the highly turbulent ambient magnetosheath remains elusive. Using Magnetospheric Multiscale (MMS) observations, we present direct evidence of magnetic reconnection in the magnetosheath driven by an HSJ. We show that as an earthward-moving HSJ interacted with sunward ambient flows, it strongly compressed the local plasma, thereby forming an intense current sheet with a guide field. Ultimately, these results establish HSJs as key drivers of magnetic reconnection, advancing our understanding of energy transfer in Earth's dynamic space environment.

1. Introduction

The Earth's magnetosheath, bounded by the bow shock and the magnetopause, serves as a natural laboratory for studying complex plasma dynamics and hosts a rich variety of transient structures (Lucek et al., 2005; Treumann & Baumjohann, 2001; Zhang et al., 2022). Among these, magnetosheath high-speed jets (HSJs) are particularly prominent (Plaschke et al., 2018). HSJs are characterized by significantly enhanced plasma dynamic pressure, with peak values reaching up to 15 times the ambient magnetosheath background, or 4 times the upstream solar wind dynamic pressure (Archer & Horbury, 2013; Plaschke et al., 2013). They occur with recurrence intervals of several minutes and exhibit spatial scales ranging from ~ 0.1 to several R_E (Guo et al., 2022; Plaschke et al., 2020). Because HSJs are predominantly observed downstream of the quasi-parallel bow shock, their generation is thought to be closely linked to dynamical processes within the foreshock and the quasi-parallel shock (Plaschke et al., 2013; Vuorinen et al., 2019). Proposed generation mechanisms include bow shock surface rippling, interactions between shock front and upstream compressive structures or magnetic directional discontinuities, as well as shock reformation (Archer et al., 2012; Hao et al., 2016; Hietala et al., 2009; Karlsson et al., 2015; Raptis et al., 2022; Ren et al., 2023; Suni et al., 2021).

HSJs can propagate across the magnetosheath and impact the magnetopause, potentially triggering various magnetospheric and ionospheric responses (Krämer et al., 2024). To reach the magnetopause boundary layer, HSJs must penetrate the relatively slow-moving ambient magnetosheath. During this penetration, the transverse velocity of HSJs tends to align with the background magnetosheath flow at an early stage (Plaschke et al., 2017;

Y Wang et al., 2026). Upon striking the magnetopause, HSJs induce localized perturbations and deformations (Amata et al., 2011; Hietala et al., 2012; Němeček et al., 2023; Shue et al., 2009; X Wang et al., 2023). This magnetopause response can be characterized by an “Indentation-Rebound-Relaxation” sequence, during which a pair of field-aligned currents may be generated due to compression and subsequent rebound processes (Ma et al., 2024). Furthermore, three-dimensional global hybrid simulations suggest that these jets may surround low pressure cavities, forming a honeycomb-like structure within the magnetosheath (Fatemi et al., 2024; Ren et al., 2024). In addition, HSJs can enhance magnetic field fluctuations (Karlsson et al., 2018), excite ultralow-frequency waves (Archer et al., 2019; B Wang et al., 2022), promote particle acceleration (Liu et al., 2019), and are even associated with auroral brightening (Qiu et al., 2024; B Wang et al., 2018). They may also modulate plasma waves in the magnetosphere, leading to the prompt disappearance of chorus waves (Zhou et al., 2024).

In addition to transient structures like HSJs, the magnetosheath is a highly turbulent region that frequently hosts intense current sheets (Karimabadi et al., 2014; Lu et al., 2020; Vörös et al., 2016). Previous studies have established that magnetosheath current sheets originate from upstream discontinuities or foreshock waves (Lu et al., 2024; Phan et al., 2007; Wang et al., 2024). As these upstream structures are convected toward the shock by the solar wind, they are compressed and transformed through the shock, ultimately forming current sheets within the magnetosheath. Magnetic reconnection can occur within these turbulent current sheets (Phan et al., 2018; Retinò et al., 2007; Stawarz et al., 2019; Vörös et al., 2017; Wang et al., 2019, 2021b; Yordanova et al., 2016). Furthermore, simulations and observations have indicated an association between current sheets and magnetosheath HSJs (Eriksson et al., 2016; Ouyang et al., 2026; Plaschke et al., 2017; Wang et al., 2024). Despite this close association within the magnetosheath, previous studies regarding HSJ-driven magnetic reconnection have primarily focused on their interaction with the magnetopause. It has been suggested that HSJs can trigger bursty dayside magnetic reconnection upon interacting with the magnetopause (Guo, Lu, Lu, Wang et al., 2026; Guo, Lu, Lu, Zhou et al., 2026; Hietala et al., 2018; Nykyri et al., 2019; Vuorinen et al., 2021). For instance, Hietala et al. (2018) provided clear observational evidence that HSJ impacts can locally thin the magnetopause current sheet, thereby facilitating the occurrence of reconnection. By producing localized compressions and strongly interacting with the surrounding plasma, the enhanced dynamic pressure of HSJs potentially contributes to the development of magnetic reconnection. However, while their role in magnetopause reconnection is increasingly recognized, whether HSJs can directly trigger magnetic reconnection within the magnetosheath remains an open question. Using high-resolution observations from the Magnetospheric Multiscale (MMS) mission (Burch, Moore, et al., 2016), the present study addresses this gap by reporting a direct observation of HSJ-induced magnetic reconnection within the magnetosheath.

2. Instrument and Data

In this study, we utilize high-resolution magnetic field, electric field, and plasma measurements from the Magnetospheric Multiscale (MMS) mission (Burch, Moore, et al., 2016). The DC magnetic field vectors are provided by the Fluxgate Magnetometer (FGM) at a sampling rate of 128 Hz (Russell et al., 2016). Electric field data are obtained from the Electric Field Double Probe (EDP) instrument with a time resolution of 8 kHz (Ergun et al., 2016; Lindqvist et al., 2016). Plasma data are provided by the Fast Plasma Investigation (FPI) suite, which delivers ion and electron measurements with high time resolutions of 150 and 30 ms, respectively (Pollock et al., 2016). During the event interval, the measurements from the four MMS spacecraft were nearly identical due to their small orbital separation. Therefore, data from MMS1 are primarily presented in this paper unless otherwise stated.

3. Observation and Analysis

3.1. Overview of the Event

During 11:18–11:24 UT on 26 December 2016, the MMS spacecraft was located at (11.6, 1.99, 0.97) R_E in Geocentric Solar Magnetospheric (GSM) coordinates. The presence of high-energy ions and the stable magnetic field indicates that MMS was initially located in the magnetosphere. A magnetopause crossing was observed at 11:20 UT, characterized by a transition of B_z from positive to negative and an abrupt increase in plasma density. Subsequently, MMS entered the magnetosheath, which was identified by the perturbed magnetic field and ion energies of approximately 1 keV (Figures 1a–1c). Immediately thereafter, MMS detected enhanced earthward flows ($|V_{ix}| > 100$ km/s), accompanied by elevated dynamic pressures (Figures 1d and 1e). The interval

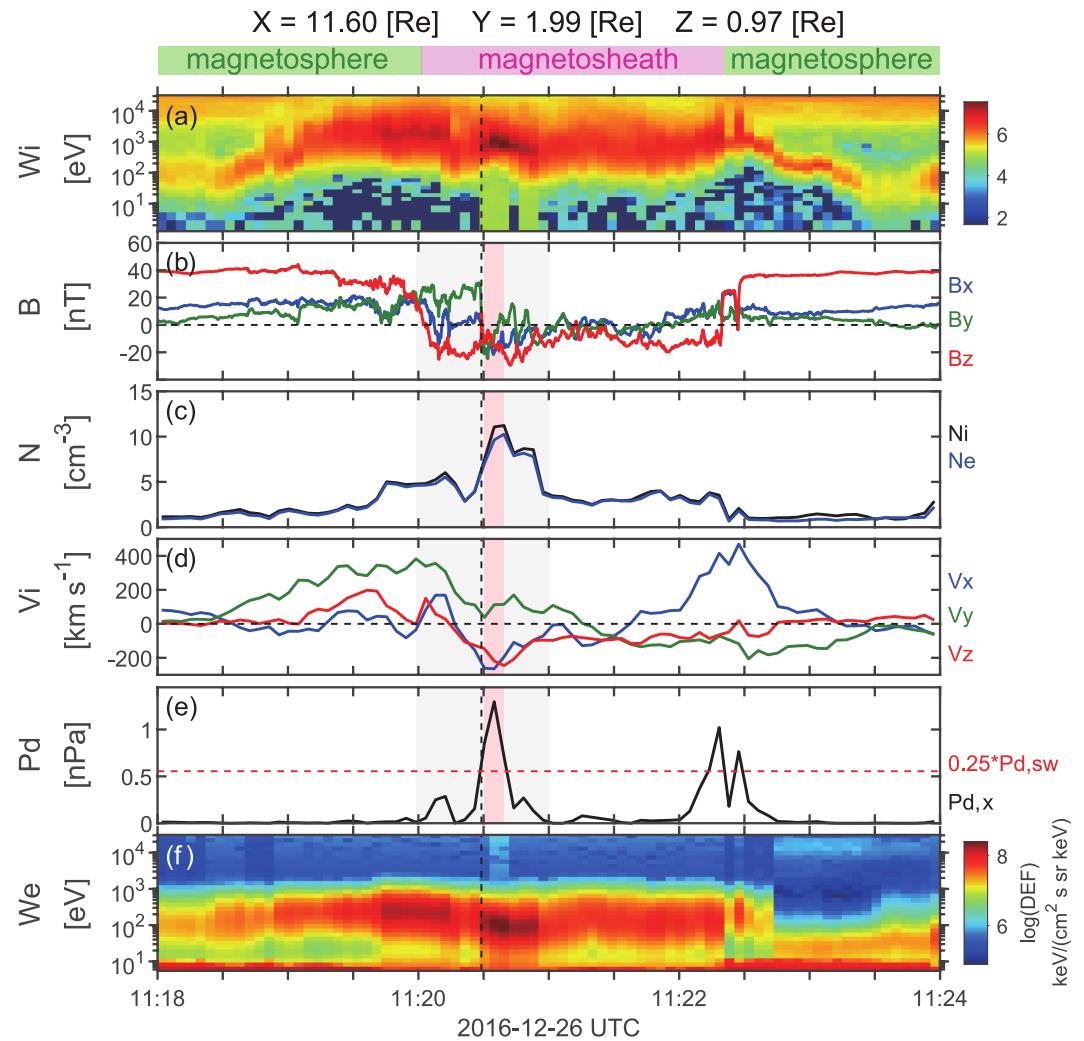


Figure 1. MMS1 observations of the event on 26 December 2016, in GSM coordinates. Panels (a)–(f) show the ion spectrogram, magnetic field, plasma density, ion velocity, earthward dynamic pressure, and electron spectrogram, respectively. In panel (c), black and blue lines denote the ion and electron density. In panel (e), the red dashed line represents the solar wind dynamic pressure ($P_{d,sw}/4$). The high-speed jet interval is marked by the red-shaded area, while the vertical black dashed line indicates the center of the current sheet. The top green- and pink-shaded regions correspond to the magnetosphere and magnetosheath periods, respectively.

highlighted in red is identified as a magnetosheath high-speed jet (HSJ) based on established criteria (Plaschke et al., 2013), specifically the dynamic pressure exceeding 0.25 times the upstream solar wind dynamic pressure (red line in Figure 1e). The upstream solar wind data were obtained from the 1-min OMNI data set, which provides parameters time-shifted to the Earth's bow shock nose.

For the first magnetopause crossing at ~11:20 UT, a four-spacecraft timing analysis (Schwartz, 1998) of high-resolution magnetic field data yielded a magnetopause velocity of -270 km/s along the normal direction $(0.66, -0.74, -0.11)$, indicating an inward motion of the boundary driven by the HSJ impact. A minimum variance analysis (MVA, (Sonnerup, 1998)) applied to the same data yielded a normal direction of $(0.64, -0.71, -0.29)$. The small angular difference (10.26°) between the timing and MVA normals confirms the reliability of these boundary estimates. At 11:22:20 UT, MMS re-entered the magnetosphere, observing a distinct sunward flow. Similarly, the timing method was applied to this magnetopause crossing, giving a magnetopause velocity of 284 km/s along the normal $(0.42, -0.87, -0.26)$, indicating an outward rebound motion of the boundary. Overall, these findings demonstrate that the HSJ drives magnetopause motion in two successive stages: first an earthward indentation, followed by an outward rebound, which is in agreement with earlier studies (Ma et al., 2024; Shue

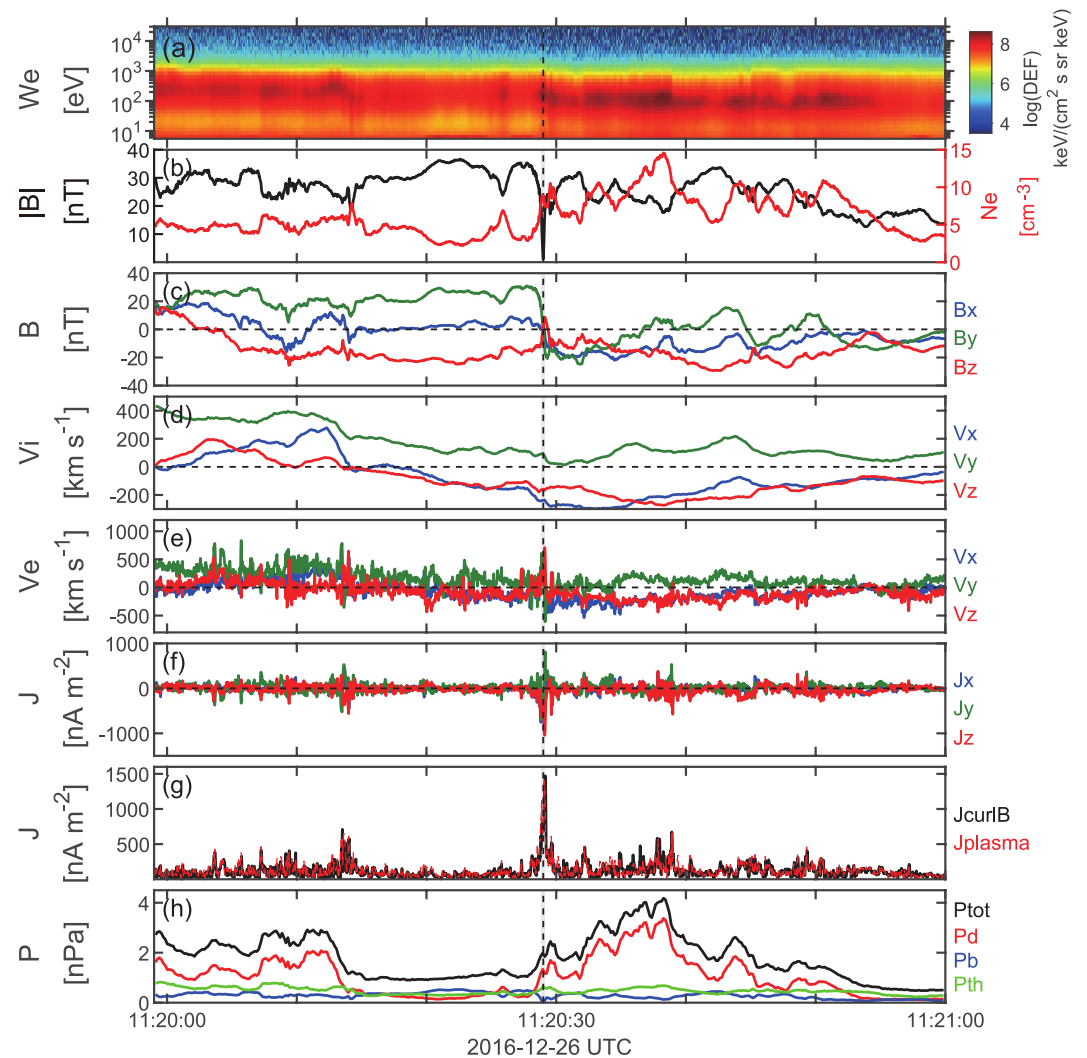


Figure 2. Overview of the current sheet from 11:19:59 to 11:21:00 UT on 26 December 2016, in GSM coordinates. The panels display: (a) electron spectrogram; (b) magnetic field magnitude (black) and electron density (red); (c) magnetic field vector; (d) ion velocity; (e) electron velocity; (f) plasma current density calculated as $J = N_e q(V_i - V_e)$; (g) plasma current density magnitude (red dashed line) compared with the current density derived independently via the tetrahedron curlometer technique (black); and (h) total (black), dynamic (red), magnetic (blue), and thermal (green) pressures. The vertical black dashed line indicates the center of the current sheet.

et al., 2009). Ahead of the HSJ leading edge, MMS observed a sharp variation in the y-component of the magnetic field (11:20:29 UT, marked by the black dashed vertical line in Figure 1), indicating the presence of a current sheet.

Figure 2 presents the MMS burst-mode observations surrounding this current sheet from 11:19:59 to 11:21:00 UT. Around 11:20:29 UT, the magnetic field magnitude exhibited a sharp depression, decreasing to about 1.1 nT (Figure 2b). At the same time, both B_x and B_y reversed sign, indicating a crossing of the current sheet. Correspondingly, a strong enhancement of current density is observed, with a peak current density of approximately 1,400 nA/m² (Figures 2f and 2g). This enhancement is consistently captured by the plasma current density J_{plasma} ($J_{\text{plasma}} = N_e q(V_i - V_e)$ where N_e is the electron number density, q is the elementary coulomb charge, and V_i and V_e are the ion and electron bulk flow velocities, respectively) and current density J_{curlB} derived independently using the tetrahedron curlometer technique (Dunlop & Eastwood, 2008). The ion bulk flow velocity (V_i) shows a large-scale variation across the interval but exhibits no significant localized response near the current sheet

(Figure 2d). In contrast, the electron velocity (V_e) displays a pronounced enhancement at the center of the current sheet (Figure 2e), indicating that the current is mainly carried by electrons.

The total (P_{tot}), dynamic (P_d), magnetic (P_b), and thermal (P_{th}) pressures are shown in Figure 2h. The total pressure (black trace in Figure 2h) was roughly balanced just ahead of the current sheet (11:20:15–11:20:28 UT), while it increased after the current sheet crossing (11:20:30–11:20:50 UT), mainly due to the enhancement of dynamic pressure, indicating that the current sheet was compressed by the HSJ. In summary, a compressed and intensified current sheet is formed at the leading edge of the HSJ as a result of HSJ-driven plasma compression. In the following analysis, we focus on this current sheet and present evidence demonstrating that magnetic reconnection is ongoing within this region.

3.2. Close View of the Reconnecting Current Sheet

Figure 3 presents a closer view of this reconnecting current sheet in the local current coordinate system (LMN). The transformation matrix was established using MVA on the magnetic field data between 11:20:24 and 11:20:34 UT. The reliability of the MVA is confirmed by the robust eigenvalue ratios, $r_{12} = \lambda_1/\lambda_2 \sim 27$ and $r_{23} = \lambda_2/\lambda_3 \sim 11$, where λ_1 , λ_2 , and λ_3 correspond to the maximum (L), intermediate (M), and minimum (N) variance directions, respectively. The resulting average eigenvectors in GSM coordinates are $L = (-0.4204, -0.9006, 0.1107)$, $M = (0.4681, -0.1107, 0.8767)$, and $N = (-0.7773, 0.4204, 0.4681)$. The MVA normal (N) is highly consistent with the normal direction obtained from the four-spacecraft timing method ($N_{\text{timing}} = (-0.79, 0.42, 0.44)$), showing a small angular deviation of only 1.76° . Using the timing method, the propagation velocity of the current sheet was calculated to be 142 km/s along the $+N$ direction. Given the sheet crossing duration of approximately 0.53 s (11:20:28.69–11:20:29.22 UT; Figure 3e), the current sheet thickness is estimated as 75.26 km. This scale is equivalent to $\sim 33.9 d_e$, where the electron inertial length $d_e = 2.22$ km, calculated based on the local electron number density $N_e = 5.72 \text{ cm}^{-3}$.

Figure 3b displays the three components of the magnetic field in the LMN coordinate system. The crossing of the current sheet is unambiguously identified by the reversal of the reconnecting magnetic field component, B_L . Specifically, B_L reversed from negative (~ -30 nT) to positive ($\sim +25$ nT), corresponding to a negative current density spike in J_M that peaked at $-1,340 \text{ nA/m}^2$ (Figure 3e). At 11:20:29 UT, precisely when $B_L = 0$, the normal magnetic component (B_N) maintained a small but positive value of ~ 0.27 nT. This positive B_N suggests that the spacecraft crossed the reconnecting current sheet on the $+L$ side of the X-line. Furthermore, the out-of-plane magnetic field (B_M) increased from a background value of approximately -15 – 8 nT, before returning to -15 nT. This pulse-like signature is highly consistent with the Hall magnetic field structure expected for a reconnecting current sheet in the presence of a guide field, in agreement with both observations and simulations (Huba, 2004; Li et al., 2023, 2025; Pritchett & Coroniti, 2004; Ricci et al., 2004). Similarly, the normal electric field (E_N , Figure 3f) displayed a bipolar variation from negative to positive. Crucially, E_N consistently pointed toward the center of the current sheet from both sides, perfectly matching the expected characteristics of the ambipolar Hall electric field. Finally, the plasma density ratio between the trailing and leading edges of the current sheet ($N_{\text{trailing}}/N_{\text{leading}} \sim 2$) indicates that this magnetic reconnection process occurred under asymmetric conditions. Such density asymmetry across the current sheet can also affect the observed Hall magnetic field, making one polarity of the Hall magnetic field much weaker and therefore difficult to observe (Shay et al., 2016).

The ion bulk flow (Figure 3c) remained relatively constant throughout the current sheet crossing. While the L -component of the ion velocity ($V_{i,L}$) differed between the two sides of the current sheet, this variation originated from a larger-scale background variation (Figure 2d). Different from ions, the electron velocity ($V_{e,L}$) exhibited two reversed jets at approximately 11:20:28.89 and 11:20:29.15 UT (Figure 3d). The magnitudes of these oppositely directed electron jets were nearly equal, reaching $|8V_{e,L}| \sim 1,200$ km/s. This velocity significantly exceeds the local ion Alfvén speed ($V_a = 258.1$ km/s, calculated using a background magnetic field $B_0 = 28.54$ nT, and an ion density $N_i = 5.81 \text{ cm}^{-3}$). These two reversed electron jets correspond to the electron inflow (negative jet) and outflow (positive jet) regions of the reconnecting current sheet (illustrated in Figure 4). Furthermore, these electron flows are expected to generate an enhancement of the Hall magnetic field in the positive B_M , consistent with the magnetic field observation. Synthesizing the observations of the magnetic field, electric field, and electron bulk flows, we conclusively identify a reconnecting current sheet located at the leading edge of the HSJ, as schematically summarized in Figure 4.

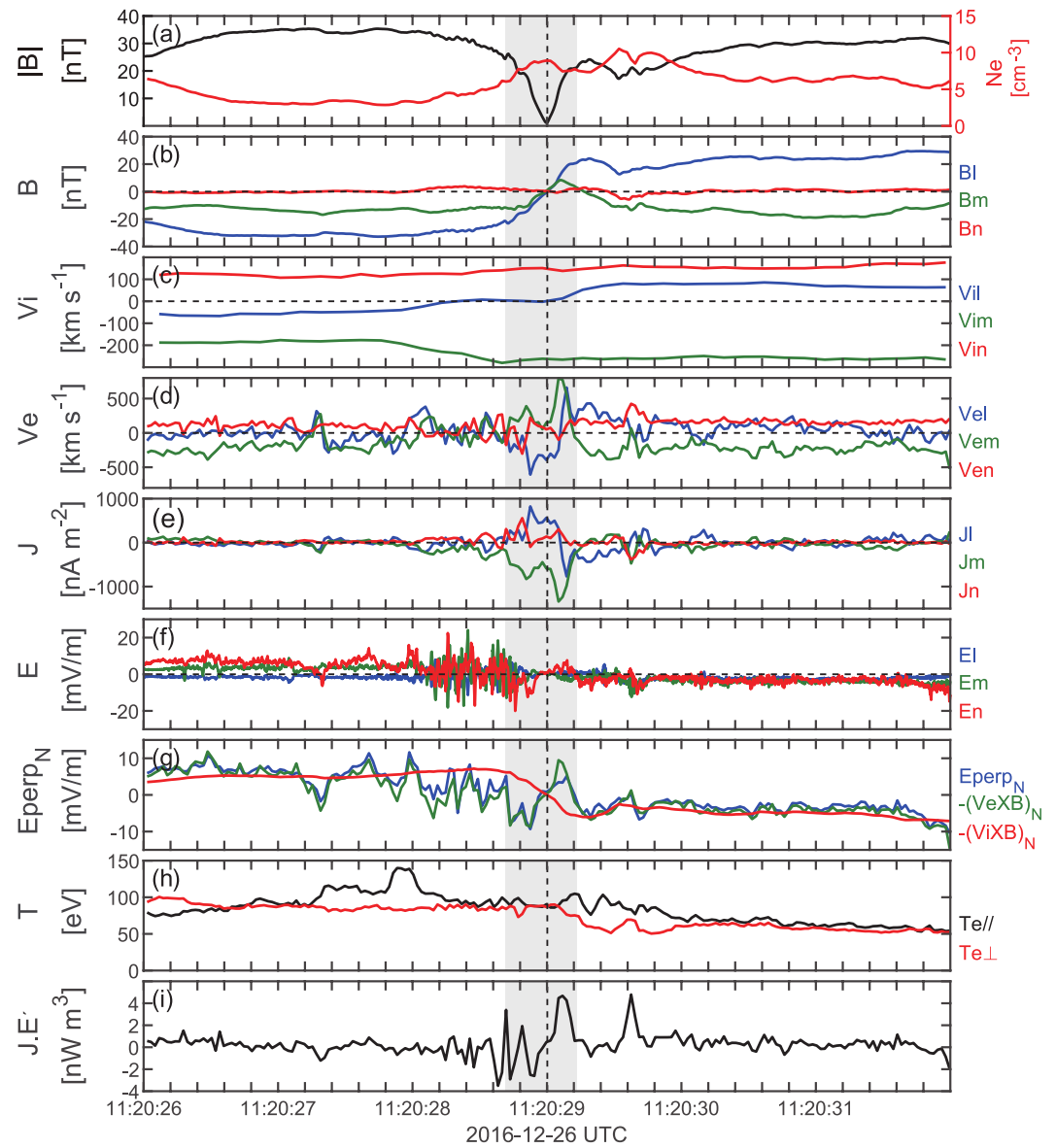


Figure 3. Closer view of the reconnecting current sheet in LMN coordinates. The panels display: (a) magnetic field magnitude (black) and electron density (red); (b) magnetic field vector; (c) ion bulk flow; (d) electron bulk flow; (e) current density vector; (f) electric field vector; (g) the N component of $-(V_i \times B)_N$, $-(V_e \times B)_N$, and perpendicular electric field; (h) electron parallel and perpendicular temperatures; and (i) $J \cdot (E + V_e \times B)$.

The current sheet was mainly supported by the intense electron flow $V_{e,M}$ (Figure 3d), suggesting that the spacecraft was located within or close to the electron diffusion region (EDR). Figure 3g presents a comparison between the measured perpendicular electric field (E_N), and $-(V_e \times B)_N$. Around the center of the current sheet (11:20:28.69–11:20:29.22 UT), a significant deviation is observed between E_N and $-(V_e \times B)_N$. This crucial discrepancy explicitly demonstrates the breakdown of the electron frozen-in condition, indicating that the electrons were demagnetized therein. The parallel ($T_{e\parallel}$) and perpendicular ($T_{e\perp}$) electron temperatures are shown in Figure 3h. Outside the center of the current sheet, $T_{e\parallel}$ was larger than $T_{e\perp}$, while at the center of the current sheet, the parallel and perpendicular electron temperatures were approximately equal (isotropy). Moreover, the positive energy dissipation rate was observed inside the current sheet, consistent with the previous studies on the EDR (Burch, Torbert, et al., 2016; Li et al., 2023; Li et al., 2019; Tang et al., 2019; Torbert et al., 2018; R Wang et al., 2020; Zenitani et al., 2011). The collective evidence of intense electron-driven currents, localized thermal

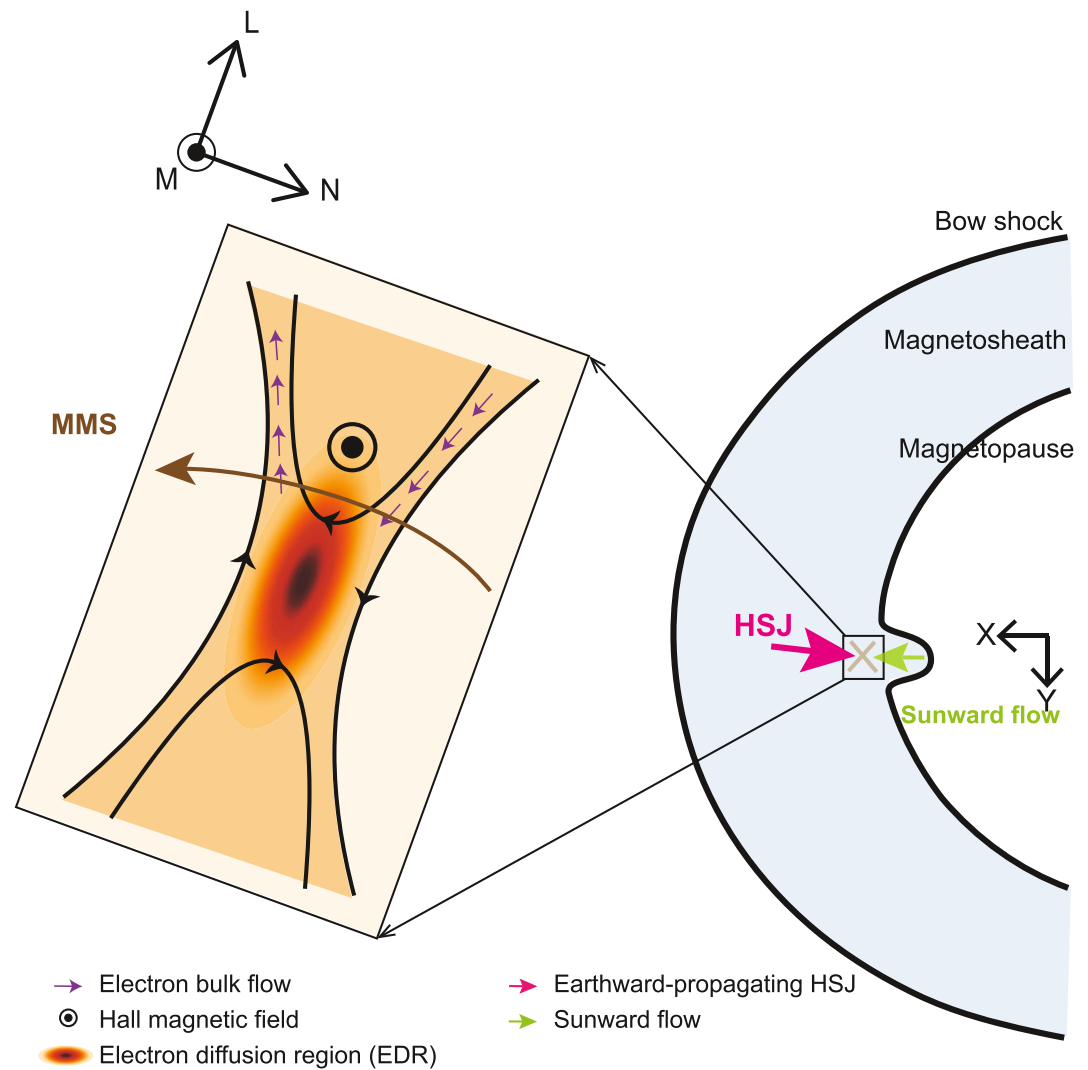


Figure 4. Schematic illustration of the magnetosheath high-speed jet (HSJ) and the reconnecting current sheet at its leading edge.

isotropy, and distinct electron demagnetization robustly concludes that the spacecraft crossed the vicinity of the EDR.

4. Conclusions and Discussion

In this study, we report the observation of a reconnecting current sheet occurring just ahead of the leading edge of a magnetosheath HSJ. Driven by the impact of the HSJ, the local plasma was strongly compressed, leading to the formation of an intense reconnecting current sheet with a guide field.

Magnetic reconnection occurs not only frequently at the magnetopause and in the magnetotail but also commonly within the magnetosheath (Lu et al., 2020, 2022; Phan et al., 2018; Retinò et al., 2007; Wang et al., 2021a, 2024). Theoretical frameworks suggest that for a given magnetic shear angle θ across a current sheet, reconnection is allowed (or suppressed) if $\Delta\beta$, the difference in plasma β between the two inflow regions, satisfies (or violates) the following condition (Swisdak et al., 2003, 2010):

$$\Delta\beta < 2(L/\lambda_i) \tan(\theta/2)$$

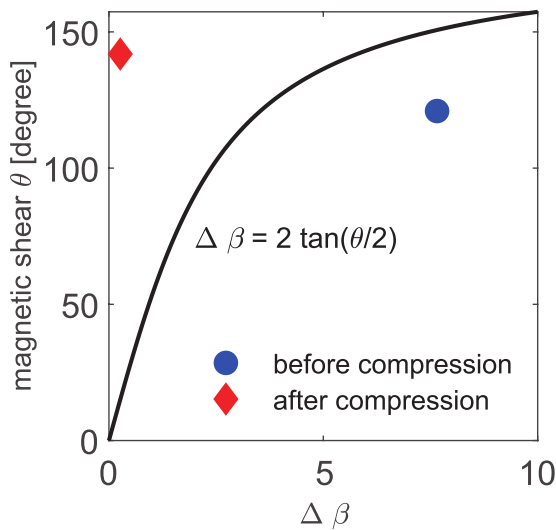


Figure 5. Magnetic shear versus the difference in β across the interface current sheet, measured before (circles) and after (diamonds) compression for the event shown in Figure 2. The theoretical curve corresponding to the condition $\Delta\beta < 2(L/\lambda_i) \tan(\theta/2)$ for $L/\lambda_i = 1$ is also plotted.

where L/λ_i is the width of the current sheet in units of ion skin depth λ_i . Due to their enhanced dynamic pressure, HSJs can produce strong localized compressions and interact intensively with the surrounding plasma environment, potentially overcoming this suppression condition to trigger magnetic reconnection. Figure 5 illustrates the observed $\Delta\beta$ and magnetic shear before (circles) and after (diamonds) the compression. The times before and after compression for the two regions are 11:19:50 UT and 11:21:06 UT, and 11:20:28 UT and 11:20:32 UT, respectively. The solid curve represents the theoretical threshold for $L/\lambda_i = 1$, a typical parameter that best characterizes this reconnection event (Phan et al., 2013; Øieroset et al., 2019). Notably, the condition transitioned from a suppressed state (i.e., below the theoretical threshold curve in Figure 5) before the compression to an allowed state (above the curve) following the compression.

A critical feature of this current sheet crossing is the distinct decoupling between ion and electron dynamics. Near the center of the current sheet (11:20:28.69–11:20:29.10 UT), the L -component of the ion velocity ($V_{i,L}$) was approximately zero, although variations were observed on a larger scale (Figure 2d). In contrast, the electron velocity ($V_{e,L}$) displayed a pronounced bipolar reversal, forming two oppositely directed jets (Figures 3c and 3d). These signatures could indicate that MMS simply crossed the vicinity of the EDR. Alternatively, they suggest the occurrence of an electron-only magnetic

reconnection (Phan et al., 2018; Stawarz et al., 2019). Given the narrow, sub-ion scale thickness of the observed HSJ-driven current sheet ($\sim 33.9 d_e$), electron-only magnetic reconnection is highly favored. Based on the presented data alone, it is observationally difficult to clearly distinguish between these two scenarios. However, the presence of intense electron-driven currents, localized thermal isotropy, and distinct electron demagnetization strongly suggests that MMS likely crossed the vicinity of the EDR.

Previous studies have established that magnetosheath current sheets originate from upstream discontinuities or foreshock waves (Lu et al., 2024; Phan et al., 2007; Wang et al., 2024). Furthermore, simulations and observations have indicated an association between current sheets and magnetosheath HSJs (Eriksson et al., 2016; Ouyang et al., 2026; Plaschke et al., 2017). Here, we propose that the observed intense current sheet was formed via the interaction between the HSJ and sunward-moving magnetosheath flows. As shown in Figure 1, before the arrival of the HSJ (red-shaded region), MMS encountered these sunward flows. The interaction between the HSJ and these sunward flows strongly compressed the local plasma, resulting in an intense current sheet with a guide field. Notably, between 11:19:40 and 11:20:25 UT, this preceding interval exhibited enhanced dynamic pressure (Figure 1e) and a distinct sequence of earthward followed by sunward ion flows (Figure 1d). Such signatures suggest that these flows may represent the sunward rebound of another preceding HSJ. Consequently, the interaction between this sunward-rebounding HSJ and the earthward-propagating HSJ would effectively compress the surrounding plasma, thereby driving the generation of the intense current sheet. Under the impact of the earthward-propagating HSJ, a reconnecting current sheet ultimately occurred ahead of its leading edge (Figure 4). However, the small spacecraft separation of the MMS constellation precludes validation of this two-jet interaction scenario for this specific event. Therefore, to fully elucidate the multi-scale dynamics and occurrence rates of jet-driven reconnection, more comprehensive studies combined with global simulations are required in the future.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Availability Statement

The MMS data used in this study are available at MMS Science Data Center (<https://lasp.colorado.edu/mms/sdc/public/about/browse-wrapper/>), and the solar wind data are from the OMNI website (<https://omniweb.gsfc.nasa.gov>).

Acknowledgments

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