Accelerated flows at Jupiter's magnetopause: Evidence for magnetic reconnection along the dawn flank

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HAL Id: insu-03677007
https://insu.hal.science/insu-03677007

Submitted on 24 May 2022

RESEARCH LETTER

Key Points:
- Observations at Jupiter's dawn magnetopause by Juno revealed accelerated ion flows and large magnetic shear angles at several crossings
- Case studies of two magnetopause crossings showed evidence of rotational discontinuities and an open magnetopause
- Compelling evidence for magnetic reconnection at the Jupiter's dawn magnetopause during Juno's approach to Jupiter and first capture orbit

Accelerated flows at Jupiter's magnetopause: Evidence for magnetic reconnection along the dawn flank

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Abstract We report on plasma and magnetic field observations from Juno's Jovian Auroral Distributions Experiment and Magnetic Field Investigation at 18 magnetopause crossings when the spacecraft was located at ~6 h magnetic local time and 73–114 Jovian radii from Jupiter. Several crossings showed evidence of plasma energization, accelerated ion flows, and large magnetic shear angles, each representing a signature of magnetic reconnection. These signatures were observed for times when the magnetosphere was in both compressed and expanded states. We compared the flow change magnitudes to a simplified Walén relation and found ~60% of the events to be 110% or less of the predicted values. Close examination of two magnetopause encounters revealed characteristics of a rotational discontinuity and an open magnetopause. These observations provide compelling evidence that magnetic reconnection can occur at Jupiter's dawn magnetopause and should be incorporated into theories of solar wind coupling and outer magnetosphere dynamics at Jupiter.

1. Introduction

Magnetic reconnection is the physical process whereby magnetic fields separated by a thin current sheet merge and are reoriented. This process also releases magnetic energy that can be converted to kinetic energy that heats and energizes the local plasma, leading to the production of accelerated plasma flows or jets that can be detected far from the reconnection site or X line. Evidence of magnetic reconnection has been observed in a number of different space environments, including the magnetopause of Earth [e.g., *Paschmann et al.,* 1979; *Phan et al.,* 2000; *Burch et al.,* 2016], Mercury [e.g., *Slavin et al.,* 2009; *DiBraccio et al.,* 2013], Saturn [e.g., *Masters et al.,* 2012; *Fuselier et al.,* 2014], and Jupiter [e.g., *Sonnerup et al.,* 1981a; *Walker and Russell,* 1985; *Huddleston et al.,* 1997].

At Earth, reconnection at the dayside magnetopause leads to the transfer of mass, energy, and momentum from the magnetosheath to the magnetosphere, triggering geomagnetic storms and aurora through a process known as the Dungey Cycle [*Dungey,* 1961]. At Jupiter, the relatively weak interplanetary magnetic field (IMF) and relatively high solar wind Mach number ($M_A \sim 10$–20) [e.g., *Jackman and Arridge,* 2011; *Ebert et al.,* 2014] and plasma beta in the outer magnetosphere are thought to suppress the occurrence and rate of dayside reconnection [e.g., *Huddleston et al.,* 1997; *Swisdak et al.,* 2003; *Desroche et al.,* 2012], though our knowledge of the conditions for and location of reconnection onset are poorly constrained due to the limited number of Jovian magnetopause observations [e.g., *Delamere et al.,* 2015]. The role of magnetopause reconnection in solar wind coupling and driving magnetospheric dynamics at Jupiter is also not well understood. Ideas include (i) a Dungey-cycle process where magnetic flux opened through reconnection at the dayside magnetopause is carried poleward and closed through reconnection in the magnetotail

[*Cowley et al.,* 2003; *Southwood and Chané,* 2016], (ii) a process whereby magnetic flux opened on the dayside remains confined to the outer magnetosphere and is closed by reconnection along the flanks of the magnetopause [*McComas and Bagenal,* 2007], and (iii) an interaction mediated by viscous interactions along the magnetopause where magnetic reconnection along the flanks is initiated by Kelvin-Helmholtz waves [e.g., *Delamere and Bagenal,* 2010]. Pulsed dayside reconnection has also been considered as a potential driver for the highly variable UV emissions and flares observed poleward of the main auroral oval [e.g., *Bunce et al.,* 2004; *Bonfond et al.,* 2011]. These theories and observations, among others, highlight the need for further analysis of magnetic reconnection at Jupiter's magnetopause.

The arrival of Juno at Jupiter has provided a new opportunity to explore Jupiter's outer magnetosphere. Launched on 5 August 2011, and following a 5 year interplanetary cruise, Juno entered into orbit around Jupiter on 5 July 2016. Approaching Jupiter from dawn at ~6 h magnetic local time (MLT), Juno first crossed Jupiter's bow shock at 8:16 UT on day of year (DOY) 176 (24 June) 2016 when the spacecraft was 128 Jovian radii (1 R_J = 71,492 km) from the planet [*McComas et al.,* 2017]. During its approach and subsequent two capture orbits [*Bagenal et al.,* 2014], Juno's suite of particle and field instruments made in situ observations of Jupiter's magnetosheath, magnetopause, and outer magnetosphere. In this paper, we present observations from Juno's Jovian Auroral Distributions Experiment (JADE) [*McComas et al.,* 2013] and magnetometer [*Connerney et al.,* 2017] during several magnetopause crossings along Jupiter's dawn flank, a number of which showed evidence of accelerated ion flows and large magnetic shears. These results provide compelling evidence for magnetic reconnection along Jupiter's dawn magnetopause during Juno's approach to Jupiter.

2. Instruments and Data Sets

JADE is a suite of plasma instruments consisting of one ion sensor (JADE-I) and two electron sensors (JADE-E). JADE-I is a spherical top-hat electrostatic analyzer (ESA) designed to measure ions in the energy range of 0.01 to 46 kiloelectron volts per charge (keV/q). It uses a time-of-flight section to provide mass per charge (M/q) resolved ion measurements between ~1 and 50 amu. It is mounted with its symmetry axis perpendicular to Juno's spin axis and has an instantaneous field of view (FOV) of 270° in elevation and 9° in azimuth. JADE-E consists of two identical sensors designed to measure the pitch angle distribution of ~0.1–100 keV electrons in Jupiter's magnetosphere using an ESA, two deflectors, and a microchannel plate detector. Each sensor has a FOV of 120° in azimuth and up to 35° in elevation through deflection. See *McComas et al.* [2013] for more details. We utilized the JADE version 01 low rate science ion time-of-flight and species data and electron data from Planetary Data System (PDS) volume JNO-J/SW-JAD-3-CALIBRATED-V1.0 for this study. The time resolution for the ion and electron observations used here was 30–60 s. The plasma moments shown here were calculated using a numerical method similar to that described in *Paschmann and Daly* [1998].

The Juno Magnetic Field Investigation (MAG) [*Connerney et al.,* 2017] consists of two independent sensor suites, each containing a triaxial fluxgate magnetometer (FGM) and a pair of imaging sensors. The MAG sensors are mounted ~10 and 12 m from the spacecraft, respectively, on a dedicated boom that extends outward along the spacecraft's +x axis and is attached to one of the spacecraft's three solar arrays. The FGMs simultaneously measure the magnetic field at a rate of 64 vector samples per second. See *Connerney et al.* [2017] for more details. For this study, we utilize 1 s averaged magnetic field vector observations from MAG from PDS volume JNO-SS-3-FGM-CALIBRATED-V1.0.

3. Magnetopause Observations at Jupiter's Dawn Flank

Figures 1a–1d show an overview of JADE and MAG observations in the vicinity of 18 Jovian magnetopause crossings by Juno when JADE was operating in high-voltage engineering mode. From top to bottom, Figures 1a–1d display energy-time count rate spectrograms for ions and, when JADE-E data were available, electrons, along with proton velocity (km s^{-1}) and magnetic field (nT) observations in a Jupiter-Sun-Orbit (JSO) coordinate system where x is aligned along the Jupiter-Sun vector, y is directed opposite to Jupiter's orbital motion, and z is directed out of Jupiter's orbital plane [e.g., *Huddleston et al.,* 1997]. The ion and electron spectrograms are shown in units of count/s since the JADE energy flux data product was still being validated at the time of this study. Figure 1e shows the location of each magnetopause crossing along the
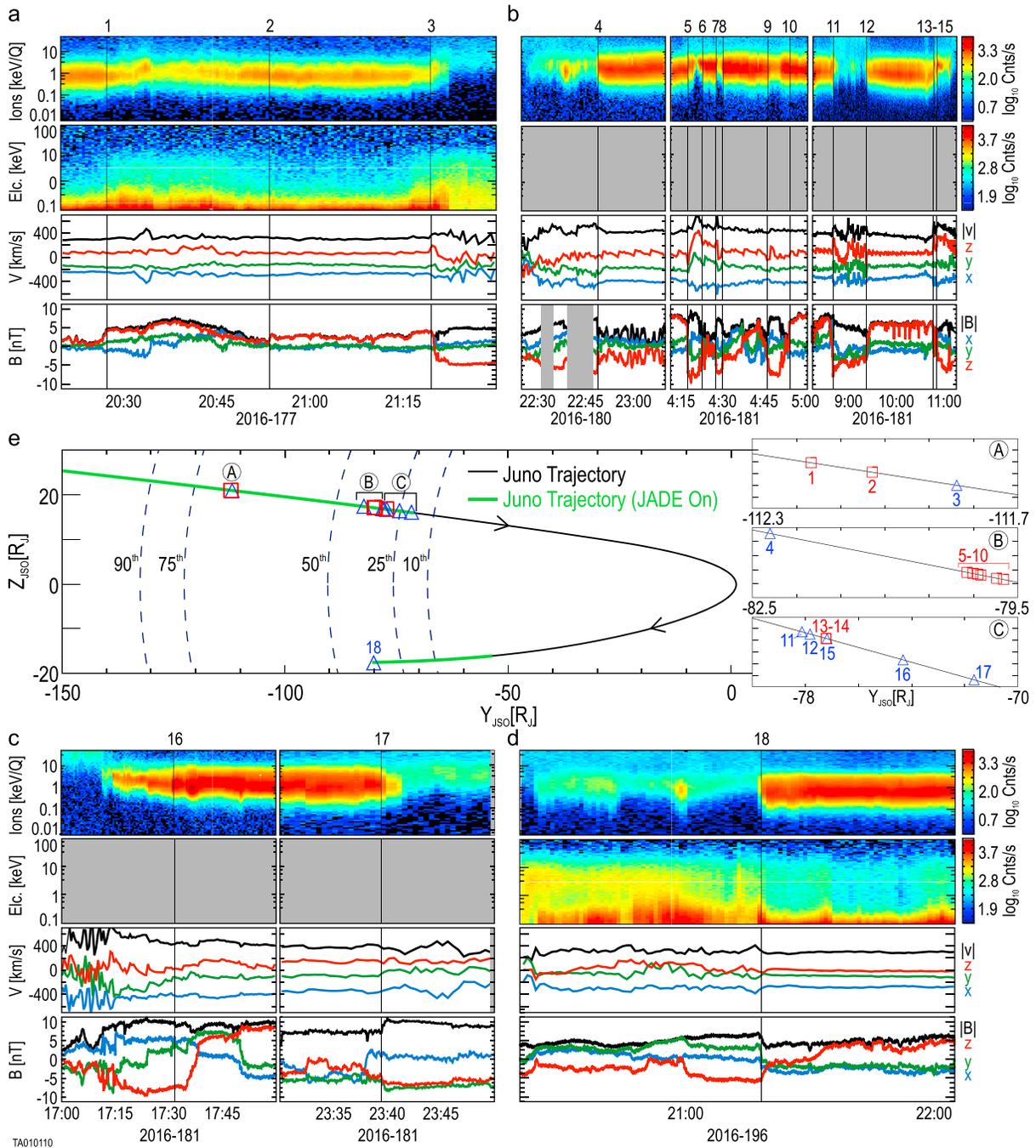
Figure 1. (a–d) JADE and MAG observations near 18 magnetopause crossings by Juno during its approach to Jupiter and the first several days of its post Jupiter orbit insertion (JOI) capture orbit. Displayed, from top to bottom, are 0.01–46 kiloelectron volts per charge (keV/Q) versus time ion coincidence count rate spectrograms, 0.1–100 keV versus time electron count rate spectrograms, and the proton velocity (3rd panel) and magnetic field (bottom panel) magnitudes (black curve) and components (x: blue curve, y: green curve, and z: red curve) in a JSO coordinate system. Common color scales for the ion and electron spectrograms and ranges for the proton velocity and magnetic field values are used in all four figures. Black vertical lines and associated numbers denote each magnetopause crossing. (e) A dawn-dusk projection of Juno's approach and post JOI trajectory in a JSO coordinate system. Dashed lines denote 10th through 90th percentile analytical model predictions of Jupiter's magnetopause location [e.g., *Joy et al.*, 2002; *Ebert et al.*, 2014]. Blue triangles and red squares denote full and partial magnetopause crossings, respectively. Green lines indicate the times when JADE was on during this timeframe. Black arrows indicate the direction of spacecraft motion. Insets labeled A–C are zoomed in views of Juno's trajectory and highlight the magnetopause crossing numbering scheme used throughout remainder of the paper.
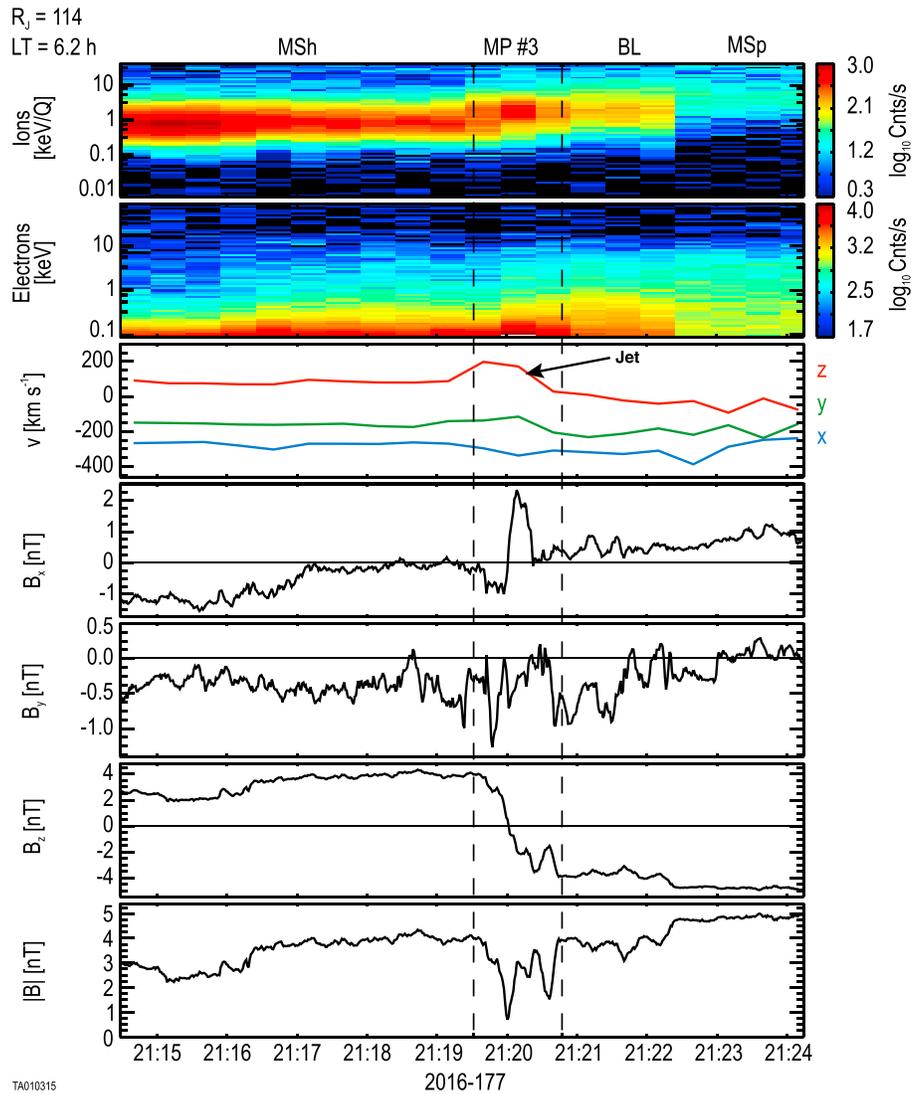
Figure 2. A Jovian magnetopause crossing by Juno at ~21:20 UT on DOY 177 2016 at 114 R_J where accelerated flows, a large magnetic shear, and a possible Hall magnetic field signature are observed. The observations are presented in a similar format as Figures 1a–1d with the magnetic field magnitude and components being shown in separate panels. Dashed lines denote the approximate boundaries for the magnetopause current sheet and the interval used in the minimum variance analysis. Intervals in the magnetosheath (MSh), magnetopause (MP), boundary layer (BL), and outer magnetosphere (MSp) are identified at the top of the figure.

Juno trajectory in a (JSO) coordinate system along with analytical model predictions for the 10th through 90th percentile locations of Jupiter's dawn magnetopause [*Joy et al.*, 2002; *Ebert et al.*, 2014]. Juno crossed the magnetopause at times when the magnetosphere was both in a more expanded and compressed state, as demonstrated by the range of locations where the magnetopause was observed.

The magnetopause crossings occurred at ~6 h MLT at a distance of 73–114 R_J from Jupiter. They were identified by transitions between the more dense magnetosheath plasma and the more tenuous, highly variable plasma in the outer magnetosphere. Magnetopause crossings were categorized as full when Juno made a complete entry into the magnetosphere or magnetosheath and partial when the spacecraft remained in a boundary layer near the magnetopause, the count rates in the boundary layer being intermediate to those in the magnetosheath and outer magnetosphere. A number of these crossings displayed evidence of ion and electron energization and increased proton velocities in the regions bounding the magnetopause. Significant rotations in the magnetic field, including fields of opposite polarity, were
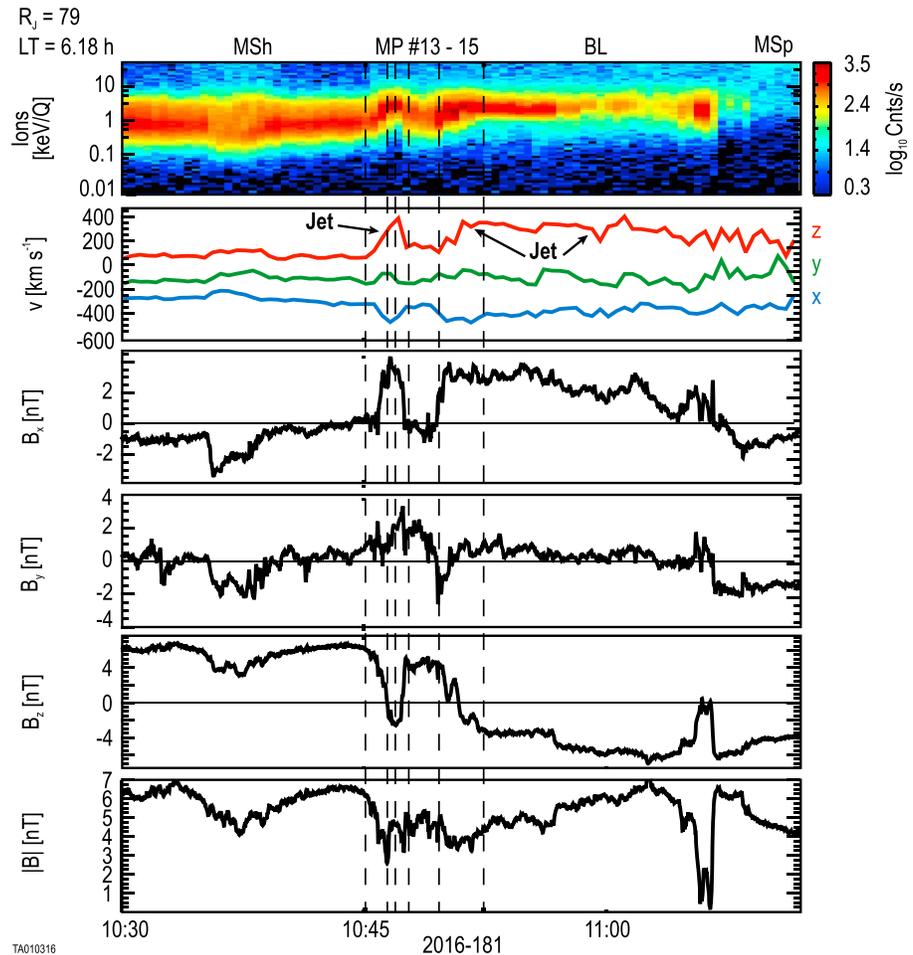
Figure 3. Similar format as Figure 2 with the panel displaying the electron spectrograms removed due to JADE-E being off during this time. This magnetopause encounter was more complex, having at least two partial crossings (#s 13 and 14) and one full crossing (#15). The partial crossings occurred at ~10:46 UT and ~10:48 UT on DOY 181 when Juno was at 79 R_J, while the full crossing occurred at ~10:52 UT. Minimum variance analysis was performed for the first partial crossing.

observed across the magnetopause, particularly in the B_Z direction (see red line in panel 4 of Figures 1a–1d). These oppositely oriented, or antiparallel, magnetic fields produce large shears that can lead to the formation of diffusion regions and X lines across the thin magnetopause current sheet and to antiparallel reconnection between the magnetosheath and magnetospheric fields [e.g., *Fuselier and Lewis*, 2011]. Increased ion velocities and ion and electron energization are also indirect signatures of magnetic reconnection [e.g., *Hesse et al.*, 2011]. Plasma acceleration resulting from the $\mathbf{J} \times \mathbf{B}$ force can produce flow speed changes up to the difference in Alfvén speeds between the regions adjacent to the magnetopause [e.g., *Sonnerup et al.*, 1981b; *Gosling et al.*, 1990; *Phan et al.*, 2004]. The accelerated plasma tends to flow tangential to the magnetopause [e.g., *Sonnerup et al.*, 1981b], which is approximately in the $X_{JSO} - Z_{JSO}$ plane for the observations presented here. The ion flows or jets are directed away, while the electrons stream away (in the magnetosheath boundary layer) or bidirectionally (in the magnetosphere boundary layer) from the reconnection site [e.g., *Fuselier et al.*, 2011].

Figure 2 shows ion and electron distributions, and proton velocity and magnetic field observations during magnetopause crossing #3 when Juno was at ~114 R_J, and the magnetosphere was in an expanded state. Starting at 21:19 UT, the mean energy of the ion distributions increased from ~0.8 keV/Q to ~2 keV/Q as the spacecraft began to traverse the magnetopause. The electron distributions also appeared to be energized starting at 21:16 UT. These magnetosheath-like ion and electron distributions extended across the magnetopause and into the outer magnetosphere. The proton velocity in the $+V_z$ direction was enhanced

across the magnetopause by ~120 km s^{-1} relative to its value in the sheath ($V_{z\,\text{sheath}}$ ~ 67 km s^{-1}). Coinciding with this velocity enhancement, the B_z component of the magnetic field changed polarity from ~4 nT in the sheath to ~−4 to 5 nT in the outer magnetosphere, indicating a large magnetic shear across the magnetopause boundary. The B_y component was ~−0.5 to −1 nT, while B_x reversed polarity and peaked at 2 nT near the center of the magnetopause current sheet. The total field magnitude ($|B|$) in the sheath and outer magnetosphere were comparable near ~4 nT; however, $|B|$ decreased to nearly 0 nT at the center of the magnetopause current sheet. The magnetic shear angle across the magnetopause was 170.3°.

There are several signatures of magnetic reconnection in this event. The ion and electron distributions show evidence of plasma energization at the magnetopause. The enhanced proton velocities in the +V_z direction are consistent with accelerated flows away from a reconnection site for an X line located at lower latitudes along the dawn magnetopause. The magnitude of the velocity change was a significant fraction of the difference in the z component of the Alfvén speed across the magnetopause ($|\Delta V_{Az}|$ ~185 km s^{-1}) that was calculated using a simplified version of the Walén relation ($|\Delta \textbf{V}| \sim |B_{\text{msphere}} - B_{\text{sheath}}|/(\mu_o m_H n_{\text{sheath}}) = |\Delta V_A|$) [e.g., *Phan et al.,* 2004]. The large shear in B_z suggests favorable conditions for forming an X line at the magnetopause such that antiparallel reconnection may occur [e.g., *Fuselier et al.,* 2011]. The peak in B_x near the center of the magnetopause current sheet provides possible evidence of a Hall magnetic field having a strength of ~50% of $|B|$. The Hall field, produced by currents generated from the differential flow between ions and electrons in the diffusion region, is oriented in the direction of the X line, likely along the dawn flank in the X_{JSO} direction for this event, and provides evidence for the spacecraft passing in close proximity to the diffusion region [e.g., *Phan et al.,* 2007; *Drake et al.,* 2008; *Halekas et al.,* 2009]. The finite B_y across the magnetopause suggests an open magnetosphere at the location of the spacecraft. This is supported by observations of sheath-like material in the outer magnetosphere. The B field depression in the region where the plasma jet is observed is also a signature of magnetic reconnection [e.g., *Phan et al.,* 2009].

A minimum variance analysis (MVA) on the B field was performed on the magnetopause crossing over the interval highlighted by the vertical dashed lines in Figure 2. The intermediate-to-minimum and maximum-to-intermediate eigenvalue ratios were 4.88 and 26.0, respectively, demonstrating well-determined results. These MVA coordinates indicate the magnetopause normal to be oriented in the Y_{JSO} direction ($B_1 = [0.11, 0.99, 0.12]$), which is consistent with the spacecraft's location near dawn. Further evidence of reconnection is illustrated by the nonzero normal component ($B_1 \sim B_y$) resulting from the MVA analysis. The field perpendicular to the magnetopause had an average magnitude of $B_y \sim B_1 = -0.36 \pm 0.01$ nT, which is ~10% of the ~4 nT background field. The existence of a nonzero normal component suggests that the boundary was a rotational discontinuity as a result of magnetic reconnection.

Figure 3 shows multiple magnetopause encounters between ~10:45 and 11:15 UT on DOY 181 when Juno was at ~79 R_J from Jupiter and the magnetosphere was in a relatively compressed state. The mean energy of the ion distributions increased from ~1 to 3 keV/Q as the spacecraft made two traversals of the magnetopause between ~10:45 and 10:49 UT and again between ~10:50 and 10:55 UT. These energized ion distributions extended into the magnetosphere after the second magnetopause crossing. Accelerated flows having a $<\Delta V>$ of ~230–240 km s^{-1} in V_z and ~−100–130 km s^{-1} in V_x relative to their values in the sheath were observed at both crossings. B_z changed polarity across both magnetopause encounters, from ~6 nT to −2 nT during the first and from ~4 nT to −4 to 5 nT during the second crossing. The B_y component was variable but remained finite and mainly positive across both magnetopause crossings, ranging between ~0.5 to 2.5 nT and ~0 to 1 nT, respectively. The B_x component was positive throughout the regions where the accelerated flows were observed, ranging between 0.5 and 4 nT, and was slightly negative in the sheath and outer magnetosphere bounding these regions. $|B|$ had several instances were it was depressed relative to its value in the sheath in the regions where the accelerated flows were observed. The magnetic shear angle ranged from 112 to 131° for these magnetopause crossings.

The energized ion distributions, presence of accelerated flows, and large rotations in B_z across the magnetopause are evidence of magnetic reconnection at Jupiter's dawn magnetopause during these crossings. The velocity change in V_z was slightly larger than that predicted by the simplified Walén relation ($|\Delta V_{Az}|$ ~175 km s^{-1}), while the velocity change in V_x showed poor agreement with the predicted value ($|\Delta V_{Ax}|$ ~11 km s^{-1}). That the accelerated flows persisted for 15 to 20 min after the second magnetopause crossing suggest a prolonged period of magnetopause reconnection and/or the presence

Table 1. List of Juno Magnetopause Crossings at Jupiter, Magnetopause Boundary Conditions, and Velocity Changes

			Juno Magnetopause (MP) Crossings[a]					Velocity Change ($V_{\text{msphere}} - V_{\text{sheath}}$; km s^{-1})				
Event	Date, Day of Year (DOY)	Time UTC (hh:mm)	X_{JSO} (R_J)	Y_{JSO} (R_J)	Z_{JSO} (R_J)	Full/Partial MP Crossing?	Magnetic Shear Angle (deg)	ΔV_x	ΔV_y	ΔV_z	$|\Delta V|$	$|\Delta V_A|$[d]
1	2016-06-25, 177	20:29[b]	4.884	−112.172	21.018	Partial[c]	39.1	−84	−16	18	87	111
2	2016-06-25, 177	20:51[b]	4.876	−112.027	21.002	Partial[c]	20.2	−7	−7	45	46	121
3	2016-06-25, 177	21:20	4.864	−111.841	20.980	Full	170.3	−49	7	118	128	197
4	2016-06-28, 180	22:49	3.177	−82.303	17.456	Full	2.7	−28	−37	−79	92[e]	38
5	2016-06-29, 181	04:16	3.058	−80.003	17.173	Partial[c]	168.8	−110	146	182	258[e]	332
6	2016-06-29, 181	04:22	3.055	−79.957	17.167	Partial[c]	36.3	−25	20	178	180[e]	162
7	2016-06-29, 181	04:27	3.054	−79.927	17.163	Partial[c]	54.2	−75	−51	29	95[e]	133
8	2016-06-29, 181	04:30	3.053	−79.904	17.161	Partial[c]	33.4	−11	−18	−42	47[e]	95
9	2016-06-29, 181	04:47	3.046	−79.783	17.146	Partial[c]	164.2	−2	−39	10	41[e]	229
10	2016-06-29, 181	04:54	3.044	−79.730	17.139	Partial[c]	171.2	2	−39	−62	73[e]	279
11	2016-06-29, 181	08:40	2.962	−78.126	16.940	Full	167.9	−81	79	135	176[e]	282
12	2016-06-29, 181	09:23	2.946	−77.821	16.902	Full	150.4	−62	−54	16	84[e]	244
13	2016-06-29, 181	10:46[b]	2.916	−77.232	16.829	Partial[c]	121.7	−136	38	237	276[e]	181
14	2016-06-29, 181	10:48[b]	2.915	−77.217	16.827	Partial[c]	112.1	−136	38	237	276[e]	181
15	2016-06-29, 181	10:52[b]	2.914	−77.186	16.823	Full	131.2	−88	19	226	244[e]	181
16	2016-06-29, 181	17:31[b]	2.770	−74.324	16.465	Full	116.3	−20	−161	−104	193[e]	174
17	2016-06-29, 181	23:39	2.637	−71.647	16.127	Full	38.0	53	102	62	130[e]	72
18	2016-07-14, 196	21:18	2.557	−80.105	−17.662	Full	94.2	−21	55	56	82	123

[a]The Juno magnetopause crossings listed here are those where JADE-I and/or JADE-E were collecting data in high-voltage engineering mode.
[b]Complicated boundary makes it difficult to assess magnetopause crossing time.
[c]Partial crossing is where the spacecraft remained in boundary layer near magnetopause.
[d]Calculated using simplified version of Walén relation $|\Delta V_A| = |B_{\text{msphere}} - B_{\text{sheath}}|/(\mu_o m_H n_{\text{sheath}})$.
[e]JADE-E was off at the time of these observations.

of a boundary layer in the outer magnetosphere during this timeframe. The finite values of B_y across the magnetopause and presence of sheath-like ion distributions in the outer magnetosphere indicate that the magnetopause was open during this period. MVA performed on the magnetopause crossing at 10:46 UT showed that the magnetopause normal was oriented primarily in the Y_{JSO} direction ($B_1 = [0.50, 0.82, 0.27]$) and that the field perpendicular to the magnetopause had an average value of $B_y \sim B_1 = 2.51 \pm 0.01$ nT which is ~40% of the ~6 nT background field. The relatively large normal component of the magnetic field indicates that the boundary was a rotational discontinuity, that the magnetopause was open, and that the reconnection rate was high [e.g., *DiBraccio et al.,* 2013] during this crossing.

Table 1 provides details for all 18 magnetopause crossings studied here including the event number (column 1), the event day and time (columns 2–3), Juno's location in a JSO coordinate system (columns 4–6), identification as a partial or full crossing (column 7), the magnetic shear angle (column 8), and values for the change in proton velocity (columns 9–12) and Alfvén speed (column 13) across the magnetopause. Eight of the magnetopause crossings were identified as full and 10 as partial. We note that 10 of the crossings had magnetic shear angles >110°, suggesting the presence of antiparallel fields. The magnitude of the velocity changes across the magnetopause ranged from ~40 to 275 km s^{-1}. Eight of the crossings showed >$|100|$ km s^{-1} enhancements in the V_z component of the flow with seven of the eight being associated with crossings having large magnetic shear angles. The change in flow velocities ranged between 18 and 240% of the value predicted from the simplified Walén relation. Eleven of the 18 events had speed changes that were 110% or less of the predicted values.

4. Discussion

We presented plasma and magnetic field observations for 18 dawn magnetopause crossings at Jupiter by Juno. Signatures of magnetic reconnection such as plasma energization, accelerated ion flows, and large magnetic shear angles were observed at several crossings. We compared the change in flow velocity across the magnetopause to a simplified version of the Walén relation, a parameter used to predict the magnitude of these speed changes based on the difference in Alfvén speeds across the magnetopause. We found ~60% of the events to show reasonable agreement with the predicted values. Case studies for two magnetopause

encounters, one for an expanded and one for a compressed magnetosphere, revealed characteristics of rotational discontinuities and evidence of Hall magnetic fields, an indication that the magnetosphere was open and that Juno passed in close proximity to the diffusion region. Taken together, these observations provide strong evidence for magnetic reconnection along Jupiter's dawn flank during Juno's approach to Jupiter and first capture orbit.

Evidence of magnetic reconnection at Jupiter's dayside magnetopause has been limited to a few crossings [e.g., *Sonnerup et al.*, 1981a; *Walker and Russell*, 1985; *Huddleston et al.*, 1997] with signatures being identified primarily in the magnetic field observations. *Sonnerup et al.* [1981a] described evidence of rotational discontinuities, a signature of quasi-steady reconnection, at two magnetopause crossings by the Pioneer spacecraft, while magnetic flux transfer events (FTEs), a process thought to be caused by intermittent or bursty reconnection, were reported at magnetopause crossings by the Pioneer [*Walker and Russell*, 1985] and Voyager [e.g., *Huddleston et al.*, 1997] spacecraft. The convective electric field ($\mathbf{v} \times \mathbf{B_N}$) produced by these FTEs was estimated to be an order of magnitude weaker than the electric field associated with Jupiter's corotating plasma (~0.25 mV/m versus 4 mV/m), and it was suggested that the influence of these FTEs was confined to Jupiter's outer magnetosphere [e.g., *Huddleston et al.*, 1997]. The two magnetopause case studies presented here had nonzero B field normal components, indicating that the boundary was a rotational discontinuity and that reconnection was quasi-steady. The reconnection electric field associated with these events was up to ~0.1 mV/m ($(v_x^2 + v_z^2)^{0.5} \sim 275 \, \text{km s}^{-1}$) and ~1.5 mV/m ($(v_x^2 + v_z^2)^{0.5} \sim 600 \, \text{km s}^{-1}$), respectively, the larger value being for a magnetopause crossing when the magnetosphere was compressed. These results support the suggestion by *Huddleston et al.* [1997] that magnetopause reconnection may play a more significant role in Jovian magnetosphere dynamics during times of high solar wind dynamic pressure when the magnetosphere is compressed.

These observations also provide important constraints for the theories and models that focus on solar wind-magnetosphere interactions at Jupiter and the magnetospheric dynamics produced by these processes. Recent modeling efforts have suggested that the large flow shears across the magnetopause and high plasma beta in the outer magnetosphere would suppress reconnection onset along Jupiter's dawn flank [e.g., *Desroche et al.*, 2012]. That reconnection that was observed at several Jovian dawn magnetopause encounters shows that it was an active process during Juno's approach and that the conditions for reconnection onset need to be examined in more detail. These results should also be incorporated into magnetic flux circulation models that invoke the need for magnetic reconnection on the dawn flank [*McComas and Bagenal*, 2007] or in the dawn sector [*Cowley et al.*, 2003] to close magnetic flux opened through dayside reconnection or to open and close magnetic flux intermittently through small-scale structures driven by viscous interactions [*Delamere and Bagenal*, 2010].

Finally, these observations may provide context for the highly variable far ultraviolet emissions observed poleward of Jupiter's main auroral oval [e.g., *Pallier and Prangé*, 2001; *Bonfond et al.*, 2011]. These emissions, sometimes referred to as polar flares, show variations on the order of tens of seconds, have been observed at MLTs between 10:00 and 18:00, and are predicted to map to radial distances of 55–120 R_J [e.g., *Bonfond et al.*, 2011]. One mechanism put forward to explain these emissions is pulsed dayside reconnection whereby magnetosheath plasma entering the magnetosphere is accelerated along magnetic field lines in the outer magnetosphere, the field-aligned particles precipitating into the ionosphere poleward of the main oval to produce these emissions [*Bunce et al.*, 2004]. The polar UV emissions were extremely active in Hubble Space Telescope observations taken during Juno's approach to Jupiter and first capture orbit [*Nichols et al.*, 2017]. While we are not yet able to determine if the reconnection onset observed at this time had a periodic trend, we can say that magnetic reconnection was active at ~6 h MLT near the time when the observations coinciding with Juno's first capture orbit were taken.

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