Contrasting properties of two ion-scale magnetopause flux ropes

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We present results from an event which occurred on December 31, 2016. At this time MMS was on its outbound leg, located near the subsolar point, when it encountered two ion-scale, magnetopause flux ropes, denoted FR1 and FR2. The two flux ropes exhibited rapid variations, occurring over sub-di spatial scales, and time scales on the order of the ion gyro period. Changes in the field line connectivity indicated reconnection was occurring

Observations

Figure 1 shows an overview of the event using data from all MMS satellites. MMS observes two sequential, asymmetric bipolar B_N signatures. The B_N reversals coincide with peaks in B_M.

The polarity of the B_N signatures indicates two flux ropes moving southward. B_L goes from positive to negative indicating an Earthward motion, with MMS crossing the magnetopause. This is in agreement the ion bulk velocity, the motion determined using the Spatio-temporal Difference method (Figure 1i) and from timing analysis. As can be seen in Figure 1i the extent of the two flux ropes are approximately 4x2.5 d_i and 4x4.5 d_i respectively.

Figure 2 shows an overview of the event illustrated with data from MMS4, focusing on the time period denoted by the shaded area in Figure 1. From this figure, we can make some key observations.

1. V_L is ~0 before entering FR1, increasing over time.
2. The perpendicular and parallel currents are of similar magnitude, i.e. the flux rope is non force-free.
3. The electrons are fully magnetized but the ions are partially demagnetized in FR1, but not in FR2.

Figures 3-5 illustrates the differences in the observations of the different MMS satellites. MMS4 was the first satellite to enter the flux ropes, followed by MMS1 (not shown), MMS3 and finally MMS2 trailing by some 15 km and ~0.5 s. By comparing the three plots we can make five key observations:

1. Rapid fluctuations and reversals of currents at the leading edge of FR1.
2. Gradual break up of the J_M current sheet of FR1.
3. Electric field going from wave dominated to quasi-static
4. Pressure driven (J.E<0) electron jet going from FR1 to FR2.
5. Negative J_M, opposite of the magnetopause current, at both edges of FR1.

Discussion and Conclusions

Despite the short separation spatial and temporal separation, 15 km (0.5 d_i) and <0.5 s (2 ω_{ci}^{-1}), we observe large differences in the current structure of FR1. These differences can not be explained by the position of the satellites but are likely to be caused by changes in the connectivity of the field line due to reconnection. However, as summarized in Table 1, the signatures observed at the in-plane null are atypical of dayside reconnection.

The increasingly negative V_L indicates that while FR1 and FR2 are moving in the same direction, FR2 is closing in on FR1. It would appear that FR1 is being compressed between the stagnation point to the south and the and the faster moving FR2 to the north. This could explain why FR1 has a larger extent in the N-direction than the L-direction.

Table 1: Comparison of reconnection signatures

	Observed	Dayside reconnection	Flux rope coalescence
J_M	Negative	Positive	Negative
B_N	Decreasing	Increasing	Decreasing
V_{FR}	Towards null	Away from null	Towards null

The asymmetric bipolar B_N signature, with weaker B_N at the interface between the flux ropes, has been considered a signature of flux rope coalescence [Zhou et al. 2017]. This suggest that we are observing flux rope coalescence occurring between the two flux ropes, and perhaps at the leading edge of FR1.

The pressure driven electron jet observed near the center of FR1 is initially narrow but broadens gradually. This in agreement with plasma escaping the compressed FR1 as more field lines are opened. The absence of significant energy dissipation near the in-plane null could either be interpreted that coalescence is very slow or has subsided by the time MMS reaches the in-plane null. This could explain why MMS2 does not observe the same electron jet.

The time scale over which we observe the large current and electric field reversals is ~0.5 s (~ 2 ω_{ci}^{-1}), similar to the 2–4 ω_{ci}^{-1} time scale reported from simulations of flux rope formation and coalescence [Drake et al., 2006a; Zhou et al., 2014].

Fully understanding these non-force free flux ropes, their high time variability and non-MHD ion properties will likely require extensive modeling efforts.

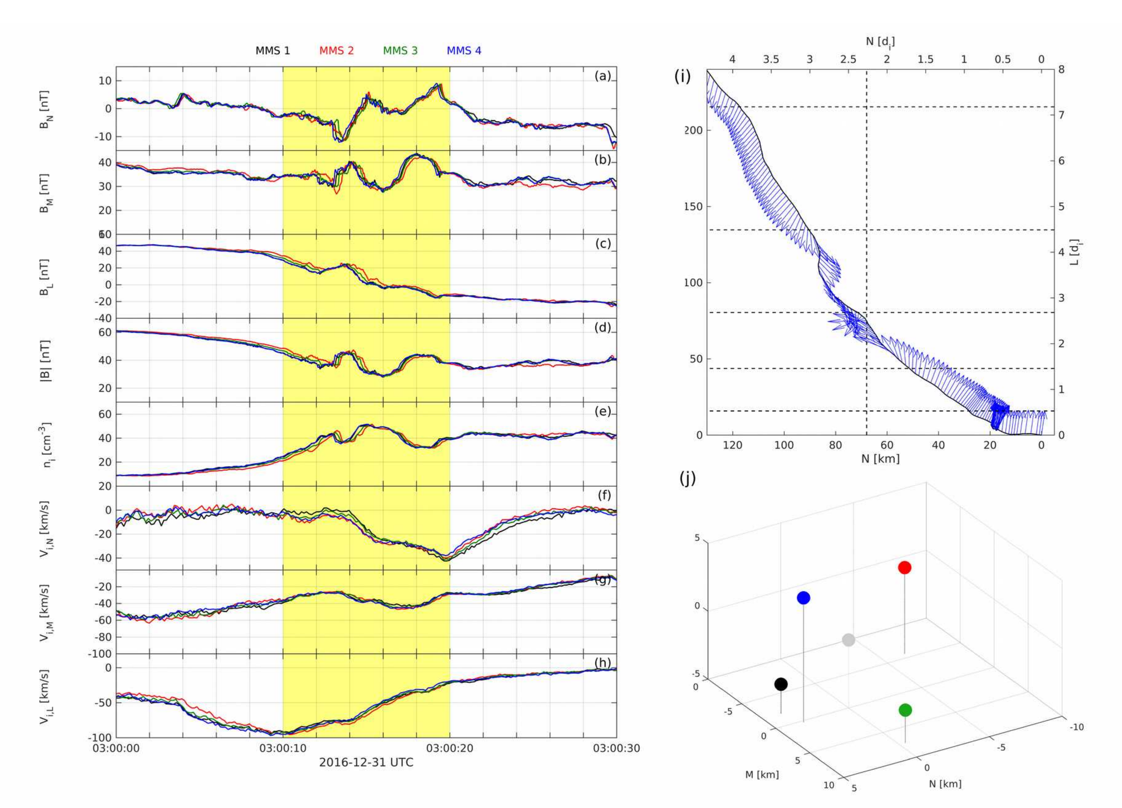

Figure 1: Overview of the events. Left: Magnetic field and ion bulk velocity. Top right: Path of MMS determined from Spatio-temporal difference method. Bottom right: MMS formation.

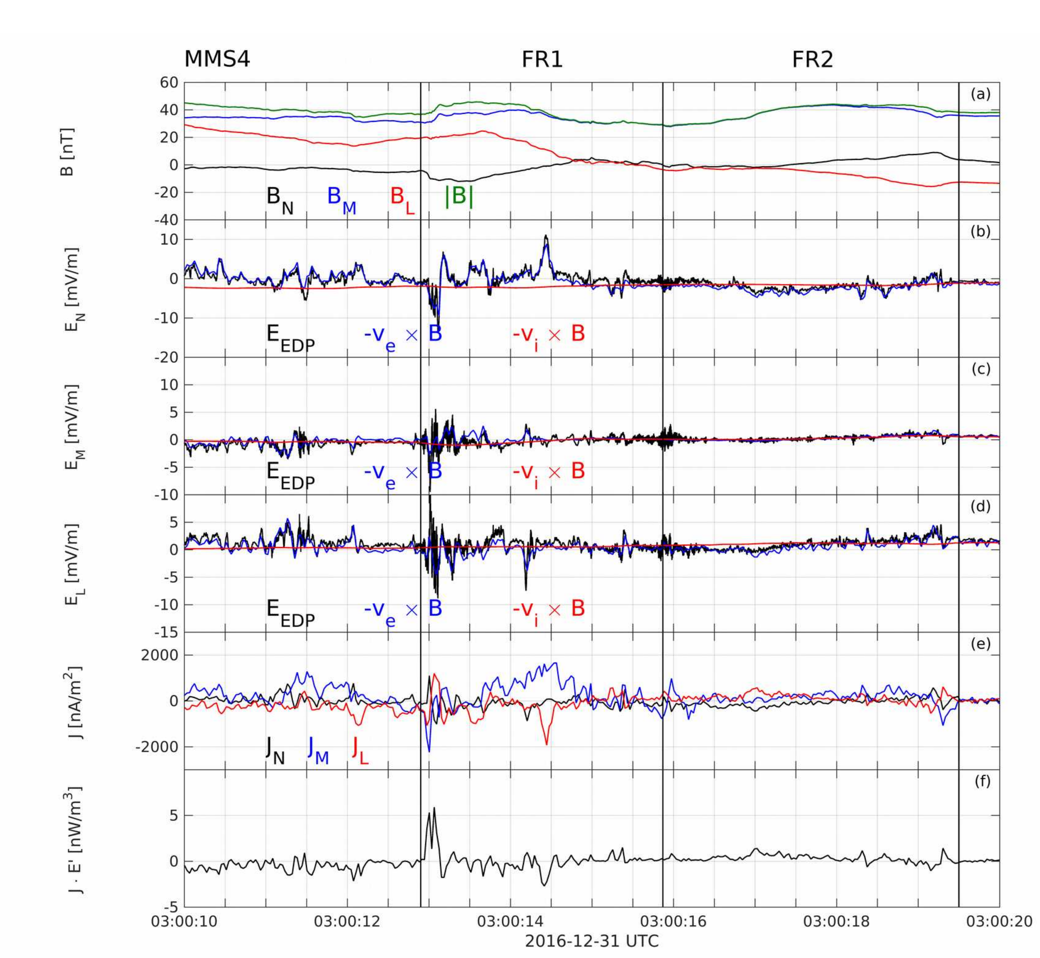

Figure 3: Comparison of particle moments and electric field from MMS 4.

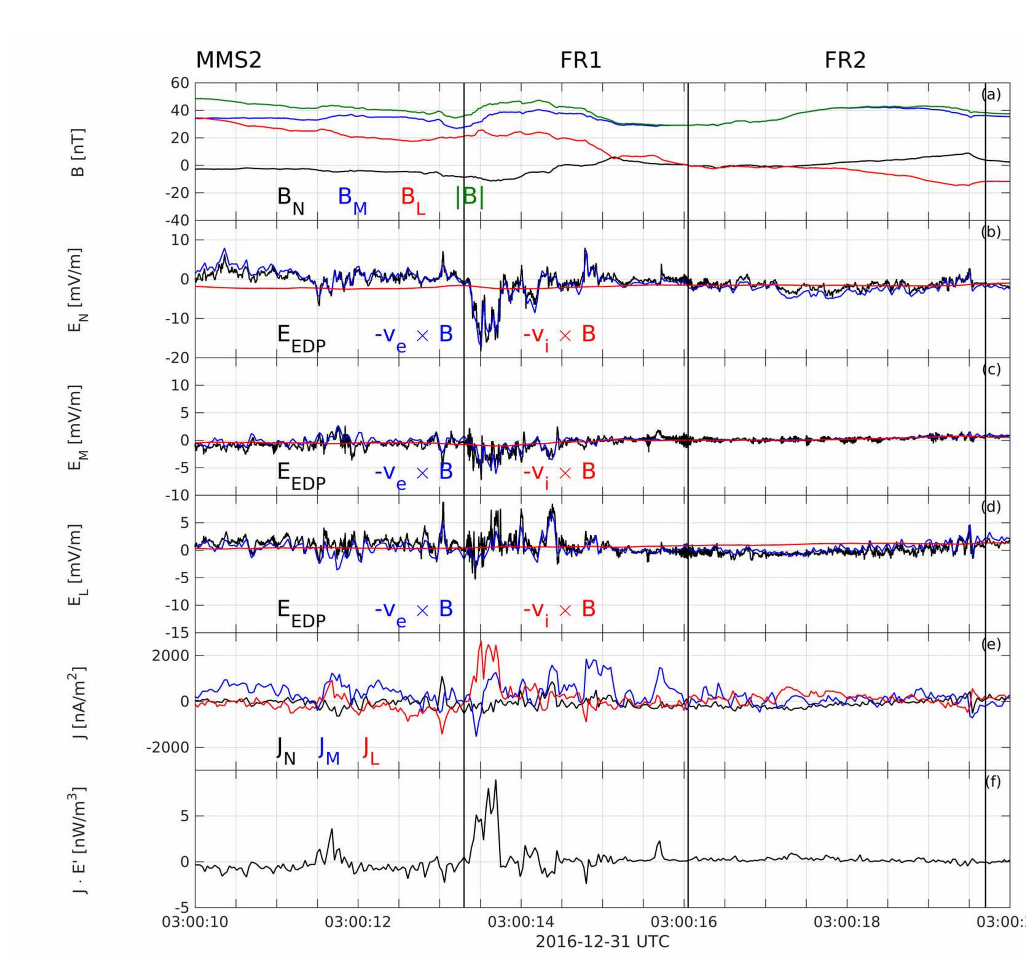

Figure 5: Comparison of particle moments and electric field from MMS 2.

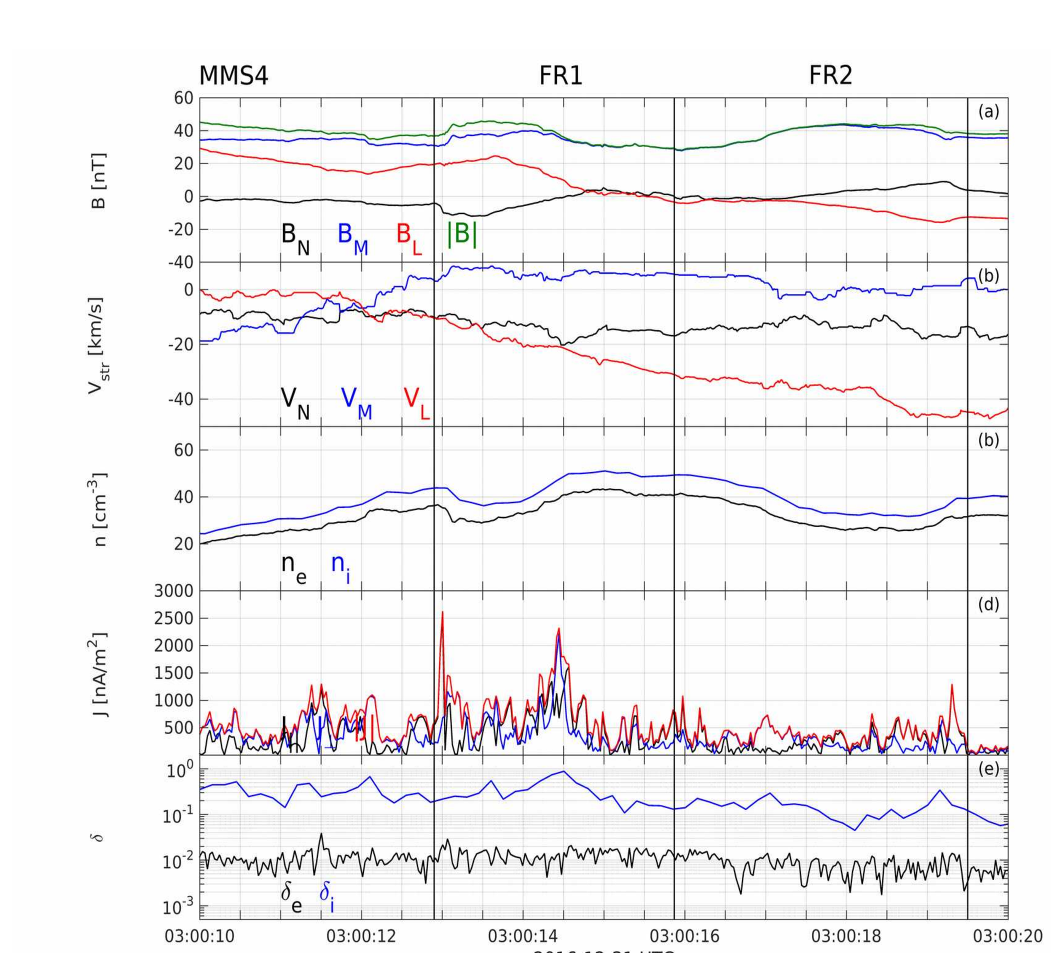

Figure 2: Summary of the two flux ropes, as observed by MMS 4.

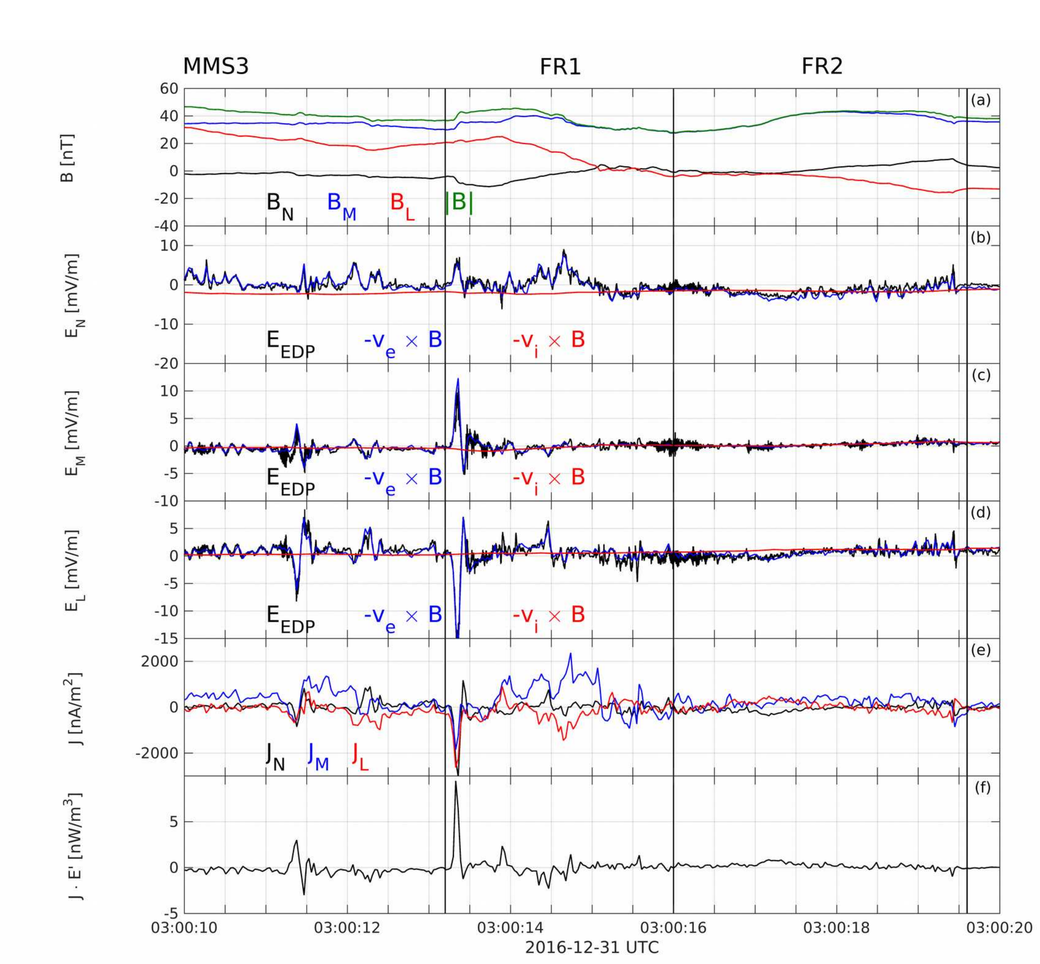

Figure 4: Comparison of particle moments and electric field from MMS 3.

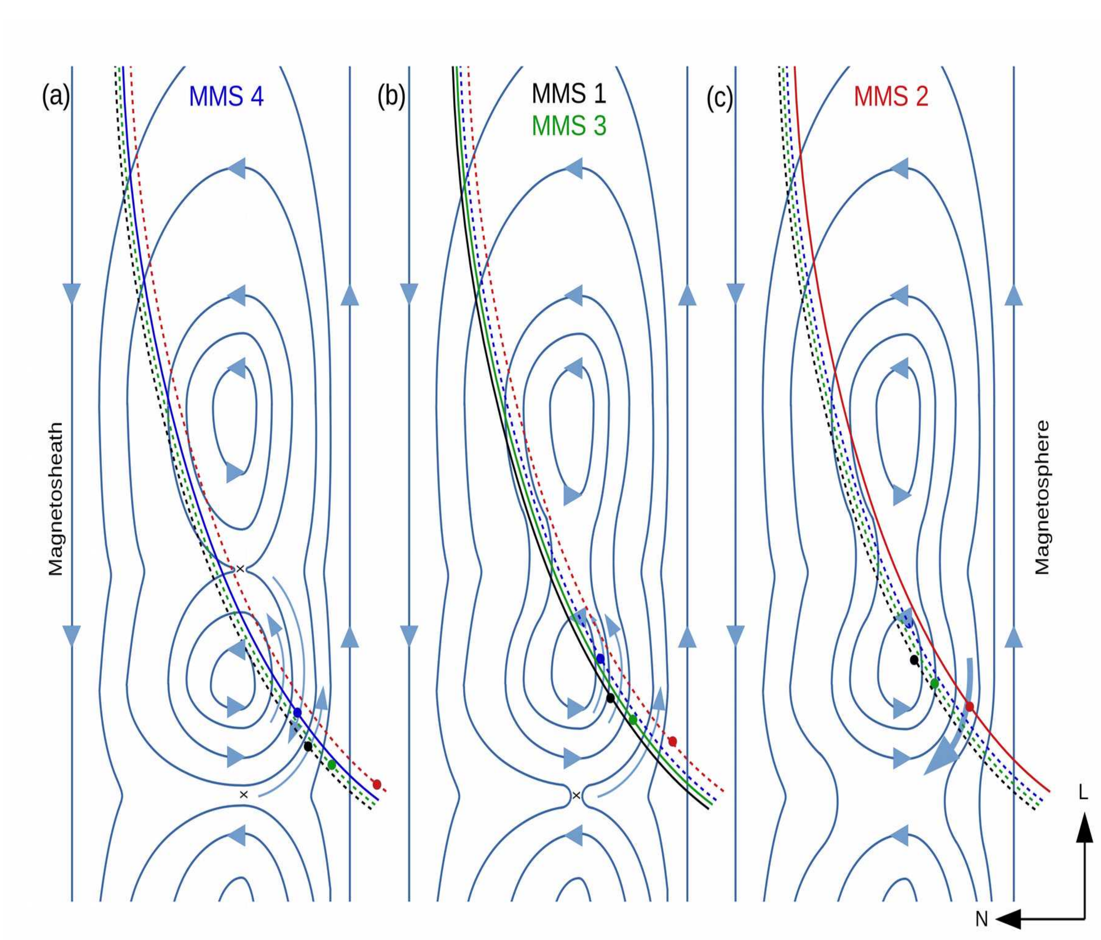

Figure 6: Cartoon of the evolution of the two flux ropes. Arrows denote the observed electron jets.