Evidence of a Non-Orthogonal X-line in Guide-Field Magnetic Reconnection

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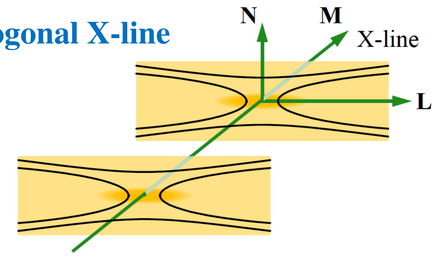
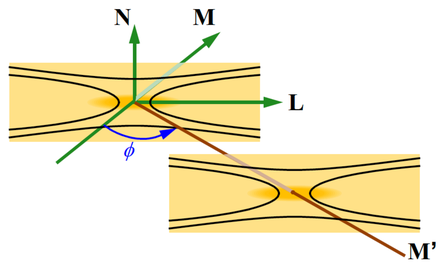
1. Introduction

Orthogonal X-line



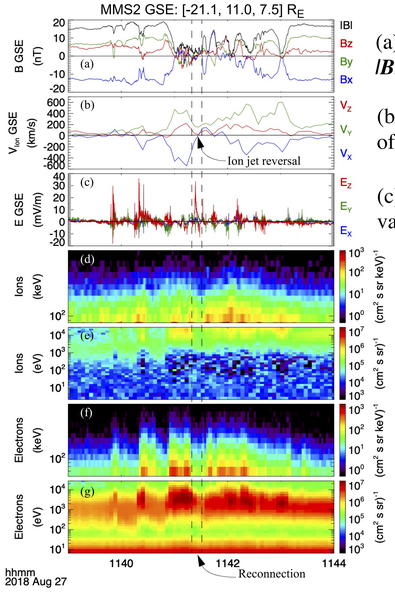
L ⟶ Direction of the reconnecting magnetic field
N ⟶ Normal to the current sheet
X-line ⟶ Orthogonal to the *L*-*N* plane ($M = N \times L$)

Non-orthogonal X-line



- MMS mission observes a guide-field magnetic reconnection event in Earth's magnetotail in which the x-line may be oblique to the L-N plane.

2. Overview of a magnetotail reconnection event on August 27, 2018



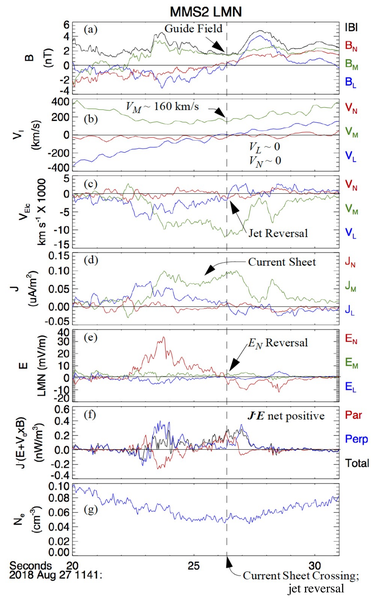
(a) ~ 11:41:26 UT, $|\boldsymbol{B}|$ decreases

(b) x-component of $\boldsymbol{V}_{Ion}$ reverses

(c) Bipolar variation in E_Z

(d)– (g) accelerated ions and electrons

3. Zoomed-in view of the magnetic reconnection event



(a) B_M ~ 1.35 nT and B_L changes from (–)ve to (+)ve

(b) $\boldsymbol{V}_{Ion}$ reverses in L direction

(c) Electron jet reversal

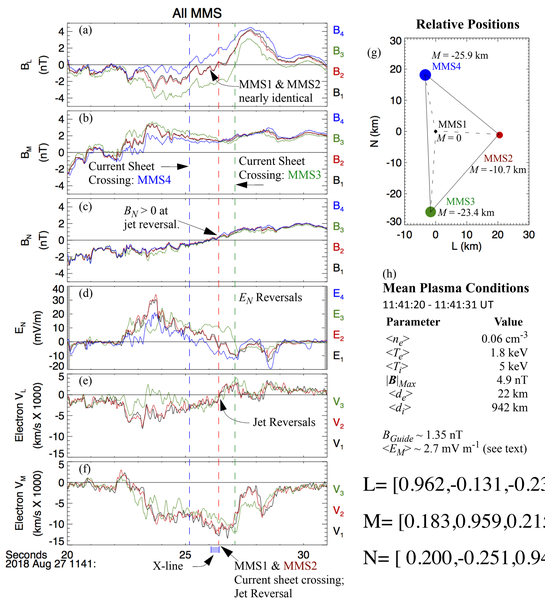
(d) $\boldsymbol{J}$ derived from electron & ion distributions

(e) $\boldsymbol{E}$

(f) Electromagnetic energy transfer

(g) Electron density

4. Multiple spacecraft observations



- Progression of the MMS spacecraft in +N and +L direction.
- MMS1 & MMS2 show almost identical measurements of B_L, B_M, B_N, E_N, electron V_L, and electron V_M, even though the both spacecraft are well-separated in L (20.5 km) and M (10.7 km).

L= [0.962,-0.131,-0.238];
M= [0.183,0.959,0.215];
N= [0.200,-0.251,0.947]

5. Puzzles

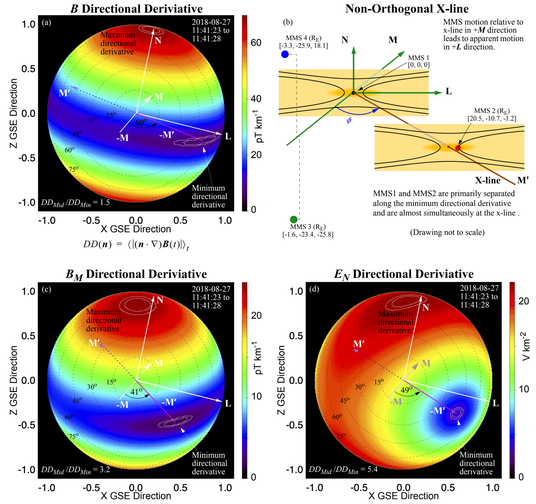
- Generally, Magnetic reconnection is thought to be embedded in ion frame. However, in this event L component of $\boldsymbol{V}_{Ion}$~ 0 , even though L component of $\boldsymbol{V}_{Elc}$~ 250 km s^{-1}.
- X-line should lie in the MMS1-MMS2 direction, which is not along M.
- $\boldsymbol{B}$ and $\boldsymbol{E}$ here, $\frac{\partial \boldsymbol{B}}{\partial M} \neq 0$ and $\frac{\partial \boldsymbol{E}}{\partial M} \neq 0$

Possibilities
L-M-N is not correct Or X- line is not orthogonal

6. Directional derivative analysis

Directional derivative for a given $\boldsymbol{n}$,

$$DD(\boldsymbol{n}) = \langle |\boldsymbol{n} \cdot \nabla \boldsymbol{B}| \rangle_t$$



One possible explanation: X-line is not orthogonal

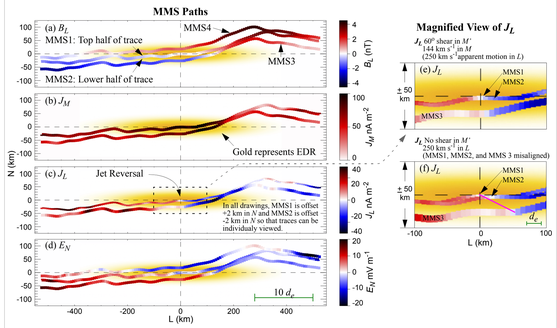
7. Resolved Puzzles

✓ $\boldsymbol{V}_{Ion}$ ~ 0 in the L direction whereas the spacecraft appear to rapidly progress in the L direction.

↳ **With a non-orthogonal x-line, motion in the M direction causes apparent motion in L.**

✓ **Non-orthogonal x-line sets MMS1 and MMS2 close to the x-line in the EDR.**

8. Measured values of B_L, J_M, J_L, and E_N along their estimated paths through the EDR using the non-orthogonal model



- Apparent motion in L (estimated V_L ~ 250 km/sec) is due to motion in M and the L-N shear. Motion in N is physical.
- N position is estimated by using: $J_M = \frac{\partial B_L}{\partial N} - \frac{\partial B_N}{\partial L}$

$$\Delta N = \frac{\Delta B_L}{J_M + \langle \partial B_N / \partial L \rangle}$$

✓ **MMS1, MMS2, and MMS3 show the jet reversal at nearly the same position under the non-orthogonal model.**

✓ **The jet reversal is misaligned using a model with physical motion in $\boldsymbol{L}$.**

9. Summary

- X-line is not necessarily orthogonal to the L-N plane.

Supporting features

✓ MMS1 and MMS2 observations are remarkable identical even though well-separated in L.

✓ MDD analysis supports the x-line is between 40° and 60° from M.

✓ Measured ion velocity is inconsistent with the apparent motion of the MMS spacecraft in the L direction through the EDR, which can be resolved if one assumes a shear in the L-N plane and motion in the M direction.

Reference

Neha Pathak, R. E. Ergun et al., Evidence of a Nonorthogonal X-line in Guide-field Magnetic Reconnection, The Astrophysical Journal Letters, 941, L34 (2022).

Acknowledgements

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