Is the EDR Aspect Ratio an Approximate Measure of Reconnection Rate?

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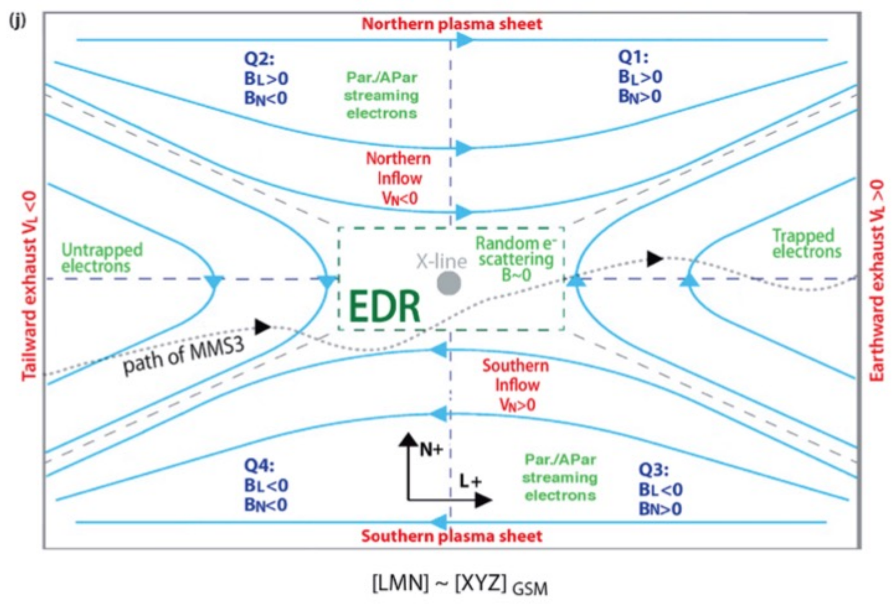
Background

- Magnetic reconnection is a process which converts electromagnetic energy to kinetic particle energy through changes in magnetic field topology.
- The rate of energy conversion is known as the reconnection rate and is generally determined by comparing energy of the plasma within the inflow and outflow regions.

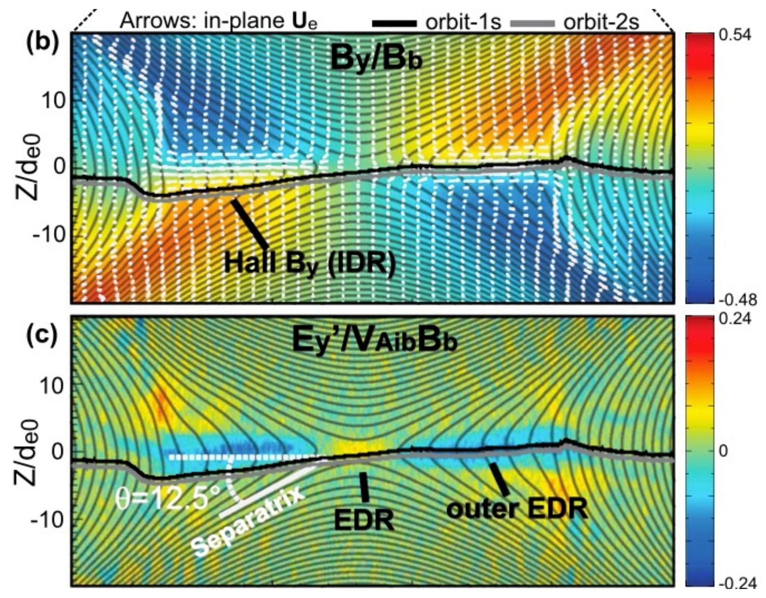


(Torbert, 2018)

- Decoupling of ion and electron dynamics within the diffusion region enables fast reconnection with a normalized rate of order 0.1

Defining the EDR Aspect Ratio

- The electron diffusion region is loosely defined as where the electrons decouple from the magnetic field (broken frozen-in flux condition)



PIC simulation of the July 11 event showing the inner and outer EDRs (Nakamura, 2018)

- In a quasi-steady state regime, reconnection occurs in two domains, the Central EDR, where reconnection occurs, accelerates electrons into extended jets (sometimes referred to as outer EDR) [2]
- The dynamics of the outer EDR are not well understood and it's unclear if it's diamagnetic drift or represents real bulk motion [8]
- We consider the limited case of the inner EDR to calculate the aspect ratio.

Calculating the EDR Aspect Ratio

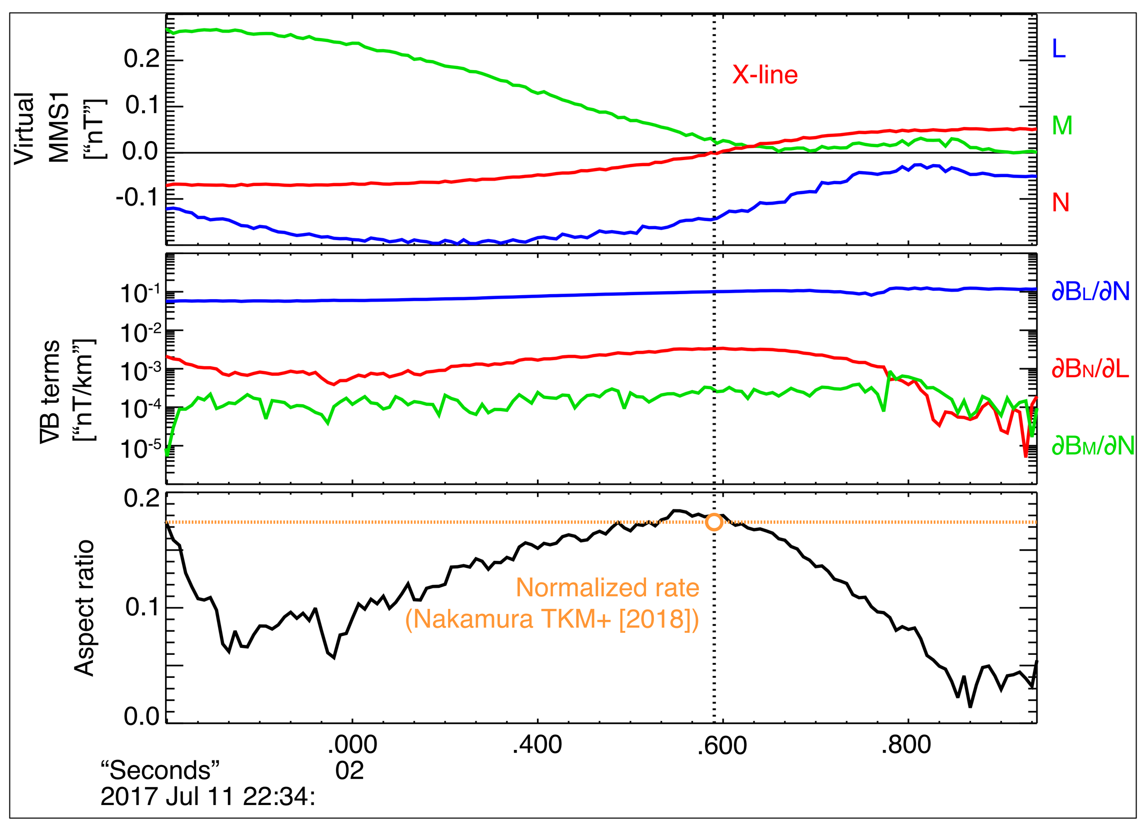
- *The EDR aspect ratio calculated as the ratio of the ΔN and ΔL magnetic field gradient scale lengths at/near the X-point.*
- Magnetic field gradient was reconstructed using the spatial interpolation method in [7] with LMN coordinates determined using maximum variance analysis of the electron bulk velocity (MVA-Ve) as found in [6]
- The dimensionality of the EDR is indicated by the $\partial B_N/\partial L$ and $\partial B_L/\partial N$ terms of the $(\nabla B)^2$ matrix in LMN coordinates. The aspect ratio R is then calculated as the ratio

$$R \sim \sqrt{(\partial B_L/\partial N)/(\partial B_N/\partial L)}$$

- In theory, this method should only work when the spacecraft trajectory passes through the reconnection X-line and the current sheet is exactly symmetric, eliminating off-axis terms of ∇B and leaving just the $\partial B_N/\partial L$ and $\partial B_L/\partial N$ terms

PIC simulation of July 11, 2017 EDR

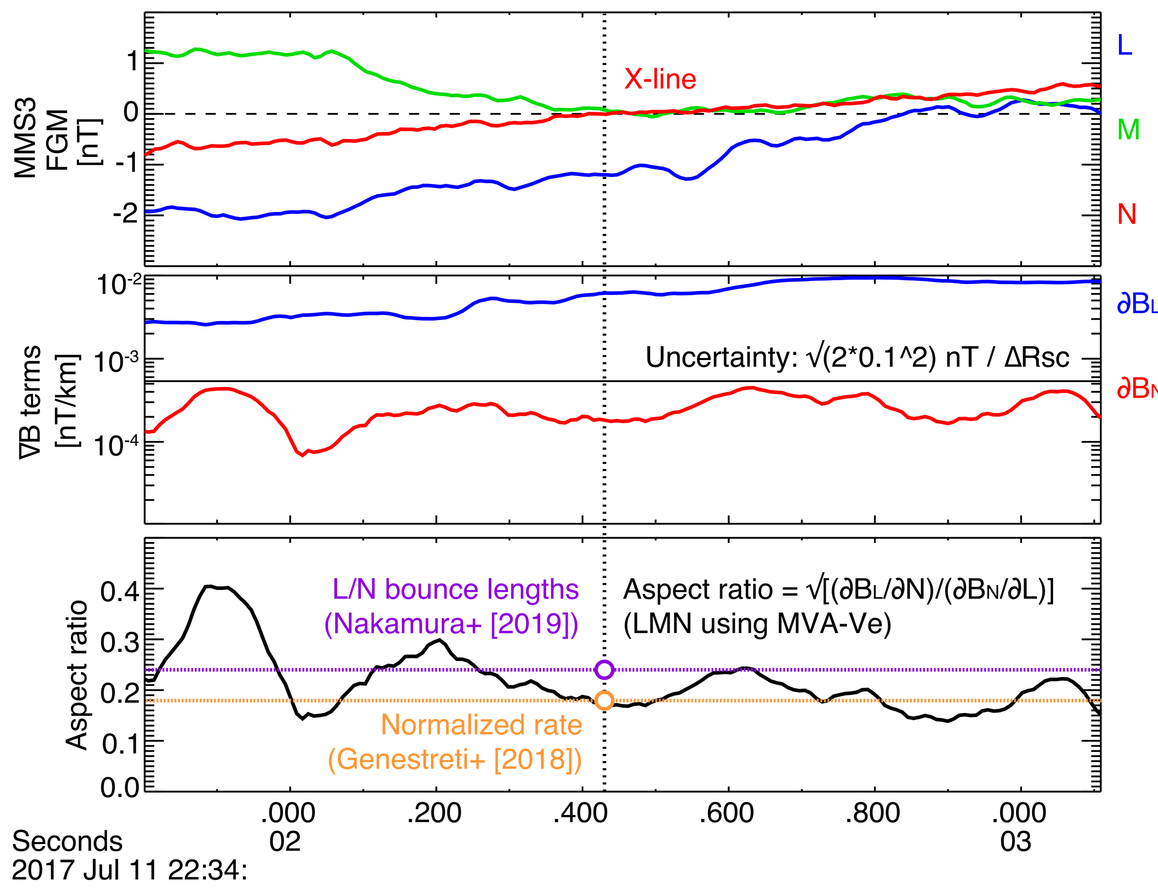
- $\partial B_N/\partial L$ and $\partial B_L/\partial N$ terms and EDR aspect ratio calculated along an MMS1 virtual trajectory with a particle-in-cell simulation of the July 11, 2017 reconnection event done by Nakamura, et al. [1]



- *The aspect ratio derived from simulation data found to be consistent with normalized rate from Nakamura 2018*

MMS Observations from July 11, 2017 EDR

- At ~22:34 UT on July 11, 2017 MMS encountered a symmetric reconnection event in the Earth's magnetotail with a weak guide field (small B_{M0}/B_{L0}) [3].
- MMS3 was the only spacecraft to cross the reconnection current sheet, providing the best measurements of the electron diffusion region around the reconnection X-line [1]



- *EDR aspect ratio calculated with MMS-derived LMN magnetic field spatial gradients is found to be consistent with published aspect ratios for the July 11 event.*
- $\partial B_N/\partial L$ term is below the nominal 0.1 nT field limit of the FGM instrument [4], but the actual uncertainty has been found to be substantially smaller [6]

Conclusions and Future Work

- *For the July 11 event, the EDR aspect ratio is very close to the normalized reconnection rate.* Additional work is needed to understand the accuracy of this technique.
- We need to analyze more events using this technique to understand what parameters control the EDR aspect ratio and whether it is always close to the normalized reconnection rate.
- Applying the technique to different virtual trajectories through the July 11 PIC simulation to determine how close to the X-line the spacecraft needs to cross
- Applying the technique to PIC simulations with different initial parameters to determine what current sheet asymmetry or guide field causes the calculation to break down.

References:

[1] Nakamura, R., et al. (2019). Structure of the current sheet in the 11 July 2017 Electron Diffusion Region event. Journal of Geophysical Research: Space Physics, 124 [2] Chen, L.-J., et al. (2008), Evidence of an extended electron current sheet and its neighboring magnetic island during magnetotail reconnection, J. Geophys. Res., 113 [3] R. B. Torbert et al., Science 10.1126/science.aat2998 (2018). [4] R.B. Torbert et al., The FIELDS Instrument Suite on MMS: Scientific Objectives, Measurements, and Data Products. Space Science Reviews. 199:105-135. 2016 [5] Genestreti, K. J., et al. (2018). How accurately can we measure the reconnection rate EM for the MMS diffusion region event of 11 July 2017?. Journal of Geophysical Research: Space Physics, 123. [6] Shi, Q.Q., et al., (2005) Dimensional analysis of observed structures using multipoint magnetic field measurements: Application to Cluster, GEOPHYSICAL RESEARCH LETTERS, VOL. 32 [7] Chanteur, G. (1998), Spatial interpolation for four spacecraft: Theory, in Analysis Methods for Multi-spacecraft Data, p. 349, Int. Space Sci. Inst., Bern. [8] P.A. Cassak and S.A. Fuselier, (2016) Reconnection at Earth's Dayside Magnetopause in Magnetic Reconnection : Concepts and Applications, edited by Walter Gonzalez, and Eugene Parker, Springer, 2016.