The structure of a perturbed magnetic reconnection electron diffusion region

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MMS observations of the Electron Diffusion Region: **laminar** EDR

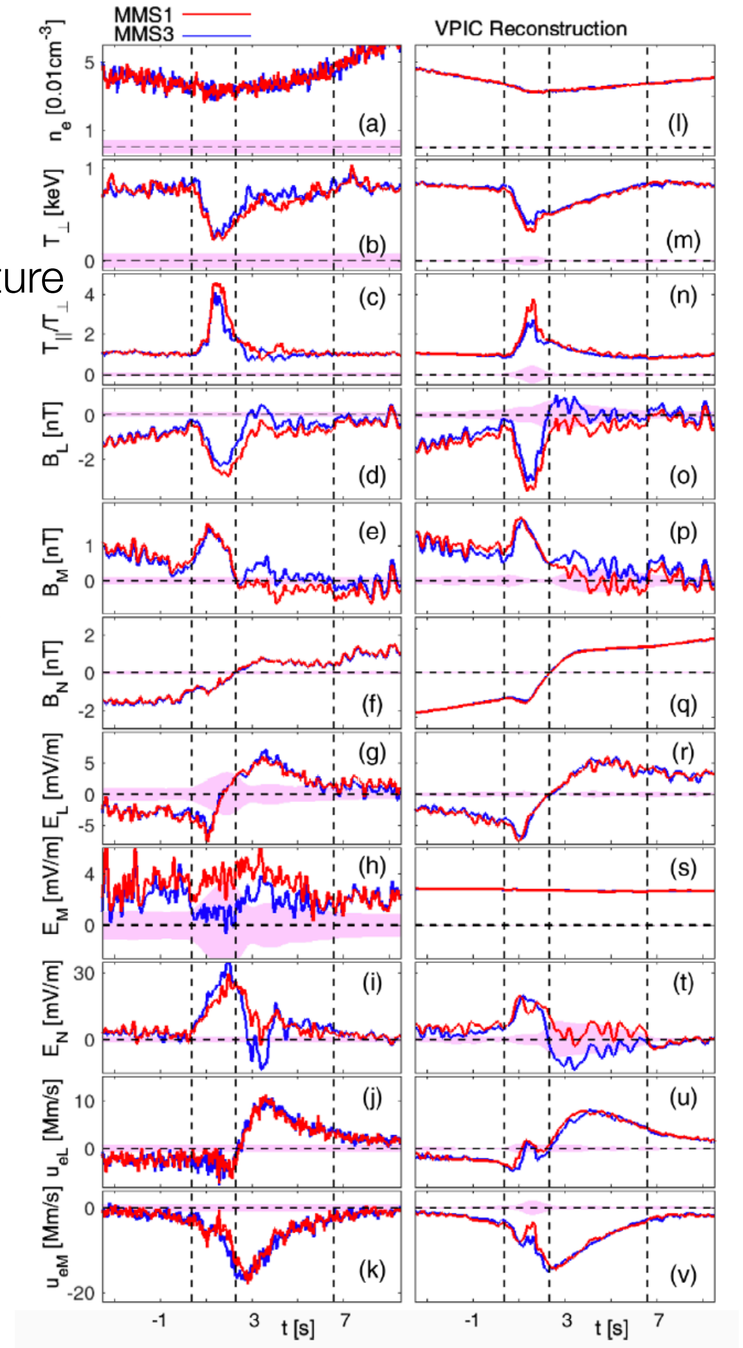
Density

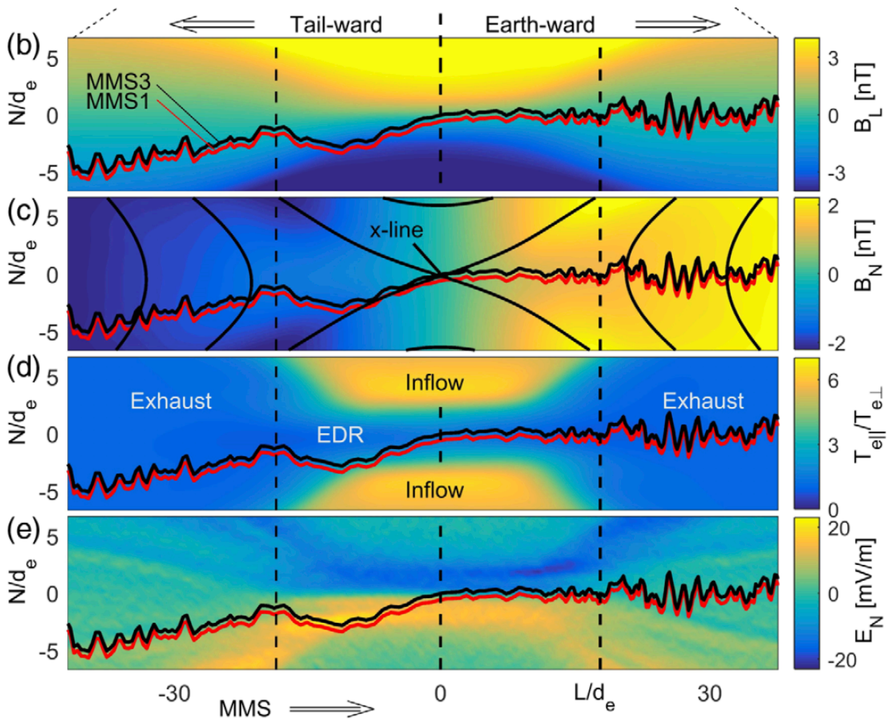
Temperature

Magnetic field

Electric field

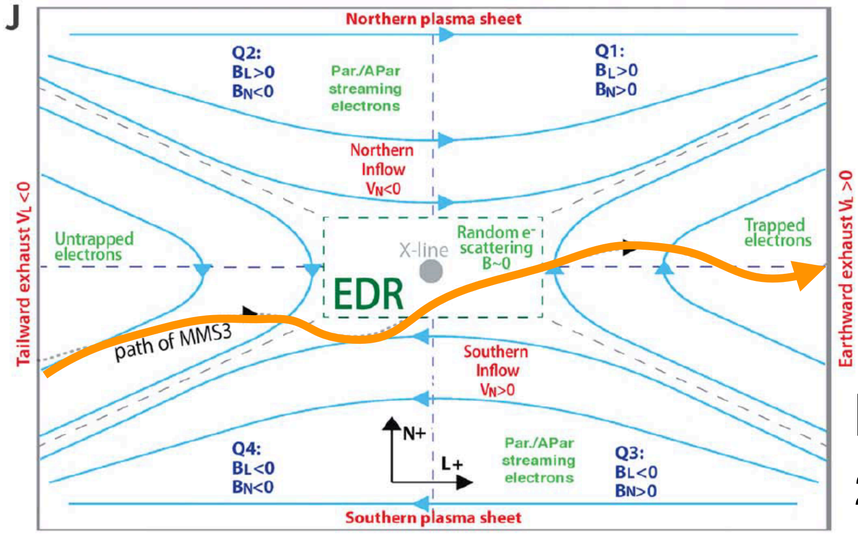
Electron Velocity



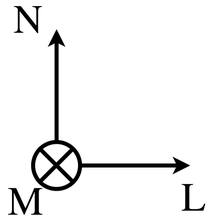


2D PIC simulations

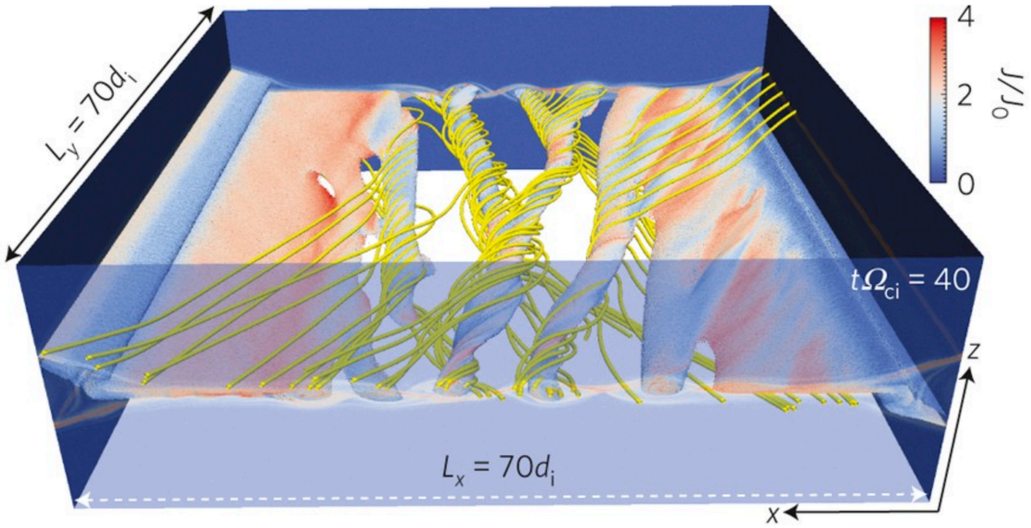
[Egedal et al., PRL, 2019]



[Torbert et al., Science, 2018]

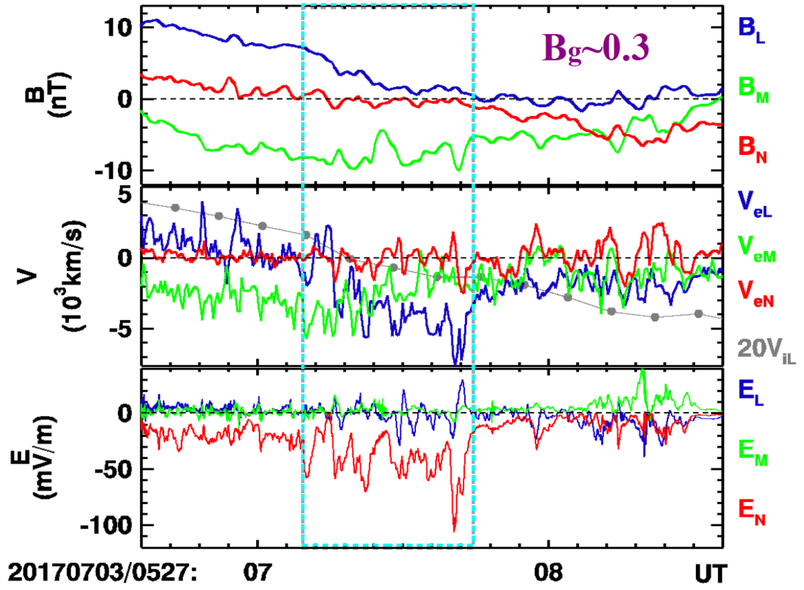


Is the 2D description enough to understand magnetic reconnection?



[Daughton et al., Nature, 2011]

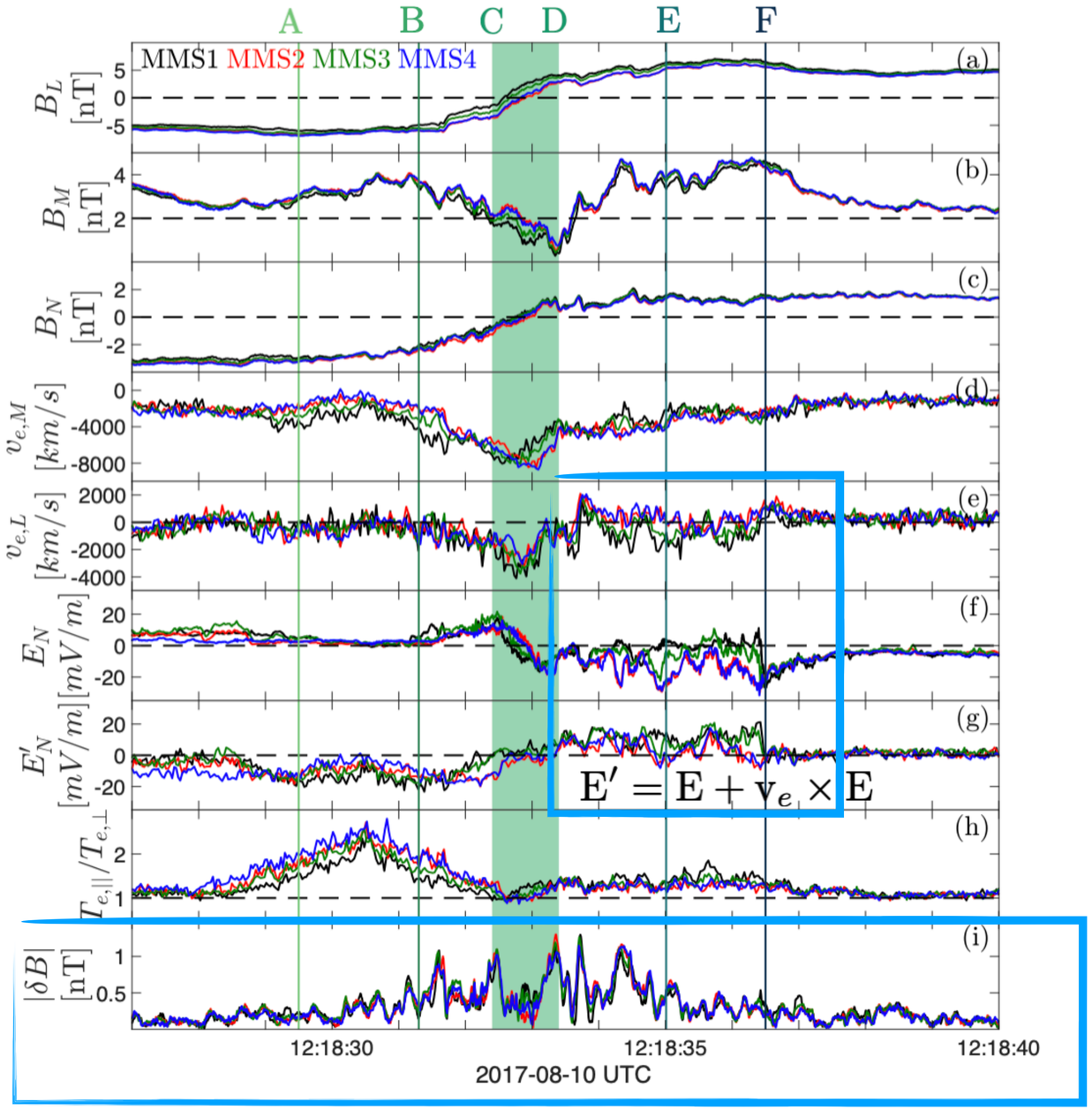
What is the role of waves and instabilities in shaping the EDR structure and the overall reconnection process?

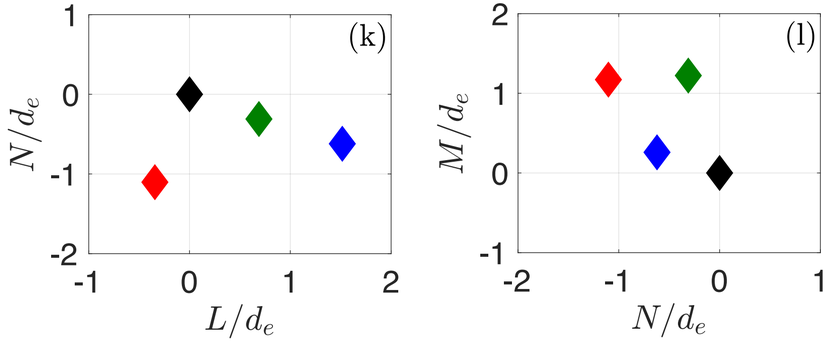


[Chen et al., PRL, 2020]

[Khotyaintsev et al., PRL, 2019]

This EDR is characterised by significant **magnetic field fluctuations** and **large, non-constant differences** between observations at **different spacecraft**

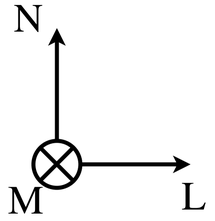


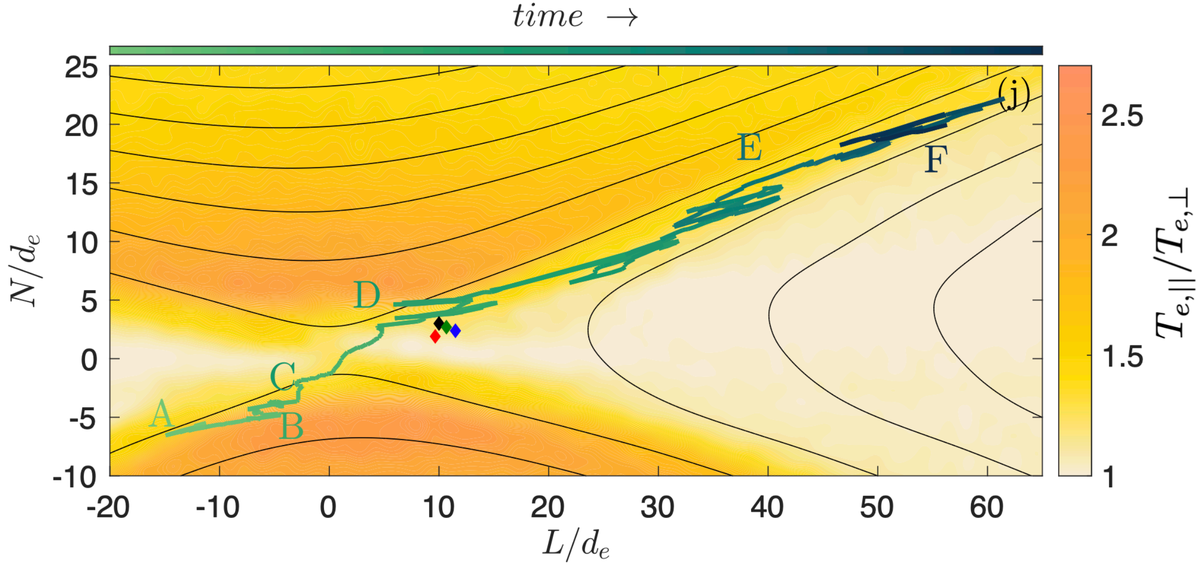


Inter-spacecraft separation ~ 20 km

$d_e \sim 13$ km

$d_{CS} \sim 2\ d_e$



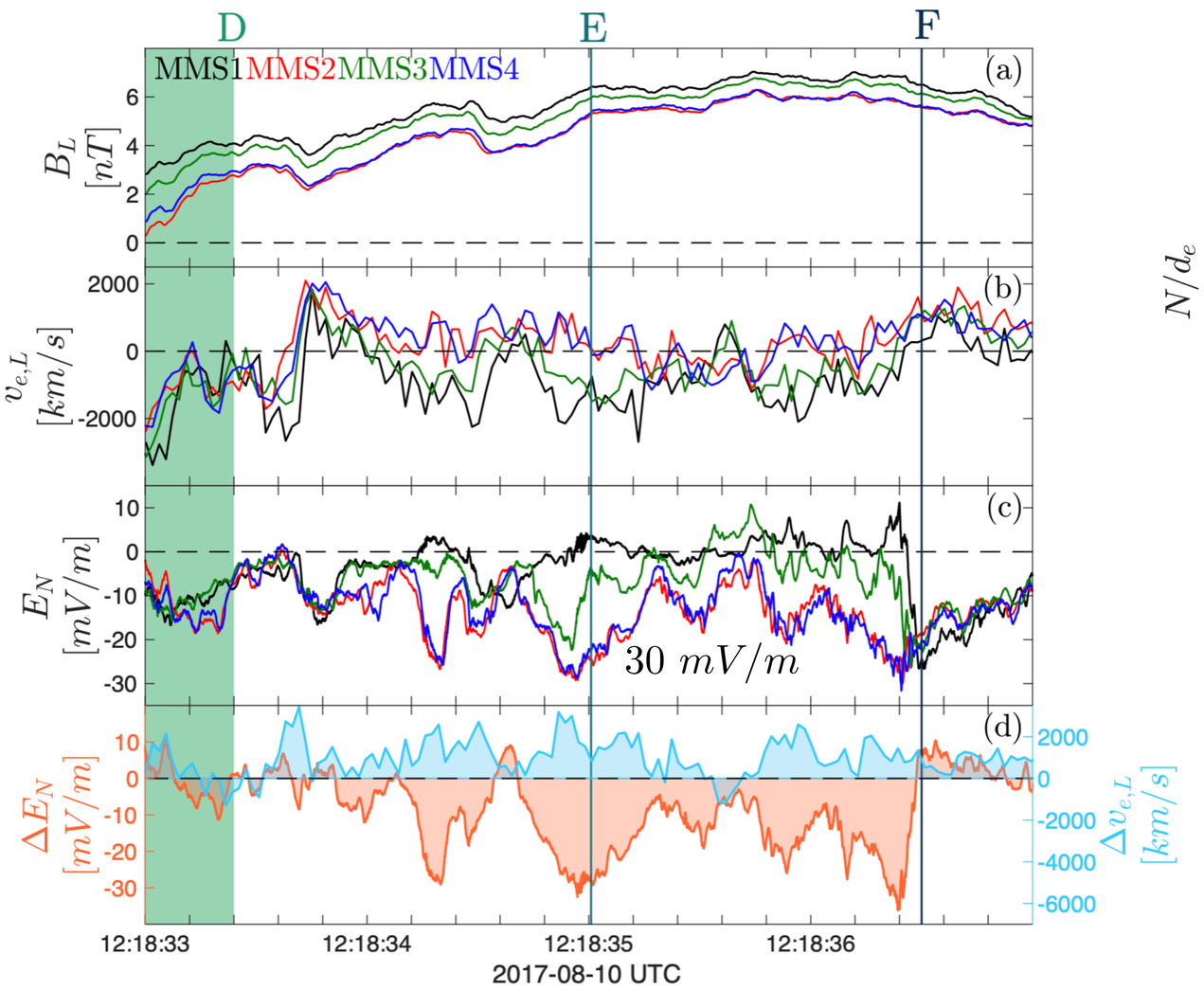


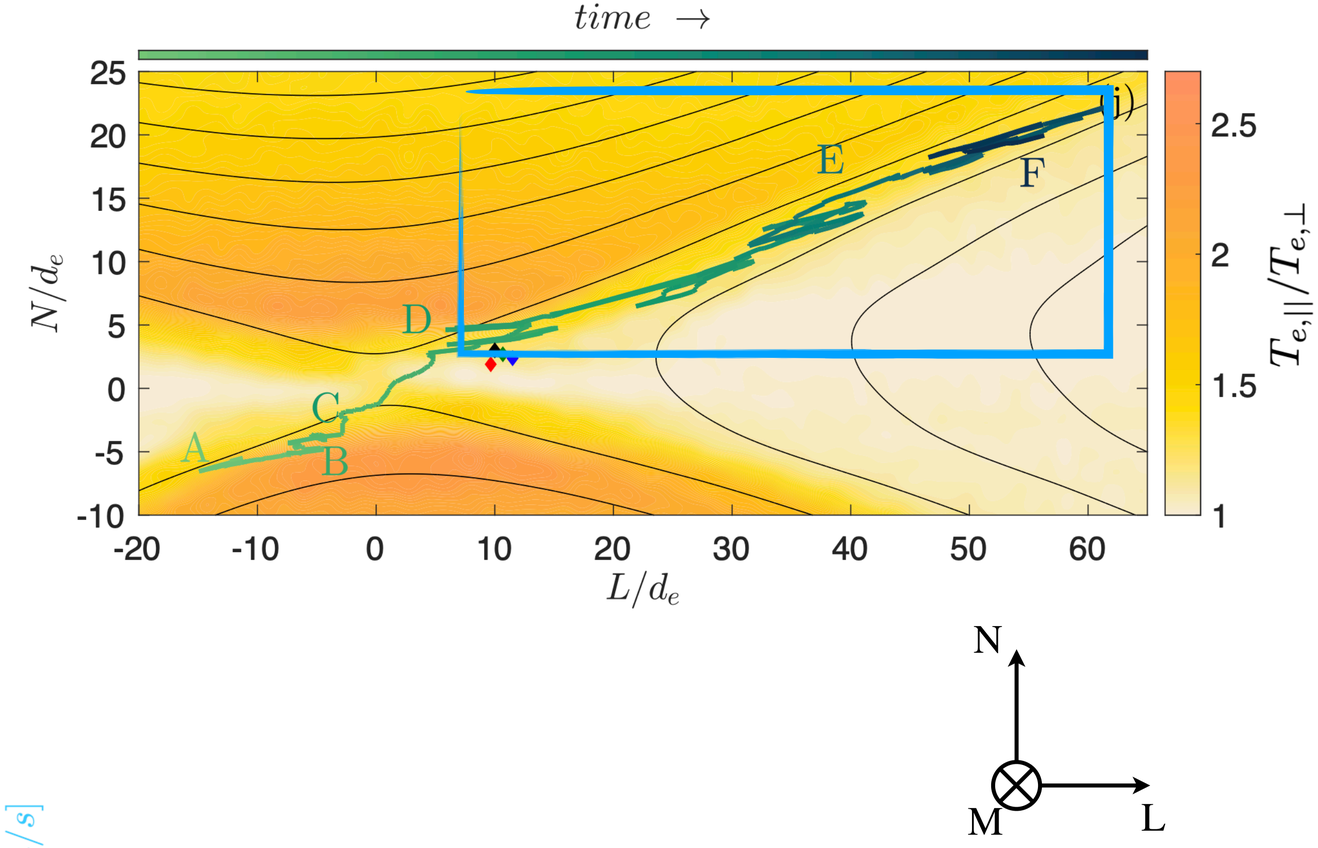
2D PIC simulation [Le et al., PRL, 2013]

EDR reported by: [Zhou et al., ApJ, 2018]

$m_i/m_e = 1836$

We observe **large, non-constant differences** between observations at **different spacecraft** in a region of **electron-scale gradients**



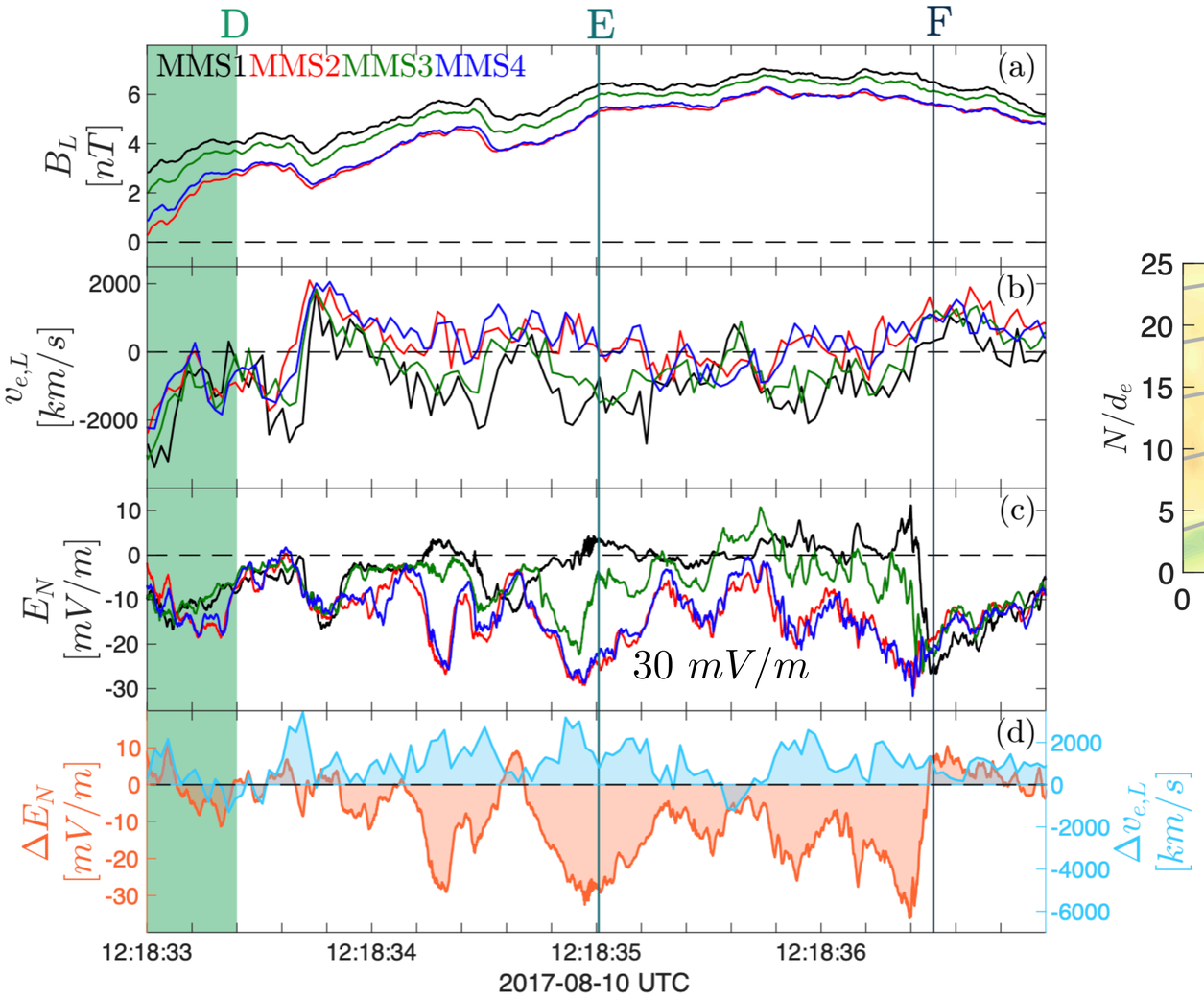


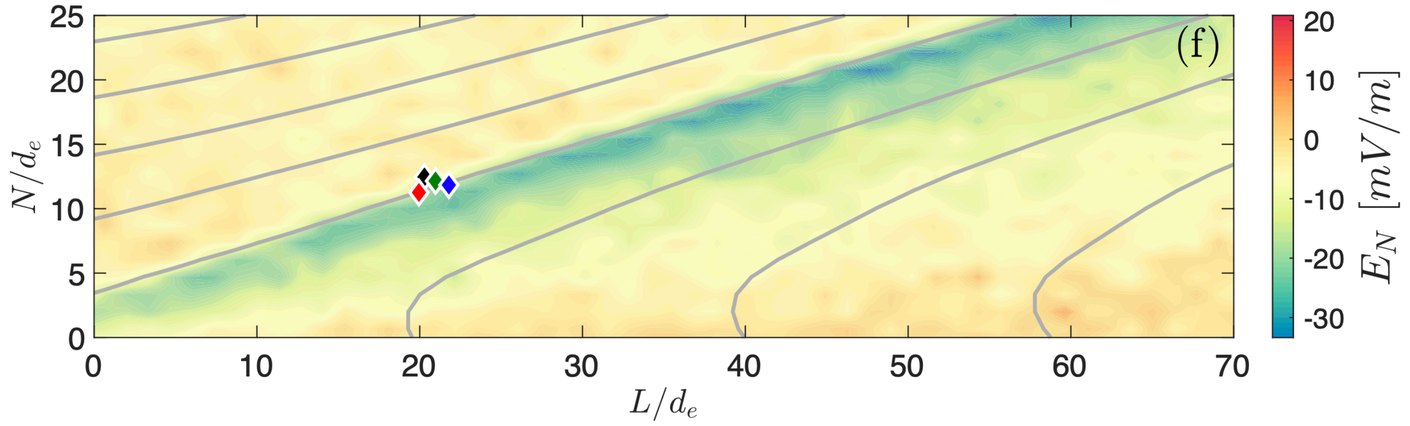
Mean scale associated to the gradients

$$L_{E_N} = \langle E_N \rangle \left(\frac{\partial E_N}{\partial N}\right)^{-1} \sim 7\ km \sim 0.5\ d_e$$

$$\Delta E_N = E_{N,MMS2} - E_{N,MMS1}$$
$$\Delta v_{e,L} = v_{e,L,MMS2} - v_{e,L,MMS1}$$

The **strong electron-scale gradients** observed **in situ** are present also in the **simulation** data





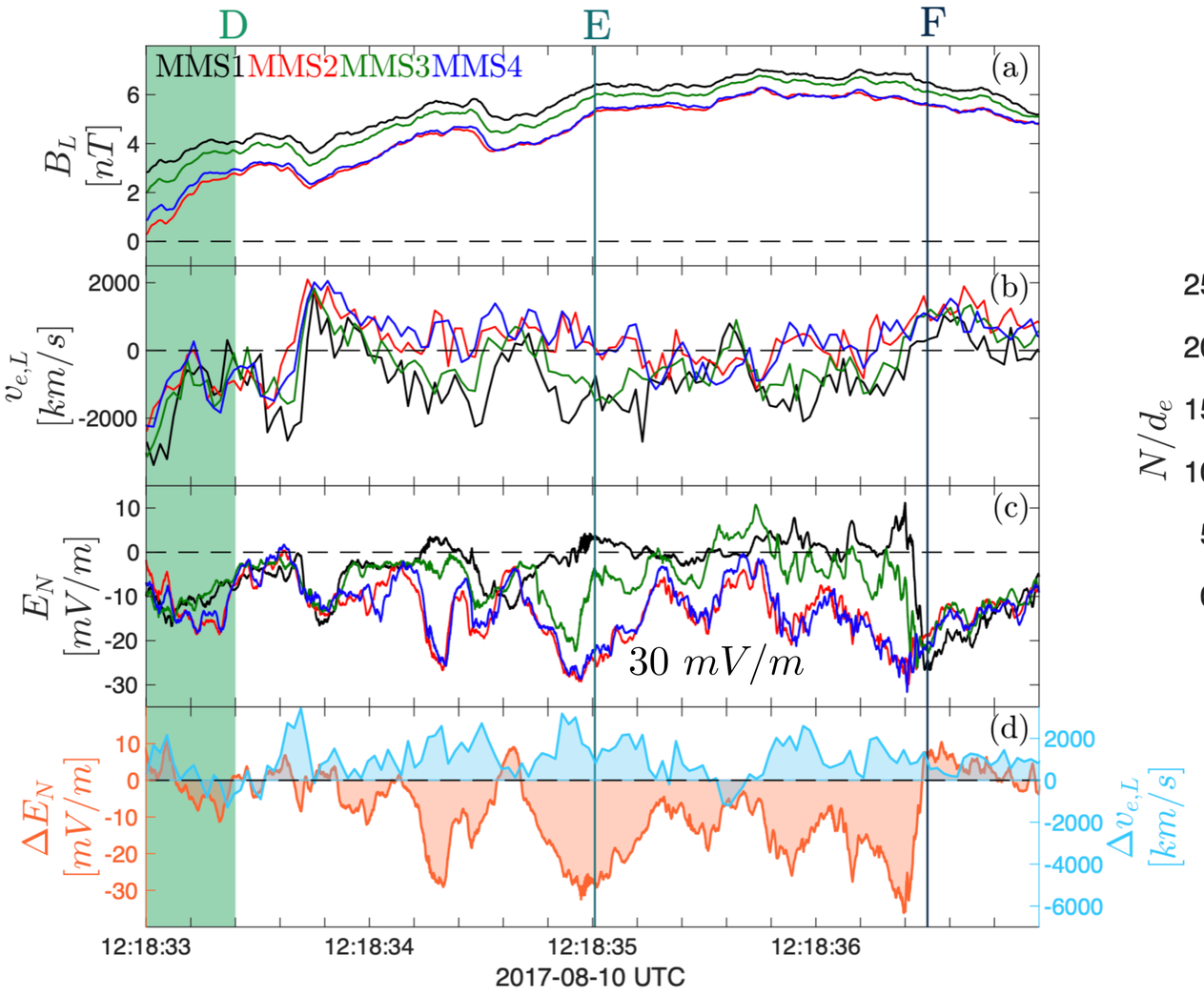
$$\Delta E_N = E_{N,MMS2} - E_{N,MMS1}$$

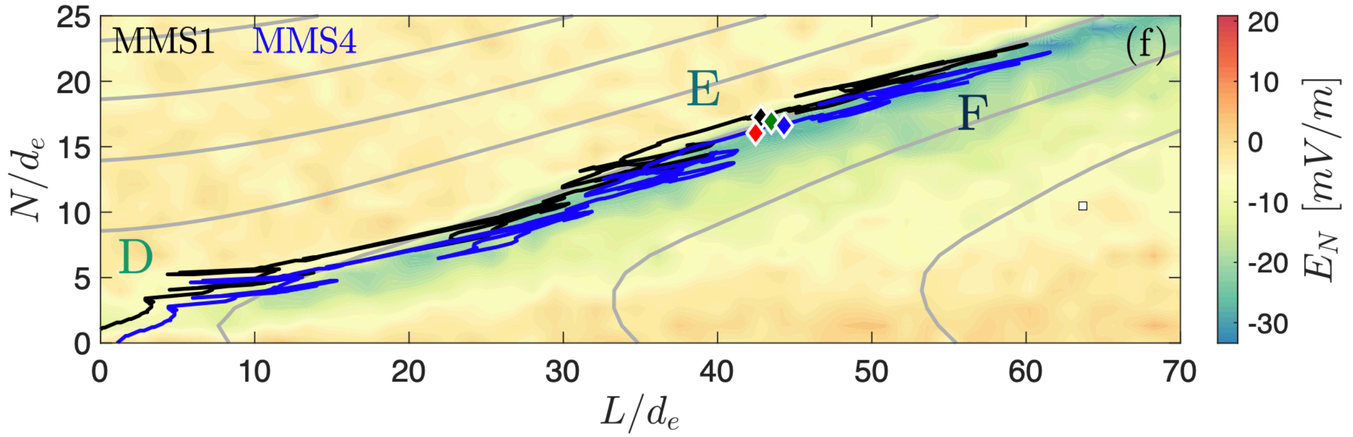
$$\Delta v_{e,L} = v_{e,L,MMS2} - v_{e,L,MMS1}$$

Mean scale associated to the gradients

$$L_{E_N} = \langle E_N \rangle \left(\frac{\partial E_N}{\partial N}\right)^{-1} \sim 7\ km \sim 0.5\ d_e$$

A good agreement between the in situ observations and the 2D PIC simulation data is obtained with a **complex trajectory**





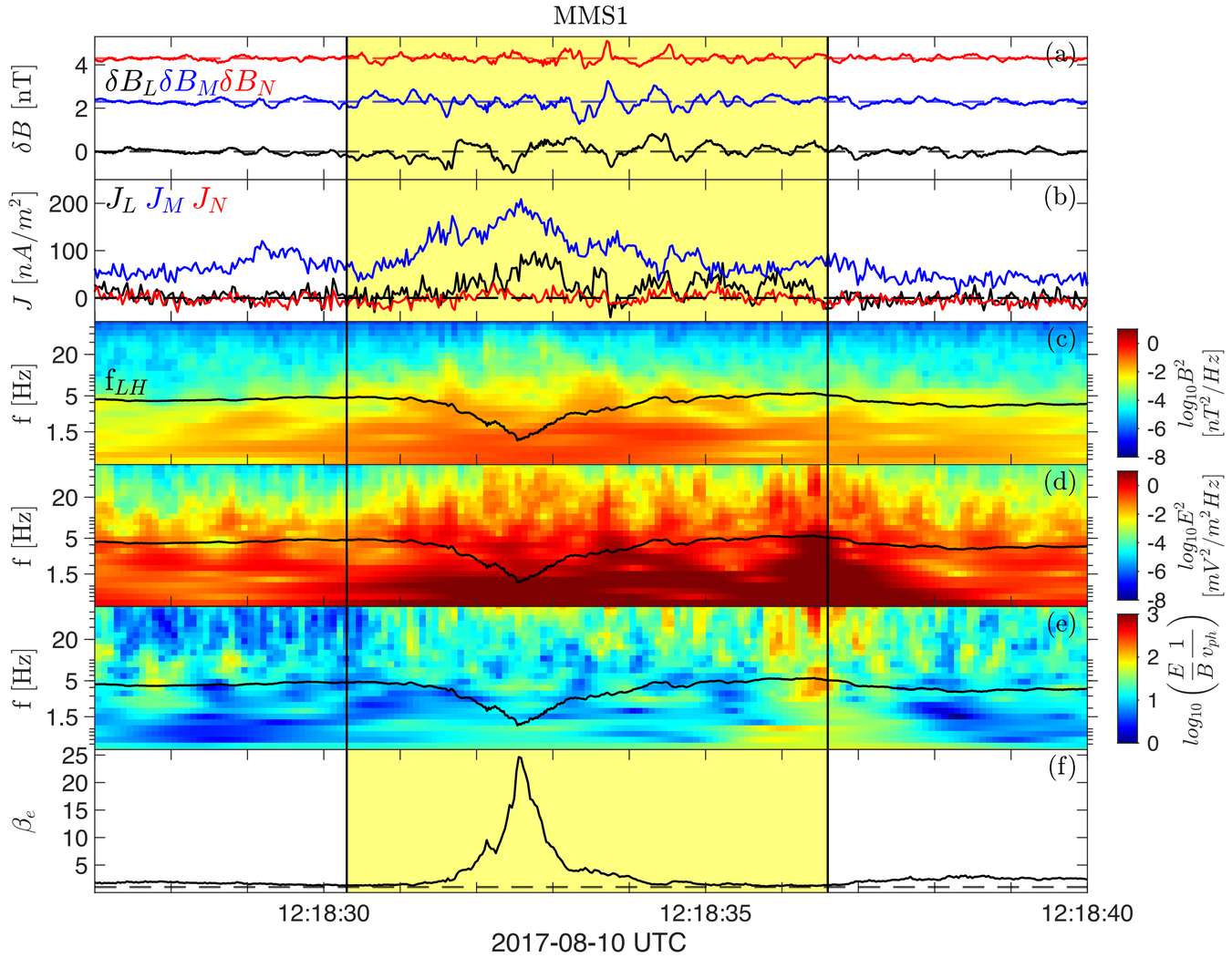
$$\Delta E_N = E_{N,MMS2} - E_{N,MMS1}$$

$$\Delta v_{e,L} = v_{e,L,MMS2} - v_{e,L,MMS1}$$

Mean scale associated to the gradients

$$L_{E_N} = \langle E_N \rangle \left(\frac{\partial E_N}{\partial N}\right)^{-1} \sim 7\ km \sim 0.5\ d_e$$

Electromagnetic fluctuations with $f \sim f_{LH}$ and **long wavelength** are observed in the center of the current sheet



$$\log_{10}\left(\frac{E}{B}\frac{1}{v_{ph}}\right) \rightarrow 0 \quad \text{Electromagnetic}$$

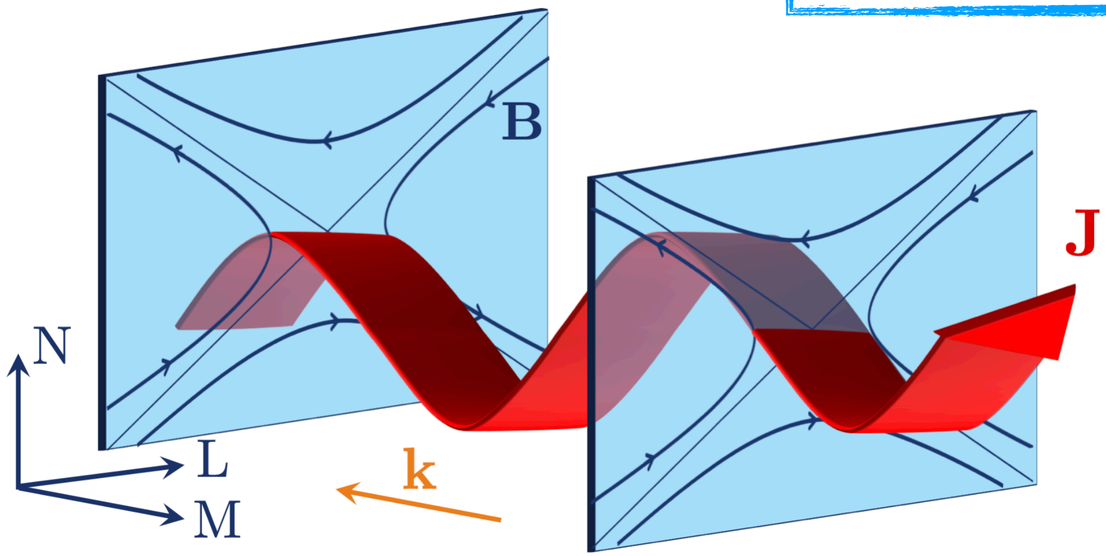
$$|\mathbf{k}|\rho_e \sim 0.3$$

$$|\mathbf{k}|\sqrt{\rho_e \rho_i} \sim 2.2$$

$$\hat{\mathbf{k}} = [0.12, -0.92, 0.38](LMN)$$

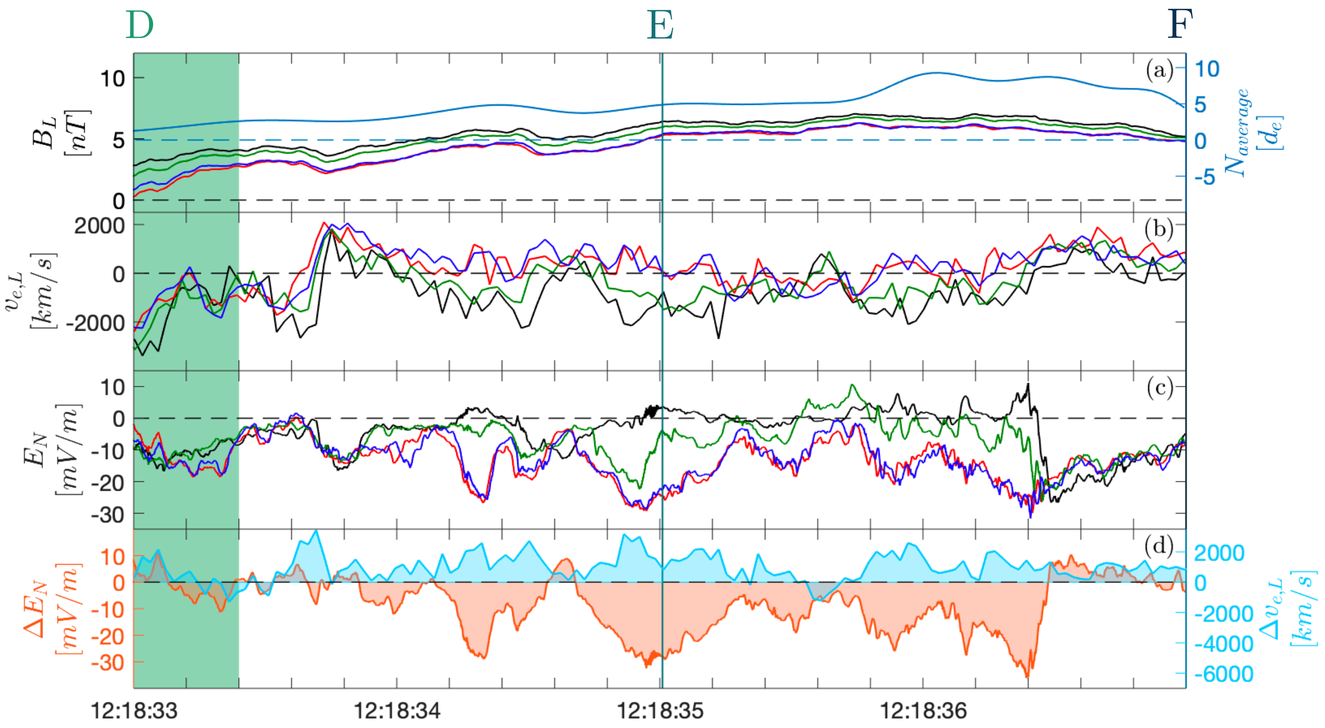
The fluctuations propagate **in the out-of-plane direction**

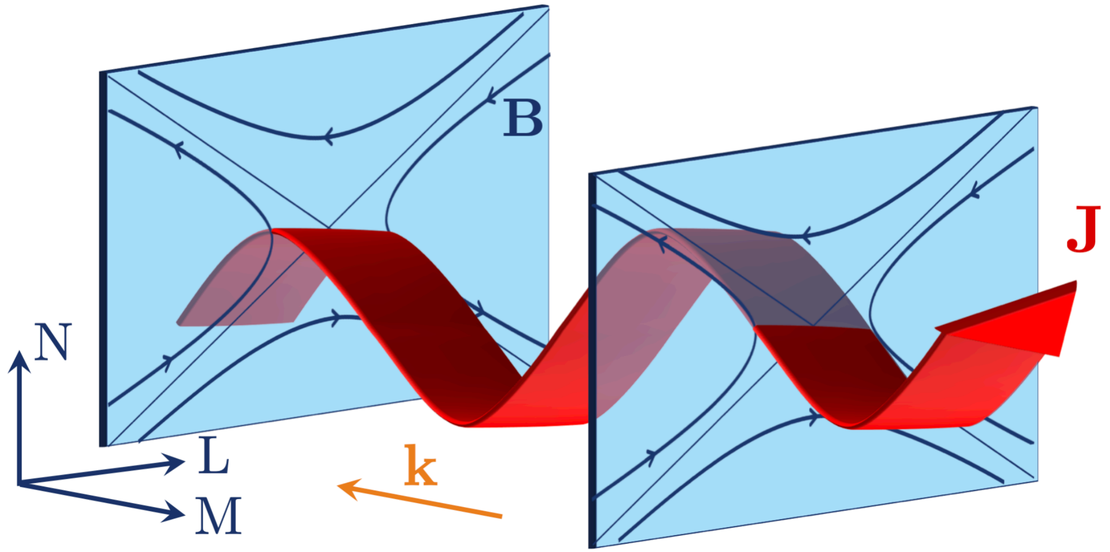
Current sheet **kink modes** ⟶ **3D dynamics**



[Yoon et al., Phys. Plasmas, 2002]
[Daughton, Phys. Plasmas, 2003] [Shinoara et al., PRL, 2001]

In conclusion, we report MMS observations of a disturbed EDR crossing in the Earth's magnetotail





We observe fluctuations of the electric, magnetic and velocity fields which are **not included** in steady state **2D** reconnection.

The observations can be explained by electromagnetic fluctuations inducing the **kinking of the current sheet** in the **out-of-reconnection-plane direction**.

These results suggest that it is needed to take into account the **three-dimensionality** of the system to understand the reconnection process.

Thank you for your attention!

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[Cozzani et al., submitted to PRL, ArXiv: 2103.12527]