TWO CLASSES OF MAGNETOTAIL DIPOLARIZATION FRONTS OBSERVED BY MAGNETOSPHERIC MULTISCALE MISSION
A STATISTICAL OVERVIEW

Laboratoire de Physique des Plasmas

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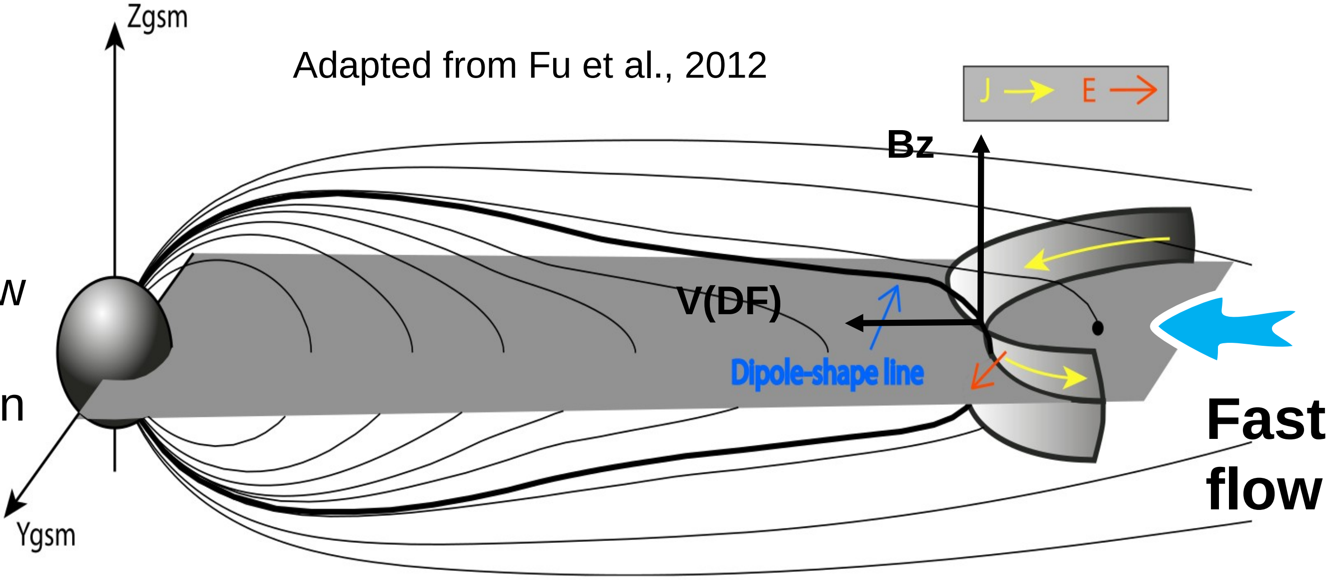
soboh.al-qeeq@lpp.polytechnique.fr

S. W. Alqeeq, O. Le Contel, P. Canu, A. Retinò, T. Chust, L. Mirioni, A. Chuvatin, R. Nakamura, N. Ahmadi, F. D. Wilder, D. J. Gershman, Yu. V. Khotyaintsev, P.-A. Lindqvist, R. E. Ergun, J. L. Burch, R. B. Torbert, S. A. Fuselier, C. T. Russell, H. Y. Wei, R. J. Strangeway, K. R. Bromund, D. Fischer, B. L. Giles, and Y. Saito

Dipolarization Front (DF)

- Sharp increase in the northward component of the magnetic field (Zdirection)
- associated with a fast plasma flow
- can be generated by reconnection or kinetic ballooning interchange instability.
- DF corresponds to a boundary between a relatively cold and dense plasma at rest and a hot tenuous fastly moving plasma.



Adapted from Fu et al., 2012

Typical DF properties
V(DF) ~ 200 km/s
Thickness ~ 500 km
Crossing time ~ 2.5 s

[e.g., Runov et al., 2009 using THEMIS; Fu et al., 2012 using Cluster]

One MMS DF example 16:46:30-16:49:00 UT

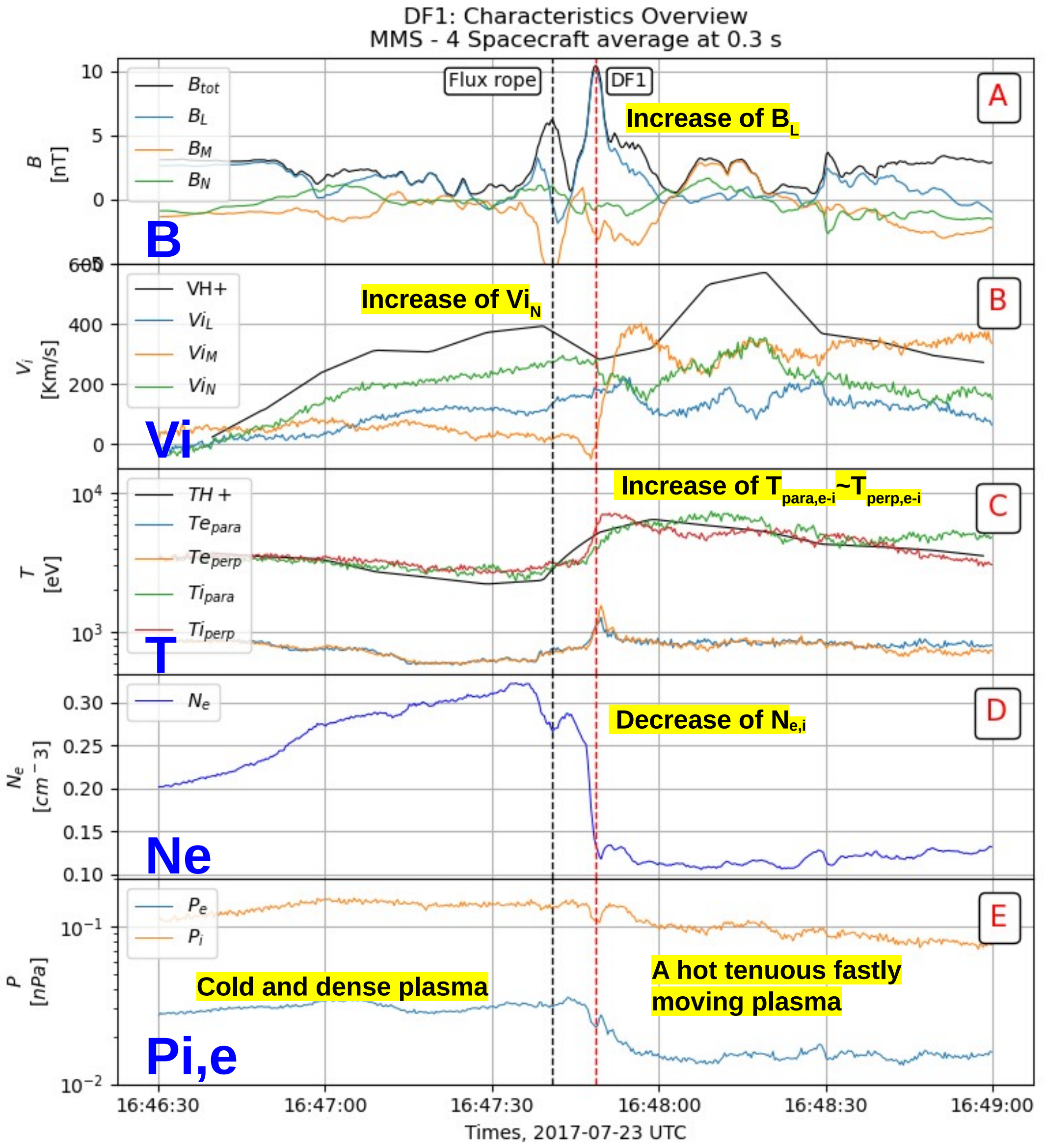
Alqeeq et al., POP 2022

DF/fast flow properties

[e. g., Runov et al., 2009, Sergeev et al., 2009]

MVAB analysis on 4 s/c averaged data between (16:47:45/16:48:00)

LMN frame of DF:
L =(0.14, 0.63, 0.76)
M=(0.13,-0.78, 0.62)
N=(0.98, 0.01, -0.19)



DF1: Characteristics Overview
MMS - 4 Spacecraft average at 0.3 s

Increase of B_L

Increase of Vi_N

Increase of $T_{para,e-i}$~$T_{perp,e-i}$

Decrease of $N_{e,i}$

Cold and dense plasma

A hot tenuous fastly moving plasma

The main objective

- In order to extend these case study results, I have carried out a statistical analysis over the full 2017 magnetotail season.

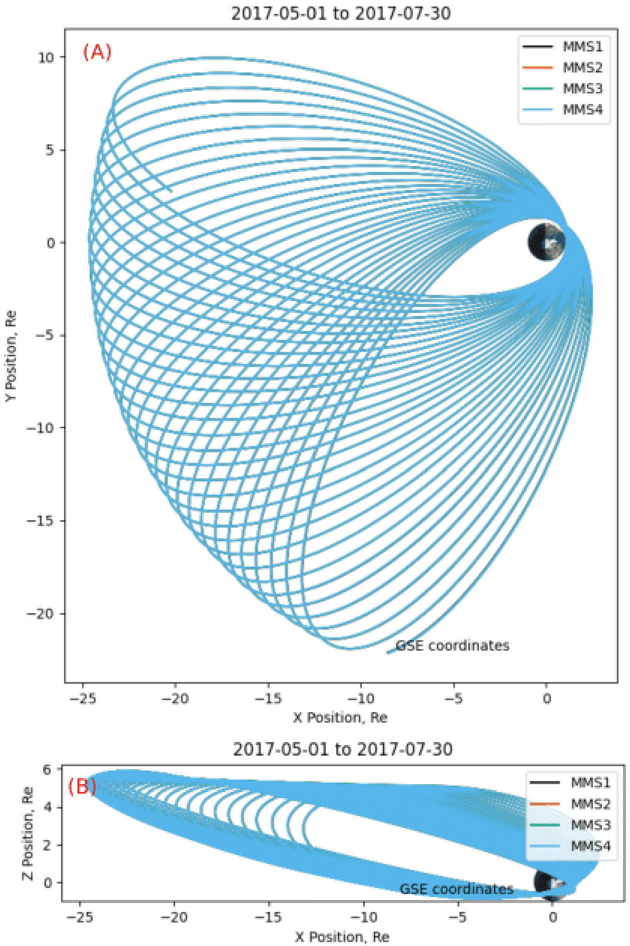
- In particular, the energy conversion process and its homogeneity at electron scales are investigated

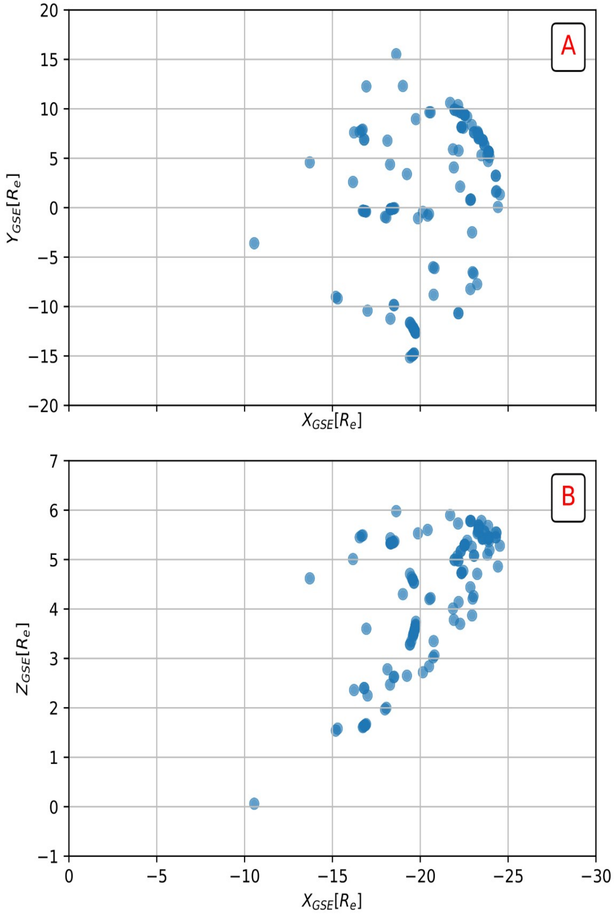
Selection criteria : A statistical study of DFs

Alqeeq et al., JGR 2023

- More than 800 “possible DF” events detected near the Earth’s magnetotail equator (|**Bx**|<5nT), using an AIDApy tool requesting **Bz** and **Vi** increases and **Ne** decrease.

- **This first automatic selection is then adjusted manually with the following criteria leading to only 132 DF events:**
- Burst mode (partmoms) data are available at least 30s before and after the DF. The head of the DF denotes the time t0.
- **Bz** increase > 5 nT
- **Vi** > 150 km/s
- $\mathbf{N_{e,i}}$ decrease
- $\mathbf{T_{para,e-i}} \sim \mathbf{T_{perp,e-i}}$ increases.



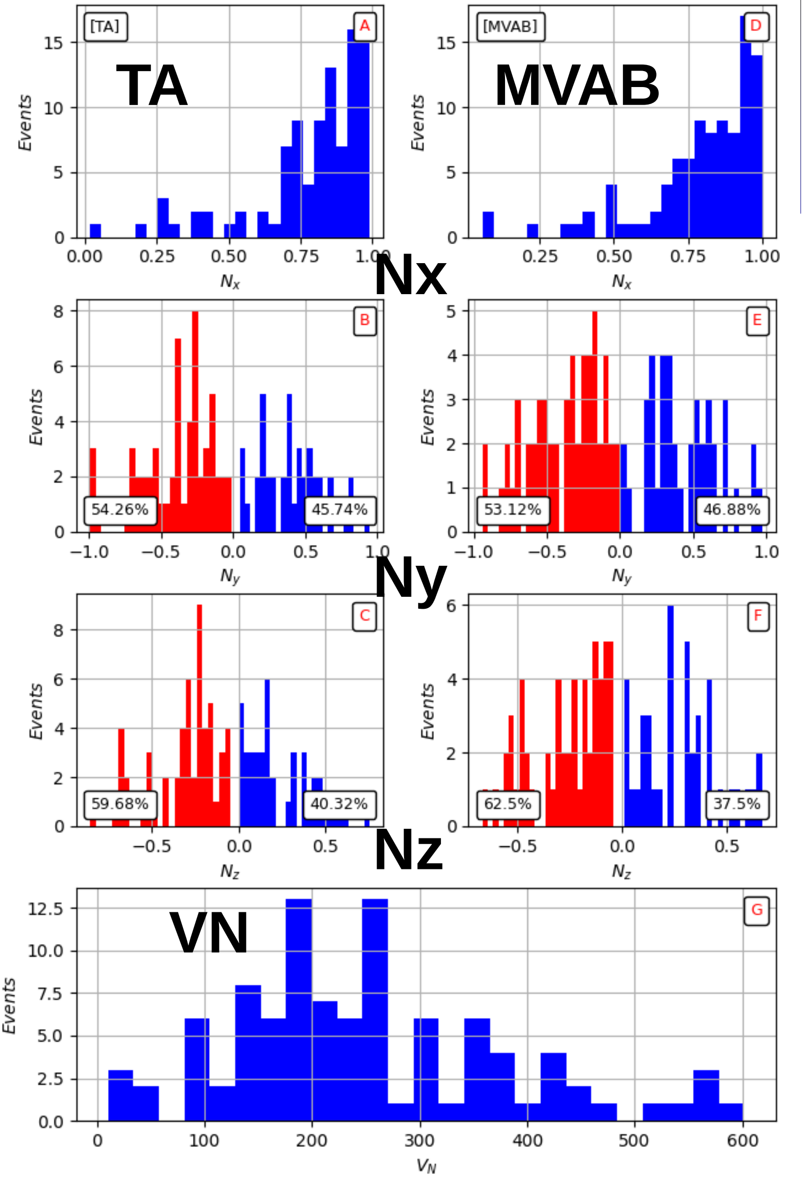


Methods

- MVAB and TA methods are applied on magnetic field data. They give similar front normal.
- MVAB was set to be:
  L : always oriented northward
  M: directed dawnward
  N: earthward

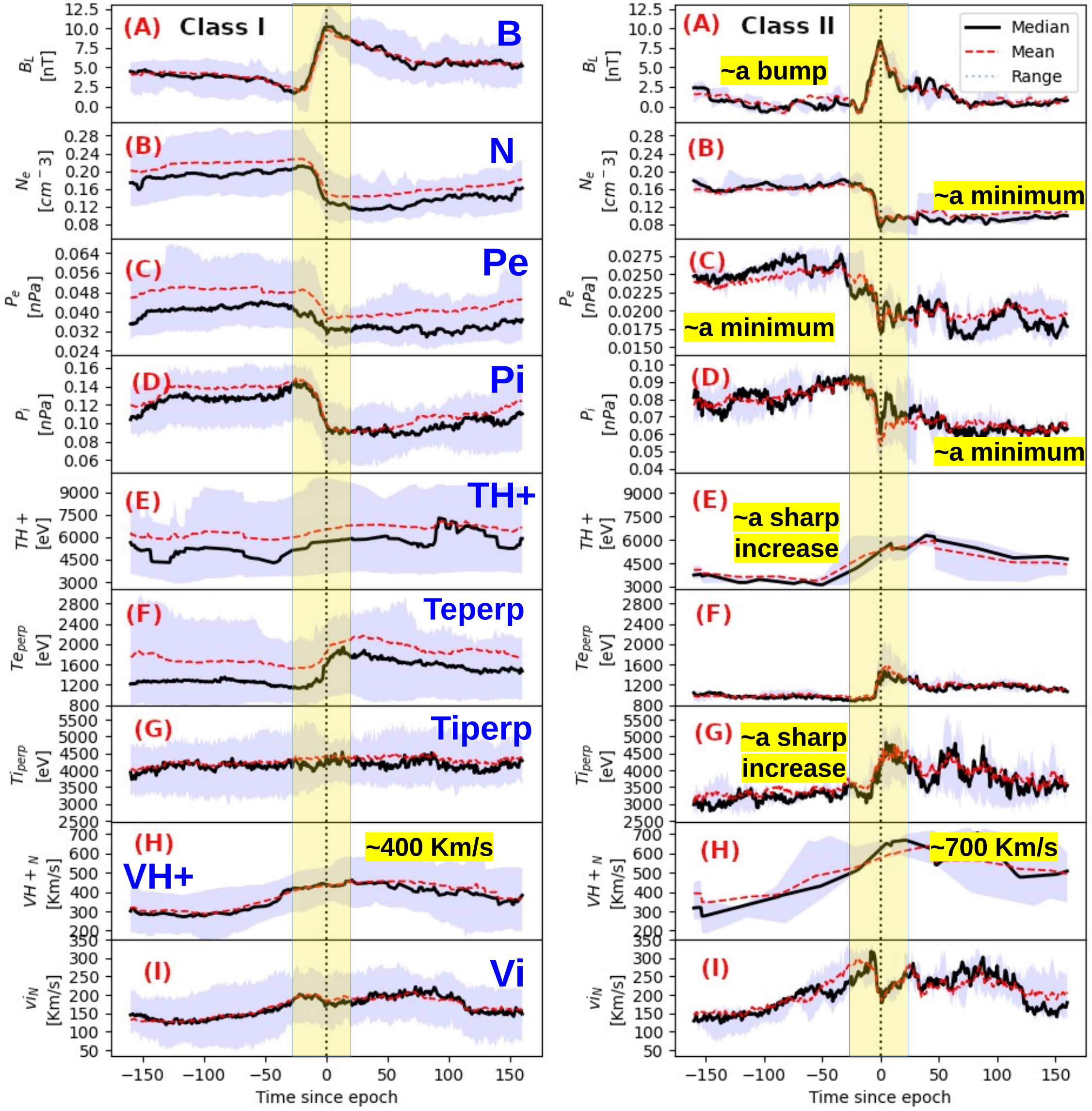
- **Almost no preferential directions of propagation along y and z.**

- **Ny: ~ (+) 54% , ~ (-) 46%**
- **Nz: ~ (+) 60% , ~ (-) 40%**
- **VN: ~200 km/s**



Two classes of magnetotail DFs

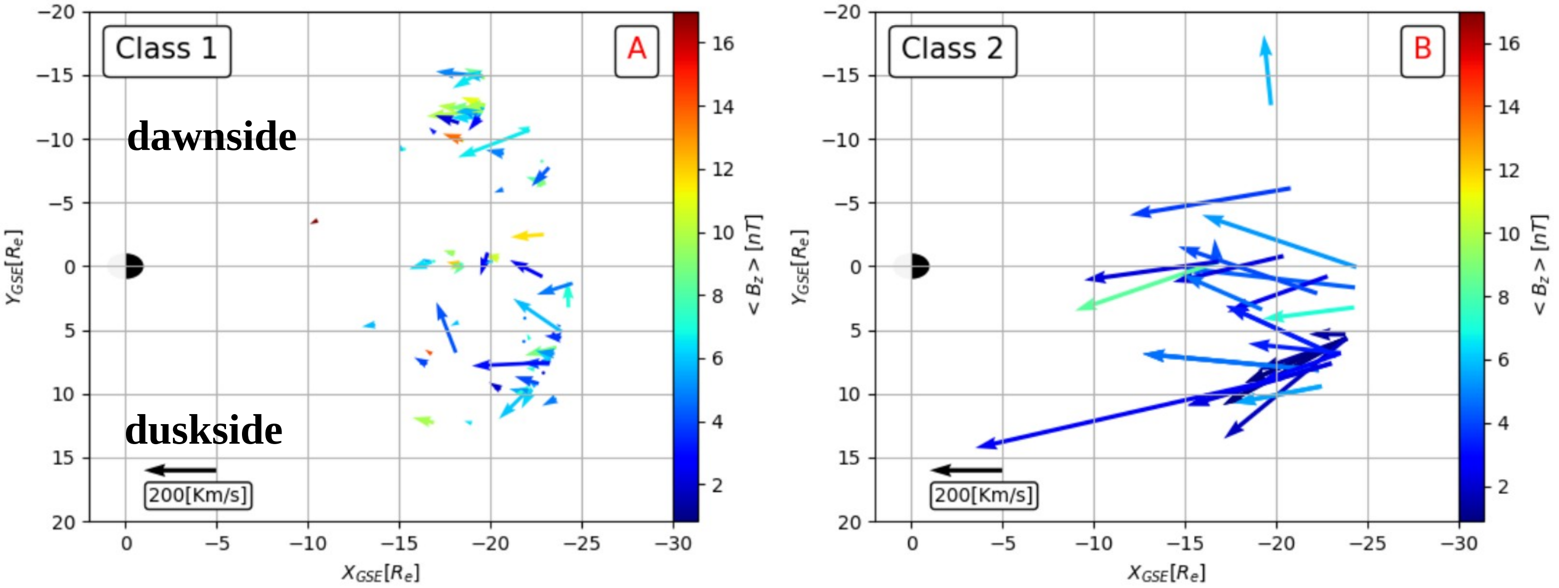
- **Class I "classic type"** (74.4%) corresponds to a slow decrease of the magnetic field after the DF and is associated with smaller ion velocity and hotter plasma [e. g., Schmid et al.,2015; Huang et al.,2015; Yao et al.,2015; Zhong et al.,2019].
- **Class II "new type"** (25.6%) has the same time scale for the rising and the falling of the magnetic field (a bump) associated with a minimum of ion and electron pressures and faster velocity [S. W ALQEEQ et al.,2022].



An overview of the Class I and Class II events

- **Class I** DF locations and propagations are relatively **random**
- **Class II** DF have preferentially **duskward locations** and propagations with **larger velocities**.

Equatorial XY GSE Plane



Current density comparisons

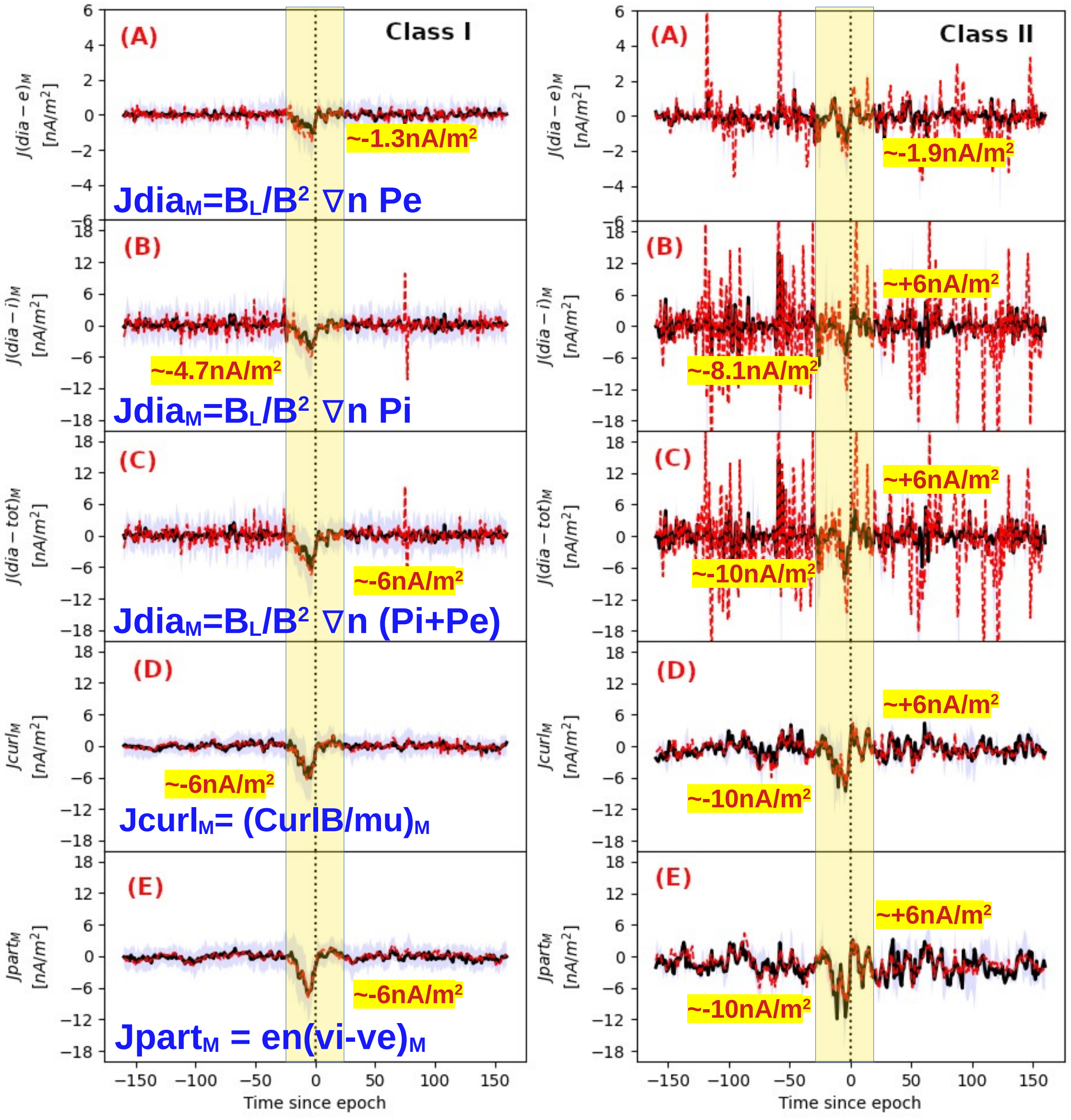
MMS - 4 Spacecraft average at 0.3s

For both classes:

Small values but good agreement within <10nA/m2

Ion diamagnetic current is dominant (~72%)

In Class II the reversal in Jpart$_M$ (E) & Jcurl$_M$ (D) is due to the reversal of the diamagnetic current (C), dominated by ions (B)



Ion Ohm’s Law

$$\boxed{\mathbf{E} + \mathbf{v_i} \times \mathbf{B}} = \boxed{\frac{\mathbf{J} \times \mathbf{B}}{en}} - \boxed{\frac{1}{en}\nabla \cdot \mathbf{P_e}} - \boxed{\cancel{\frac{m_e}{e}\frac{d\mathbf{v_e}}{dt}}}$$

Ideal ion frozen-in

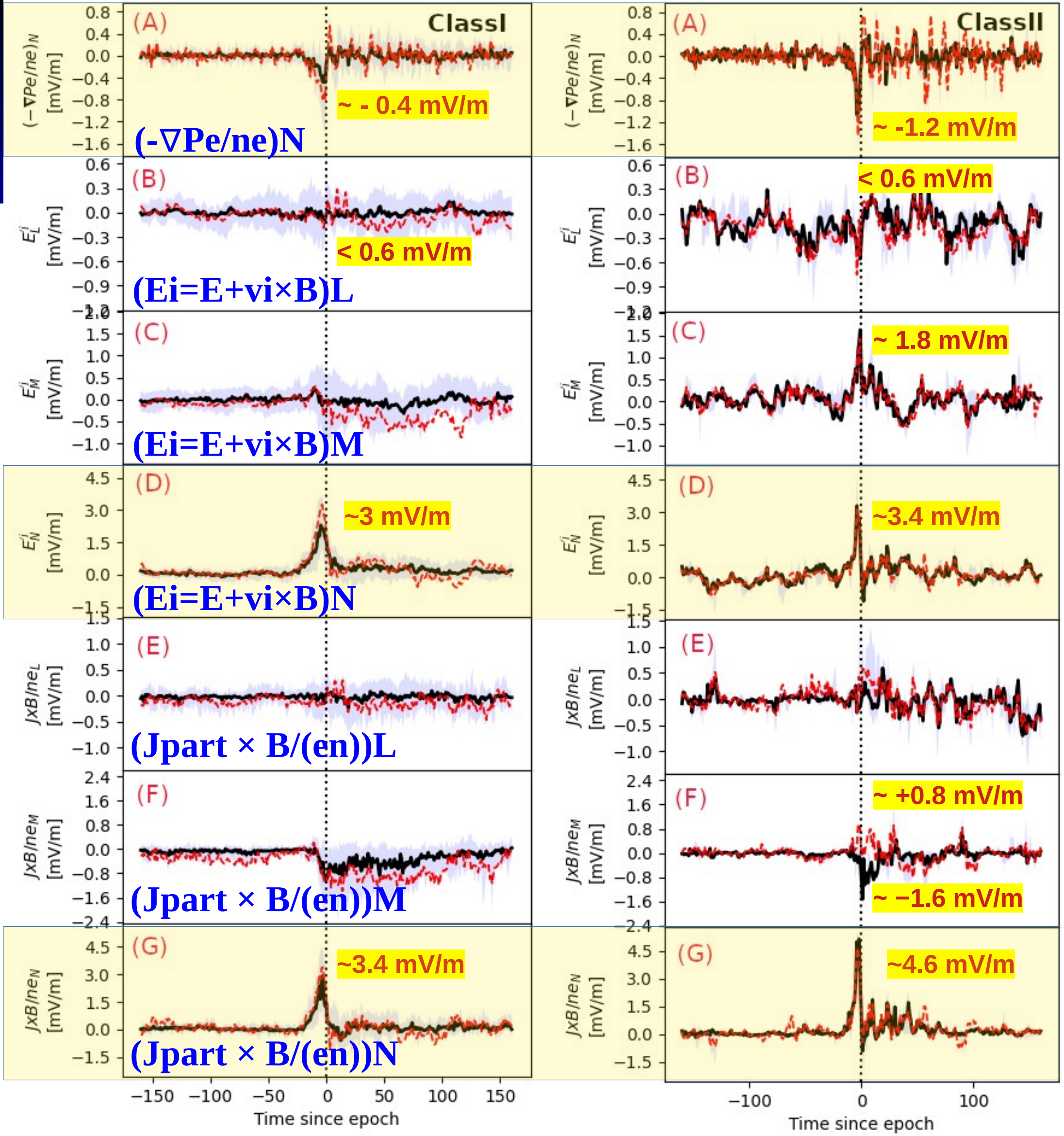
Hall electric field

Electron pressure gradient

Initial term

For both classes **in the N direction, ions are decoupled** (D) **mostly by the Hall electric field** (G) but electron pressure could also contribute (assuming non-zero curl) (A).

- For class II in the M direction, ions are decoupled (C), but the Hall field (median ~ −1.6 mV/m, mean +0.8 mV/m) suggests that the contribution from the electron pressure gradient could be quite large too (~+3.4 mV/m, +1 mV/m, respectively).



Energy conversion

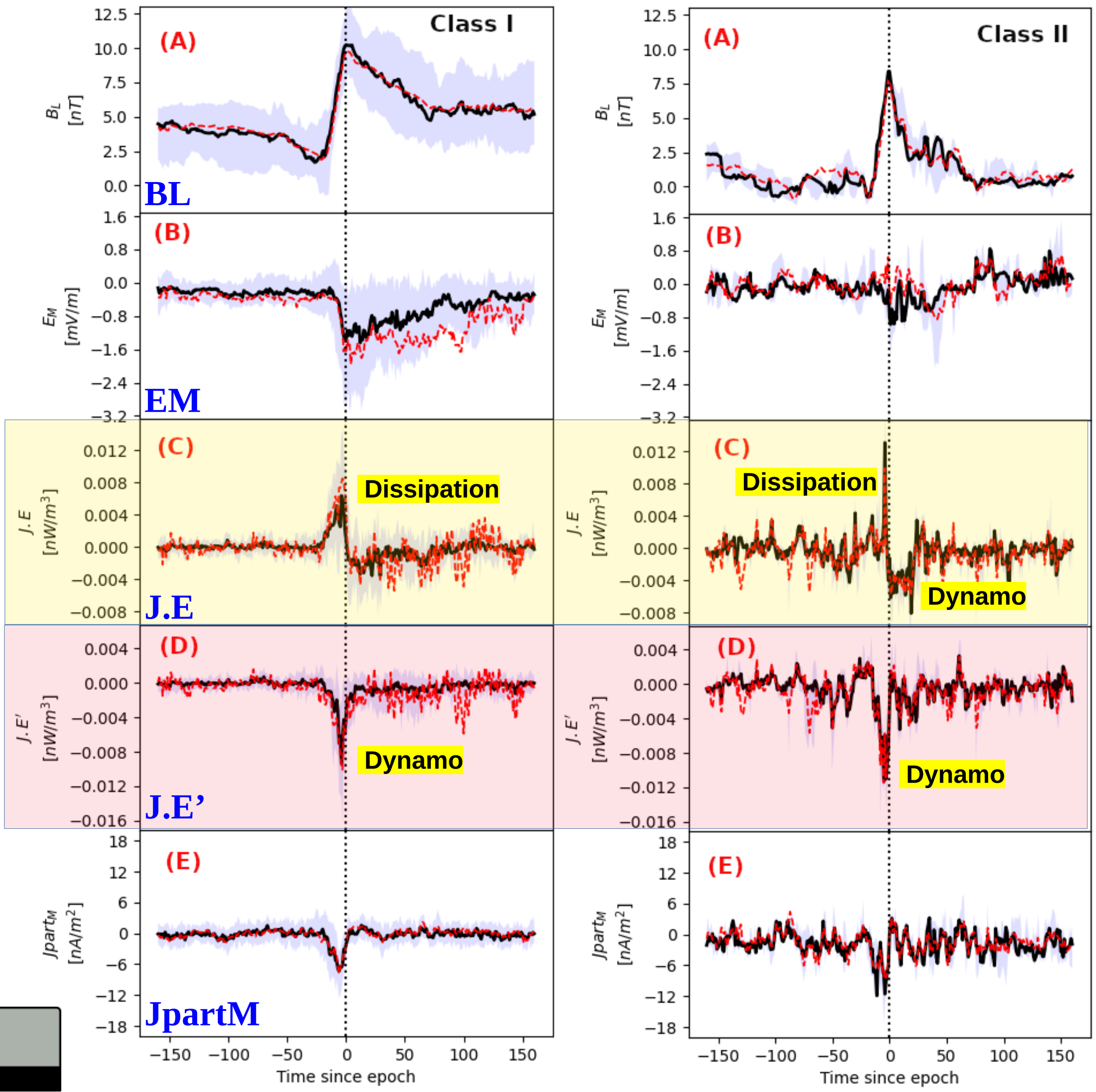
MMS - 4 Spacecraft average at 0.3s

- For both classes ahead of DF, in the s/c frame, **Jpart.E >0 Dissipation** (C) (energy is dissipated from the electromagnetic field to the particles).

- For class II behind DF, in the s/c frame, **Jpart.E <0 Dynamo** (C) (the energy is transferred from the particles to the electromagnetic field).

- For both classes ahead of DF, in the ion & electron frames, **Jpart.E'<0 Dynamo** (D) (energy goes from particles to field).

- In Class II the **reversal** of **Jpart.E** (C), in the s/c frame is due to the **reversal of the diamagnetic current**.



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Standard Deviation analysis for E’ & Jpart

Compute the standard deviation (SD) **normalized** by its error bar:

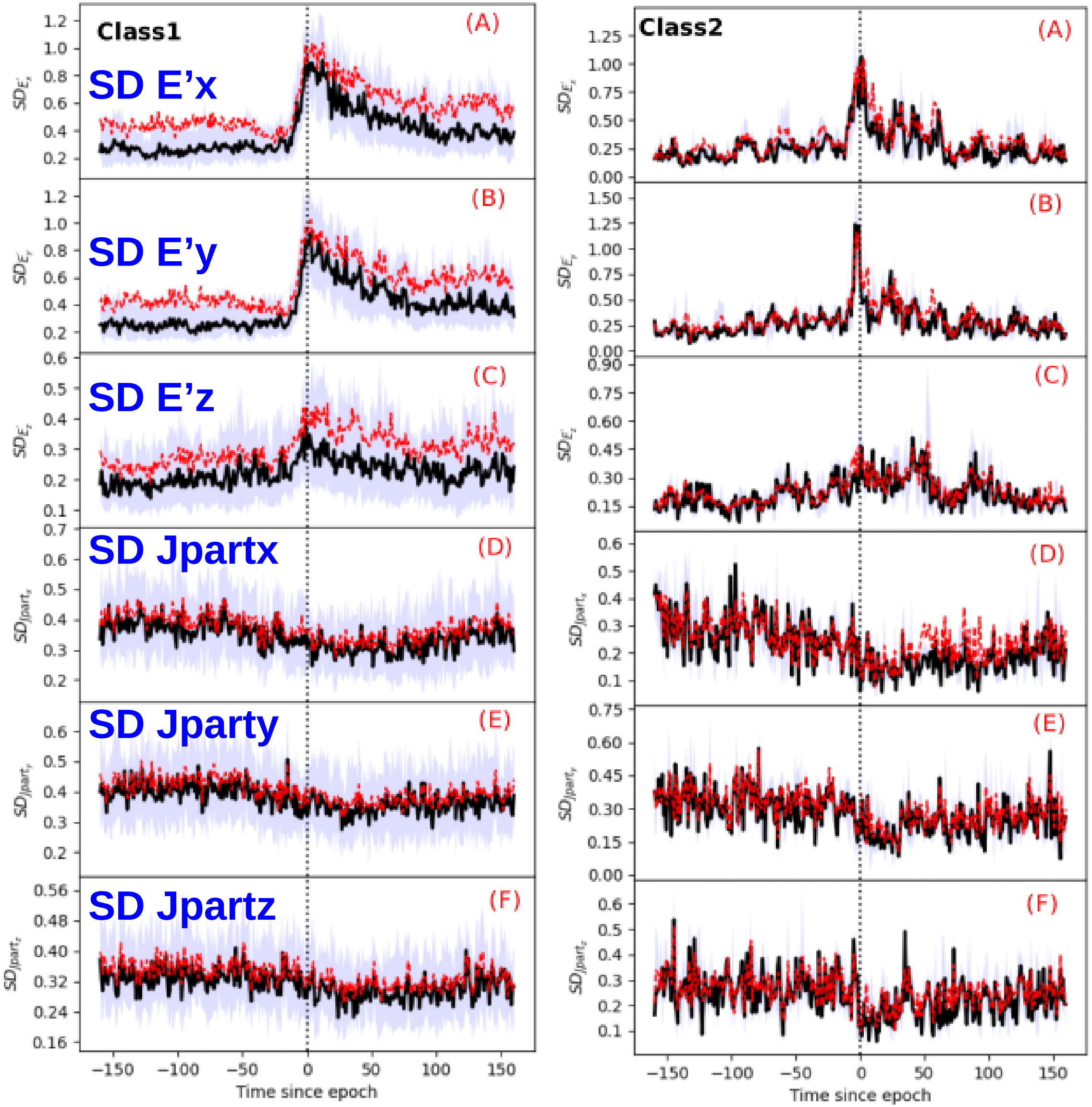
$$SD(X)/\Delta X = \sqrt{\Sigma_{i=1}^{4}(X_i - \langle X\rangle)^2/4}/\Delta X$$

<X> : The four spacecraft average of the X component
ΔX : Respective estimated error bar
ΔE’ ~1.7 mV/m
ΔJ ~6.8 nA/m2

- For both classes **normalized** SD of **E’** fields is about 1 for x and y components (A & B) whereas SD of current densities is always smaller than 1 for all components.

Thus:

- These statistical results confirm that **the non homogeneity comes from the E’ field** as shown by Alqeeq et al. 2022 for six DF events.



Conclusion (I)

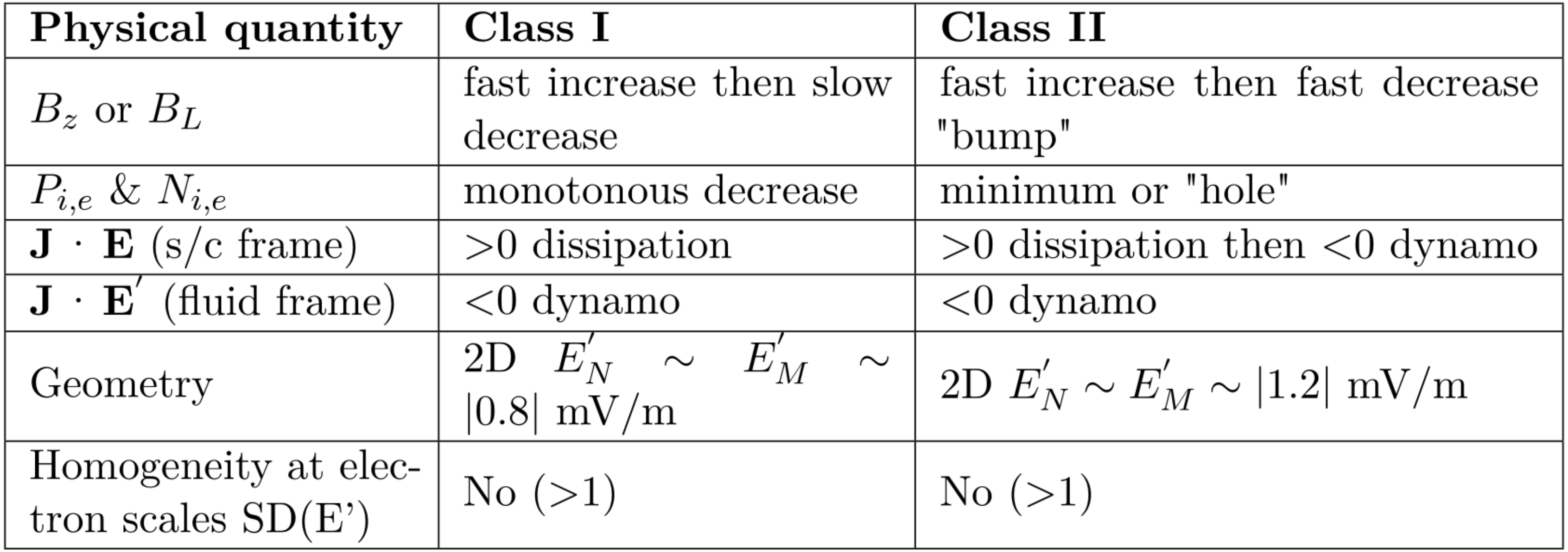
For the full magnetotail season of 2017 (132 DF events):

- **Class I "classic type"** (74.4%) corresponds to **a slow decrease of B** after the DF and is associated with smaller ion velocity and hotter plasma.
- **Class II "new type"** (25.6%) has a **bump B profile** associated with a minimum of ion and electron pressures and faster velocity as shown in Alqeeq et al. 2022, and it is found mostly on the duskside.
- For both categories we found a good agreement between current densities calculated from particles, Curl B and $Jdia_M$ (single S/C method).
- For both categories we found that **ions are mostly decoupled from the magnetic field by the Hall fields**.

The non- zero curl of the **electron pressure gradient term is also contributing to the ion decoupling and responsible for an electron decoupling** at DF.

Conclusion (II)

Summary of class I and class II signatures



Physical quantity	**Class I**	**Class II**
B_z or B_L	fast increase then slow decrease	fast increase then fast decrease "bump"
$P_{i,e}$ & $N_{i,e}$	monotonous decrease	minimum or "hole"
$\mathbf{J} \cdot \mathbf{E}$ (s/c frame)	>0 dissipation	>0 dissipation then <0 dynamo
$\mathbf{J} \cdot \mathbf{E}'$ (fluid frame)	<0 dynamo	<0 dynamo
Geometry	2D $E'_N \sim E'_M \sim \lvert 0.8 \rvert$ mV/m	2D $E'_N \sim E'_M \sim \lvert 1.2 \rvert$ mV/m
Homogeneity at electron scales SD(E’)	No (>1)	No (>1)

The electron pressure gradient term could also contribute (assuming a non-zero curl) to the ion decoupling and lead to the electron decoupling.

Merci de votre attention

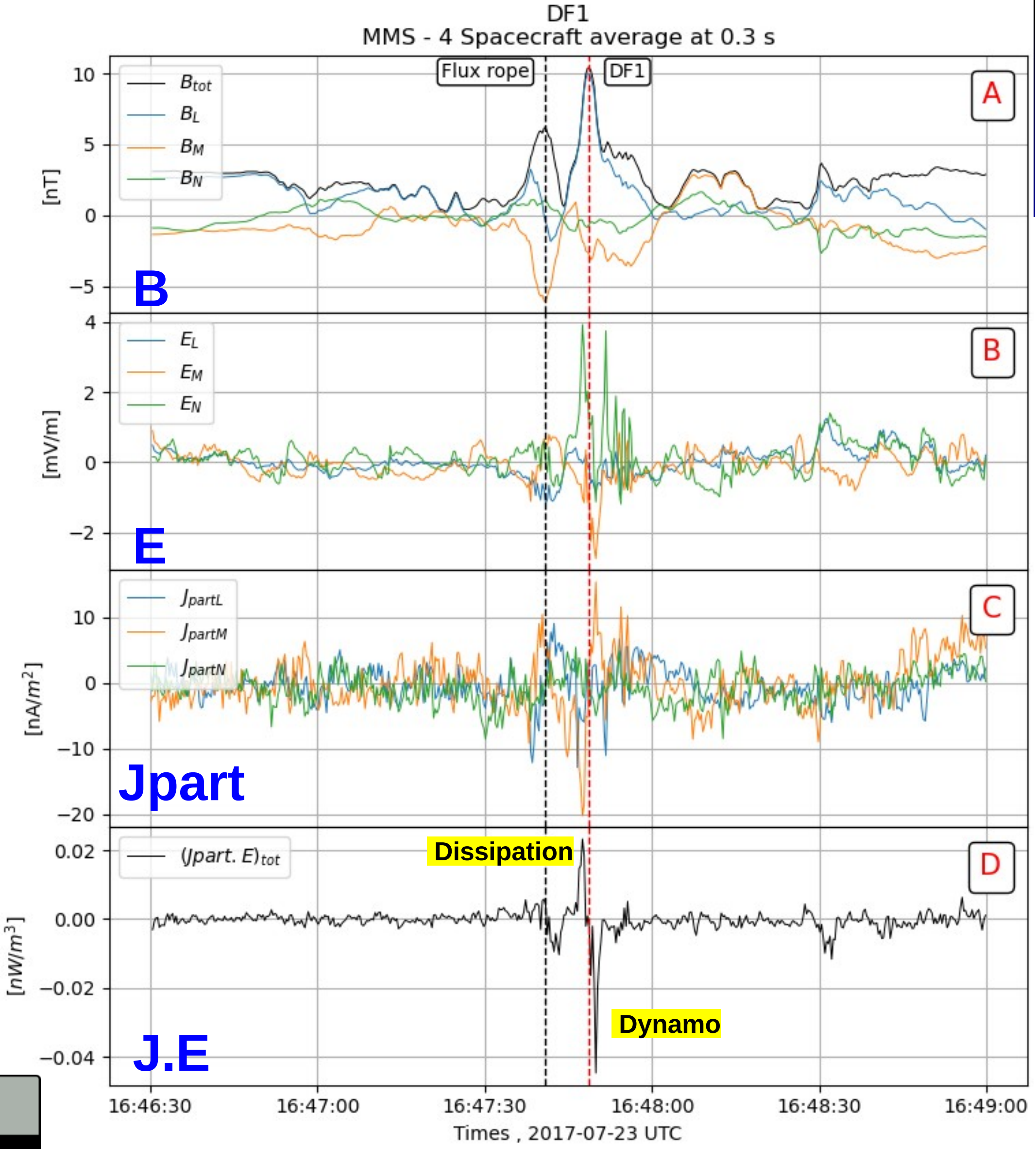
Energy conversion (I)

In s/c frame:

- **"Dissipation" ahead of the front**, the energy is transferred from the electromagnetic field to the particles **J.E** ~ +0.023 nW/m^3.

- **"Dynamo" behind the front**, the energy is transferred from the particles to the electromagnetic field **J.E** ~ - 0.043 nW/m^3.

- Convective field (EM<0~ vxB) dominant
- Sign(**J.E**) ~ sign(Jpart,M)



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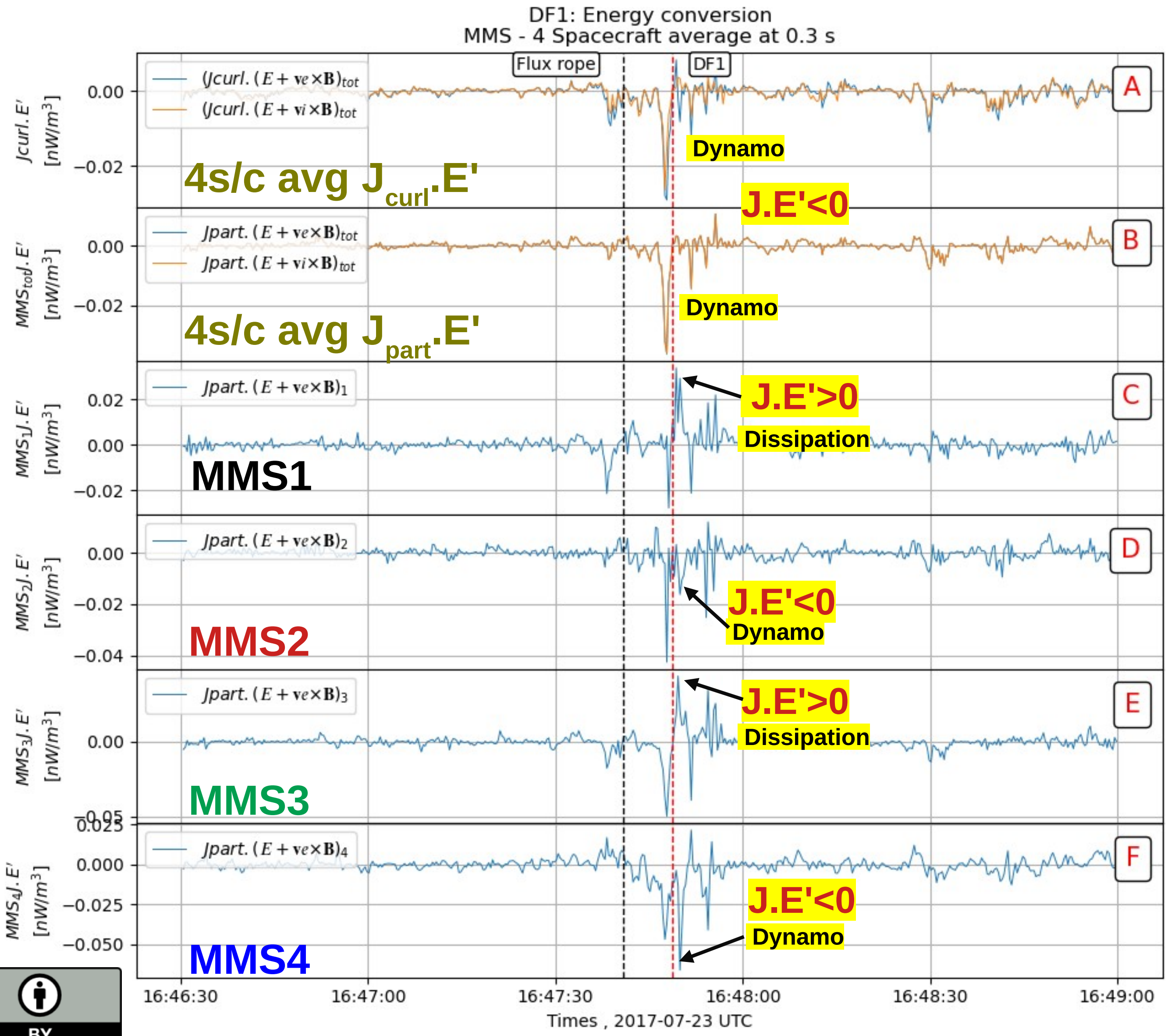
Energy conversion (II)
16:47:30-16:48:40 UT

In Ion & electron frames:

- => Good confidence with all **J.E'=J.(E+vi,exB)** calculations.
- **J.E'**>0, **Dissipation** (energy goes from field to particles) ~ after the DF (from single s/c MSS1, 3)
- **J.E'**<0, **Dynamo** (energy goes from particles to field) ~ at DF (from 4 s/c and all singles s/c)
- These results are consistent with [Yao et al., 2017].



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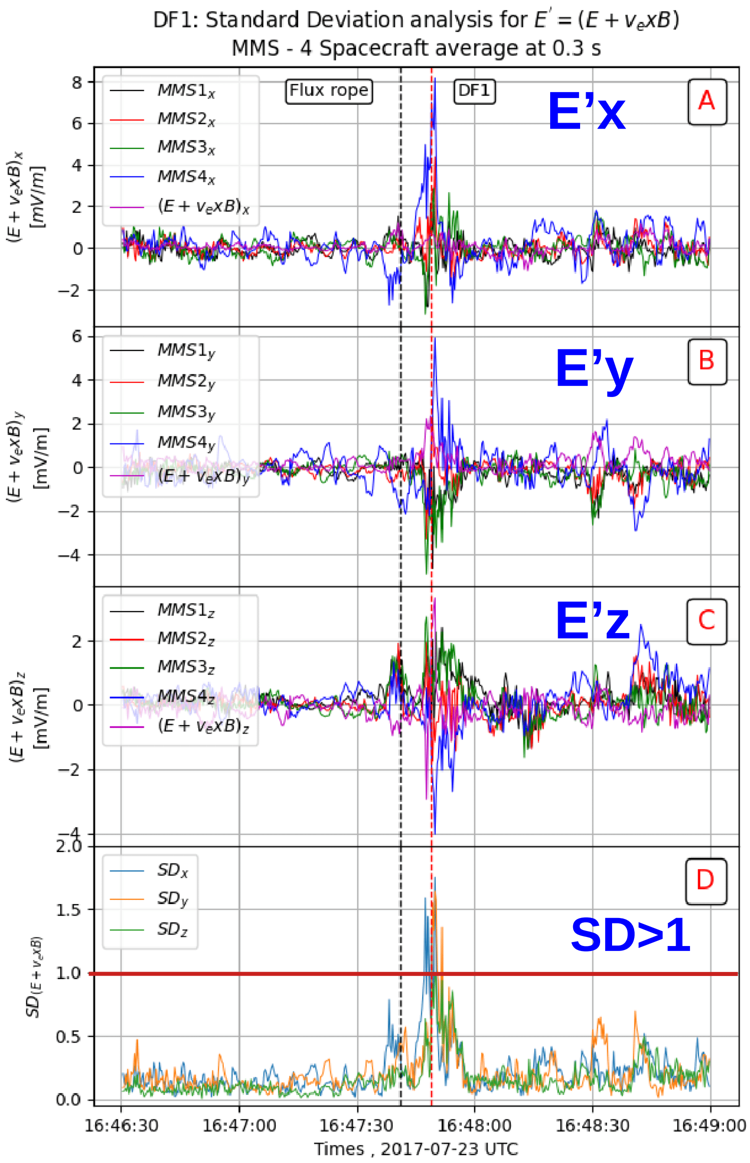
Standard Deviation analysis for E’ & Jpart



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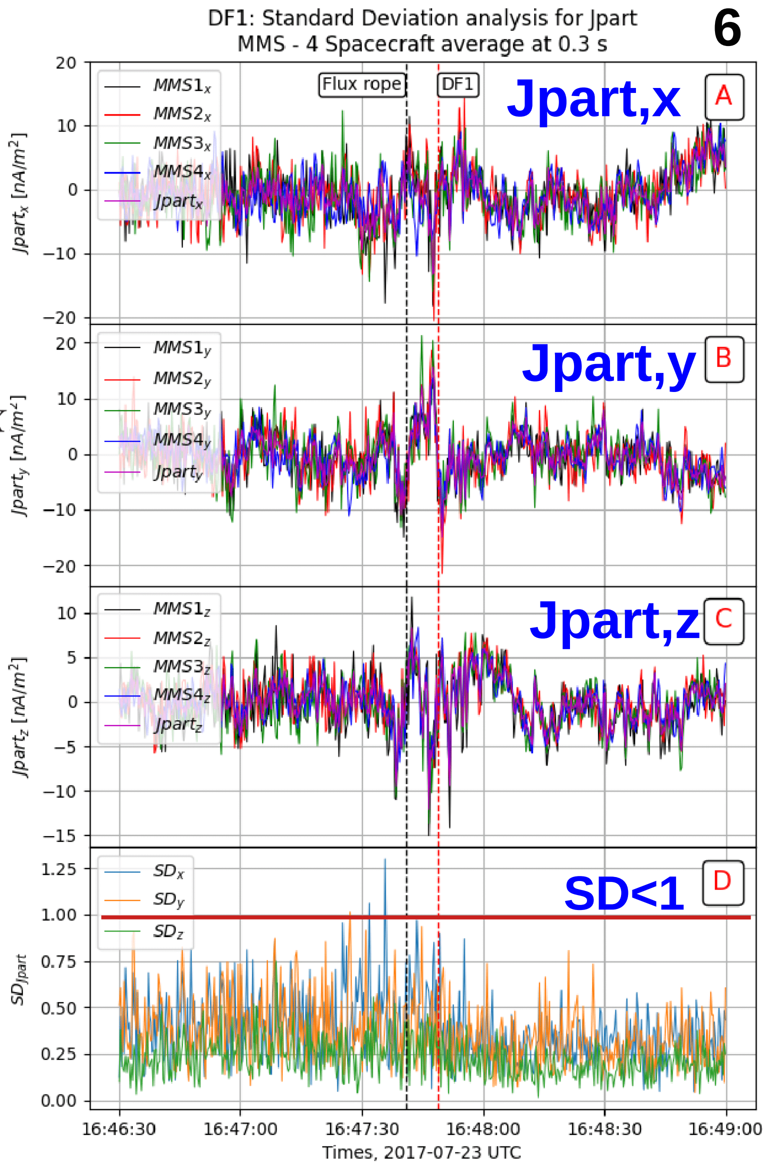
$$SD(X)/\Delta X = \sqrt{\Sigma_{i=1}^4 (X_i - \langle X \rangle)^2/4}/\Delta X$$

<X> : The four spacecraft average of the X component
ΔX : Respective estimated error bar
ΔE’ ~1.7 mV/m
ΔJ ~6.8 nA/m2

Larger **normalized** SD for E’ field than for Jpart suggest that non homogeneity comes from the E field.



Case study summary

[Alqeeq et al., PoP, MMS special issue, 2022]

- Good agreement between current densities calculated from particles and curl B.

Ions are decoupled at DF mostly due to Hall field but also possibly due to electron pressure gradient assuming a non- zero curl of of this term.

- **In the frame of the satellite**, the energy is dissipated (**J.E>0,** dissipation or load region) ahead of the DF but transferred from the plasma to the field behind the front (**J.E<0,** dynamo or generator region).
- **In the fluid frame**, the energy is transferred from the plasma to the fields (**J.E'<0,** dynamo) as also found in a previous MMS single DF event [Yao et al., 2017].
- The energy conversion is **not homogeneous** at the electron scale (scale of the tetrahedron) mostly due to the E field fluctuations which are likely related to LHD waves [e. g., M. Hosner et al. 2022].

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