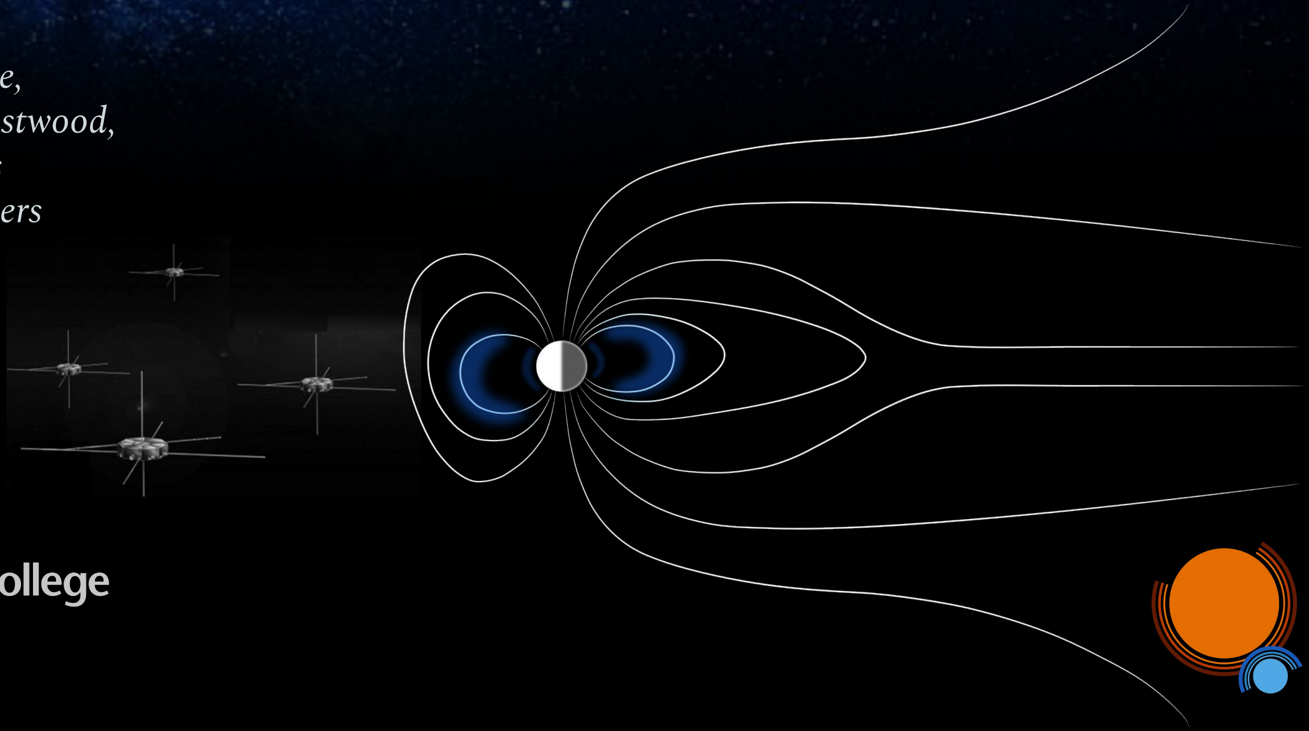
Energy Conversion and Transport in Dayside Electron Diffusion Regions

Naïs Fargette,
Jonathan Eastwood,
Cara Waters
and co-workers



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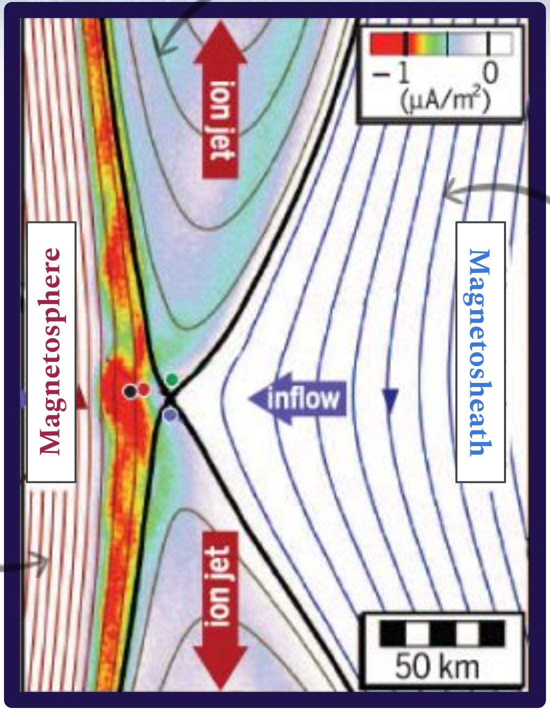
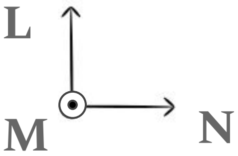
Electron diffusion regions (EDRs)



From
Burch et al. 2016

Frozen in conditions

$$\mathbf{E} + \mathbf{v} \wedge \mathbf{B} = 0$$



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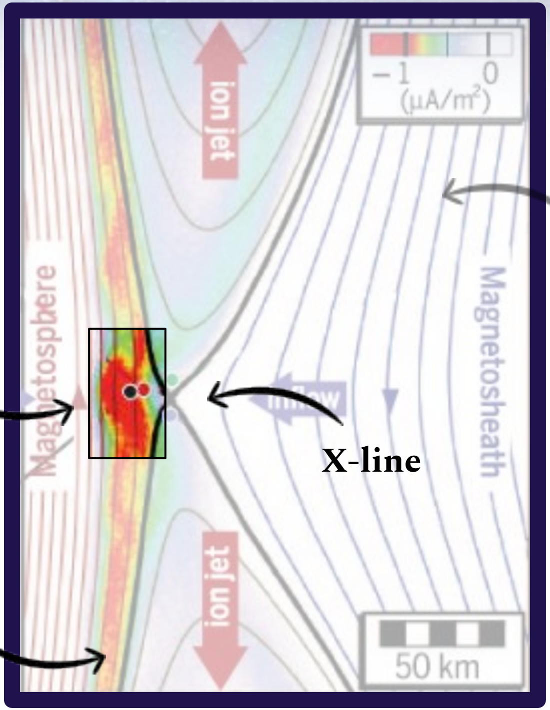

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Frozen in conditions

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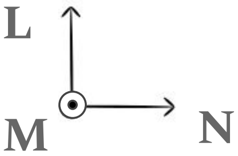
Dissipation region

X-line

$$\mathbf{E} + \mathbf{v} \wedge \mathbf{B} \neq 0$$

Separatrix



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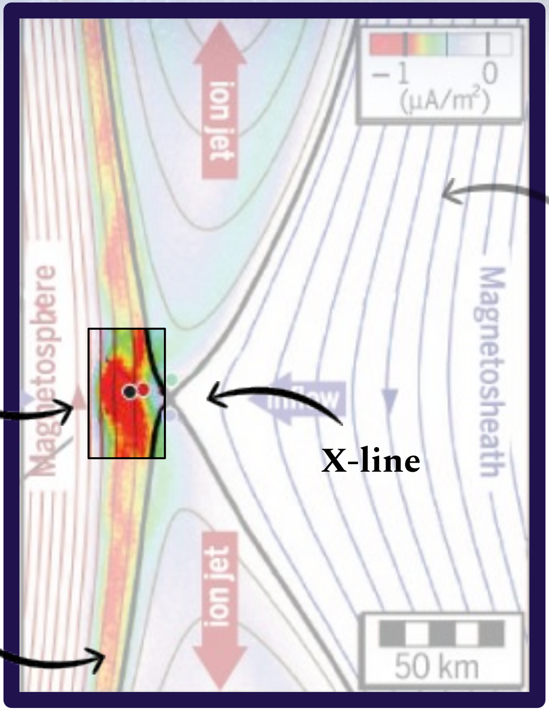

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Dissipation region

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Frozen in conditions

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L

M

N

At electron scales:

- ❑ **How is the energy converted** from magnetic to kinetic and thermal ?
  What is the **nature of energy conversion ?**
- ❑ What controls the **energy partition** and transport near the EDR ?

(see also Eastwood et al. 2020 for a case study analysis)

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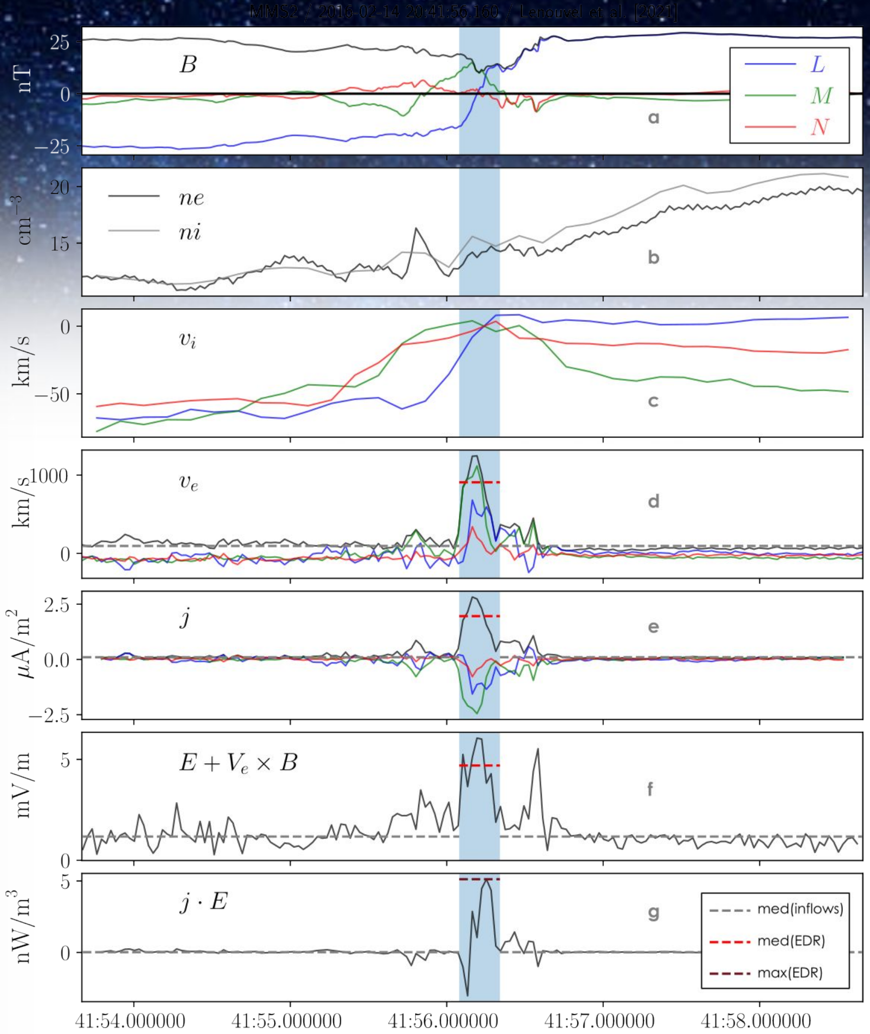
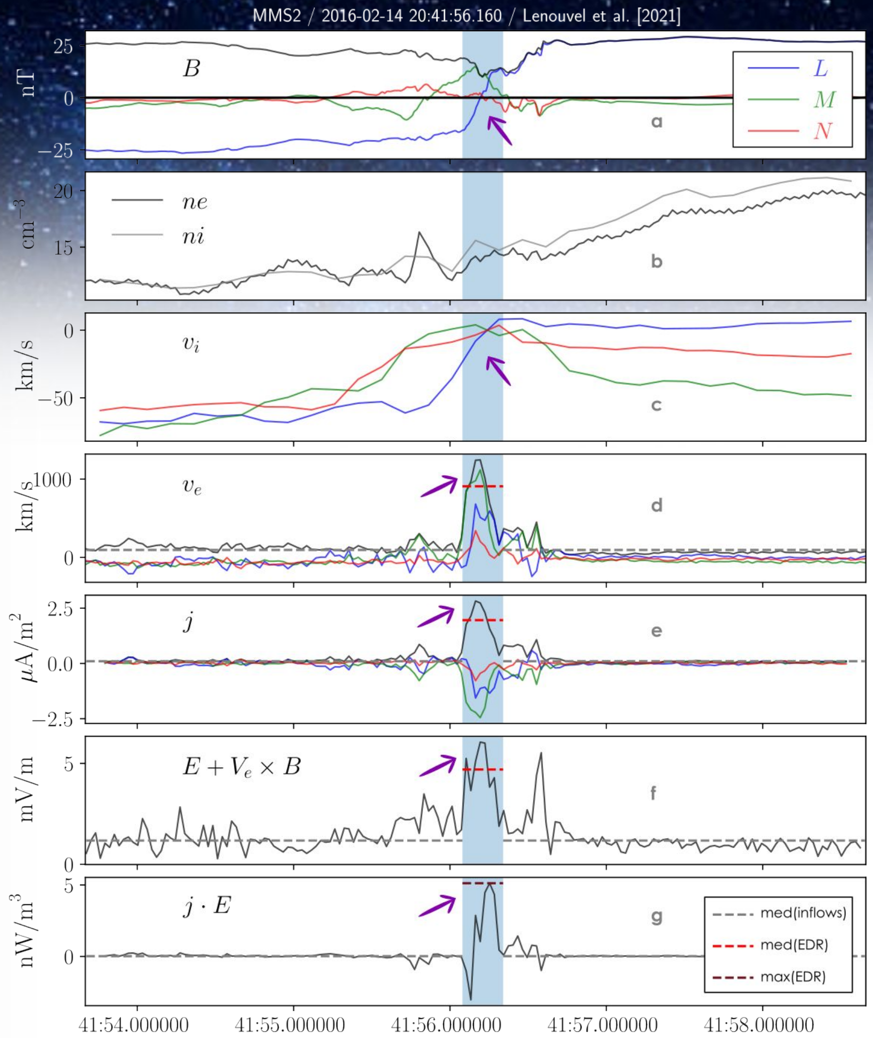
What are EDR signatures ?



Lenouvel et al. 2021



What are EDR signatures ?

Current sheet, min B

Strong current

Lenouvel et al. 2021

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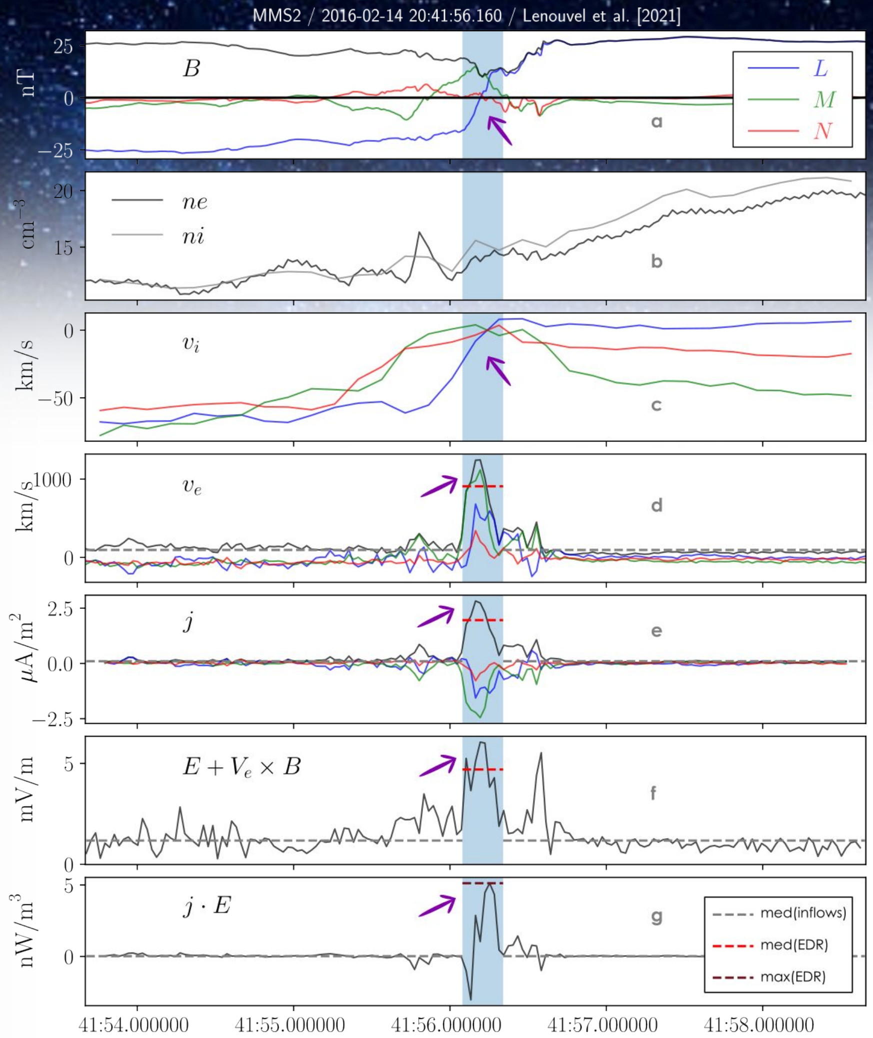

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Ion flow reversal

Electron jet

Strong current

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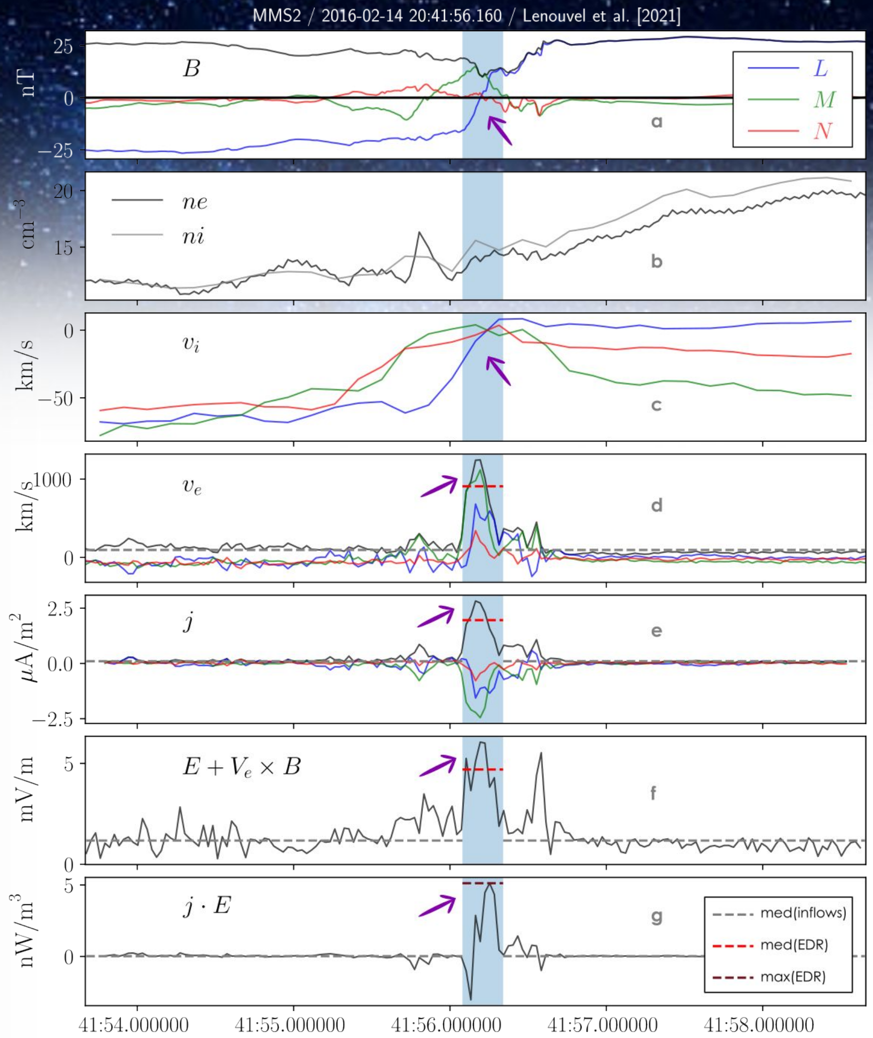


Current sheet, min B

Ion flow reversal

Electron jet

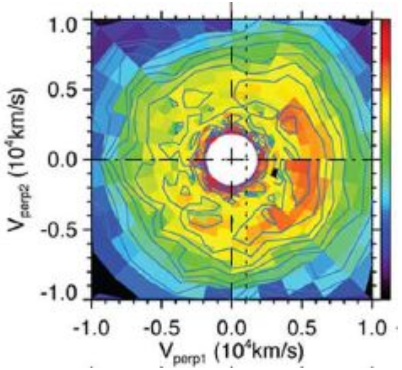
Strong current

Demagnetisation

Energy conversion

Lenouvel et al. 2021

Crescents in distribution function



Literature review : 80 near X-line events

Burch et al. (2016)	
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Recently, a machine learning approach found 36 new EDR candidates

Classification of 80 near X-line events

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Class A : a clear inner EDR encounter where

- *all previously defined variations are sufficiently large*

Class B : a probable inner EDR encounter with

- *clear signatures of electron physics occurring, but lacking one or more expected signature*

Class C : probably not an inner EDR encounter, based on either

- *a lack of clear signatures and/or*
- *the observation of a clear ion jet during the event crossing.*

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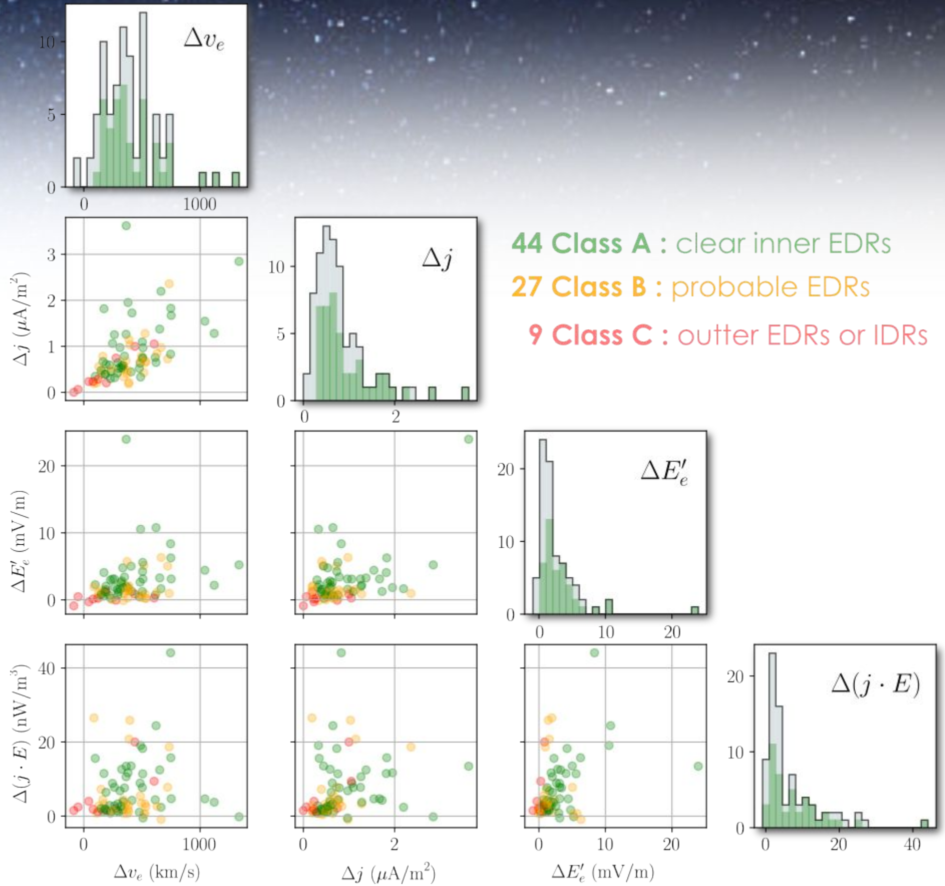

44 Class A : clear inner EDRs
27 Class B : probable EDRs
9 Class C : outter EDRs or IDRs

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Energy conservation equation

$$\frac{\partial}{\partial t}\left(\sum_s U_s + U_{EM}\right) + \sum_s \nabla \cdot (\mathbf{K_s} + \mathbf{H_s} + \mathbf{q_s}) + \nabla \cdot \mathbf{S} = 0$$

Energy conservation equation

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Time derivative of total energy
(bulk kinetic, thermal and electromagnetic)

Energy conservation equation

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Time derivative of total energy
(bulk kinetic, thermal and electromagnetic)

Kinetic energy flux density

$$\mathbf{K_s} = \frac{1}{2}\rho_s v_s^2 \mathbf{v_s}$$

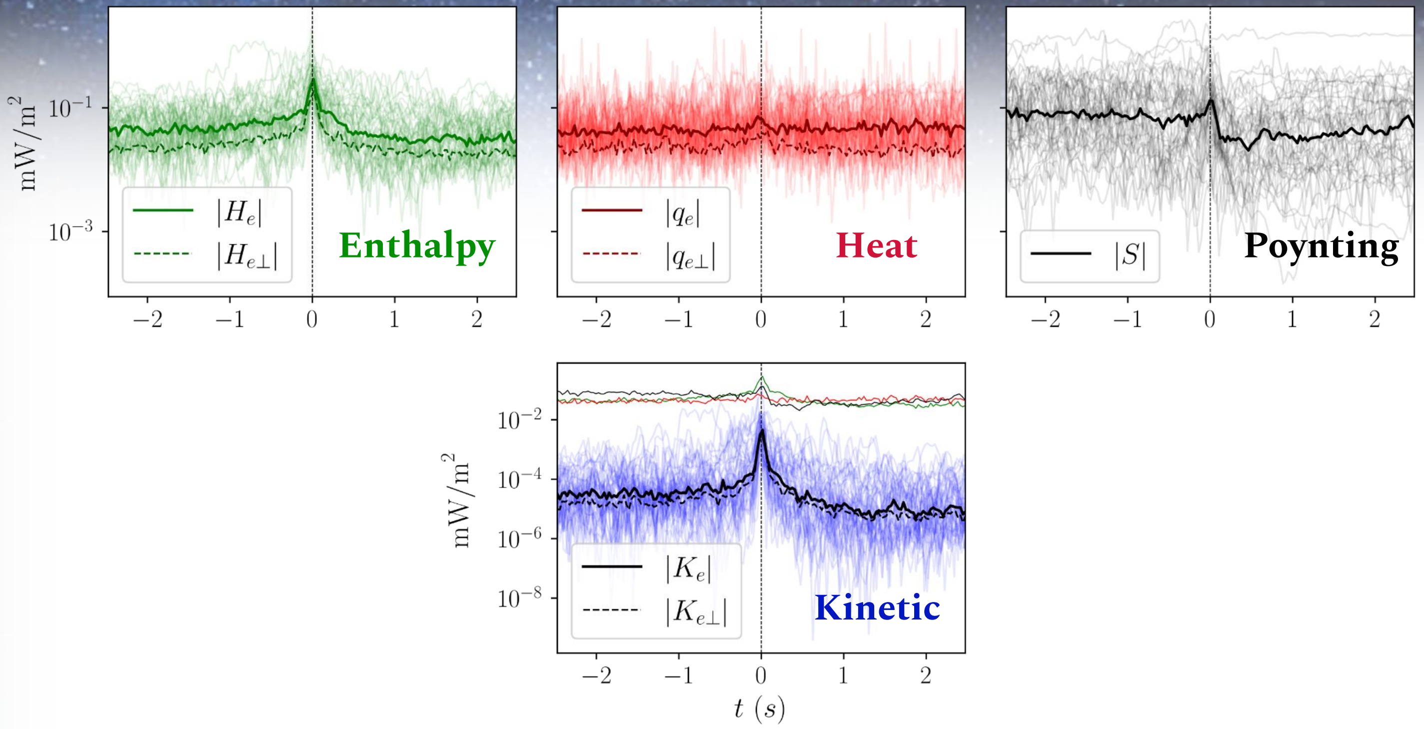
Heat flux density

Poynting flux density

Enthalpy flux density

$$\mathbf{H_s} = \frac{\mathbf{v_s}\mathrm{tr}(\mathrm{P_s})}{2} + \mathbf{v_s} \cdot \mathrm{P_s}$$

Mapping of energy flux densities near EDRs



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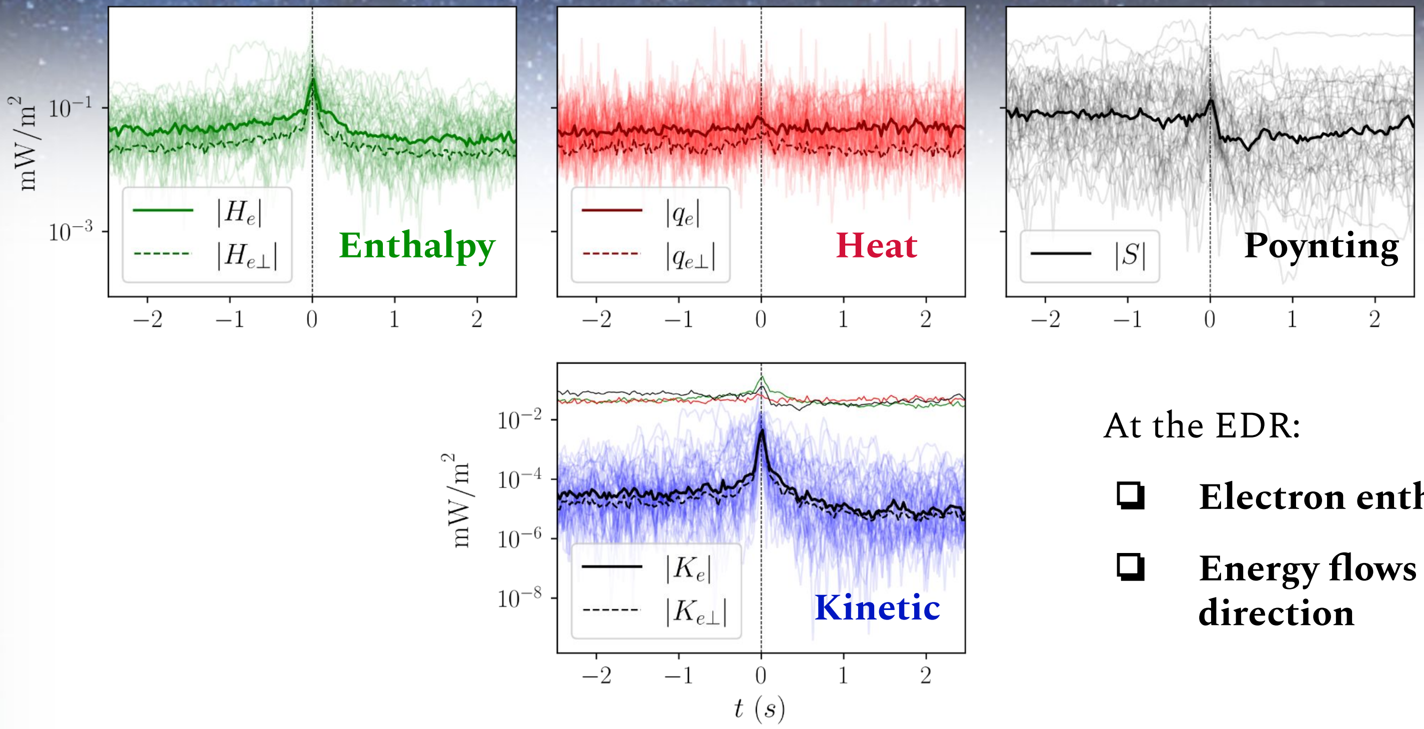


At the EDR:

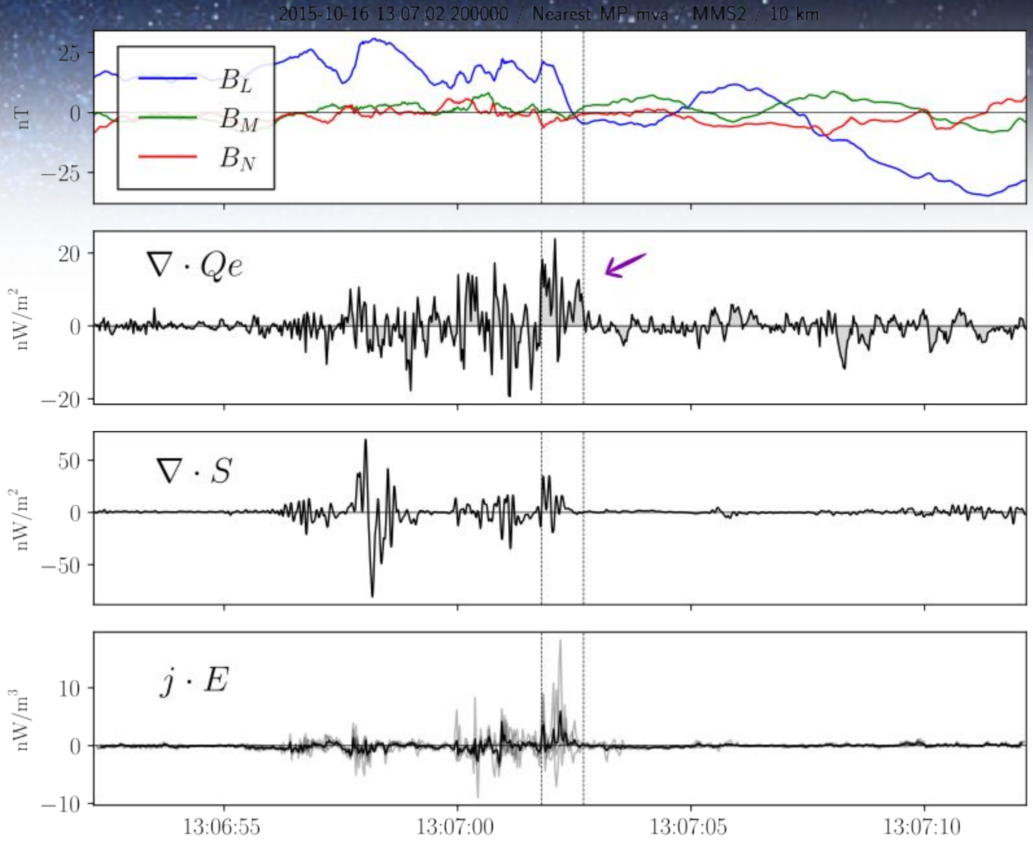
- ❑ **Electron enthalpy flux dominates**
- ❑ **Energy flows in the perpendicular direction**

$$\frac{\partial}{\partial t}\left(\sum_s U_s + U_{EM}\right) + \sum_s \nabla \cdot (\mathbf{K_s} + \mathbf{H_s} + \mathbf{q_s}) + \nabla \cdot \mathbf{S} = 0$$

Flux Divergence

Event from Burch et al 2016

$$\nabla \cdot Q_e = \nabla \cdot (K_e + H_e + q_e)$$



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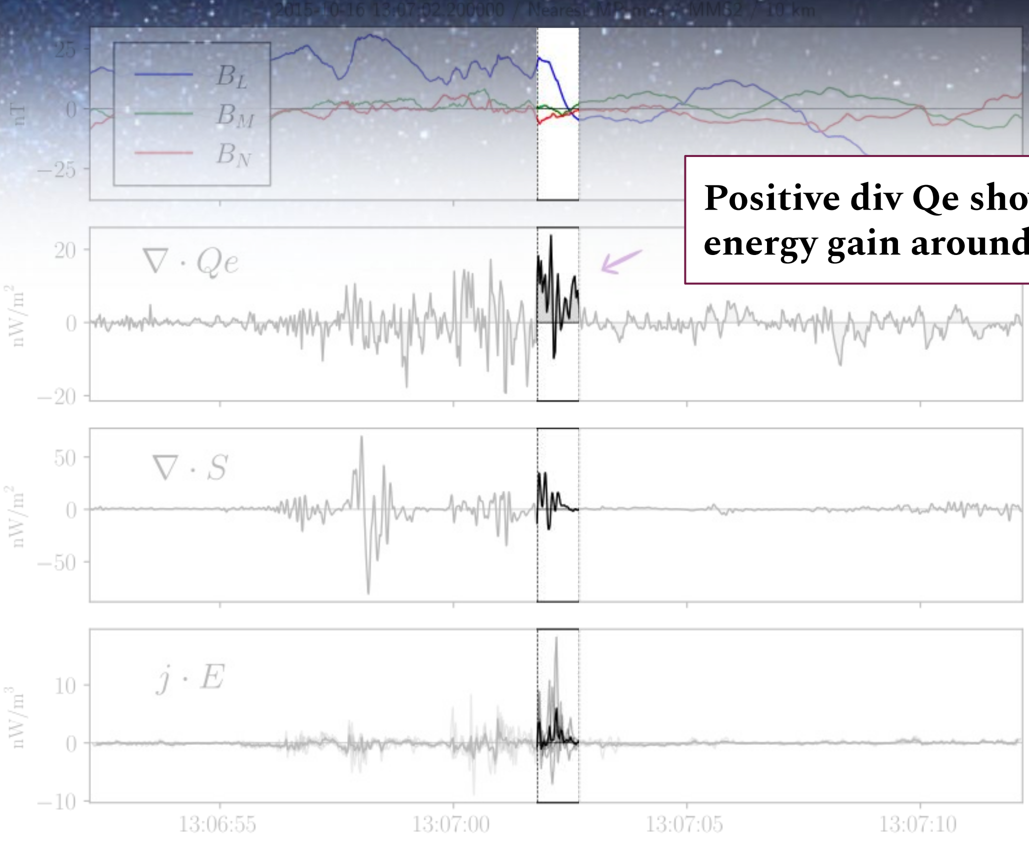
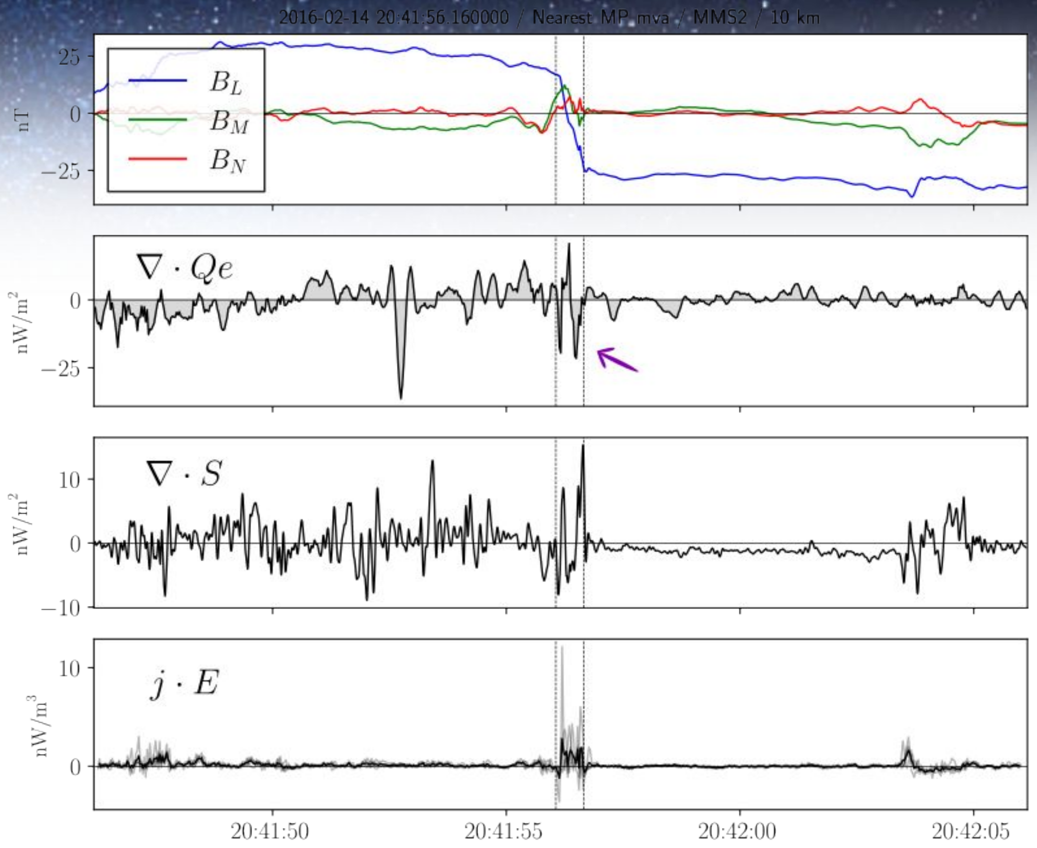


Positive div Qe shows for electron energy gain around EDR

Flux Divergence

Event from Lenouvel et al 2021

$$\nabla \cdot Q_e = \nabla \cdot (K_e + H_e + q_e)$$



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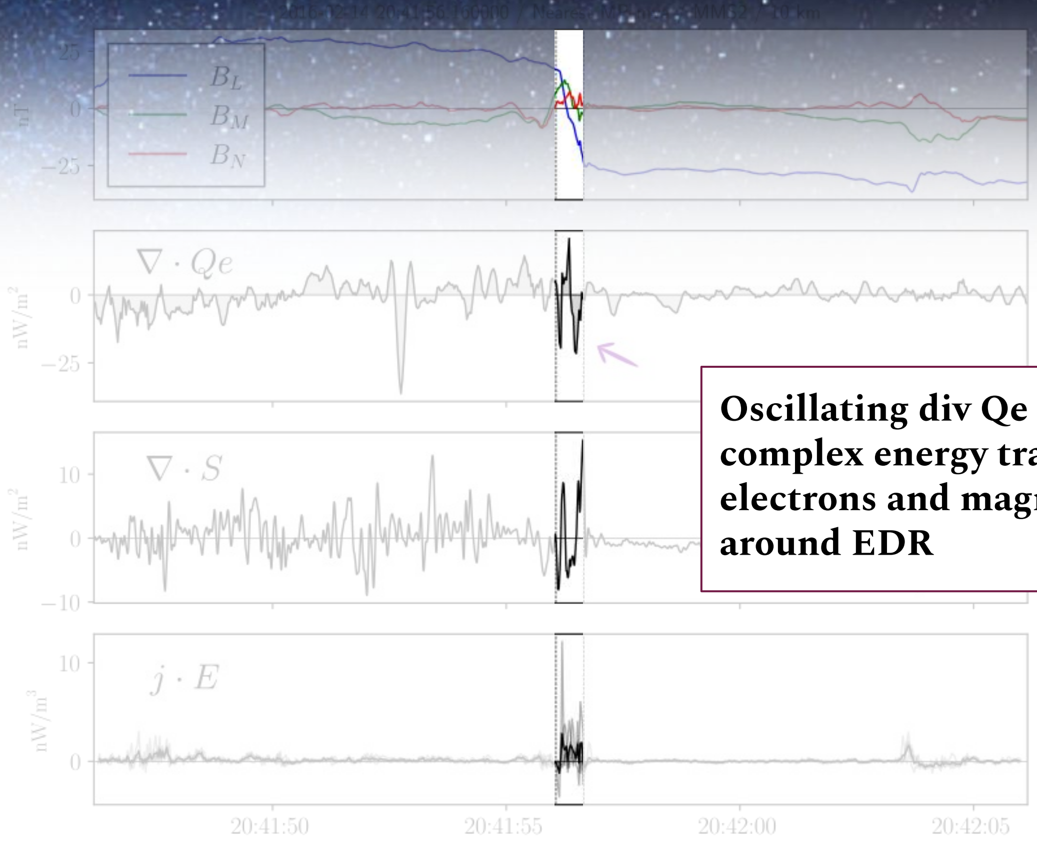

Oscillating div Qe shows for complex energy transfer between electrons and magnetic field around EDR

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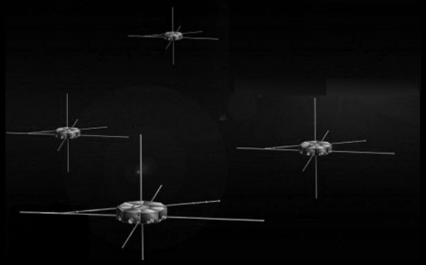
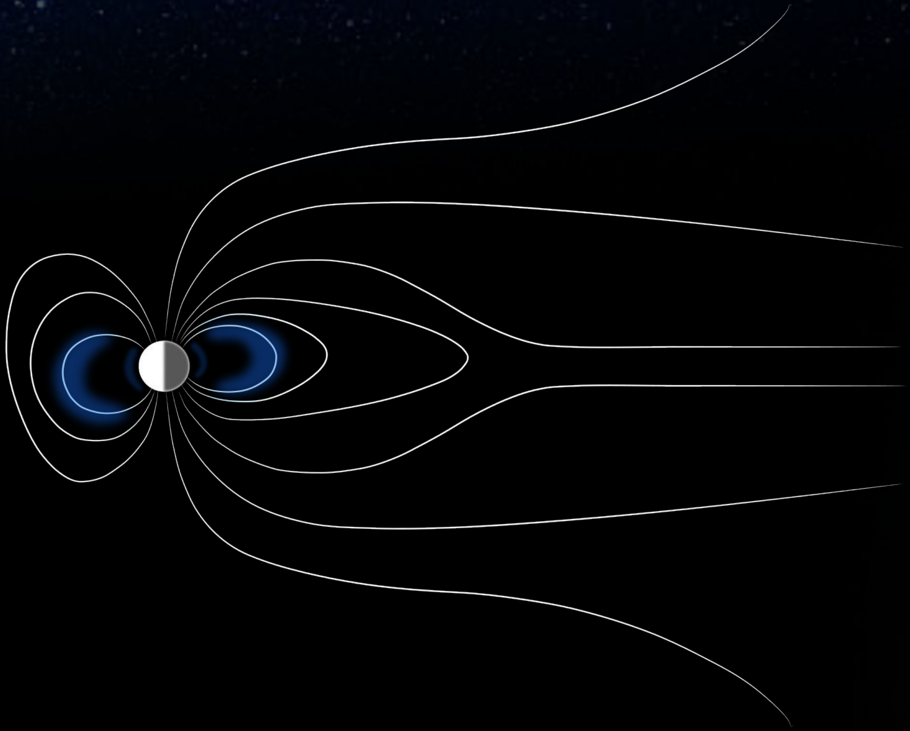
Conclusions

- Using **a statistical approach**, we investigate energy partition and transport in the vicinity of EDR crossings
- **Electron enthalpy flux dominates the energy partition** at EDRs
- We find that energy flows primarily in the out of plane direction, showing **the importance of 3D effects in magnetic reconnection**
- We show that **energy transfer occurs in a non linear and rather turbulent way at EDRs**

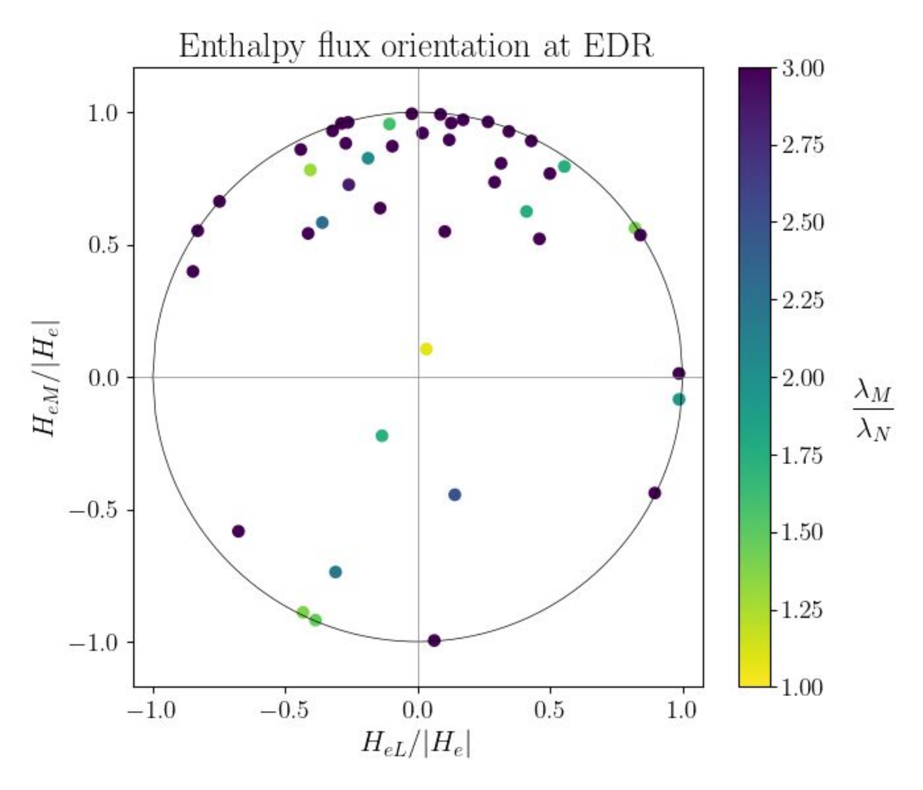
nais.fargette@imperial.ac.uk

Thank you for your attention !





Enthalpy flux mainly in the M direction



J.E’ ratio versus guide field