Diffusion region's structure during magnetic reconnection in near-Earth space

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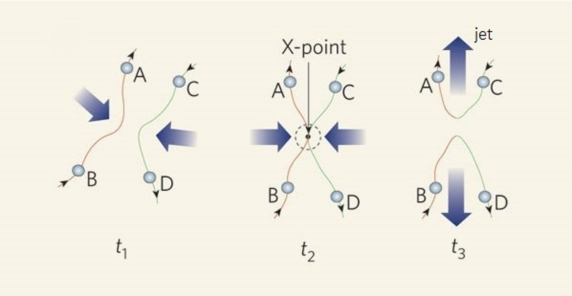
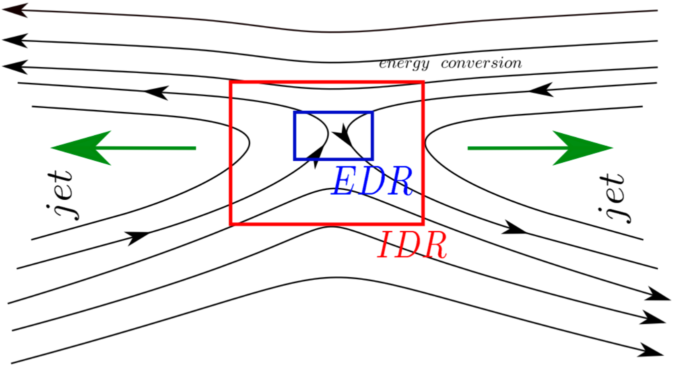
October 22, 2018

Magnetic reconnection: a fundamental process



Magnetic reconnection induces topology change of the magnetic field and energy release

Magnetic reconnection: a multi-scale process



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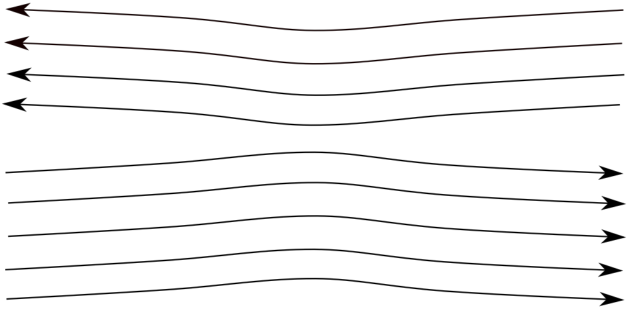

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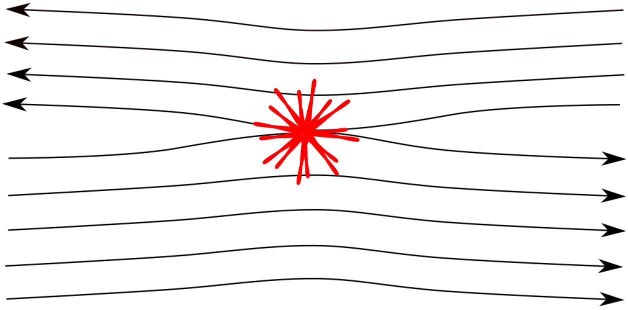
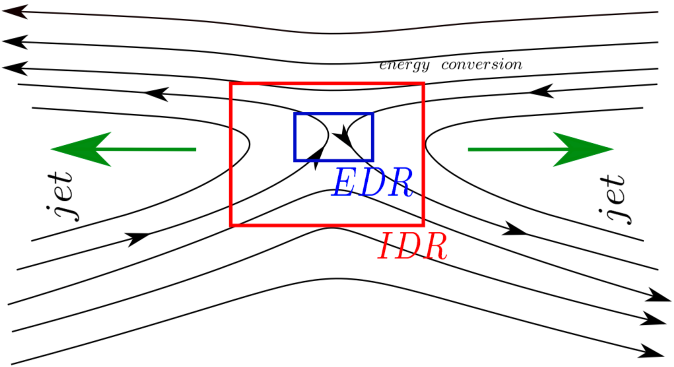


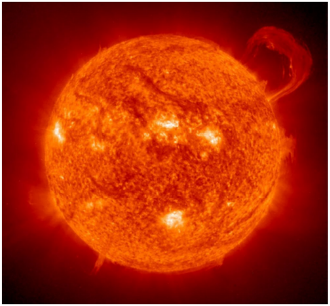
Magnetic reconnection induces topology change of the magnetic field and energy release

Magnetic reconnection: a multi-scale process

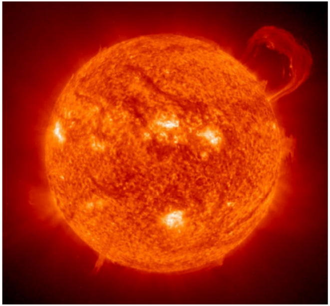


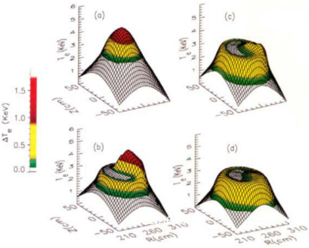
Dynamics and structure of the EDR are largely unknown

An ubiquitous process



An ubiquitous process





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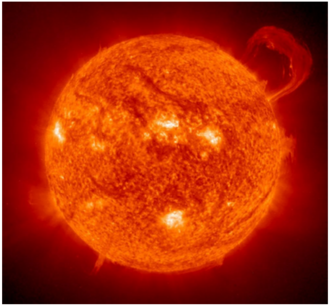

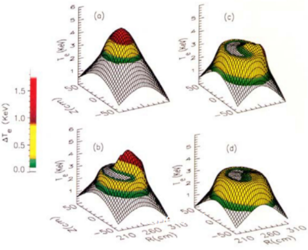

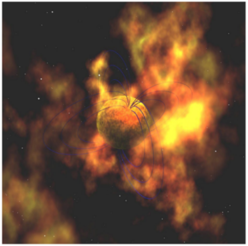

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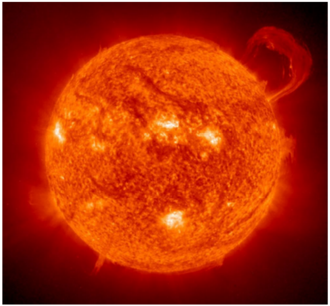
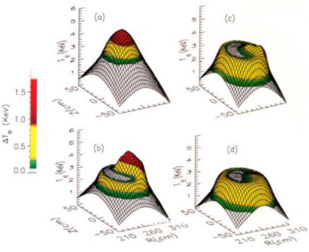
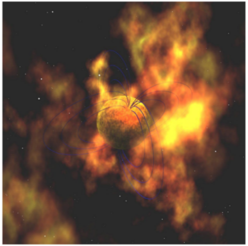
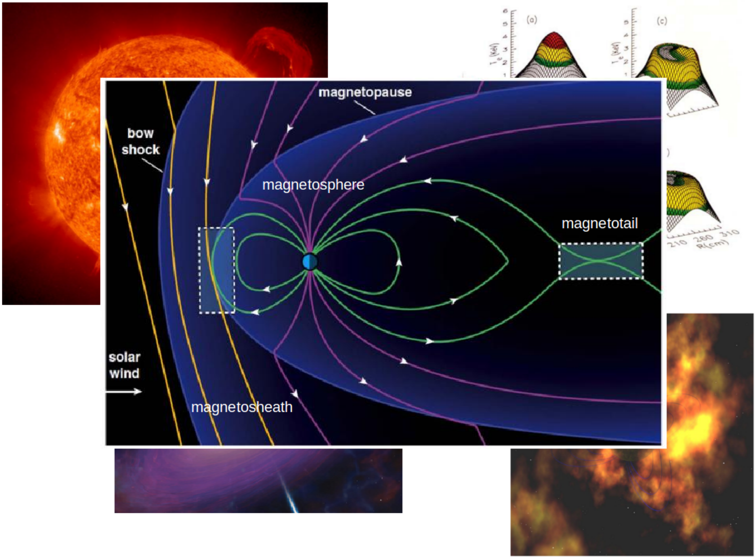






An ubiquitous process



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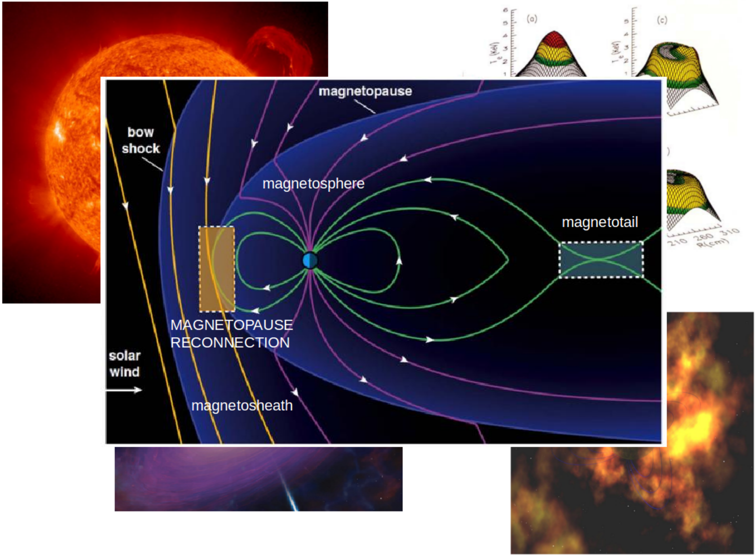
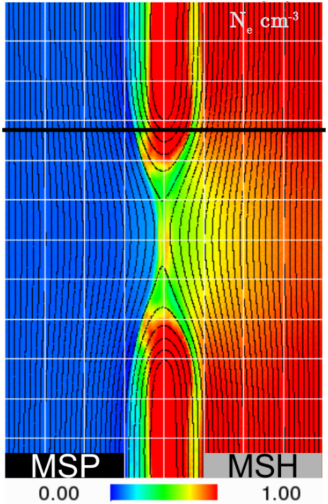


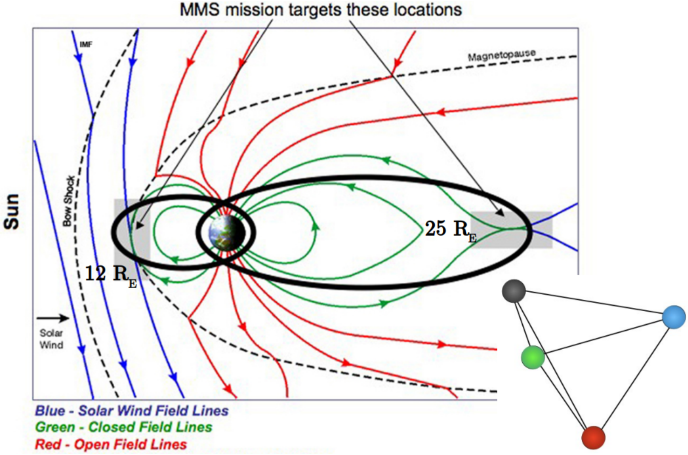
Magnetopause reconnection

- Collisionless
- Asymmetric
- Mixing of solar wind and magnetospheric plasma
- $d_{IDR} \sim d_i \sim 80\ km$
- $d_{EDR} \sim d_e \sim 2\ km$



Tanaka et al., Ann. Geophys., 2008

Magnetospheric MultiScale (MMS) mission is designed to study magnetic reconnection in the near-Earth space



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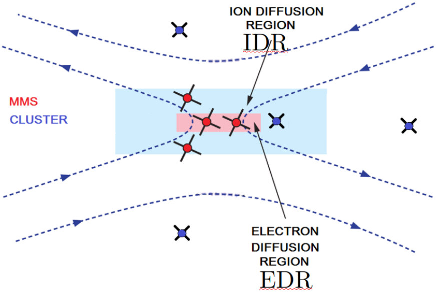


$d_{S/C} \sim 100\ km$

$d_{S/C} \sim 10\ km$

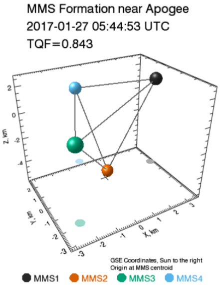
$d_e \sim 2\ km$

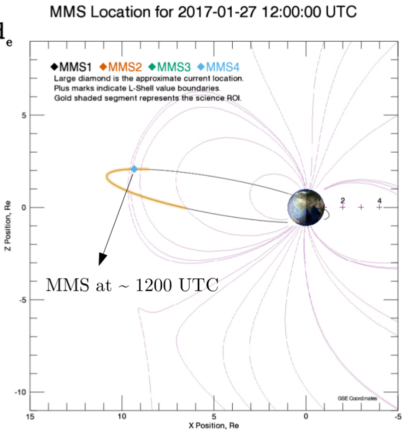
$d_i \sim 80\ km$

Cluster resolution: 250 ms. MMS resolution: 30 ms (electrons) and 150 ms (protons)

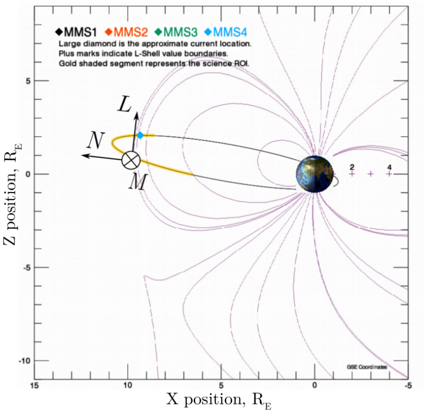
Looking for an Electron Diffusion Region encounter

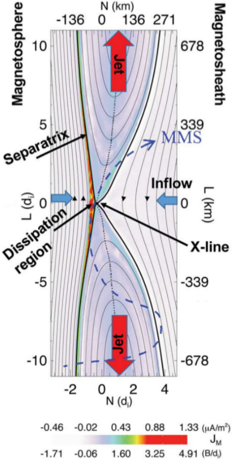
Spacecraft separation ~ **7 km** ~ **3 d$_e$**



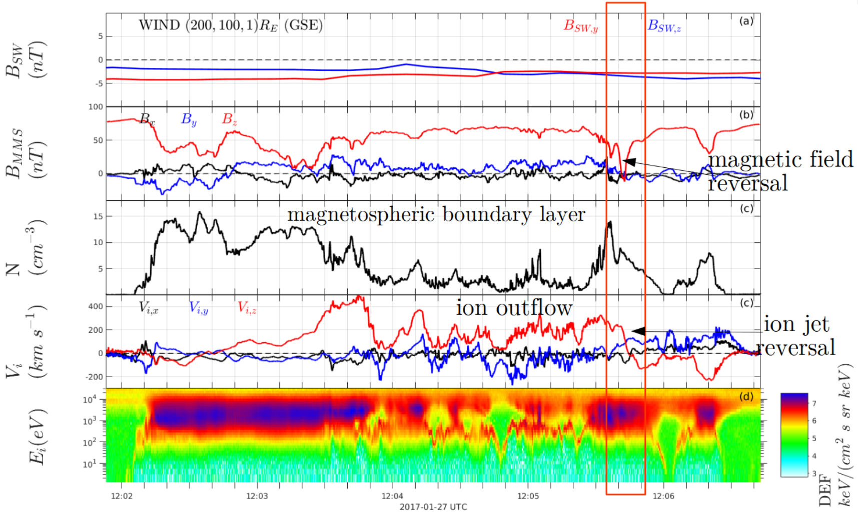


Magnetopause's local coordinate system

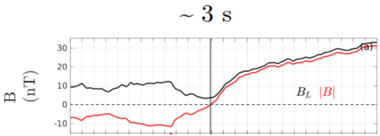


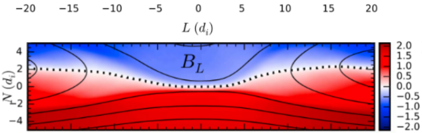


Magnetic reconnection event



Electron diffusion region signatures

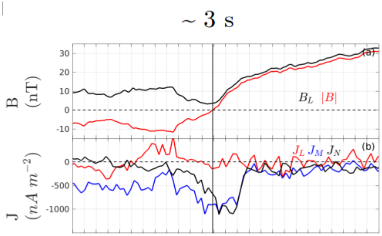


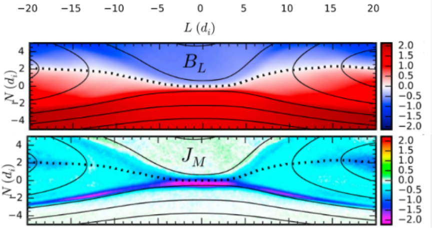


Data from MMS2

Adapted from Shay et al., GRL (2016)

Electron diffusion region signatures





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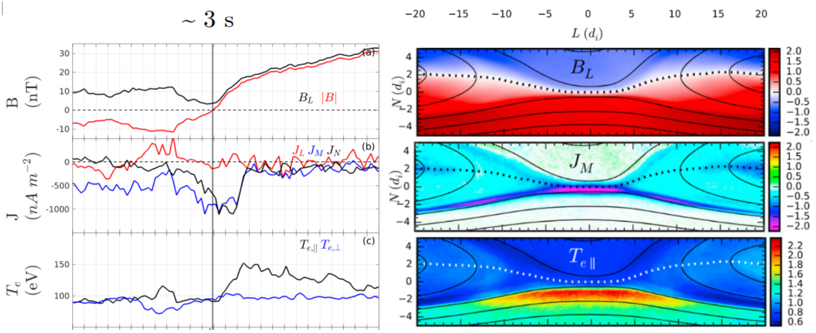

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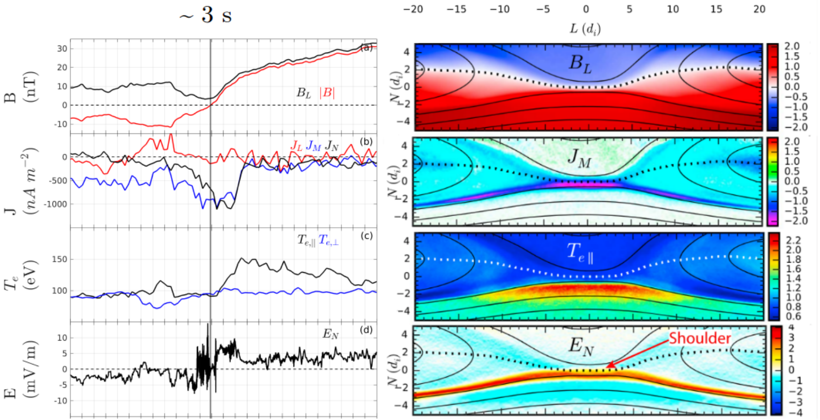

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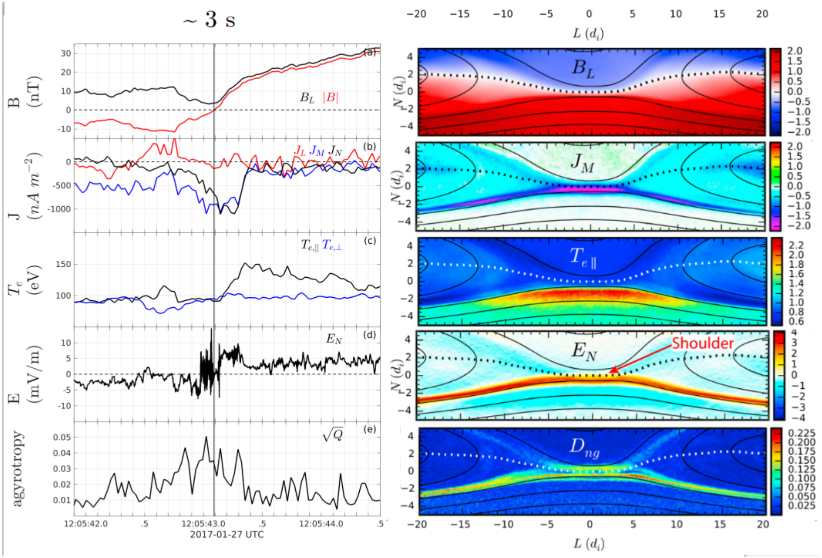

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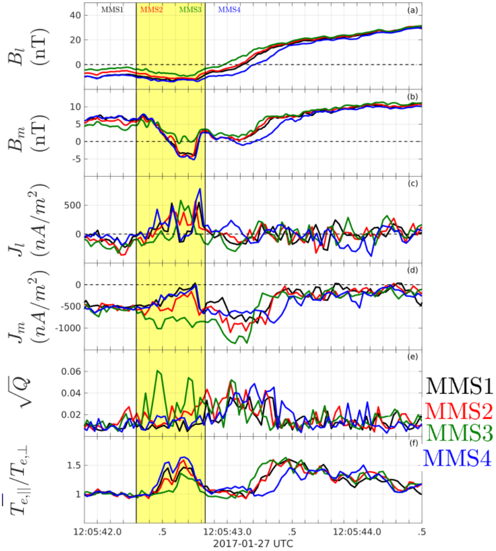
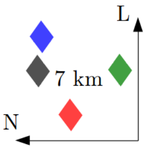
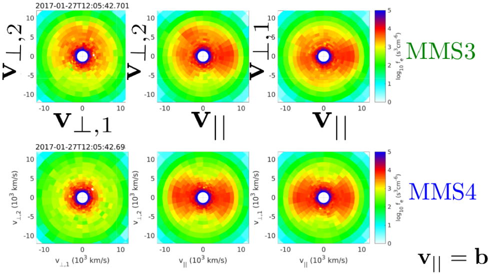
Differences among spacecraft observations are recorded during the EDR encounter





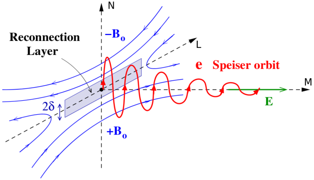
Differences among spacecraft observations are recorded during the EDR encounter: electron distribution functions



$$\mathbf{v}_{||} = \mathbf{b}$$

$$\mathbf{v}_{\perp,1} = \mathbf{v} \times \mathbf{b}$$

$$\mathbf{v}_{\perp,2} = \mathbf{b} \times (\mathbf{v} \times \mathbf{b})$$



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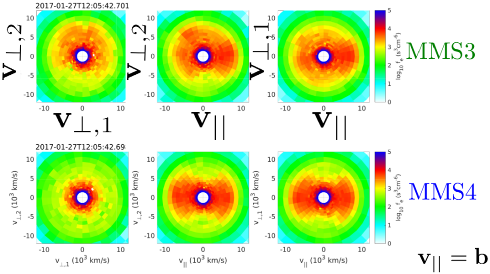

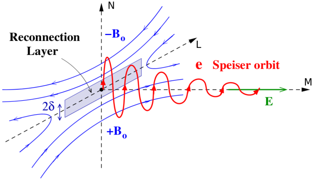

$$\mathbf{v}_{||} = \mathbf{b}$$
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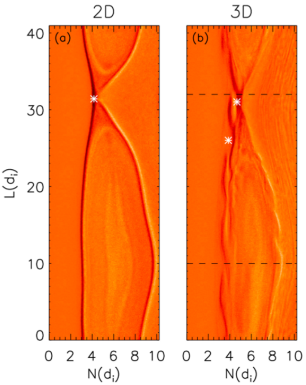
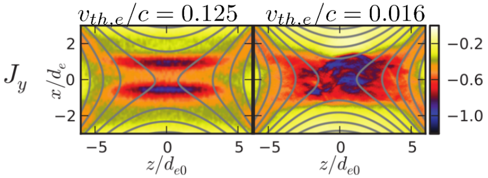
EDR is a complex and structured region

Cozzani et al., submitted

EDR turbulence is observed also in simulations



Price et al., GRL, 2016



Jara-Almonte et al., PoP, 2014

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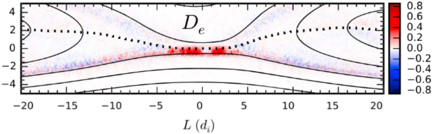
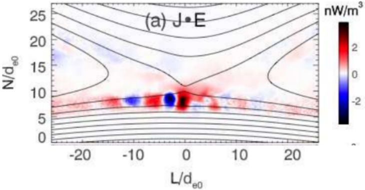


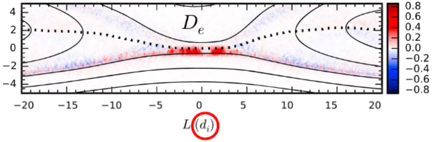
Shay et al., GRL, 2016



Swisdak et al., ArXiv, 2017

PIC code

EDR turbulence is observed also in simulations



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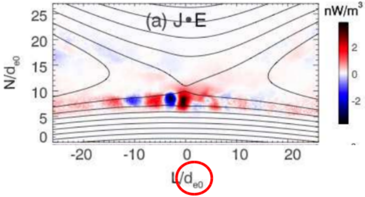

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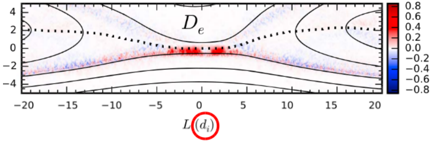
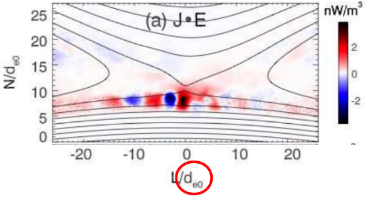


Shay et al., GRL, 2016



Swisdak et al., ArXiv, 2017

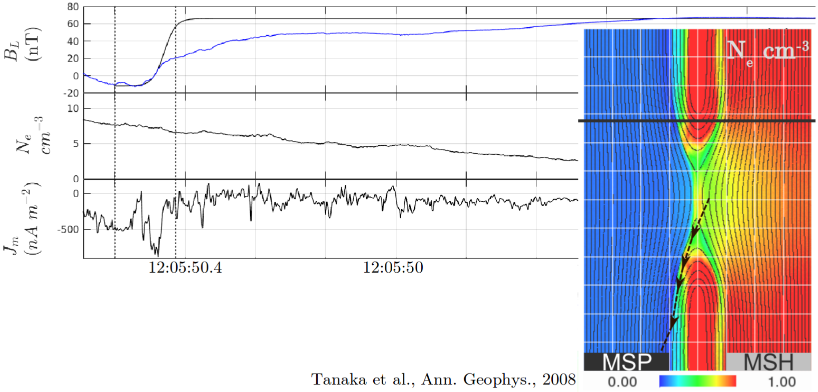
PIC code

We need a high resolution, low noise code to model the EDR

The Vlasov-Darwin code

$$
\begin{cases}
\partial_t f_\alpha + (\mathbf{v}_\alpha \cdot \nabla) f_\alpha + \dfrac{Z_\alpha}{\mu_\alpha} (\mathbf{E} + \mathbf{v}_\alpha \times \mathbf{B}) \cdot \nabla_{\mathbf{v}_\alpha} f_\alpha = 0 \\
\nabla^2 \phi = -\zeta^2 \sum Z_\alpha n_\alpha \qquad \mathbf{E}_L = -\nabla \phi \\
\nabla^2 \mathbf{B} = -\beta^2 \zeta^2 \nabla \times \mathbf{j} \\
\nabla^2 \hat{\mathbf{E}}_T - \beta^2 \zeta^2 \sum_\alpha \dfrac{Z_\alpha^2 n_{\alpha,0}}{\mu_\alpha} \hat{\mathbf{E}}_T = \beta^2 \zeta^2 \left[-\nabla \cdot \sum_\alpha Z_\alpha \langle \mathbf{v}_\alpha \mathbf{v}_\alpha \rangle_\alpha + \right. \\
\left. + \sum_\alpha \dfrac{Z_\alpha^2}{\mu_\alpha} (n_\alpha \mathbf{E}_L + \langle \mathbf{v}_\alpha \rangle_\alpha \times \mathbf{B}) \right] \\
\nabla^2 \Theta = \nabla \cdot \hat{\mathbf{E}}_T \qquad \mathbf{E}_T = \hat{\mathbf{E}}_T - \nabla \Theta \\
\nabla \cdot \mathbf{B} = 0
\end{cases}
$$

The initial condition reproduces MMS data

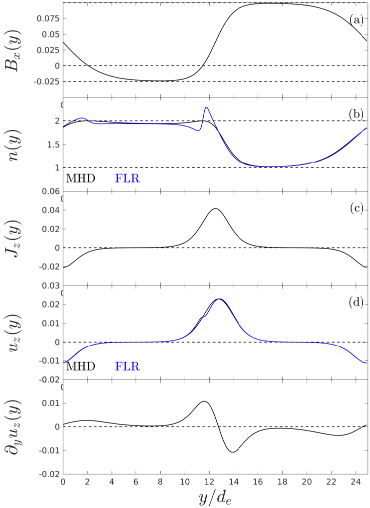


Tanaka et al., Ann. Geophys., 2008

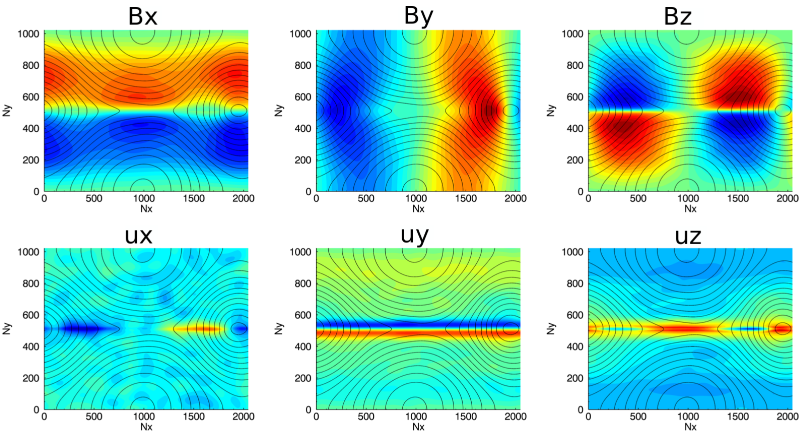
$$B(x) = \frac{B_{msp} + B_{msh}}{2} \tanh\left(\frac{x}{L_{cs}}\right) + \frac{B_{msp} - B_{msh}}{2}$$

Looking for the equilibrium

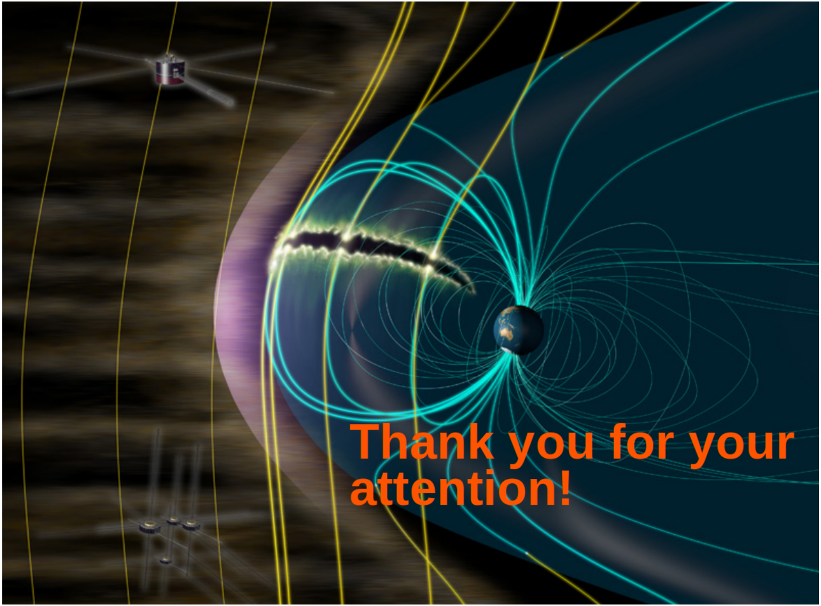
- MHD force balance + Finite Larmor Radius (FLR) effects
- Non negligible agyrotropy
- $$\mathsf{P} = \begin{pmatrix} P_{||} & P_{12} & P_{13} \\ P_{12} & P_{\perp} & P_{23} \\ P_{13} & P_{23} & P_{\perp} \end{pmatrix}$$



First results: 2D magnetic reconnection simulations



$$L_{cs} = 10\ d_e,\ L_x = 120\ 2\pi,\ L_y = 60\ 2\pi,\ d_x = d_y = 0.37,\ m_i/m_e = 100$$


Thank you for your attention!

Simulation parameters

Run FG_3/03	
L_1	10
$L_2 = 5\ L_1$	50
B_{msp}	0.1
B_{msh}	0.1
B_{z0}	0.01
n_{msp}	1
$T_{e,msp} = T_{e,msh}$	1
$T_{i,msp} = T_{i,msh}$	1
amp	0.001
ϵ	0.1
$N_{p,row}$	128
$N_{p,col}$	64
N_x	2048
N_y	1024
L_x	$120\ 2\pi$
L_y	$60\ 2\pi$
d_x	0.37
d_y	0.37
$\lambda_{D,e}/d_e = v_{th,e}/c$	0.05
N_{vx}	51
N_{vy}	51
N_{vz}	71
$V_{x,e,max}$	5
$V_{y,e,max}$	5
$V_{z,e,max}$	5
dt	0.1
m_i/m_e	100