Study of a dayside magnetopause reconnection event detected by MMS and related to a large-scale solar wind perturbation

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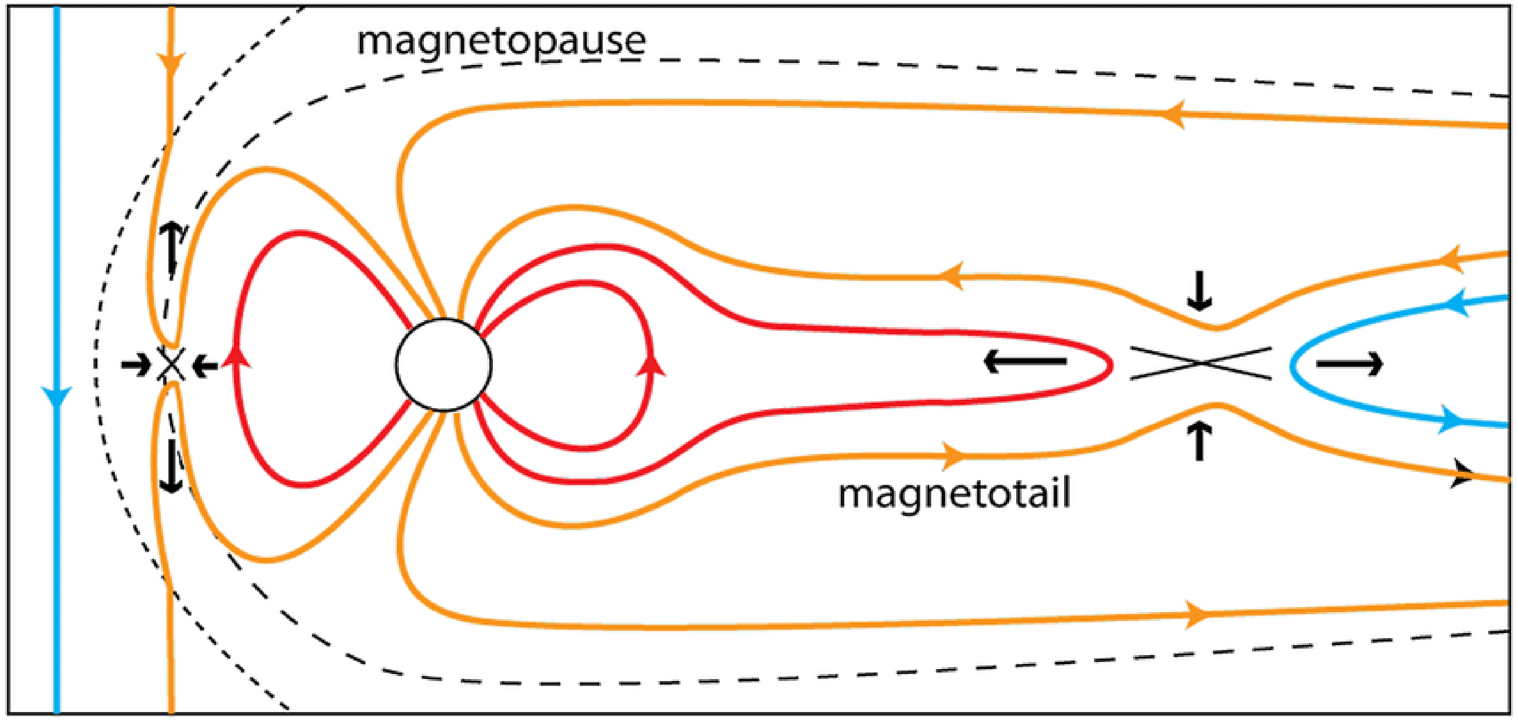
Magnetic reconnection

Magnetic reconnection between the solar wind and Earth's magnetic field is a fundamental driver of the dynamics of the magnetosphere. Reconnection at the magnetopause leads to magnetic flux transfer and formation of the extended magnetotail.



Adapted from (Eastwood et al, 2017)

In-situ observation of Magnetic reconnection at Earth

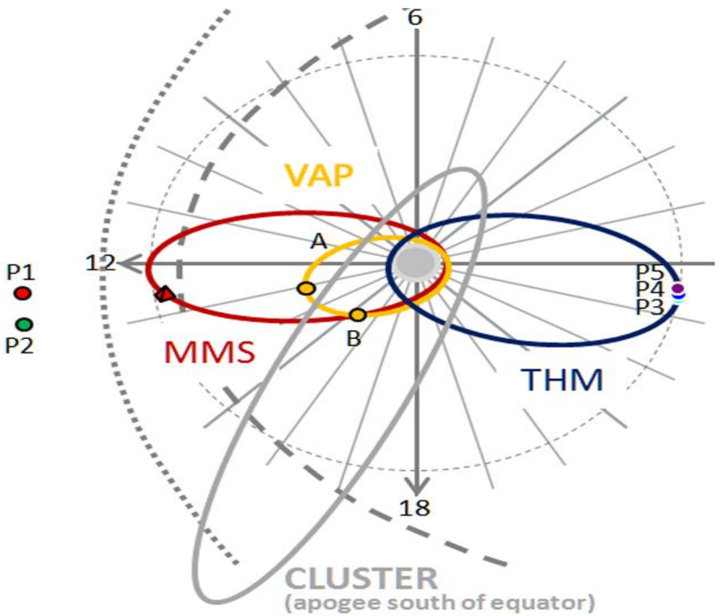


Image credit: Themis website

- What is the role of large density gradient on reconnection process?
- What is the possible role of cold ions in maintaining the electric field far away from the x-line along the separatrix in the presence of the guide field?

Solar wind observation at L1

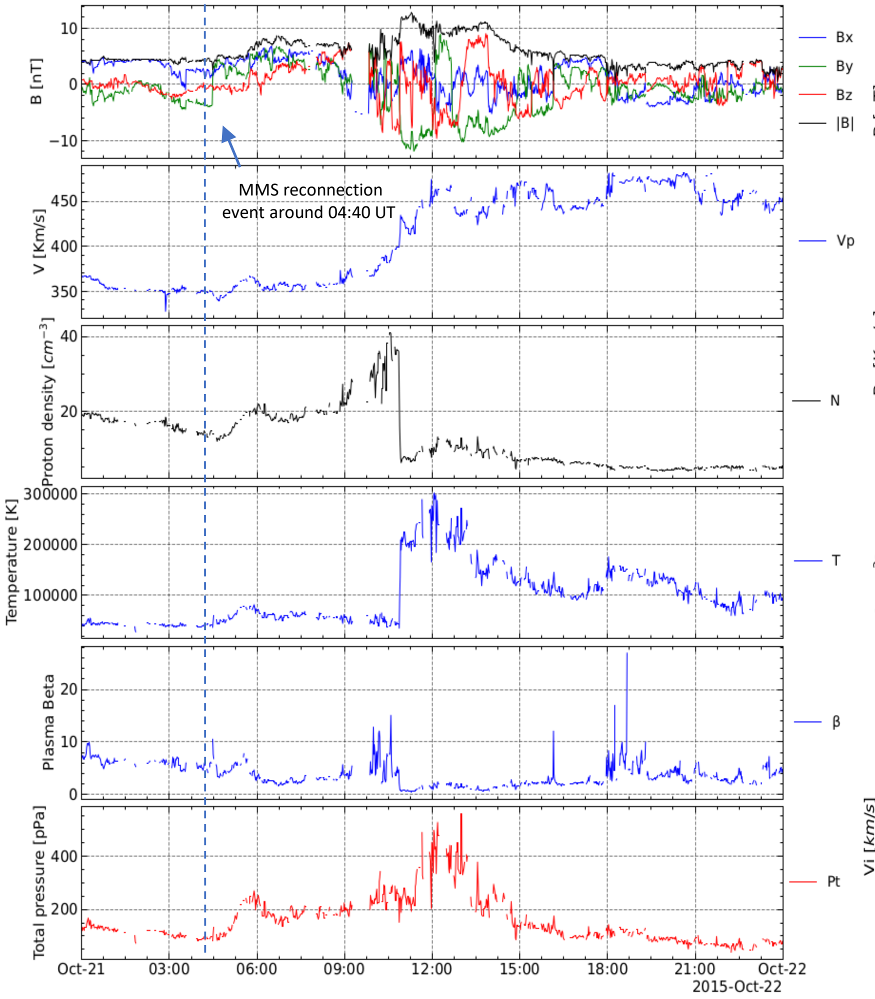
- The reconnection event detected by MMS on Oct. 21, 2015 during a period when the magnetosheath density is very large (up to 160 cm $^{-3}$) is related to the arrival of a weak SIR.

- The **B_Y** reversal observed in the solar wind is detected by MMS.

- The SIR event is considered as shock-less (Jian et al, 2006).

21/10/2015 Shock-less SIR event

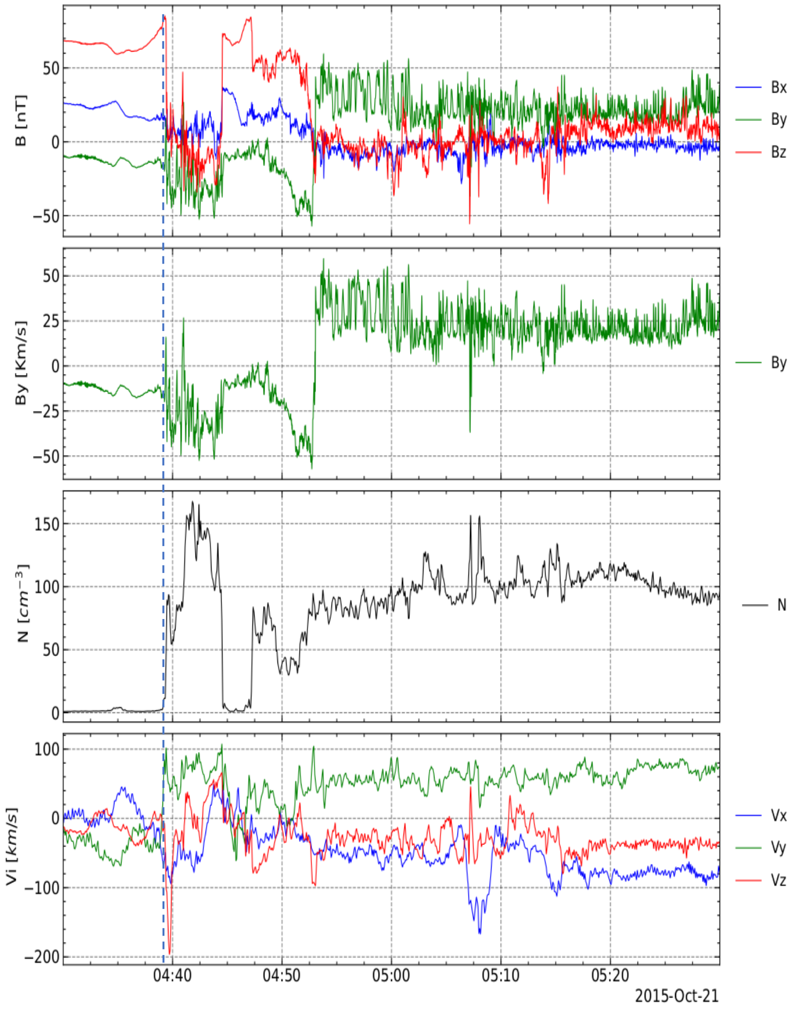
OMNI data (Observation at L1)



OMNI data from 21-22/Oct/2015 (Data shifted to the bow shock time scale) with 1-MIN resolution.

21/10/2015 reconnection event

MMS Observation



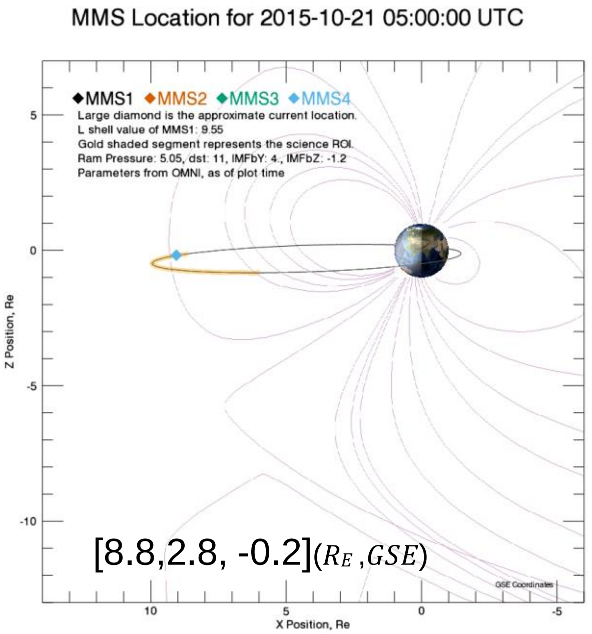
MMS fast data in GSE coordinates from 04:30 UT-05:30 UT 21/Oct/2015

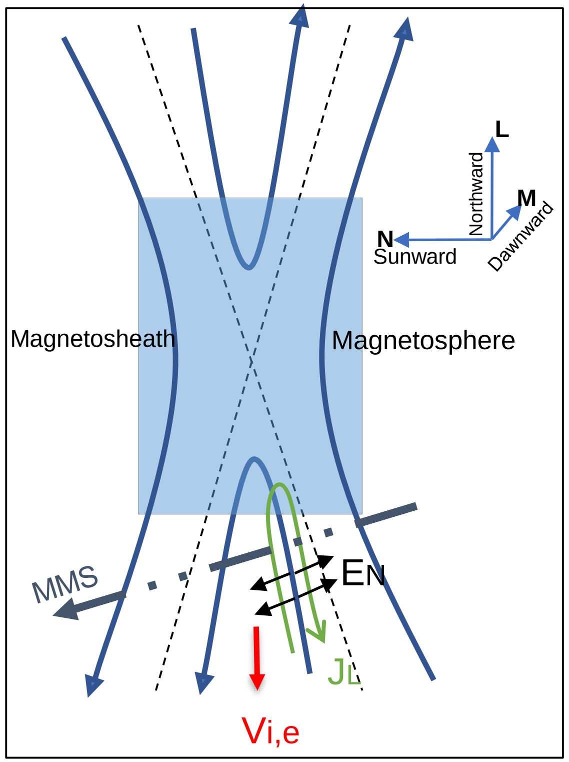
Event overview

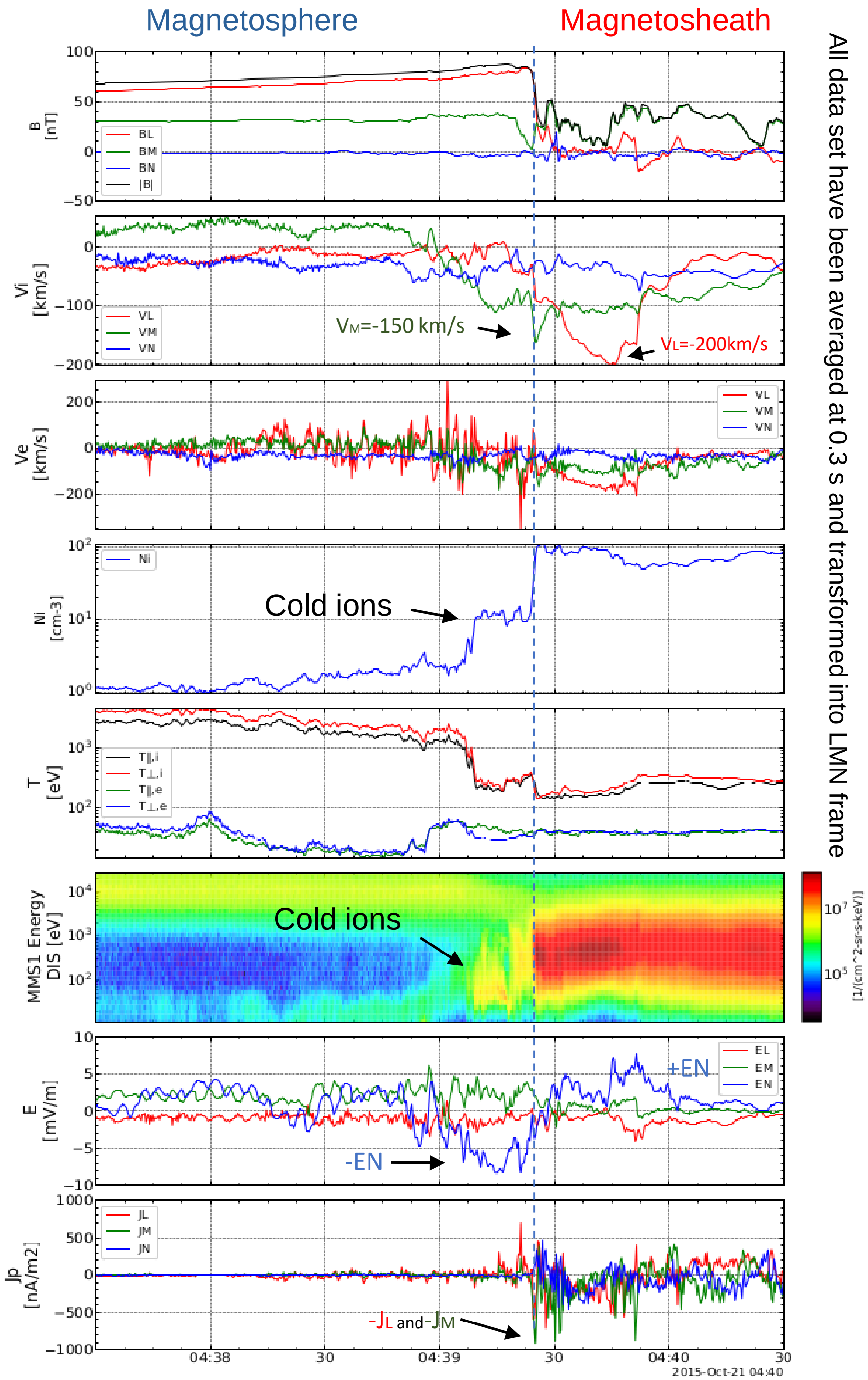
- Highly asymmetric reconnection: $\mathbf{N_{SH}/N_{SP}}$ = 50, $\mathbf{B_{SP}/B_{SH}}$=2.46
- A moderate guide field directed dawnward: 0.42 $\mathbf{B_{SP}}$, 0.96 $\mathbf{B_{SH}}$
- Ion and electron jets V_L -200 km/s
- First peak in density (10 cm^{-3}) is dominated by cold ions.
- Reversal of E_N (directed away from the magnetopause).
- Current density peaks ($-J_M$ and $-J_L$) at 04:39:25 UT.

	MSP	MSH
|B| (nT)	76	31
|BL| (nT)	67	0.5
|BM| (nT)	32	30
|N| (cm^{-3})	1.5	73.67

L =[0.11,0.24,0.96]
M =[0.30,-0.93,0.19]
N =[0.94,0.26,-0.17]
$\mathbf{V_{MP}}$= -47 km/s **N** (TA)







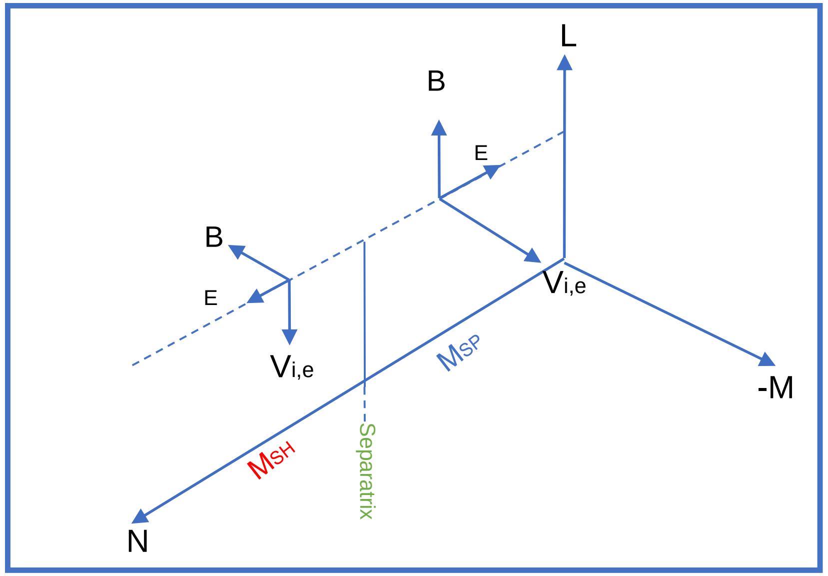
Generalized Ohm's law

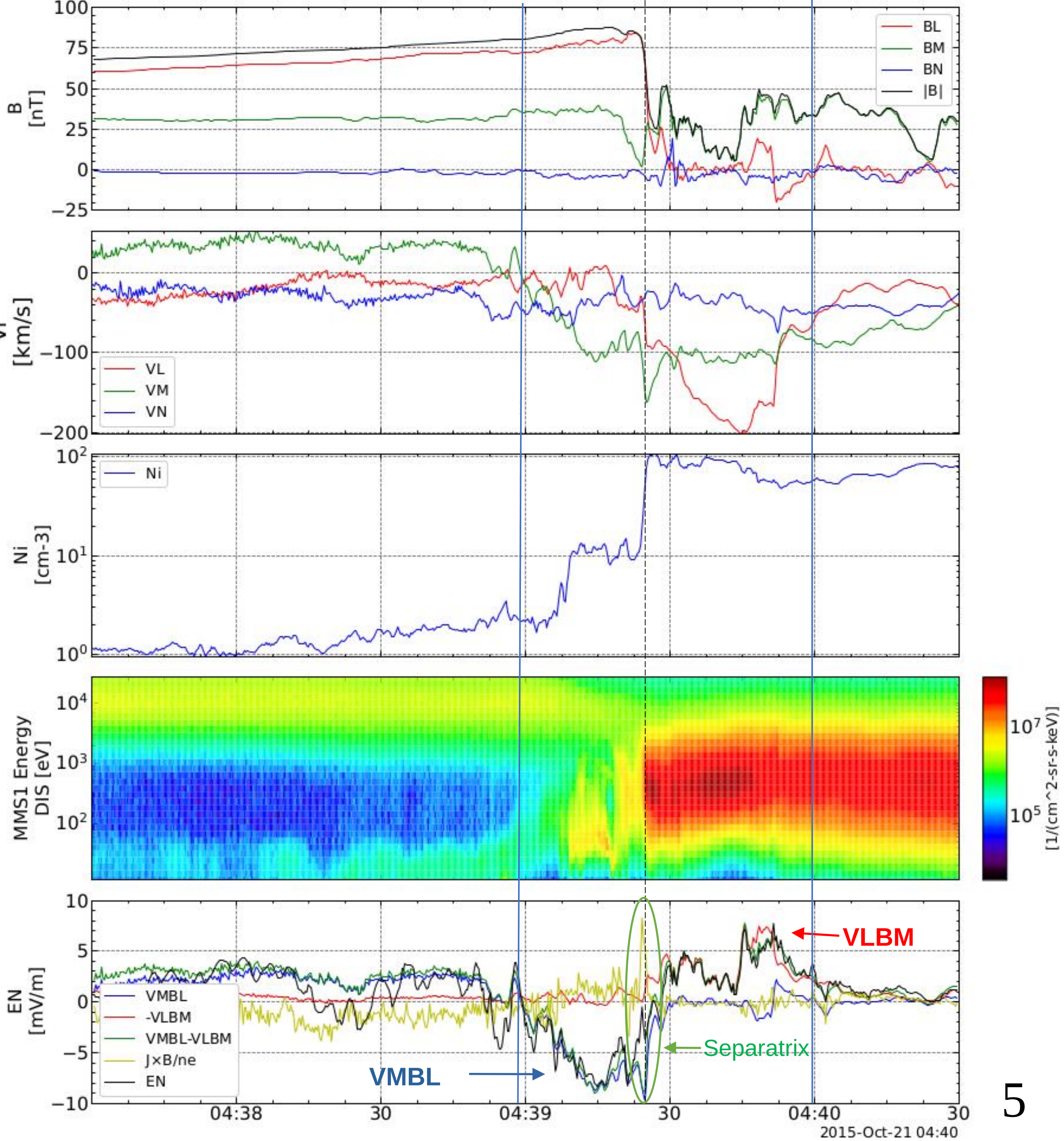
$$\mathbf{E} + [\mathbf{u}_i \times \mathbf{B}] = \frac{1}{ne}\mathbf{j} \times \mathbf{B} - \frac{1}{ne}\nabla p_e.$$

VMBL-VLBM

- Outflow region is far from EDR and IDR.
- Magnetospheric Separatrix crossing at 04:39:24 UT
  Ions are decoupled, Electrons remained magnetized (not shown).
- **J**×**B** term is compensated by **v**×**B** term (vertical black line)

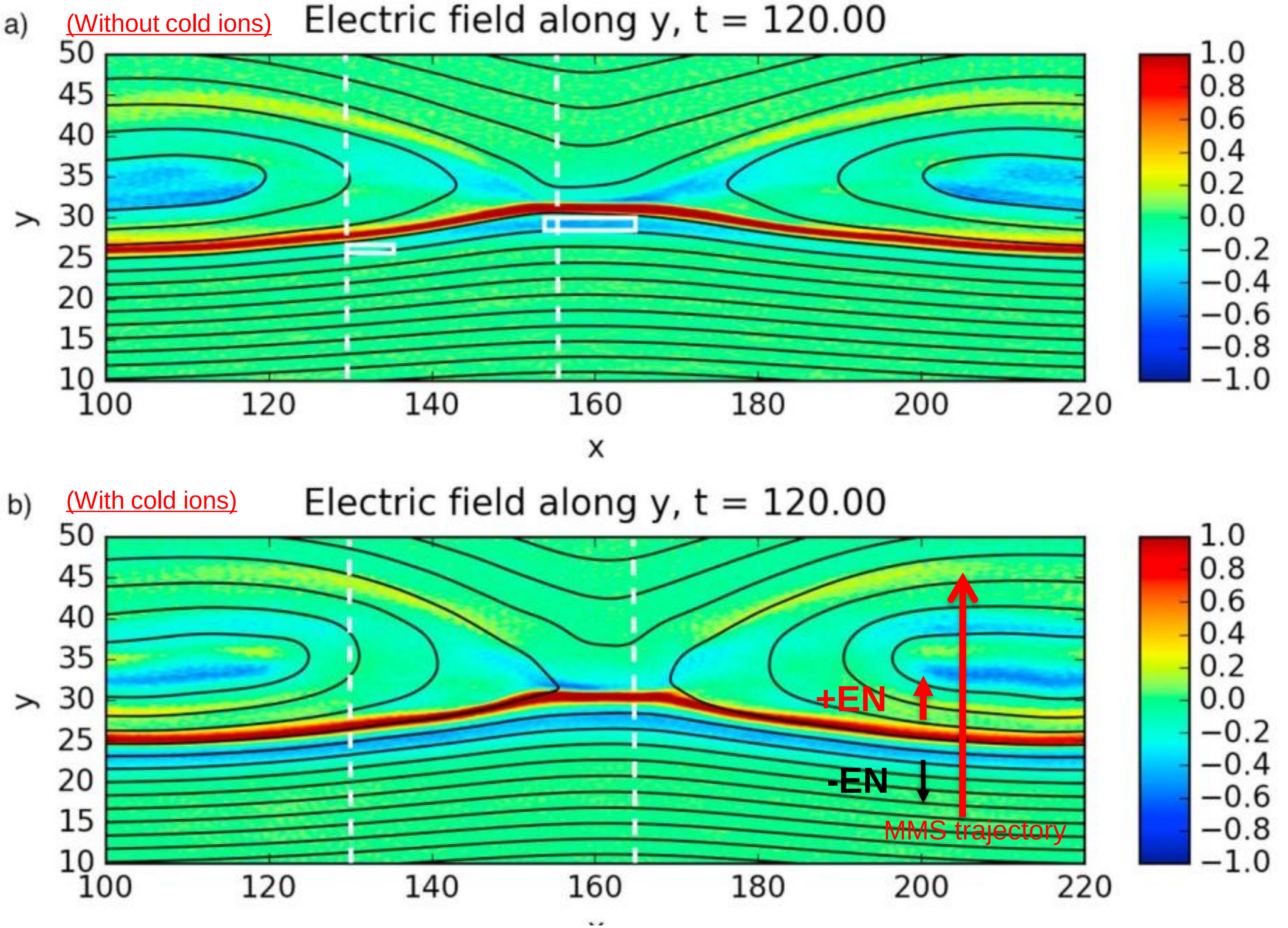
The following schematic illustrates the process between the two blue vertical lines in the figure:





Cold ions effect

- Kinetic simulation of asymmetric magnetic reconnection with cold ions (without guide field).
- Cold ion very low temperature (below 300 eV) enables them to E × B drift in the electric field structure.
- This signature maintained away from the x-line see panel (b).



[Dargent et al, 2017]

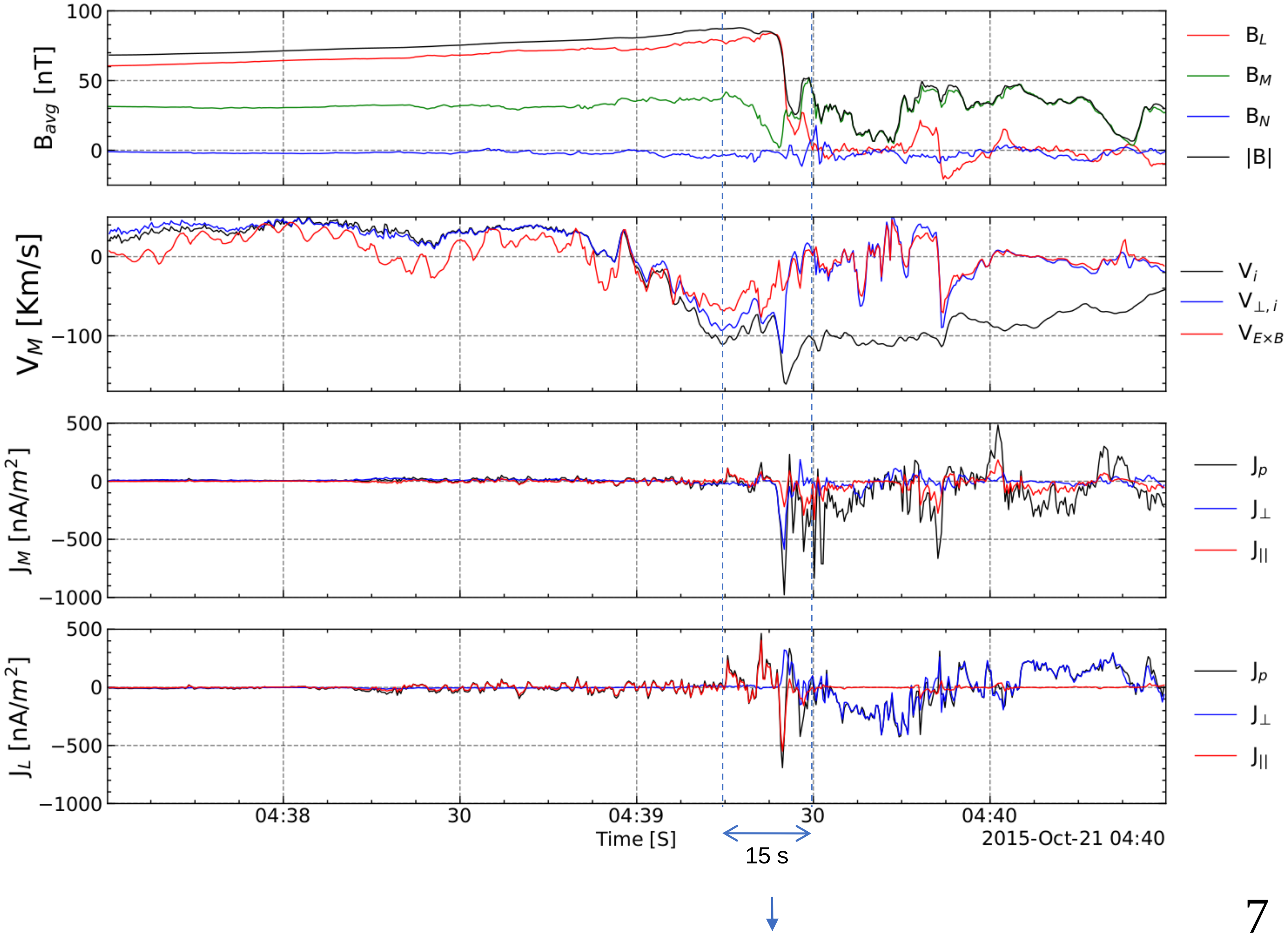
(We thank J. Dargent and S. Toledo-Redondo for the useful discussions)

Perpendicular and parallel currents

- Out of plane velocity correspond to the drifting of ions $\boldsymbol{V_{E\times B}}$ and they maintain the electric field in the region before crossing the separatrix.

- Currents in -L and -M directions while crossing the separatrix.

- The data between the two dashed blue vertical line is zoomed-in in the following slide to investigate the source of these currents.



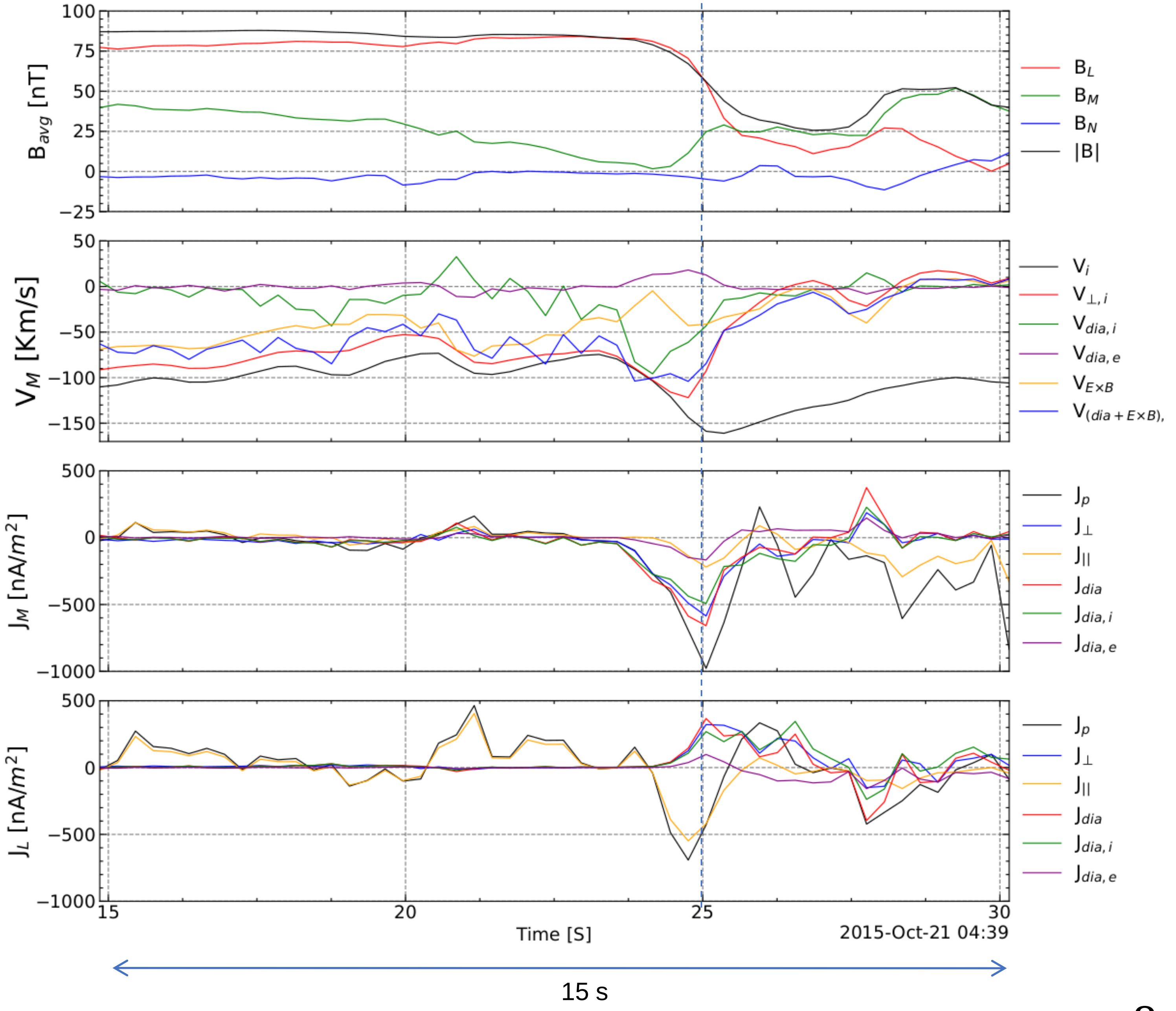
Diamagnetic currents

Equations:

$$\boldsymbol{V}_{\boldsymbol{dia,e}} \equiv \frac{\nabla P_e \times B}{enB^2}, \quad \boldsymbol{V}_{\boldsymbol{dia,i}} \equiv -\frac{\nabla P_i \times B}{enB^2}$$

$$\boldsymbol{J}_{\boldsymbol{dia}} = -en\left(V_{dia,e} - V_{dia,i}\right) = \frac{B \times \nabla P}{B^2}$$

- $V_{\perp,i}$ is consistent with $V_{(dia+E\times B)}$
- $V_{dia,i}$ $V_{\perp,i}$ in the separatrix region where the pressure gradient is large.
- Most of the source of the perpendicular current in M direction is $\boldsymbol{J}_{\boldsymbol{dia,I}}$ (although $\boldsymbol{J}_{\boldsymbol{dia,e}}$ Is not negligible)
- The current in L direction is mostly field aligned at the peak



Conclusions

- The reconnection event which is far away from the x-line detected by MMS on Oct. 21, 2015 during a period when the magnetosheath density is very large (up to 160 cm $^{-3}$) is related to the arrival of a weak SIR.
- The negative values of $\mathbf{E_N}$ (Earthward) on the magnetospheric side is due to the relative motion of ions in the out of plane direction ($\mathbf{V_M B_L}$).
- The positive values of $\mathbf{E_N}$ (Sunward) on the magnetosheath side is due to the existence of the guide field ($-\mathbf{V_L B_M}$).
- $\mathbf{J} \times \mathbf{B}$ term is due to the large diamagnetic current which is the largest contributor in the out of plane current ($-\mathbf{J_M}$) at the separatrix (mostly produced by ion pressure gradient).

What is next?

- In order to distinguish between the magnetosheath ions, magnetospheric ions and ionospheric ions we have to separate the different ion distribution functions depending on the energy.
- Analyze in details more MMS reconnection events related to large scale solar wind perturbations notably by calculating diamagnetic current related to strong pressure gradients.