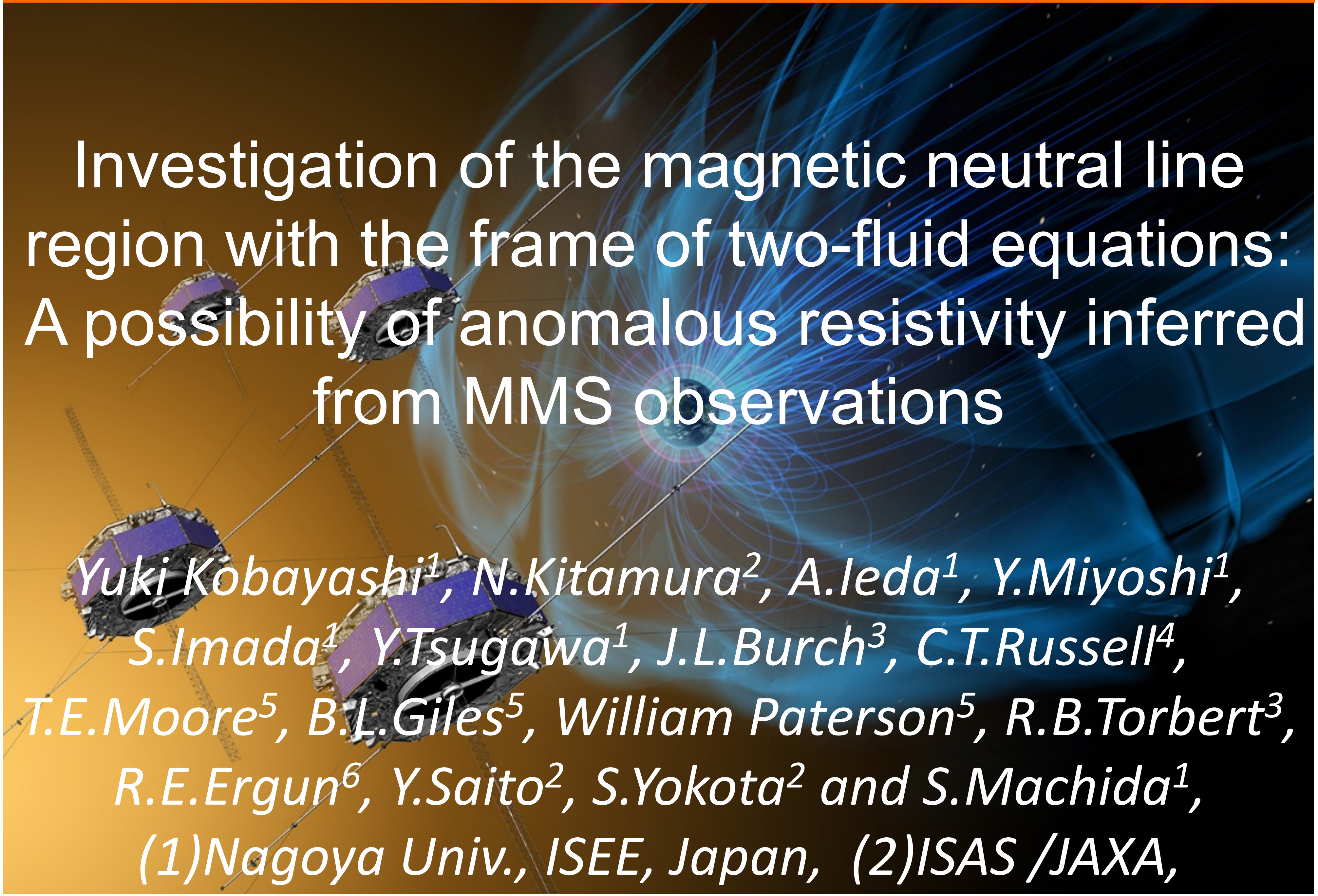
# 磁場観測から決定するリコネクション構造

今田晋亮 (名古屋大学、ISEE)



# Investigation of the magnetic neutral line region with the frame of two-fluid equations: A possibility of anomalous resistivity inferred from MMS observations

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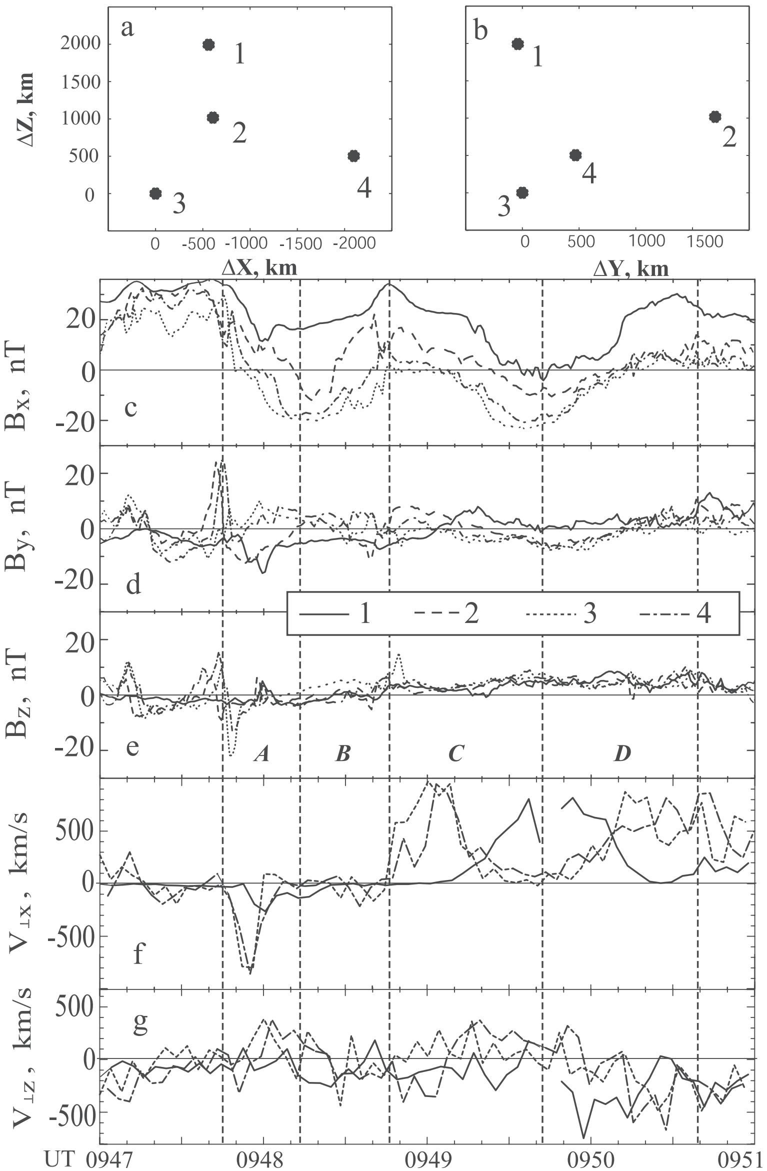
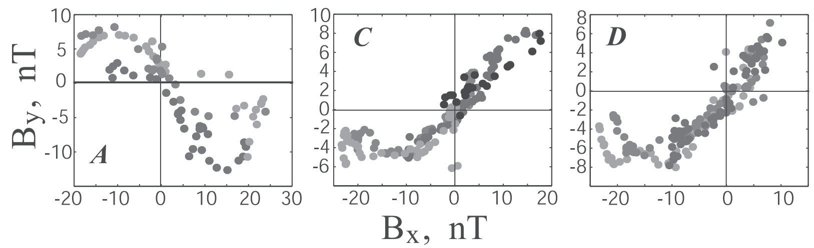
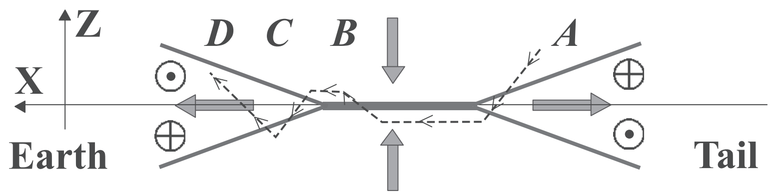
*(1)Nagoya Univ., ISEE, Japan, (2)ISAS /JAXA,*

# Runov et al. 2003

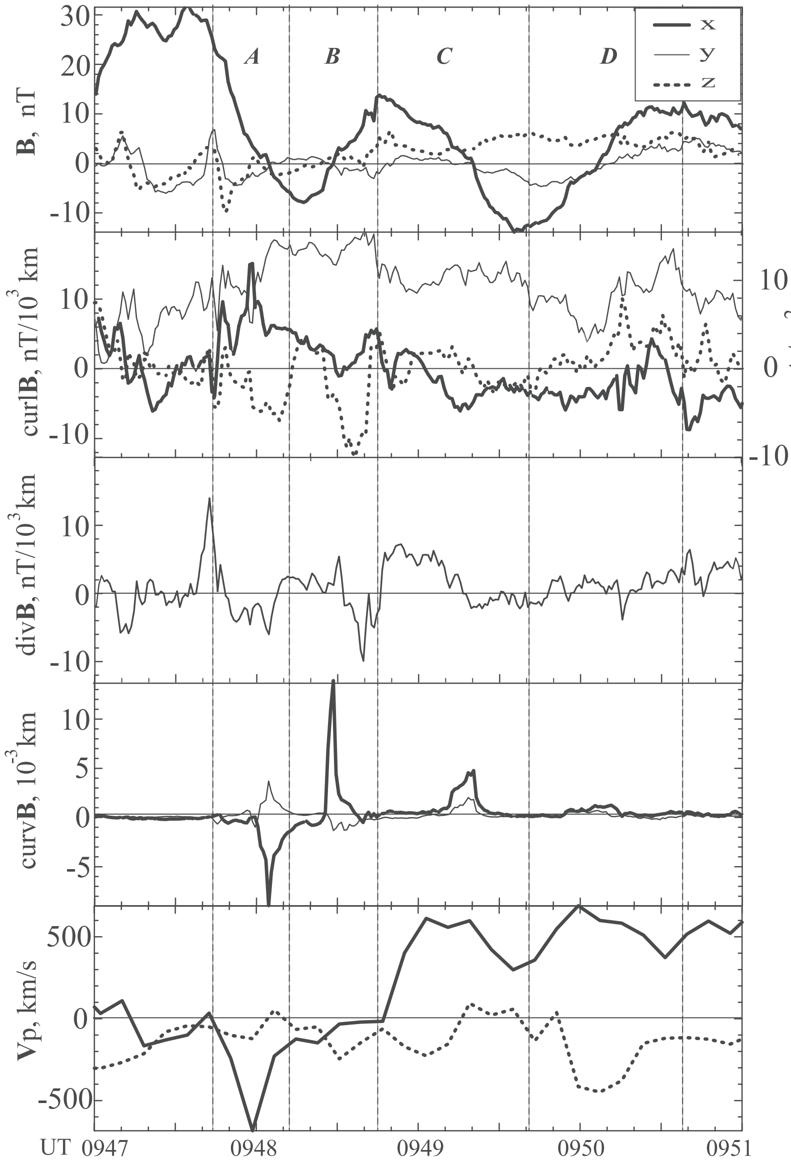


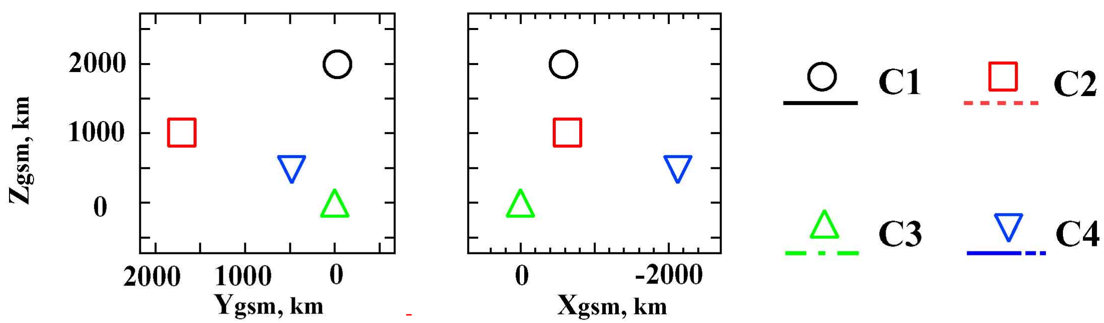



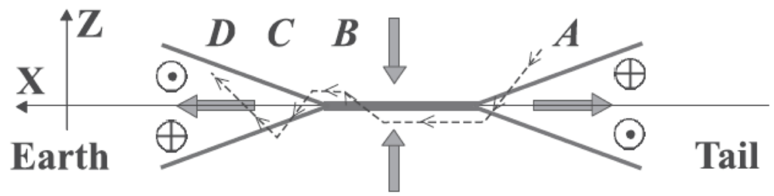
# curv B を求める

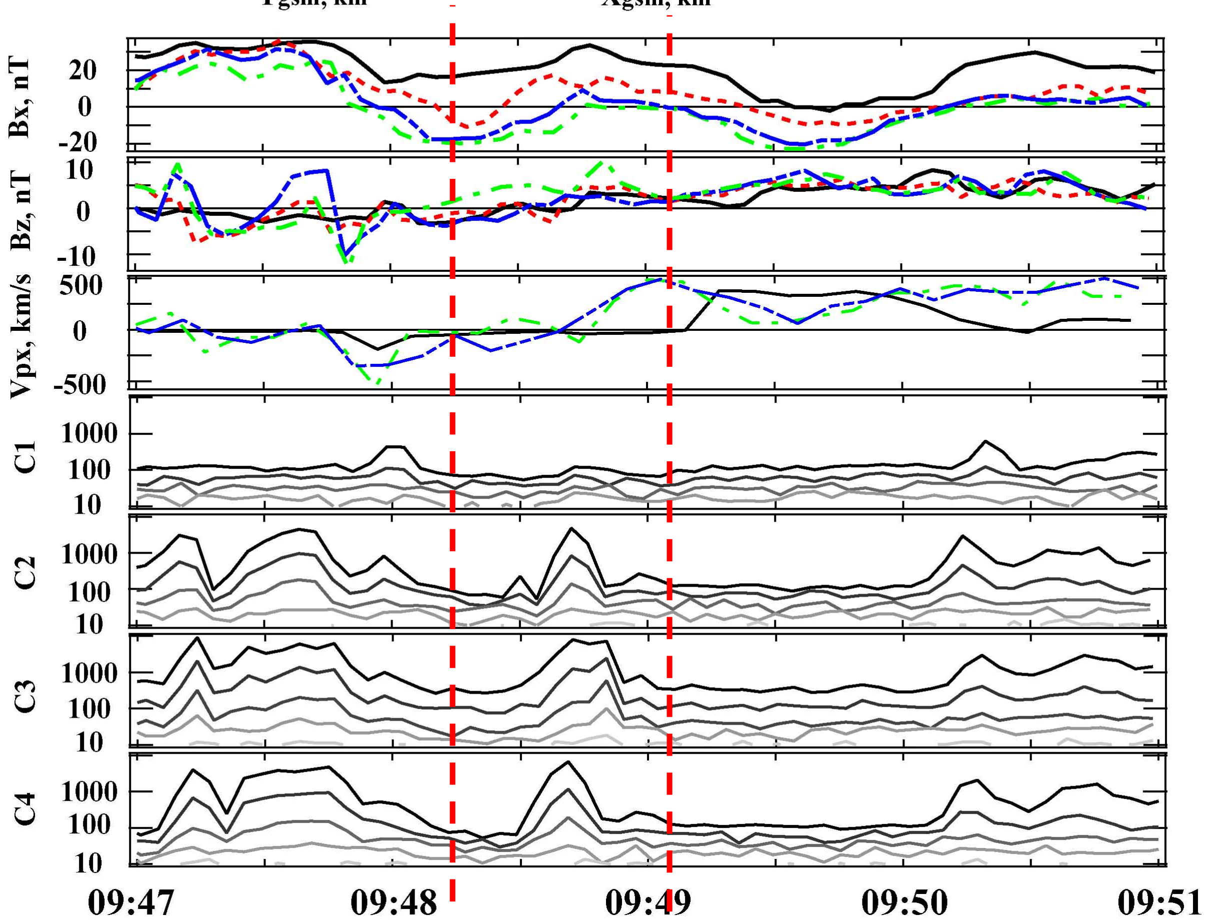
cient 0.82 < $R$ < 0.95). Hence all spacecraft stay in the same physical region, and the linear gradient and curl estimator technique [*Chanteur*, 1998] can be applied. Figure 2 shows the magnetic field components in the tetrahedron barycenter (upper panel), the **curl B** components, $X$ and $Y$ GSM components of the magnetic field curvature vector **curv B** = (**b** · ∇)**b**, magnetic field divergence *div B*, and $X$- and $Z$-components of the bulk proton flow from the mean value of the s/c 1, 3 and 4 CIS/CODIF measurements. The $y$-component of **curl B** has a



# Overview of Oct 1 2001 event



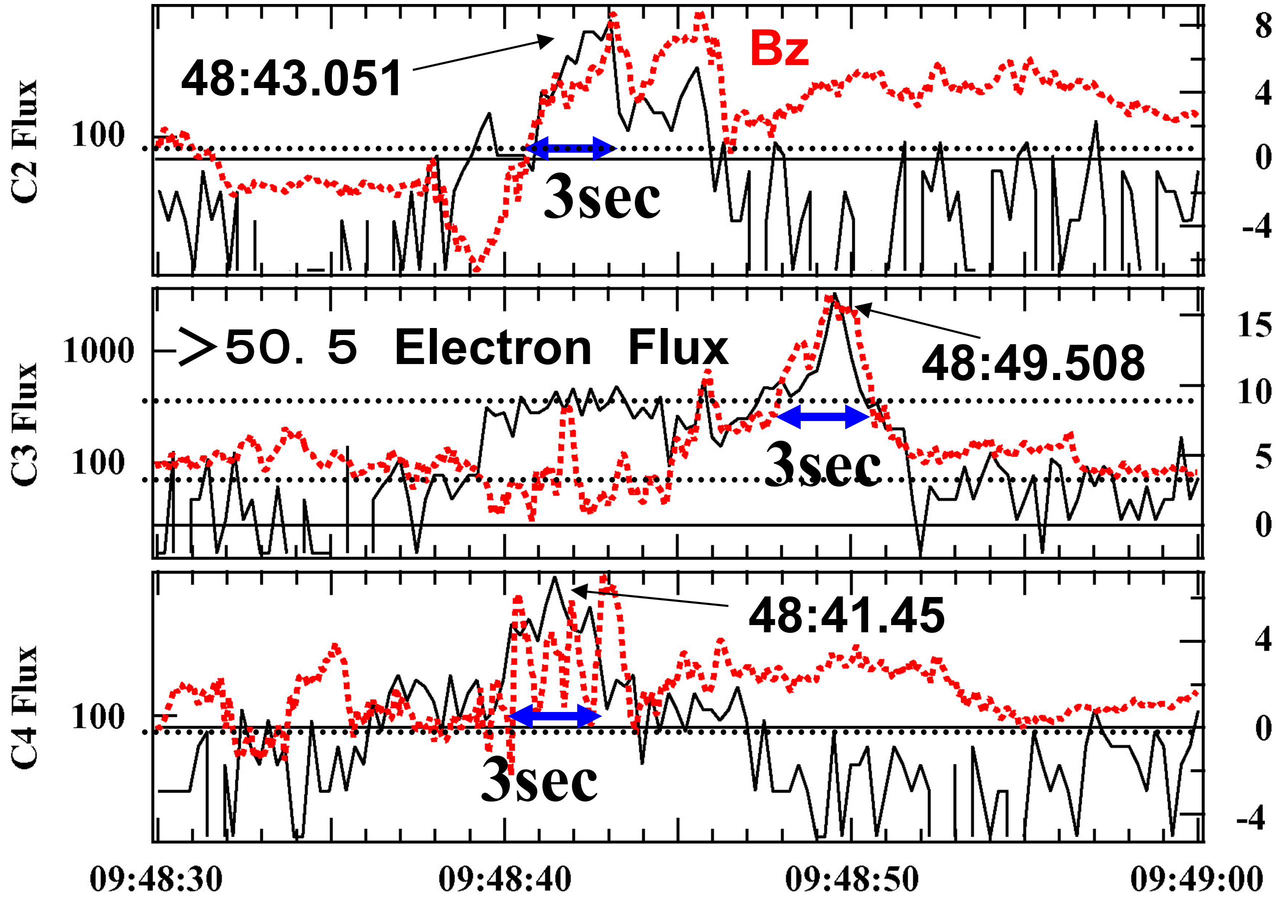

Two plasmoid passed, flow reversal with Bz reversal

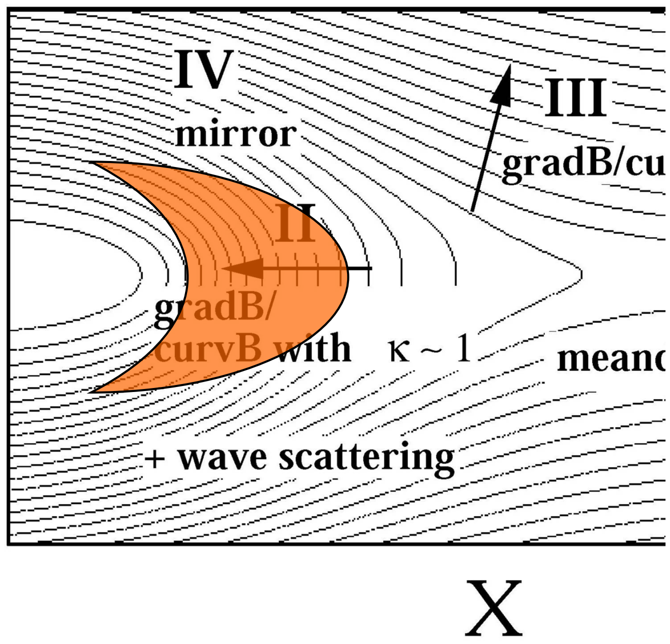
Energetic electron: RAPID（34.5 ~ 50.5 ~ 68.1 ~ 94.5 ~ 127.5 ~ 175.9keV）

Cluster passed near X-line.

**Imada et al., 2007 JGR**

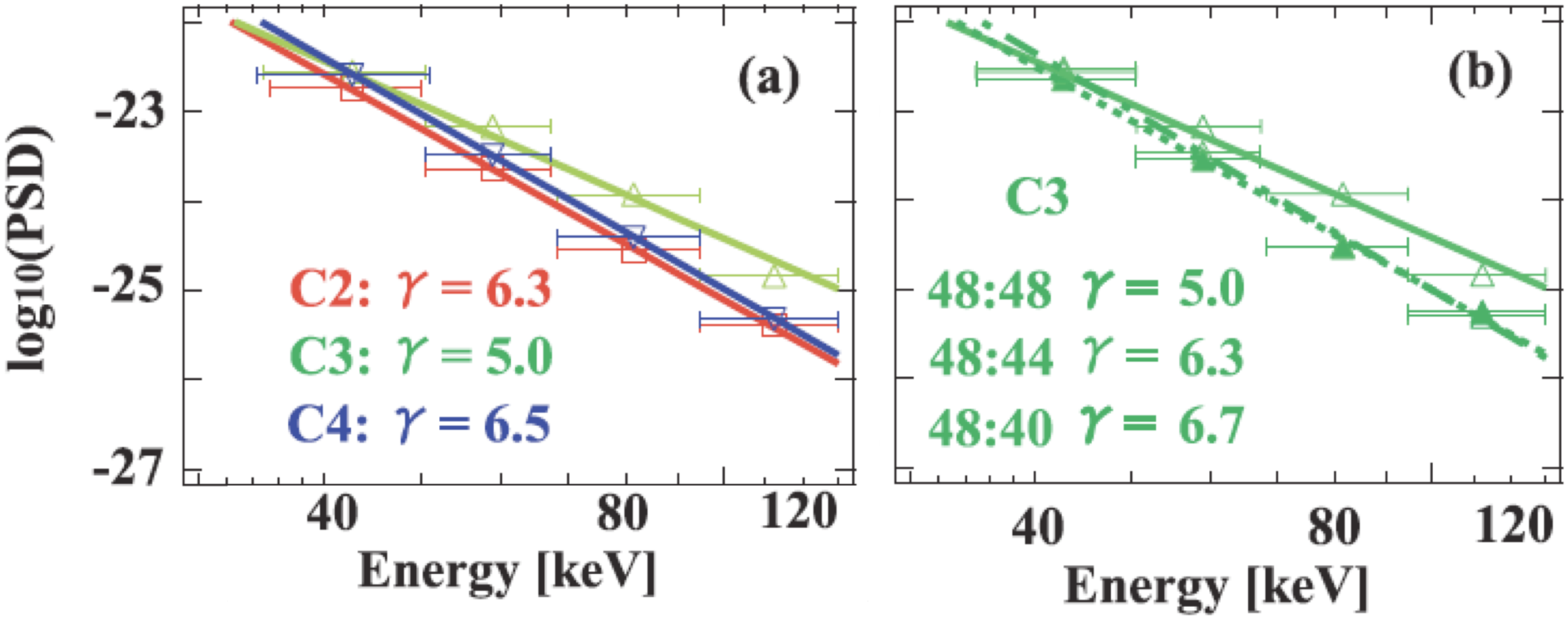
# Relationship between Energetic electron and normal magnetic field




**Red reconnected magnetic field**
**increasing magnetic field 4nT -> 8nT -> 16nT**
**Black energetic electron Flux**

# Energy Spectrum




**C4: at first**

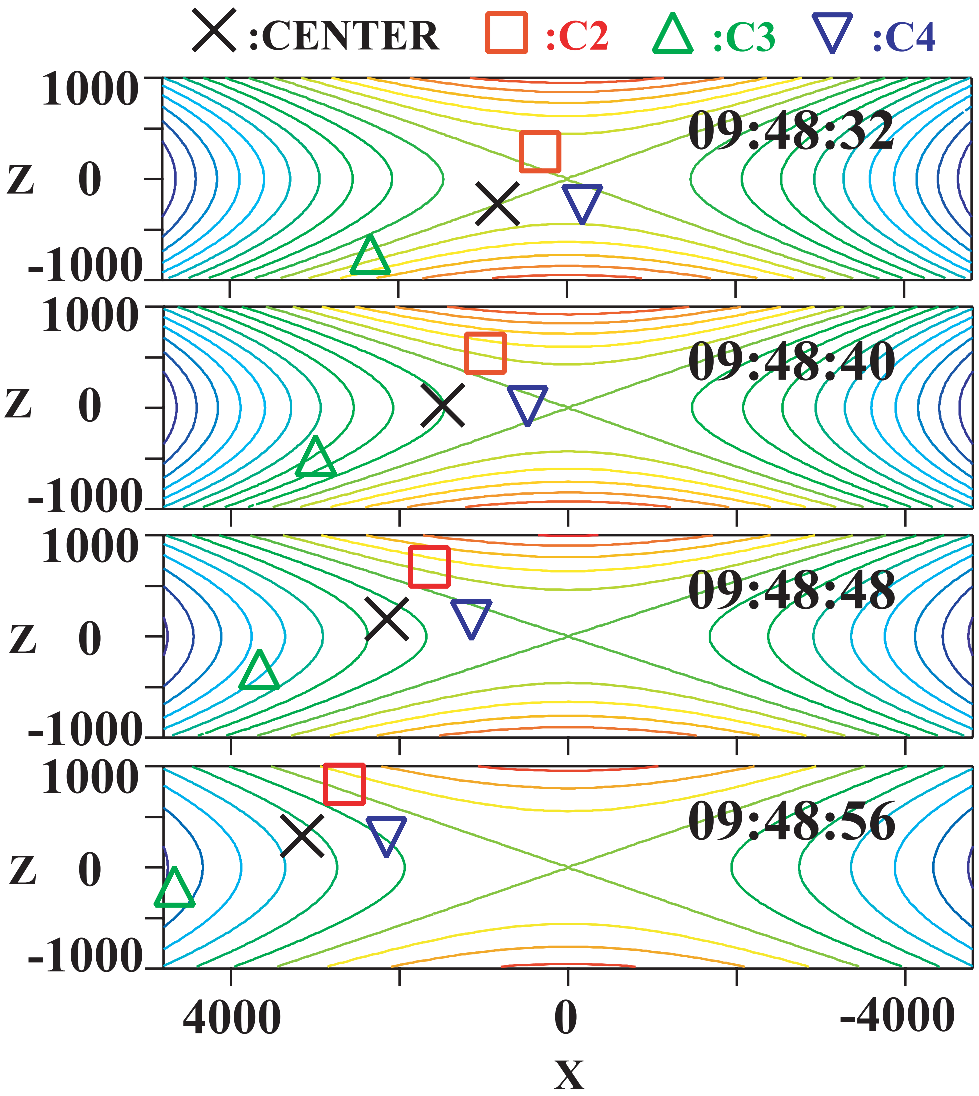
**C2: 1．6 sec after**

**C3: 6．5sec after Hardest!**

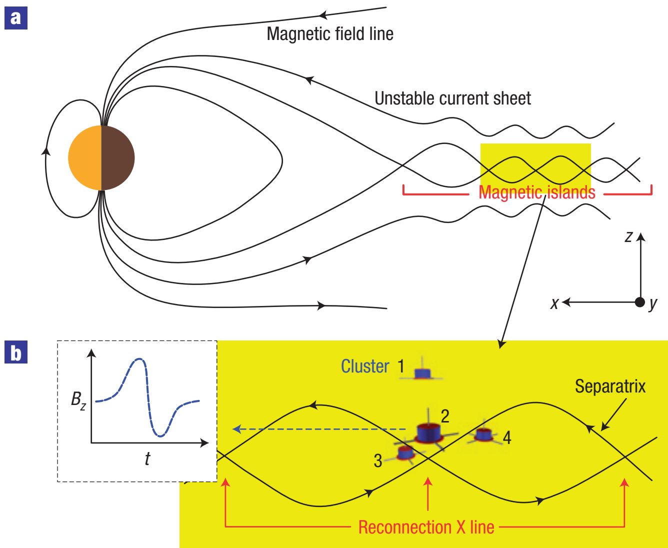
Energy spectrum get harder with time. ->non adiabatic

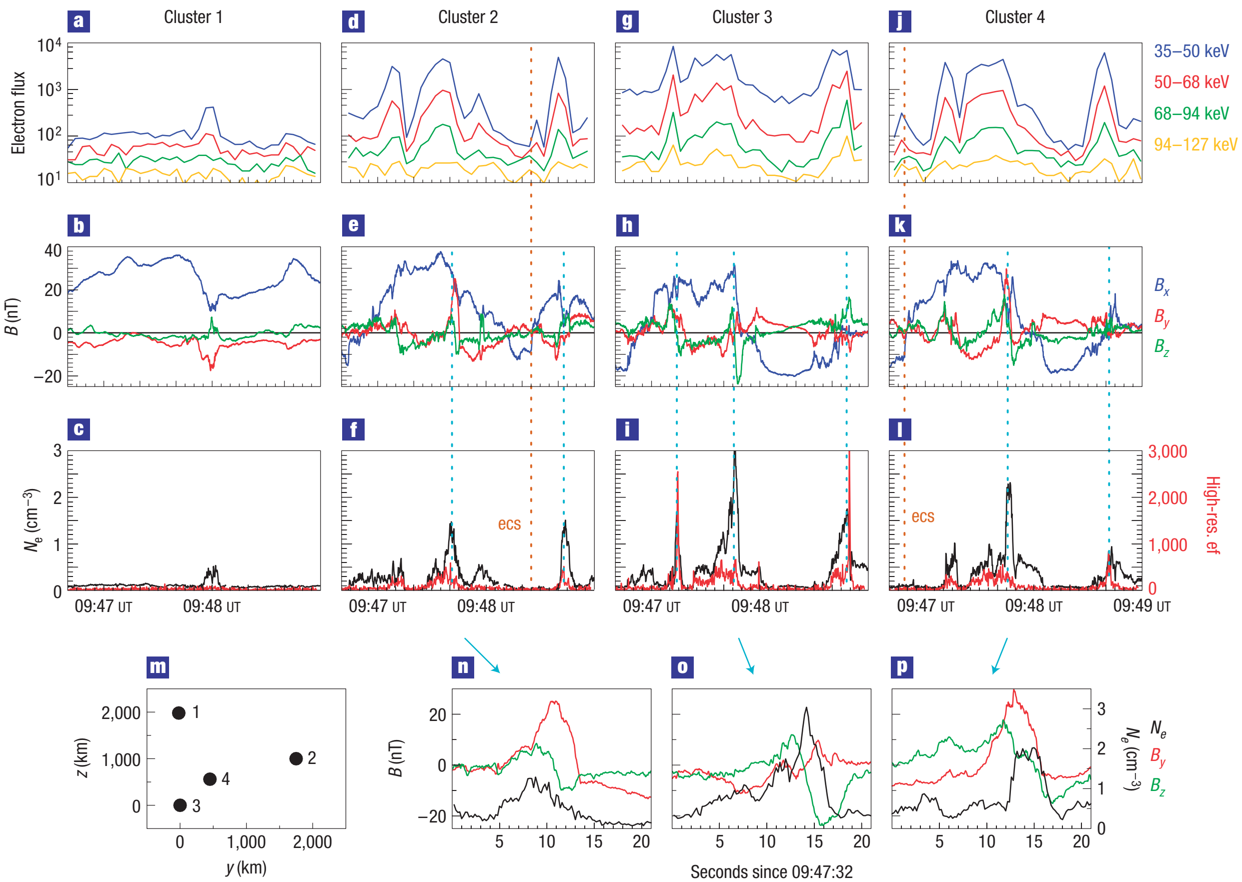
Note that normal magnetic field also enhance.

$$\mathbf{B} = B_{lobe}\left(\alpha\frac{x}{\lambda_x}\mathbf{e_z} + \tanh\left(\frac{z}{\lambda_z}\right)\mathbf{e_x}\right),$$



# Islands and flux rope




Chen + 2008, NatPh

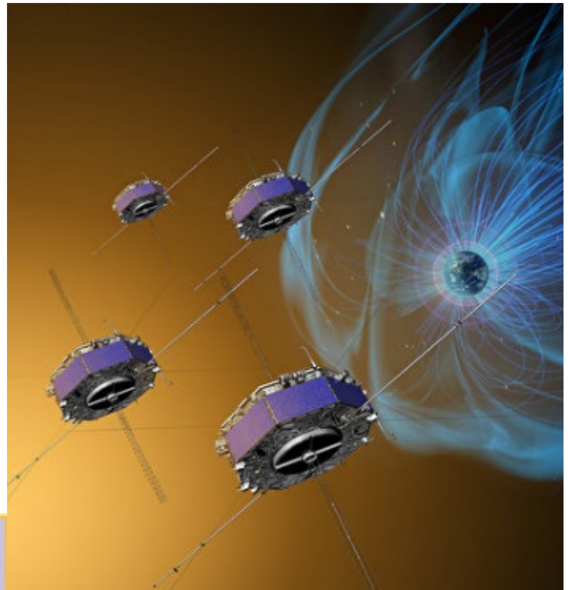
# Purpose

*Magnetospheric Multiscale mission（MMS）*

- Explores electron scale physics in magnetic reconnection
- Achieves high time resolution mesurements for plasmas
- Enables us to calculate spatial gradient of plasma moments

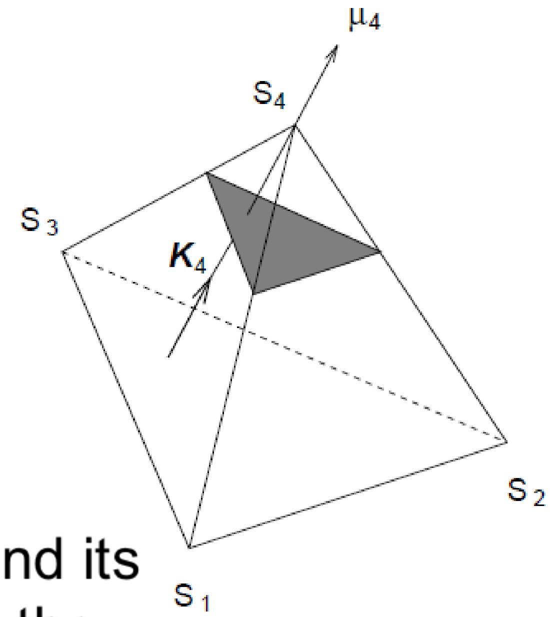
MMS enables us to evaluate two fluid equations.

What generate anomalous resistivity?



We try to clarify generation of anomalous resistivity in two fluid equations model.

# Calculation method of spatial gradient




We use Reciprocal vectors (*Chanteur 1998*).

$$\boldsymbol{k}_a = \frac{(\boldsymbol{r}_{1b} \times \boldsymbol{r}_{1c})}{\boldsymbol{r}_{1a} \cdot (\boldsymbol{r}_{1b} \times \boldsymbol{r}_{1c})} \qquad \boldsymbol{r}_{\alpha\beta} = \boldsymbol{r}_\beta - \boldsymbol{r}_\alpha$$

For example,

$$\boldsymbol{k}_4 = \frac{(\boldsymbol{r}_{12} \times \boldsymbol{r}_{13})}{\boldsymbol{r}_{14} \cdot (\boldsymbol{r}_{12} \times \boldsymbol{r}_{13})}$$

This vector directs from $\Delta S_1 S_2 S_3$-plane to $\boldsymbol{S}_4$-point and its length is equal to the reciprocal of the distance from the $\Delta S_1 S_2 S_3$ -plane to $\boldsymbol{S}_4$-point.

With this vector, linear interpolation of gradient (*G*) and divergence (*D*) are expressed as follows:

$$G(\boldsymbol{v}) = \sum_{a=1}^{4} \boldsymbol{k}_a \boldsymbol{v}_a^T \qquad \mathrm{D}(\boldsymbol{v}) = \sum_{a=1}^{4} \boldsymbol{k}_a \cdot \boldsymbol{v}_a$$

# Two fluid equations

$\boldsymbol{R}_e$, $\boldsymbol{R}_i$ : Collision terms

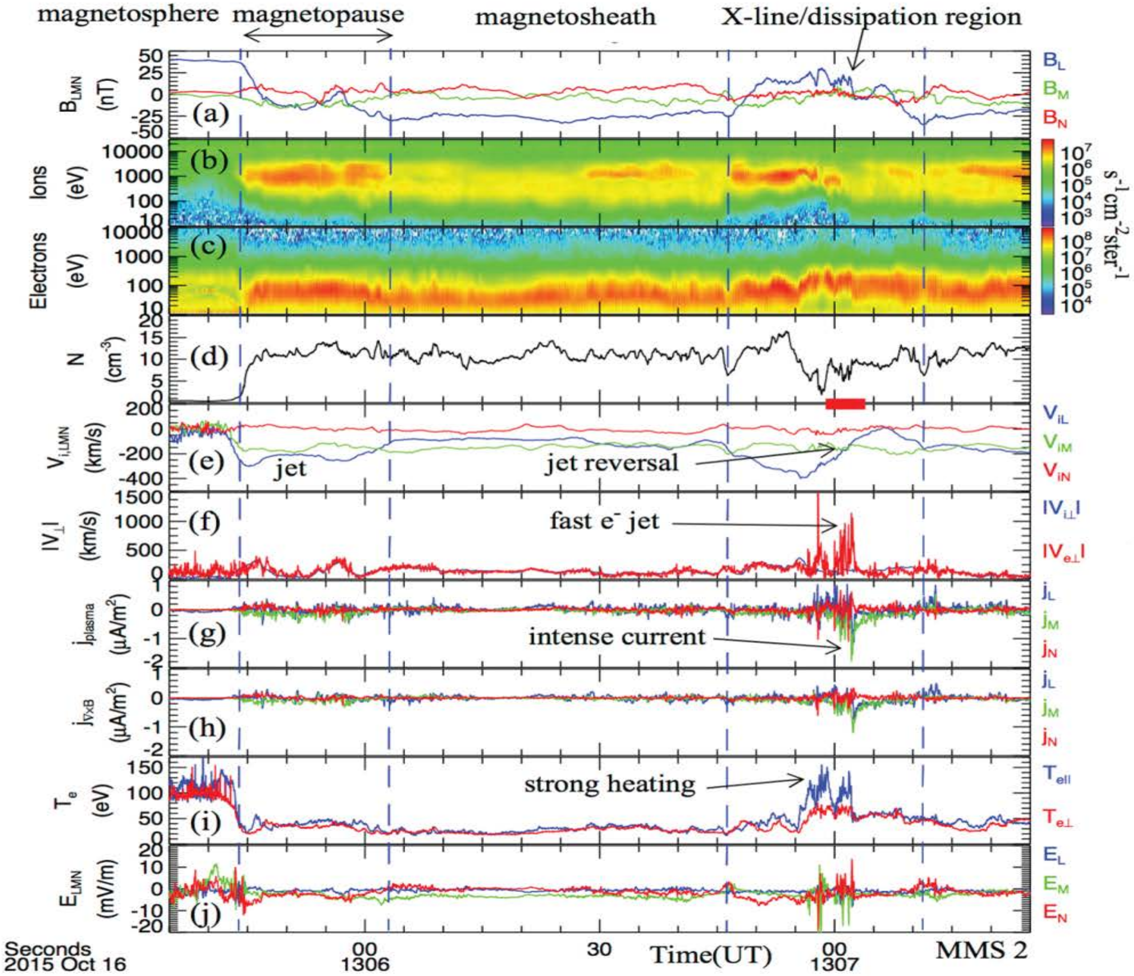
$$n_e m_e \left( \frac{\partial \boldsymbol{v}_e}{\partial t} + \boldsymbol{v}_e \cdot \nabla \boldsymbol{v}_e \right) = -e n_e (\boldsymbol{E} + \boldsymbol{v}_e \times \boldsymbol{B}) - \nabla \cdot \overleftrightarrow{p_e} + \boldsymbol{R}_e$$

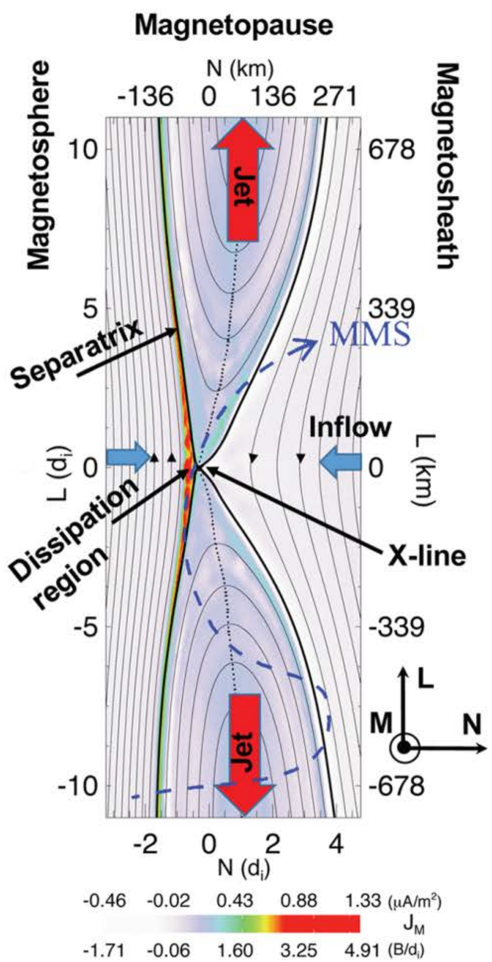
$$n_i m_i \left( \frac{\partial \boldsymbol{v}_i}{\partial t} + \boldsymbol{v}_i \cdot \nabla \boldsymbol{v}_i \right) = e n_i (\boldsymbol{E} + \boldsymbol{v}_i \times \boldsymbol{B}) - \nabla \cdot \overleftrightarrow{p_i} + \boldsymbol{R}_i$$

In the above two-fluid equations, we can evaluate each term with MMS data except collision terms $\boldsymbol{R}_e$ and $\boldsymbol{R}_i$. Unknown terms $\boldsymbol{R}_e$ and $\boldsymbol{R}_i$ can be obtained as residues of the two equations.
For assessment of the two-fluid equations, we use four spacecraft data.

# Analyzed event (2015 , Oct 16)

[Burch et al., 2016]

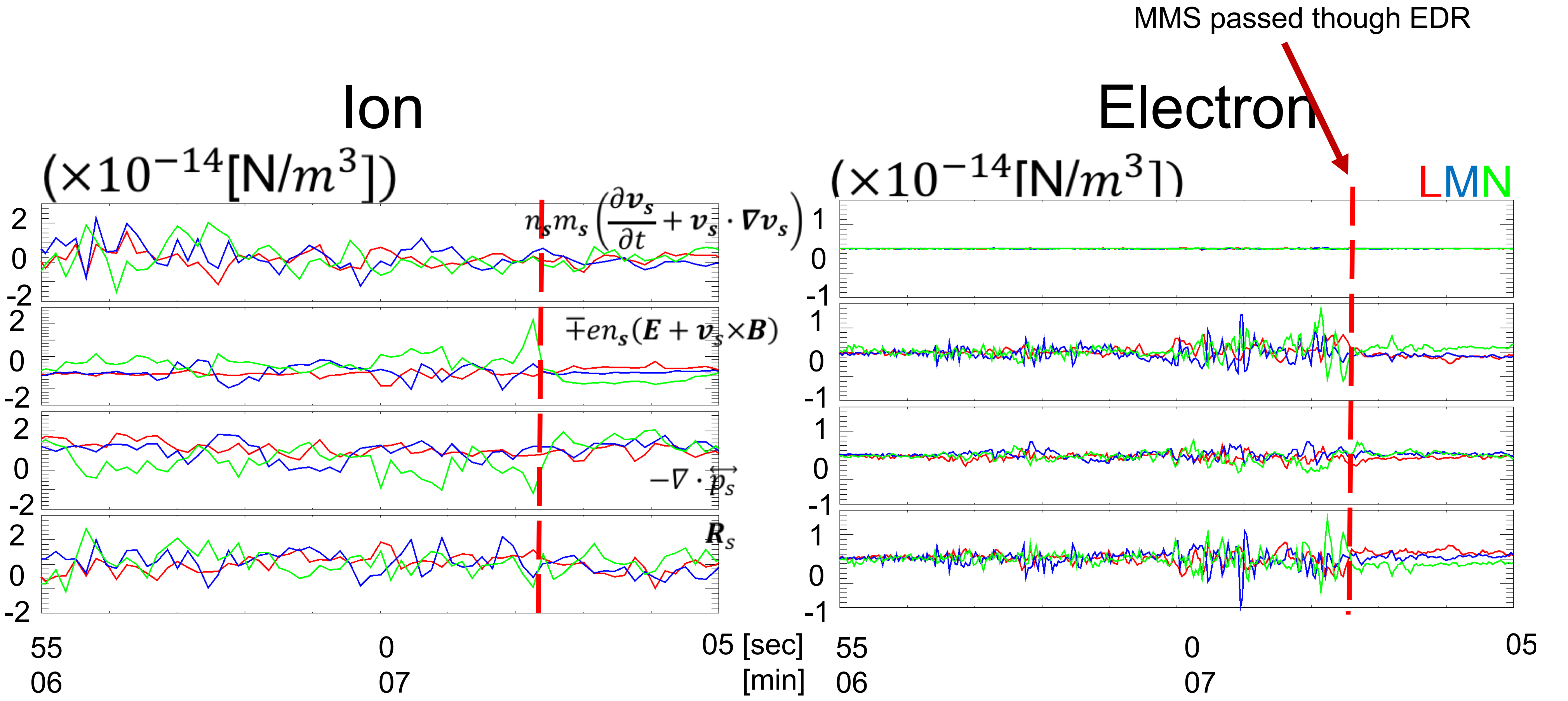


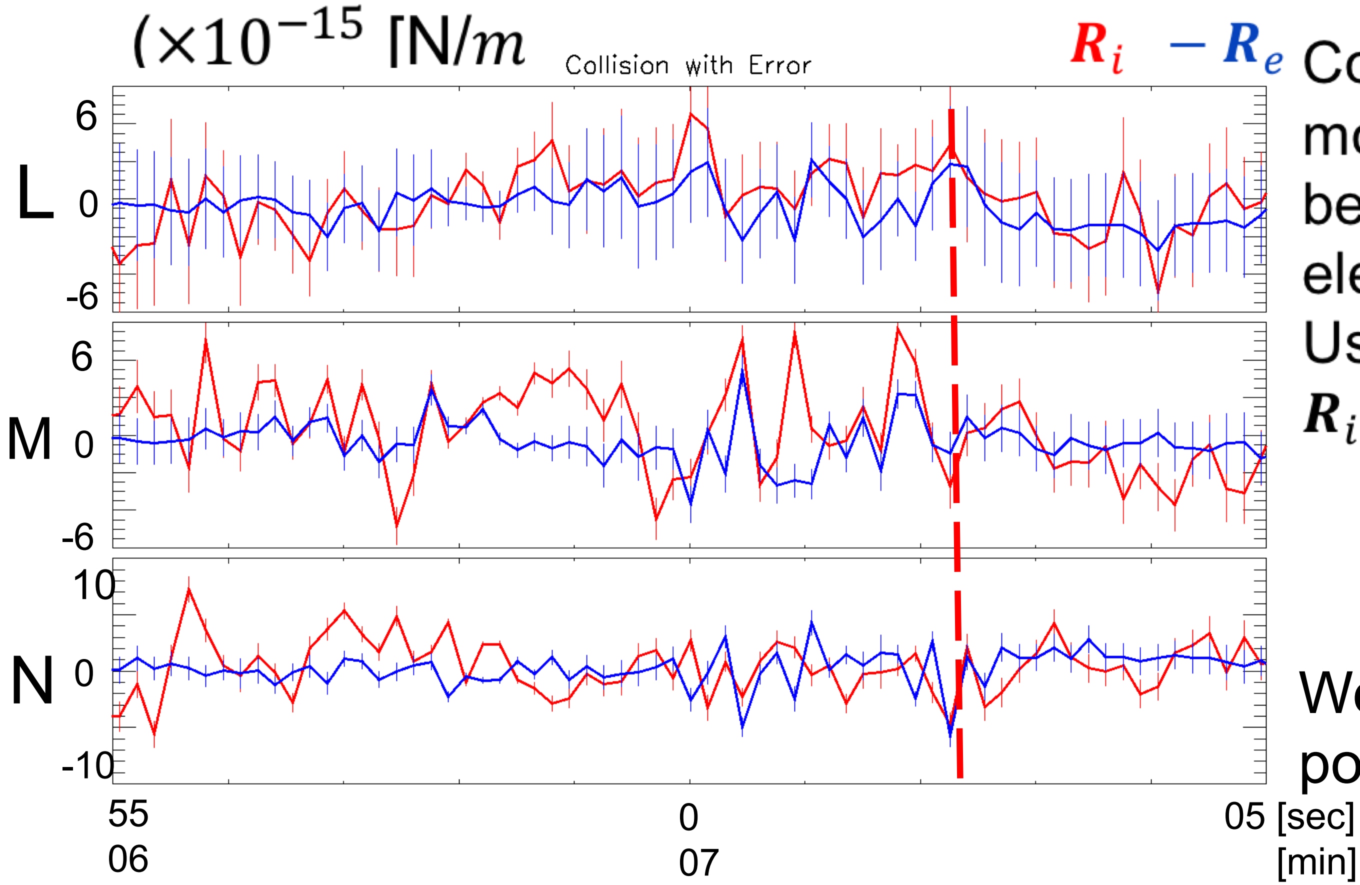

LMN coordinate system ( L : Northward, M : Dawnward, N : Perpendicular to MP)

# Evaluation of two fluid equations

$$n_s m_s \left( \frac{\partial \boldsymbol{v}_s}{\partial t} + \boldsymbol{v}_s \cdot \boldsymbol{\nabla} \boldsymbol{v}_s \right) = \mp e n_s (\boldsymbol{E} + \boldsymbol{v}_s \times \boldsymbol{B}) - \nabla \cdot \overleftrightarrow{p_s} + \boldsymbol{R}_s$$



# Evaluation of collision terms




Collision terms express momentum exchange between ions and electrons.
Usually, we regard that $\boldsymbol{R}_i = -\boldsymbol{R}_e$ .

We consider two possible reasons.

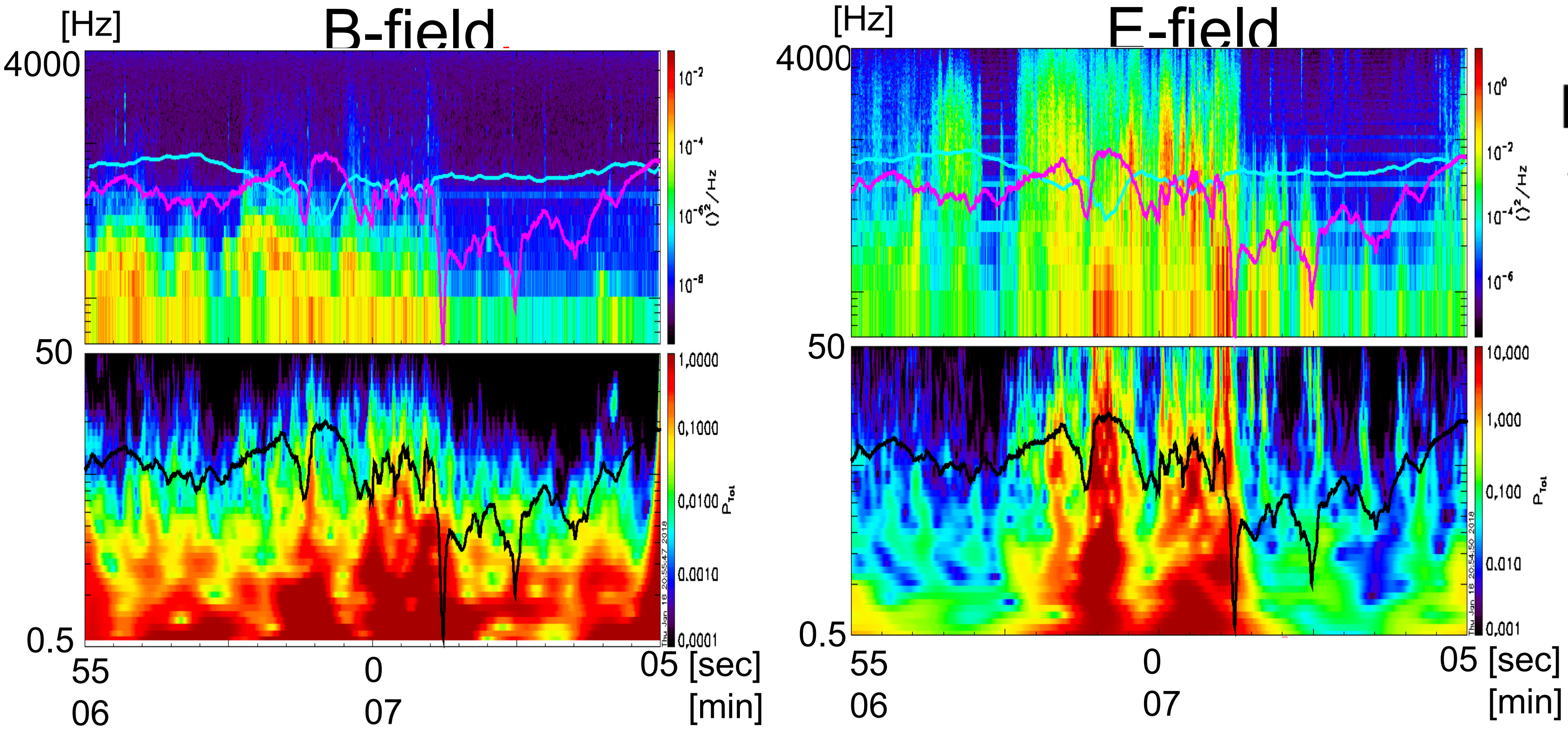
Error bars are evaluated based on the errors in the electric fiel

$f_{LHR} \approx$10[Hz]

① Ion sampling frequency is 6.66 [Hz] → Ion sampling is biased by LHV
Electron sampling frequency is 33.3[H

② There is momentum exchange between particles and waves and also momentum escape carried by waves.

# Observed waves (2015 , Oct 16)



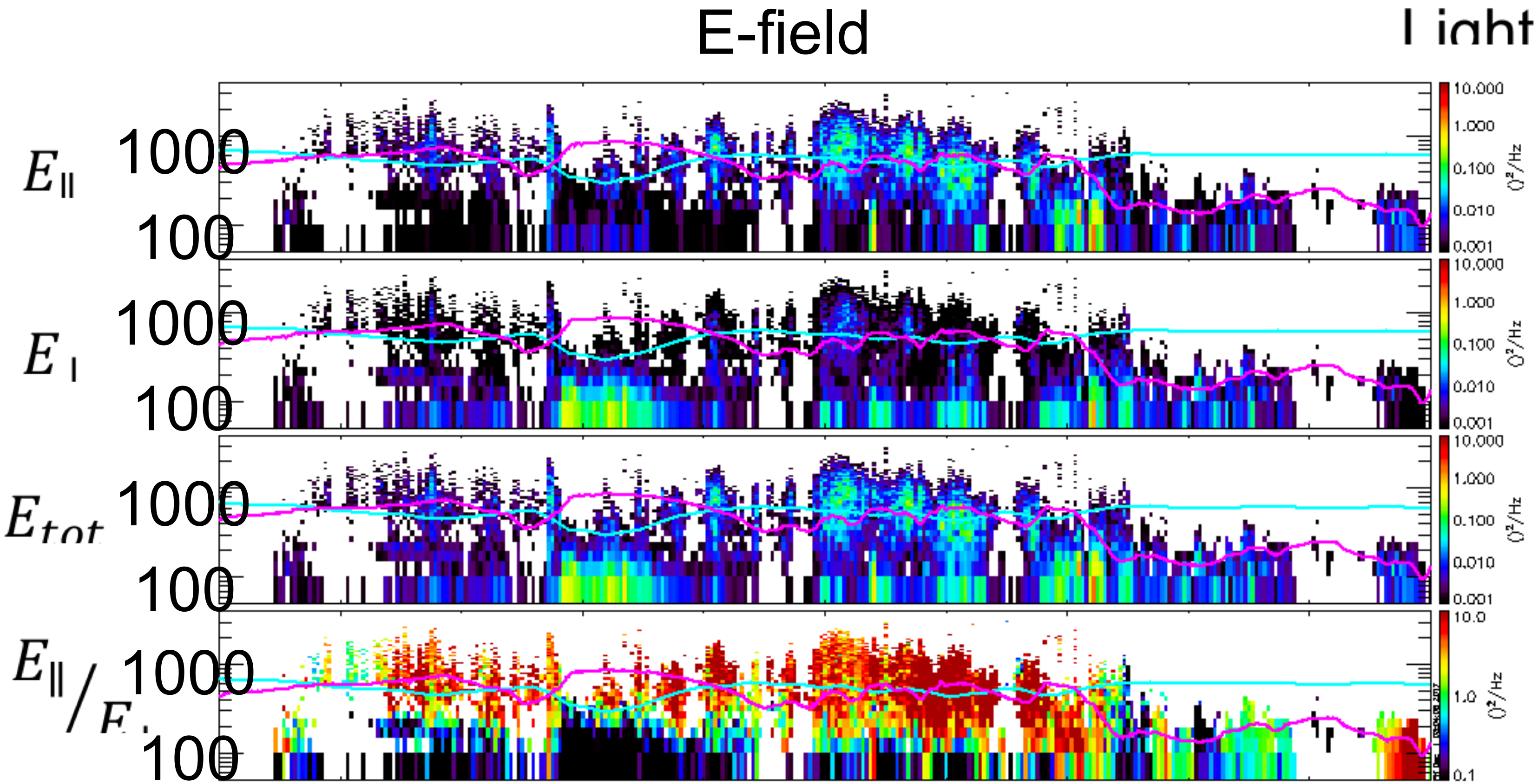

Magenta:

Black line:

During this interval, MMS observed  high frequency electrostatic waves and lower hybrid waves.
The emission of high frequency electrostatic waves is found around the electron cyclotron and ion plasma frequencies.

# High frequency electrostatic waves

Magenta :
Light blue :




The high frequency electrostatic waves have strong parallel component and are similar to that reported by Ergun et al. [2016], and can be regarded as the acoustic mode waves.

# Collision term and waves

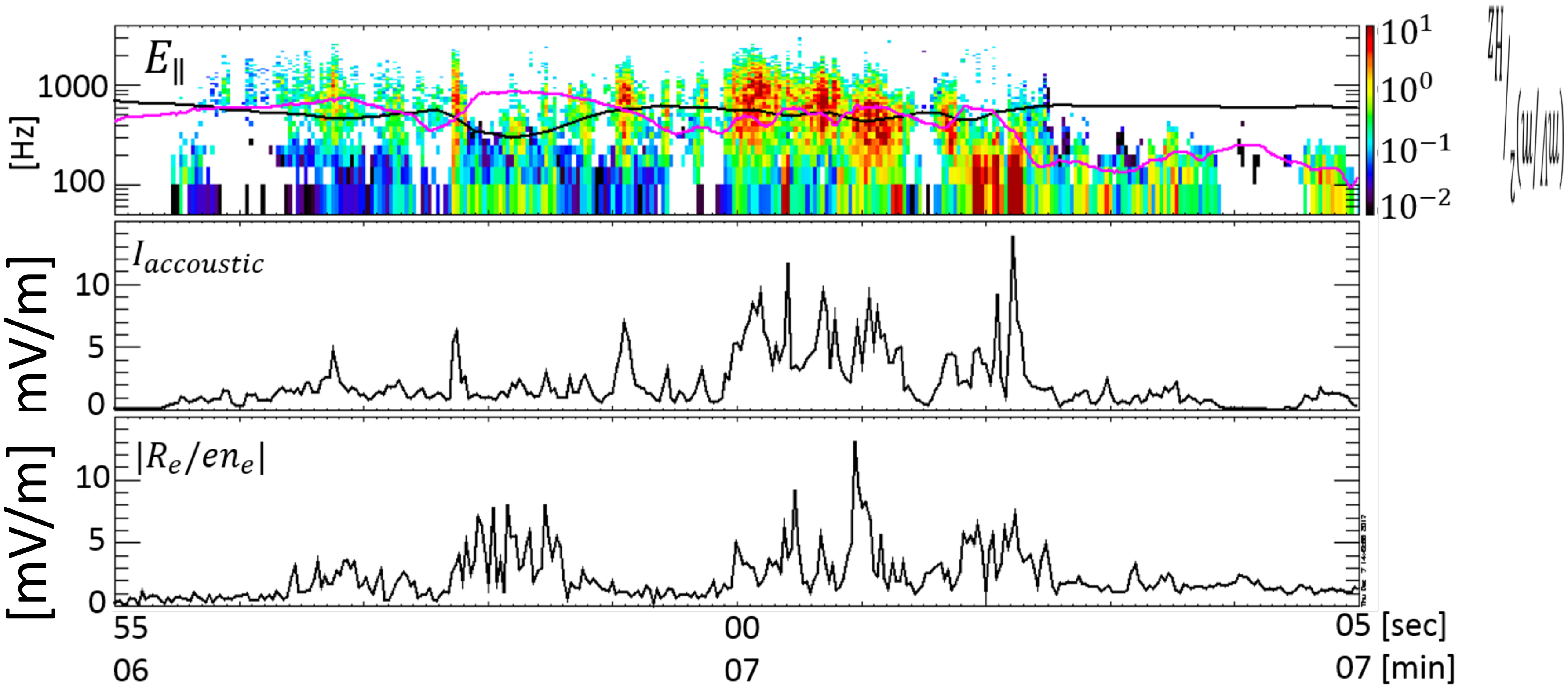



Figure 6(a) Frequency spectrum of parallel wave electric-field (magenta line : $f_{ce}$, black line : $f_{pi}$) (b) Intensity of the acoustic mode waves (integral range $f < 4kHz$) (c) Absolute value of electron collision term

The intensity of acoustic mode waves is partially correlated with the value of electron collision term.

# Collision term and waves

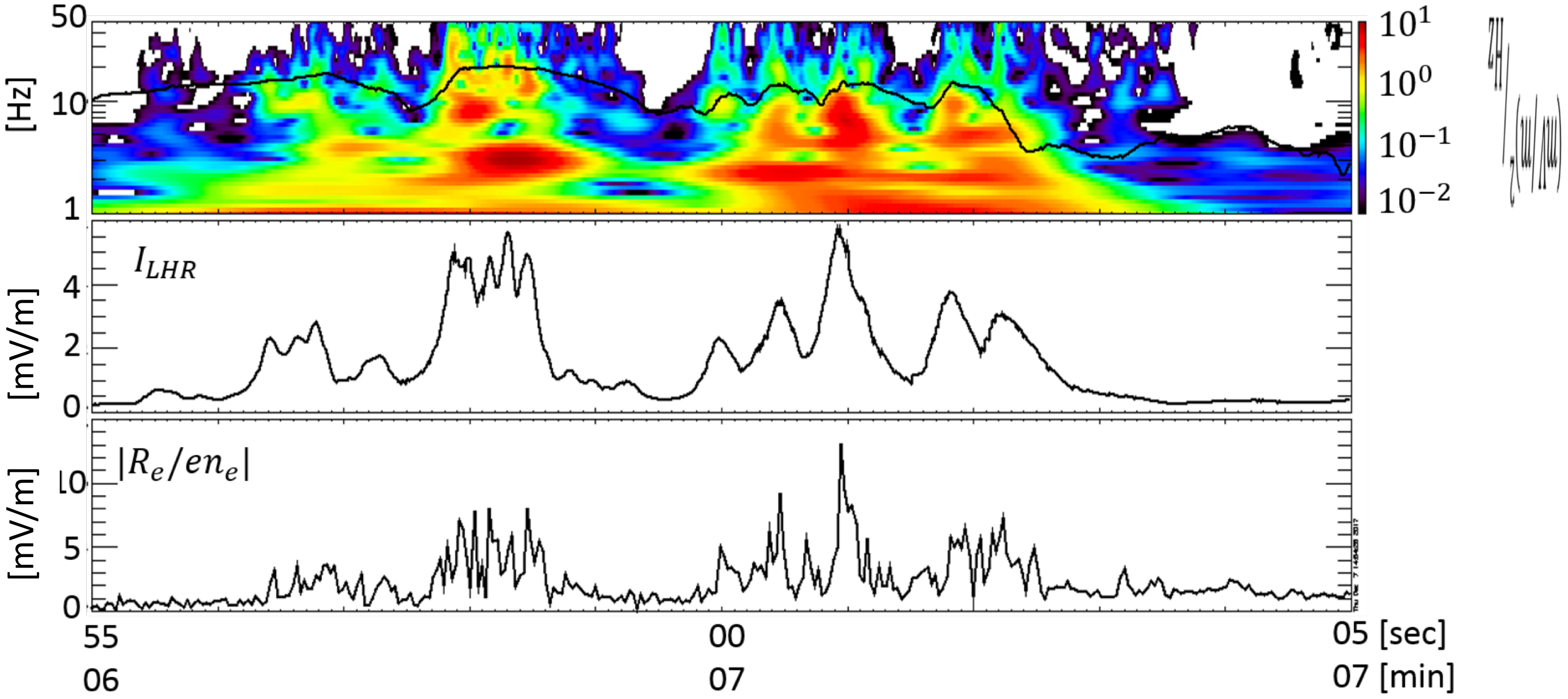


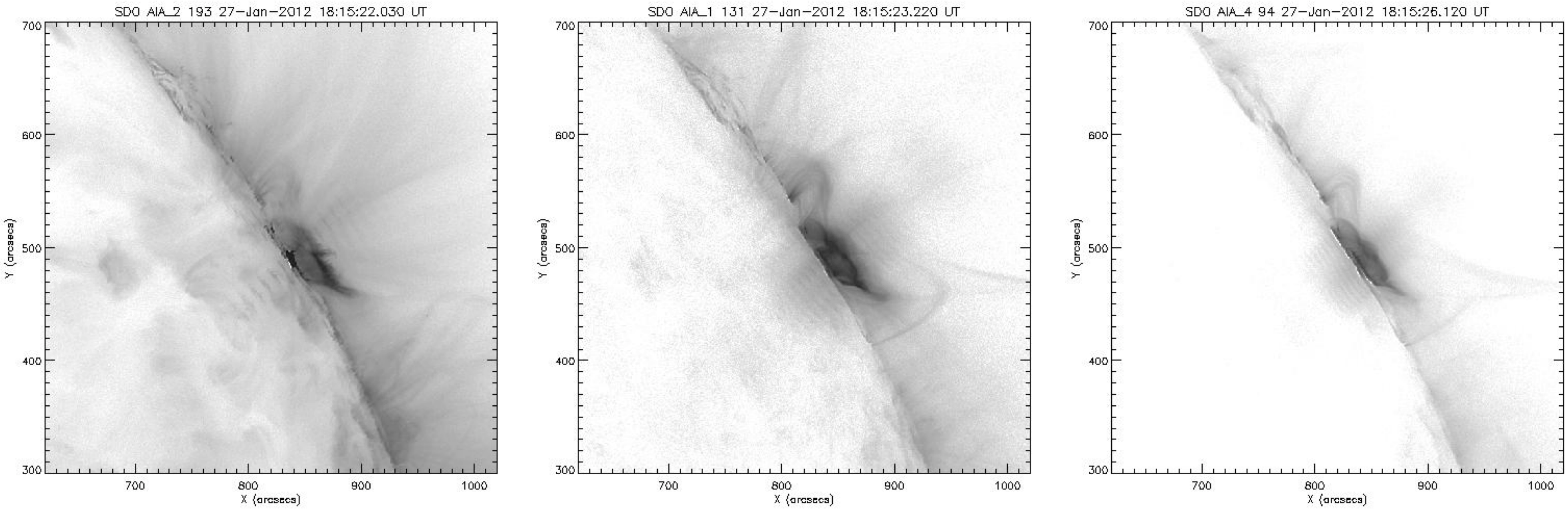

Figure 5(a) Frequency spectrum of wave electric-field (black line : $f_{lhr}$) (b) Intensity of the lower hybrid wave (Integral range $f_{lhr}/_2 < f < {}^{3f_{lhr}}/_2$) (c) Absolute value of electron collision term

The lower hybrid wave is supposed to significantly affect the motion of electrons and contribute to generate the anomalous resistivity.

# Summary

- We evaluated the collision terms $\boldsymbol{R}_e$ and $\boldsymbol{R}_i$ with two the fluid equations. However, these terms are not always anti-correlated.
- Enhancements of the lower hybrid waves are well correlated with the collision terms. This suggests the significance of wave-particle interaction and generation of anomalous resistivity due to the lower hybrid waves.

# 太陽でのリコネクション



# プロミネンス