Super thin current sheets of electron scales observed in planetary magnetotails

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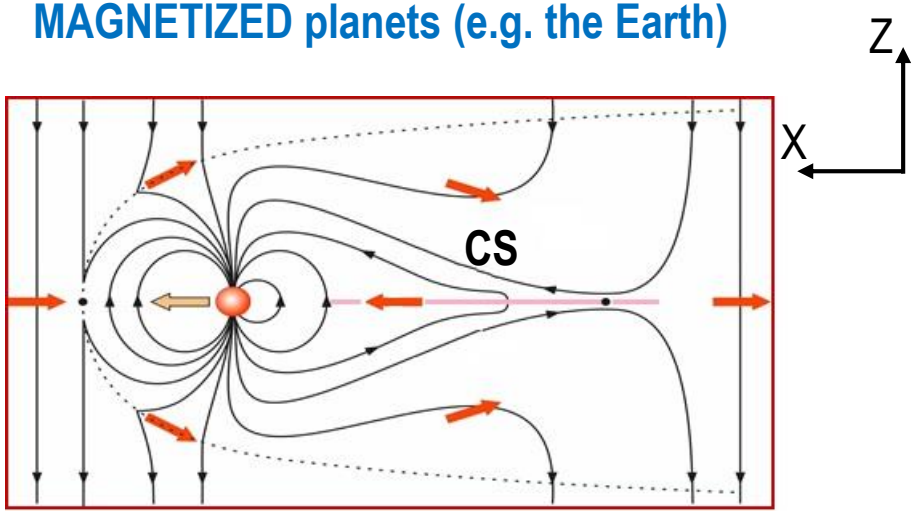
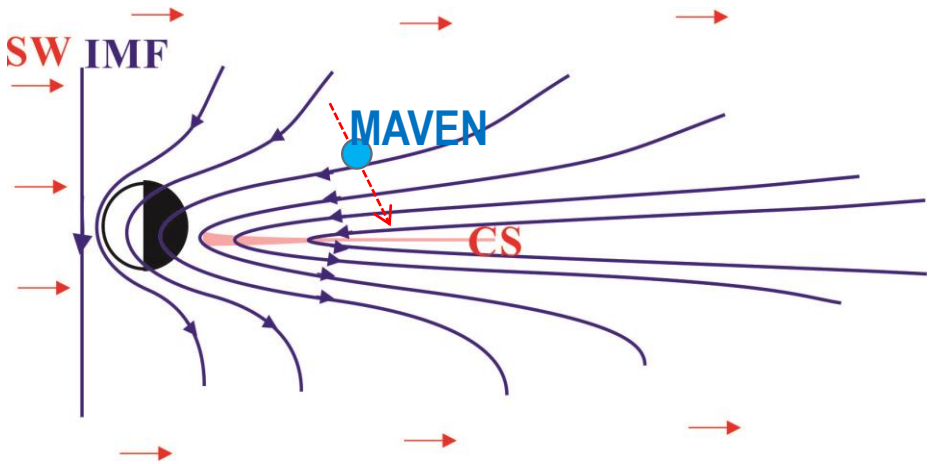
Thin Current Sheets (TCSs) are general structures in planetary magnetotails

MAGNETIZED planets (e.g. the Earth)



UNMAGNETIZED planets (e.g. Mars)

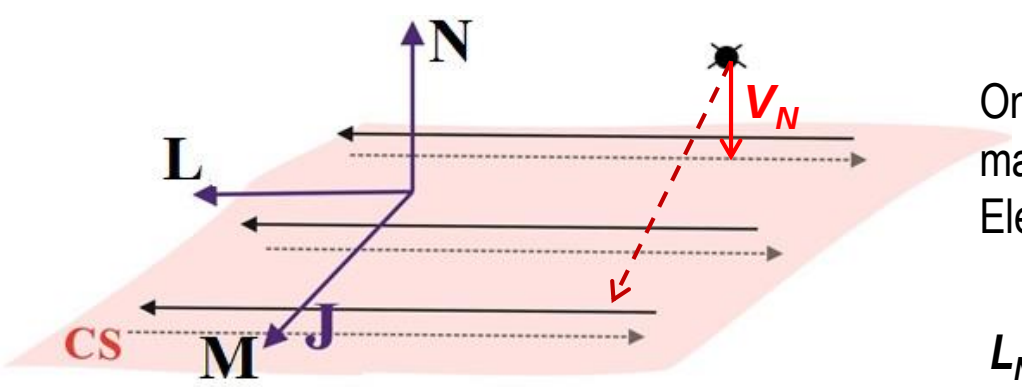


The cross-tail CS is observed in both types of magnetosphere.

The Earth: the cross-tail TCS is the main region of magnetic energy conversion, usually observed during substorm growth phase *(e.g. Sergeev et al., 1993; Baker et al., 1996; Nakamura et al., 2006; Runov et al., 2008)*

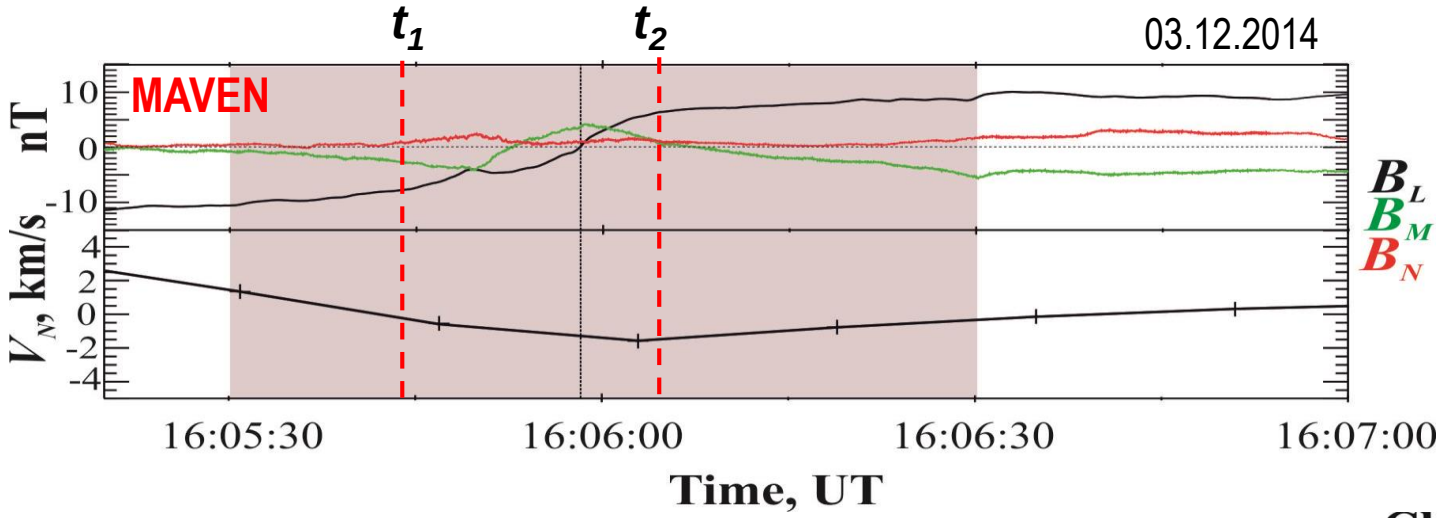
Mars: the cross-tail CS separates the tail lobes with opposite polarity of the magnetic field. It has been identified as a main ion escape channel at Mars *(e.g., Yeroshenko et al.,1990; Dubinin et al.,1993; Fedorov et al.,2006;2008; Barabash at al.,2007; DiBraccio et al.,2015; Grigorenko et al., 2017).*

Signatures of energy conversion via magnetic reconnection were reported recently *(e.g. Harada et al., 2015; 2017; Hara et al., 2017)*



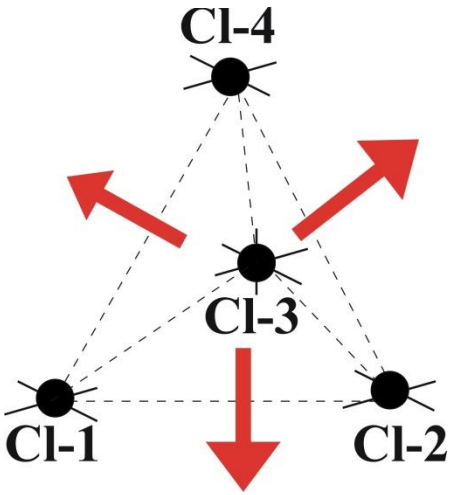
One-spacecraft observations (e.g. in the Mars's magnetotail)allow estimation of 1D Electric current density as: $J_M = \Delta B_L / [L_N \cdot \mu_0]$,

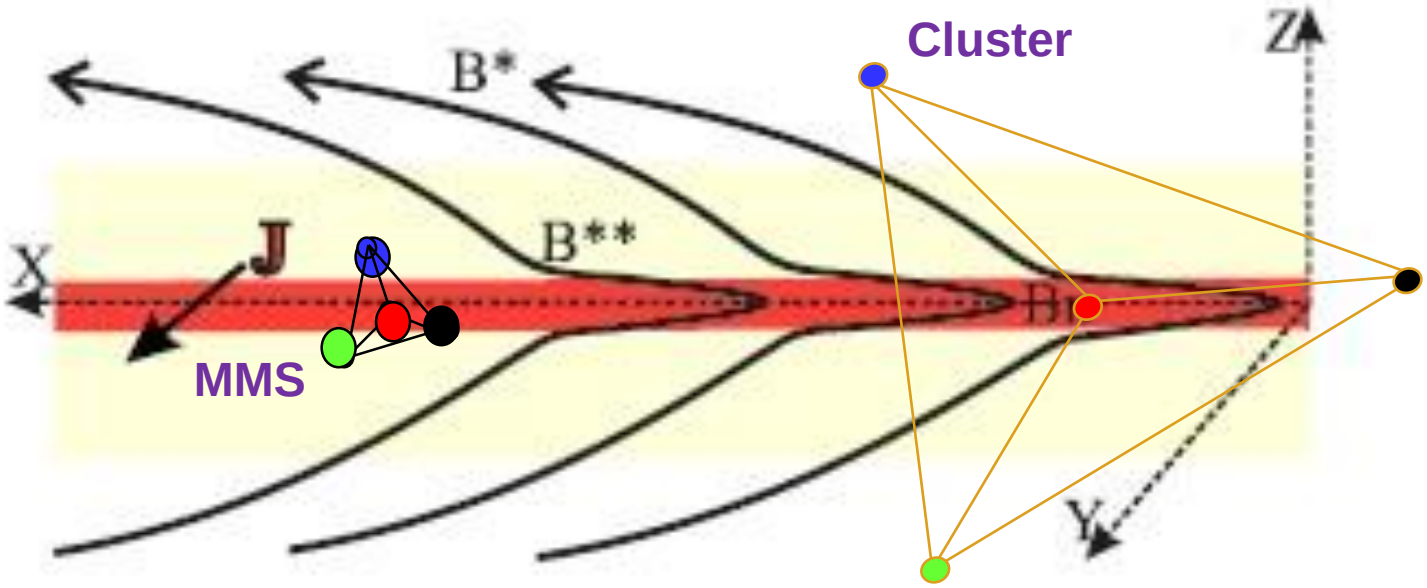
L_N is a half-thickness of the CS: $L_N = \int_{t1}^{t2} V_N dt$



In the Earth's magnetotail four-point Cluster and MMS observations allow the precise calculation of 3D electric current density by **curlometer technique:**

$$J_{i3j} = \frac{\Delta B_{3i} \cdot r_{3j} - \Delta B_{3j} \cdot r_{3i}}{\mu_0 \cdot (r_{3i} \cdot r_{3j})}$$





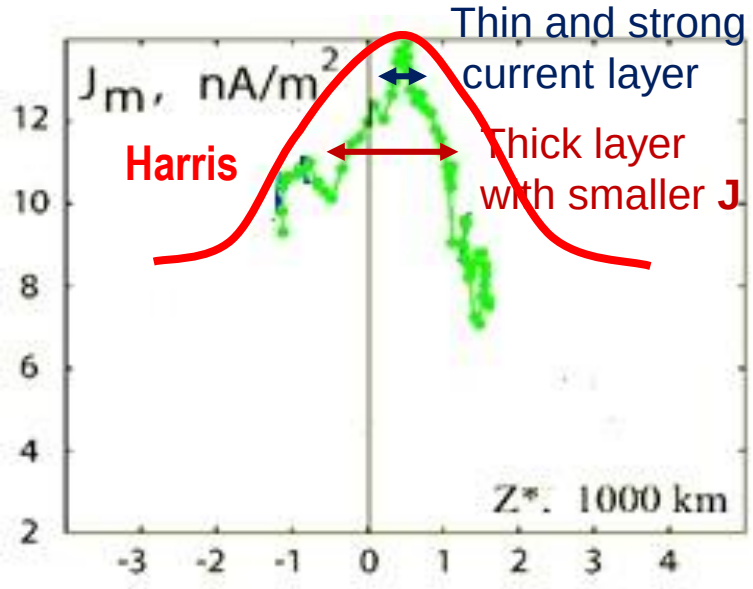
The minimal characteristic scale **of Cluster tetrahedron** is ~ a few hundreds km **(~ ρ_P)**. **Cluster can observe ion-scale Current Sheet**.

The characteristic scale **of MMS tetrahedron** ~ 15 km (**a few ρ_e**)

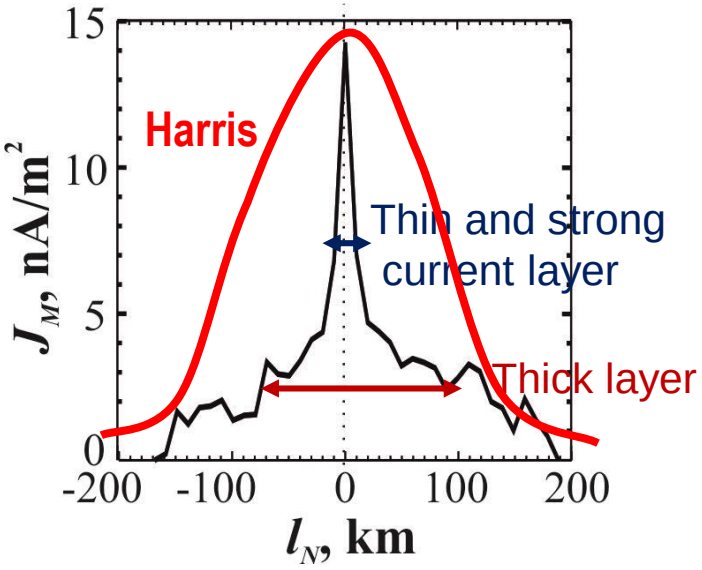
In **burst mode** the magnetic field is measured at **128 samples/s**
3D electron velocity distribution function (~ 100 eV – 30 keV) is measured at **30 ms** resolution

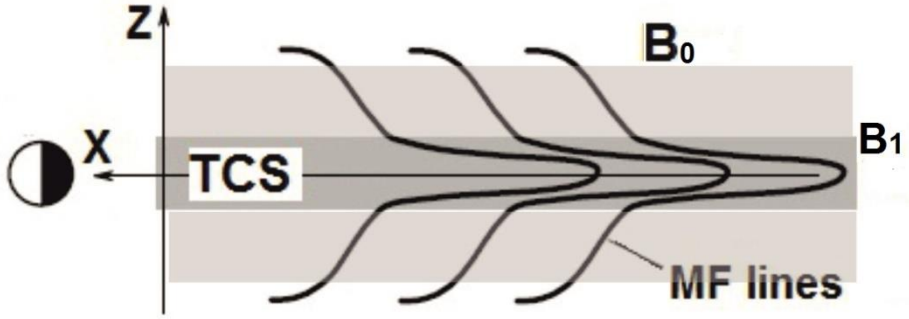
MMS is a perfect tool to study electron-scale STCS in the Earth's magnetotail.

CLUSTER observations in the Earth's magnetotail *(e.g. Runov et al., Ann, Geophys. 2005)*



MAVEN observations in the magnetotail of Mars *(e.g. Grigorenko et al., JGR, 2017)*



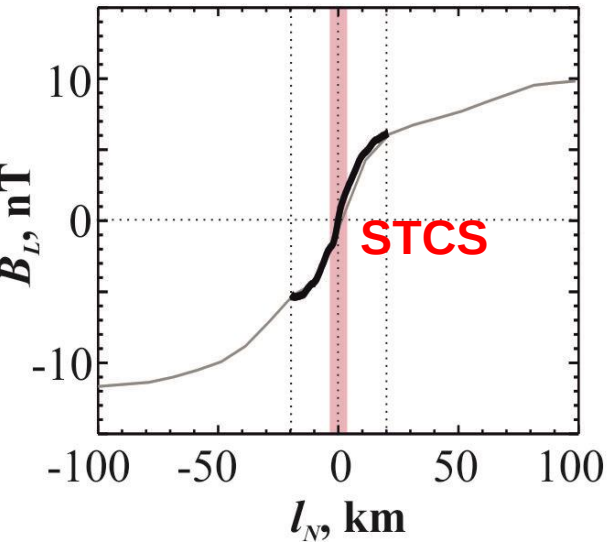


In spite of the different mechanisms of the Earth's and Martian magnetospheres formation the similar features are observed in their cross-tail CSs

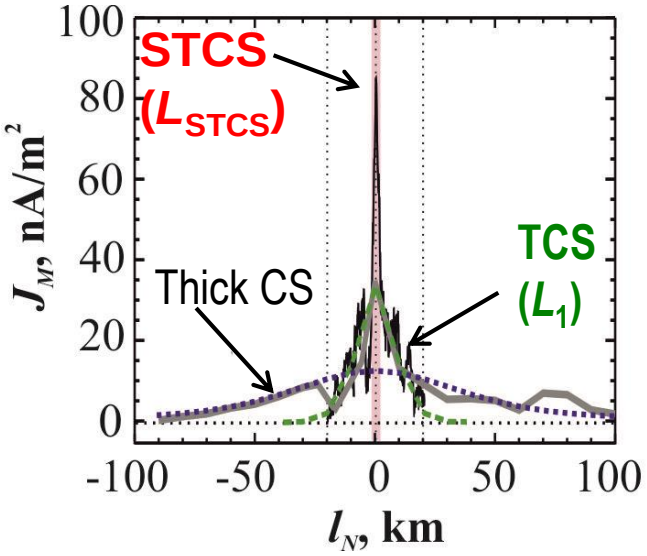
However, these observations cannot detect the strong super thin current layer at the center of the CS produced by electrons at electron kinetic scale.

MAVEN observations of Electron-scale Super Thin Current Sheets (STCSs) in Mars's magnetotail

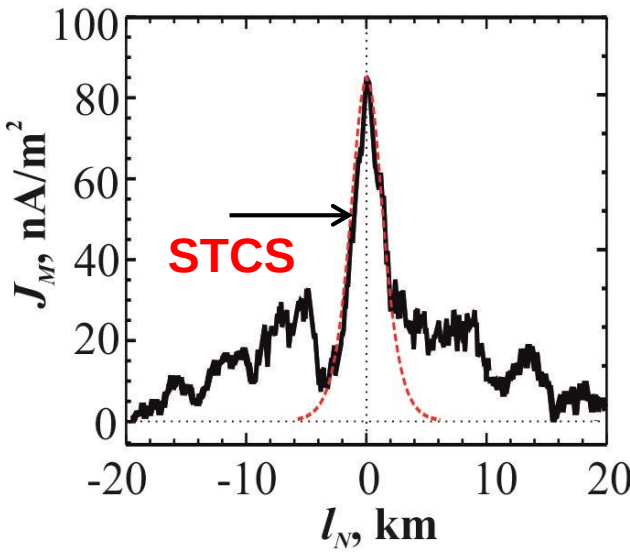
Spatial profile of the $\boldsymbol{B_L}$ field across the CS plane



Spatial profile of $\boldsymbol{J_M}$ across the CS plane



Zoom of the spatial profile of STCS current density



Three layers of embedding:

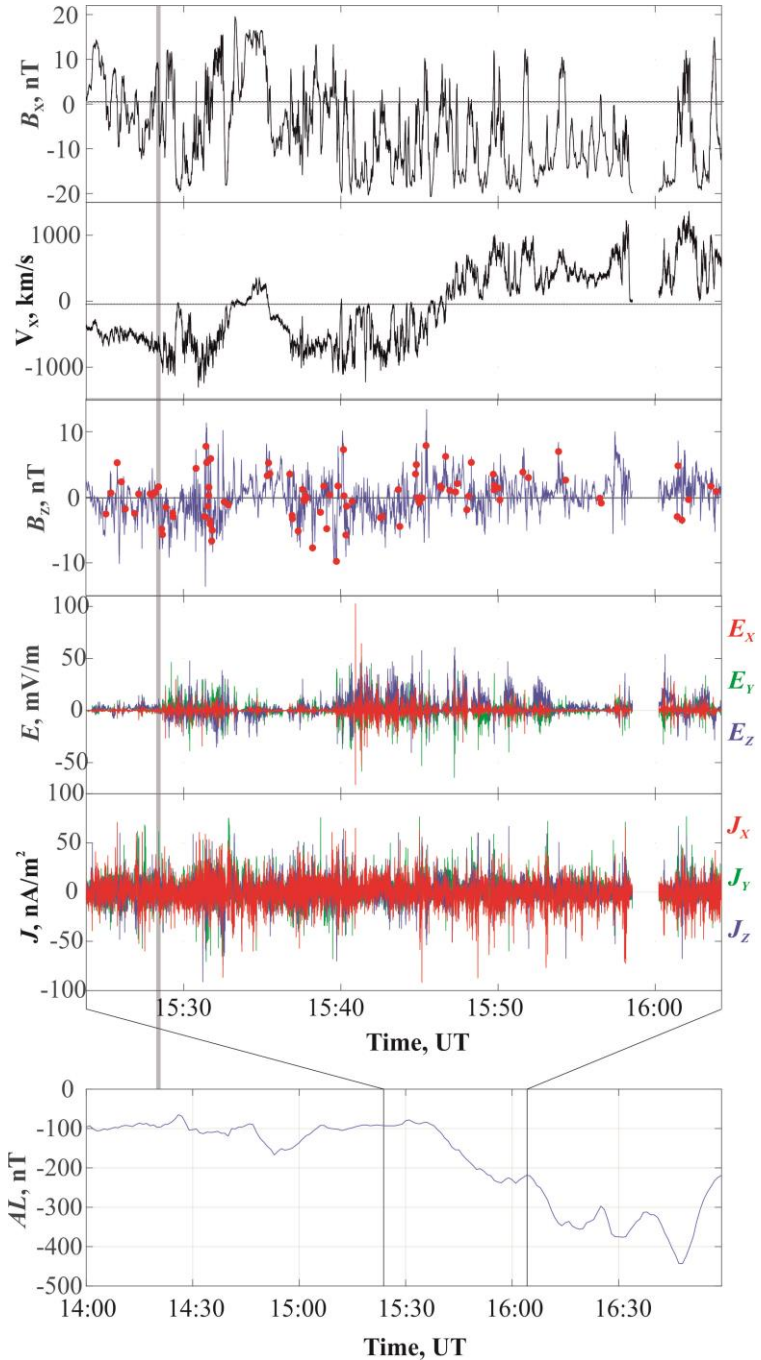
(Grigorenko et al., GRL. 2019)

Electron STCS: L_{STCS} ~ 2 km, J_{STCS} ~ 85 nA/m^2

Proton TCS: L_1 ~ 15 km (ρ_p~ 20 km), J_{TCS} ~ 34 nA/m^2

Thick CS: L_2 ~ 50 km, J ~ 13 nA/m^2

MMS observations of STCSs during the growth phase of substorm



Strong CS flapping

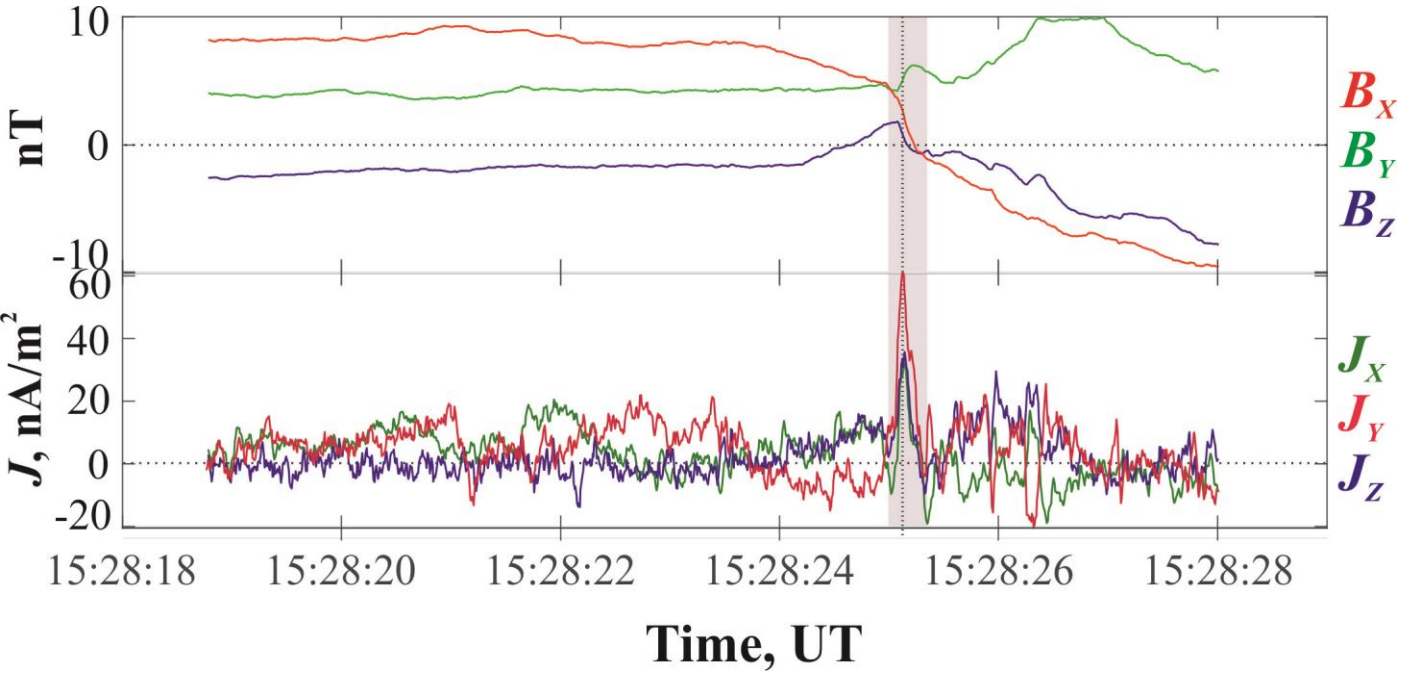
High-velocity plasma flow reversal

Multiple bipolar B_Z variations (magnetic islands) with STCSs (marked by red dots)

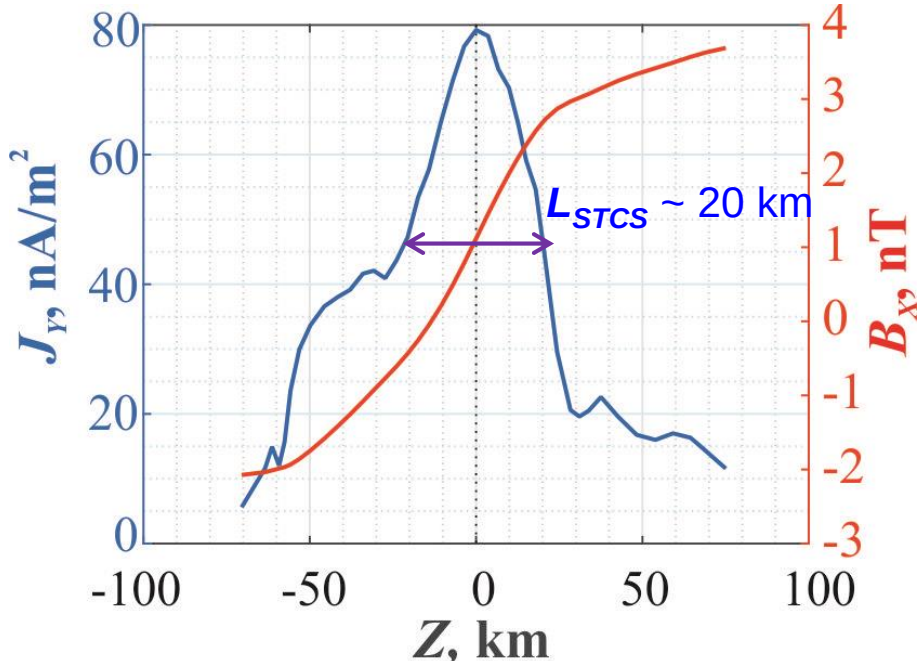
Spikes in the electric field (tens mV/m)

Spikes in the electric current density (tens of nA/m^2)

(Leonenko et al., JGR, submitted)



Reconstruction of the spatial structure of the STCS

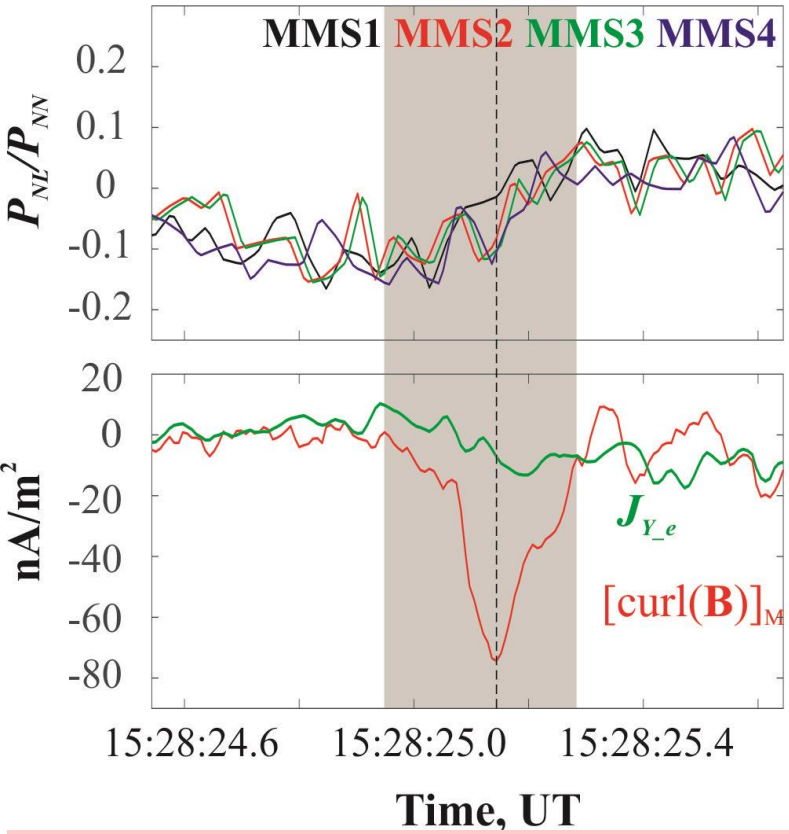


Electron current $J_Y = e \cdot n_e \cdot V_{Y\_e}$ and **components of the pressure tensor** were calculated **separately** for two electron populations:

1) magnetized electrons (W_e < 1.2 keV) and
2) unmagnetized electrons (W_e > 1.2 keV)

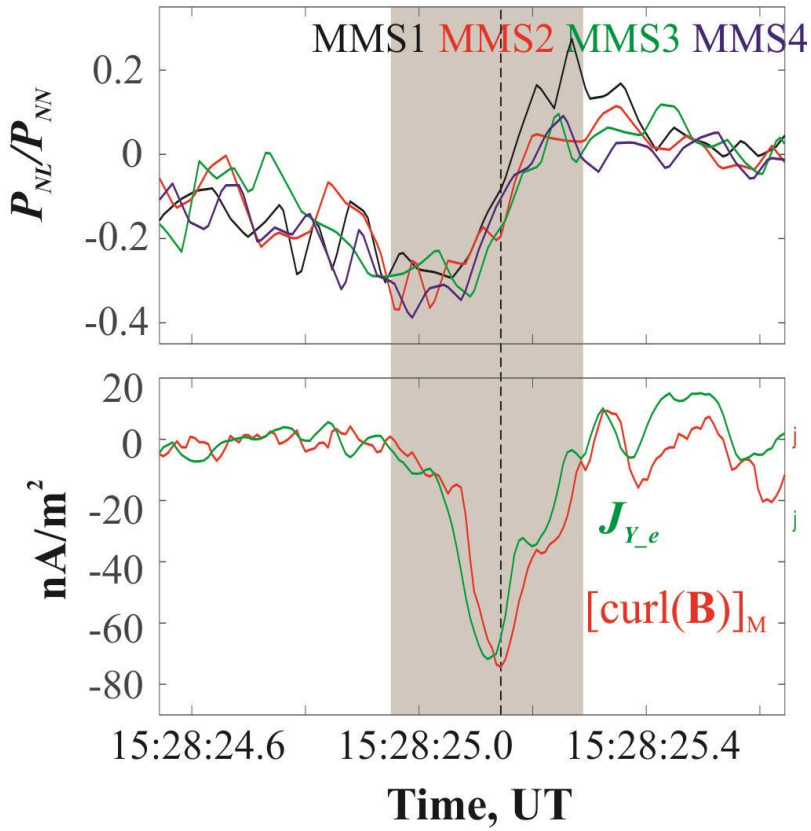
Low-energy magnetized electrons

$W_e \sim 0.11 - 1.2$ keV



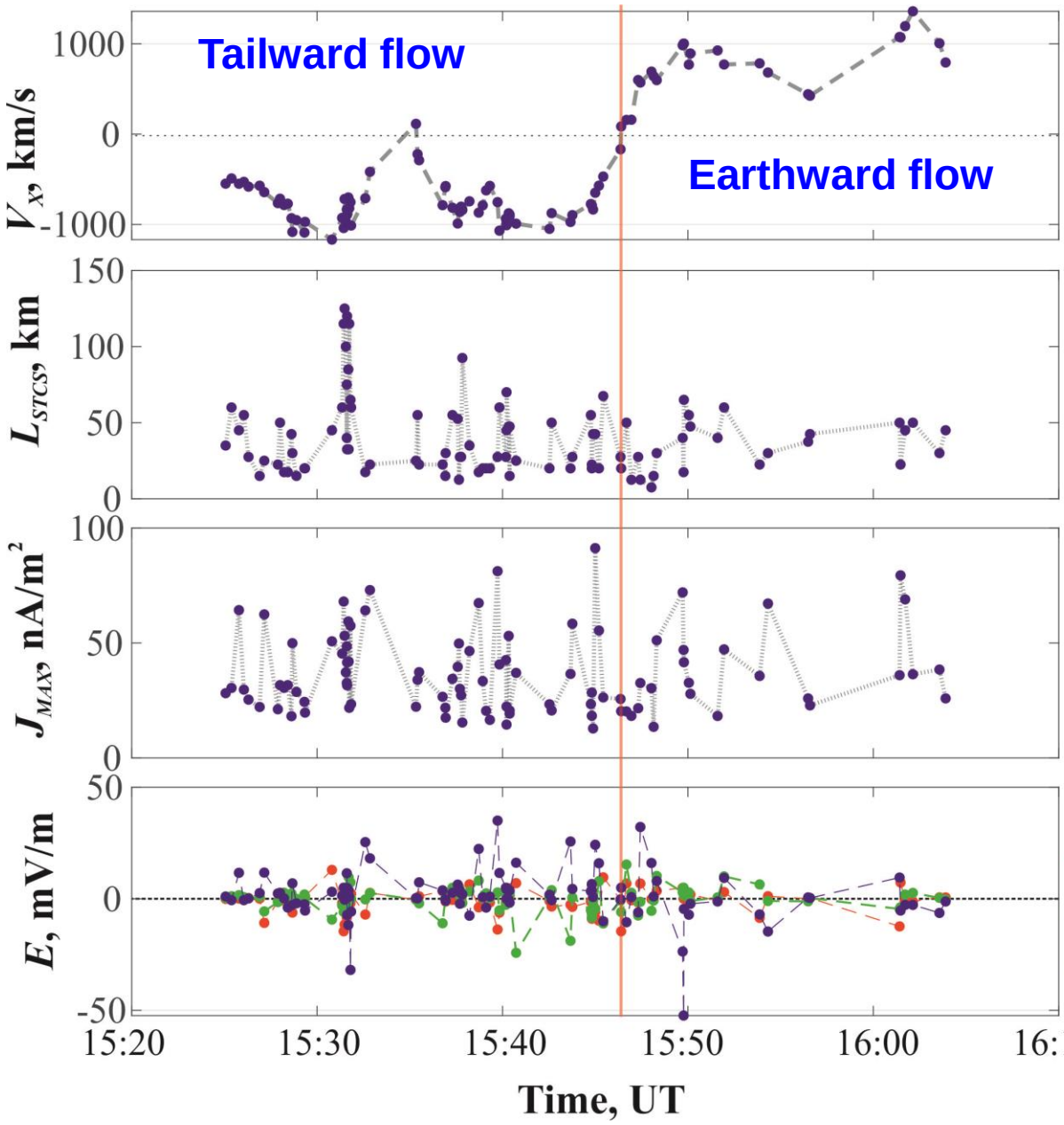
Suprathermal unmagnetized electrons

$W_e \sim 1.2 - 2.8$ keV



The electric current in the STCS is carried by the **unmagnetized electrons and the stress balance** is supported by **the gradient of off-diagonal components** of their pressure tensor

Open question: evolution of the STCSs



95 STCSs were observed by MMS during the interval of interest (marked by blue dots)

Strong variations of the STCS half-thickness from ~ $10\rho_e$ to ~ $1\rho_e$

Strong variations of the electric current density

E_L
E_M
E_N
Strong variations of the electric field

Periodic disruption and formation of the electron-scale STCSs?

Conclusions

- MAVEN and MMS observations revealed the Super Thin Current Sheets (L_{STCS} ~ a few kilometers ≤ a few ρ_e) embedded into the cross-tail current sheet in the Mars's and Earth's magnetotail

- In STCSs the current is carried by unmagnetized electrons and stress balance is supported by off-diagonal terms of their pressure tensor

- In the STCSs the higher energy electrons carry the current, while the low-energy electrons support the stability of the STCS

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