Magnetotail thermal electrons as tracers of thin current sheets fine structure

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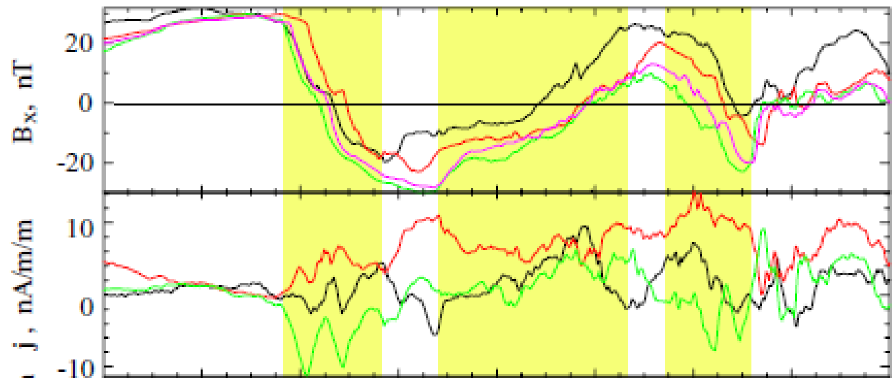
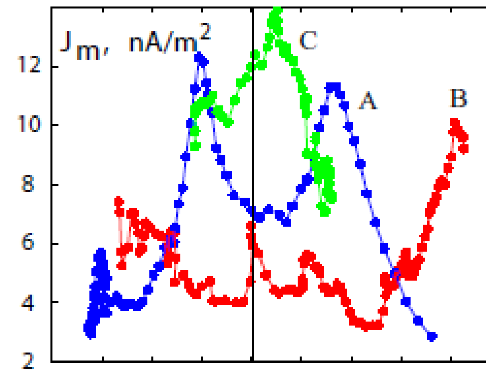
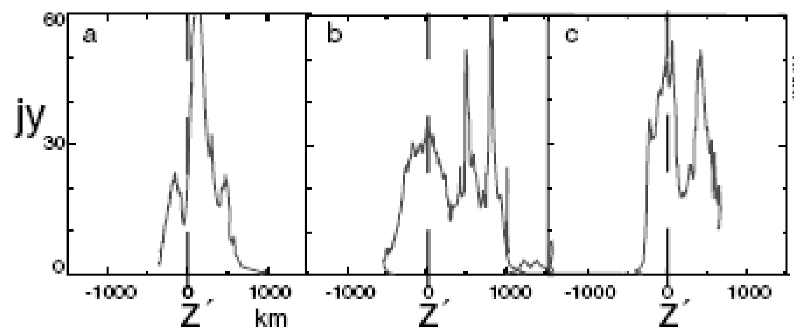
EGU-11

Thin current sheets in the Earth magnetotail



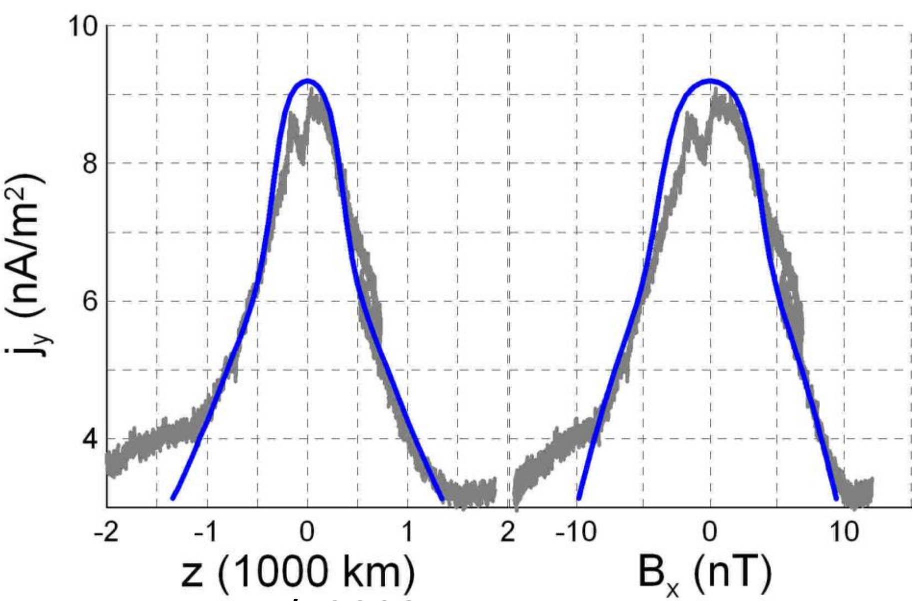


Runov et al. 2005

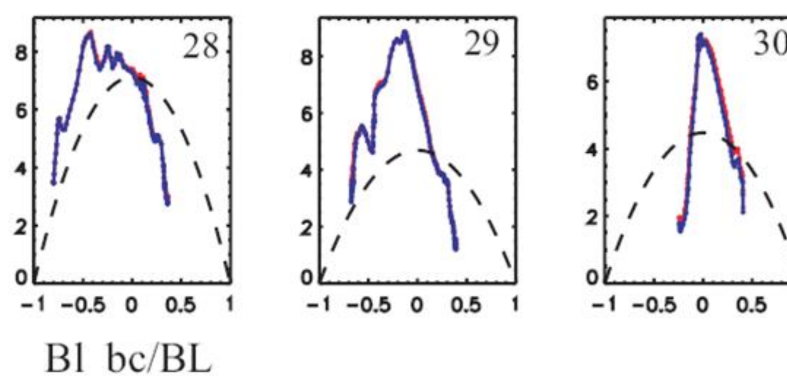


Nakamura et al. 2006

Observed current density profiles can be approximated by **thin current sheet (TCS) model (*Zelenyi et al. 2004*)**



Artemyev et al. 2008



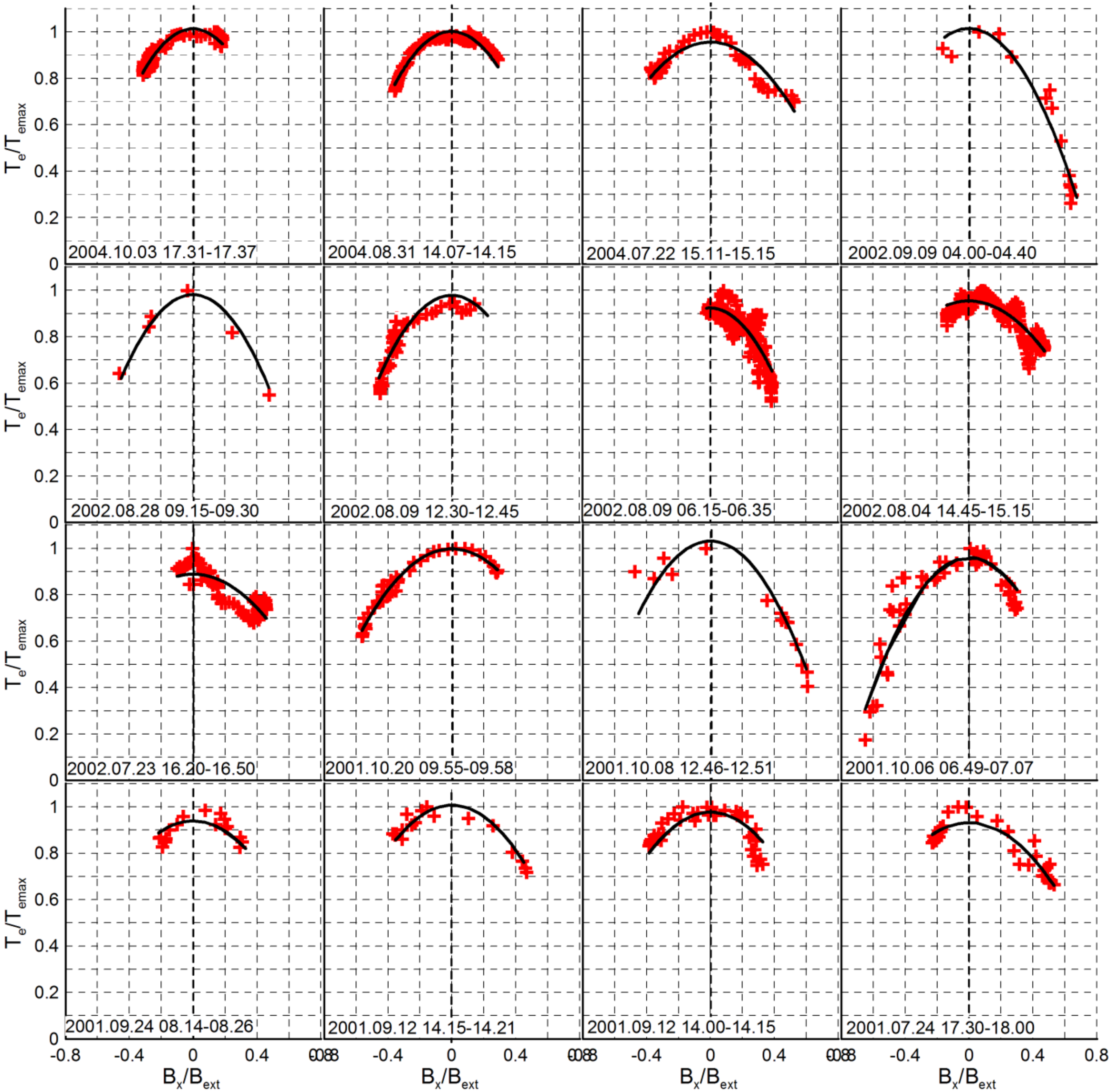
Runov et al. 2006

Profiles of electron temperature

Electron temperature (C2) as a function of magnetic field for 16 TCS crossings.

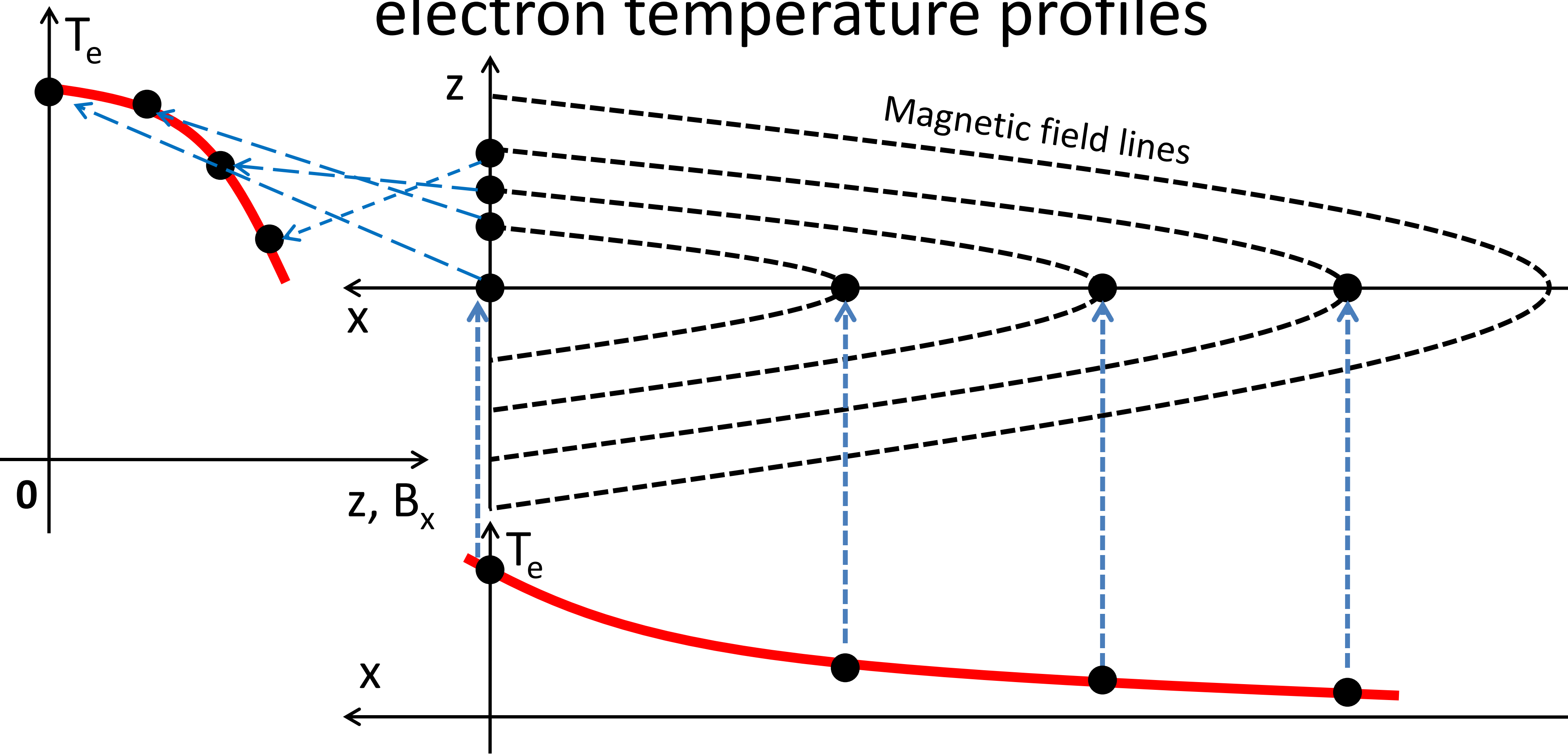
Black curve is the approximation

$$\frac{T_e}{T_{e\max}} = 1 - \alpha_{Te}\left(\frac{B_x}{B_{ext}}\right)^2$$



Electron temperature decreases towards the TCS boundary!

Theoretical assumptions of formation of electron temperature profiles

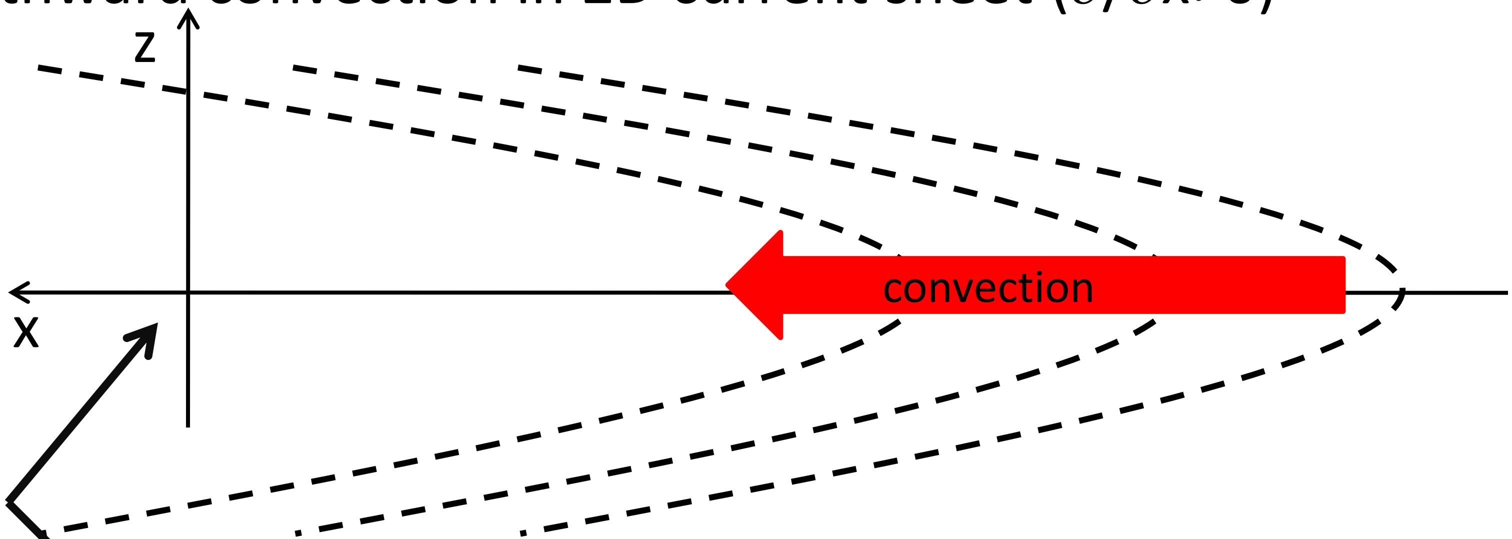


The growth of the electron temperature corresponds to the growth of $\mathbf{B_z}$

Tverskoy 1972 $T_e \sim B_z^{2/5}$ For particles with distant mirror points

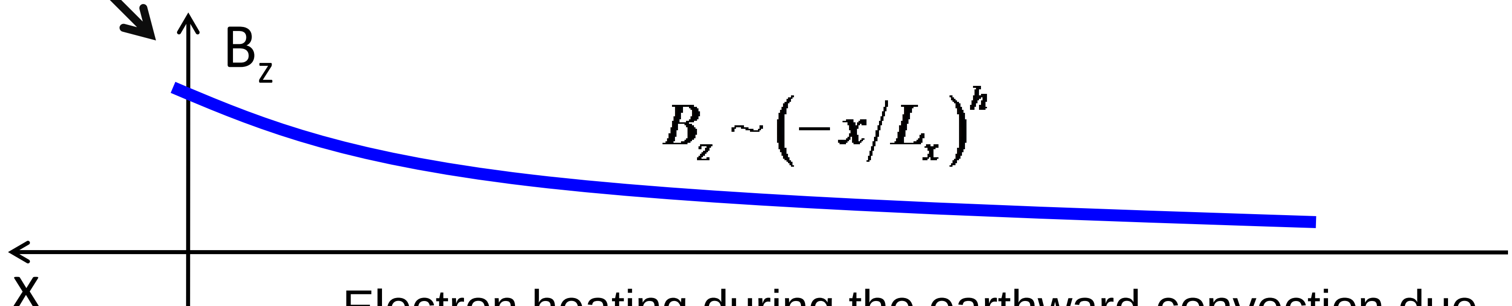
Lyons 1984 $T_e \sim B_z^{2a}, \quad a \sim 1/3$

Electron heating due to the earthward convection in 2D current sheet ($\partial/\partial x \neq 0$)



The TCS parameters in the point of observation

$b_e = B_{ext}/B_0$
$b_n = B_z/B_0$



Current sheet thickness

$$L \sim B_0 / j_{max}$$

Electron heating during the earthward convection due to the conservation of the adiabatic invariants

$$\mu = \frac{m_e v_\perp^2}{B} = \mathrm{const}$$

$$J_\parallel = \oint p_\parallel ds = \mathrm{const}$$

Tverskoy 1972, Zelenyi et al. 1990

Electron heating due to earthward convection

Invariants

$$\mu = \frac{m_e v_\perp^2}{B} = \text{const}$$

$$J_\parallel = \oint p_\parallel ds = \text{const}$$

$$\frac{v_\perp^2}{B} \sim \text{const}$$

$$B^{3/2}\Phi\left(1+\frac{v_\parallel^2}{v_\perp^2}\right) \sim \text{const}$$

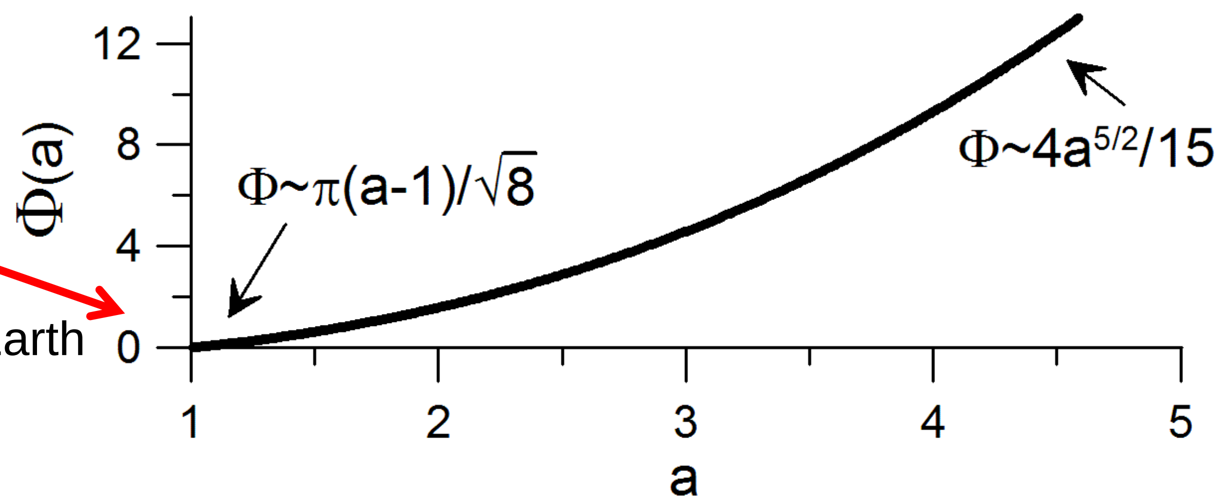
$$\Phi(a) = \int_1^a \frac{\sqrt{a-b}}{\sqrt{b^2-1}} b^2 db$$

$$T_e \sim B_z^{2/5}$$

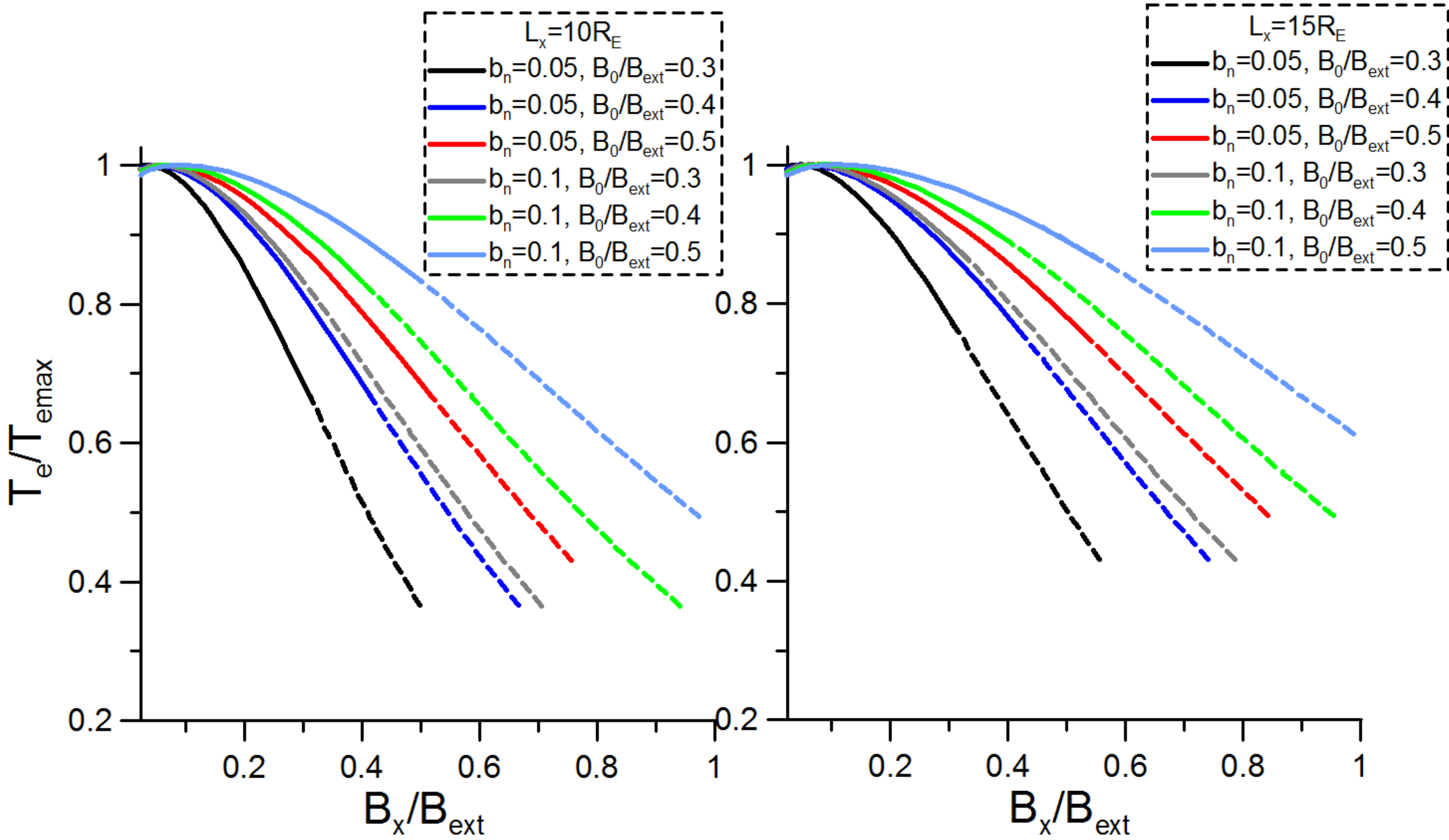
Electrons with far mirror points

$$T_e \sim B_z$$

Electrons drifts towards the Earth On the neutral plane



Theoretical model of the electron heating

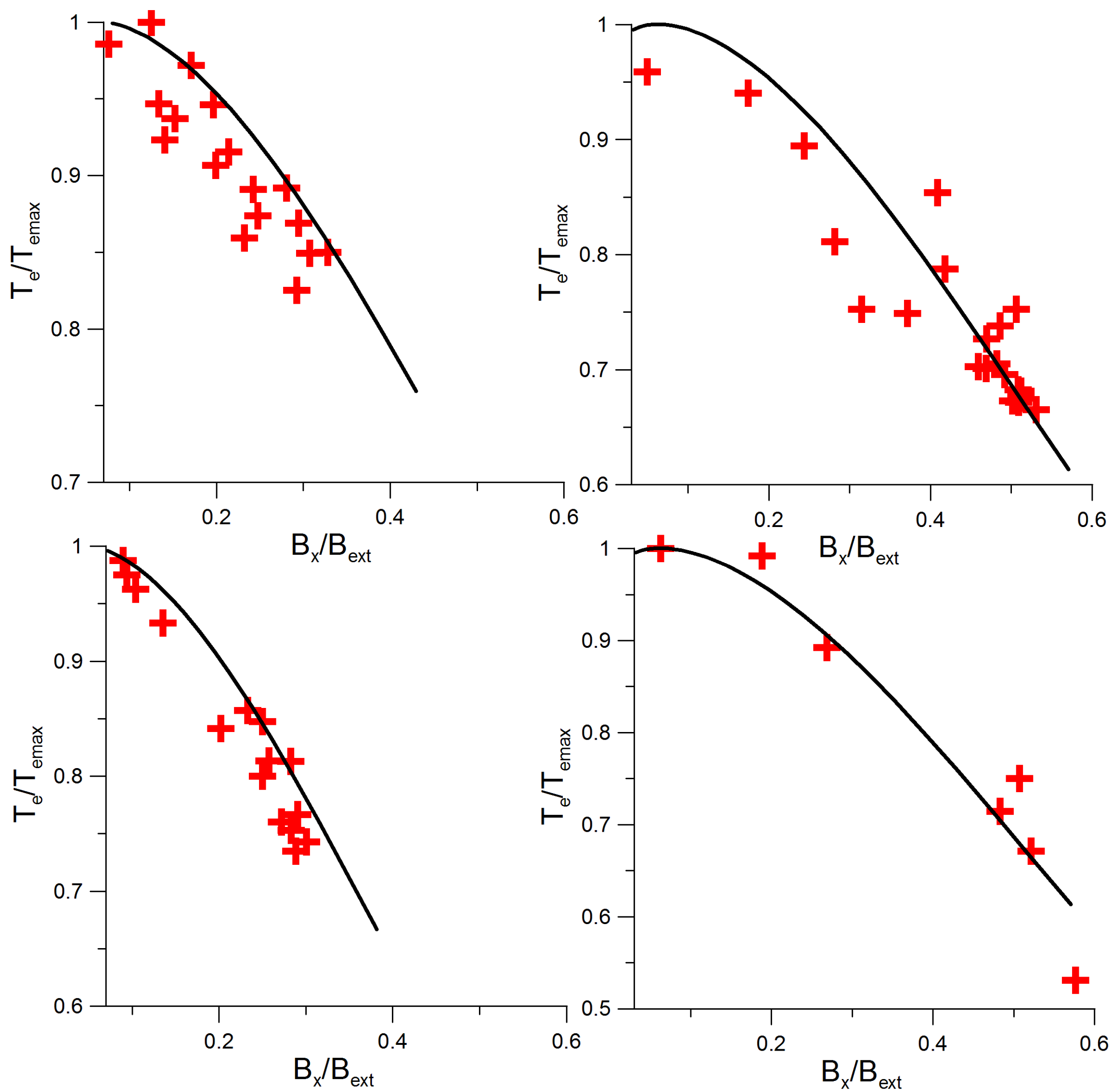


Electron temperature profiles for various values of current sheet parameters: L_x, B_z, B_0

Comparison of model profiles $T_e(B_x)$ and observations

Electron temperature as a function of magnetic field for four TCS crossings →

Electron temperature decreases towards the TCS boundary!



Spacecraft (Cluster 2) observations

Model profiles $T_e(B_x)$ with h=-0.8

The estimates of current sheet parameters from comparison of observations and model profiles $T_e(B_x)$

Input model parameters:

B_0 – amplitude of TCS magnetic field → **direct observation**

B_z – normal component of magnetic field → **direct observation**

B_{ext} - magnetic field magnitude at the lobe → **direct observation**

L_z – current sheet thickness → **$\sim B_0/j_{curl}$ from mutlispacecraft observations**

L_x – spatial scale along Earth-Sun direction → **free model parameter**

Output model parameters: $T_e(B_x)$ profiles

Comparison of model $T_e(B_x)$ profiles and observed $T_e(B_x)$ can give estimates of L_x

We vary the model input L_x to approximate the observed profiles $T_e(B_x)$

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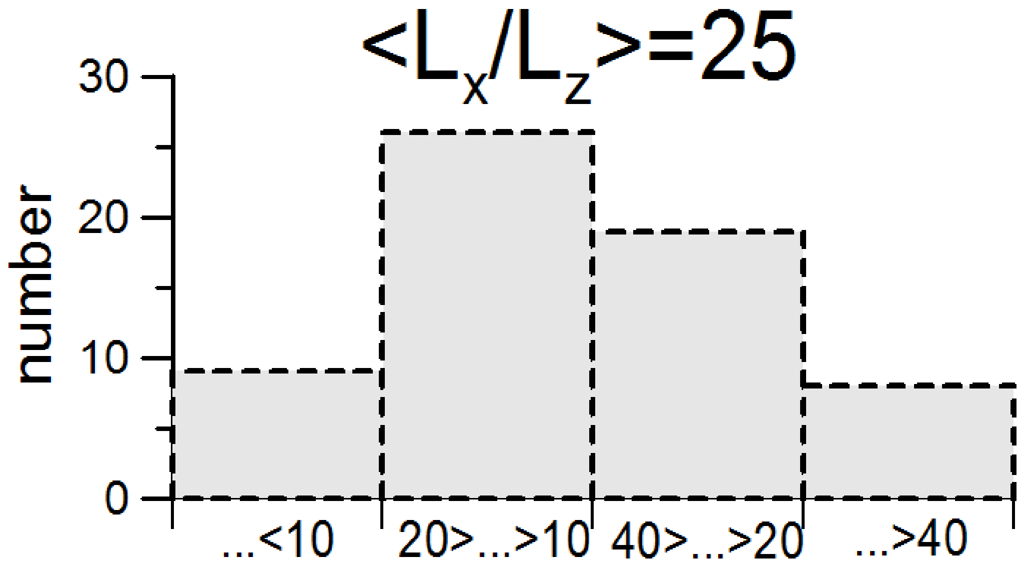
We use the statistics of 62 TCS crossings from 2001, 2002 and 2004 years

As a result, we obtain the statistics of L_x

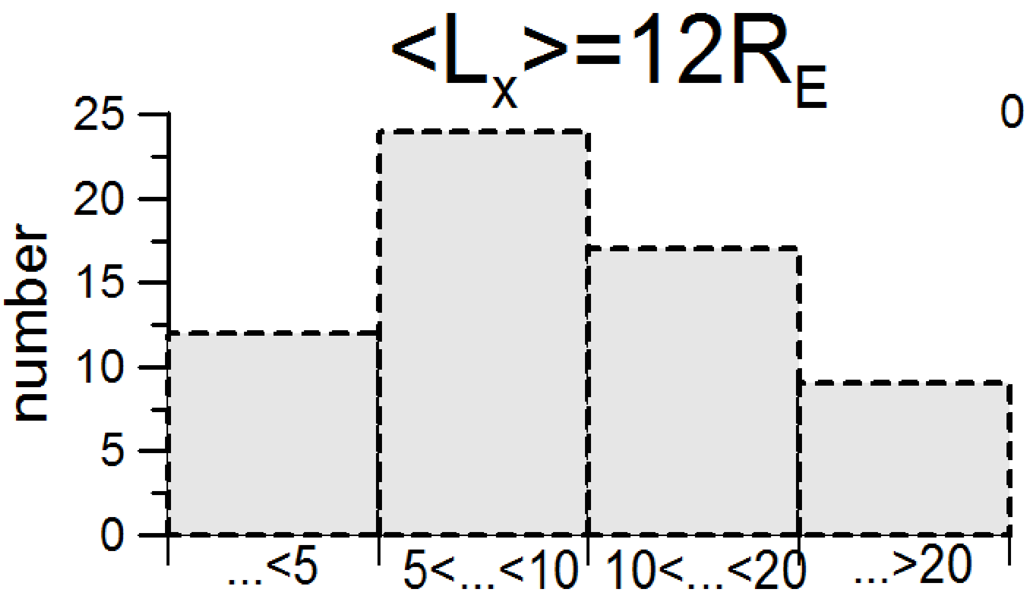
Distribution of L_x estimates



Distribution of L_x/L_z ratio

The most TCSs have $\mathbf{L_x/L_z}$~25

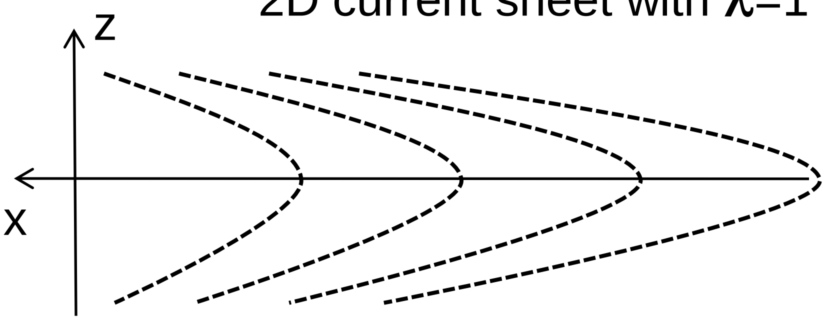
Distribution of L_x



The most TCSs have $L_x \in [5, 20]\ R_E$.

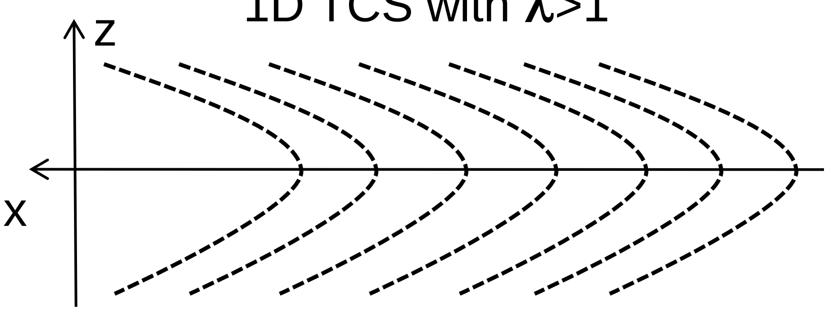
The ratio L_x/L and pressure balance in TCS

2D current sheet with λ=1



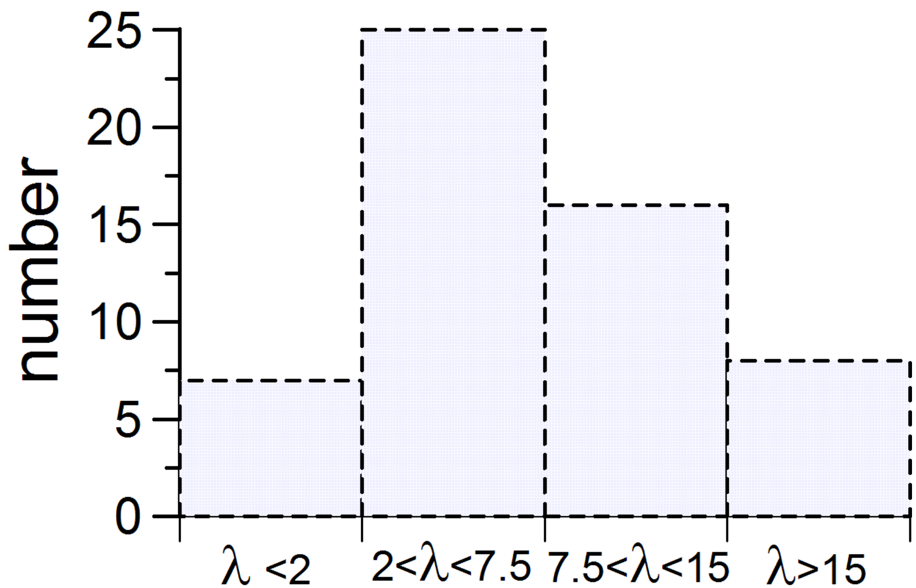
$$\frac{\partial p}{\partial x} = \frac{1}{c} j_y B_z$$

1D TCS with λ>1



$$\frac{\partial p_{xz}}{\partial z} = \frac{1}{c} j_y B_z$$

Effect of nongirotropy



$$\lambda = 2B_z L_x / B_0 L_z$$

For the 2D current sheet **λ =1**, and longitude pressure balance is maintaince due to the gradient along x (*Schindler 1972, Lembege and Pellat 1982*). For TCS **λ>1** and part of pressure balance corresponds to the inertia of transient particle motion (*Burkhart and Chen 1993*)

conclusions:

- The dynamics of adiabatic electron in the magnetotail current sheet is essentially influenced by $\partial B_z(x)/\partial x$
- The model of electron adiabatic heating during earthward convection can describe the observed profiles of $T_e(B_x)$ with the reasonable accurancy
- The comparison between the model and observed profiles $T_e(B_x)$ allow to estimate the longitudial spatial scale of current sheet $L_x \sim (\partial \ln B_z/\partial x)^{-1}$:

$5\ R_E < L_x < 20\ R_E$ $\langle L_x/L_z \rangle \approx 25$ $\langle 2B_z L_x / B_0 L_z \rangle \sim 5$

This result points out to the essential role of transient ions in pressure balance