Near-Earth plasma sheet as a seed population for the outer radiation belt

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Plasma sheet electrons

The distributions of electrons with **1 to few hundreds of keVs** and their variations **at distances 6.6-11 Re** not sufficiently studied in detail.

Modeling attempts: *Jordanova and Miyoshi*, 2005; *Miyoshi et al*., 2006; *Chen et al*., 2006; *Jordanova et al*., 2014.

The electron flux at the keV energies is largely determined by convective and substorm-associated electric fields and varies significantly with geomagnetic activity driven by the solar wind [*Mauk and Meng*, 1983; *Kerns et al*., 1994; *Liemohn et al*., 1998; *Ganushkina et al*., 2013, 2014].

Studies on keV electrons: *Korth et al*. [1999], *Denton et al*. [2005], *Sicard-Piet et al*. [2008], *Denton et al*. [2015] (LANL MPA and SOPA electron data), *Friedel et al*. [2001] (Polar Hydra instrument), *Kurita et al*. [2011] (THEMIS spacecraft), *Asnes et al*., [2008], *Burin des Roziers et al*. [2009] (GEOTAIL and CLUSTER data)

In the near-Earth plasma sheet, continuous measurements of plasma sheet electrons are not available, in contrast to geostationary orbit

No solar wind driven empirical relations for electron fluxes or moments of electron distribution function which can be used easily for radiation belt modeling.

Boundary conditions in the plasma sheet for modeling of keV electrons

Our previous studies [*Ganushkina et al*., 2013, 2014]:
we set the model **boundary at 10 R_E** and use the **kappa electron distribution** function.
Parameters of the kappa distribution function: **number density *n* and temperature *T*** in the plasma sheet given by the empirical model derived from Geotail data by TM03
Tsyganenko and Mukai [2003].

The **electron *n* is assumed to be the same as that for ions** in the TM03 model,
but **Te/Ti = 0.2** is taken into account (*Kaufmann et al*., 2005; *Wang et al*., 2012).

Applying this model for boundary conditions has a number of **limitations**:

(1) Model was derived from Geotail data for ions (limited detector energy range <40keV).

(2) ratio Te/Ti can vary during disturbed conditions.

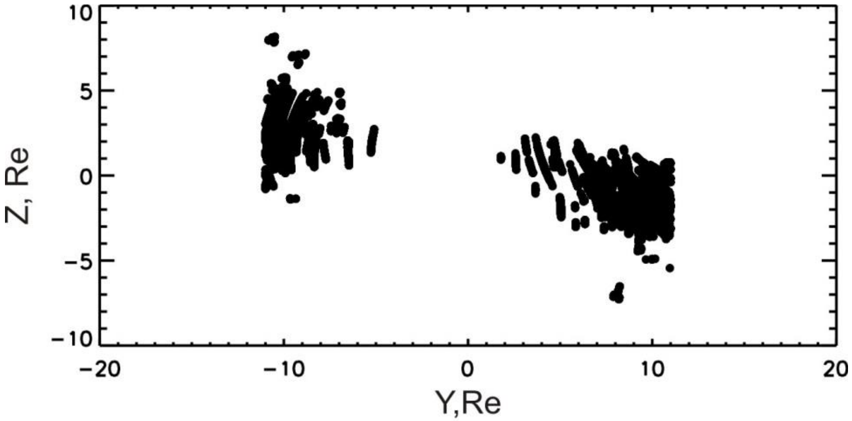
(3) at distances closer than 10 Re, the correlation between Ti and Te might not exist at all and no certain ratio can be determined (*Runov et al*., 2015).

(4) simple $\sin^2$ MLT dependence.

Revision of boundary conditions in the plasma sheet using Cluster data

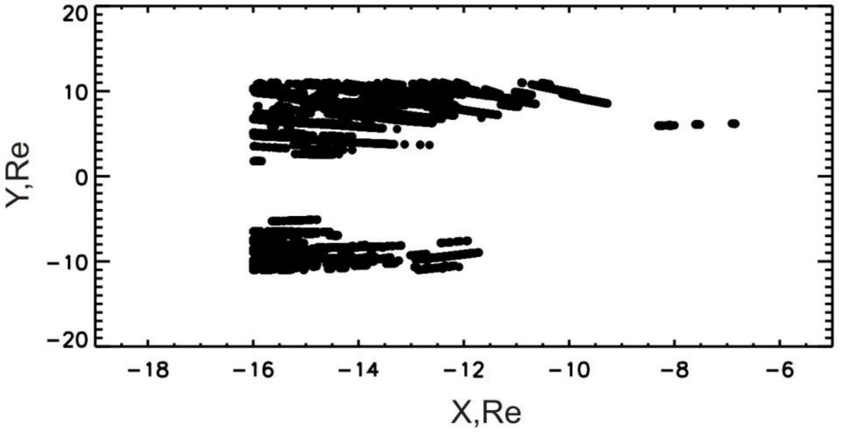
Cluster data for ions and electrons used:
HIA, from C1 and/or C3 (5 eV - 32 keV) and **PEACE** (0.7 eV - 26 keV).

Figure courtesy: E. Grigorenko



For the Cluster magnetotail session in 2001-2005 we choose 70 orbits, which cross the CPS at -16Re < Xgsm < -5Re and |Ygsm|<11Re. The CPS was identified as a region where |Bx| ≤ 5nT.
Totally from four Cluster satellites
174558 moments (4s bins) of the CPS.

For each CPS moment the IMF and solar wind data (Bz, Nsw, Vsw in GSM) were determined by taking into account the time delay due to the solar wind propagation from ACE to Subsolar point.

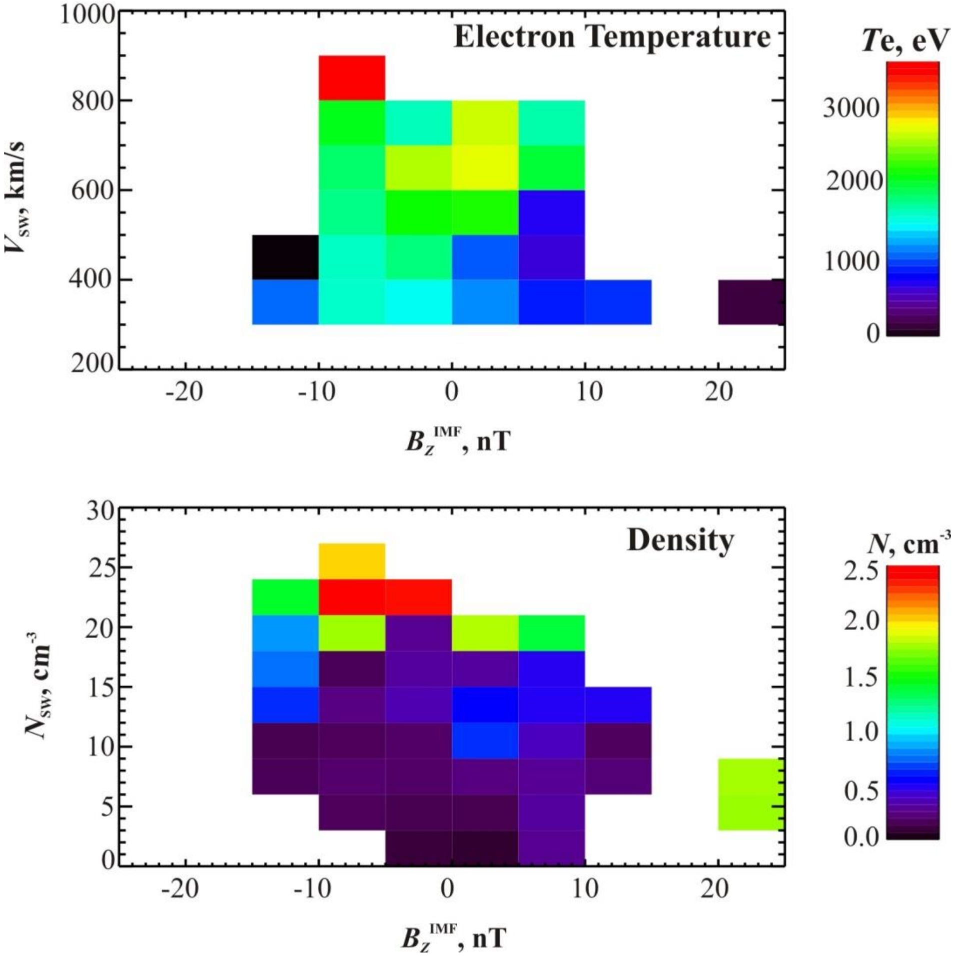


Electron density and temperature observed by Cluster and averaged for each (IMF Bz, Nsw) and (IMF Bz, Vsw) bin

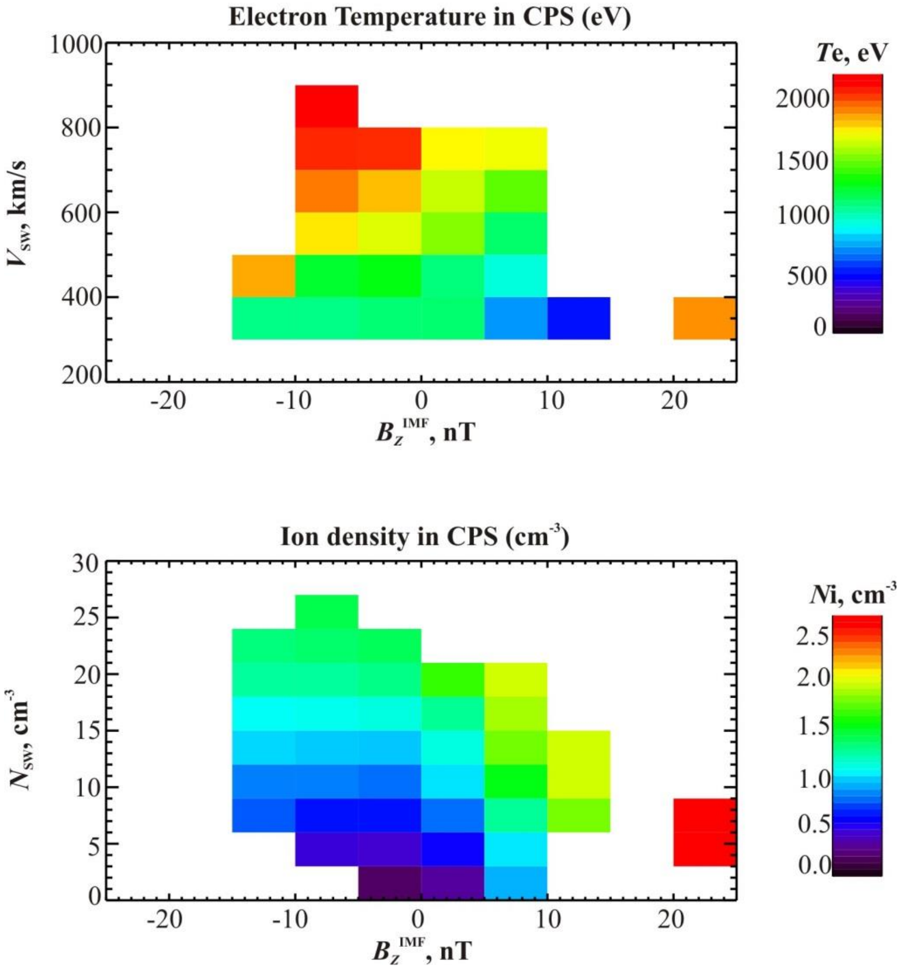
Ion density (assume Ni=Ne) and electron temperature Te=Ti*0.26 using Tsyganenko and Mukai (2003) model

Figure courtesy: E. Grigorenko

CLUSTER Observations

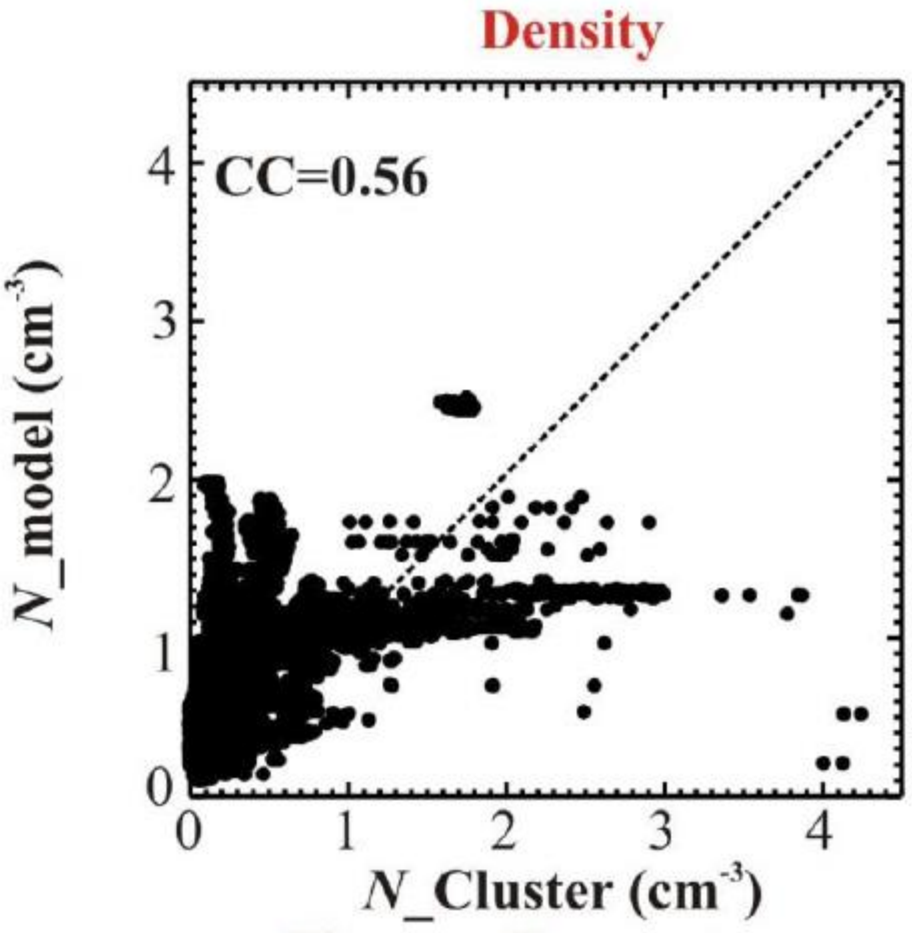


Tsyganenko - Mukai model



Measured electron temperature and number density different than those given by TM03 model

Comparison of electron density from Cluster data and *Tsyganenko and Mukai* [2003] model



Tsyganenko and Mukai [2003] model does not describe well the electron density in the CPS.

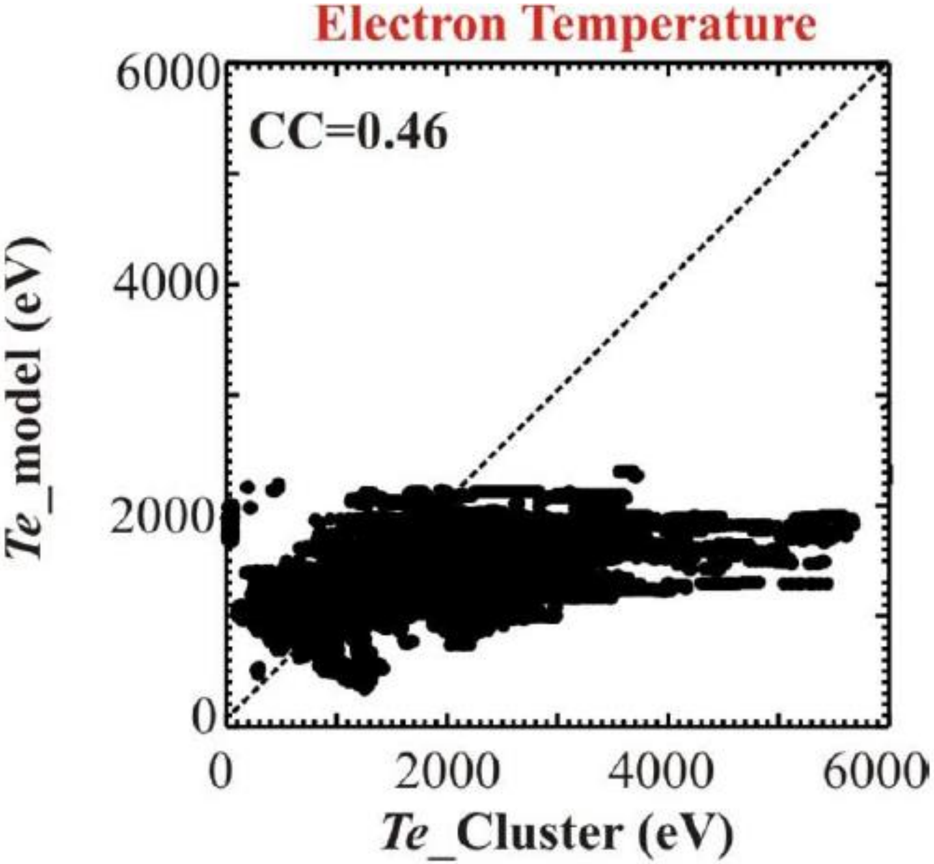
Also lower correlation coefficients for ion number density from Cluster and from the model obtained than in original paper.

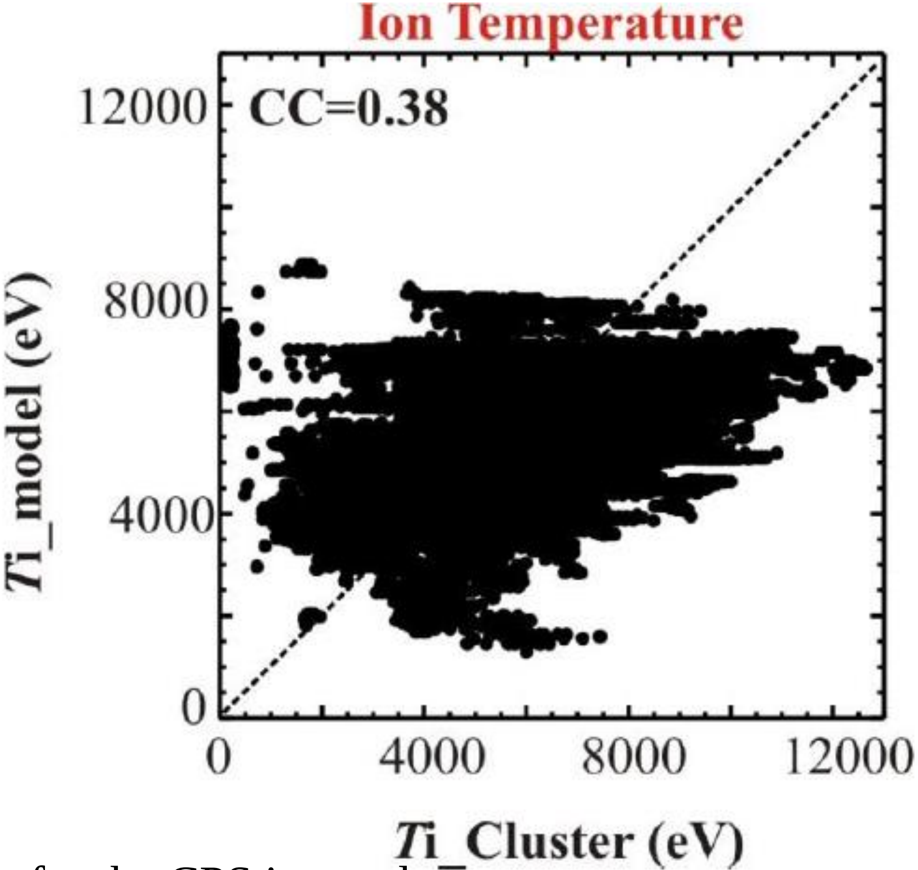
Figure courtesy: E. Grigorenko

Comparison of electron and ion temperatures from Cluster data and *Tsyganenko and Mukai* [2003] model

The ratio of Ti/Te varies in the CPS in a wide range of values from 0.17 to 18.0 and the average <Ti/Te>=3.8, thus Te=Ti*0.26.

Figure courtesy: E. Grigorenko



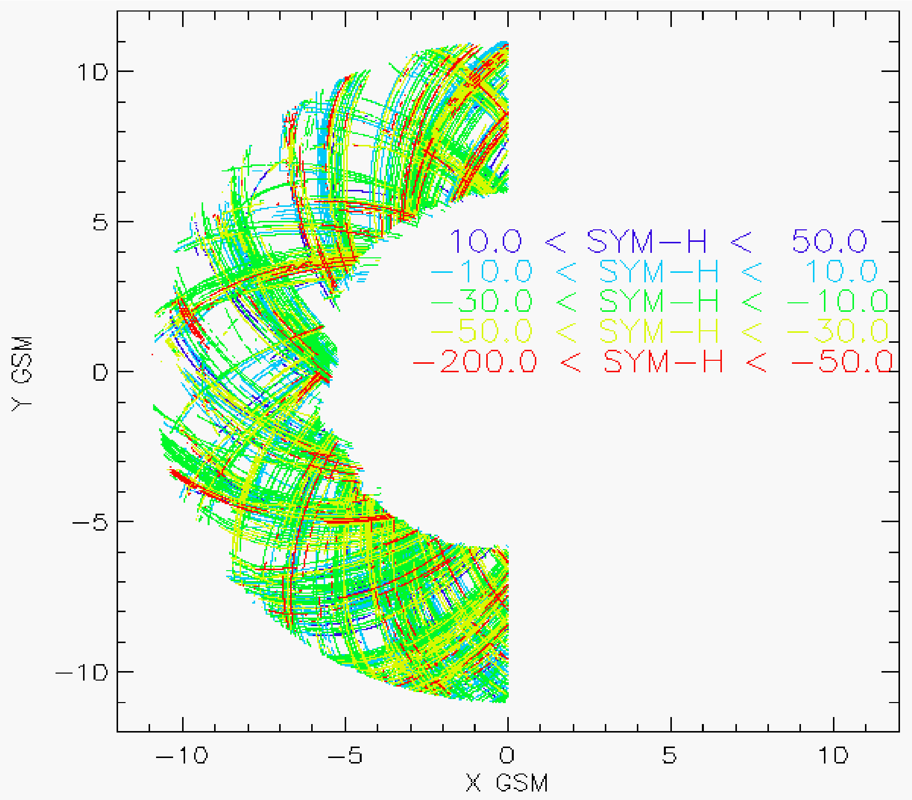


Reason of inconsistency is the selection criterion for the CPS intervals:
***Tsyganenko and Mukai* [2003] model include** only “quiet” CPS intervals without flapping, while we used all CPS intervals. Intervals of CPS with hot electrons (Te_Cluster > 2000 eV) cannot be described.

Revision of boundary conditions in the plasma sheet using THEMIS data

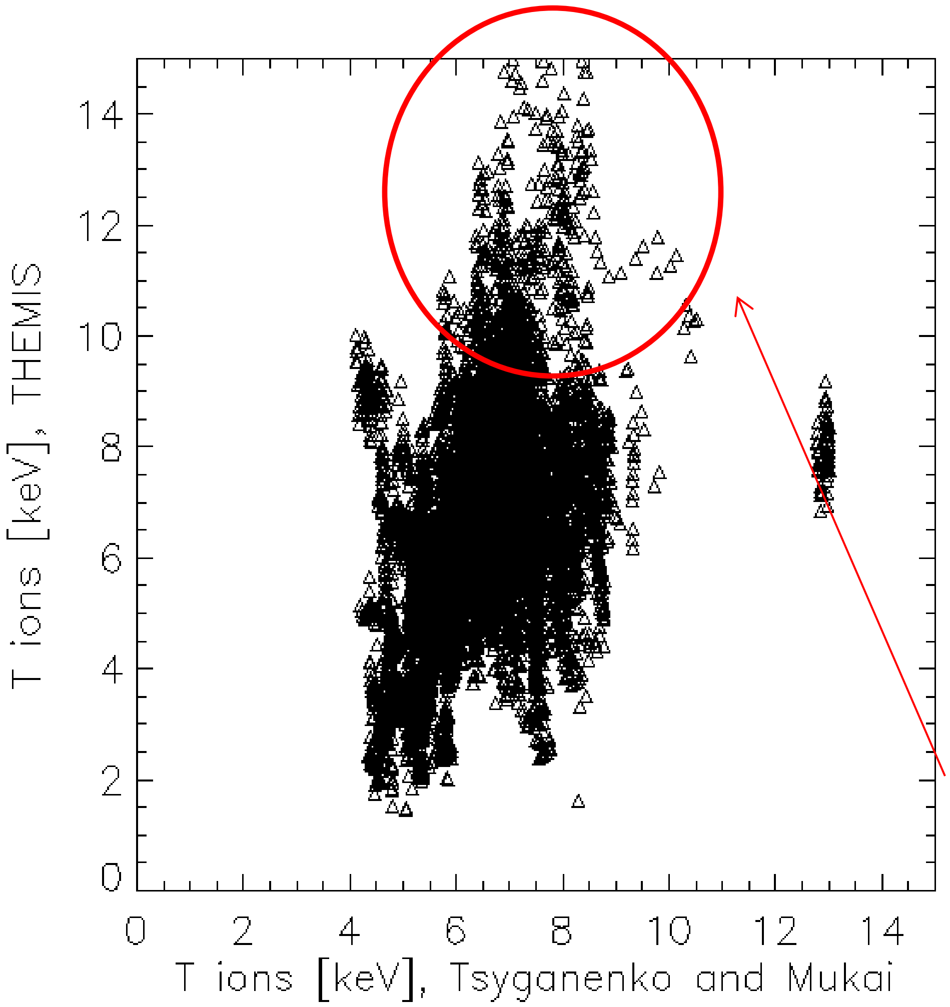
THEMIS data for ions and electrons used (2007-2014):
ESA (a few eV up to 25 (30) keV) and **SST** (25 keV- few eVs).

Then we computed the **plasma moments** using last calibration procedures. After synchronization of the solar wind data with THEMIS plasma moments we got ~66,000 datapoints at 1.5 min resoluton.



Comparison of ion temperatures from THEMIS data and *Tsyganenko and Mukai* [2003] model

Subset of the data with R=10-10.5 R_E used.



Correlation is very low (CC = 0.22**)** in comparison with high correlation obtained for such comparison in TM03 paper (CC=0.7).

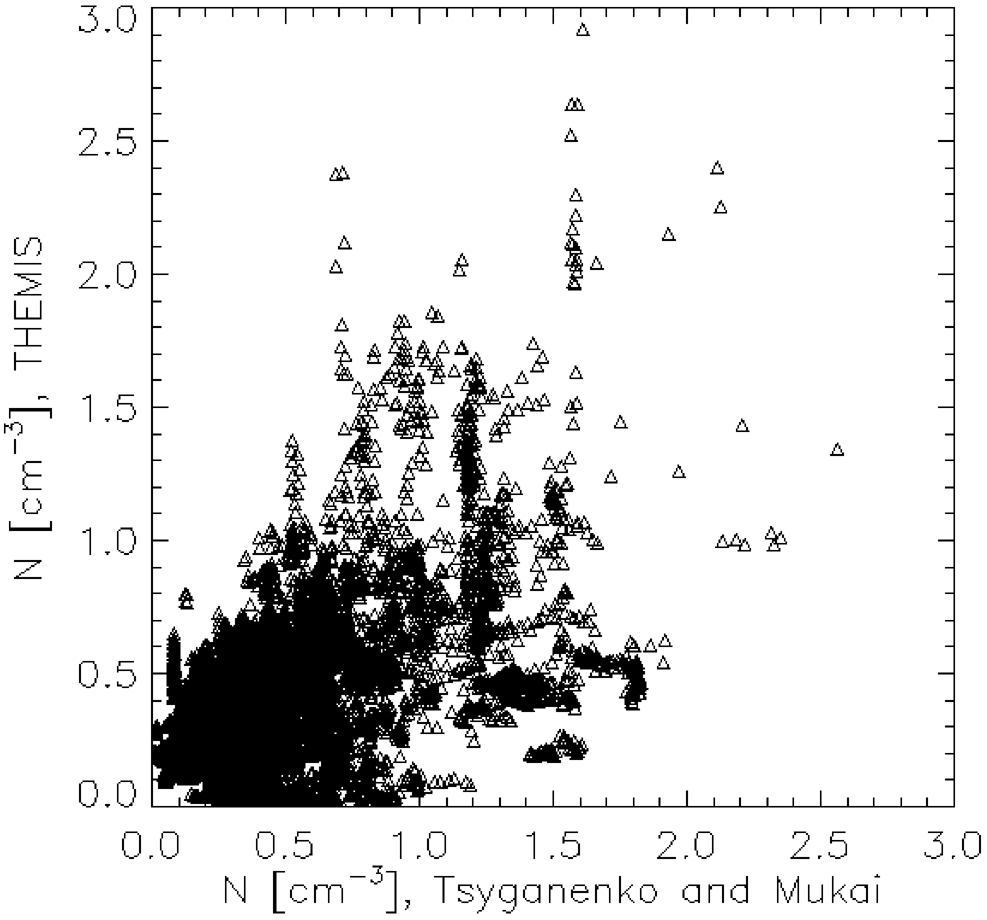
Due to limited range of radial distances in our comparison while the whole range of the Geotail (R=10-50 R_E) was used in TM03 model.

However, the points mostly fit the TM03 dependence confirming high quality of the THEMIS plasma data.

TM03 might systematically underestimate Ti for high-temperature part of the distribution due to limited energy range of Geotail spectormeter

Comparison of number densities of electrons from THEMIS data and of ions from *Tsyganenko and Mukai* [2003] model

Subset of the data with R=10-10.5 R_E is used.



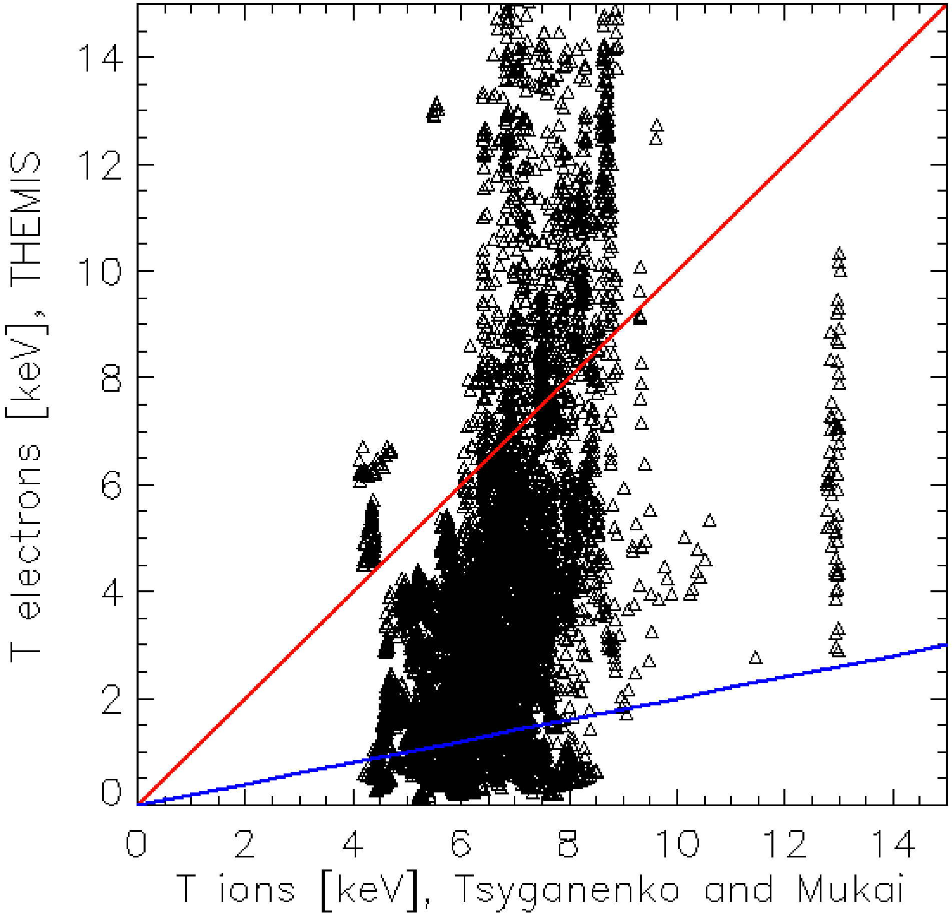
The correlation is 0.49 (close to 0.56 by TM03) in spite of limited range of the radial distances.

The TM03 equation for number density for ions can be used for electrons for IMPTAM simulation.

However, we are working towards improving the model for Ne.

Comparison of temperatures of electrons from THEMIS data and of ions from *Tsyganenko and Mukai* [2003] model

Subset of the data with R=10-10.5 R_E is used.



Red line: Te=Ti
Blue line: Te=Ti/5

If the relation Te=Ti/5 would have been valid in this region, the points would be distributed along blue line.

TM03 ion temperature shows **almost no correlation** with measured electron temperature.

Similar to *Runov* [2015] (private communication): there is **no correlation between Ti and Te at geocentric distances closer than R=12Re.**

Empirical model for electron temperature at 6-11 R_e based on Cluster and THEMIS data (1)

It was found that **solar wind velocity** shows highest correlation with electron temperature for at 6-11 R_E. IMF is of secondary importance.

Having experimented with time lag and duration of the average, we found that highest correlations are achieved for 1h delayed solar wind velocity.

$V^* = V_{SW}(t-1h) / 400 km/s$

Bs is averaged over dt= 1h 15 min and delayed 30min

$$BS = \left(\int_{t-1.75\,h}^{t-0.5h} Bs * dt\right)/\Delta t$$

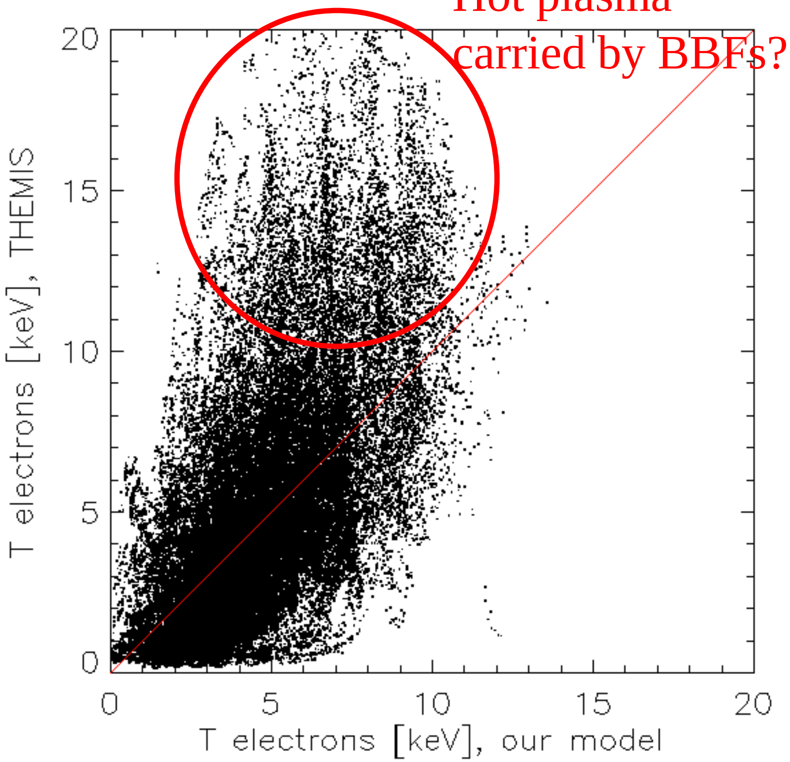
$BS^* = BS / 2\ nT$

BN is averaged over dt= 2h delayed 1h

$$BN = \left(\int_{t-3\,h}^{t-1h} Bn * dt\right)/\Delta t$$

$BN^* = BN / 2nT$

Empirical model for electron temperature at 6-11 R_e based on Cluster and THEMIS data



Hot plasma carried by BBFs?

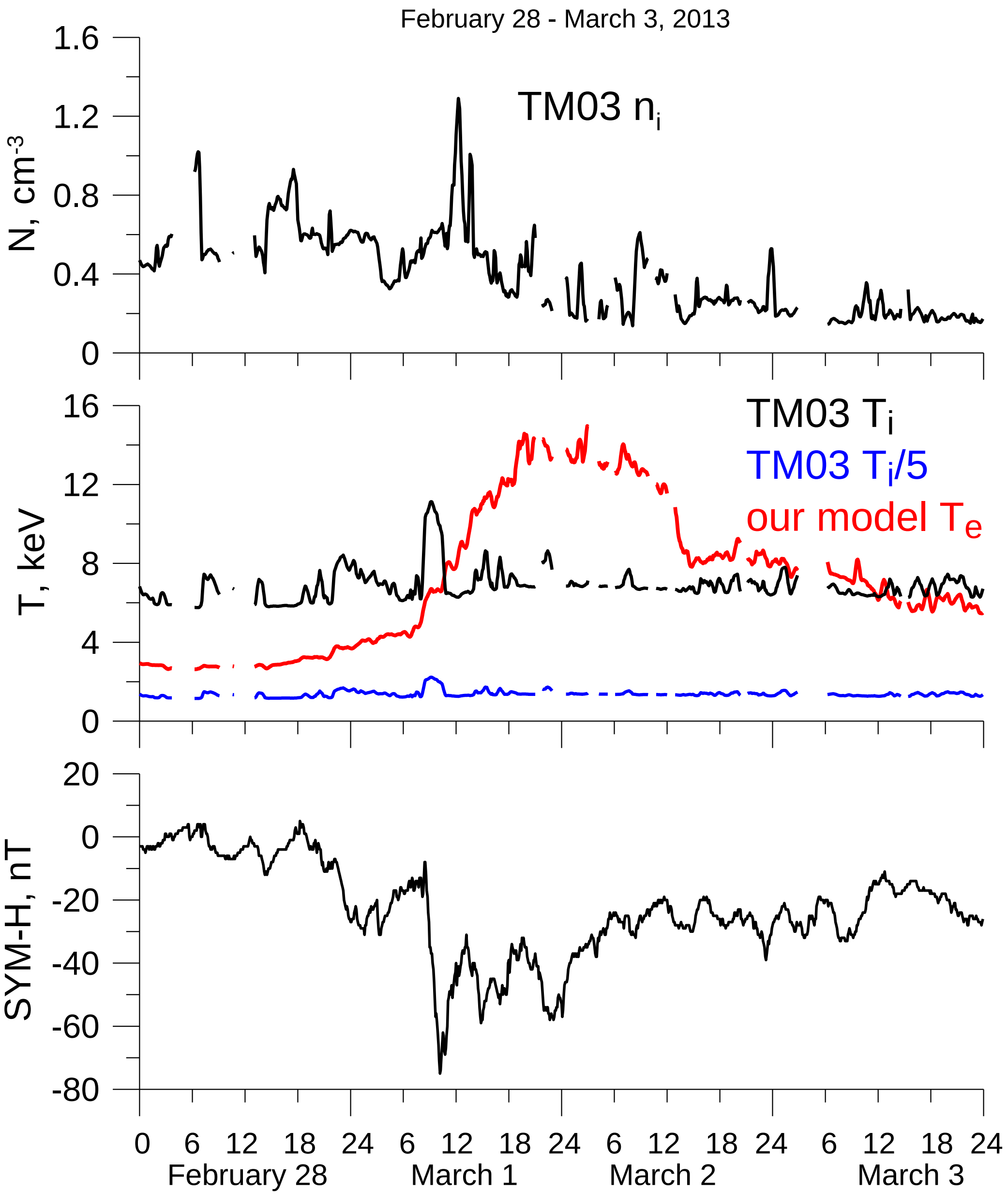
Model depends on coordinates
$R^*=R/10R_E$, and Ψ

$$\Psi = arctg\left(-\frac{Y_{GSM}}{X_{GSM}}\right)$$

The **correlation coefficient** for the whole range of distances R= 6-11 R_E is **0.61.**
The mean absolute deviation is 2keV

$$T_e = \left[\begin{array}{l} 2.92 - 2.92\cdot R^* + 0.538\cdot\Psi - 0.707\cdot R^*\cdot\Psi + 1.09\cdot R^*\cdot\Psi^2 + \\ (1.84\cdot R^* + 1.35\cdot\Psi^2 - 2.48\cdot R^*\cdot\Psi^2)V_{SW}^* - 0.127\cdot\Psi\cdot BS^* - 0.267\cdot R^*\cdot BN^* \end{array}\right]^2$$

Example for February 28 –March 3, 2013 storm



Summary

1.keV electrons in the near-Earth geospace are of a key importance though not studied in details: as low energy electron seed population for radiation belts, as responsible for surface charging on satellites.

2. Source of low energy electrons is in the plasma sheet

3. Continuous measurements are not available, thus we need a model with time-dependent boundary conditions in the plasma sheet. TM03 developed for ions are not suitable for electrons.

4. Long-term data analysis from Cluster HIA (2001-2005) and THEMIS ESA and SST (2007-2014) for development of empirical relations for electron temperature and number density at distances 6-11 Re.

5. As a first version of the model:
Ne = Ni
Te is driven mainly by 1 hour delayed Vsw and Bs, BN.

6. Final version: Ne dependence and Te with cold and hot populations