Space Research Institute of Russian Academy of Sciences

7. Cooperation with Bulgarian and Polish scientists and experts in the field of fundamental space research

Scientific results of Russian-Bulgarian cooperation. Project "Magnetoplasma"

Observation of small-scale filamentation of the current sheet and cross-tail current reduction in the near-Earth magnetotail followed by significant electron heating.

On the basis of five CLUSTER and THEMIS spacecraft observations a small-scale spatial structure (at the scales ≤ ρ_i, where ρ_i is a gyroradius of thermal protons) of the near-Earth (X ≥ -10 Re) current sheet (CS) is studied. The small-scale filamentation of the CS and the reduction/disruption of the cross-tail current are revealed.

These phenomena were followed by strong electron heating. These findings indicate on a possible formation of the region of anomalous resistivity in the near-Earth CS. Simultaneously with the formation of this region the ground stations, located near the ionospheric footpoint of THEMIS-P3 spacecraft, observed the reduction of the horizontal component of the geomagnetic field B_H denoting the formation of the substorm current wedge. Thus we define the relation between the process of cross-tail current reduction/disruption in the near-Earth magnetotail and geomagnetic activity (*Grigorenko et al*., 2016).

Project goals in 2011 – 2015:

1. studies of the spatial structure and dynamics of field-aligned currents in the Plasma Sheet Boundary Layer (PSBL) of the Earth's magnetotail by CLUSTER observations;
2. studies of contributions of the field-aligned currents produced by accelerated ion beams in the PSBL in the magnetospheric-ionospheric coupling;
3. the construction of algorithm of the PSBL automatic search (without the visual analysis of spacecraft data);
4. studies of the Current Sheet (CS) structure and ion dynamics near a magnetic reconnection region in the Earth's magnetotail;
5. studies of the CS structure and stability in the near-Earth magnetotail (at $X > -10$ Re, where Re is the Earth radius) during the periods of high-velocity plasma flow propagation. The definition of the relation between the phenomenon of CS reduction/disruption and geomagnetic activity.

Main scientific results obtained for the period 2011-2015.

1. It is revealed that ion beams, accelerated in the distant CS in the course of nonadiabatic resonant interaction with the CS (so-called Type I ion beams, *Grigorenko et al.,* 2012), do not produce significant field-aligned currents in the PSBL of magnetotail. During such periods the density of field-aligned currents in the PSBL does not exceed 2 nA/m^2. Such ion beams are mapped in the high-latitude edge of quasi-stationary auroral arc. The auroral intensifications are not observed during such periods (Fig.1).
2. It is revealed that field-aligned ion beams, accelerated near a reconnection region (so-called Type II ion beams, *Grigorenko et al.,* 2012), produce significant field-aligned currents in the PSBL of magnetotail. During such

periods the density of field-aligned currents in the PSBL exceeds 5 nA/m^2. The cross scale of these field-aligned currents is about the cross scale of the PSBL ~ 1 Re. Such ion beams are mapped near the polar edge of a discrete arc structure.

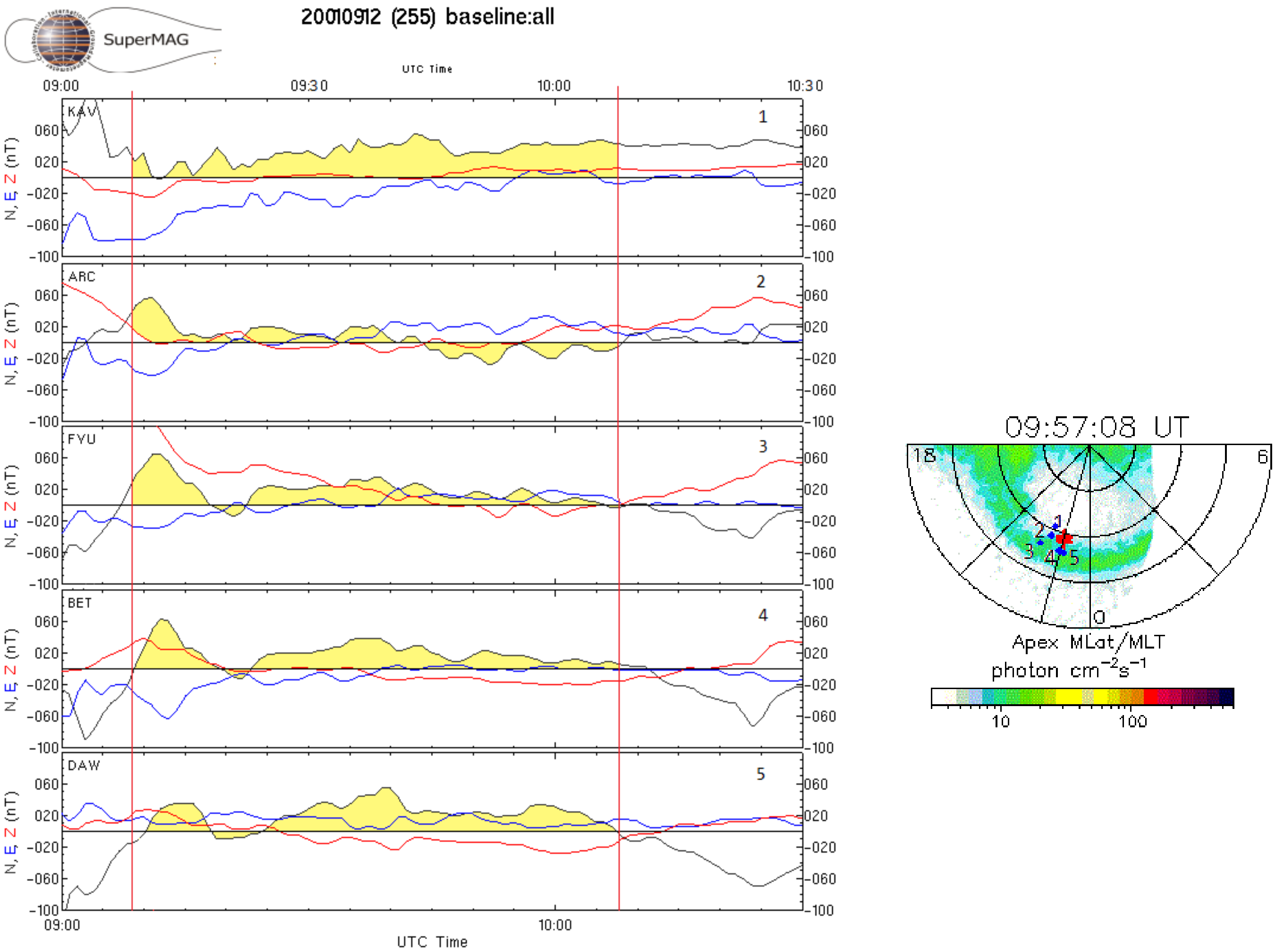

Fig.1 *In the left:* the variations of geomagnetic field observed by the ground stations located near the ionospheric footpoint of CLUSTER spacecraft during the period of Type I ion beam propagation in the PSBL of magnetotail. The time interval of the ion beam observation is marked by the red vertical lines. *In the right*: the UV image of the auroral region (the UV intensity is shown by the colored scale in the bottom of the figure) at the moment of the Type I ion beam propagation. The ground stations, which data are shown in the left plot, are indicated by the blue circles and numbers. The CLUSTER ionospheric footpoint is shown by a red cross.

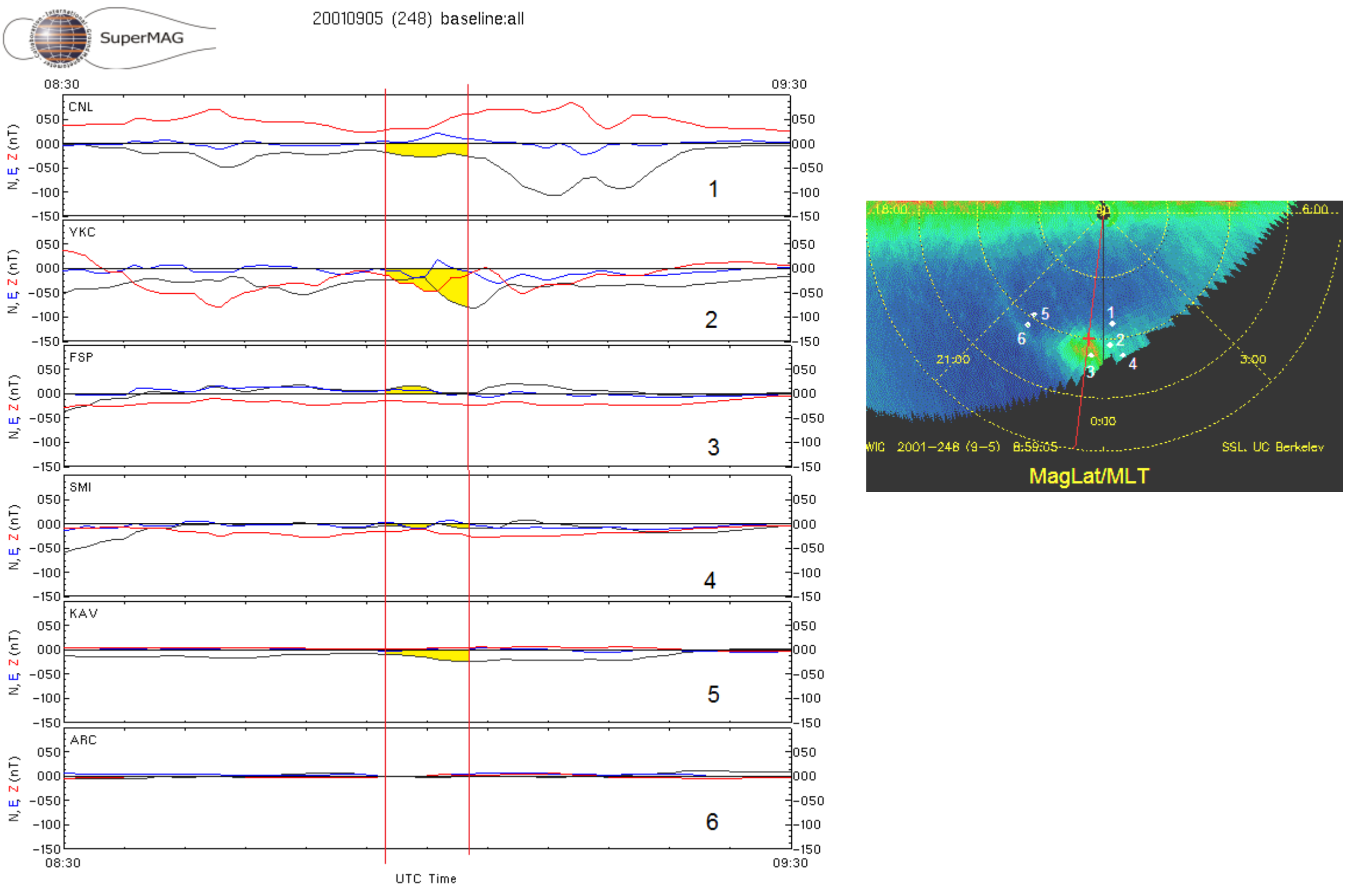

Fig.2. *In the left:* the variations of geomagnetic field observed by the ground stations located near the ionospheric footpoint of CLUSTER spacecraft during the period of Type II ion beam propagation in the PSBL of magnetotail. The time interval of the ion beam observation is marked by the red vertical lines. *In the right*: the UV image of the auroral region at the moment of the Type II ion beam propagation. The ground stations, which data are shown in the left plot, are indicated by the white circles and numbers. The CLUSTER ionospheric footpoint is shown by a red cross.

3. The algorithm of automatic search (without the visual analysis) of the PSBL intervals in spacecraft data is constructed. It is demonstrated that the use of plasma β and bulk velocity as a searching parameters (as it was suggested in earlier studies) leads to a large error (≥ 50%) in the PSBL identification. We suggest to use the following searching condition: $V_{i||} > 400$ km/s, where $V_{i||}$ is ion field-aligned velocity calculated for energy range 2 - 35 keV. The use of this condition allows to identify the intervals of the PSVL crossings by a spacecraft with error < 30% (*Grigorenko et al.,* 2012).
4. The CS structure and ion dynamics near a magnetic reconnection region are studied by use CLUSTER and Double Star observations. The spacecraft

simultaneously observed magnetic reconnection in the near-Earth CS being located at the opposite side of the magnetic X-line. It is shown that close to the reconnection region the quadrupole spatial distribution of a shear magnetic field B_Y is formed in the Plasma Sheet (PS) due to the generation of the Hall current system. In the tailward side of the magnetic X-line the closed plasmoid-like magnetic configuration is formed. At the neutral plane of the plasmoid the B_Y field is increased. We revealed the mechanism of the increase of the B_Y field due to the asymmetry in nonadiabatic ion reflection/refraction in the course of their interaction with the plasmoid's CS (Fig.3). Due to these kinetic features in ion dynamics the system of the oppositely directed ion currents (a current loop) is formed in the PS. This current system leads to the further enhancement of the B_Y field in the plasmoid's CS. The enhancement stops when the B_Y field becomes large enough to magnetize ions and destroy the kinetic effects in ion dynamics (*Grigorenko et al.*, 2013). This mechanism demonstrates how the features of ion dynamics operating at kinetic scales influence on the large-scale magnetic configuration of the CS.

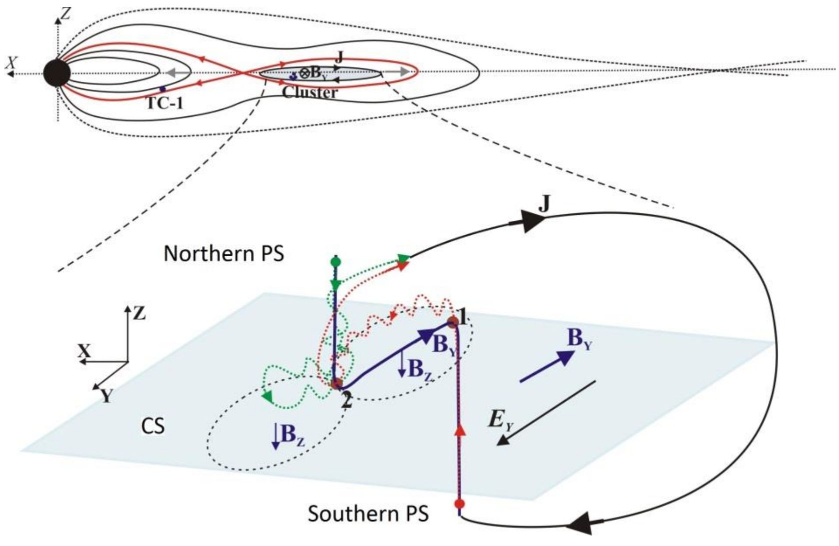

Fig.3. An illustration of the mechanism of the B_Y field enhancement in the CS of magnetotail (the CS is shaded by blue color) due to the formation in the PS of a current loop *J*. Due to the partial magnetization by the initial B_Y field quasi-adiabatic ions coming to the CS from the northern PS (their trajectories are shown by green color) are ejected back to the northern PS after the interaction with the CS. Ions coming to the CS from the southern PS (their trajectories are shown by red color) are also ejected to the northern PS after the interaction with the CS.

This results to the "north-south" asymmetry in ion ejections from the CS. These ions generate the current loop *J* around a plasmoid. In the central plane of this loop the B_Y increases.

5. On the basis of five CLUSTER and THEMIS spacecraft observations a "fine" spatial structure (at the scales ≤ ρ_i, where ρ_i is a gyroradius of thermal protons) of the near-Earth (X > -10 Re) CS is studied. The small-scale filamentation of the CS and the reduction/disruption of the cross-tail current are revealed. These phenomena were followed by strong electron heating. These findings indicate on a possible formation of the region of anomalous resistivity in the near-Earth CS. Simultaneously with the formation of this region the ground stations, located near the ionospheric footpoint of THEMIS-P3 spacecraft, observed the reduction of the horizontal component of the geomagnetic field B_H denoting the formation of the substorm current wedge. Thus we define the relation between the process of cross-tail current reduction/disruption in the near-Earth magnetotail and geomagnetic activity (*Grigorenko et al*., 2016).

References:

1. E.E. Grigorenko, R. Koleva, J.-A. Sauvaud, On the problem of Plasma Sheet Boundary Layer identification from plasma moments in Earth's magnetotail, Annales Geophysicae, 30, 1331–1343, 2012, http://www.ann-geophys.net/30/1331/2012/angeo-30-1331-2012.
2. E.E. Grigorenko et al., Non-adiabatic ion acceleration in the Earth magnetotail and its various manifestations in the Plasma Sheet Boundary Layer, Space Sci. Rev., 164, N 1, 133-181, 2012.
3. E. E. Grigorenko, H. V. Malova, A. V. Artemyev O. V. Mingalev E. A. Kronberg, R. Koleva, P. W. Daly, J. B. Cao, J.-A. Sauvaud, C. J. Owen, and L. M. Zelenyi, Current sheet structure and kinetic properties of plasma flows during a near-Earth magnetic reconnection under the presence of a guide field, J. Geophys. Res., 118, 3265–3287, doi:10.1002/jgra.50310, 2013.

4. E.E. Grigorenko, R. Koleva, E.A. Kronberg, P.W. Daly, Yu. Khotyaintsev, S. Dubyagin, L.M. Zelenyi, Particle dynamics and small-scale structure of the magnetic dipolarization observed in the near-Earth tail by Cluster and THEMIS spacecraft, Planetary and Space Sci., 2016 (in press).

List of abstracts:

1. Grigorenko E.E., Koleva R, Zelenyi L.M., Sauvaud J.-A., PSBL plasma structure during different periods of geomagnetic activity observed by Cluster spacecraft and ground station network, International Workshop "Solar influences on the magnetosphere, ionosphere and atmosphere, Sozopol, Bulgary, June 6-10, 2011.
2. Koleva R., E. Grigorenko, Discrete Structures in the Magnetotail Lobes, paper # 3499, IUGG 2011, Melbourne, Australia, 28 June-7 July 2011, Detailed Scientific Program, p.262, http://www.iugg2011.com/pdf/IUGG2011_FinalEntireProgram.6June.pdf
3. Koleva R., E. E. Grigorenko, L. M. Zelenyi, J.-A. Sauvaud., PSBL Plasma Structures during Different Periods of Geomagnetic Activity and Their Possible Ground Manifestations, International Symposium on Recent Observations and Simulations of the Sun–Earth System II, Borovets, Bulgaria, September 11–16, 2011, Abstract Book, p. 46, http://www.isroses.lanl.gov/abstract_book.pdf
4. Grigorenko et al., Different regimes of particle acceleration in the Earth magnetotail and their PSBL manifestations, CLUSTER 21th Workshop and ESLAB 2011 "Solar System Plasma Physics: Remote and in-situ Measurements", Brugge, Belgium, September 19-23, 2011
5. Koleva, R., Grigorenko, E. E., Zelenyi, L.M., Sauvaud, J.-A., Field-aligned currents in PSBL and their possible auroral and ground manifestations, paper D3.2-0016-12, presented at the 39th COSPAR Scientific Assembly, 14 - 22 July

2012, Mysore, India, https://www.cospar-assembly.org/abstractcd/COSPAR-12/abstracts/D3.2-0016-12.pd

6. Grigorenko, E., Zelenyi, L., Sauvaud, J.-A., Koleva, R., Effects of near-Earth magnetic reconnection simultaneously observed in the Plasma Sheet by Cluster and DSP spacecrafts, Paper D3.2-0015-12, presented at the 39th COSPAR Scientic Assembly, 14 - 22 July 2012,Mysore, India, https://www.cospar-assembly.org/abstractcd/COSPAR-12/abstracts/D3.2-0015-12.pdf
7. Koleva, R., Grigorenko, E. E., Zelenyi, L.M., Sauvaud, J.-A., PSBL field-aligned beams and currents, and their auroral and ground manifestations, paper presented at the 9th International Conference “Problems of Geocosmos”, St. Petersburg, Petrodvorets, October 8 - 12, 2012, Book of Abstracts, p. 183.
8. Koleva, R, Grigorenko, E. E., Zelenyi, L. M, Sauvaud, J.-A., Auroral and Ground Manifestations of PSBL Field-Aligned Plasma Structures, paper EGU2013-4613, presented at EGU General Assembly 2013, Geophysical Research Abstracts, Vol. 15, EGU2013-PREVIEW, 2013
9. Grigorenko E.E., Malova H.V., Koleva R., Kronberg E., Sauvaud J.-A., Zelenyi L.M.. A possible mechanism of a strong guide By field formation in a thin Current Sheet of the Earth magnetotail, paper presented at the Fifth Workshop “Solar influences on the magnetosphere, ionosphere and atmosphere", Nesebar, Bulgaria, 1-7 June 2013, http://ws-sozopol.stil.bas.bg/2013Nesebar/Grigorenko_oral.pdf
10. Koleva R., Grigorenko E. E., Zelenyi L. M., Sauvaud, J.-A., Auroral and Ground Manifestation of Different Ion Acceleration Mechanisms Operating in PSBL, paper presented at the Fifth Workshop “Solar influences on the magnetosphere, ionosphere and atmosphere", Nesebar, Bulgaria, 1-7 June 2013, http://ws-sozopol.stil.bas.bg/2013Nesebar/Koleva_oral.pdf.

11. Koleva R., Grigorenko E. E., Zelenyi L. M., Sauvaud, J.-A., Ion Beams in PSBL and Their Auroral and Ground Manifestations, paper presented at the 12th Scientific Assembly of the IAGA Merida, Mexico, 25-31 August 2013.
12. Koleva R., Grigorenko E. E., PSBL Plasma Structures Related to Auroras, paper at the Ninth Scientific Conference with International Participation SES 2013, Sofia, 20-22 November 2013.
13. Koleva R., Grigorenko E. E., Zelenyi L.M., Sauvaud J.-A., PSBL filed-aligned plasma structures related to auroras, paper D3.2-0023-14 presented at the 40th COSPAR Scientific Assembly, Moscow, Russia, 02 - 10 August 2014.
14. Grigorenko E.E., Koleva R., L. Palin, Sauvaud J.-A., Zelenyi L.M.. Currrent sheet dynamics in the near-Earth magnetotail and its relation to geomagnetic activity, SES 2014, Sofia, 12-14 November 2014.
15. Koleva R., Grigorenko E. E., Auroral display of PSBL field-aligned currents, SES 2014, Sofia, 12-14 November 2014.
16. Grigorenko E.E. et al., Cluster advances in studies of ion beams in the Earth's magnetotail, invited paper presented at Cluster 25th workshop, Cluster 25th workshop, 12-16 October 2015, Venice, Italy.
17. Koleva R., Grigorenko E. E., Criteria for Earth's magnetotail Plasma Sheet Boundary Layer Identification from Spacecraft Data, SES 2015, Sofia, 4-6 November 2015.

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