

MAGNETOSPHERIC SOURCES OF AURORAL LUMINOSITY DURING THE STEADY MAGNETOSPHERIC CONVECTION

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Abstract. The association of the auroral discrete and diffuse forms in the high latitudes with the magnetospheric plasma domains are discussed. The distribution of the luminosity and plasma precipitation during steady magnetospheric convection (SMC) intervals has been covered especially in detail. Comparison of these data with Feldstein-Galperin scheme of the auroral precipitation [1985, 1993, 1996] which takes into account the auroral precipitation dynamics under different levels of magnetic disturbances and different phases of magnetospheric substorms has been performed. It has been established that the observed data by *Yahnin et al.* [1997] fit in this scheme. The statement of *Yahnin et al.* that the Feldstein-Galperin scheme is a particular case of their scheme is based on the inaccurate comprehension of the cited papers.

1. Comparison of the ground location of auroral forms with meridional profiles of particle flux measured simultaneously by the low-altitude NOAA satellites above the ground observation region of the aurora has been performed in [*Yahnin et al.*, 1997]. It has been established that discrete auroral arcs are always located poleward of (or very closed to) the isotropic boundary (IB) of the 30 keV and more energetic electrons. In some events the auroral arcs occupy a wide latitudinal range. In these cases the most equatorial arcs are found at the poleward edge of the diffuse aurorae, the most poleward arcs being simultaneously observed on the closed field lines near the polar cap boundary. These results are compared with the global schemes of the auroral precipitation in the night sector described in literature.

Yahnin et al. [1997] have supposed that their observations disagree both with Feldstein-Galperin scheme [1985, 1993, 1996], where according to *Yahnin's et al.* statement the discrete auroras originate exclusively in the near Earth region of the plasma sheet, and with the schemes from [*Eastman et al.*, 1984; *Lyons and Nishida*, 1988; *Lyons*, 1991] in which it is supposed that magnetic field lines connect the discrete auroras with the plasma sheet boundary layer (PSBL).

Results of ground-based and satellite observations of the aurora have been summarized in [*Feldstein and Galperin*, 1985]. Figure 1 shows the space-time distributions of different type auroral luminosity during quiet (left) and disturbed (right) periods. Values of the aurora region boundary latitudes are obtained from the observations.

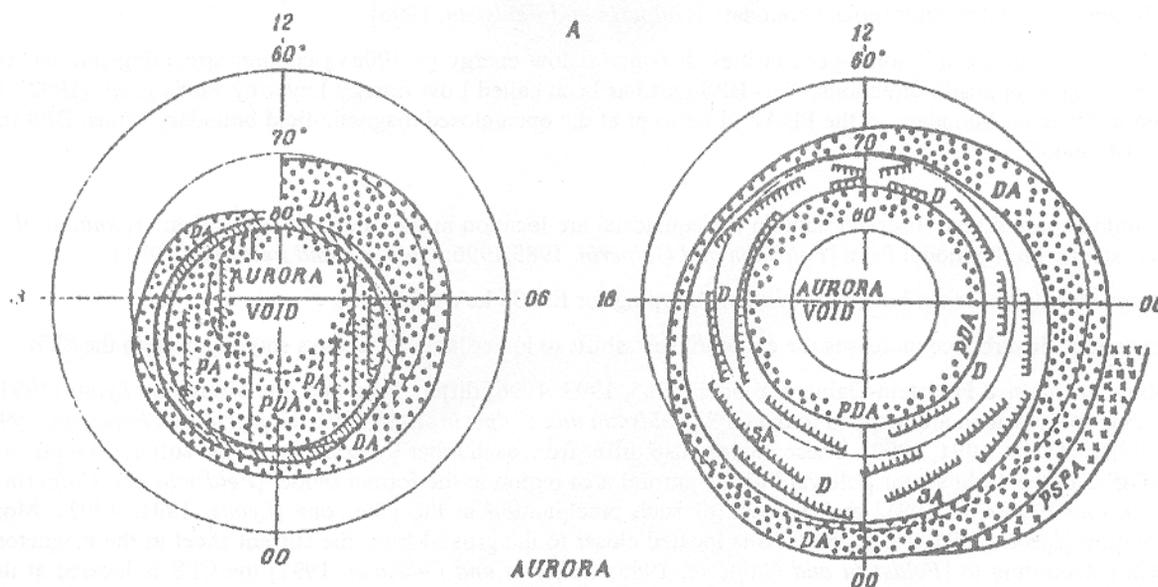


Fig.1. Schematics of the different types of auroral distributions during quiet ($K_p = 0$, left) and magnetically disturbed ($K_p = 5$, right) periods. The coordinate system is corrected geomagnetic latitude and local time. The auroral oval for $K_p = 0$ is hatched, and for $K_p = 5$ structured aurorae is depicted. The auroral forms included are: PA, high latitude polar arcs; PDA, polar diffuse aurorae; SA, structured auroras in the auroral oval; D, diffuse aurorae in the auroral oval; DA, diffuse aurorae equatorward of the auroral oval; PSPA, postsubstorm plasmaspheric aurorae (from [*Feldstein and Galperin*, 1985]).

During quiet periods the discrete auroral oval looks like a narrow ring around the pole located at the corrected geomagnetic latitude $\Phi \approx 70^\circ$ in the nearmidnight time sector. There are diffuse luminosity bands located both poleward and equatorward of the discrete aurora; i.e. the diffuse band (DAZ) of the nearly ring form located equatorward and the polar diffuse auroral band which is narrow during disturbed periods but considerably expanding poleward during quiet time (PDAZ).

During disturbances discrete forms are observed in a wide high latitude region. In Figure 1 the equatorial oval boundary in the midnight is located approximately at $\Phi \approx 62^\circ$, while the polar one shifts poleward to $\Phi \approx 74^\circ$. The auroral oval region with the most active aurorae is controlled by a substorm phase. At the expansion and recovery phases of the auroral substorm the most bright and active aurorae take place in the oval polar part. At the substorm expansion phase discrete forms dynamically though irregularly fill up the whole cross-section of the oval night part, but at the recovery phase they mainly stay in the oval polar and equatorial parts. So-called "oval splitting" [Gusev, 1980] occurs which is referred to as "double oval" [Elphinstone *et al.*, 1995]. The diffuse luminosity poleward of the discrete oval is confined to a narrow band and becomes considerably more brighter and wider equatorward of the oval.

The stable trapping boundary (STB) for high energy (> 35 keV) electrons is the most significant boundary for the auroral structures being mapped into the magnetosphere and often the easiest one to be measured by a satellite equipped with a high energy particle detector with pitch-angle resolution [Frank, 1971; McDiarmid and Burrows, 1964]. The STB signature is a disappearance of the typical trapped particle anisotropy (i.e. the intensity peak at 90° pitch angle) with invariant latitude increasing. It is accompanied by a drop of the high energy electron intensity. It is very important that the STB is located at or very close to several other principal magnetospheric plasma boundaries: the isotropic boundary (IB) for energetic electrons, inner boundary of the plasma sheet, inner boundary of the tail current, surface between Region1/Region2 of the field-aligned currents.

Poleward of the discrete forms there is a weak diffuse luminosity region registered by optical measurements and a band of weak and soft electron precipitation with the energy typically less than 0.5 keV adjacent to the auroral oval polar edge. It has been called polar diffuse auroral zone (PDAZ) from measurements of the red auroral emission, but weak electron precipitations within this band can be fairly inhomogeneous with bursts of the accelerated low energy electrons. Obviously some discrete aurora displays can be found within PDAZ, but they are usually weaker than the bright discrete auroras in the auroral oval.

VDIS 2 events (velocity dispersed ion structure type 2) may be very important natural phenomena for PSBL tracing. According to different satellite measurements VDIS 2 events occur poleward of the inverted V events typical for the auroral oval. So PSBL connected with VDIS 2 is mapped to PDAZ, but not to the whole auroral oval as some researchers have suggested [Eastman *et al.*, 1984; Lyons and Nishida, 1988; Lyons, 1991 and others]: PSBL is a BPS part adjacent to the CPS outer (polar) boundary [Galperin and Feldstein, 1996].

The BPS outer part exhibit some peculiarities. It contains low energy (< 100 eV) counter streaming ion and electron beams moving in opposite directions. This BPS part has been called Low Energy Layer by Parks *et al.* [1992]. LEL is mapped to the polar boundary of the PDAZ close to or at the open/closed magnetic field boundary. Thus, BPS includes both PSBL and LEL.

2. It should be noted that observed data on the equatorial arc location in the midnight sector from Yahnin *et al.* [1997] are consistent with the model from [Feldstein and Galperin, 1985,1996; Galperin and Feldstein, 1991]:

- a) the arc is located near the boundary of stable trapping for $E > 35$ keV electrons;
- b) as magnetic disturbance increases the equatorial arc shifts to lower latitudes always staying close to the STB.

The above mentioned Feldstein-Galperin model [1985, 1993, 1996] differs from that one offered by Lyons [1991,1992] by discrete forms which are mapped to the CPS [Feldstein and Galperin, 1985,1996; Galperin and Feldstein, 1991], not to the PSBL [Lyons, 1991, 1992]. These models also differ from each other by existence of the soft auroral precipitation and VDIS 2 in the night sector poleward of the auroral arcs region in the former model [Feldstein and Galperin, 1985; Galperin and Feldstein, 1991] and absence of such precipitation in the latter one [Lyons, 1991, 1992]. Moreover, according to [Lyons, 1991, 1992] the CPS is located closer to the ground from the current sheet in the magnetospheric tail, while according to [Feldstein and Galperin, 1985; Galperin and Feldstein, 1991] the CPS is located at the both sides (upper and lower) of the current sheet.

Yahnin *et al.* [1997] have discussed different authors' concepts on the discrete aurora sources location. The difference consists not only on auroral luminosity distribution but in the connection of the discrete aurora occurrence region with different plasma structures in the nighttime magnetosphere: with the PSBL according to Lyons; with the main (central) plasma sheet according to Feldstein and Galperin; with the whole plasma sheet according to Yahnin *et al.* Presented in [Yahnin *et al.*, 1997] observation data were summarized there also as a scheme. The data correlate well with the Feldstein-Galperin scheme and repeat it in many respects, namely:

- 1) the equatorial arc of the discrete aurora region is mapped by magnetic field lines to the current sheet inner boundary;
- 2) the polar boundary of the auroral precipitation region is mapped to the DNL;
- 3) the discrete form occurrence region is mapped entirely to the current sheet in the magnetospheric tail;
- 4) the suggestion about some principal difference between the *Feldstein-Galperin* and *Yahnin et al.* schemes is caused by the fact that the description of the magnetosphere tail plasma domain dynamics versus magnetic activity presented in [*Feldstein and Galperin, 1993*] has been ignored by *Yahnin et al.* [1997].

3. *Yahnin et al.* [1997] consider that stable magnetospheric convection events (SMC) are convincing examples of the discrete form location only in the polar oval high-latitude region mapping to the plasma sheet periphery. During SMC the interplanetary magnetic field is stably southward, the magnetic activity is increased (AE is ~ 300 nT), but during long time there are no pronounced substorms. Such events are very rare. During several decades of satellite observations only several time intervals with SMC have been found [*Sergeev et al., 1996*].

Let's discuss in detail the first one from the available SMC events, when the auroral luminosity data have been attracted [*Sergeev and Vorobjev, 1979*]. Figure 2a shows the aurora location along geomagnetic meridian by all sky camera data and the H-component magnetogram of Dixon Island station ($\Phi \approx 68^\circ$) on 3 December, 1973; figure 2b shows the aurora location along the Loparskaya station meridian ($\Phi \approx 65^\circ$); figure 2c shows the aurora structure scheme during SMC period. Discrete forms are marked by lines or blackened, the diffuse aurora are marked by points. It is established that the brightest auroras is permanently observed at $\Phi \approx 68^\circ-70^\circ$ northward of Dixon Island station. In figure 2a intensive luminosity near the southern horizon of this station at $\Phi \approx 64^\circ-65^\circ$ is marked by the solid line. The auroral arc existence in the near midnight sector at $\Phi \approx 64^\circ$ is confirmed by simultaneous observations at Loparskaya station (figure 2b), where the polar arc is located close to the zenith. Sometimes auroral luminosity distribution has typical for substorms large scale auroral bulge. It shows that there were weak substorms (or activation) during this SMC interval.

Thus, during this particular SMC event the discrete auroras have been simultaneously located at the polar and equatorial boundaries of the auroral oval with the most dynamic and intensive auroral luminosity being observed close to the oval polar edge. The latitudinal range between these discrete form systems was filled by diffuse luminosity. In the generalized scheme showing auroral luminosity distribution during SMC intervals (figure 2c) the equatorial arc existence has been "forgotten" while the main attention has been paid to the discrete forms in the oval high-latitude part. It has allowed to note later on that during SMC intervals discrete auroral forms exist only near $\Phi \approx 70^\circ$ and are mapped by magnetic field lines to the plasma

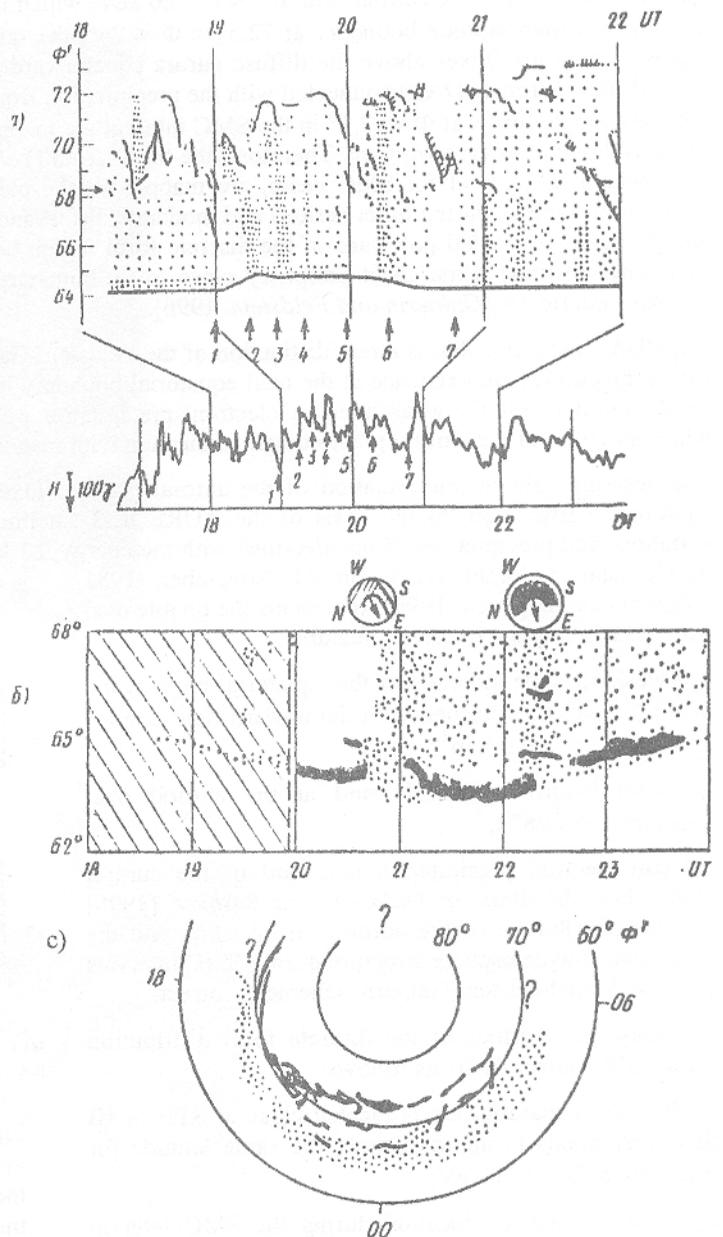


Fig.2. Aurora location at the Dixon Island station meridian and the H-component magnetogram of this station (a); aurora location at the Loparskaya station meridian (b); auroral structure scheme during steady magnetospheric convection (c) (from [*Sergeev and Vorobjev, 1979*]).

sheet periphery. In this particular case the observations suggest a different result, i.e. that discrete auroral forms are located in the auroral oval close to its polar and equatorial boundaries. In the midnight sector the auroral oval is mapped to the whole central plasma sheet from its inner boundary (the equatorial arc) to the periphery (the polar discrete forms).

Yahnin et al. [1997] have presented the data on the auroral precipitation distribution according to the NOAA-6 satellite measurements during the SMC event on 24 November, 1981. Let us consider the measurements during the pass through the late night sector (1900-2000 MLT) at 2041-2046 UT (figure 1k in [*Yahnin et al.*, 1997]).

IB practically coincides with STB and for electrons with $E > 30$ keV they both are located at $\Phi \approx 64.5^\circ$. At this boundary the energy flux of precipitating electrons with $0.3 < E < 20$ keV suddenly increases and reaches maximum of more than $1 \text{ erg/cm}^2\text{sec}$. Such electron flux has to lead to auroral discrete forms occurred close to STB. The energy flux peaks up to $10 \text{ erg/cm}^2\text{sec}$ have been recorded in the high-latitude part of the precipitation region extended to $\Phi \approx 72.5^\circ$. Thus, in this case the discrete form region is located in the range $64.5^\circ < \Phi < 72.5^\circ$.

Equatorward of the discrete auroras (IB) all-sky camera has recorded the diffuse luminosity band at $62.5^\circ < \Phi < 64.5^\circ$ with the energy flux of electrons with $0.3 < E < 20$ keV, which is lower than the instrument threshold. Poleward of the auroral oval high-latitude boundary at $72.5^\circ < \Phi < 76^\circ$, the satellite has recorded electron fluxes, which were more intensive than the fluxes above the diffuse aurora equatorward of the auroral oval. Such precipitation has to lead to weak diffuse aurora (PDAZ) connected with the precipitation from BPS. The fact of the PDAZ existence means that the auroral discrete forms at $\Phi \approx 72.5^\circ$ in the SMC interval are mapped not to the plasma sheet periphery, but much closer towards the inner magnetosphere. Therefore, the thesis from [*Yahnin et al.*, 1997] that bright auroral arcs in the auroral oval, which are typical for SMC cases, are mapped to the plasma sheet periphery is wrong. In fact, during SMC intervals, as well as during quiet periods and moderate disturbances, the soft precipitation region with low intensity and energy fluxes is located poleward of the discrete form region boundary. It is this region that is mapped by magnetic field lines to the plasma sheet periphery close to its boundary and to the distant part of the current sheet in the magnetospheric tail [*Galperin and Feldstein*, 1996].

It is PDAZ existence that is a real distinction of the Feldstein-Galperin scheme from the scheme *Yahnin et al.*, [1997]. But if the auroral arc existence at the oval equatorial boundary has been forgotten to draw in the scheme in the figure 2c, then in this case the weak intensity electrons precipitation poleward of the auroral oval, which sharply changes the whole structure of the auroral precipitation connection with magnetosphere plasma domains has been ignored.

The described above interpretation of the auroral plasma fluxes precipitating during SMC intervals has gained an additional verification on the basis of the AUREOL-3 satellite measurements. Figure 3 shows the magnetic field variations and precipitation of the electrons with the energy 0.1 keV and 1.8 keV during the auroral oval cross-section in the near midnight sector on 24 November, 1981 [*Galperin and Bosqued*, 1998]. It presents the double oval pattern including the following features:

- i) a weak arc type structure at the equatorial edge of the oval ($\Phi \approx 64^\circ$), collocated with the upward field-aligned current sheet $\sim 1.0 \mu\text{A/m}^2$;
- ii) more intensive auroral band at the auroral oval boundary ($\Phi \approx 68^\circ$);
- iii) soft electron precipitation poleward of the auroral oval. Thus, the thesis of *Galperin and Bosqued* [1998] that the distribution of the auroral precipitation and the large scale magnetosphere structure during SMC intervals agree with the Feldstein-Galperin scheme is correct.

The main peculiarities of the discrete form distribution during SMC intervals are as follows:

- 1) the most equatorial arc is located close to STB or IB that corresponds to approximately the same latitude for electrons with $E \approx 30$ keV;
- 2) the equatorial arc location during the SMC interval may vary from case to case but it always remains at the STB (or IB) boundary at the latitude $\Phi \approx 64^\circ$ that is typical for the auroral oval equatorial boundary during moderate magnetic disturbances;

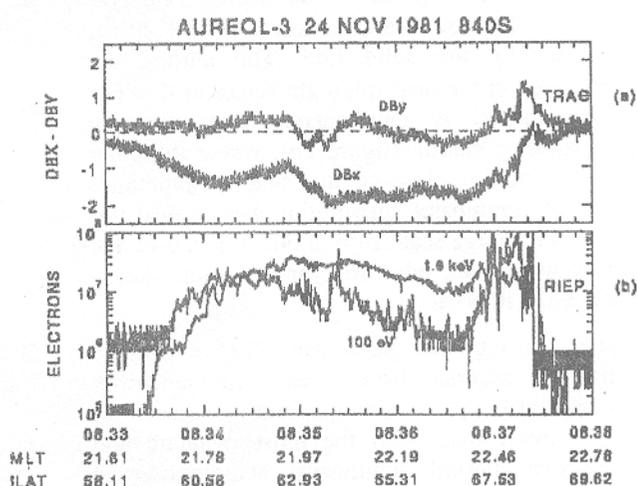


Fig.3. Overview of AUREOL-3 data for pass 840 North versus time. From top to bottom the figure shows: (a) the DC magnetic field ΔB_y and ΔB_x components (nT) measured by the TRAC instrument; (b), (c) electron and ion fluxes $(\text{cm}^2.\text{s}.\text{ster}.\text{keV})^{-1}$ in 2 separate energy channels of 0.1 and 1.8 keV (RIEP instrument), sampling rate: 320 ms (from [*Galperin and Bosqued*, 1998]).

3) the discrete forms region during SMC intervals covers a wide latitudinal range and is mapped to the substantial part of the central plasma sheet starting from its inner boundary (or from the current sheet boundary located close to it);

4) the narrow region of the soft auroral precipitation leading to red diffuse luminosity appearance is located between the high-latitudinal boundary of the SMC region with bright auroral forms and polar cap boundary.

These results do not agree with Sergeev's conclusions that the auroral discrete form region during SMC intervals is mapped exclusively far to the magnetospheric tail, to PSBL up to the distant neutral line.

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References

- Eastman T.E., L.A. Frank, W.K. Peterson and W. Lennartsson, The plasma sheet boundary layer, *J. Geophys. Res.*, **89**, 1553-1572, 1984.
- Elphinstone R.D., J.S. Murphree, D.J. Hearn et al. The double oval UV auroral distribution. 1. Implication for the mapping of auroral arcs, *J. Geophys. Res.*, **100**, 12075-12092, 1995.
- Feldstein Ya.I. and Yu.I. Galperin, The auroral luminosity structure in the high-latitude upper atmosphere: its dynamics and relationship to the large-scale structure of the Earth's magnetosphere, *Rev. Geophys. Space Phys.*, **23**, N 3, 217-275, 1985.
- Feldstein Ya.I. and Yu.I. Galperin, An alternative interpretation of auroral precipitation and luminosity observations from the DE, DMSP, AUREOL, and Viking satellites in terms of their mapping to the nightside magnetosphere, *J. Atmos. Terr. Phys.*, **55**, 105-121, 1993.
- Feldstein Y.I. and Yu.I. Galperin The auroral precipitation structure in the magnetosphere night sector (in Russian), *Space research*, **34**, N3, 227-247, 1996.
- Frank L.A. Relationship of the plasma sheet, ring current, trapping boundary, the plasmapause near the magnetic equator and local midnight, *J. Geophys. Res.*, **76**, 2265-2275, 1971.
- Galperin Yu.I. and Ya.I. Feldstein, Auroral luminosity and its relationship to magnetospheric plasma domains, in *Auroral Physics*, Cambridge UP, eds. Meng C.-I., M.J. Rycroft, and L. A. Frank, 207-222, 1991.
- Galperin Yu.I. and Ya.I. Feldstein, Mapping of the precipitation regions to the plasma sheet, *J. Geomag. Geoelectr.*, **48**, 857-875, 1996.
- Galperin Y.I., and J.-M. Bosqued, Stationary magnetospheric convection on November 24, 1981: 1. A case study of "pressure gradient/minimum B" auroral arc generation, *Ann. Geophys.*, 1998, in press.
- Gusev M.G. About bizonal structure in the auroral distribution (in Russian), *Magnetic storms and geophysical phenomena*, Yakutsk, 112-116, 1980.
- Lyons L.R. and A. Nishida, Description of substorms in the tail incorporating boundary layer and neutral line effects, *Geophys. Res. Lett.*, **15**, 1337-1340, 1988.
- Lyons L. R. Discrete aurorae and magnetospheric processes, in: *Auroral Physics*, Eds. Meng C. -I., M. J. Rycroft and L. A. Frank, Cambridge UP, Cambridge, 195-205, 1991.
- Lyons L. R. Inferences concerning the magnetospheric source region for auroral breakup, *Proceedings of the ICS-1*, ESA SP-335, 257-261, 1992.
- McDiarmid I. B. and J. R. Burrows, High latitude boundary of the outer radiation zone at 1000 km, *Can. J. Phys.*, **42**, 616-626, 1964.
- Parks G.K., R. Fitzenreiter, K.W. Ogilvie et al. Low-energy particle layer outside of the plasma sheet boundary, *J. Geophys. Res.*, **97**, 2943-2954, 1992.
- Sergeev V.A., R.J. Pellinen, and T.I. Pulkkinen, Steady magnetospheric convection: a review of recent results, *Space Sci. Rev.*, **75**, 551-604, 1996.
- Sergeev V.A., and V.G. Vorobjev, Auroral structure during developed stable convection. Researches results on international geophysical projects (in Russian), *Geomagnetic researches*, **25**, Moscow, Soviet Radio, 60-68, 1979.
- Yakhnin A.G., V.A. Sergeev, B. B. Grozhevsky and S. Vennerstrom, Magnetospheric source region of discrete auroras inferred from their relationship with isotropy boundaries of energetic particles, *Ann. Geophys.*, **15**, 943-958, 1997.