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TOPOLOGY OF HIGH LATITUDE MAGNETOSPHERE AND THE MAIN FEATURES OF AURORAL PHENOMENA

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Abstract. Processes in the plasma sheet are ordinarily considered as a source of the main auroral phenomena, including auroral substorms and storms. The reasons leading to the appearance of such point of view are summarized. Here we analyze the results of observations, which demonstrate the existence of high-latitude quasi-ring structure. Presence of this plasma structure is a clear evidence of the existence of a high-latitude continuation of ring current – the “cut ring current”. The possibility of observing the picture of upward field-aligned currents using the data of auroral oval observations is discussed. The existence of field-aligned potential drops in the upward current region is taken into account. It is shown that the analysis of the structure of magnetospheric currents allows to obtain adequate picture of transverse and field-aligned currents.

1. Introduction

2007 year was announced International Heliophysical Year (IHY). 50 years ago during the International Geophysical Year it became possible to collect the information which became the base for many later investigations and discoveries. It is possible to see analyzing this 50- years period that the development of the main approaches for the understanding of the nature of auroral substorm has the form of Hegel spiral (see Fig. 1).

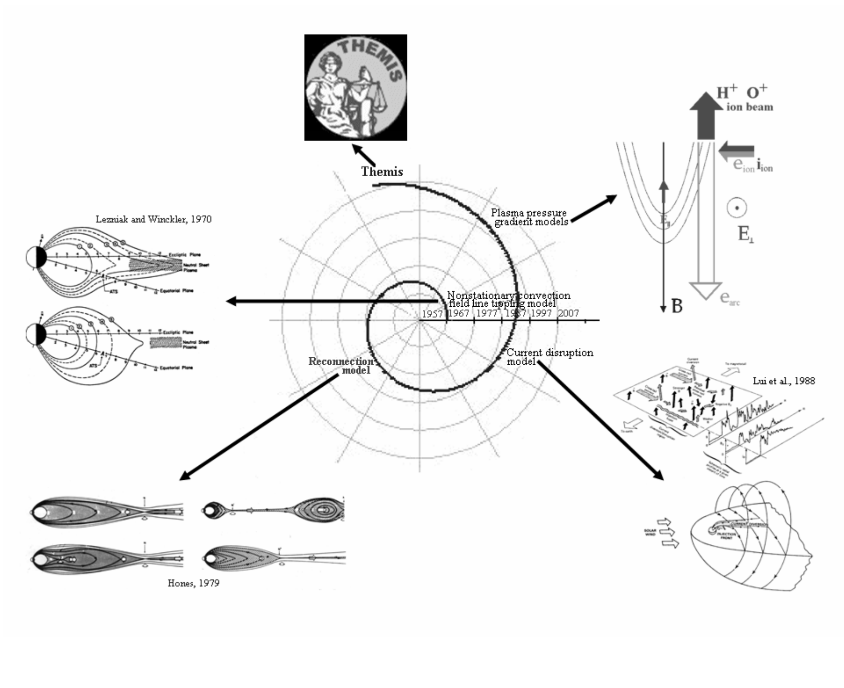

Figure 1. A scheme illustrating the development of the main ideas concerning the nature of substorm expansion phase onset

The pioneering works by Tverskoy (1969), Lezniak and Winckler (1970) were the first in which they formulated the “catapult” principle. According to this principle, particles during substorms are accelerated by inductive electric field in the transition region from dipole to the tailward stretched magnetic field lines due to the field line shortening. Therefore the development of instability at geocentric distances ~7-8 R_E was considered as a cause of substorm expansion phase onset. Existence of dispersionless injections into geostationary orbit and of injection boundary (see Mauk and Meng, 1983) can be considered as an argument supporting this point of view. The theory of substorm developed by Tverskoy (1972) described the main features of the observed phenomena. The discovery of plasma sheet and geomagnetic tail activate the attention to the processes in this region. The high level of correlation of the change of the sign of B_z component of the magnetic field in the tail and substorm expansion phase onset led to the appearance of the concept of magnetic reconnection as the cause of magnetospheric substorm (see Hones, 1979) and later numerous papers). AMPTE/CCE observations of localization of substorm expansion phase onset (see Takahashi et al., 1987) at the geocentric distances less than 9 R_E led to strong modifications of the developed approaches. It was shown that the observed phenomena were not initiated by magnetic reconnection or tearing instability occurring locally because the normal component of the magnetic field was too strong which impedes the development of magnetic reconnection or tearing instability. Later Lui et al. (1988) formulated the concept of tail current disruption. Location of substorm expansion phase onset at the quasidipole magnetic field lines and well known first auroral arc brightening at the equatorial boundary of the auroral oval lead to the appearance of other theories (see the discussion in the paper Stepanova et al., 2002) which explain the observed phenomena due to instabilities of plasma pressure distribution and field-aligned currents or velocity shear. The results obtained by Dubyagin et al. (2003) contain the support of the inner magnetosphere substorm expansion phase onset and are in a real agreement with the predictions of the theory developed by Antonova (2002), Stepanova et al. (2002). Nevertheless, the concept of tail reconnection continues to be rather popular. It is possible to hope for the solution of the problem due to the beginning of the multisatellite program Themis, with 5 satellites successfully launched February, 16 2007. One of the main goals of the program is to compare predictions of tail reconnection and inner magnetosphere substorm expansion phase models. The first types of theories predict the existence of a signal or plasma flow from the tail to the Earth, the second types – formation of a wave from the Earth to the tail. The situation is especially difficult as bursty bulk flows (BBFs) are constantly present in the plasma sheet. Therefore the probability to observe BBF in the plasma sheet 1–5 min before a substorm expansion phase onset is very high. BBF can be considered as elements of plasma sheet turbulence. Such turbulence is a constantly existing feature of the Earth's plasma sheet as it can be considered as a turbulent wake under an -obstacle formed under the conditions of very high Reynolds number ($>10^{10}$ in accordance with Borovsky and Funsten, 2003).

In this paper we analyze the main features of high latitude field-aligned current distribution and try to show that popular schemes of high latitude magnetospheric topology can be reanalyzed taking into account the results of auroral observations.

2. Bright aurora and field-aligned currents

Bright forms of aurora can not be considered as a result of plasma sheet particle precipitation. The measured plasma sheet electron distribution functions in the first approximation can be fitted with comparatively high accuracy by isotropic Maxvellian distribution. Maximal energy flux of precipitating electrons in the case of absence of field-aligned potential drop is equal (see Antonova, 1981)

$$\varepsilon^* = n_0 T_e^{3/2} / \left(\pi m_e\right)^{1/2}$$

where n_0 is the electron density near the equatorial plane, T_e is the electron temperature, m_e is the electron mass. For n_0=0.5-1 cm^{-3} and T_e=0.5 keV ε^*~0.3-0.6 erg/cm^{2}c. Such energy flux is close to the threshold of measurements of the Polar satellite (~0.5 erg/cm^{2}c). The difference of DMSP and Polar observations of aurora was analyzed by Vorobjev and Yagodkina (2007). A visually observed aurora of the I class of brightness requires 0.6 erg/cm^{2}c (Akasofu and Chapman, 1972). The existence of field aligned potential drop accelerating electrons up to ~10 keV at the altitude ~R_E leads to an order of magnitude increase of the energy flux value and to the appearance of the II class of aurora. Nevertheless, polar aurora of the III and IV class can not be created by accelerated magnetospheric electrons with energies 1-10 keV. They are produced by accelerated till 1-2 keV dense (with density ~10^2-10^3 cm^{-3}) electrons of ionospheric origin. Accelerated electron beams produce the upward field-aligned current. That is why the existing picture of polar aurora simultaneously represents the distribution of upward field-aligned currents.

The analysis of auroral imager observations allows to select two main systems of auroral structures corresponding to upward field-aligned currents (Chua et al., 1998; Shue et al., 2002). The first system corresponds to the upward Region 1 and Region 2 current systems of Iijima and Potemra (1976). Fig. 2 contains the comparison of Iijima and Potemra (1976) picture (right part of the figure) and results of Polar UVI observations 10 February 1997. The nightside gap in this picture is filled with auroral structures during substorms. Fig. 3 illustrates this feature. It contains the results of Polar observations carefully analyzed by (Shue et al., 2002). The field-aligned current configuration in the nightside gap region is now extensively debated.

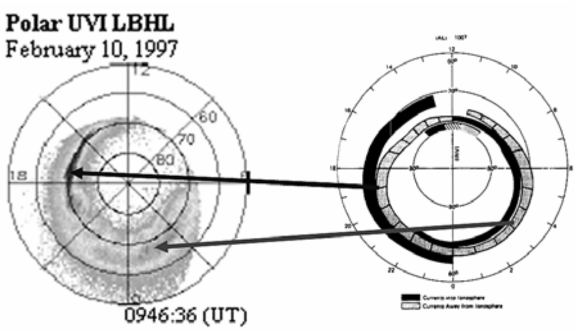

Figure 2. Comparison of Iijima and Potemra field-aligned currents picture with Polar UVI observations

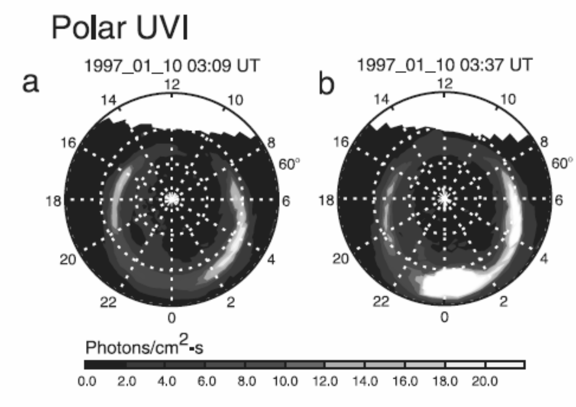

Figure 3. Polar UVI auroral structures 01.10.1997

3. Auroral observations and magnetospheric topology

It is frequently believed that auroral oval is a result of plasma sheet mapping into ionospheric altitudes. It is easy to understand this point of view analyzing Fig. 3. The bright auroral forms have a horse shoe like structure. At the same time the dayside gap is filled with less intense aurora. Previous studies of plasma sheet structure mapping into ionospheric altitudes also supported this point of view. For example, Fig. 4 shows the results of straight line *X*=const mapping into ionospheric altitudes (Stasiewicz, 1991) using Tsyganenko-87 model. It has a quasiring form. It is necessary to say only that daytime part of the ring must be a result of low latitude boundary layer mapping.

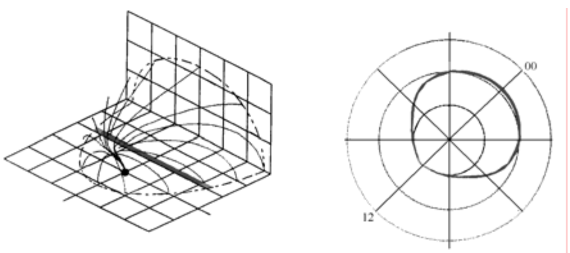

Figure 4. Results of *X*=const mapping on the auroral altitudes (Stasiewicz, 1991)

Even the first observations of auroral oval recognized it as a closed quasiring structure. Picture of DMSP observations of Newell and Meng (1992) contains plasma sheet particle precipitations coming from a region situated to the equator from the low latitude boundary layer. This picture was improved by Starkov et al. (2002). The latest results of Yagodkina and Vorobjev (2004) show the closed loop structure of plasma sheet precipitations under all geomagnetic conditions. These investigations support the early picture of plasma sheet plasma structure (see Fig. 5 reproducing Fig. 9.1 from the book Models of Space, 1973) and means the existence of quasiring transverse magnetospheric current in the region of quasitrapping (see the review Antonova, 2004) named by Antonova and Ganushkina (2000) a cut ring current.

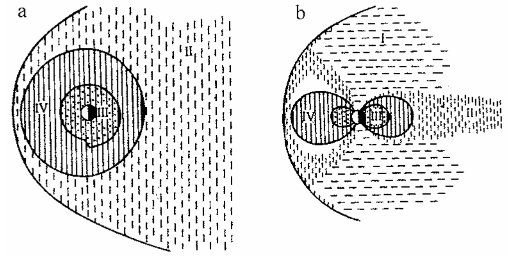

Figure 5. Distribution of charged particles in the magnetosphere of the Earth in accordance with Models of Space (1973). a – equatorial cross section, b –meridian cross section

The analysis of particle spectra in the Region 1 field-aligned currents show that sources of the most part of such currents can not be localized in the magnetospheric boundary layers as it was postulated in the popular picture of magnetospheric current structures (see Kivelson and Wolker, 1995; De Keyser et al., 2005). The field-aligned current configuration (see Fig. 2,3) and the results of electron spectra analysis show that Region 1 currents are mapped into the analyzed quasiring structure around the Earth. The improved picture of magnetospheric current structure is shown in Fig. 6. Using this picture it is only necessary to take into account the high level of magnetic field fluctuations.

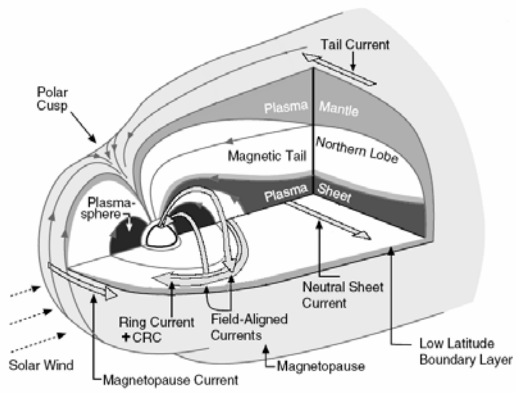

Figure 6. The improved structure of the main magnetospheric currents

4. Conclusions and discussion

The results of our analysis show that the picture of auroral brightening can be used for the investigation of the upward field-aligned current distributions. Observations from auroral imagers give global information, ground-based observations – local picture of upward field-aligned currents with high temporal and spatial resolution. The obtained information is important for the solution of the problem of field-aligned current generation. The reanalyzed picture of magnetospheric current structure shows the generation of Region 1 currents of Iijima and Potemra due to the divergence of transverse currents in the quasiring high latitude continuation of the plasma sheet.

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