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FIRST AURORAL ARC BRIGHTENING AND MAGNETOSPHERIC SUBSTORM

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Abstract. Results of observations of substorm expansion phase onset are analyzed. The main features of substorm expansion phase onset are the auroral brightening at the equatorial boundary of auroral oval and beginning of equatorial magnetic field depolarization and Pi2 onset ~1 min after the first auroral arc brightening. Results of observations are compared with theoretical predictions. It is shown that observed substorm features create the real limitations on the possible scenario of substorm expansion phase onset. The development of quazielectrostatic instability can explain the time delay between first auroral arc brightening and magnetic disturbance leading to magnetic field line dipolarization and intensification of geomagnetic micropulsations. The process of auroral arc brightening is analyzed. The formation of powerful beam of electrons at the boundary of inverted V structure is selected as the most probable mechanism of bright aurora formation during substorm onset. The role of particle beams in the magnetospheric electrodynamics is discussed.

1. Introduction

The mechanism of substorm expansion phase onset continues to be one of the unsolved problems of the physics of the magnetosphere. During the last 40 years, numerous investigations were concentrated on the solution of this problem. In particular, realization of multi satellite projects such as Interball, Cluster and Themis have provided new interesting information about substrom development. Despite of this effort, the substorm expansion phase onset mechanism continues to be under debate. The main attention is concentrated now on the selection between the inside-out and outside-in models.

First auroral arc brightening at the equatorial boundary of nightside auroral oval in accordance with outside-in models is connected to first near Earth neutral line (NENL) formation in the midtail region and earthward flow braking. In the inside-out model tail current disruption takes place in the near-Earth region, which launches a rarefaction wave tailward. Nevertheless, the outside-in scenario has significant obstacles. First of all, plasma sheet is rather turbulent region (see reviews of Antonova [2002a], Borovsky, and Funsten [2003]). Bursty bulk flow (BBF) are the most pronounced features of such turbulence (see Angelopoulos et al. [1993]). The probability to observe BBF in the plasma sheet 1–3 min before the substorm expansion phase onset is very high. Therefore, any observation of fast plasma flow to the Earth before substorm expansion phase onset can not be considered as a proof of first auroral arc brightening without corresponding auroral observation demonstrating the existence of some disturbance in auroral arc system to the pole from most equatorial arc 1-5 min before its brightening. Results of ground based and satellite observations does not reveal the existence of such disturbance (see Frank and Sigwarth [2000], Mende et al. [2007], Kornilov et al. [2008]). Such arguments show that the inside-out models are more probable.

In this paper we analyze some features of one of inside-out scenarios suggested by Antonova [1993, 2002b], Stepanova et al. [2002] and try to show that it gives the possibility to obtain the self consistent picture of observed phenomena during isolated substorm. We also put attention on practically not discussed features of near Earth dynamics connected to the existence of powerful ion beams from the ionosphere to the magnetosphere.

2. Plasma flow before substorm expansion phase onset and magnetic disturbances

Substorm expansion phase theory developed by Antonova [1993, 2002b], Stepanova et al. [2002] is based on the analysis of the stability of azimuthal plasma pressure gradients. Such gradients were considered as a source of large-scale and middle scale field-aligned currents. It was known, that first auroral arc brightening takes place before the beginning of Pi2 micropulsations and magnetic field line dipolarization (see Liou [2000]). Therefore, quasielectrostatic instability was analyzed. It was shown, that the instability has a threshold connecting to the field-aligned current density. It was obtained that the increment of the instability in the upward field-aligned current region is much larger than the increment of the instability in the downward current region. Theory predicted the appearance of fast local plasma flow ~1-5 min before first auroral arc brightening and localization of such disturbance in the region of maximal upward field-aligned current density. Stepanova et al. [2000] showed that the system of multiple inverted V structures has pronounced equatorial asymmetry during growth phase of isolated substorm. The most equatorial inverted V is the most powerful one. Upward field-aligned current is concentrated in inverted V structures. Therefore, the most equatorial inverted V structure can be selected as the most probable place of analyzed instability development. Results of radar observations (see Bristow et al. [2003]) demonstrated the appearance of enhanced plasma flows ~5 min prior to the most equatorial auroral arc brightening near this arc. Such feature can be considered as the support of theory predictions.

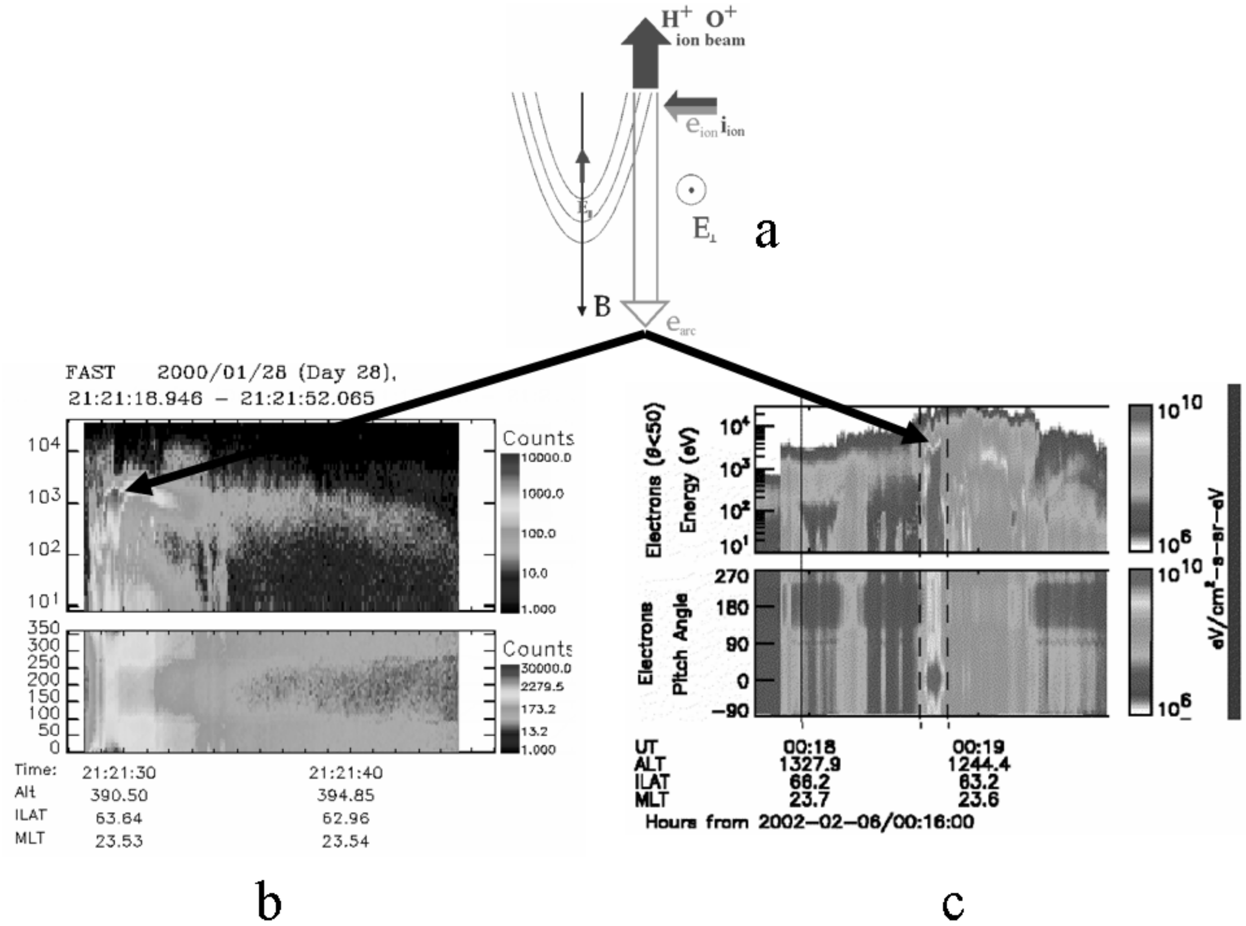

Fig. 1. Comparison of theory predictions with the results of Fast observations. (a) is the scheme of first auroral arc brightening, (b) and (c) are the results of Fast observations at the moment of substorm expansion phase onset 28 January 2008 (Dubyagin et al. [2003]) and 6 February 2002 (Mende et al. [2006]).

3. The process of first auroral arc brightening

One of the main predictions of Stepanova et al. [2002] analysis is the first auroral arc brightening due to the formation of thin anisotropic electron beam at the equatorial boundary of auroral oval. Such beam is formed due to the penetration of cold ionospheric plasma inside the region of field-aligned potential drop at the boundary of most equatorial inverted V structure. Fig. 1a shows the scheme of such process (Stepanova et al. [2000]). Nevertheless, very good spatial and temporal satellite resolution has been required to observe this feature. It was done using the Fast satellite observations in the moment of first auroral arc brightening (see Dubyagin et al [2003], Mende et al. [2006]), shown in Fig. 1b,c. As can be seen, powerful anisotropic electron fluxes are observed at the equatorial boundary of inverted V structure in the moment of substorm expansion phase onset. The energy of electrons in the observed anisotropic powerful electron beam does not exceed the energy of magnetospheric electrons, accelerated in the nearby inverted V structure. Such feature is difficult to understand using traditional explanation of anisotropic electron beam particle acceleration by oblique Alfven waves. Particle fluxes are larger than 10^{10} particles/cm^{2}s. Such intensity can be connected only to the acceleration of dense electrons of ionospheric origin.

4. Ionospheric ion beams and field line stretching

The role of ionospheric ion source in the magnetospheric electrodynamics is poorly studied till now. It is recognized only that ionospheric oxygen ions can have great contribution to the magnetospheric ion population during magnetic storms. Nevertheless ion fluxes from the ionosphere can be an important factor of magnetospheric electrodynamics not only during magnetic storms.

Field aligned potential drop producing acceleration of electrons in the inverted V structure also accelerates ions from the ionosphere to the magnetosphere till ~10 keV energies. Such ion beams were observed many times at the auroral field lines (see, for example, Mozer et al. [1980], Mozer and Hull [2001]). Downward electron flux at the boundary of inverted V structure produced in accordance with scheme on Fig. 1a has the intensity $>10^{10}$ $sm^{-2}s^{-1}$. The same upward ion beam is formed. Such beam can considerably change flux tube density. For example, empty flux tube at *L*~7-8 will be filled by ionospheric ions till ion density ~1 cm^{-3} for 2-4 min. Therefore, it is not possible to ignore the role of ionospheric ion beams in the substorm flux tube volume electrodynamics.

One of not well explained feature of substorm dynamics is the field line stretching before the substorm expansion phase onset. Ohtani et al. [1992] selected two stages of antisunward stretching of the tail field (see Fig. 2b). During the conventional growth phase the current intensity continues to increase gradually during 0.5-1.5 h time period. The explosive enhancement in the transverse current intensity during a short interval just prior to the current disruption is observed. This phase of current growth was named the explosive growth phase. The duration of this distinctive interval is typically ~1 min, much shorter than that of the conventional growth phase (see Ohtani et al. [1992]). It also became clear (see Sergeev et al. [1993], Yahnin et al. [2002]) that the formation of thin current sheet imbedded in the region of more thick plasma sheet is observed in the near tail region. Unfortunately, the forms of particle distribution functions in thin current sheets are not clear till now. However, the existing theories of thin current sheet formation (see Kropotkin et al. [1997], Zelenyi et al. [2002], ets.) predict the sharp ion anisotropy inside thin current sheet. Necessary for the formation of thin current sheet ion anisotropy at the geocentric distances $\leq 10R_E$ in accordance with Fig. 1a is possible to create taking into account the existence of field-aligned potential drop and upward ion acceleration.

Formation of thin electron beam at the boundary of inverted V structure ~1 min before the beginning of substorm dipolarization means the formation of corresponding very intense thin ion beam from the ionosphere to the magnetosphere. It is natural to connect the appearance of such beam to the explosive growth phase of substorm. Fig. 2 illustrates discussed processes. It is necessary to mention that field-aligned ionospheric ion beam instabilities and beam particle crossing the equatorial region, where the magnetic field lines can have large curvature, can lead to ion beam isotropization. In such a case the increase of plasma pressure in the flux tube can be a consequence of field line stretching (due to interchange like motion development). However, such process is not investigated until now and will require attention in the future.

Very intense anisotropic ion beam, connected to brightening arc, probably produce very unstable plasma configuration. Different instabilities can be developed. Instabilities related to magnetic configuration, lead to the appearance of intense electric and magnetic field fluctuations and all effects traditionally studied in the frame of current disruption models (irregular geomagnetic micropulsations, field line dipolarization). Such events will appear ~1 min after first auroral arc brightening.

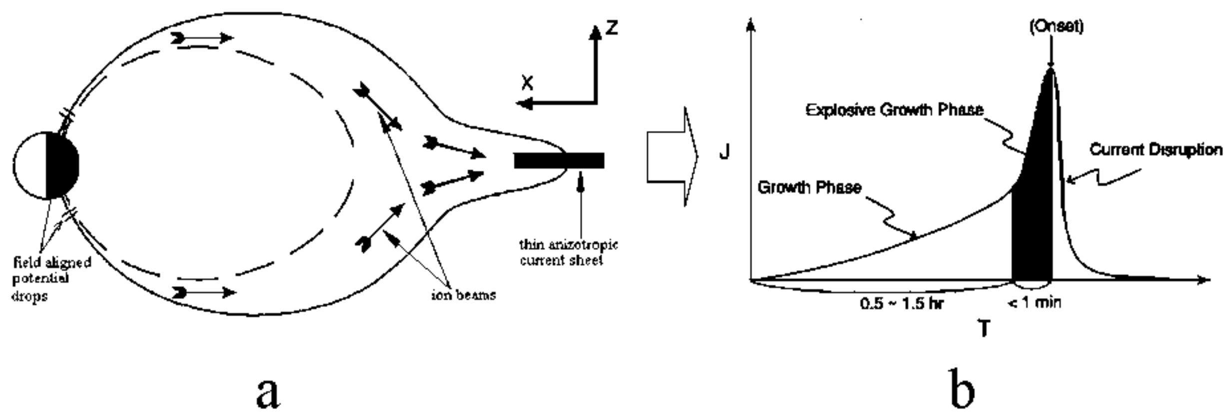

Fig. 2. Schemes illustrating the role of ionospheric particle beams for the field line stretching before the substorm expansion phase onset. (a) is the cartoon illustrating thin current sheet formation, (b) is the scheme of the change in the tail current intensity of Ohtani et al. [1992].

5. Conclusions and discussion

We select some features of substorm expansion phase onset which seems have been overlooked or have not been implemented by the more popular existing models. Naturally, all discussed substorm expansion phase features require additional study using ground based and satellite observations. It can be done using data of modern satellite projects. In any case, it is necessary to take into account that ionospheric particle beams can be an important constituent of plasma configuration in the region of substorm expansion phase onset.

Traditionally discussed mechanism of tail current growth during substorm growth phase requires the increase of the whole near Earth tail current. The main feature of discussed theoretical approach is rather limited longitude and latitude localization of isolated substorm processes. It does not require the change of the magnetosphere as a whole. The analysis gives the possible to explain large field line stretching and dipolarization in the longitudinally selected sector of the nighttime magnetosphere.

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