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DISCRETE AURORAL ARC DYNAMICS IN THE BULGE REGION AT THE BREAKUP AS OBSERVED AT HIGH-LATITUDE STATION LONGYEARBYEN

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Abstract. We present the results of an investigation of the auroral discrete arc motion during the expansion phase of a substorm, as observed at high-latitude station Longyearbyen (geographical latitude 78,20). All-sky camera data recorded during the period of 4 years (1996,97,98,99) were analysed. It turned out, that at high-latitudes the dynamics of discrete arcs had the following tendency: while the polar boundary of auroral oval jumped polewards, almost all separate discrete arcs moved equatorward after their formation. This result confirms the new theory of auroral arc generation presented by Semenov et. al. According to this theory auroral arcs are caused by the arrival of shock waves into the ionosphere. These shock waves are generated during reconnection pulses in the magnetotail current sheet. This model predicts the same dynamics of discrete aurora at high latitudes, as observed in Longyearbyen.

1. Introduction

In this article we present experimental illustration of a recently suggested mechanism for interpreting the observed dynamics behaviour of the aurora during the expansion phase of a substorm [*Semenov et al.,* 1999]. Structure and dynamics of auroral arcs have been extensively studied [*Kornilova et al.*, 1996; *Elphinstone,* 1996; *Nakamura et al*., 1993], and common features are well known, so here we present a short information. It is known that substorm onset coincides with the rapid poleward jump of an auroral arc [*Akasofu*, 1965, *Sergeev and Tsyganenko*, 1980]. The poleward auroral expansion is realised as successive formation of new auroral arcs ~50-100 km poleward of the previously activated arcs [*Sergeev and Yahnin*, 1979; *Kornilova et al*., 1996]. The typical time between the formation of poleward arcs is 1-3 min [*Sergeev and Yahnin,* 1979]. The lifetime of these newly formed arcs ranges from 1 to 10 min. After their initial activation and deformation, auroral arcs often drift equatorward. Furthermore, the arcs observed during the breakup have a small-scale complicated structure [*Atkinson et al*., 1989; *Kornilova et al.*, 1996]. The discrete auroral activations are associated with precipitating electron fluxes peaked at energies between 1 and 10keV [*Evans,* 1968], they are placed in the region with upward field-aligned currents [*Bythrow and Potemra,* 1987], and in auroral field lines at the distance of *(1-3)* R_E upward to the ionosphere there exists a region with a field-aligned potential drop [*Mozer,* 1981]. Additionally, according to the latest experimental observations, there is in fact a 1-2 min delay between the onset of reconnection in the magnetotail and the appearance of auroral arcs in the ionosphere [*Petrukovich et al.,* 1998; *Shiokawa et al.,* 1998]. Now the common point of view on auroral arc appearance is that an arc is the result of two processes: the generation process of plasma flow in the magnetotail and the electron acceleration process in the near-Earth region of the magnetosphere [*Borovsky,* 1993].

The expansion phase of the substorm can be explained in the terms of the onset and subsequent enhancement of magnetotail reconnection. The reconnection model is built on the hypothesis that magnetotail reconnection is central to the development of a substorm, and that the auroral breakup observed at substorm onset is associated with processes which occur in the vicinity of the near-Earth X-line [*Hones,* 1984; *Atkinson et al.,* 1989; *Pudovkin and Semenov,* 1985; *Baker et al,* 1996]. In this model the polar boundary of the auroral oval is an ionospheric projection of the X-line produced by charged energetic particles directly accelerated in the diffusion region. Discrete arcs observed in this region are believed to be connected with separate pulses of the reconnection near the X-line [*Sergeev et al*., 1987]. There are some major difficulties associated with reconnection model, for example, this model can not explain the fine-structure of aurora motion and can not explain the time delay between the expansion phase onset in the magnetotail and in the ionosphere. We have modified the reconnection model and took into account the shock wave propagation in the tail.

2. Shock wave model of auroral substorm

In our model, auroral arcs are interpreted as the ionospheric manifestation of upward field-aligned currents, induced by shock waves generated at the X-line in the magnetotail current sheet. The delay between the onset of reconnection and the appearance of discrete arcs can then be explained in terms of the finite propagation speed of the shock waves as they travel from the reconnection site in the magnetotail into the ionosphere.

We suppose that reconnection is initiated through an abrupt drop of plasma conductivity inside the diffusion region, accompanied by the appearance of a dissipative electric field $E^*(t)$. In the process, non-linear shock waves are generated and they propagate along the magnetic field lines at the local Alfven speed, $V_A(z) = B_0 \big/ \sqrt{\mu_0 \rho(z)}$.

In this case, the resulting auroral dynamics depends upon the non-uniform nature of plasma medium through which the waves propagate. To predict the resulting arc dynamics, we have analysed the way in which shock wave fronts are changed as they travel from the X-line to the ionosphere. In this analysis we take into account the non-uniform number density n in the magnetotail [*Sergeev et al.,* 1980]: observations indicate that $n = 2\,cm^{-3}$ in the central part of the current sheet, and $n = 10^{-2}\,cm^{-3}$ in the tail lobes, so that there is a strong gradient of the number density perpendicular to the current sheet. Therefore the local Alfven speed has a strong gradient, so that the speed at which the shock fronts propagate depends on the distance from the magnetotail current sheet.
To illustrate this idea we have, in the article [*Semenov et al.,* 1999], considered a simple model consisting of a two-dimensional current sheet configuration and found that the location and shape of shock fronts can be derived from an equation of the form:

$$x(z,t) = V_A(z)[t - t_{rec}(z)],$$

where $t_{rec}(z)$ is the time elapsed since the onset of the reconnection for the field line marked by the value of z.

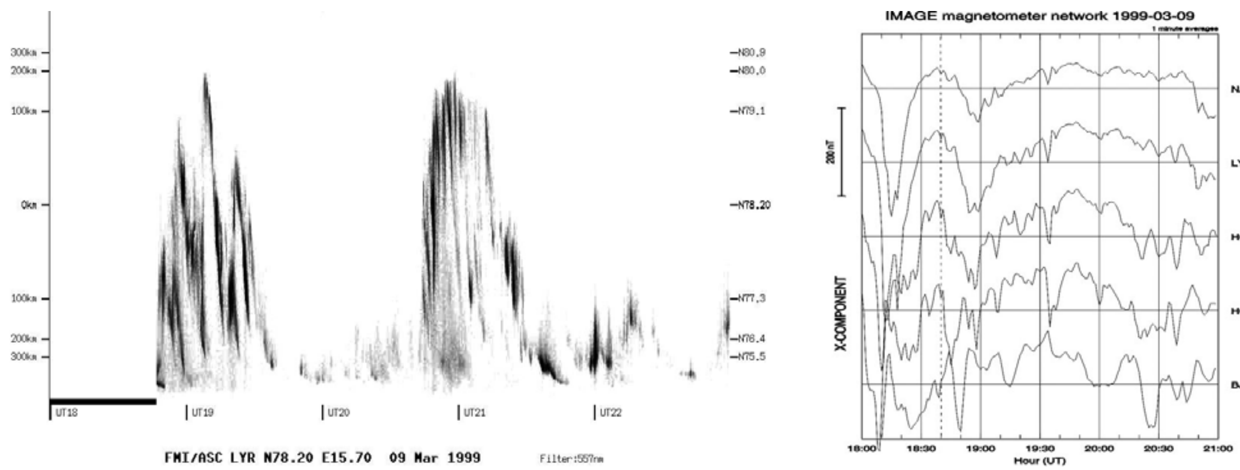

Fig. 1 Auroral breakup recorded at Longyearbyen on the 09th March 1999 at 18:40 UT. Left panel is a keogram of this event: the horizontal axis is the time and the vertical axis is the geographical latitude. Right panel is a magnetic field variation in H (X) component traces from high-latitude stations at 1 min resolution. The vertical dashed line indicates the auroral breakup onset.

To examine how the dispersion of the shocks affects the corresponding motion of auroral arcs, we have set *x(z,t)* equal to a constant value, corresponding to the distance between the X-line and its ionospheric projection, and then differentiated the above expression to obtain the following equation for the north-south component of the arc velocity, U_{arc}:

$$U_{arc} = \frac{dz}{dt} = \left(\frac{dt_{rec}}{dz} - \frac{1}{V_A} \frac{dV_A}{dz} \Delta t \right)^{-1},$$

where $\Delta t = t - t_{rec}$ is the time it takes to travel from the X-line to the ionosphere. From this expression we can see that auroral arc velocity can be positive (this means that arc drifts to the north) or negative (this means that arc moves to the south) and aurora dynamics is dependent on three parameters: the gradient of the Alfven speed in the magnetotail, the position of the X-line, and the behaviour of the reconnection rate (t_{rec} connects with reconnection rate). If two parts of the above expression are equal, this means that auroral arc remains in one place. In the next section we plan to check how aurora motion depends on the X-line site in the magnetotail.

3. Observations of breakups at station Longyearbyen

We have investigated all-sky camera data from high-latitude station Longyearbyen (geographical latitude 78.2) for 4 years – 1996, 1997, 1998, 1999 - and found several events of breakup activations. The data were taken through a narrow bandpass filter (557.7 nm - ie. green line) with 20 seconds resolution. To identify the substorm phases we have used IMAGE magnetometer network data. The all-sky data are not very good, sometimes it was cloudy, sometimes the data were not available, so we have found 9 clear events of auroral breakup. We have found the following events: 1996/12/22, 23.00-23.14 UT, 00.13-00.32 UT; 1997/01/02, 21:20-21:35 UT; 1997/01/04, 00:10-00:25 UT; 1997/01/12, 19:35-19:43 UT, 20:10-20:15 UT; 1997/01/21, 18:00-18:20 UT; 1999/02/19, 18:10-18:27 UT; 1999/03/09, 18:40-19:00 UT.

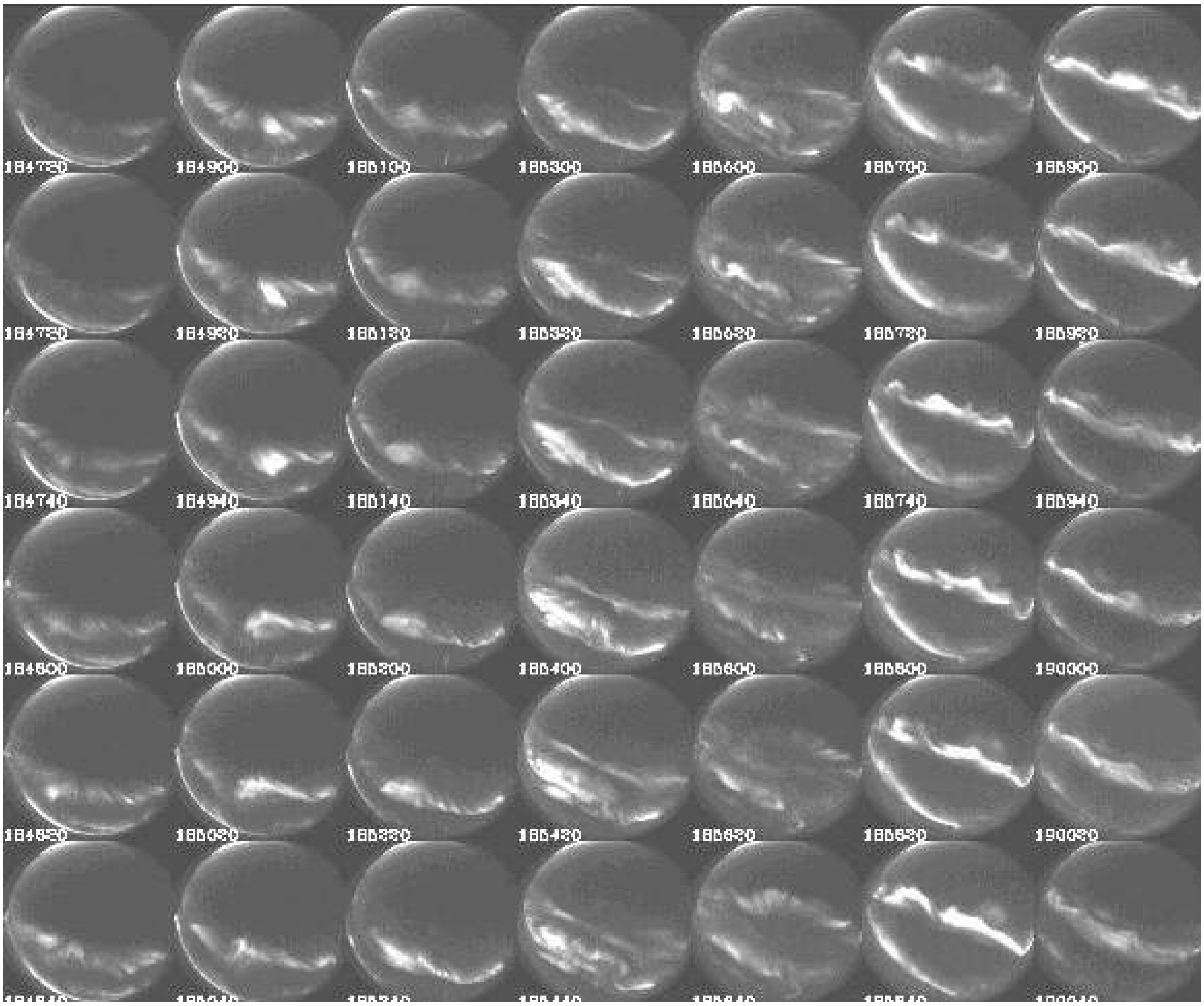

Fig. 2 Frames of all-sky camera presenting evolution of auroral breakup in course of time. This panel plotted for breakup observed at station Longyearbyen on the 09th March 1999 at 18:40 UT. Time of first frame is 18:47 UT, time of last frame is 19:01 UT. Time interval between subsequent images is 20 seconds.The time rises from top to bottom. One can see that during breakup almost all new arising arcs move equatorward.

We consider here in detail one event observed on the 9th March 1999 at 18:40 UT as a typical case of aurora activations during the breakup. The keogram for this case is presented in the left panel of figure 1. We can see a jump of auroral oval polar boundary to the north at 18:40 UT. The magnetograms (the right panel of figure 1) shows a sharp breakup onset at 18:40 UT (negative bay is 200 nT at station Longyearbyen) and the following development of a large perturbation in the magnetic field, so the observed arcs take place during the expansion phase of the substorm. Subsequent all-sky camera frames for this event are presented in figure 2. We can see that during expansion phase some new arcs appear at 18:47, 18:53,18:57 UT, new arcs emerge at higher latitudes than the previously activated arcs. After their formation, arcs move equatorward with small velocity and disappear with time. As we said, we present a typical case – all aurora activations which we investigated show the same behaviour, discrete arcs during the breakup move equatorward and the polar boundary jumps to the north because of the formation of new arcs poleward of previous arcs.

4. Conclusions

In this paper we present an experimental evidence of validity of the shock-wave model of auroral breakup. According to this model, the auroral discrete arcs are the ionospheric manifestation of upward field-aligned currents, induced by shock waves generated during the reconnection pulse in the vicinity of an X-line in the magnetotail current sheet. In this model the dynamics of arcs depend on three parameters: the gradient of the Alfven speed in the magnetotail, the site of reconnection in the tail and the behaviour of the reconnection rate. In details, if the reconnection line site is at the distant tail and the shock wave propagates from the X-line to the ionosphere dring a long time, the wave front has a large deformation and with great probability we could expect to see an equatorward moving discrete arc in the ionosphere. This supposition we have checked out. For this purpose we are investigated the aurora dynamics during breakups at high-latitude station Longyearbyen for four years. Our study shows that at high latitudes the equatorward moving arcs during a breakup are observed very frequently.

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