"Physics of Auroral Phenomena", Proc. XL Annual Seminar, Apatity, pp. 27-29, 2017

Polar Geophysical Institute

ON THE OCCURRENCE OF PERIODIC AURORAL ARC RESTRUCTURING BEFORE SUBSTORM ONSET

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Abstract. We show that periodic arc restructuring manifesting as repetitive poleward excursions of auroral arcs 3-15 min before T_0 is typically observed at the location of subsequent substorm onset by the precise optical data of Lovozero, Loparskaya, Tumanny and Gillam. This feature can be explained by an apparent latitudinal motion of the phase of oscillations inside Alfvénic field-lined resonance layer (FLR) conjugate to the onset arc. However, to claim that the occurrence of the FLR is the necessary condition of substorm initiation, one should explain the lack of such restructuring in other events. Here, by investigating statistically the presence or absence of arc restructuring depending on substorm intensity characterized by the value of magnetic bay, as well as on the amplitude of the associated Alfvénic (flapping) fluctuations in the boundary plasma sheet, we test the possibility that for weak events the field-aligned currents inside the corresponding Alfvén resonance layer may be not sufficient to produce the optical effect under study.

A transition to substorm explosive phase is a longstanding complicated problem. Among numerous scenarios of this phenomenon, there is one in which the preonset arc is associated with the Alfvén resonance [*Southwood*, 1974; *Chen and Hasegawa*, 1974; *Samson*, 1992; *Rae et al*., 2014] that occurs at the location of subsequent substorm onset. In our view, within this scenario the main optical signatures of substorm initiation can be reasonably explained. Among these features there are (i) narrowing and brightening of the preonset arc as a manifestation of resonance narrowing and resonant Alfvénic (flapping) oscillations growing in time [*Greenwald and Walker*, 1980]; (ii) periodic auroral arc restructuring 3-15 min before T_0 (the periods are 1-3 min) as a manifestation of apparent phase propagation within the Alfvén field-line resonance layer (FLR) [*Wright et al*., 1999]; (iii) the appearance of the fine structure in the preonset arc (auroral breakup onset) as a manifestation of resonance transfer to the nonlinear stage *[Rankin et al*., 1995]. Whatever is the mechanism of further substorm development [e.g., *Lui and Murphree*, 1998], the ultimate cause of cross-tail current diversion to the ionosphere in the suggested scenario are resonant oscillations that grow in time, reach large amplitudes and spoil the cross-tail conductance in the magnetospheric current sheet along the onset arc.

In this study we investigate the above point (ii) in more detail in order to clear up if the occurrence of Alfvénic resonance is the necessary condition of subsequent explosion onset. For this purpose, we compare substorm events with and without optical signatures of apparent phase propagation within the resonance layer before T_0.

A representative event, where periodic auroral restructuring is clearly seen ~ 3 min before T_0 by filtered optical observations in LOZ, is shown in Fig. 1. The time T_0 is identified as the beginning of full-scale auroral poleward expansion.

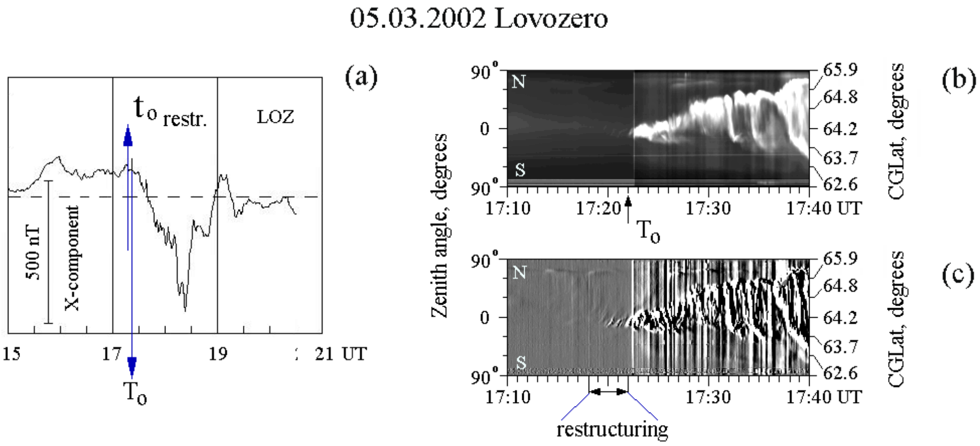

Figure 1. Magnetic X-component (**a**) from LOZ (LOZ, 64.2^0, 114.4^0 CGM coordinates, MLT = UT + 2.6 h), original (**b**) and filtered (**c**) N-S keograms constructed by all-sky auroral observations at LOZ station for the event of 5 March, 2002; $t_{0\ restr}$ and T_0 signify the moments of the restructuring and magnetic bay onset, respectively.

An event where periodic auroral restructuring before T_0 is not observed by optical data is illustrated in Fig. 2. Our working hypothesis was that an apparent latitudinal motion of the phase of oscillations *always* occurs inside Alfvén field-lined resonance layer. However, in the case of weak events the associated field-aligned currents may be not sufficient to produce the optical effect of periodic auroral restructuring before T_0.

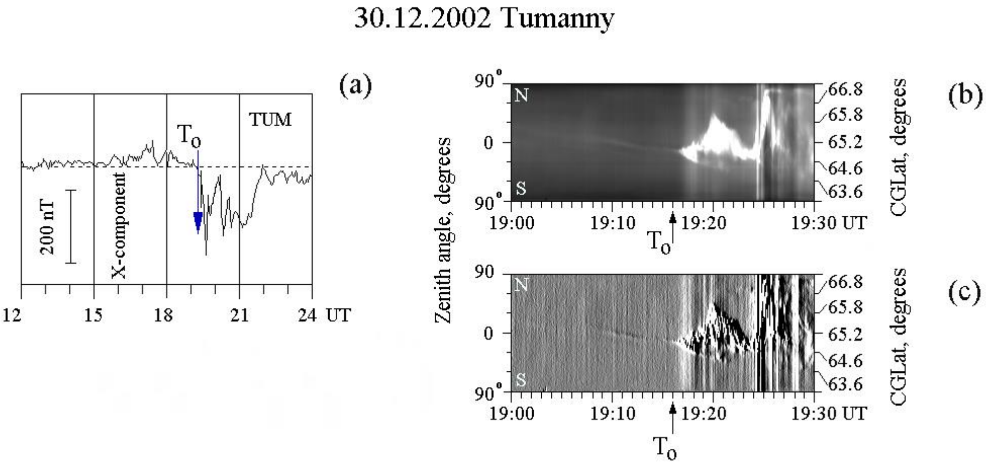

Figure 2. The same set of data as in Fig. 1 but for substorm on 30 December 2002, as observed at Tumanny station (TUM, 65.2^0, 115.9^0 CGM coordinates).

First, as a characteristic of the 'strength' of event, we used the value of magnetic bay observed after T_0 by the ground-based magnetometers, meaning that fluctuations inside a 'strong' Alfvén resonance must spoil the conductance in the magnetospheric current sheet more readily and thus divert more of the cross-tail current into the ionosphere. While, indeed, the average value of magnetic bay (~ 230 nT) for 13 substorms, where there were periodic auroral restructuring before T_0, appeared to be somewhat larger than that (~ 186 nT) for 6 substorms lacking the auroral restructuring before T_0, the discrepancy was not so large.

Then, a more precise analysis has been performed consisting in a direct comparison of the amplitude of Alfvénic (flapping) fluctuations in the boundary plasma sheet before T_0 (those presumably connected to the FLR) by in situ spacecraft measurements with the presence or absence of conjugate auroral restructuring in the ionosphere.

In the event of 05 March 2008 shown in Fig. 3, the auroral restructuring before T_0 took place (Fig. 3b) and was associated with fluctuations in the boundary plasma sheet observed by THEMIS P3 (THD) spacecraft (Fig. 3c). The amplitude of fluctuations in the magnetic Bx component was as high as 7-10 nT. The Alfvénic (flapping) nature of those fluctuations was previously demonstrated by *Kornilov et al.* [2015]. Note that the period of auroral restructuring (~ 2-3 min) in the ionosphere (Fig. 3b) is close to the period of the field oscillations in the plasma sheet (~ 2 min at 05:57-06:04 UT, Fig. 3c).

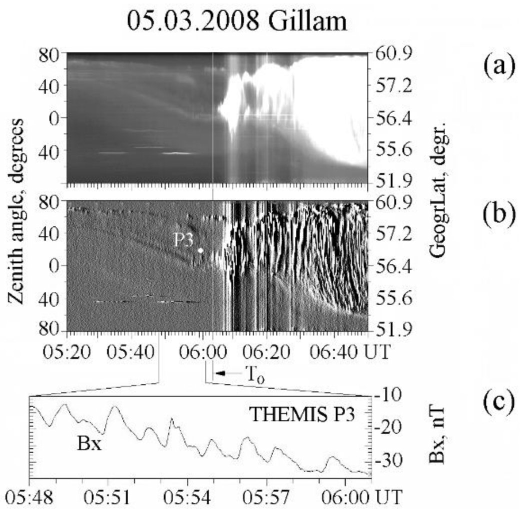

Figure 3. Original (**a**) and filtered (**b**) N-S keograms constructed by all-sky auroral observations at Gillam station (GILL, 66.18^0, 332.78^0 GM coordinates) for the event of 5 March, 2008 and (**c**) conjugate magnetic field Bx-component measured by THEMIS P3 probe in the boundary plasma sheet. In Fig. 3b the P3 footprint at 110 km altitude obtained by T96 model and designed to the central meridian of the GILL camera field of view is indicated by circle.

We note that the fluctuations in the Bx component measured by THEMIS P3 probes (Fig. 3c) are connected with the vertical (flapping) motions of the boundary plasma sheet due to gradient in the Bx component directed from the equatorial plasma sheet to the lobe inside the FLR layer. In the case of the presence of auroral restructuring before T_0 (Fig. 3b) there were significant magnetic oscillations in the plasma sheet (7-10 nT in the Bx component).
On the contrary, in the substorm event on 15 March 2009, where no auroral restructuring before T_0 was indicated by optical observations (Fig. 4b), there were no pronounced oscillations in the plasma sheet, as suggested by conjugate in situ observations of THEMIS P2 (THC) probe (Fig. 4c). Thus the amplitude of associated Bx-oscillations did not exceed 2 nT (Fig. 4c).

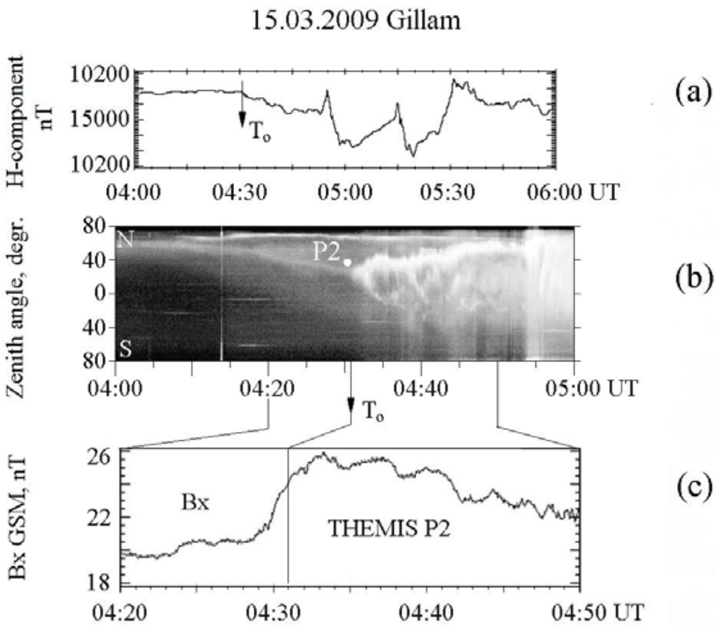

Figure 4. The set of data for substorm on 15 March 2009 by (**a**) magnetic, (**b**) optical observations at GILL station and (**c**) conjugate magnetic field Bx-component measured by THEMIS P2 probe in the boundary plasma sheet.

Conclusions

1. By filtered optical data it is shown that the periodic auroral arc restructuring often develops 3-15 min before T_0. They can be reasonably explained if one suggests that an Alfvén resonance is formed at the location of a subsequent substorm onset.
2. In the events here considered, the observed direction of apparent phase propagation across the resonance layer in the linear stage is poleward rather than equatorward. This indicates that the Alfvén resonance forms in the magnetospheric region with the earthward gradient of the Alfvén resonant frequency of the magnetic field lines.
3. For the events with auroral restructuring it is shown the presence of conjugate oscillations of Alfvén (flapping) type in the plasma sheet with approximately the same period (~ 2-3 min) as the period of auroral restructuring before T_0. This supports the scenario, in which an Alfvén resonance forms at the location of subsequent substorm onset.
4. The conjugate Alfvénic oscillations in the magnetosphere are of smaller amplitude in the events where auroral restructuring is not observed by optical data before T_0. Thus, the absence of auroral restructuring before T_0 in these cases can be explained by weak field-aligned currents inside the corresponding Alfvén resonance layer, not sufficient to produce the optical effect under study.

Acknowledgments. This work was supported by Program 7 of the Presidium of the Russian Academy of Sciences.

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