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Some Aspects of Individual and Multiple Polar Arcs Generation

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Abstract. Sunward oriented arcs appear at time intervals of positive Bz IMF, when auroral zone activity is strongly suppressed, but intense spatio-temporal dynamics and noticeable brightness of the arcs indicate high-energy dissipation, comparable with the energetics of auroral breakup. At present, a common viewpoint is that polar cap arcs are generated on the closed magnetic field lines crossing the plasma sheet. In this study we have analyzed both a rare case of isolated individual polar cap arc generation and more common events of active multiple arcs, using polar cap and auroral zone TV camera data as well as space magnetic field measurements in the solar wind and magnetotail.

Keywords. Solar wind, magnetosphere, polar cap aurora, polar breakup, field lines reconnection.

1 Introduction

Polar cap aurora has been studied for many years, but it is still a very surprising phenomenon. Now, it is generally accepted that the polar arcs are generated on closed magnetic field lines crossing the plasma sheet, when the magnetosphere is almost closed, and this fact is well confirmed by direct satellite measurements. All plasma properties (the fluxes, energies, pitch-angle distributions of e-, H+, He+, O+) above the polar arcs and inside the plasma sheet are nearly identical (Meng, 1981; Peterson and Shelley, 1984; Frank et al., 1986; Frank and Craven, 1988; Huang et al., 1987, 1989). And though the polar arcs can occur very close to the magnetic pole (up to 83°-85° MLAT), the magnetosphere never happens to be completely closed (Troshichev, 1990). First, several decades of satellite observations have not revealed a single case of clear absence of magnetospheric tail signatures at distances about 100 Re and more. Second, there is no correlation between relativistic electron fluxes measured near the Earth and solar wind magnetic field. Those electrons are generated in the solar flares and penetrate into the magnetosphere along the open magnetic field lines. Important is the fact that the polar arcs are always sun-aligned, it means that during arc generation in the magnetosphere there is a special, favorable direction along the Sun - Earth line.

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2 Event of individual polar cap arc generation, March 7, 2002 case study: Polar pseudobreakup?

We demonstrate here a rare case of isolated, individual polar cap arc generation. The data were obtained by all-sky TV camera in Barentsburg (Spitsbergen, 78.05°N, 14.2°E) operating in the integral light (4000 - 8000 angstroms with maximum sensitivity about 5000) and analyzed with applying some new methods of TV data processing. The methods allow, for example, a keogram profile to be of any form, width and in any direction within the TV frame. It is also very helpful that the profile can be dynamic, i.e., moving and deforming along with an auroral arc under study. The initial TV frame rate (25 frames per second) is redundant for this study, so it was integrated to 2 seconds resolution, thus improving the data dynamic range. Different procedures of TV frame and keogram filtering for better revealing fine subvisual details of aurora dynamics have been applied. More information about TV camera operation, data recording and image processing can be found in Kornilov et al. (2004) and Kornilova et al. (2008) .

Fig. 1 presents aurora TV frames for 20 minutes time interval (21.11 - 2130 UT). In the left-sided frames (1-3), the positions of keogram profiles, which are discussed further, are shown schematically. The elements of TV frame matrix are integrated across keogram profile, which, together with the frame integration, significantly improves the dynamic range of initial data. A polar arc appeared perpendicularly to a typ-

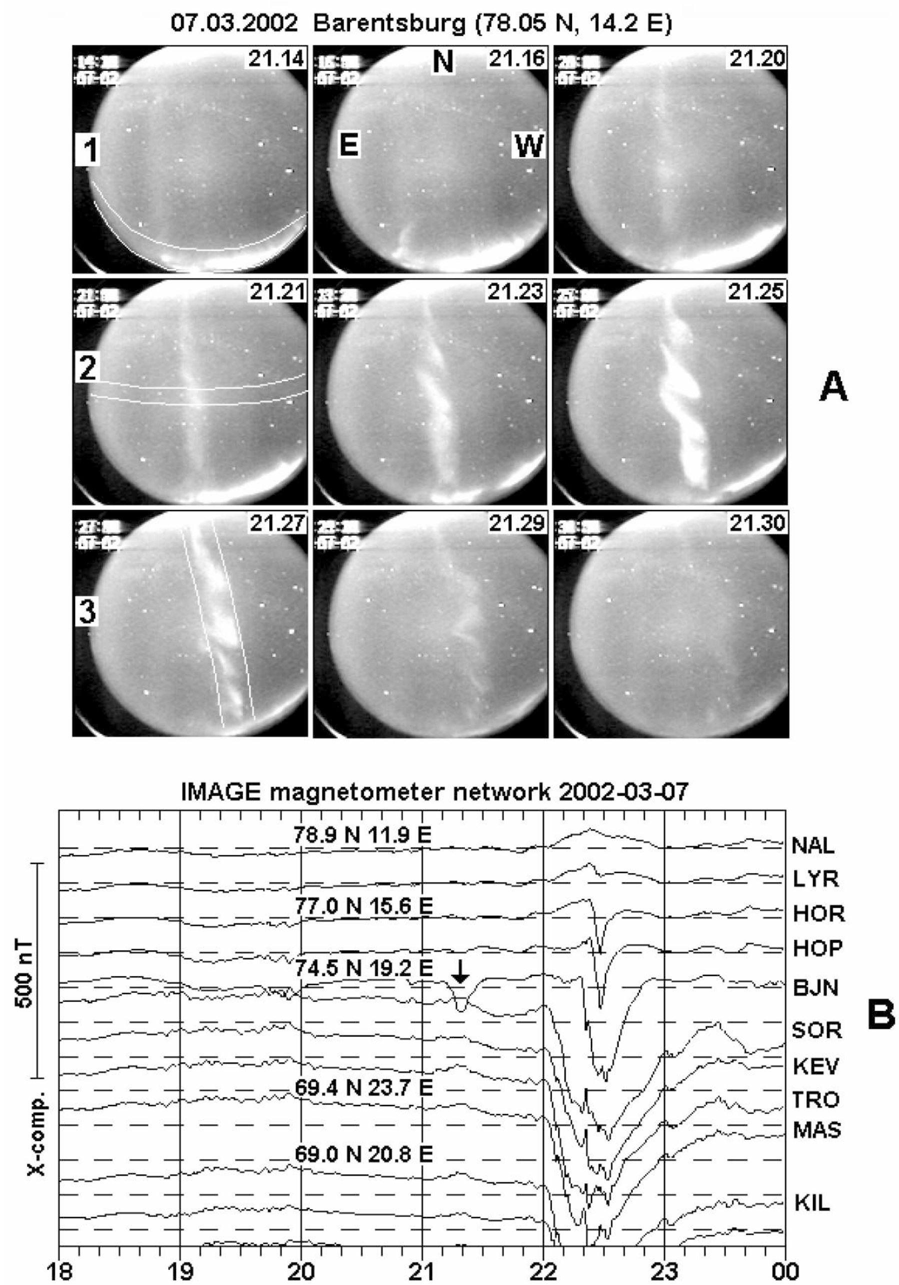

Fig. 1. Integrated TV frames for 3 March, 2002 - case of individual polar arc generation (A). Positions and size of keogram profiles are schematically shown in the frames 1-3. Ground-based magnetometers data of Scandinavian network (B). Moment of polar arc activation marked by arrow.

ical auroral zone arc on the southern horizon, slowly moved through TV camera field of view, and faded. The arc became active and exhibited strong deformations at the time of maximum brightness (about 21.23 - 21.27 UT). Fig. 1(B) shows some selected magnetograms of the Scandinavian IMAGE magnetometer network. One can see an enhancement and inversion of the electrojet inside a narrow latitudinal region (marked by the arrow), and this is approximately where the southern auroral arc was located. Fig. 2 presents different keograms constructed from Barentsburg TV camera frames for the time interval 21.10 - 21.32 UT, 660 integrated frames total. All keograms are high pass filtered to reveal the fine details of spatio - temporal auroral structure. Keogram A (frame 1) shows the motion of luminosity irregularities inside

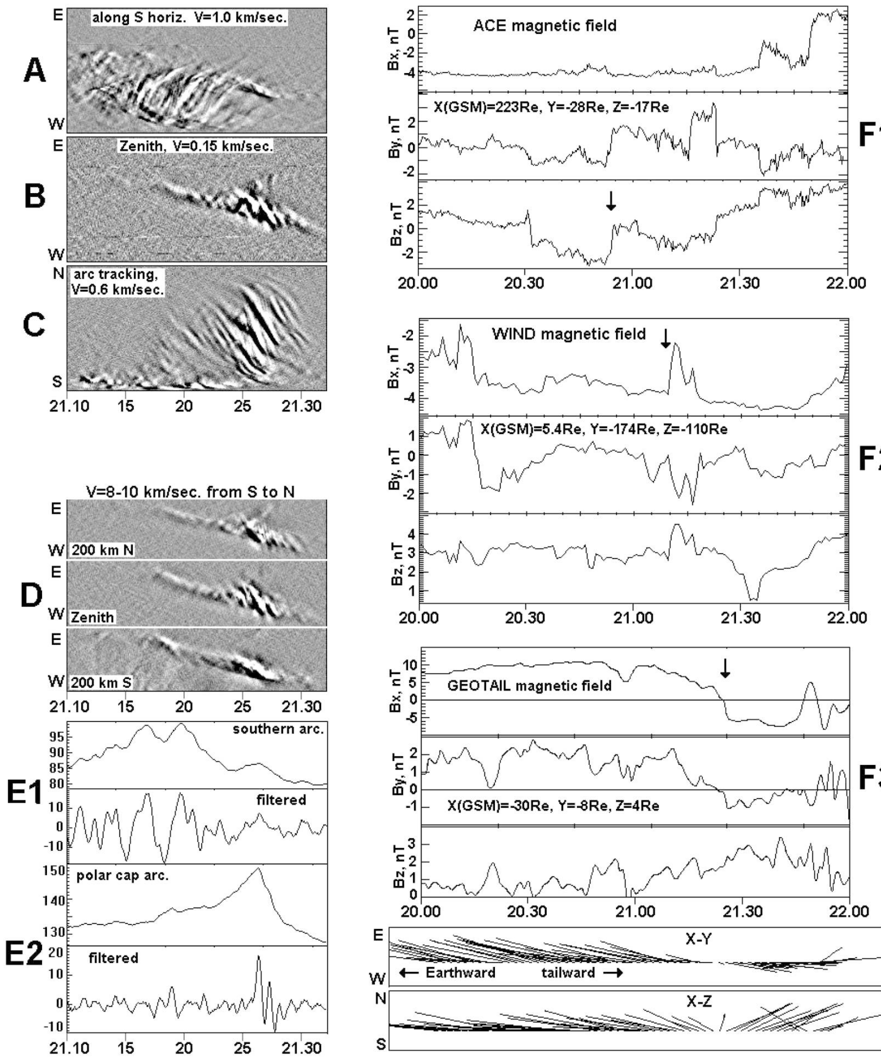

Fig. 2. Filtered keograms, showing irregularities motion in E-W direction inside southern auroral arc (A) and E-W polar arc motion (B). Arc-tracking polar arc keogram (C), demonstrating N-S motions inside E-W moving polar arc and integral luminosity variations (E1, E2). Satellites magnetic field measurements in solar wind (F1, F2) and magnetotail (F3).

the auroral zone arc located along at the southern horizon of the TV camera field of view. Though the spatial dynamics of the oval arc is rather complicated, the irregularities predominantly moved from West to East with the velocity of about 1 km/sec (we assume aurora lower border altitude to be 110-120 km for the auroral zone, and 140-150 km for the polar cap region). The auroral zone arc brightened prior to polar arc generation and faded after it. The horizontal East-West keogram (B), which crosses zenith (frame 2), indicates the direction and velocity of polar arc motion (about 150 m/sec from East to West). So, not only the velocities but also even the directions of motions inside the southern arc and generated polar cap arc are quite different. It means that the polar arc after its appearance was entirely separated from the southern mother arc.

Keogram C (example of keogram profile position marked in frame 3) realizes the arc-tracking method, i.e. the keogram profile continuously covers the studied arc, moving and deforming together with the arc. The method enables to accurately control the velocities and directions of irregularities motion inside the traveling polar arc (as the keogram indicates, the irregularities move from North to South with a velocity of about 600 m/sec). To estimate the average velocity of northward development of the luminosity at the moment of polar arc generation, three similar keograms were plotted in the E-W direction along magnetic longitude (through the zenith, 200 km to the north and 200 km to the south (D)). The time shift between the keograms is well displayed, indicating that at the moment of arc generation the luminosity spread from the South to the North with a finite but quite large velocity of about 10 km/sec. The luminosity integrated along the southern arc and the polar arc, as well as filtered out pulsations of brightness (Fig. 2, E1 and E2) also reveal a complete difference in the spatio-temporal dynamics of the polar arc and southern mother arc.

Fig. 2 (F1, F2, F3) shows the magnetic field variations, detected by the ACE, WIND and GEOTAIL satellites, respectively. Accounting for the satellite positions and the value of solar wind velocity, polar arc generation corresponds to the magnetic field variations detected by ACE at 20.47 UT, by WIND at 21.10 UT, and by GEOTAIL at 21.25 UT (marked by the arrows). Very interesting data were recorded by GEOTAIL, whose position was rather close to the region of polar arc generation, perhaps somewhat downtail. At 21.25 UT the satellite detected fast changes in the sign of the Bx and By magnetic field components without significant variations in the Bz component, indicating a radical change of the local magnetic field direction. More obviously this is seen in the bottom part of the figure, where the amplitude and orientation of magnetic field vectors in the X-Y and X-Z planes are shown. After polar arc generation, the earthward direction of the local magnetic field quickly changed to tailward.

3 January 4, 2005: An event of multiple and active polar arcs generation: Polar breakup?

Fig. 3 (A) presents the TV frames for a rather usual case of intense and active sunward oriented polar arcs detected in Barentsburg. The TV camera was operating in the white-light without interference filters, and so was not calibrated, but we were able to control the actual camera sensitivity and roughly estimate the auroral arc brightness by comparing the amount of stars visible in all-sky frame. In the case presented, the polar arcs were very bright (about an order of magnitude brighter than in the previous case) and dynamic, displaying fast and intense motions and deformations. Though we do not have direct spacecraft information about the energy of precipitating electrons (nor IMAGE satellite pictures), it was definitely not a polar rain precipitation, whose average electron energy is about 100 eV. As in the previous case of individual polar cap arc generation, the characteristic energy of precipitating electrons was at least about 1 keV. The auroral dynamics along the E-W direction is presented in the ordinary (B) and filtered (C) keograms (the profile is shown in the top left frame). In the keogram (B) we can also see a significant enhancement in polar arc brightness, and plot (D) is a result of TV frame elements integration in the region of the camera field of view. Arc brightness increased several times in the time interval of about 10-15 minutes. The IMF data recorded by ACE and WIND satellites are shown in the plot (E). One can see continuous variations of Bz from -4 to +4 nT, probably producing strong twisting deformation of the magnetospheric tail. The arrow marks the moment of polar arc intensification. A preceding time interval of positive Bz IMF (19.00-20.00 UT) also exhibits intense polar arcs with occasional brightening and activations.

4 December 18, 2006: Comparative study of auroral zone and polar region activity.

It would be interesting to compare the TV data obtained simultaneously at northern latitudes and in the auroral oval during active polar arc generation. We have synchronously operating TV cameras in Barentsburg (78.05°N, 14.2°E) and Lovozero, (67.97°N, 35.08°E), but to perform such a comparison is rather difficult because of weather conditions (for the two above cases of March 7, 2002 and January 4, 2005, dense clouds were above Lovozero). We were lucky to find one day of observations when both cameras could see active auroras, and three different types of auroral activity in series followed each other in the time interval from 17 to 23 UT.

Fig. 4 presents the TV frames from Barentsburg (A, B, C) and selected frames for the same time interval from Lovozero (D). Plot (A) shows TV frames from Barentsburg for the period of polar arc activation. This interval marked by the arrow (1) in the plot (E) presenting solar wind magnetic field variations recorded by the ACE and WIND spacecraft. During about 15 minutes, IMF Bz component changed from -5 to +5 nT and back. The camera in Lovozero registered a weak activation of the arc on the northern horizon (Fig. 4, D, and the keogram in Fig. 5, B1). The TV frames in plot (B) indicate small high-latitude aurora activation, very similar to a usual auroral zone pseudobreakup. This interval corresponds to the arrow (2) in plot (E). A sharp increase in the solar wind velocity triggered a high-latitude pseudobreakup. No auroral intensification was detected by the Lovozero camera (keogram B1 in Fig. 5. The third time interval (C) corresponds to a strong breakup, which started in the auroral zone and spread far to the North. Unfortunately, there was rather strong fog above Barentsburg, and high aurora brightness sometimes overloaded the TV camera in Lovozero (C and D). This breakup classically developed after an IMF Bz southward turning (marked by arrow 3 in plot E).

In Fig. 5 the ordinary (A1, B1, C1) and filtered (A2, B2, C2) keograms for the better revealing of fine details of arc dynamics above Lovozero and Barentsburg are plotted for the time interval 17.00-23.30 UT. Keograms clearly indicate the above-mentioned three types of activity (A1, A2, A3, time intervals 18.00-19.30 UT, 20.15-21.30 UT, and 22.00-23.20 UT correspondingly). The position and orientation of E-W keogram profile for Barentsburg and N-S profile for Lovozero cameras are shown in Fig. 4 (frames 1 and 2). Plots (A3, B3 and C3) demonstrate average auroral brightness integrated over the camera field of view. The auroral luminosity during polar arc activation at 18.40 UT (marked by

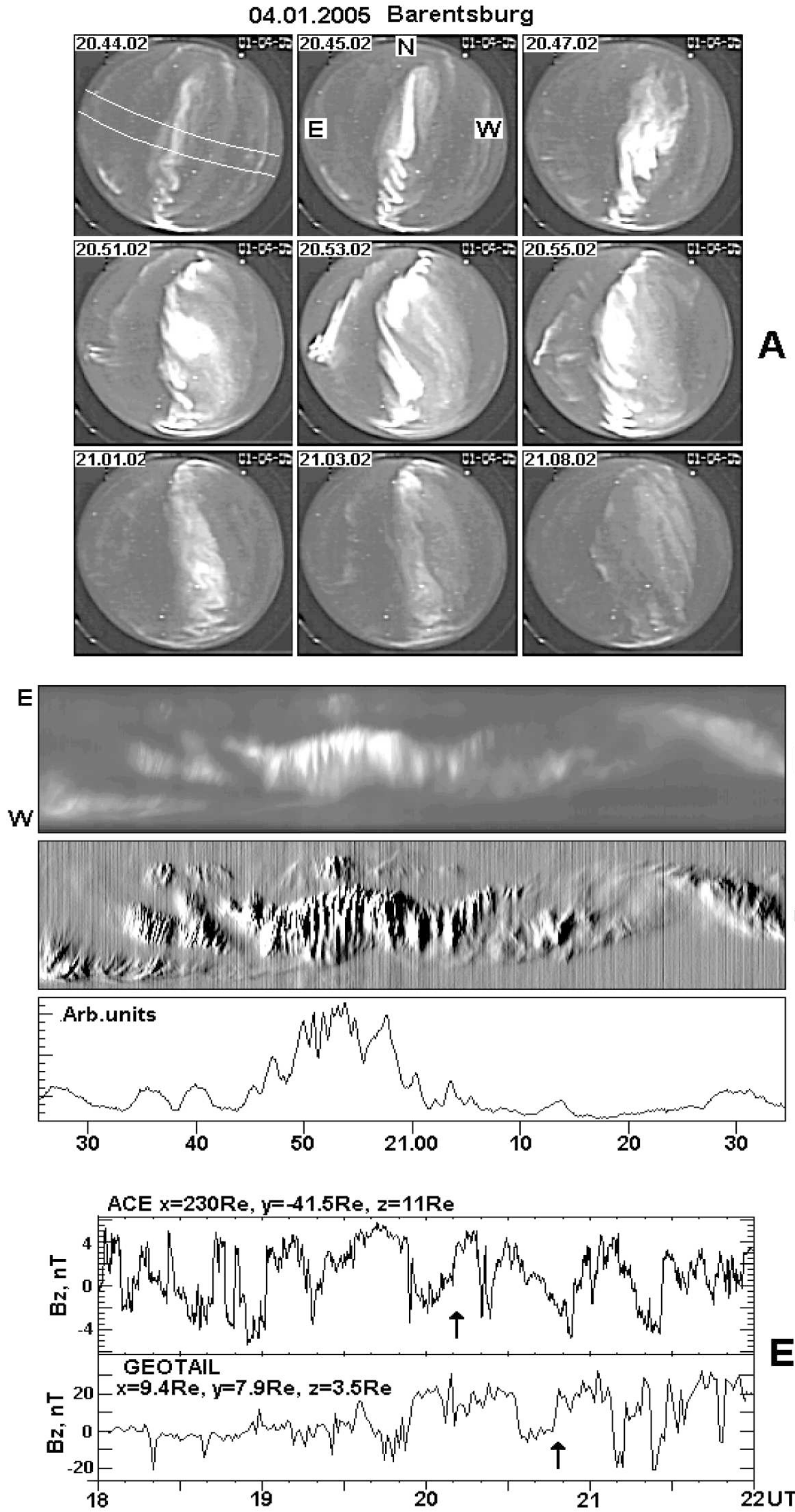

Fig. 3. Case of multiple polar arcs generation. TV frames for Barentsburg (A). Position of keogram profile marked in the top-left frame. Ordinary (B) and filtered keogram (C), integral auroral luminosity (D). IMF variations detected by ACE and GEOTAIL spacecrafts (E).

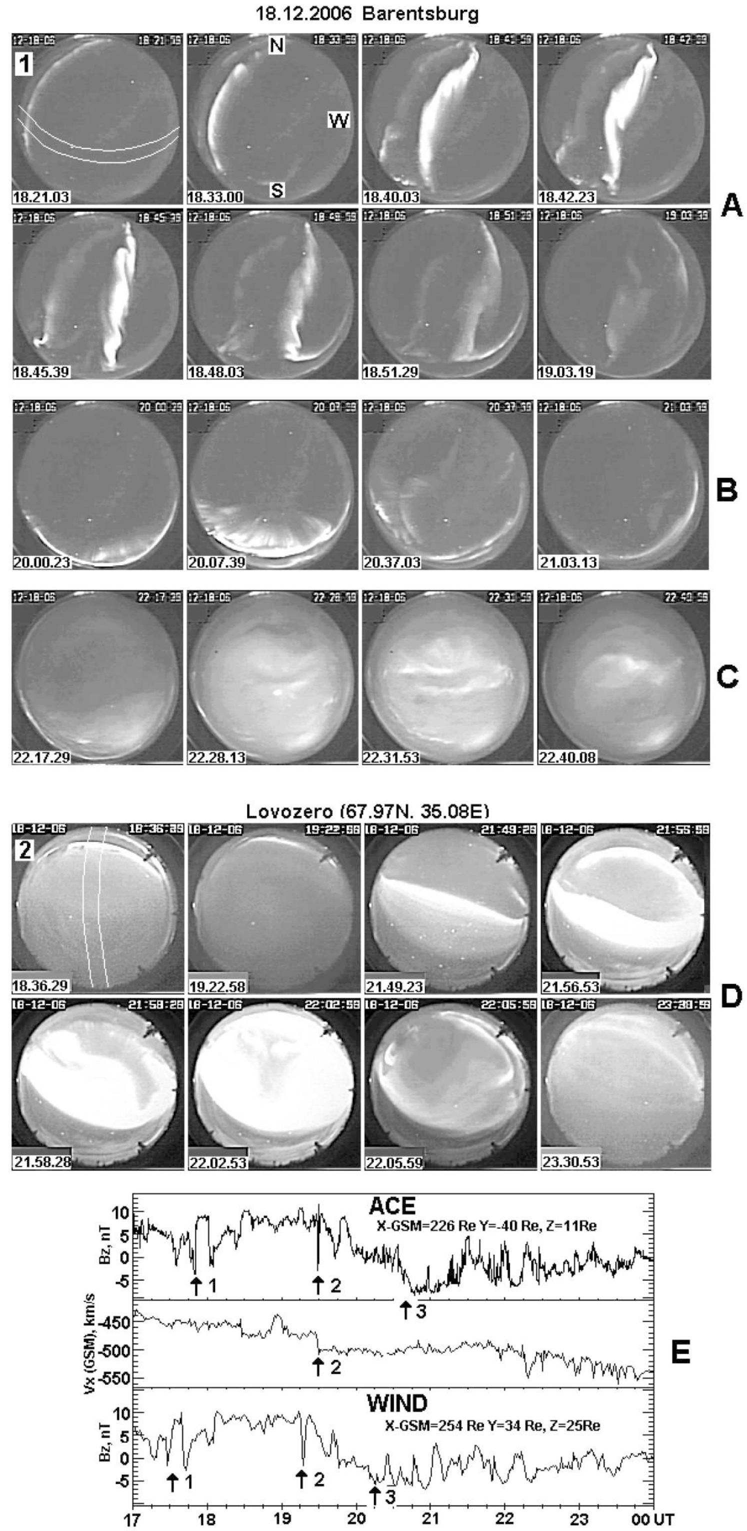

Fig. 4. Comparative study of auroral zone (Lovozero) and polar activity (Barentsburg). A, B, C - TV data from Barentsburg. Case of polar arcs generation (A), high-latitude breakup (B), and strong auroral zone breakup spreading for to the North (C). TV data from Lovozero for time interval of study (D). ACE and WIND satellites magnetic field measurements (E). Arrows (1, 2, 3) mark IMF variations triggering different types of activity.

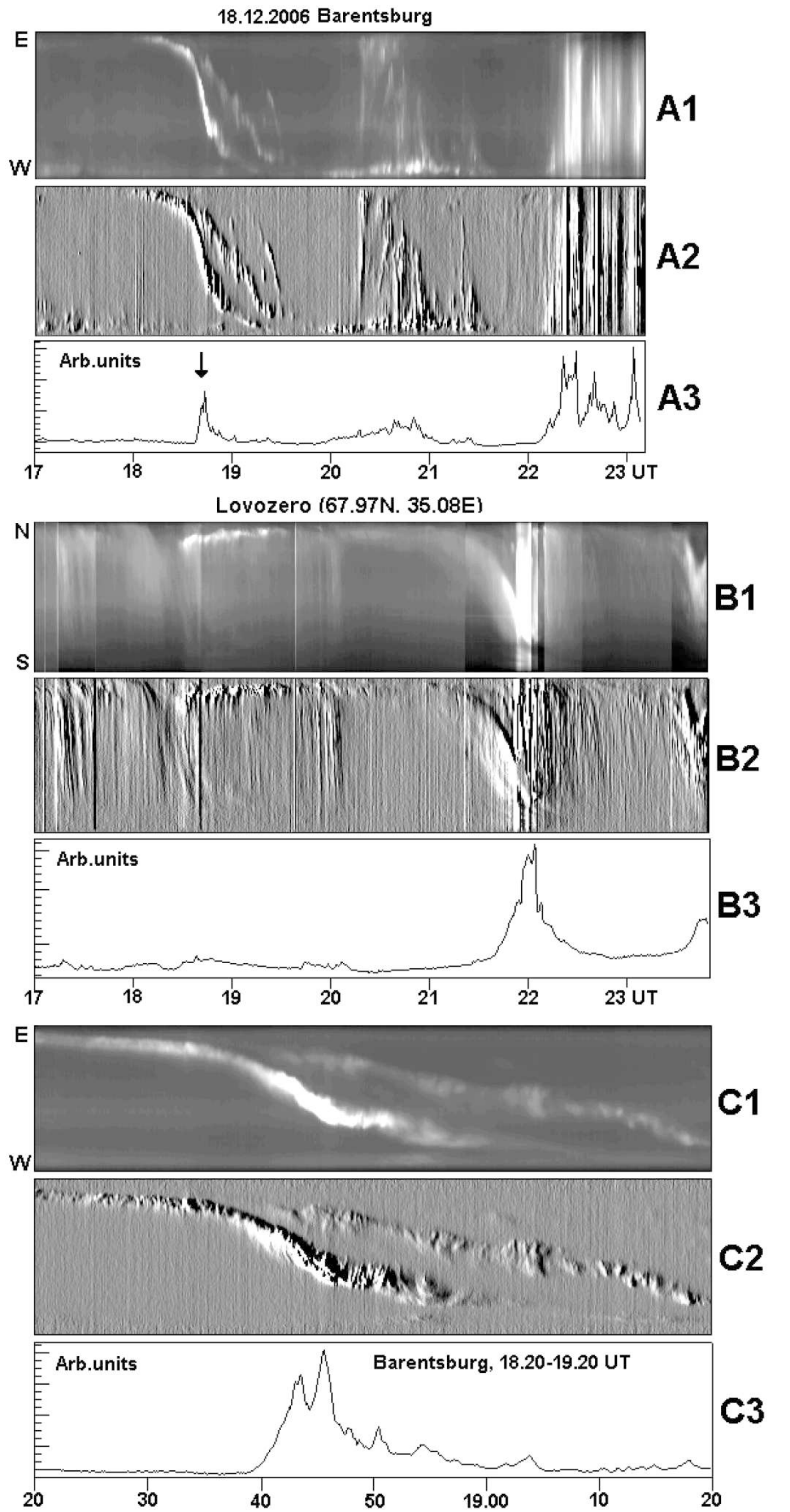

Fig. 5. Ordinary (A1, B1, C1) and filtered (A2, B2, C2) keograms for 18.12.2006, and integral luminosity variations (A3, B3, C3). Data set for Barentsburg (A1, A2, A3), for Lovozero (b1, B2, B3), and for time interval of polar arc generation with higher time resolution (C1, C2, C3). Keogram profile positions are shown in TV frames in Fig. 4.

the arrow in plot A3) is quite comparable with auroral zone breakup intensity (22.00-23.20 UT) and with polar arc intensification shown in Fig. 3. In Fig. 5 (C1 - C3) an enlarged fragment of polar arc generation event is shown (18.20-19.20 UT).

5 Discussion

At the first glance, the phenomenon of polar arc activation is looking as a pure directly driven process. That is, during positive Bz IMF conditions, solar wind energy and particles directly penetrate into the magnetosphere and produce polar cap aurora. The data we presented in the previous sections actually give an additional support to this viewpoint. Indeed, the times of polar arc appearance and duration of the process correlate well with the positive Bz IMF (Fig. 2 and Fig. 4, 5). Still, we think that the phenomenon displays some features of a storage-release process as well:

1. The arc brightness does not repeat solar wind magnetic field variations in all details. We can see flat step-like changes of Bz in Fig. 4 (arrow 1) and much more complicated polar arc intensity variations in Fig. 5 (C1, C3, 18.40-19.00 UT).

2. Arc brightness is increased 10-20 times on the time scale of 5-10 minutes. At the peak of brightness, a polar arc exhibits fast motions and deformations, the duration of this active phase being much shorter than the whole time interval of arc existence. In fact, in TV frames polar arc activation often looks like an auroral zone breakup, but 90 degrees rotated.

3. A dramatic change in the local magnetic field detected by GEOTAIL for the event of March 7, 2002 shows the presence of fast and complicated processes during polar arc generation.

Our hypothesis is that in the polar arc generation process we deal with a special type of reconnection and power dissipation event, which may be called 'a polar breakup'. Probably, in the event of 07.03.2002 we detected a final result of this reconnection when previously closed plasma sheet magnetic tubes at the most northern region of auroral oval suddenly became open, moved towards the magnetosphere border together with plasma sheet particles that they contain, and created polar cap aurora. We can suppose that the final cause of this reconnection and power dissipation is a local twisting deformation of the magnetotail during positive Bz.

6 Summary

A preliminary conclusion can be made that high energy dissipation associated with the polar arcs and radical modification of the local magnetic field during polar arc generation have some elements of a special type of auroral activation, which can be called 'a polar breakup'. In contrast to the ordinary auroral zone breakup, where energy is stored in the compressed magnetotail, polar breakup can gain energy from elastic deformation of twisted magnetotail. This twisting deformation of the tail is around the Sun - Earth line and arise during periods of positive Bz component of the solar wind magnetic field. From this viewpoint, the case of individual polar arc generation can be considered as a polar pseudo-breakup.

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