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LOCALIZATION OF ELECTRON INJECTION REGION ON BARENTSBURG AND LOVOZERO TV CAMERAS DATA

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Abstract

After injection, i.e. simultaneous acceleration of electrons with different energies supposedly by magnetosphere inductive electric fields, more energetic electrons move faster, reach ionosphere first, and produce luminosity at lower heights in compare with less energetic ones. Optically this phenomenon can be detected as a fast wave of luminosity moving upward along the brightening auroral arc or separated beams with a speed 50 – 200 km/sec. Very rarely, this wave can be seen by naked eye, and has a special name in auroral forms classification atlas as a flaming aurora. Measuring time delays of arc or active beams brightening at the different heights (and so for the different electron energies), it is possible to localize the place of electrons injection inside magnetosphere. This method can be applied for Barentsburg and Lovozero TV data (all-sky TV cameras can see in all details the vertical structure of aurora along the northern or southern horizon with a 20 milliseconds time resolution). Effective procedure of TV data processing was developed to reveal and measure this very weak and hardly detectable effect, and initial results are presented.

Introduction

Very rarely beautiful aurora looking as the fast waves of luminosity spreading upward along the narrow separated auroral beams or broad arc can be seen by naked eye. This phenomenon has a special name 'FLAMING AURORA' in the aurora classification atlas [Major, 1954, Omholt, 1974, Starkov, 1993 Oguti, 1980]. First TV observations of flaming aurora have been done by [Cresswell, 1969], but for three individual events only. Cresswell calculated the speed of wave is 70 - 80 km/sec. He also supposed that flaming aurora produced by precipitating electrons velocity dispersion and differential atmospheric penetration of multi-energy electrons, i.e., moving from the region of injection more energetic electrons reach ionosphere first, and produce aurora at the lower heights in compare with the less energetic ones. Using information about the time delays of luminosity modulation at the different heights (and so for the different electron energies), the region of electron injection inside magnetosphere can be localized (Fig.1). Upward moving auroral waves were also studied by narrow angle photometers looking at the different regions of sky with crosscorrelation analyses of the data [Carleton, 1967, private communication]. He detected very

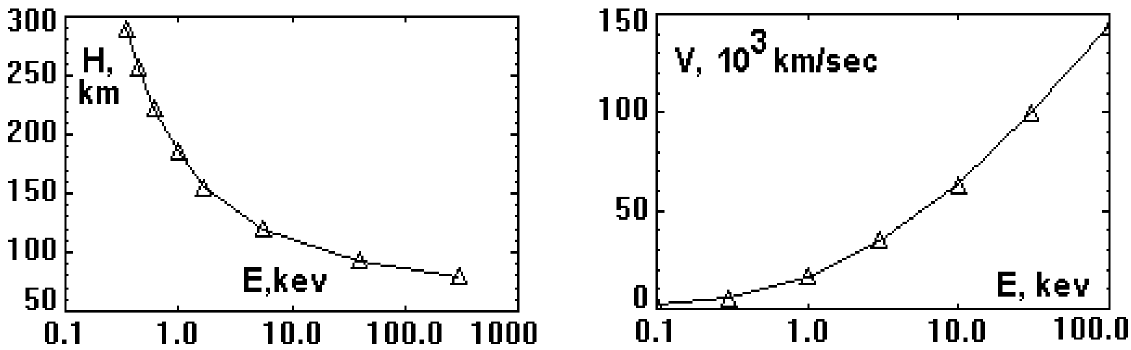

Fig.1 Aurora height (ionisation rate maximum) vs. electron energy (left). Field aligned speed of electron motion (right plot).

fast waves of luminosity moving upward with a speed about 1000 km/sec. This fact means that the distance from ionosphere to the source of auroral electrons is not more than 2000-2500 km. However, three cases of upward moving wave detection by TV camera [Cresswell, 1969], located the place of electron injection at 2.5 – 3 Re.

Though real well visible flaming aurora is very rare phenomenon, some traces of velocity dispersion, i.e., probably very weak wave of luminosity spreading upward along the beam or arc should be detected quite often. It would be interesting to apply this methodic for the massive processing of TV cameras data (only in PGI there are several thousand hours of TV recordings from Lovozero and Barentsburg). When auroral arc with a well-pronounced vertical structure is located just along the horizon of TV camera field of view, assuming the height of lower border of aurora to be 110 – 120 km, one can roughly estimate the speed of luminosity wave using single camera data.

Data processing

Unfortunately, simple idea of using TV camera data for the wave of luminosity detection happened to be very difficult for the practical realization. Fast horizontal motions of auroral beams and brightness irregularities along the arc absolutely reject the using of ordinary keograms with any shape and orientation. Moving beam can penetrate inside the keogram profile by the top or bottom part first, and so resulting information about the speed of upward wave could be completely wrong. Because the speed of luminosity wave is very high, about 100-200 km/sec., it is impossible to summarize many TV frames for dynamic range broadening and weak auroral details revealing (time interval of the wave motion is about 3-10 TV frames only). It is also very difficult to integrate TV information along the frame (summarize different beams or arc elements in one narrow fragment). Because optical and magnetic zeniths do not coincide, beams are slightly curved, and they are curved not equally in the different parts of the frame. Besides, another big problem is a TV camera target inertion, i.e. slow reaction on the fast changers of brightness (neighbor frames are almost identical). If, for example, TV frame is a bright white square on the black background, and this square suddenly also becomes black, in TV signal this fragment will slowly disappear during 20-30 TV frames, i.e., 1 – 1.5 seconds. To detect this very weak wave of luminosity special procedure has been developed (Fig.2). In the figure one can see TV frame of Lovozero camera with active auroral beams near the southern horizon of camera field of view, and sequence of curves plotted with 5 pixels step from the southern horizon to magnetic zenith. Four key points for the automatic curves plotting are indicated for IDL program by cursor – three points along the horizon, and point of magnetic zenith location. Starting from the southern curve, we summarized all TV frame matrix elements along this curve, and then consequently for all curves shifted one pixel north. In every step information was normalized on the curve length. Resulting 90-100 points vector were plotted as one vertical keogram line. This procedure was repeated for all TV frames of the time interval of interest (usually 50,000-100,000 frames total for 1.5-2 hours of TV recording), and then standard procedures of keogram integration and filtering were applied to resulting every 500-800 lines keogram fragments. The tilted elements in this final special keogram could directly demonstrate the presence and value of integrated along the frame aurora luminosity time delays at the different heights.

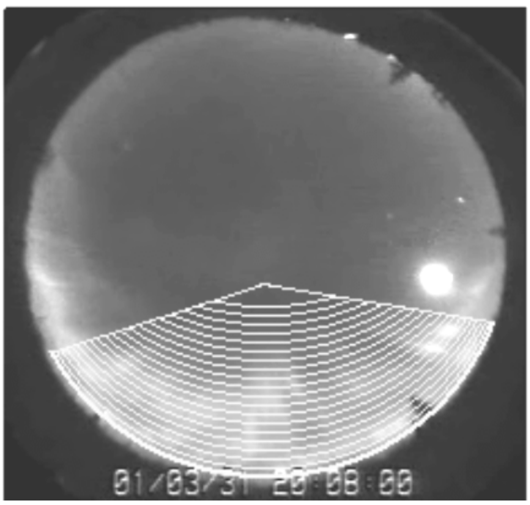

Fig.2 Integration of TV frame elements along the curves consequently shifted from the horizon to magnetic zenith.

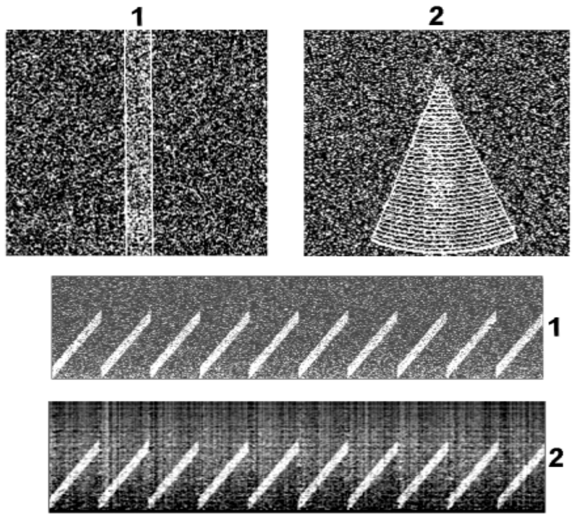

Fig.3 Modelling of vertical auroral beam with the wave of luminosity moving upward. S/N ratio < 0.1

Developed procedure of the data processing has been checked with some model data (Fig.3). In the synthesized TV frame with a strong noise addition (signal to noise ratio was less 0.1) was added some periodically moving in the vertical direction square fragment (Fig.3, 1) with intensity about 5% exceeding average frame intensity and with amplitude of motion about half of the frame size (fragment is slightly visible in the bottom of frame, and well visible in the movie i.e., TV frames animation). Then two types of keogram were plotted. One was an ordinary vertical keogram with a profile marked by vertical lines in the frame (1). Despite of noise, periodical motion of the brightened fragment is well visible in the keogram. Another keogram was plotted with the using of newly developed procedure (2). For this keogram brightened square fragment in TV frames moved not only in the vertical direction, but also had rather large amplitude horizontal motion. This horizontal motion noticeably corrupted ordinary keogram and strongly masked all information about the vertical wave of brightness (this keogram is not presented). Nevertheless, nothing has been changed in the keogram, constructed with the using of developed procedure (2).

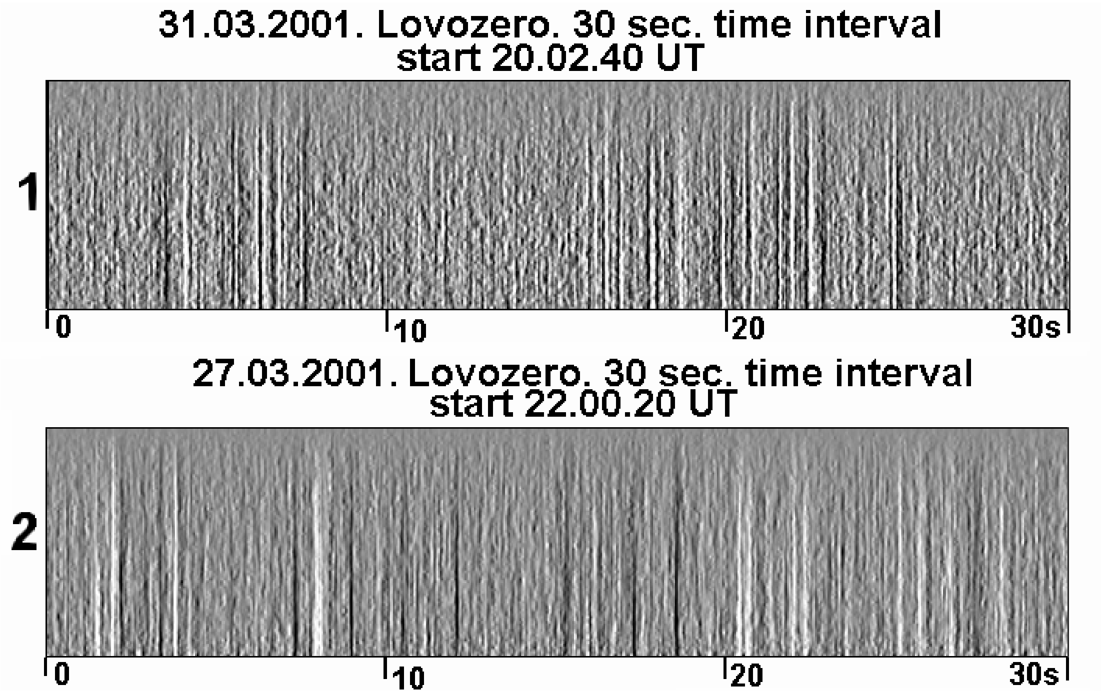

Fig.4. Vertical structure keograms without tilted elements. 30 seconds time intervals (750 TV frames).

Results

Figure 4 and 5 present some initial examples of time delay measurements with the using of new methodic. Keograms have 750 vertical lines and demonstrate 30 seconds time intervals. Gradient filtering was applied to keograms to emphasis fine details of the horizontal time structure. White vertical elements in all presented keograms indicate fast brightening of one or several beams or irregularities inside the arc (as mentioned above, data are integrated along the frame), and dark elements correspond to the fading. All keograms were analyzed together with the detailed study of TV frames animation. Fig.4 (1) represents bright and active auroral beams at the southern horizon of Lovozero TV camera. Beams are moving along the horizon, but without any sudden, explosive and fast activations, in average picture of beams is rather stable. Example of TV frame for this time interval one can see in the Fig.2. Almost the same auroral situation corresponds to the keogram in Fig.4 (2), but in this case bright beams are at the northern horizon of Lovozero camera. We cannot see any tilted elements in both keograms, and it means that speed of upward wave (if this wave exist) is very high and above the time resolution of TV camera we use. If the speed of wave would not exceed 400-500 km/sec, it definitely could be detected. These results are in agreement with an earlier photometric study by Carleton and demonstrate that in these cases acceleration of precipitating electrons took place just above ionosphere, at the distance not more than 2000-4000 km, probably in the double layers and inverted-V structures.

Three keogram plots with the tilted elements are shown in the Fig. 5. Top keogram corresponds to the bright omega structure moving along the southern horizon in the West-East direction. Bright beams are in front and behind, and inside the structure there are well pronounced pulsations with periods 5-10 seconds. Two definitely tilted elements around 10-th and 23-th seconds are visible; they are also shown inside enlarged keogram fragments. Time delays between the top and bottom parts of the tilted elements were calculated. First event (10-th second) corresponds to sudden activation inside omega structure, and the second coincide with the fast explosive brightening of the small group of beams in front of the omega band. Estimation of electron injection position gives about 10-12 Re for the first event, and 4-6 Re for the second. Middle keogram represent rather calm homogeneous arc along the southern horizon without active beams. North from the arc there is broad band of diffuse luminosity with a weak pulsations. At the time interval of the tilted elements appearing fast brightening of small arc fragment was noticed slightly above the horizon. Bottom keogram shows very similar auroral situation, and almost the same time interval as keogram in the Fig.4 (1), but 10 minutes later. The main difference is sharp and fast local activation of the small group of beams at time interval of tilted elements.

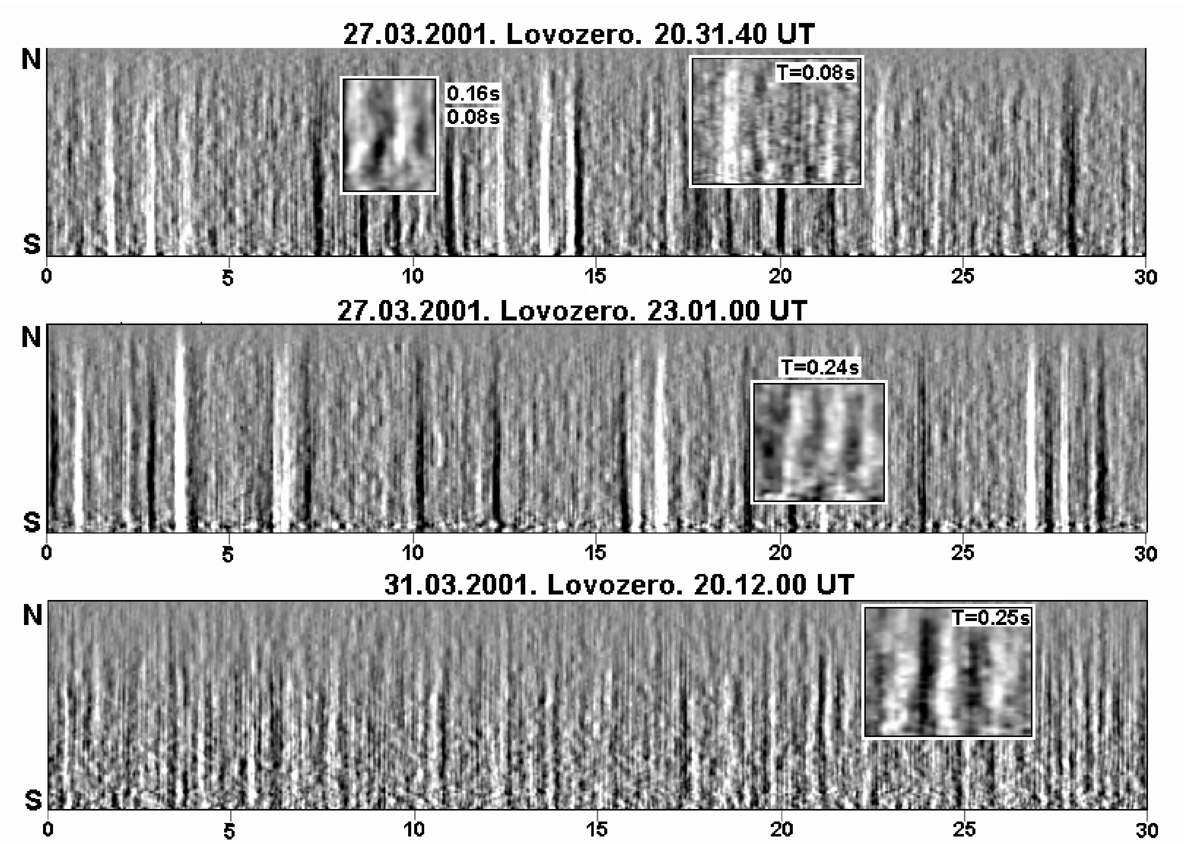

Fig.5. Examples of vertical structure keograms with some tilted elements (velocity dispersion). 30 seconds time intervals are presented. Enlarge fragments with time delays between top and bottom ends of auroral beam are shown.

Conclusions

Effective procedure was developed for detecting very weak waves of luminosity spreading upward in the auroral arc. Using this procedure for massive TV data processing potentially gives a possibility to investigate and localize the positions of electron injection regions with a good statistical background. No velocity dispersion was found in the active structured auroral arcs, so the main region of electron acceleration in this case was just above ionosphere (2000-4000 km). Velocity dispersion of precipitating electrons was also found in the events of fast activations.

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