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ON TRIANGULATION BY AURORAL CAMERAS

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Abstract. The data of the MAIN (Multiscale Aurora Imaging Network) auroral cameras located in Apatity and all-sky camera in Lovozero observatory have been used to triangulate auroral structures. Two pairs of cameras are possible to employ: i) narrow (18°) field-of-view cameras with ~4 km distance between them and ii) two all-sky cameras which are ~86 km spaced. Triangulation abilities and discrepancies are tested by events of satellite flashes and meteor tracks. The results are compared with previous findings and theoretical estimations.

Introduction

There is a long history of triangulation measurements of the aurora altitude. Already *C. Störmer* [1910, 1911] used first photographic registrations of aurora to deduce the height profile of the glow. Later, in 60-70-th years of XX century, this method was used systematically [*Иванов*, 1975; *Иванов и Старков*, 1977; *Brown et al.*, 1976; *Stenbaek-Nielsen et al.*, 1978]. That time, the knowledge of the particle collisional physics in the Earth's atmosphere was enough to obtain important information about energies of the auroral particles from the altitude profiles of auroral luminosity [*Omholt*, 1971]. Later more complicated tomographic methods and direct measurements of the particle spectra by satellites were widely used. However the simple triangulation still can be useful tool for auroral studies with specific equipment. Here we present an example of such equipment aimed to triangulation of small-scale aurora structure. The triangulation method abilities and discrepancies are tested by events of satellite flashes and meteor tracks. An example of triangulation of pulsing aurora event is discussed. The results are compared with previous findings and theoretical estimations.

Equipment

Last years a new system of auroral cameras has been installed at Kola Peninsula. A schema of the observational system is shown in Fig. 1. Four cameras were operated automatically during dark time, independently of weather conditions. The cameras were installed on the main building of the Apatity division of the Polar Geophysical Institute (PGI) and at Apatity stratospheric range. The system is described in details in paper [*Kozelov et al.*, 2012].

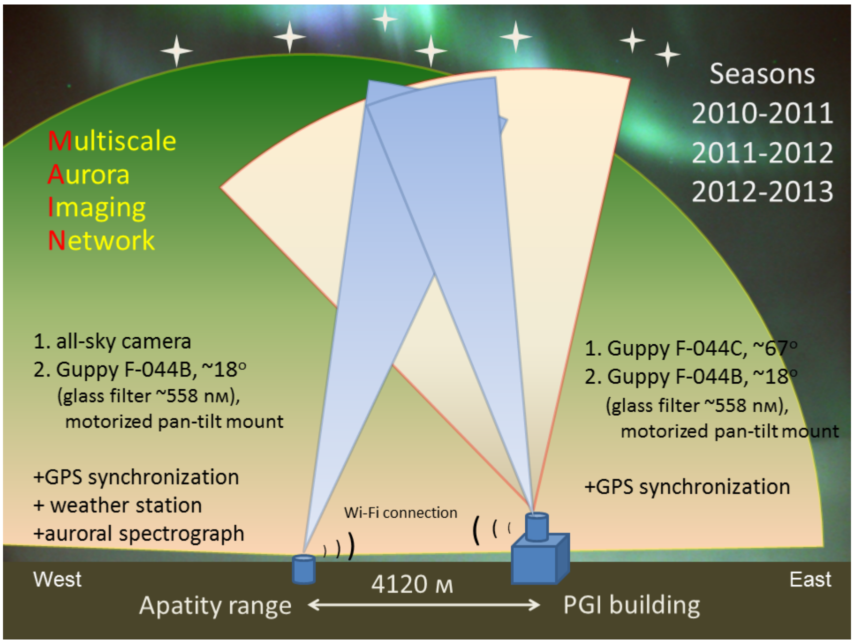
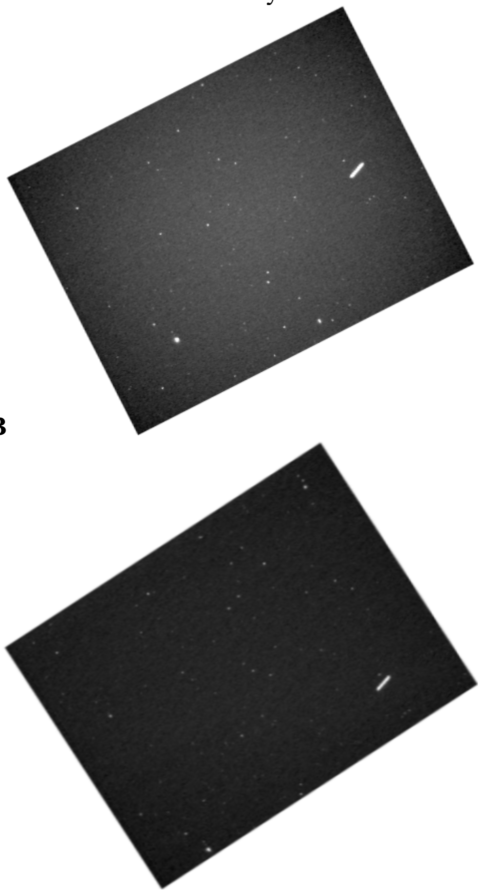


Fig. 1. Schema of the auroral camera network.

Two identical cameras AVT Guppy F-044B NIR with narrow (18°) field of view are aimed to be used for triangulation. More information on the cameras is available at vendor's web-site http://www.alliedvisiontec.com. Here we only mention that the cameras contain the most sensitive non-intensified Sony CCD sensors of TV format. Each camera is placed in an individual housing box with a heater located near the input glass window. Both cameras are additionally equipped by blue-green glass filter to decrease influence of long-lived excited states. The cameras were mounted on industrial pan-tilt motorized mounts to fit the direction of observation. Usually the cameras are directed to a region near magnetic zenith. The distance between the points of observation is 4120 m, so identical monochromatic cameras can be used as a stereoscopic system to resolve auroral structures at altitudes of 90-300 km. A special module was developed for precise synchronization of image capture by the cameras. The estimated precision of time synchronization for simultaneous images is better than a few milliseconds, which is a good precision for auroral observations.

Tests by sharp objects

Auroral structures typically have smooth boundaries, therefore the triangulation abilities of the system have been tested by known sharp objects at different altitudes. Figure 2 demonstrate a bright flash of IRIDIUM-37 satellite observed by both cameras.



APB

APP

Fig. 2. IRIDIUM-37 satellite observed by cameras Guppy-1 (APB) and Guppy-2 (APP). Exposition 1 s.

One can see visual parallax of the satellite location against the background of stars. The satellite is a very sharp object, so from stereo pair of images the visual parallax can be estimated with sub-pixel precision. Our estimation is 7.5±0.5 pixels, which corresponds to $\alpha=0.30^{\circ}\pm0.02^{\circ}$ for angular resolution ~0.04° per pixel. Then the distance from observational point to the satellite is d /sin α, where d = 4.12 km is distance between observational points. Taking into account the elevation angle ψ (between the directions to the satellite and to the horizon), we deduce for the considered event:

$$H = d \sin\psi / \sin\alpha =$$
$$4.12 \sin 76^{\circ} / \sin 0.30^{\circ} = 760\pm50 \text{ km}$$

This agrees quite well with typical altitudes of the IRIDIUM satellites. However the discrepancies are relatively larger due to too small distance between the cameras to resolve so large altitudes.

Typical objects observed at smaller altitudes are meteors. Figure 3 presents an example of such meteor track. Reconstruction of the track geometry is shown in Figure 4. The altitudes 94-103 km are typical for small meteors. Note that the discrepancies of the altitude estimation in this region are ~1.5 km.

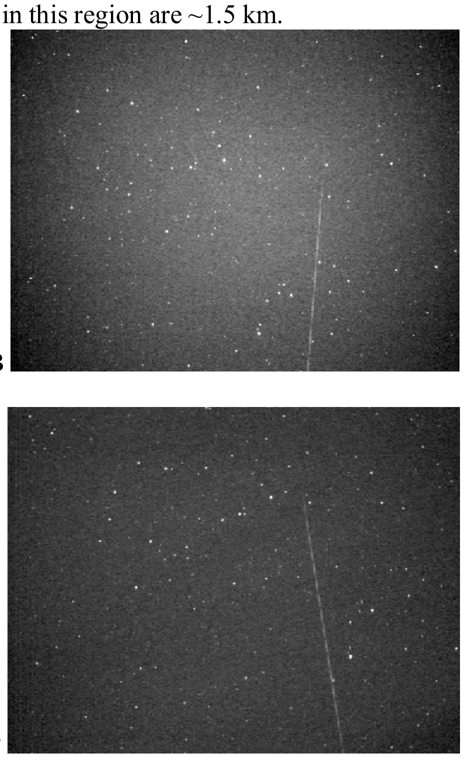


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Fig. 3. Meteor track observed by cameras Guppy-1 (APB) and Guppy-2 (APP). Exposition 1 s.

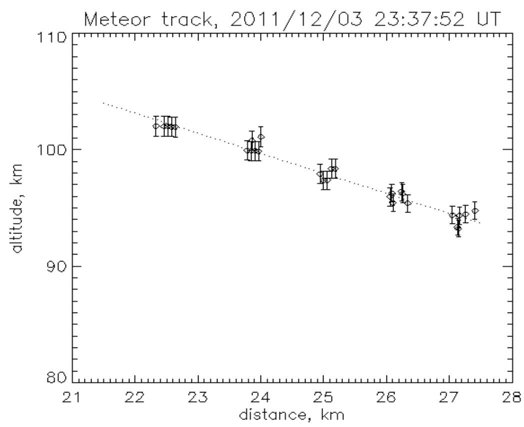

Fig. 4. Reconstruction of the meteor track by triangulation.

Altitude estimations for pulsating aurora

Pulsing auroral forms are usually considered connected with developing of the instability in the magnetosphere [*Trakhtengerts*, 1984, *Davidson*, 1990, *Trefall et al.*, 1975]. Simultaneous registration of such events as pulsing auroral forms, riometric absorption and ELF/VLF choruses in morning sector is usual for recovery phase of substorm and supports this point of view [*Helliwell,* 1965, *Tagirov*, 1986]. The models of VLF emission generation are based on cyclotron wave-particle interaction mechanism. According to such models the generation of waves is accompanied by a modification of particles pitch-angle distribution, that can lead to their precipitation in a loss cone. The dissipation of energetic particles in the atmosphere is accompanied by excitation of auroral emissions at altitudes of 90-200 km, that is observed by optical instruments [*Helliwell et al*., 1980; *Tsuruda etal.,* 1981;*Tagirov et al*., 1999]. Detailed knowledge of the precipitated electron energy, especially in dynamics, can give important information for theory and modeling of these events [*Trakhtengerts et al.*, 2005].

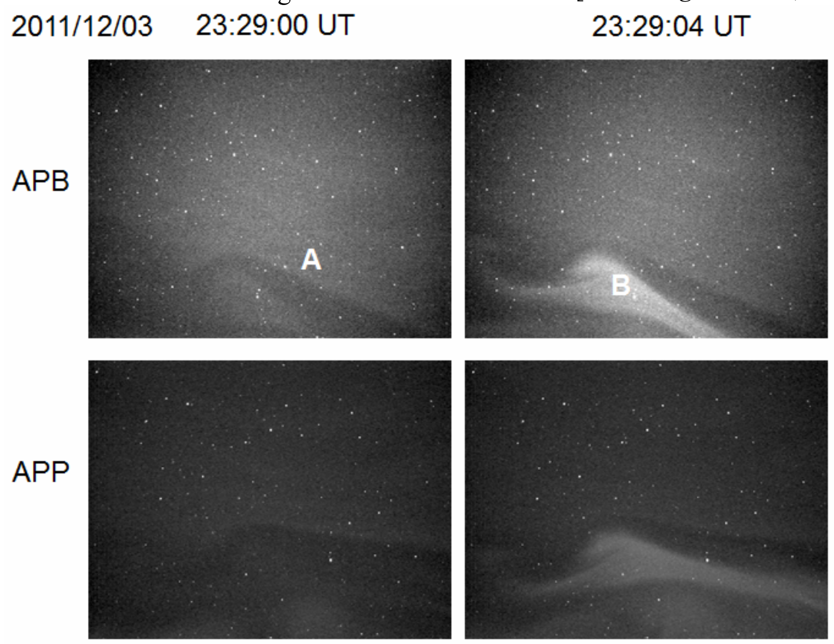

Fig. 5. Triangulation of pulsing auroral event: region A is a diffuse background at ~150 km, region B is a bright pulsing filament at ~100 km.

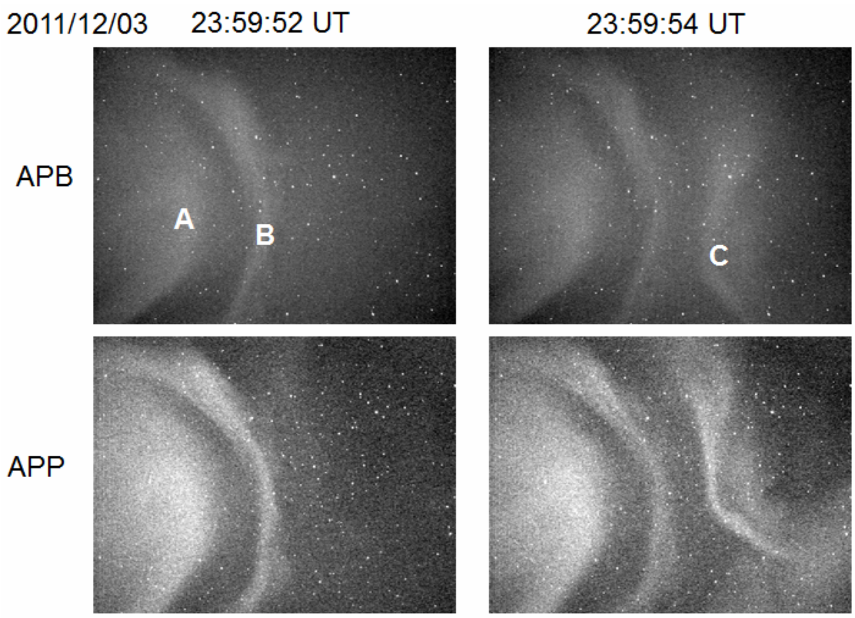

Fig. 6. Triangulation of pulsing auroral event: filaments A and B are located at ~97 km, filament C at ~104 km.

Figures 5 and 6 present two examples of triangulation of pulsing aurora forms. First event (Fig.5) is a bright pulsing filament in diffuse background. By dark boundary of the background region and boundary of the filament we estimate the altitude of the background as ~150 km, and ~100 km for the filament. These altitudes correspond to energies of precipitated particle ~ 1.5 keV for background and ~20 keV for the filament (see Fig.7). For second example (Fig.6) the energies are: ~ 30 keV for filaments A and B, ~10 keV for the filament C. These energies correspond well to theoretical estimations and typical values measured by low-latitude satellites in the morning sector.

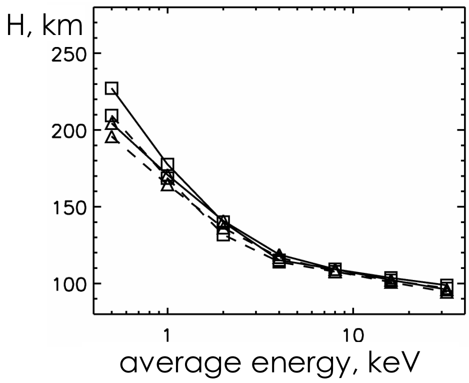

Fig. 7. Altitude of the maximum at the altitude profile of the 1NG 391.4 nm emission excited by precipitated electron flux as a function of average energy of the electrons: triangles – for monoenergetic flux, squares – for maxwellian energy distribution in the flux, solid lines – for isotropic angle distributions, dashed lines – for field-aligned beams.

Conclusions

New abilities of triangulation measurements of the aurora altitude were presented and tested by known sharp object in the sky. Two examples of triangulation of pulsing auroral forms were shown. Estimated energy of precipitated electrons correspond well to theoretical estimations and typical values measured by low-latitude satellites in the morning sector.

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