Author’s response to Referee 1 comments.

1. RC: The paper title refers to multi-scale auroral observations, but all the analysis examples only use one type of camera, which restricts the observations to a certain range of auroral scale sizes. A report of a new imaging system does not have to have examples of all kinds of scientific purposes, but I would expect to see at least a motivation for deploying the three different fields-ofview in the same area with accurately synchronized imaging.

AC: Our major motivation is presented in Introduction. A starting initial point was our interest in spatio-temporal scaling features of the aurora. In the paper (Kozelov et al., 2004) statistical distributions obtained from data of ground based TV observations and Polar satellite for different ranges of scales were combined in one plot. They look like a universal power law for all observed scales. However there are some intrinsic problems typical for TV observations, therefore we need to reproduce the results with other datasets. Small spatial (<1 km) and temporal (< 1s) scales are of most interest for us because these scales cannot be resolved by earlier TV white-light observations. Therefore we need observations of filtered narrow field-of-view camera directed to magnetic zenith. (We cannot simply use one camera with several-megapixel sensor for all scales because i) it is very expensive, ii) such a camera typically needs very large time (a few seconds) for image saving, or it should be even more expensive). Also, we need an estimation of the height of auroral structures to decrease discrepancies in the measurements of spatial scales, therefore we use a synchronized stereoscopic pair of cameras.

A color camera with intermediate field-of-view gives us a possibility to deduce what type of structure is really observed (aurora or clouds). An all-sky camera is used for largest scales.

Statistical distributions obtained with data of all cameras will be combined in one plot as it was done in (Kozelov et al., 2004) for TV and Polar observations. However, we still need more observations to have good statistics. Therefore here we present the camera system and a few examples of scientific applications.

2. RC: The reasoning for selecting these particular cameras into the current setup would be very useful. Is the combination of monochromatic all-sky, color and green-filtered for the narrower fields-of-view the best combination for multi-scale studies, or the studies aimed at with this system?

AC: In our case, the main reasons for camera selecting were i) sensitivity and ii) low cost to build and operate the system, because the project started without appreciable financial support. We use a green filter for the narrow fields-of-view camera to cut long-lived 6300/6364 emission. It would be perfect to cut 5577 emission also, and then increase the frame rate at least up to 4-5 frames per second but the sensitivity of the cameras is not enough for that. A color camera for intermediate field-of-view is a very good solution because we can definitely separate auroral structures from clouds. This camera have balanced spatial and temporal resolution for this field-of-view.

3. RC: The wavelet analysis for studying the scaling features includes a number of references to previous work but no references are given for the earlier auroral pulsation studies or altitude estimations. There must be some. Have the observed periods been reported before in similar conditions or is the example an atypical one? What kind of a method was used to estimate the altitude of the IRIDIUM satellites? Are the altitudes for auroral patches, arcs and rays typical with respect to earlier observations?

AC: We suggest to make the following corrections:

Page 33, line 17: Include references to the studies of pulsating aurora: (Omholt, 1971; Brekke, 1972; Brown et al., 1976; Yamamoto, 1988; Tagirov et al., 1999; Sato et al., 2002; Jones et al., 2011);

Page 36, line 27: Include sentence:

"These features correspond well to previous observations (Brown et al., 1976; Yamamoto, 1988; Tagirov et al., 1999; Sato et al., 2002). "

We suggest to extend paragraph 1, p.37 by this description of the altitude estimations:

"A stereoscopic pair of cameras #2 and #3 enables altitude estimations. Stereoscopic or triangulation methods have been used to determine the altitude of auroras already in pioneering works of Störmer (Störmer, 1910, 1911). Later the stereo-imaging method was applied not only to measure the altitude of aurora (Stenbaek-Nielsen et al., 1978) but also to noctilucent clouds (Witt, 1962) and even to reconstruct a three-dimensional map of the OH-layer centroid heights (Moreels et al., 2008). Through the last decades other method became more popular for studying aurora: more sophisticated tomography reconstruction, direct measurements by rockets and radars, theoretical estimation by transport model from measured parameters of precipitated flux of auroral particles. In our case the distance between observational points is relatively small, therefore we can use very simple mathematics for altitude estimates.

Here, we use simultaneous registration of bright satellite flash to demonstrate the altitude estimates. The motion of the satellite (possibly IRIDIUM 37) as a sequence of anaglyph stereo images is shown in a Supplement file AP 2011-02-06-02-40-13 20s.avi. Due to the precise time synchronization of the cameras we can obtain visual parallax against the background of stars. The satellite is a very sharp object, so from stereo pairs of images the visual parallax is estimated as 7.5±0.5 pixels, which corresponds to α=0.30°±0.02° 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:

$H = d \sin \psi / \sin \alpha = 4.12 \sin 76^{\circ} / \sin 0.30^{\circ} = 760 \pm 50$ km

This agrees quite well with typical altitudes of the IRIDIUM satellites. For auroral structures similar estimations give expected altitudes: 100–105 km for pulsing patches, 130–140 km for quiet arcs, 150–200 km for rays. These are typical values known from the literature (Omholt, 1971; Brown et al., 1976). The estimations of aurora altitude by the camera system is possible if there is a structure with sharp luminosity gradient in the East-West direction. In such a case, the accuracy of the method is restricted by 1-2 pixels discrepancy for visual parallax estimation, which for altitudes 100-120 km corresponds to 2-5 km."

A couple of more specific comments:

1. RC: Does pulsing aurora mean pulsating aurora? There are many studies on the latter but nothing found on the former.

AC: Yes, we mean pulsating aurora. The word "pulsing" throughout the text should be changed for "pulsating".

2. RC: Could the approximate coverage of the narrower fields-of-view be plotted on the top of the larger fields-of-view in Figure 3 as well as in the animations of the supplementary material?

AC: New versions of Fig.3 and animation are attached. The field-of-view of camera #4 is plotted on the all-sky camera image by color frame. The fields-of-view of cameras #2 and #3 are plotted on the field-of-view of camera #4. The caption for Fig.3 is modified.

3. RC: One of the web archives is not responding and the other requires a password. The availability of these data may need to be clarified.

AC: We think there are several reasons for the problems with the web access mentioned by the Referee. The most important ones are: i) there were technical interruptions of power in the Apatity stratospheric range during daytime in November-December 2011; ii) sometimes the connection speed is low because of large traffic. Unfortunately, we cannot resolve these problems. Now, from our location, all links mentioned in the paper are working perfectly.

Additional references

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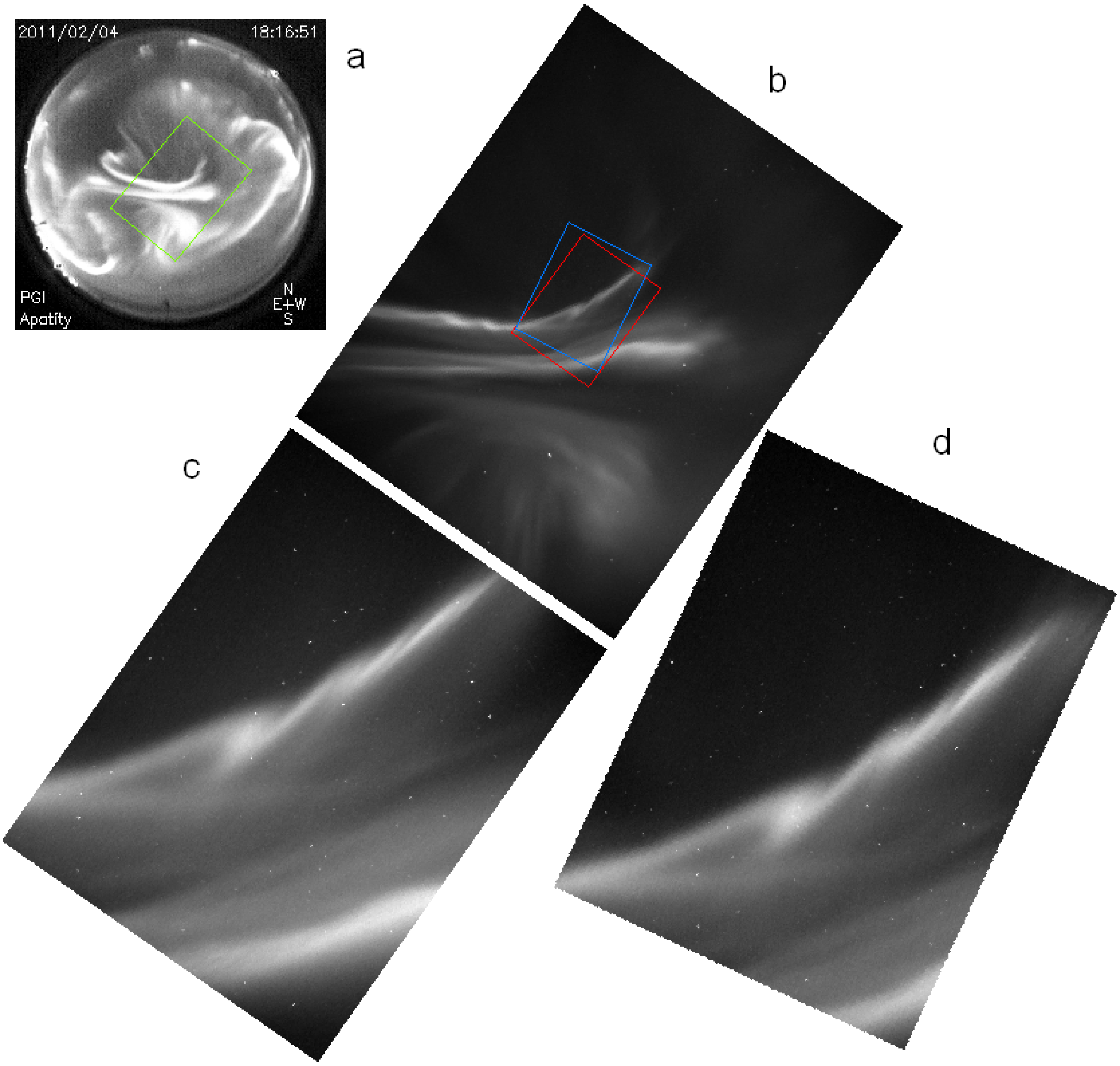

Fig. 3. Simultaneous observations by four auroral cameras listed in Table 1: (a) – all-sky camera (#1), the green frame is the field of view (67°) of camera #4; (b) – camera #4 (green channel), the red and blue frames are the fields of view (18°) for cameras #3 and #2, correspondingly; (c) – camera #3 (PGI building); (d) – camera #2 (Apatity range).