Observation and time dependent modelling of the metastable O^+ ion in discrete aurora

H. Dahlgren[(1)], N. Ivchenko[(1)], M. Ashrafi[(2)], B. Lanchester[(2)], D. Whiter[(2)], G. Marklund[(1)], J. Sullivan[(2)]

[(1)] Space & Plasma Physics, Royal Institute of Technology (KTH), Stockholm, Sweden, [(2)] Solar and Environmental Physics, University of Southampton, UK

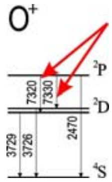
Introduction

Imaging of active structured aurora in the forbidden O^+ ion doublet at 7320 Å and 7330 Å provides a possibility of direct observation of plasma drifts in the topside ionosphere. The metastable O^+ ^2P state has a radiative lifetime of 5 s, so the oxygen ions can be detected after the precipitation creating them has ceased. We report on three examples of observations of this [OII] afterglow that have been observed with the ASK imager, placed outside Tromsø, Norway, in 2006. The measured intensities of [OII] and a prompt OI emission at 7774 Å are compared with results of an ion chemistry model. The time decay of the [OII] emission is studied, and an example is given of drift velocity estimation from analysis of the afterglow motion.

Instrumentation

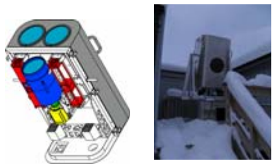
The observations were carried out with the ASK (Auroral Structure and Kinetics) instrument, a set of three sensitive narrow FOV imagers equipped with narrow band filters. ASK was placed in Ramfjordmoen, Norway, during the winter 2006/2007. The FOV is 3.1° × 3.1° and the time resolution 20 - 32 Hz.

Central λ	Species
ASK1a: 6730 Å	N_2
ASK1b: 5620 Å	O_2^+
ASK2: 7319 Å	O^+, also N_2 1PG, OH
ASK3: 7774 Å	O (O + e^-), O (O_2 + e^-)



Forbidden [OII] doublet

radiative lifetime 5 s
doublet in near IR: 7320/7330 Å
quenched below 250 km
produced by low energy e^- impact

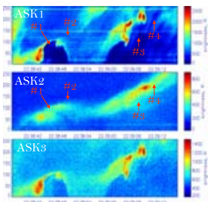


The ASK instrument, sketch and reality.

Observed afterglow events

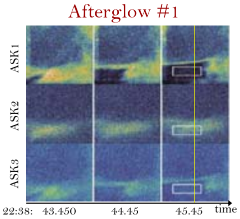
ASK2 has a filter centered on the forbidden O^+ (7320Å) emission. Thanks to its long lifetime, it is possible to detect afterglows in this channel, compared to prompt emissions in the ASK1 and ASK3 channels. Three afterglow events have been analysed in detail here, in terms of their appearance, decays and velocity of detected drifts.

9 November 2006

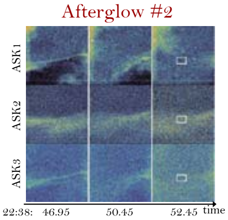


The keograms (left) from 30 s of data show 4 cases of afterglow in ASK2 compared to prompt ASK1/3 emission. Images from #1 and #2 are shown below. The yellow line shows the keogram cut.

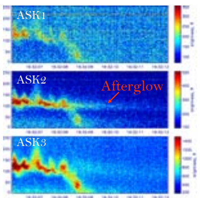
Afterglow #1



Afterglow #2

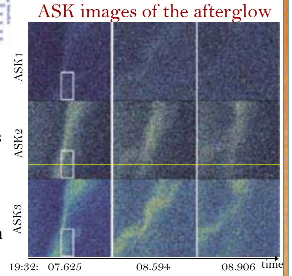


12 December 2006



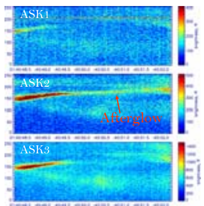
Keogram (left) produced by images from a horizontal cut (marked yellow in figure below) turned vertically and stacked in time. The afterglow is marked in the ASK2 keogram.

ASK images of the afterglow



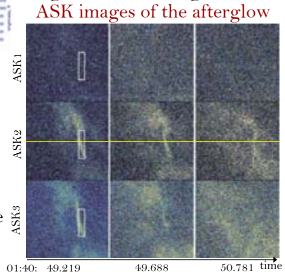
The prompt emission in ASK3 moves away to the left, but the ASK2 afterglow stays as a vertical filament, when the emitting region moves away. Thus, the structure in ASK2 is divided.

15 December 2006



Keogram (left) produced by a horizontal cut (marked yellow in figure below) turned vertically and stacked as a function of time. The whole keogram is 4 s in length.

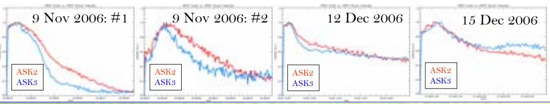
ASK images of the afterglow



The filament in the centre of the images is hardly detectable in ASK1 → it is caused by low energy precipitation. Prompt emission is gone in the last column of images.

ASK2 vs ASK3 decay

The decay of the O^+ afterglow was obtained by measuring the intensity within specific regions (marked in white in the ASK images) for all times. The O^+ ^2P state has a lifetime of 4.7 s, so that 2 s after the emission is cut off, the brightness should decrease from 1 to 0.65, and more slowly than the prompt ASK3 emission. This is observed in our four events, although ASK3 has an increase in background emission in the last case.



Modelling

The emission brightness for the 7320 Å (ASK2) and 7774 Å (ASK3) emissions can be modelled with an ion chemistry and electron transport model, where the input energy spectrum of the electrons at the top of the ionosphere is Gaussian with a flux of 1mW/m². The resulting emission curves are shown in Figure 1.

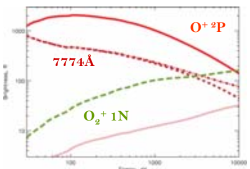


Figure 1: Emission brightness vs. energy, obtained with an ion-chemistry model.

Time-dependent modelling

To model correctly the decay of O^+ ^2P emission in ASK2, a time-dependency must be introduced. The brightness is proportional to the metastable O^+ ^2P population, which is determined by the balance of production and losses (radiation, collisional quenching and transport). Figure 2 shows how the ionospheric density of O^+ varies with height and time, for 1 s input flux of 1 mW/m² at four different energies. Low energies give a higher brightness and longer decay times (Figure 3).

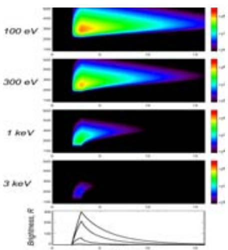


Figure 2 (left): n(O^+ ^2P) vs. height and time, for four different input energies. Bottom panel: Brightness vs. time for the four spectra.

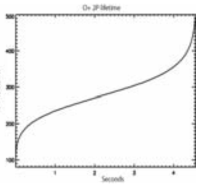


Figure 3: The lifetime of the O^+ emission varies with altitude.

Estimating drifts in the ionosphere

An estimation of whether and how fast the metastable O^+ population drifts away from the production site has been made for the 9 Nov event. Figure 4 shows the region of interest (ROI), where a "blob" of O^+ ^2P afterglow was detected. This figure also shows the region of background that was subtracted from the image. By calculating the position of the centre of mass of the afterglowing blob for each frame, we can trace its movement.

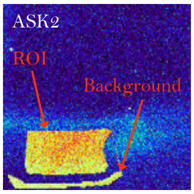


Figure 4: ASK2 image with ROI.

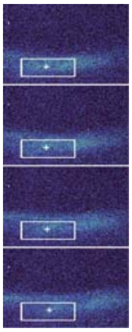


Figure 5: Movement of the centre of mass in the ROI.

The centre of mass is marked with a cross in our ROI for 4 consecutive ASK2 images in Figure 5. The position is also plotted in Figure 6, where the black curve is the position in x-direction and red in y-direction.

A measured drift of 6 pixels/30 frames gives a drift velocity of 230 m/s in the west direction, with the ASK FOV of 3° and assuming that the height of emission is 300 km.

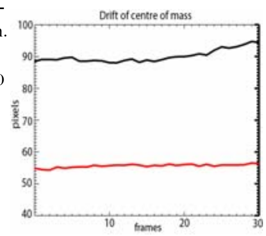


Figure 5: x- and y-drift of centre of mass.

Summary

Three events with clear afterglows in the metastable O^+ ion have been analysed. In all three cases the 7320 Å emission in ASK2 has a detected afterglow of up to several seconds, compared to the prompt 7774 Å (ASK3) emission. The decay and drift of the O^+ ion was investigated, and a time-dependent ion chemistry and electron transport model is used to model the brightness of the O^+ emission as a function of energy, and the altitude dependence of its lifetime.

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