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High-Latitude Artificial Aurora from EISCAT: An Unique Phenomenon?

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Abstract. The EISCAT HF-facility is capable of transmitting up to 210 MW of effective radiated power into the ionosphere around 4 MHz. Beam swinging experiments have been undertaken with O- and X-mode transmissions. During O-mode pumping soon after sunset, F-region electrons were accelerated sufficiently to excite the oxygen atoms, resulting in observable optical emissions. It has been found that the O^1D emission at 630 nm appears near the magnetic field aligned direction regardless of the HF transmitter beam pointing direction. This is not consistent with similar lower latitude observations. The strongest optical emission is produced when HF-pumping is approximately along the magnetic field line direction. This geometric phenomenon is presented for the first time and suggests that the magnetic field orientation is important for the mechanism of high-latitude artificial aurora. X-mode pumping does not produce an artificial aurora.

1 Introduction

Man-made ionospheric optical emissions at 630 nm have been produced at mid-latitudes by high-power HF-pump facilities such as Platteville (Haslett and Megill, 1974), Moscow (Adeishvili et al., 1978), Arecibo (e.g. Sipler et al. (1972), Gordon and Carlson (1974) and Bernhardt et al. (1988)) and Sura near Vasilsurk (Bernhardt et al., 1991). The first high-latitude attempts at Tromsø (Stubbe et el., 1982) were inconclusive (Henriksen et al., 1984). The first unambiguous detection of a high-latitude artificial aurora occurred on 16 February 1999 using the EISCAT HF-facility (Rietveld et al., 1993) and the ALIS camera system (Brändström et al., 1999) in northern Scandinavia. This was followed by the second successful detection on 21 February 1999 (Kosch et al., 2000) using DASI (Kosch et al., 1998). Kosch et al. (2000) first noticed that the optical emission came from the direction of the magnetic field line despite HF pumping in the zenith. This result has been confirmed by the third observation of high-latitude artificial aurora on 18 March 1999 by the HAARP facility in Alaska, USA (Pedersen and Carlson, 2001). The unexpected displacement of high-latitude artificial aurora towards the magnetic field line direction partially explains the lack of success of earlier high-latitude detection attempts, which used narrow field-of-view photometers orientated towards the zenith or poleward of the HF-facility.

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We present the first optical data from beam-swinging experiments where the O-mode HF beam was stepped in zenith angle along the magnetic meridian from 24° south to 12° north. At Tromsø the magnetic field direction is ∼12° south of zenith. The first high-latitude optical observations from X-mode pumping are also presented. Fig. 1 show the geometric arrangement of the experiments on a map of northern Scandinavia. The EISCAT HF-facility is located at Ramfjord (69.59° N, 19.23° E) and DASI is located at Skibotn (69.35° N, 20.36° E) in Norway. The separation between Ramfjord and Skibotn is 50 km, which gives a near co-aligned view of the artificial aurora (see inset) for a typical emission altitude of 200-300 km.

2 Observations and Discussion

Fig. 2 shows uncalibrated DASI images from 24 February 2001 using a narrow-band 630 nm interference filter and 10 sec integration. The filter bandwidth of 2.5 nm makes the star field invisible except for a few very bright stars. The HF beam was directed along the magnetic field direction at Ramfjord and continuous wave (CW) pumping occurred at 4.9128 MHz with an effective radiated power (ERP) of 50 MW. DASI was pointing into the zenith at Skibotn. The field of view of the circular images is 50° with south and east at the top and right of the images, respectively. Each panel is labelled according to the start time of the 10 sec integration. The images are arranged in 5 strips, with each strip labelled according to the activity of the HF transmitter. For O-mode pumping the artificial aurora appears as a diffuse blob south-

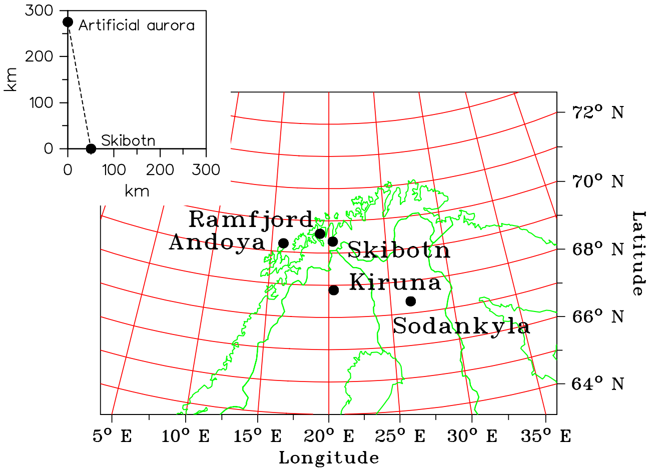

Fig. 1. The geometric arrangement of the experiments on a map of northern Scandinavia. The EISCAT HF-facility is located at Ramfjord and DASI is located at Skibotn in Norway with a separation of 50 km. The inset shows the near-vertical view of the artificial aurora for a typical emission altitude of 200-300 km.

west of Skibotn. Although Ramfjord is northwest of Skibotn, when the HF beam is tilted southward along the magnetic field line, the artificial aurora appears to the southwest from the perspective of Skibotn. The time separation between images is 120 sec, which indicates that a stable optical emission can be produced over 10 minute intervals. The fading of the optical emission during O-mode transmissions around 19:46 UT is due to foF2 falling below the pump frequency. No detectable artificial aurora is present during X-mode pumping and these images appear identical to the period of no HF transmissions, which are shown for comparison. It is well established that the X-mode reflection altitude is always below that of the O-mode wave. The lack of any observable optical emission is probably due to the fact that the X-mode does not reach the critical height or the upper-hybrid resonance height where instabilities and subsequent electron heating or acceleration are possible. In addition, the increased N_2 density at lower altitudes effectively prevents emission of the O^1D photon by quenching.

Fig. 3 shows DASI images from 17 February 2001 in the same format as fig. 2. The HF beam zenith angle was redirected along the magnetic meridian at Ramfjord in 6° steps every 120 sec. The limits of the scan were zenith and 24° south. CW O-mode pumping occurred at 4.04 MHz with an ERP of 40 MW. Each image is the last 10 sec integration for each beam position, giving the most stable and intense optical emission. It is clearly seen that the artificial aurora is brightest at 12° south, which corresponds to the magnetic field direction. It is also clear that the optical emission remains stationary in space as seen from Skibotn. If the artificial aurora came only from within the HF beam, the movement of the optical emission would be very easily detected since the scan covers 24° in zenith angle and the images have a 50° field of view.

Fig. 4 shows DASI images from 3 November 2000 in the same format as fig. 3. except the limits of the scan were 12° south and 12° north and the O-mode ERP was 120 MW. The scan to the north was performed in order to simulate previous lower latitude experiments where the magnetic field inclination is large (e.g. 45° at Arecibo). It is clearly seen that there is no detectable optical emission to the north of the scan. The artificial aurora is obviously most intense towards the magnetic field direction (∼12° S).

Since the initial observation in February 1999, successful recordings of the artificial aurora have been repeated in March and October 1999, March and November 2000, February and November 2001, and more campaigns are planned. Experience indicates that the following conditions must be met: (1) Cloud-free viewing, (2) Sun zenith angle greater than 99°, (3) Zero natural aurora within the pumping volume, (4) $K_p \leq 2$, (5) Pump frequency less than foF2, and (6) HF reflection height ∼200-350 km. Points 1 and 2 simply relate to observing conditions. Points 3 and 4 stem from the fact that the artificial aurora is much weaker (∼100 Rayleighs) than the natural aurora (kilo-Rayleighs). Point 5 is a necessary condition otherwise the HF pump wave simply passes through the ionosphere with little effect. The 4 MHz minimum frequency of the EISCAT HF facility poses a significant limitation to artificial aurora experiments, which have only succeeded within 2-3 hours of sunset around solar maximum because of this. At other times, foF2 > 4 MHz generally only occurs as the result of auroral precipitation, which makes the optical detection of the artificial aurora impossible. Point 6 appears to relate to the O and N_2 density. The O^1D emission at 630 nm is stimulated by electrons with energies above the 1.96 eV although the effective threshold to excite the O^1D state is ∼3-3.5 eV due to quenching by N_2 (Haslett and Megill, 1974). Below 200 km, the increasing N_2 density seems to effectively quench the O^1D excited state resulting in no photon emission. Above 350 km, the density of O seems to be too low to produce a detectable optical emission because most of the energised electrons travel too far before colliding with an O atom, resulting in an extremely diffuse artificial aurora. Sometimes, despite all the necessary conditions for artificial aurora being met, no detectable optical emission can be produced. We speculate that the ratio O/N_2 and its variations with geomagnetic activity may provide a clue as N_2 quenches the O^1D excited state. This is currently the subject of a modelling investigation.

3 Conclusions

The artificial aurora appears near the magnetic field direction at Tromsø regardless of the pointing direction of the HF pump beam. The O^1D emission is brightest when pumping close to the magnetic field direction. When pumping at zenith angles poleward of the HF-facility the artificial aurora cannot be detected. These observations are novel and are reported here for the first time. X-mode HF pumping produces no observable optical emission, probably because the HF reflection altitude is too low coupled with N_2 quenching. This

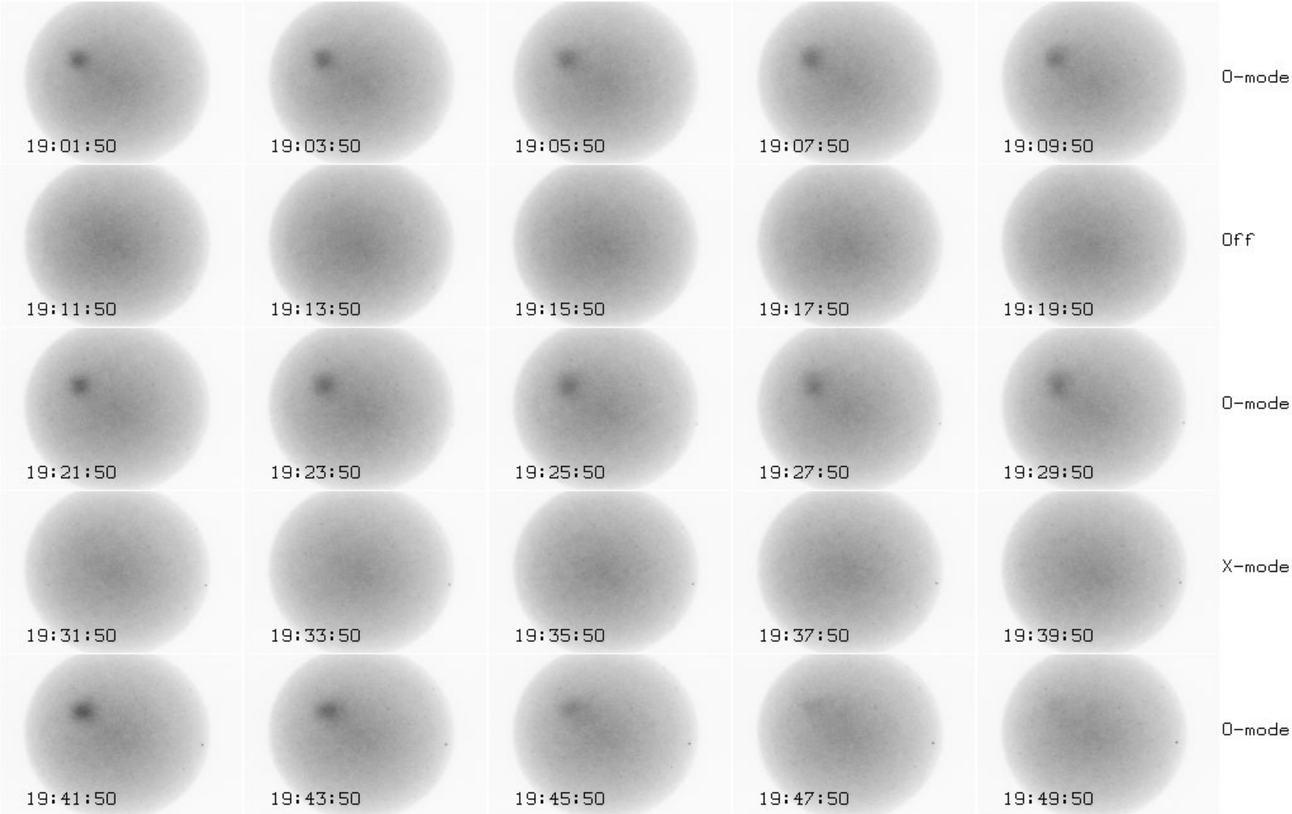

Fig. 2. Uncalibrated DASI images from 24 February 2001 at 630 nm and 10 sec integration. The camera orientation is into the zenith at Skibotn with south and east at the top and right of the images, respectively. The field of view of the circular images is 50°. Each panel is labelled according to the start time of the integration. The images are arranged in 5 strips, with each strip labelled according to the activity of the HF transmitter.

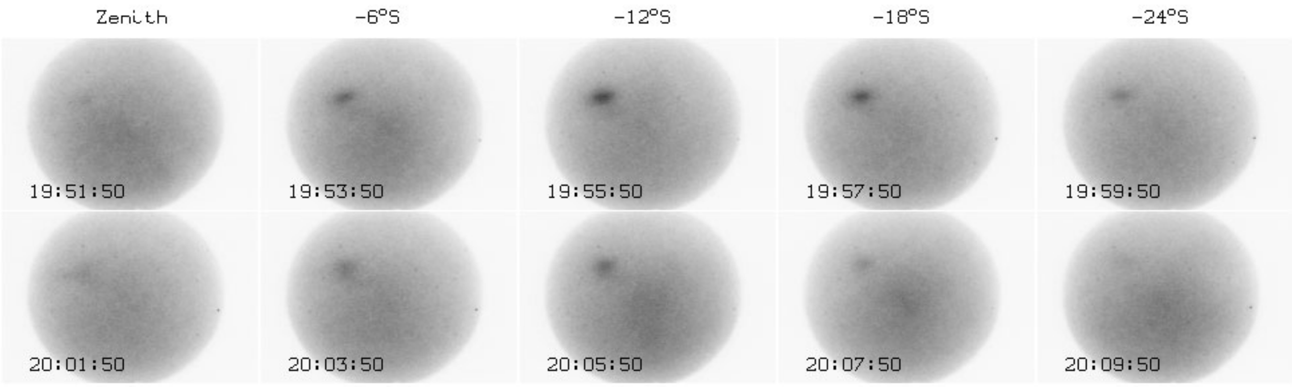

Fig. 3. DASI images from 17 February 2001 in the same format as fig. 2. The images are arranged in 2 strips, with each column labelled according to the pointing directions of the HF beam.

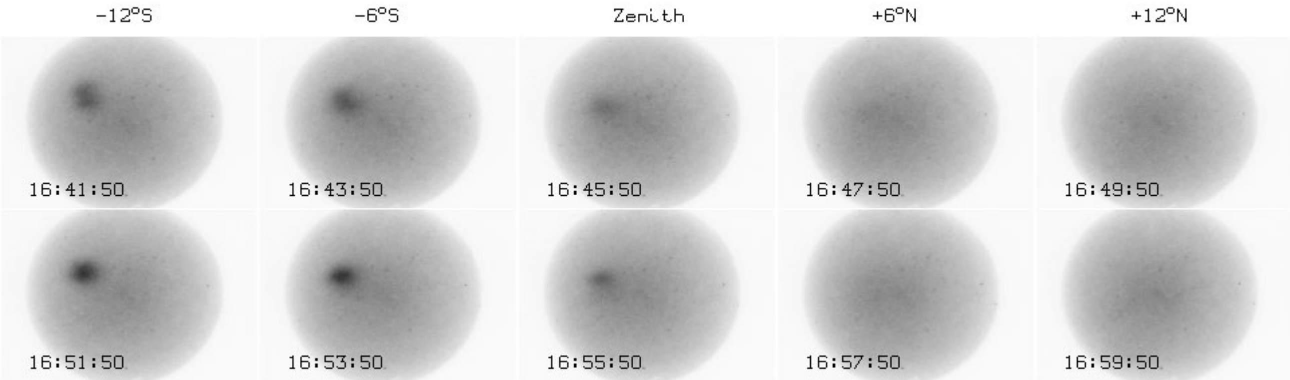

Fig. 4. DASI images from 3 November 2000 in the same format as fig. 2. The images are arranged in 2 strips, with each column labelled according to the pointing directions of the HF beam.

is consistent with previous experiments.

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