HIGH-LATITUDE ARTIFICIAL AURORA USING THE EISCAT HIGH-GAIN HF FACILITY

M. J. Kosch(1), M. T. Rietveld(2), A. J. Kavanagh(1), J. Jussila(3), B. Isham(4), K. Kaila(3), I. W. McCrea(5), A. Senior(1), H. Holma(3), F. Honary(1) and T. Hagfors(2)

(1)University of Lancaster, Lancaster LA1 4YR, UK, m.kosch@lancster.ac.uk
(2)Max-Planck-Institut für Aeronomie, 37191 Katlenburg-Lindau, Germany
(3)University of Oulu, FIN-90014 Oulu, Finland
(4)EISCAT Scientific Association, N-9027 Ramfjordbotn, Norway
(5)Rutherford Appleton Laboratory, Didcot OX11 0QX, UK

ABSTRACT

The EISCAT high-frequency (HF) transmitter facility at Ramfjord, Norway, has been used to accelerate F-region electrons sufficiently to excite the oxygen atoms and nitrogen molecules, resulting in optical emissions at 630, 557.7 and 427.8 nm. During O-mode transmissions at 5.423 MHz, using 630 MW effective radiated power, in the hours after sunset on 12 November 2001 several new observations were made, including: (1) The first high-latitude observation of an HF induced optical emission at 427.8 nm and (2) Optical rings being formed at HF on followed by their collapse into a central blob. Both discoveries remain unexplained with current theories.

INTRODUCTION

The typical airglow/auroral optical emissions for oxygen atoms are O^1D (630 nm) and O^1S (557.7 nm), which are stimulated by electrons with energies above 1.96 and 4.17 eV threshold, respectively, neglecting nitrogen quenching. The N_2^+ optical emission (427.8 nm) is stimulated by electrons with energies above 30 eV. It has been known since the early 1970s that high-frequency (HF) pumping can induce optical emissions in the F layer [1,2] at mid- and low latitudes. However, attempts to produce similar effects at high latitudes [3] were inconclusive [4] until 1999 [5,6]. Since then numerous HF induced optical emissions have been observed using the EISCAT HF facility [7] at Ramfjord (69.59° N, 19.23° E), Norway. These have always used O-mode waves up to 200 MW effective radiated power (ERP) from the broad beam (full width at half maximum (FWHM) = 15°) low-gain transmitting antenna array. Here we report the first observations from the high-gain aerial array, which offers not only a greater ERP but also a narrower beam width (FWHM = 7°). The magnetic dip angle for EISCAT is 12.8° at a geographic azimuth of 183.3°.

Fig. 1. shows the basic geometry of the artificial aurora experiments on a map of northern Scandinavia. The Digital All-Sky Imager (DASI) is located at Skibotn (69.35° N, 20.36° E) about 50 km south-east of Ramfjord. This separation gives a near co-aligned view of the artificial aurora (see inset) for a typical emission altitude of 200-300 km. Skibotn is the location of choice over Ramfjord for optical recordings because of its superior dark sky viewing conditions. In addition, being off the transmitter site aids in altitude triangulation studies of the HF induced aurora. For these campaigns DASI observes in the local zenith with a 45° field-of-view lens. In addition, a multi-channel meridian-scanning auroral photometer system was located at Ramfjord alongside a CCD camera.

OBSERVATIONS

During the artificial aurora campaign on 12 November 2001 there was a very stable ionosphere after sunset with foF2 up to 8 MHz despite no detectable natural electron precipitation. It is often true that foF2 is less than 4 MHz when the sky gets dark enough to start optical recordings (sun > 9° below the horizon). This unusual occurrence may be due to the experiment occurring during a solar proton event. The ACE satellite data shows high fluxes of MeV protons in the solar wind during this period. The GOES-8 satellite confirms that 12 November was during the declining phase of a solar proton event (maximum 0215 UT, 6 November), which did not reach background levels before the end of the campaign. The high foF2 permitted the high-gain HF facility, which only operates above 5.4 MHz, to be used for the first time to produce an artificial aurora. Optical observations co-located with the HF facility were made using narrow field-of-view photometers operating at 427.8, 557.7 and 630 nm (as well as the H-beta emission), which were scanning between 45° south and 30° north zenith angle, and a white-light CCD imager operating on a 15 s cycle. In addition, wavelengthselective images of the artificial aurora were made at 557.7 and 630 nm from Skibotn using 5 s and 10 s integrations, respectively.

On 12 November 2001, the HF facility was operated at 5.423 MHz transmitting O-mode waves with 630 MW ERP. The HF transmitters were cycled continuously with 2 min on and 2 min off. The HF beam pointing direction was swept in 3° steps along the geographic meridian for zenith angles from 3° north to 15° south, spending each HF on cycle at one position. The EISCAT UHF radar measured electron density as well as electron and ion temperatures with a 5-km range resolution throughout the E and F layers. Large enhancements in backscatter power (up to a factor of 2), apparent electron temperature (a few thousand Kelvin) [8] and ion temperature (a few hundred Kelvin) occurred during HF pumping. Stimulated electromagnetic emissions (SEE) were also recorded to establish the spectra of the HF induced waves. During this campaign the HF pump frequency was near the 4th electron gyroharmonic. Several new optical observations were made which differ from previous low-gain (ERP < 200 MW) HF induced aurora experiments. They include the following:

(1) The first observation of an high-latitude artificial optical emission at 427.8 nm has been made using photometers. The measurement proves that a significant number of electrons are accelerated to energies above 30 eV. Achieving such high energies is indicative of an electron acceleration mechanism that is non-thermal. The variations in apparent electron density (up to a factor of 2) during HF pump cycling, which relate directly to incoherent backscatter power in the UHF radar data, are probably unrealistic. This is a clear sign that the analysis of the incoherent scatter data, which relies on a Maxwellian model, has encountered non-thermal spectra.

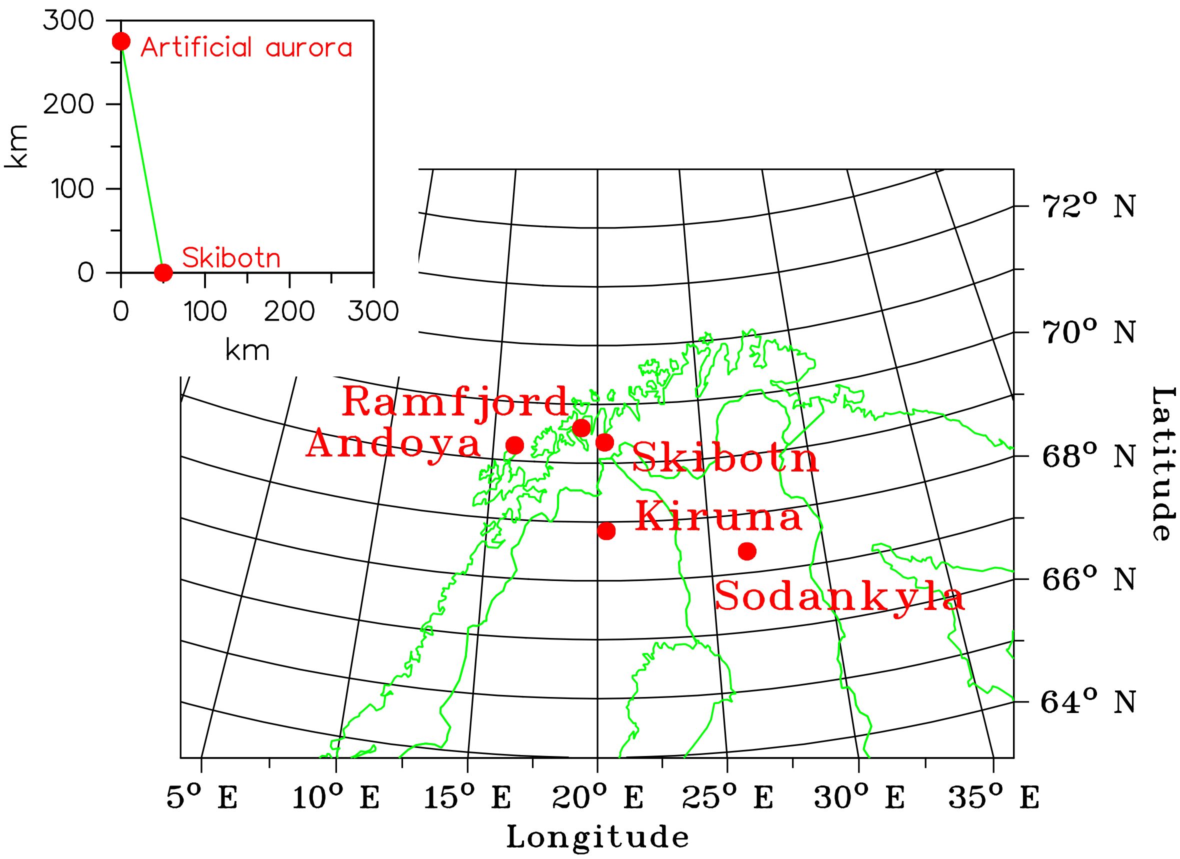

Fig. 1. The geometric arrangement of artificial aurora experiments on a map of northern Scandinavia. The EISCAT HF facility, auroral photometer system and white-light CCD camera are located near Ramfjord and DASI is located at Skibotn in Norway. The inset shows the near-vertical view of the artificial aurora for a typical emission altitude of 200-300 km.

(2) Swinging the HF transmitter beam in the north-south meridian results in the optical emission following the beam. Many previous observations of low-gain HF pumping show that the optical emission usually remains close to the magnetic field line direction regardless of the beam pointing direction [6]. This new result may indicate differences in the mechanism of artificial aurora depending on the HF power or frequency used.

(3) Novel observations have been made of optical rings being formed at HF on followed by their collapse into a central blob. Fig. 2 shows a sequence of DASI images from 12 November 2001 at 557.7 nm and 5 s integration. The camera's 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 45^o. Each panel is labelled according to the start of the integration. The sequence of images shows the 2 min HF on starting at 16:25 UT with the HF beam pointing at 9^o south zenith angle. Note the immediate development of a well defined ring structure, which then collapses into the more standard blob shape before the HF wave is turned off (16:27 UT). This phenomenon occurred many times but only at one special zenith angle (9^o south) and has never been observed with low-gain HF pumping. The optical rings sometimes show striations similar to the corona effect in natural aurora, which may indicate some vertical extent in the artificial aurora. The DASI image data for 630 nm and the white-light CCD images from Ramfjord show the same morphology. No image data for the 427.8 nm nitrogen emission was available. A ring-shaped formation has been reported once before [2], however, this singular structure evolved from an existing artificial emission region. The phenomenon remains unexplained.

CONCLUSIONS

Unique observations of HF induced optical emissions have been obtained using the EISCAT HF facility at a very high ERP of 630 MW whilst pumping close to the 4th electron gyroharmonic. Three unique optical observations have been made: (1) the first 427.8 nm observation, which is a strong indicator that non-thermal processes are taking place, (2) the optical emission moves with the HF beam, which does not happen for an ERP < 200 MW, and (3) optical ring structures may form which then collapse into blobs, a phenomenon which currently defies explanation.

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Fig. 2. Uncalibrated DASI images from 12 November 2001 at 557.7 nm and 5 s integration. The camera's 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 45^o. Each panel is labelled according to the start of the integration. The sequence of images shows the 2 min HF on starting at 16:25 UT. The HF beam pointing direction is 9^o south zenith angle.

12/11/01 5577 45° field of view East-RHS South-TOP

Start time - 16:25:00 UT Integration - 05 sec Step - 05 sec