Stimulated Brillouin Scattering During Electron Gyro-Harmonic Heating at EISCAT

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ABSTRACT

Observations of secondary radiation, Stimulated Electromagnetic Emission (SEE), produced during ionospheric modification experiments using ground-based high-power high frequency HF radio waves are considered. The High Frequency Active Auroral Research Program (HAARP) facility is capable of generating narrowband SEE in the form of Stimulated Brillouin scatter SBS and Stimulated Ion Bernstein scatter SIBS in the SEE spectrum. Such narrowband SEE spectral lines have not been reported using the European Incoherent scatter (EISCAT) heater facility before. Our work reports the first EISCAT results of narrowband SEE spectra within 1kHz of the pump frequency during electron gyro-harmonic heating. Also, simultaneous measurement of electron temperature by EISCAT/UHF radar and field aligned irregularities by CUTLASS HF radar are discussed. The narrowband SEE features observed at EISCAT are compared to those previously observed at HAARP during electron gyro-harmonic heating for varying heater antenna beam angles as well. The EISCAT narrowband SEE observations have consistencies with Stimulated Brillouin Scatter observed at HAARP.

1. INTRODUCTION

Ionospheric plasma turbulence can be created by injection of powerful high-frequency (HF) radio waves from ground based transmitters. The interaction between high power electromagnetic waves and plasmas in the ionosphere can produce stimulated electromagnetic emissions (SEEs) [*Leyser*, *2001*]. Recently, the first experimental detection of stimulated Brillouin scattering (SBS) during ionospheric modification experiment with high power radio waves was reported using the HAARP transmitter in Alaska [*Norin et al., 2009*]. Subsequent experiments have provided additional verification of this process and quantitative interpretation of the scattered wave frequency offset to yield measurement of the electron temperature in the heated region of the ionosphere [*Bernhardt et a.,* 2009]. The SBS electrostatic ion cyclotron (EIC) emission has also been successfully measured at the HAARP facility with oblique wave propagation angles and utilized for other important diagnostic purposes [*Bernhardt et al.,* 2010; *Bordikar et al.,* 2013; *Mahmoudian et al.,*2014]. The SBS for different aspect beam angles relative to the magnetic field has been studied near electron gyro-harmonic [*Fu et al.,* 2013]. The threshold for exciting SBS has been studied at HAARP [*Mahmoudian et al.,* 2013]. It was reported that SBS can be excited using the lower power EISCAT HF transmitter as well [*Fu et al.,* 2014]. The paper compares SBS near the third electron gyro-harmonic $3f_{ce}$ at EISCAT and at HAARP.

2. OBSERVATIONS

The EISCAT HF facility (69.59°N, 19.23°E) near Tromsø, in Northern Norway, was used to produce SEE during a campaign on July 3-10, 2012. The HF transmitter operated at O-mode polarization during experiments. The pump frequency was stepped upward and downward through the third harmonic of the ionospheric electron gyrofrequency $3f_{ce}$. The heater duty cycle was typically 1 minute on and 1 minute off. All 12 transmitters on array 2 were used at 80kW each, resulting in a gain of 22.4dBi and the effective radiated power (ERP) approximately 148 MW. The SEE receiver was installed near Breivikeidet, Norway (69.64 deg. N, 19.49 deg. E), about 13 km ENE of the EISCAT site. The diagnostics data were also collected simultaneously by the CUTLASS SuperDARN radar facility on Finland and EISCAT 931MHz UHF incoherent scatter radar for electron temperature measurement.

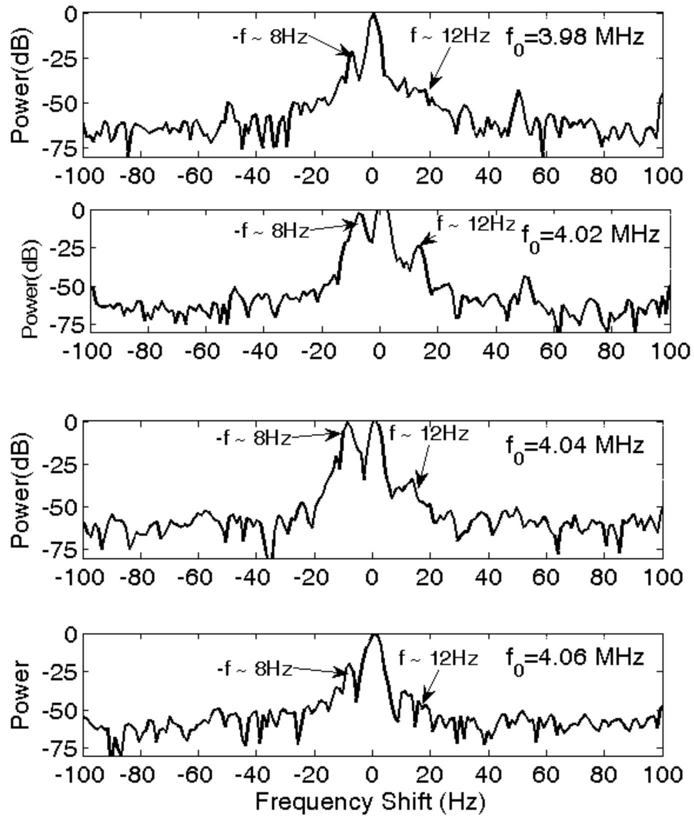

Figure 1. Measured frequency spectra of radio emissions from the EISCAT transmitter near $3f_{ce}$ for the magnetic zenith pumping during 19:20 -19:32 UT on July 3, 2012

Figure 1 shows narrowband frequency spectra of the scattered HF pump wave at EISCAT for heating near the third electron gyro-harmonic frequency $3f_{ce}$ during 19 : 20−19 : 32 UT on July 3, 2012. The EISCAT HF transmitter operates with an effective radiated power (ERP) 148MW for the magnetic zenith beam. Dynasonde data at 19:28 UT on July 3, 2012 indicates quiet ionospheric status. The reflection altitude for the pump frequency 4.04MHz is approximately ~ 215km according to Dynasonde data. Strong emissions downshifted by ~ 8Hz and upshifted by ~ 12Hz in the spectra are clearly observed in Fig. 1. The power of the downshifted (or Stokes) emission line is larger than the upshifted (anti-Stokes) emission. These shifted spectral lines observed in Fig.1 show similar frequency shift and relative amplitude of Stokes and anti-Stokes lines when compared to experimental observations at HAARP as will be shown in Fig. 3. (e. g., *Norin et al.*, 2009; *Bernhardt et al.*, 2009).

The strength of observed sideband emissions in Fig. 1 depends on the EM pump wave frequency as well. During the frequency sweeping, the strongest SBS emissions were observed at pump frequencies 4.04MHz, 4.02MHz and 4.00MHz, relatively close to $3f_{ce}$. The frequency dependence of the emission may be attributed to the EISCAT HF transmitter power being near the threshold for excitation. It may be postulated that when less anomalous absorption occurs near 3fce, more heater power can be transmitted to a higher resonance altitude where SBS occurs. Anomalous absorption is due to scattering of the electromagnetic waves on FAI with a wide spatial spectrum. For pump frequency near nf_{ce} (n = 3,4), FAI intensity is minimum and there is minimum anomalous absorption (Leyser, 2001).

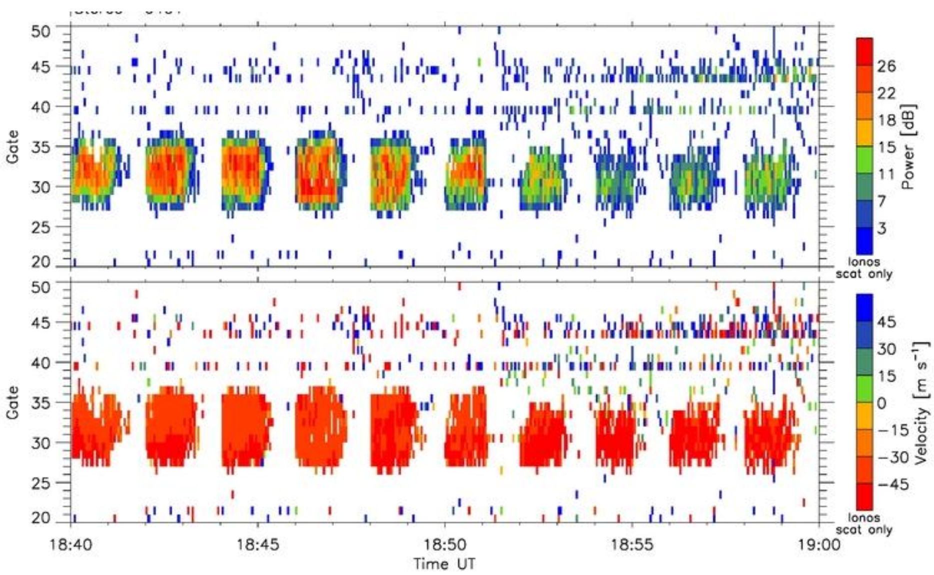

Figure 2. CUTLASS backscatter power, Doppler velocity, versus slant range in the heating region over EISCAT during one minute on (e. g. 18:44-18:45) and one minute off (e. g. 18:45-18:46) duty cycle during 18:40-19:00 UT on July 3, 2012.

Figure 2 shows the CUTLASS backscatter power and the Doppler velocity from beam 5, Hankasalmi radar. The backscattered signals are produced by Bragg scattering of the sounding waves from pre-existing or pump induced field-aligned striations. Only 13.2MHz corresponds to strong backscatter from FAIs of wavelength ~ 11m.When the pump frequency approaches 4.04MHz during the time period 18 : 52−18 : 53, there is a clear reduction observed in the backscatter power from a peak of 30dB to approximately15dB. There exists a minimum of the backscatter power during the time periods 18 : 54−18 : 55 (f_0 = 4.06MHz) and 18 : 56−18 : 57 (f_0 = 4.08MHz). The suppression of FAIs near $3f_{ce}$ makes more power available to reach the plasma resonance region for exciting SBS.

The strength of the SBS f_l emission line also depends on the heater aspect angle relative to the magnetic field. Figure 3 shows narrowband frequency spectra of the scattered HF pump wave at HAARP provided for comparison purposes with the EISCAT results operating at 4.2 MHz for different aspect angles during UT 4 :15−4 : 60 UT on July 22, 2010. The frequency shift of SBS emissions are downshifted by ~ 8 Hz, which amplitude is stronger than that for the upshifted emission ~12Hz. Experimental results indicate that the maximum SBS usually occurs between the zenith angle 14° (along the magnetic field line) and 21° (7 degree off the magnetic field line). As the beam angle is tilted further for the zenith angle 28°, more emissions appear, including the second emission ~26 Hz and the third emission ~ 52 Hz above the ion gyro-frequency for the dominant ion species O+ in the heated ionospheric regions.

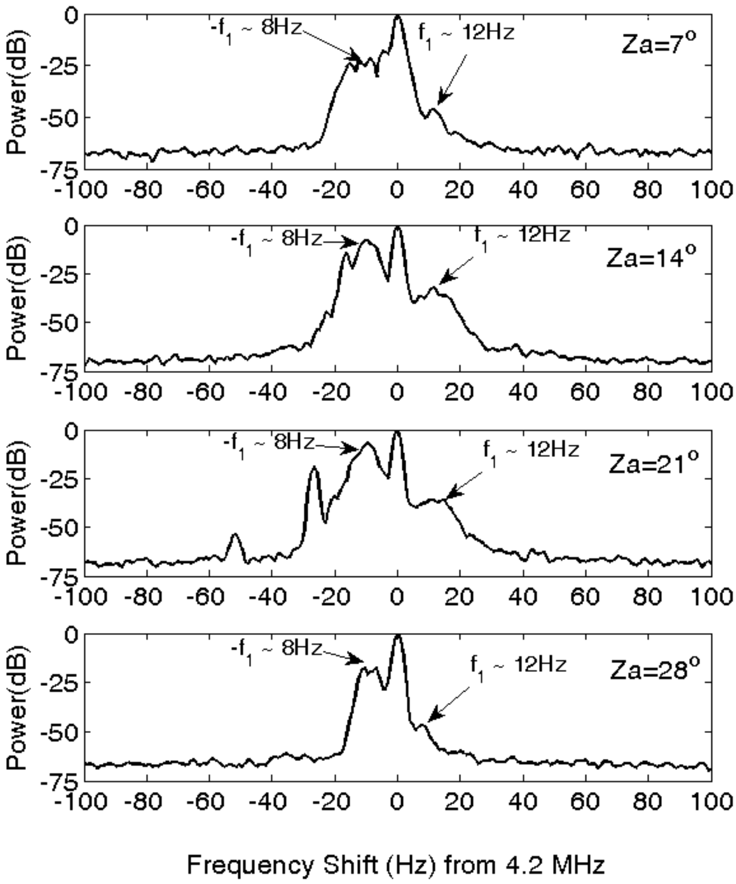

Figure 3. Measured frequency spectra of radio emissions from the HAARP at 4.2 MHz relatively close to $3f_{ce}$ for different heater beam angles 14° (for the magnetic zenith) during 04:15-04:60 UT on July 22, 2010.

3. CONCLUSIONS

In summary, we compared SBS observations at EISCAT with that at HAARP near the third electron gyro-harmonic $3f_{ce}$. It is concluded that EISCAT HF heating facility can generate SBS emissions as well. We demonstrated that SBS depends on the wave propagation angle relative to magnetic field, the pump power and the pump frequency near electron gyro-harmonic. Further experiments are needed at EISCAT to demonstrate alignment with other aspects of the behavior of SBS observed at HAARP.

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