HF Stimulated Electromagnetic Emissions and Radar Observations of Ionospheric Heating from HAARP

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Abstract

High power radio waves excite electrostatic waves in the ionosphere. Electrostatic waves can be detected either by mode conversion into Stimulated Electromagnetic Emission (SEE) or scatter of radar signals. We present the results of SEE observations conducted through high-power HF heating experiments at the High-Frequency Active Auroral Research Program. Multiple receiving instruments have been used to observe many low frequency electrostatic modes from a high power electromagnetic pump. These modes are not well characterized. Our ionospheric heating experiments are attempts to understand the process by which an electromagnetic pump wave is converted into high and low-frequency modes.

1. Introduction

The Earth's ionosphere has been studied extensively through the use of radio frequency observations. Typical techniques such as UHF Incoherent Scatter Radar (ISR) or ionosondes use reflected radio waves to observe the ionosphere in its natural state. In contrast, the technique of ionospheric heating uses high power HF waves to artificially excite the ionosphere. This technique allows for a fully repeatable experiment making the ionosphere a large scale plasma physics laboratory. These experiments provide opportunities to observe non-linear wave interactions in a plasma environment. The High-Frequency Active Auroral Research Program (HAARP) facility located in Gakona, AK (USA) is the largest such heating facility in the world. HAARP is able to transmit between 2.8 to 10 MHz up to 3.6 MW total power.

One of the goals of our HAARP experiments is the generation electrostatic waves in the ionosphere. These wave can be observed directly using in situ plasma wave receivers on satellites, and indirectly with Stimulated Electromagnetic Emission (SEE) and UHF radar scatter. SEE is generated when the high power HF transmitted wave reaches the portion of the ionosphere where the plasma frequency is equal to the transmit frequency. The pump wave then parametrically decays into a low frequency electrostatic wave and a high frequency electrostatic or electromagnetic wave. The parametric decay products may be detected with radar scatter of the waves. The 446 MHz Modular UHF Ionospheric Radar (MUIR) located at the HAARP facility has detected scatter from both electron plasma and ion acoustic waves. Scatter from other modes is being attempted. Figure 1 is an illustration of the multi-instrument observation process.

The low frequency wave product of parametric decay can be an electrostatic ion-cyclotron wave, a slow magnetosonic wave below the ion gyro frequency, an ion-acoustic wave above the ion gyro frequency, or a lower hybrid wave. These low frequency waves are detected by stimulated electromagnetic emission as downshifted offsets from the HF pump frequency. A ground HF antenna feeds software-based HF receiver to capture the SEE signals with 100 dB dynamic range.

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Frequency analysis of the stored data provides a spectrum that allows identification of the modes in the ionosphere.

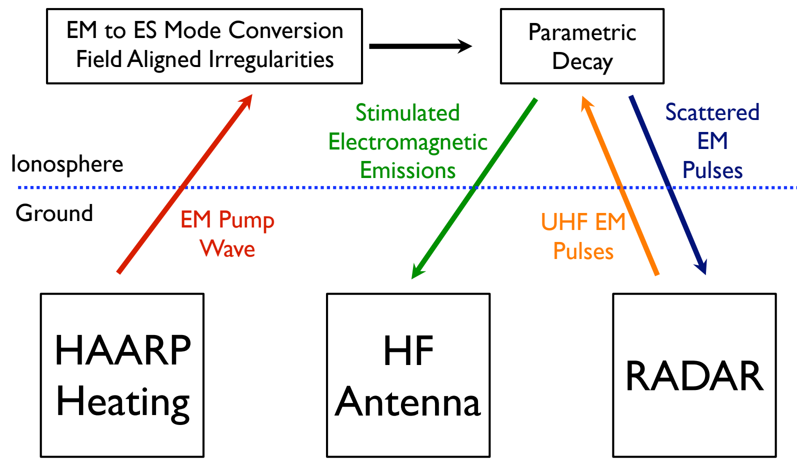

Figure 1. Ground diagnostics for Stimulated Electromagnetic Emission (SEE) in the ionosphere.

When the HF pump wave is tuned near the second harmonic of the electron cyclotron frequency in the ionosphere, there is strong evidence that the electron Bernstein and ion Bernstein modes are excited [1, 2]. The stimulated electromagnetic emission spectra shows a comb spectrum with downshifted harmonics of the ion cyclotron frequency (Figure 2).

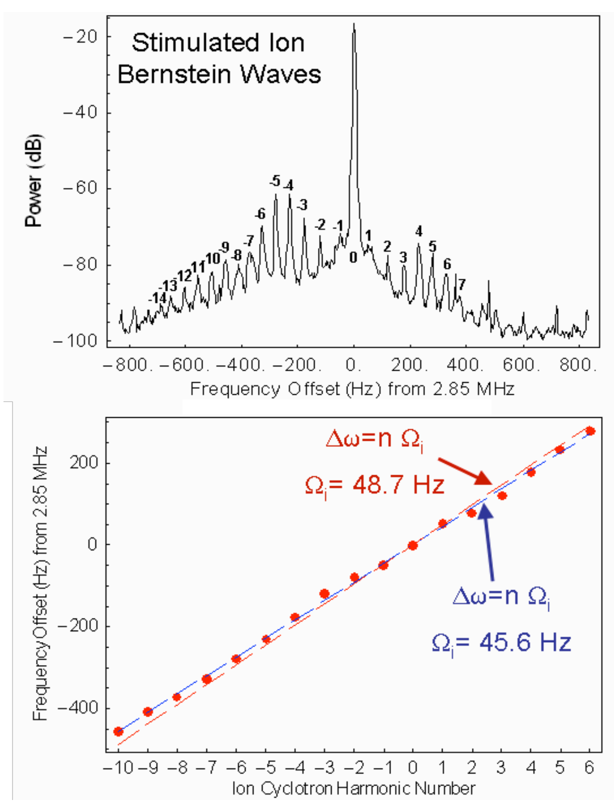

Figure 2. Measured stimulated ion Bernstein wave spectra produced by the HAARP transmitter operating at the second electron cyclotron harmonic in the ionosphere. The spectral lines are separated by 45.6 Hz and the computed ion cyclotron frequency is 48.7 Hz near the 2.85 MHz reflection point in the ionosphere.

While SEE associated with the upper hybrid waves and field aligned irregularities have frequently been observed at HAARP, electron Bernstein waves are much harder to generate. Recent experiments at HAARP have produced multiple ion-Bernstein modes that are thought to be the parallel parametric decay of an electron-Bernstein wave [2, 3]. Experiments were conducted at HAARP to specifically generate the ion-Bernstein modes. Since these decay products are not well understood, an additional purpose of the HAARP experiment was to better characterize the parametric decay of the pump wave into modes by using UHF radar scatter from the low-frequency electrostatic waves.

Another series of experiments were conducted to better understand how the pump wave parametrically decays. Under certain conditions the pump waves directly scatter into other EM waves by the Magnetized Stimulated Brillouin Scatter (MSBS) process. In MSBS the pump wave decays into an electromagnetic mode and a low-frequency electrostatic wave. The conditions for initiating MSBS are not well defined so our experiments have been designed better characterize the scatter. In one series of experiments, the power was varied in an effort to determine the threshold for the onset of MSBS. Additional experiments were designed to determine if there was any aspect sensitivity for MSBS by changing the orientation of the HAARP HF beam with respect to the Earth's magnetic field lines.

2. Experimental Setup

The experiments discussed here were conducted between 18-22 July 2010 at the HAARP heating facility in Gakona, AK. High power HF waves were transmitted at HAARP at maximum power (3.6 MW) between 2.8 and 5.0 MHz. In all of the experiments were run with patterns of 30 seconds ON and 3o seconds OFF. Observations were collected with different instruments from several locations in Alaska. MUIR is a phased array radar able to record the enhanced plasma or ion lines produced by HAARP transmissions in the F-region ionosphere. A 998 μs uncoded pulse was transmitted with a sampling rate of 100 kHz. The inter pulse period (IPP) was 10 ms. HF backscatter from field aligned irregularities is provided by the SuperDARN radar installate on Kodiak Island, AK. This radar uses 7 degree radar beams to observe the heated region of HAARP. The SuperDARN radar is able to detect the buildup of Field Aligned Irregularities (FAIs) using HF backscatter. A direct digitizing HF receiver was also set up seven kilometers from the HAARP installation to collect HF signals of stimulated electromagnetic emissions. This HF receiver is the primary diagnostic for detecting EM emissions the result from parametric decay.

3. Results

For heating experiments, HF backscatter from Field-Aligned Irregularities (FAI) was observed. Figure 1 shows a typical range-time-intensity plot of FAIs using the SuperDARN HF radar. The short heating cycle did not provide enough time for the relaxation of the ionosphere between successive excitations. The enhanced plasma and ion lines were detected with MUIR. Figure 3 shows a typical example of the enhanced plasma line generated by HAARP heating. SEE was analyzed for all times with positive MUIR results. The SEE detected was part of a broad continuum spanning several orders of magnitude in frequency. Electron-Bernstein and ion-Bernstein modes were also detected and correlated to radar observations.

The July campaign revealed that MSBS is dependent on the relative position of the HAARP heating beam and the magnetic field lines. However, no such power threshold dependence was observed. The desired electron-Bernstein and ion-Bernstein decay products were also produced in greater amounts than one would expect for experiments not concerned about which SEE modes would be generated. Due to the field aspect geometry of the electron-Bernstein and ion-Bernstein waves these modes were not seen with MUIR but were detected as part of the HF backscatter from SuperDARN.

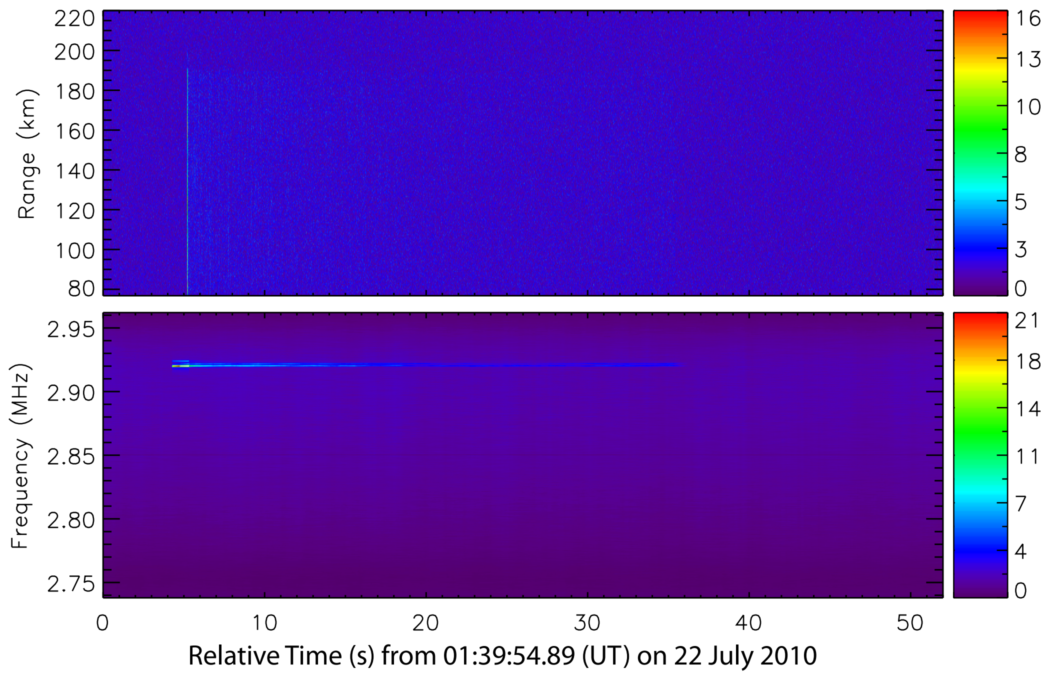

Figure 3. Detection of the enhanced plasma line using MUIR. The top image is the range-time intensity plot from the returned pulse showing heating beginning around 5s. The bottom image is the spectrogram of the upshifted plasma line.

4. Conclusions

Parametric decay of electrostatic and electromagnetic waves have been observed through multiple ground receivers at the HAARP heating facility in Gakona, AK. Experiments involving frequency and power stepping have identified thresholds for the onset of SEE. These experiments were designed to emphasize EB and IB modes instead of the generation of the upper hybrid mode. The electron-Bernstein and ion-Bernstein waves detected during these experiments have provided insight into the parametric decay mechanisms that generate these elusive wave modes.

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