URSI GASS 2020, Rome, Italy, 29 August- 5 September 2020

Nonlinear phenomena in the high latitude ionosphere F region induced by O- and X-mode HF pumping at EISCAT

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Abstract

Experimental results from multi-instrument observations at the EISCAT HF heating facility at Tromsø, Norway, are presented. We compare distinctive features of artificial plasma turbulences in the high latitude ionosphere F-region induced by powerful HF electromagnetic waves with the ordinary (O-mode) and extraordinary (X-mode) polarization.

1 Introduction

Powerful high frequency electromagnetic waves (HF pump waves) with the ordinary (O-mode) polarization are commonly used for the ionospheric modification. It is due to the fact that extraordinary (X-mode) polarized HF pump wave does not reach the resonance altitudes where the artificial turbulences are excited. Nonetheless, a large number of repeatable and easily reproducible experiments carried out at the EISCAT (European Incoherent Scatter Scientific Association) HF heater facility clearly demonstrated that an X-mode HF pump wave radiated into the high latitude ionosphere F-region towards the magnetic zenith is capable to excite the artificial field-aligned irregularities (FAIs), radio-induced optical emissions, Langmuir and ion-acoustic turbulence, spectral components in the narrowband stimulated electromagnetic emission (NSEE) spectra observed at distance far away the HF heater [1, 2, 3, 5]. The paper is aimed to compare the features of artificial plasma turbulences in the high latitude ionosphere F-region induced by powerful HF electromagnetic waves with the ordinary (O-mode) and extraordinary (X-mode) polarizations.

2 Experimental setup

Modification of the high latitude ionosphere was produced by using the EISCAT (European Incoherent Scatter Scientific Association) HF heater facility near Tromsø, northern Norway (69.6° N, 19.2° E). An alternating O/X-mode HF pumping was made into the magnetic zenith at heater frequencies f_H = 5.4 - 8 MHz by 10 min on, 5 min off pulses. Phased Array 1 with a beam width of 5-6°, resulting in the effective radiated powers of 456 – 715 MW, was utilized. In the course of experiments the f_H was near or below the critical frequency foF2 when the excitation of the O- and X-mode phenomena is possible. Experiments were carried out in day and early evening hours under quiet magnetic conditions.

As diagnostic instruments were utilized the following: the EISCAT UHF incoherent scatter radar (930 MHz) at Tromsø which run in the magnetic field-aligned direction with 5 s resolution; technique for the narrowband stimulated electromagnetic emission (NSEE) observations in the frequency band of 1 kHz around the heater frequency located at St. Petersburg (60.3° N, 29.4° E), at a distance about 1200 km away the HF Heater; the CUTLASS (SuperDARN) HF coherent radar in Finland with a beam 5 oriented to Tromsø.

3 Observational results

3.1 Langmuir and ion-acoustic turbulence

Incoherent scatter radar (ISR) co-located with the HF heating facility is available to provide the investigations of elongated plasma oscillations such as the Langmuir and ion-acoustic plasma waves, which are directly evidenced from the ISR signal spectra as HF-enhanced plasma and ion lines (HFPLs and HFILs). The behavior of the HF-enhanced plasma and ion lines from the EISCAT UHF radar spectra are compared with the growth time of artificial field-aligned irregularities (FAIs) from CUTLASS measurements. It was found the principal difference in the temporal evolution of HFPLs and HFILs excited by O- and X-mode HF pump waves. Namely, under O-mode HF pumping the abrupt enhancements of the ion and plasma line intensity in the UHF radar spectra appeared from the "cold" start as immediate response to the onset of HF heating and observed in the first 5 s dumps. It is a clear signature of the excitation of parametric decay instability (PDI). Thereafter Langmuir and ion-acoustic waves are normally quenched by fully generated small-scale field-aligned artificial irregularities (FAIs) preventing further generation of (PDI). However, under high effective radiated power (Peff > 250 – 300 MW) the reappearance of HFPLs and HFILs lines can occur after the initial overshoot. It was shown that X-mode ion and plasma lines developed with a time delay relative to the onset of HF heating. After appearance, their intensity gradually increased and reached a maximum within about 1 min or even longer when FAIs are fully generated. It was found the coexistence of strong HF-induced plasma and ion lines and FAIs under X-mode pumping through the whole pump pulse. HF power stepping experiments from 50 to 560 MW clearly demonstrated that Langmuir and ion-acoustic turbulences excited by the O- and X-mode HF pump waves have the different thresholds of excitation.

3.2 Narrowband stimulated electromagnetic emission

Recently it was found that an X-mode HF pump wave is able to excite the NSEE which was recorded at a distance about 1200 km away the HF Heater [3]. Results of observations are illustrated by Figs. 1 and 2.

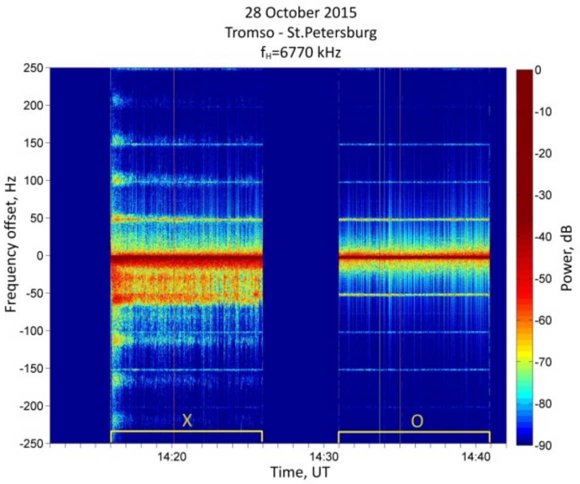

Figure 1. The spectrogram of the NSEE structures recorded at a distance about 1200 km away the EISCAT Heater for contrasting O/X-mode HF pumping at f_H = 6.77 MHz on 28 October 2015.

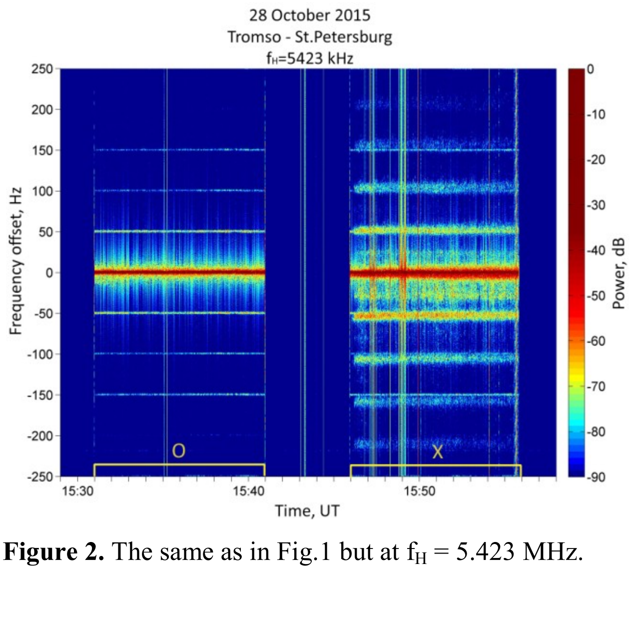

Figure 2. The same as in Fig.1 but at f_H = 5.423 MHz.

As seen from Figs. 1 and 2, NSEE spectra, recorded near St. Petersburg, at a distance about 1200 km away Tromsø, demonstrate a wide variety of spectral components in the course of X-mode pumping. Main peaks in the NSEE spectra were similar those observed in the close vicinity of HAARP in the course of O-mode HF pumping near the second electron gyro-harmonic [4].

The generation of intense discrete downshifted and upshifted harmonic spectral structures separated by about the ion gyro-frequency for O^+ ions (Stokes and anti-Stokes lines) occurred only for X-mode pulses (see Figs. 1, 2). Such structures are associated with the electrostatic ion cyclotron waves and their harmonics, otherwise known as neutralized ion Bernstein (IB) waves. They gradually decayed from the first to the fourth ion harmonic structure. It was also recorded the downshifted spectral harmonic at about one half ion gyro-frequency. There is an asymmetry in the behavior of electrostatic ion cyclotron (EIC) harmonic waves with respect to the sign of frequency offset. By a contrast, O-mode pulses did not exhibit any spectral structures in the narrowband SEE spectra obtained at a long distance from HF heater.

4 Discussion and Summary

The radical difference in the temporal development of HF-enhanced Langmuir and ion-acoustic turbulence excited by O- and X-mode HF pump wave waves after the onset of HF pumping was found. Artificial field-aligned irregularities (FAIs) play a crucial role in the PDI development. CUTLASS radar observations clearly demonstrated the FAI occurrence under O- and X-mode pumping. By a contrast to the O-mode HF pumping, when FAIs prevent to the PDI development, Langmuir and ion-acoustic turbulence under an X-mode pumping developed with a time delay relative to the HF turn-on when FAIs are fully generated. So, the parametric instability decays directly into discrete field-aligned ducted wave modes. As a result, the excitation of Langmuir waves and field-aligned irregularities are linked in the region of Langmuir/ion turbulence.

Experimental results obtained in the course of the X-mode HF pumping have shown that the excitation of the electrostatic ion cyclotron (EIC) harmonic waves occurred when the heater frequency f_H was below the electron gyro-harmonics, nfce, where fce is the electron gyro-frequency and n is a number of harmonic. In our experiments such downshifted and upshifted spectral components were observed for f_H < 4fce, 5fce, and 6fce. It was found the experimental evidence of the sensitivity of EIC harmonic waves to pump frequency stepping across the 5fce [5]. Drastic changes in the behavior of the narrowband spectral structures occurred as the frequency of the X-polarized pump wave reached 5fce. At first they are greatly suppressed and then disappeared just above the 5fce, (5fce + 10) kHz. The mechanism of the EIC harmonic structure excitation could be the parametric decay instability of extraordinary electromagnetic waves into electrostatic electron Bernstein (EB) and ion Bernstein (IB) waves. Then the EB wave, which exhibits a frequency offset equal to the frequency of the neutralized IB modes, is converted back to an electromagnetic wave due to scattering by X-mode FAIs.

5 Acknowledgements

We thank the staff of European scientific association EISCAT for providing and help with EISCAT HF pumping experiments.

6 References

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