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

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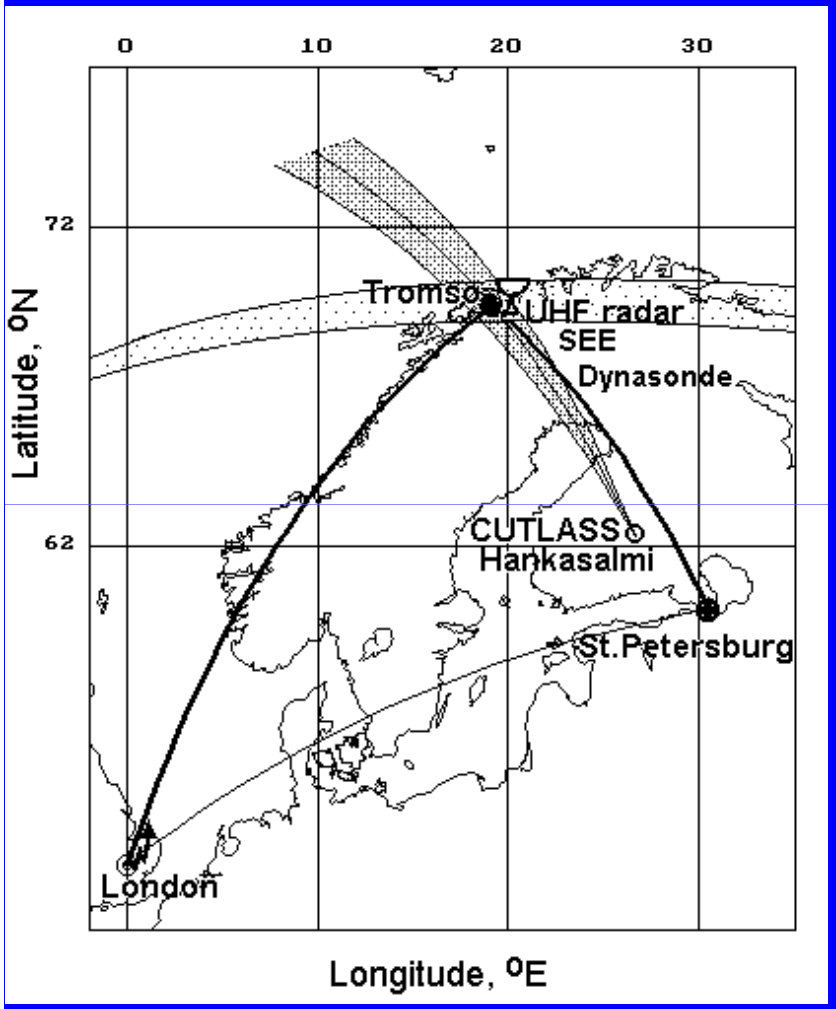
A large amount of repeatable experimental results at EISCAT have clearly demonstrated that an X-mode HF pump wave injected into the high latitude ionosphere F2 layer towards the MZ, is capable of generating AFAIs, radio-induced optical emissions at red and green lines, the ion acoustic and Langmuir electrostatic waves, and spectral components in the NSEE spectra observed at a large distance from the HF heater (*Blagoveshchenskaya et al.*, 2011; 2014; 2015; 2017;). It is important that the X-mode phenomena are excited under f_H /foF2 >1 as well as f_H / foF2≤ 1. We report and compare experimental results related to the features and behaviors of the artificial plasma turbulences induced by the X- and O-mode HF pump waves at frequencies from 5.423 to 7.953 MHz.

OUTLINE

- Temporal evolution of the HF-enhanced Langmuir and ion acoustic plasma turbulences directly observed from the EISCAT UHF incoherent scatter radar spectra as HF-enhanced plasma and ion lines (HFPLs and HFILs);
- Thresholds of effective radiated power (ERP) required for the excitation of HF-induced plasma turbulence;
- Distinctive features and behaviors of the narrowband stimulated electromagnetic emission.

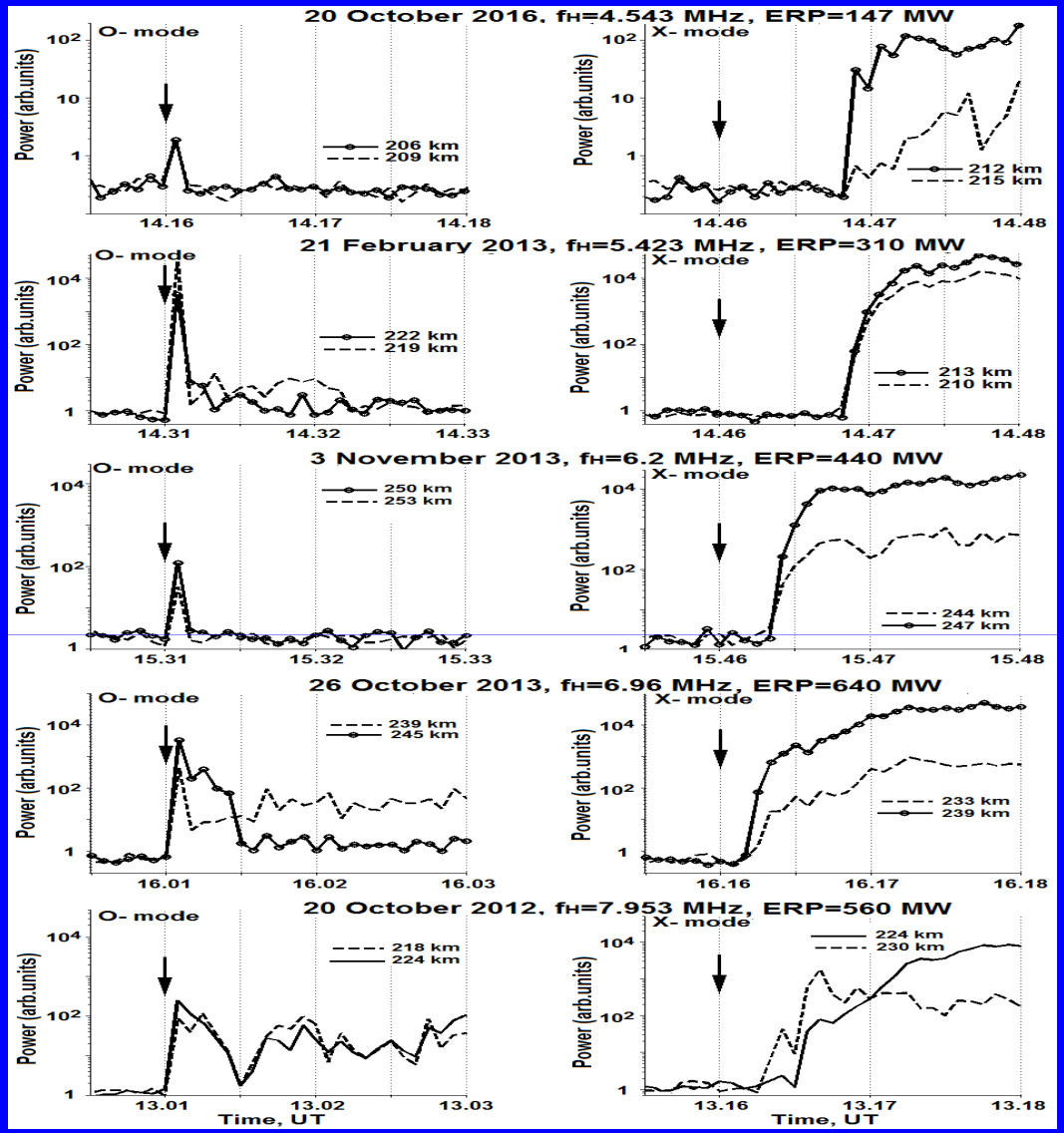
Instrumentation



A map showing the experiment geometry. The EISCAT/Heating facility at Tromsø was used for HF ionospheric modification of the ionospheric F-region. HF heating facility was operating at at high heater frequencies (f_H = 5.423 – 7.953 MHz) with the use of phased array 1 resulting in the effective radiated power of 450 – 650 MW.

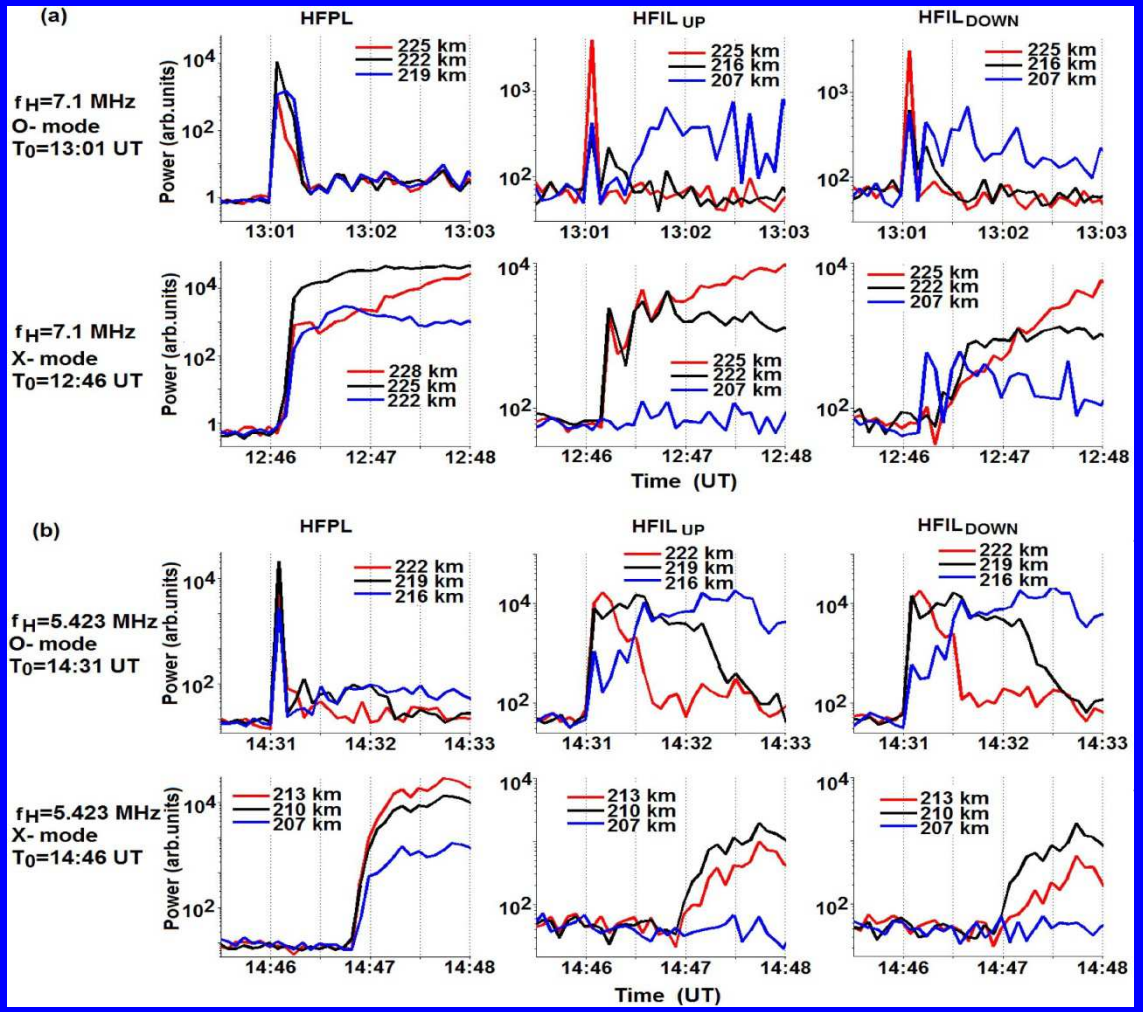
Multi-instrument diagnostics from the European Incoherent Scatter (EISCAT) UHF radar (930 MHz), the Finland CUTLASS (SuperDARN) HF radar, NSEE equipment allowing the recording of heater signals within 1 kHz frequency band at St. Petersburg, and the Tromsø ionosonde have been used during campaigns.

Time development of O- and X-mode HFPLs at different HF pump frequencies



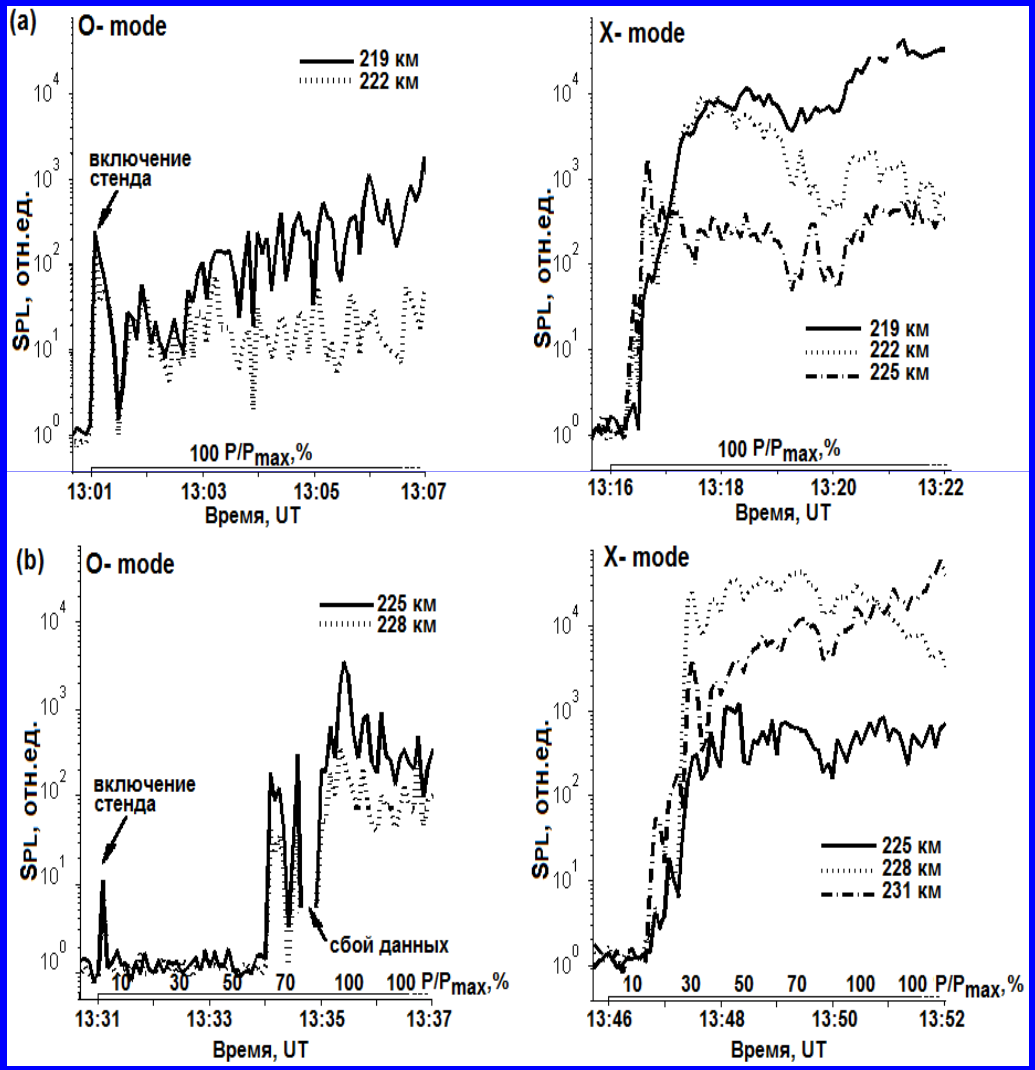
- **The power of the downshifted HFPL from EISCAT UHF radar measurements during 2.5 min intervals starting 30 s before the heater turned on for O- and X-mode pulses at the pump frequencies of 4.543, 5,423, 6.2, 6.96, and 7.953 MHz. The power of the HFPLs was found as the maximum in spectra derived every 5 s with 3 km altitude steps.**

Comparison between HFPL and HFIL development for O-and X-mode pumping



- **The power of HFPL, $HFIL_{UP}$ and $HFIL_{DOWN}$ from EISCAT UHF radar measurements during 2.5 min intervals starting 30 s before the heater turned on for O- and X-mode pulses on February 21, 2013. (a) Heater frequency of 7.1 MHz, Рэфф = 550 МВт; (b) Heater frequency of 5.423 MHz, Рэфф = 310 МВт. The power of the HFPLs and HFILs was found as the maximum in spectra derived every 5 s with 3 km altitude steps.**

Behavior of the HFPL intensity under O- and X-polarization of pump wave depending on effective radiated power

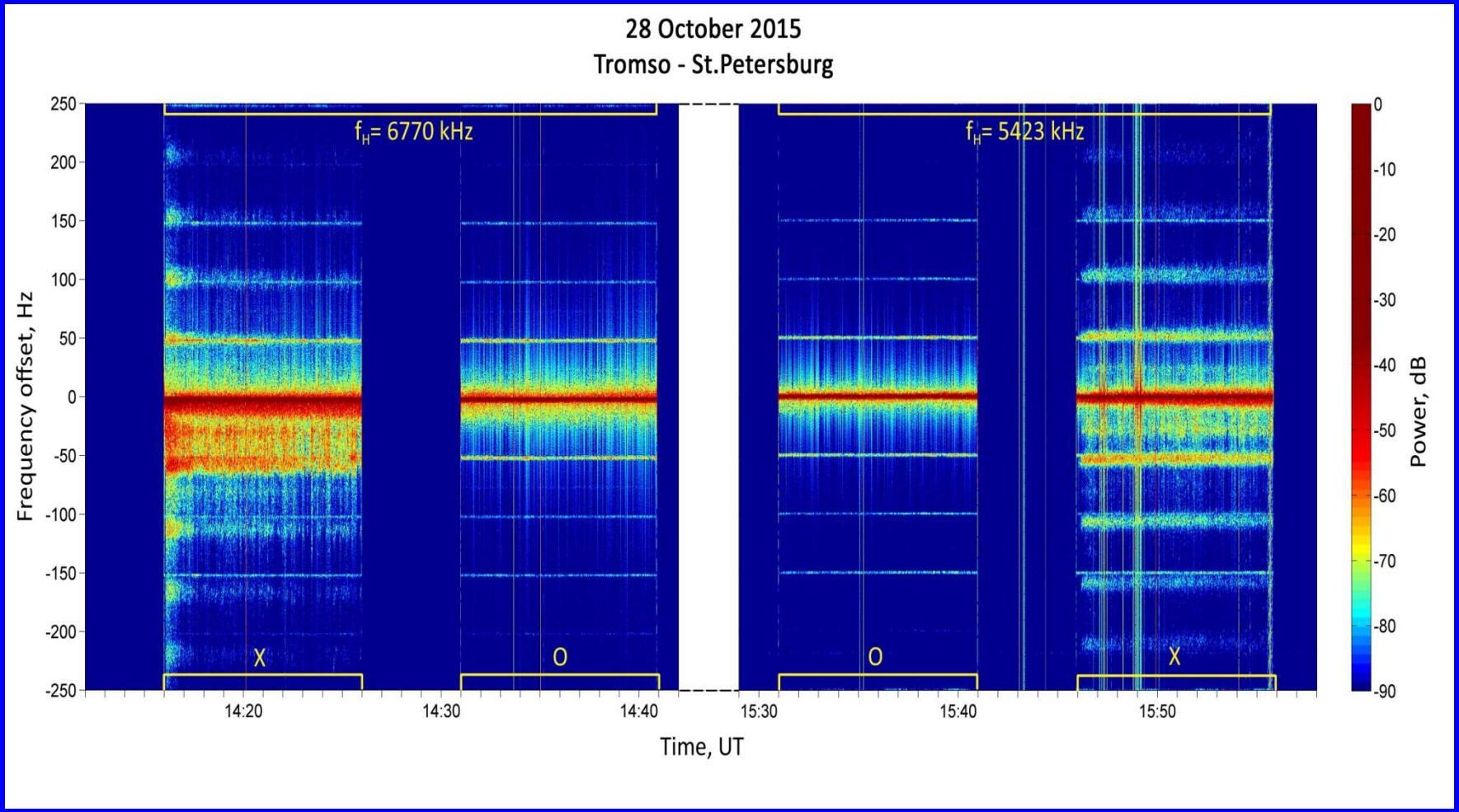


Behavior in time of O- and X-mode HFPL intensity during 6 min after the HF pumping onset on 20 October 2012. The O- or X-mode HF pump wave was radiated towards the magnetic zenith at frequency of 7.953 MHz. The maximum effective radiated power was Pmax = 560 MW, the ratio of f_H /foF2< 0.95 .

(a)HFPL inensity for O- and X-mode HF pumping when ERP = P_{max} ;

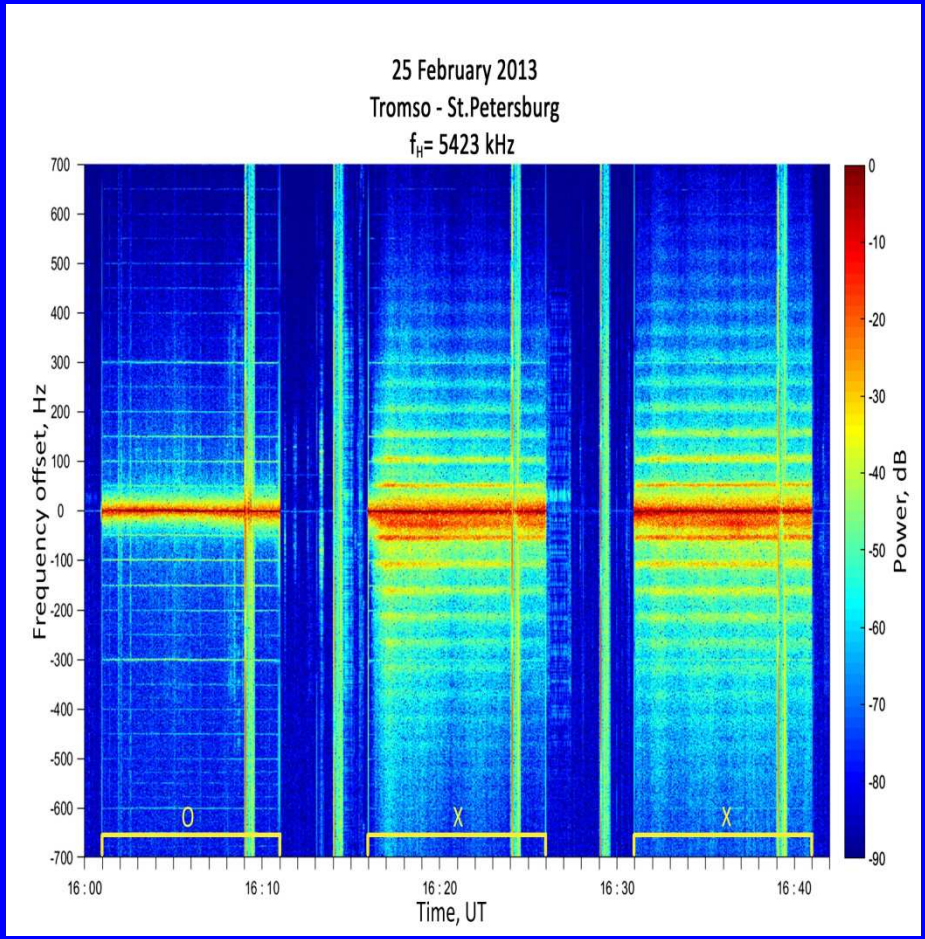
(b) HFPL intensity for O- and X-mode HF pumping when the power stepping in ERP was produced in the sequence of ERP = (10-30-50-75-100-100%) P_{max} . Duration of each power step was 1 min.

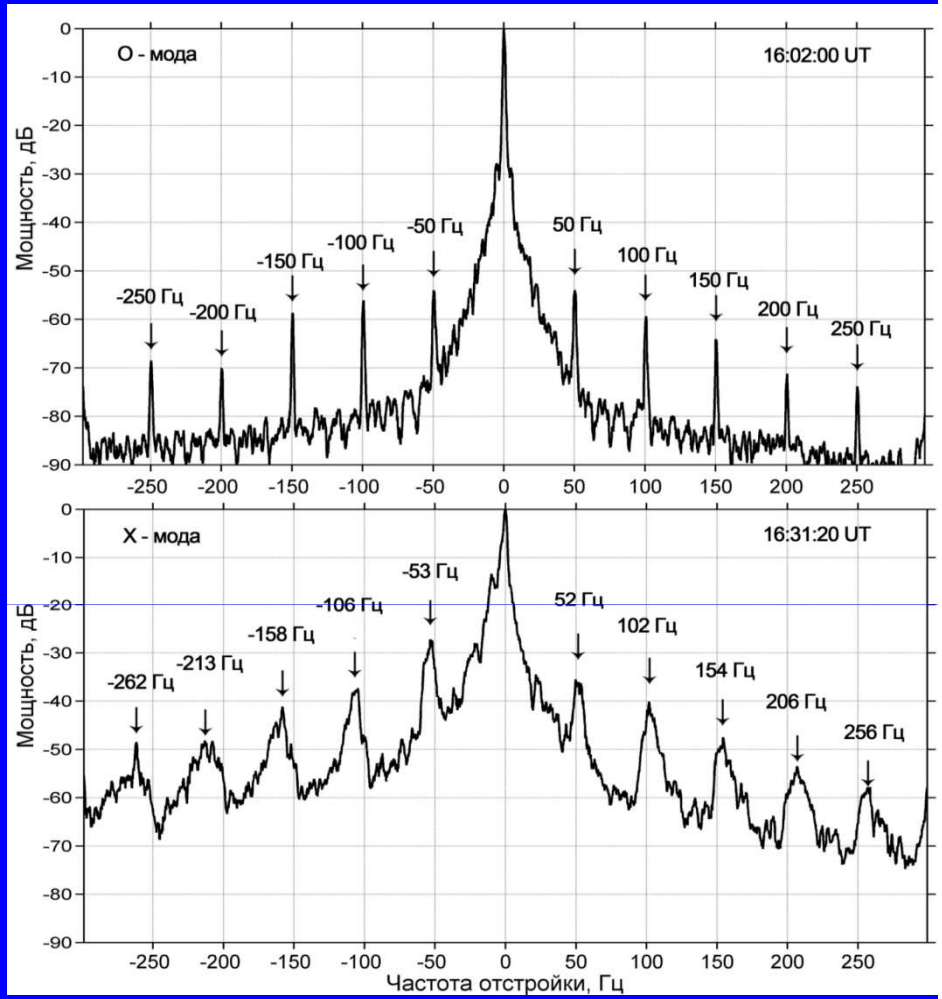
Narrowband SEE (NSEE) at the pump frequency below 5fce, 4fce



- The spectrogram of the NSEE on 28 October 2015 in the frequency band of ± 250 Hz off the pump frequency recorded near St. Petersburg at 1200 km away the EISCAT/Heating facility for O/ X-mode HF pumping at frequencies of f_H = 6.77 MHz and f_H = 5.423 MHz which are below 5 fce and 4fce respectively..

Narrowband SEE (NSEE) at the pump frequency below 4fce





The spectrogram of the NSEE with a frequency resolution of 0.16 Hz and time resolution of 3 s at a distance of 1200 km from the EISCAT/Heating for O/X-mode HF pumping at fH=5.423 MHz, which was below 4fce, on 25 February 2013.

Narrowband SEE spectra at fH=5.423 MHz, which was below 4fce, on 25 February 2013 during the heater O- and X-mode pulses recorded at a distance of 1200 km from the EISCAT/Heating .

Summary

It was found the radical difference in the evolution of the X- and O-mode plasma and ion line spectra after the heater turned on.

Under O-mode pumping the abrupt enhancements in the ion and plasma line spectra were seen in the first 5 s radar data dump. Thereafter Langmuir and ion-acoustic waves are normally quenched by fully generated AFAIs. However, under high effective radiated power the reappearance of HF-enhanced ion and plasma lines can occur after overshoot.

The X-mode ion and plasma lines delayed relative to the onset of HF pumping. Thereafter their intensity gradually increased and saturated within about 1 min or even longer.

It was found that the excitation of the X- and O-mode HFPLs and HFILs requires different thresholds of effective radiated power.

It was shown that an X-mode HF pump wave at frequencies below the fourth, and fifth electron gyro-harmonics, is able to excite up to ten downshifted discrete ion gyro-harmonic structures paired with the upshifted spectral components in the NSEE spectra . recorded at a distance more than 1000 km from the HF Heating facility. It was suggested that observed spectral structures ordered by the ion gyro-frequency (for O+ ions) have connection with magnetized stimulated Brillouin scatter (MSBS) process...

References

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