Artificial small-scale field-aligned irregularities in the high latitude ionosphere F region: Comparison between O- and X-mode HF pumping at EISCAT

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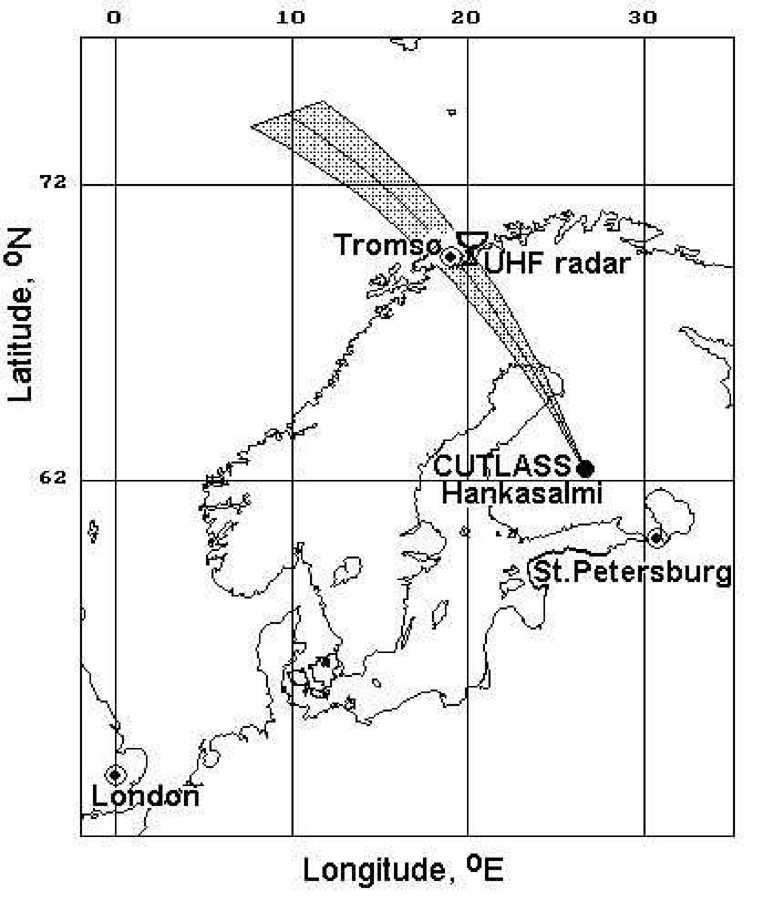
One of the most prominent phenomena discovered from HF heating experiments is the generation of artificial small-scale field-aligned irregularities (AFAIs), which were investigated with profit at all HF heating facilities in the world. Such irregularities are excited by the ordinary polarized (O-mode) powerful HF pump radio waves (HF pump waves) at the upper hybrid resonance altitude due to the thermal parametric (resonance) instability. However, numerous experiments carried out at the EISCAT (European Incoherent Scatter Scientific Association) HF heater facility have shown that an extraodinary polarized (X-mode) HF pump wave radiated towards the magnetic zenith is capable to generate AFAIs in the F-region of the high latitude [Blagoveshchenskaya et al., 2011; 2014; 2015]. We present experimental results related to the comparison between behaviors and distinctive features of AFAIs in the F-region of the high-latitude ionosphere excited by O- and X-mode HF pump waves **at high ($f_H \geq 5.5$ MHz) and low ($f_H <5.5$ MHz) pump frequencies .**

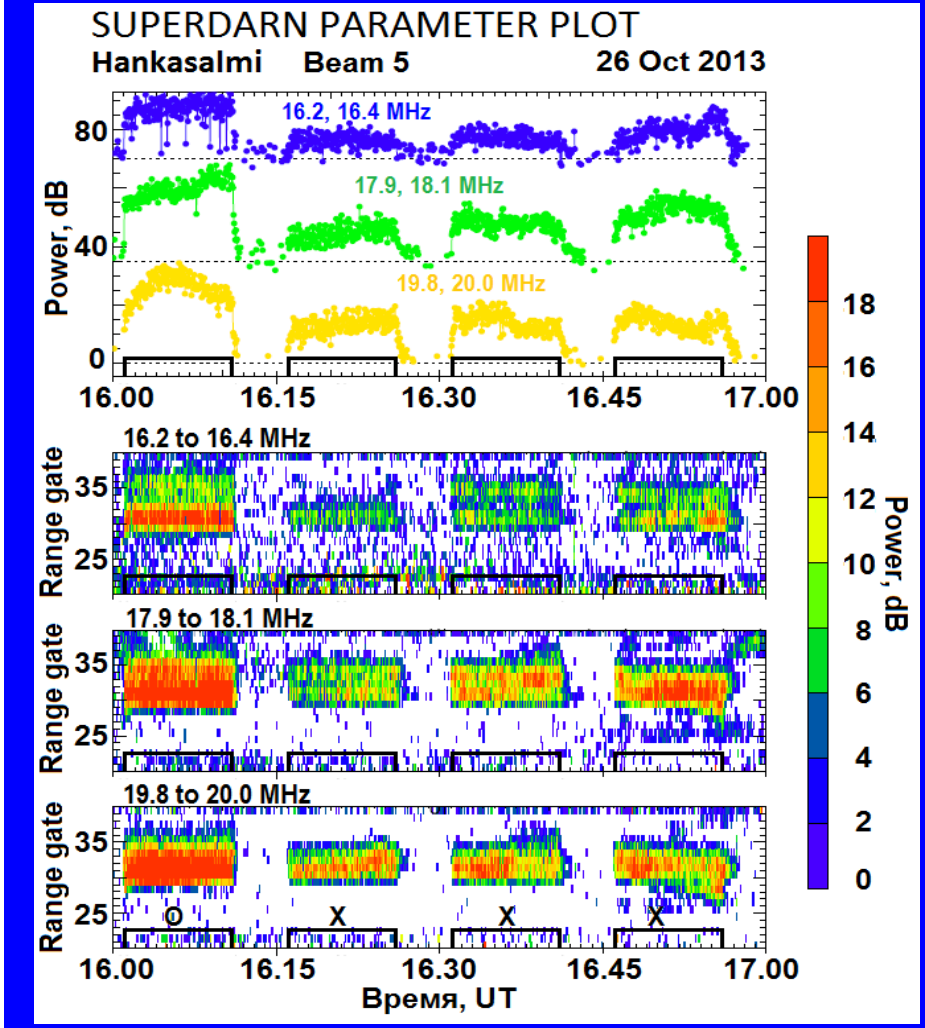
Experimental setup



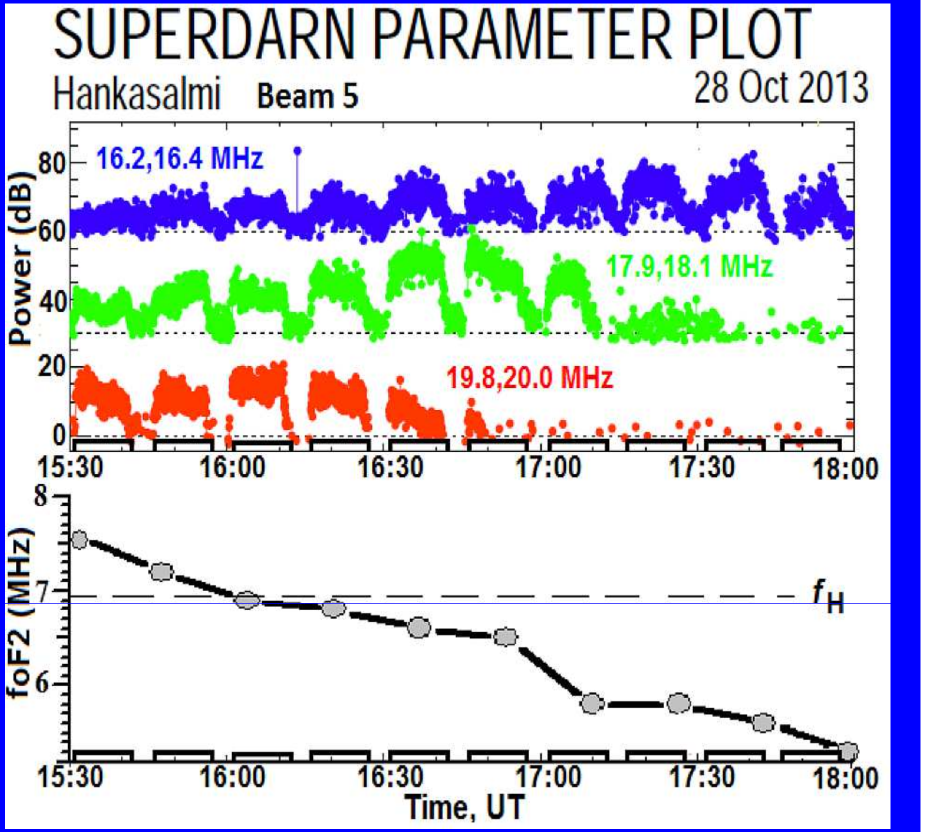
A map showing the experiment geometry. The EISCAT/Heating facility at Tromsø was used for HF ionospheric modification of F-region. HF heating facility was operating at heater frequencies of 4.0 – 8.0 MHz with an effective radiated power of 100 – 750 MW. HF pump wave with ordinary (O-mode) or extraordinary (X-mode) polarization was injected towards the magnetic zenith.

Instrument diagnostics included the CUTLASS radar located at Hankasajmi (Finland), the European Incoherent Scatter (EISCAT) UHF radar at 931 MHz near Tro (Finland)msø and the EISCAT ionosonde (dynasonde).

AFAIs at high pump frequencies (f_H = 6.96 MHz)

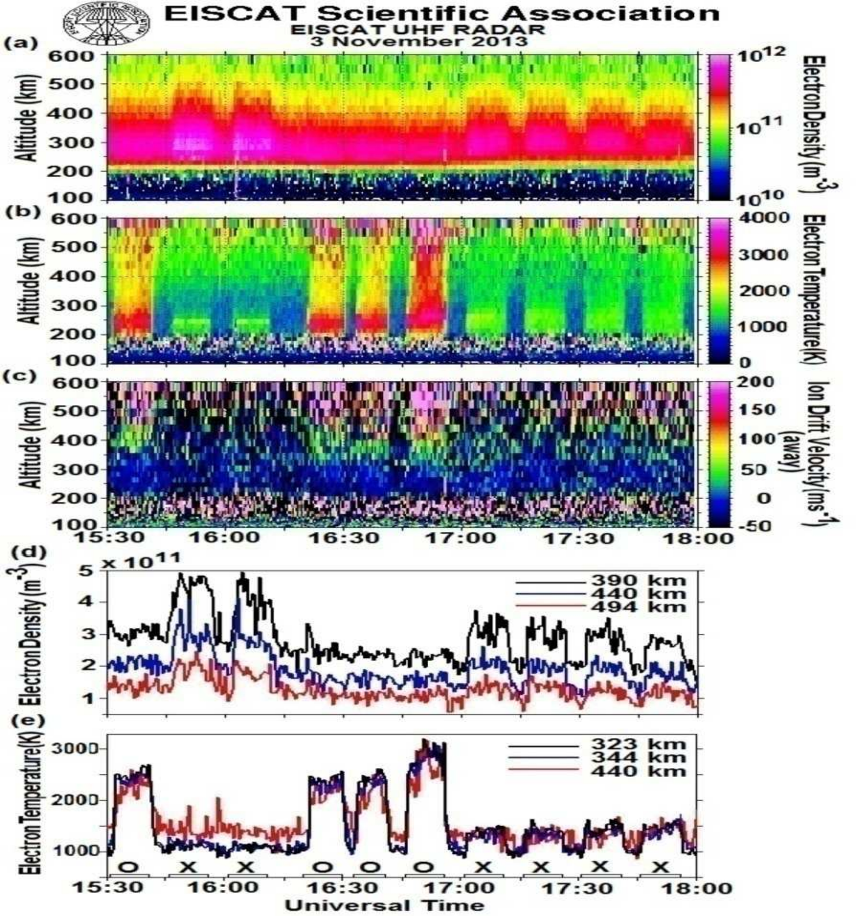


Backscattered power from the UTLASS radar (beam 5) at frequencies of 16, 18 and 20 MHz on 26 October 2013. O/X-mode HF pump wave was radiated into MZ (ERP = 550 MW) , , fH ≤ foF2.

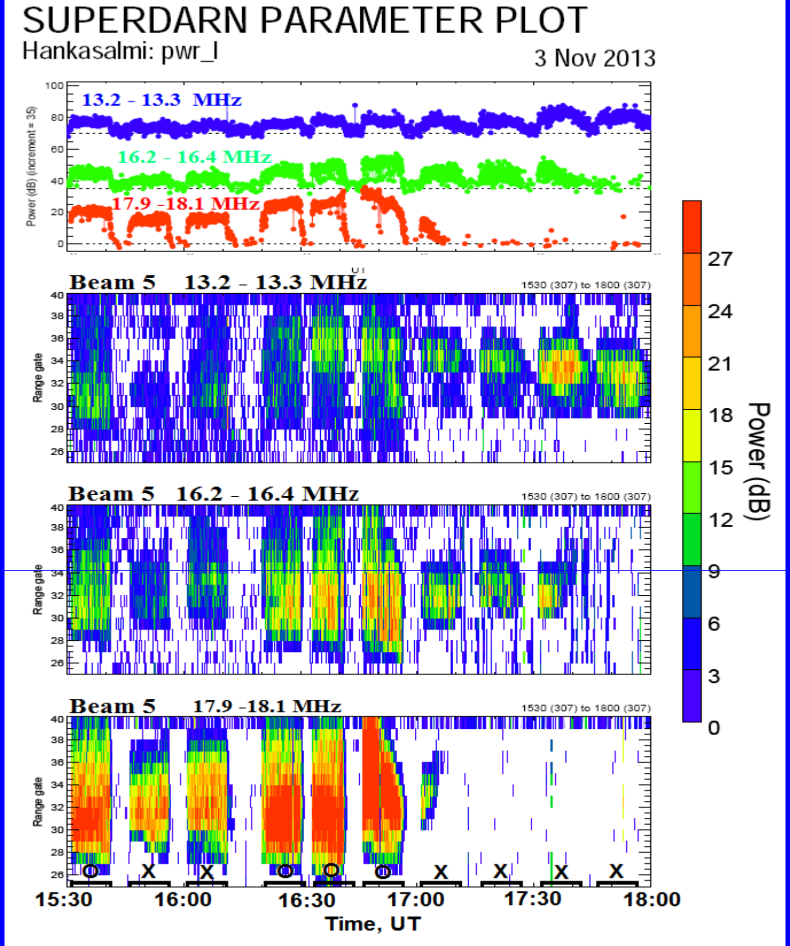


CUTLASS backscatter power (beam 5) at frequencies of 16, 18, and 20 MHz and the behavior of the foF2, on 28 October 2013. An X-mode pump wave was radiated towards MZ, (ERP = 550 MW. (**fH ≤ foF2** from 15:30 – 16:30 f UT, and fH > foF2 from 16:30 – 18 UT)..

O/X-mode HF pumping at high pump frequency (f_H = 6.2 MHz), when foF2 dropped from 6.7 to 5.2 MHz

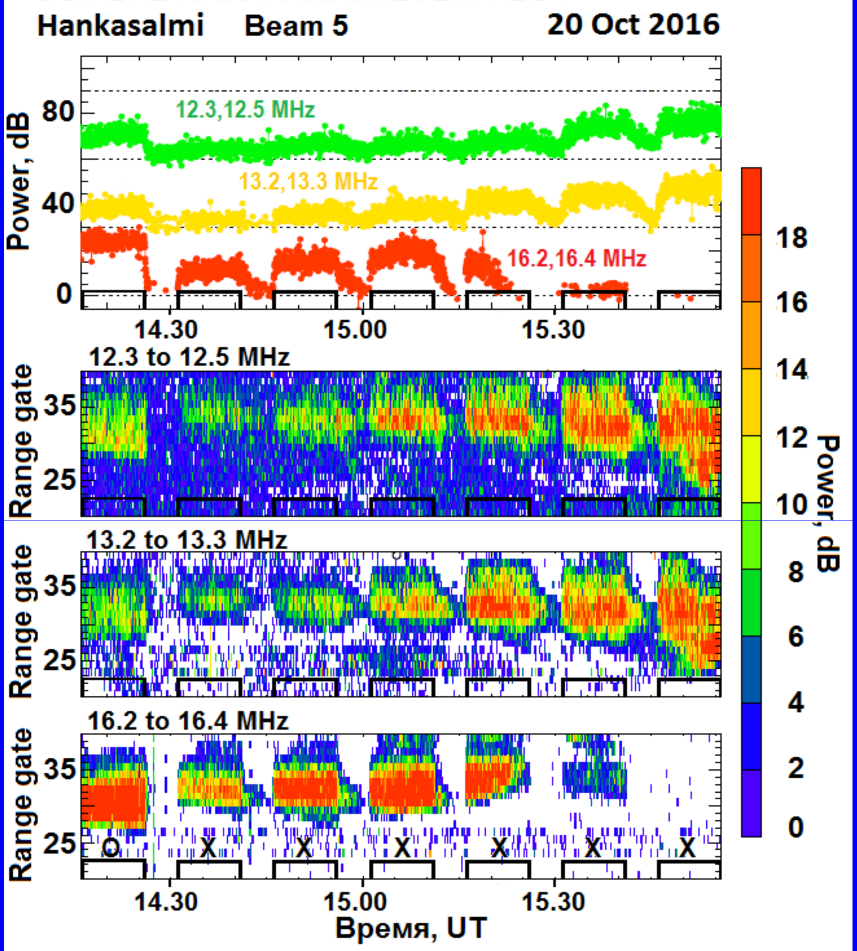


The behaviour of the Ne, Te , Vi from the EISCAT UHF radar observations at Tromso for O/X-mode heating on 3 November 2013. The O/X-mode HF pump wave (ERP = 450 MW) was radiated towards MZ by 10 min on, 5 min off cycles. The critical frequency foF2 dropped from 6.7 MHz at 15.30 UT to 5.2 MHz at 18 UT (f_H / foF2 = 0.92 – 1.2).

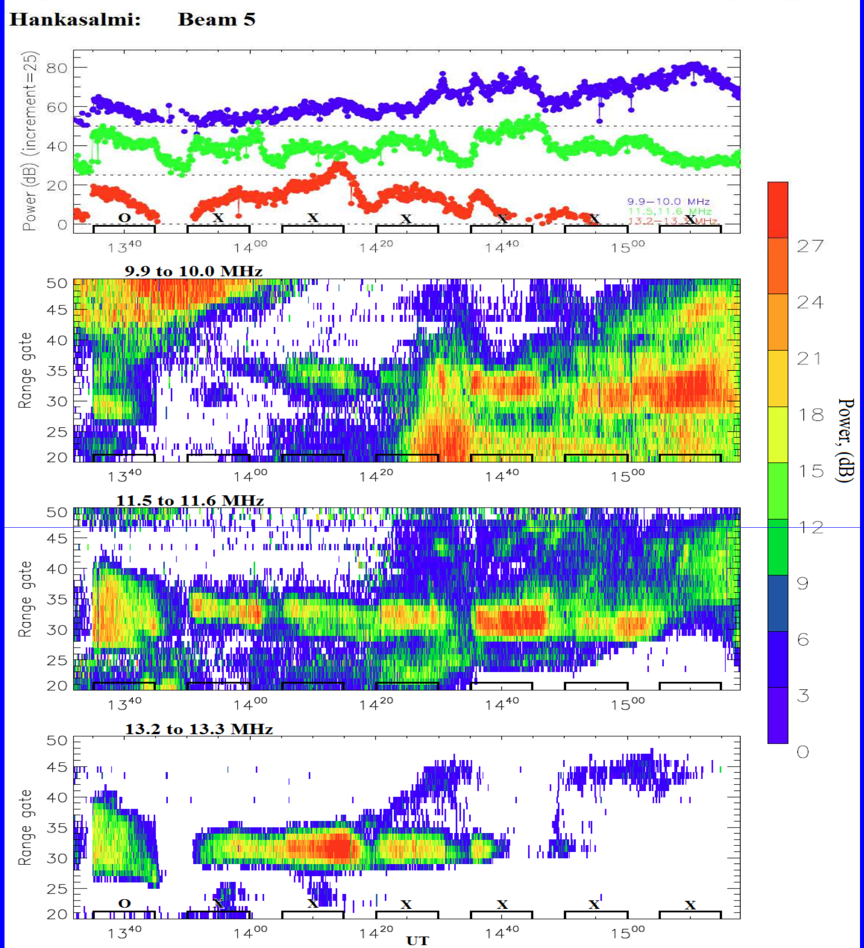


CUTLASS backscatter power (beam 5) at operational frequencies of 13, 16 and 18 MHz on 3 November 2013. O/X –mode HF pump wave was radiated towards MZ (ERP = 450 MW) .

AFAIs at low pump frequencies (f$_H$ = 4.544 MHz)

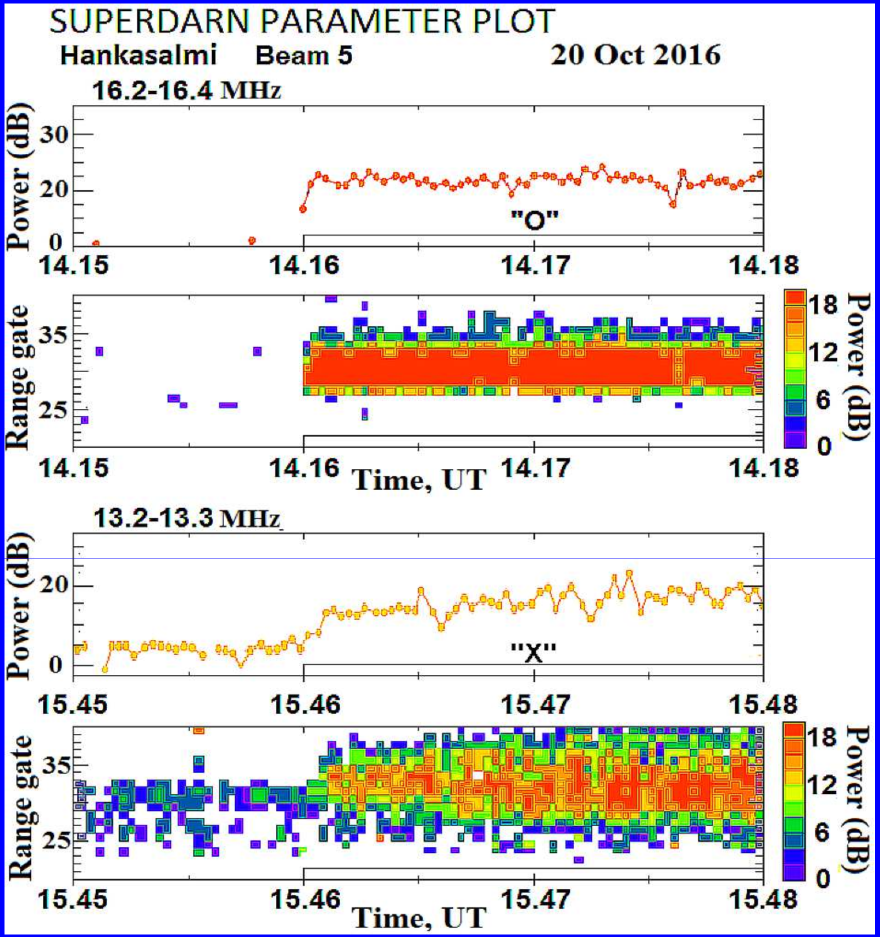


,CUTLASS backscatter power (beam 5) at f ≈ 12, 13, and 16 MHz for O/X-mode heating at f$_H$ = 4.544 MHz (ERP=130 MW) on 20 October, 2016, **fH ≤ foF2.**

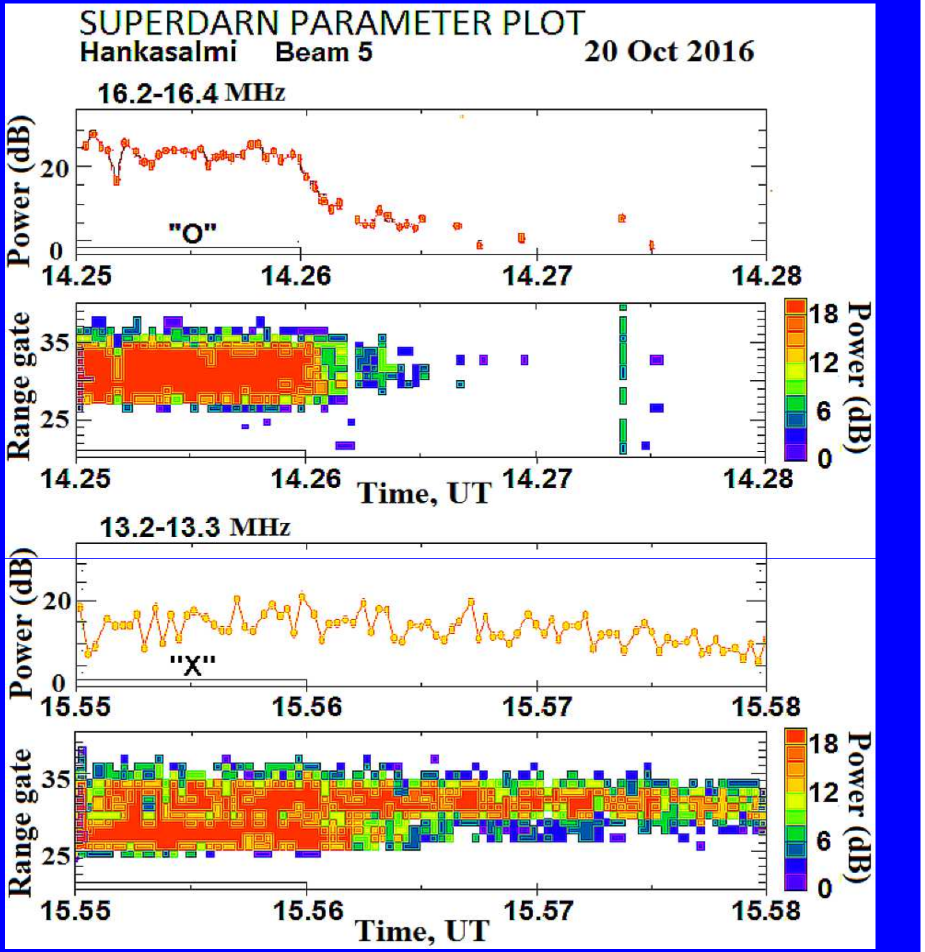


CUTLASS backscatter power (beam 5) at f ≈ 12, 13, and 16 MHz for O/X-mode heating at f$_H$ = 4.544 MHz (ERP=113 MW) on 10 November 2010, **fH > foF2.**

Growth and decay times of O/X-mode AFAIs (f_H = 4.544 MHz)



CUTLASS backscatter power (beam 5) at operational frequencies of about 16 and 13 MHz on 20 October 2016 for O- and X-mode pump cycles starting 1 min before and during first 2 min after the onset of HF pumping.



CUTLASS backscatter power (beam 5) at operational frequencies of about 16 and 13 MHz on 20 October 2016 for O- and X-mode pump cycles during the last minute of a pump pulse and first 2 min after the EISCAT/Heating was turned off.

Distinctive features of FAIs

	X-mode	**O-mode**
generation	$f_H \le$ foF2 ;	$f_H \le$ foF2
	$f_H >$ foF2 (up to 2 MHz)	
spatial scale	$l_\perp \approx 7.5 – 15$ m	$l_\perp \approx 7.5 – 15$ m
growth time	12 – 120 s	3 – 9 s
decay time	40 – more than 300 s	12 – 30 s
threshold of excitation from the “cold start”		
low f_H = 4 MHz	75 MW	8 – 10 MW
high f_H = 8 MHz	160 MW	26 MW

- Generation mechanisms of the FAIs under O-mode HF pumping at $f_H \le$ foF2 is the thermal parametric (resonance) instability at the upper hybrid resonance altitude (Grach and Trachtengertz, 1975; Gurevich and Vas’kov 1978).
- Generation mechanisms of the FAIs under X-mode HF pumping excited at $f_H \le$ foF2 and $f_H >$ foF2 both is not completely understood. It is suggested that X-mode FAIs are generated via two-step process (Borisov et al., 2018; Blagoveshchenskaya et al., 2011). In the first step the generation of elongated large-scale irregularities (with the spatial scale across the geomagnetic field of the order of 1 -10 km) due to the self-focusing instability is occurred. Excitation and behavior of small-scale FAIs is driven by large-scale irregularities. Their possible generation mechanisms can be the temperature gradient-drift instability (Borisov et al., 2018) or the filamentation instability (Kuo, 2015).

Summary

- It was found that the features and physical driving mechanisms of AFAIs with the spatial scale across the geomagnetic field of 7.5 – 15 m are significantly different for O- and X-mode HF pumping, presenting challenges for understanding the relevant processes.

- X-mode AFAIs are excited in the regular high-latitude ionosphere F-region under quiet magnetic conditions when $f_H \leq$ foF2 as well as much above foF2 (up to 2 MHz), whereas the O-mode AFAIs can not be fundamentally generated when the pump frequency f_H i> foF2.

- The X- and O-mode AFAI behaviors exhibit the different growth and decay times that is indicative of different physical mechanisms of their generation.

- By a contrast to the O-mode AFAIs, excited by a thermal parametric (resonance) instability,, the X-mode AFAIs are generated via two-step process. At first the generation of elongated large-scale irregularities (with the spatial scale across the geomagnetic field of the order of 1 - 10 km.) is occurred. As a second step, we suggest that the filamentation instability can be responsible for the generation of small-scale AFAIs..

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Acknowledgements

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