STIMULATED ELECTROMAGNETIC EMISSION AND PLASMA LINE DURING PUMP WAVE FREQUENCY STEPPING NEAR 4TH ELECTRON GYROHARMONIC AT HAARP

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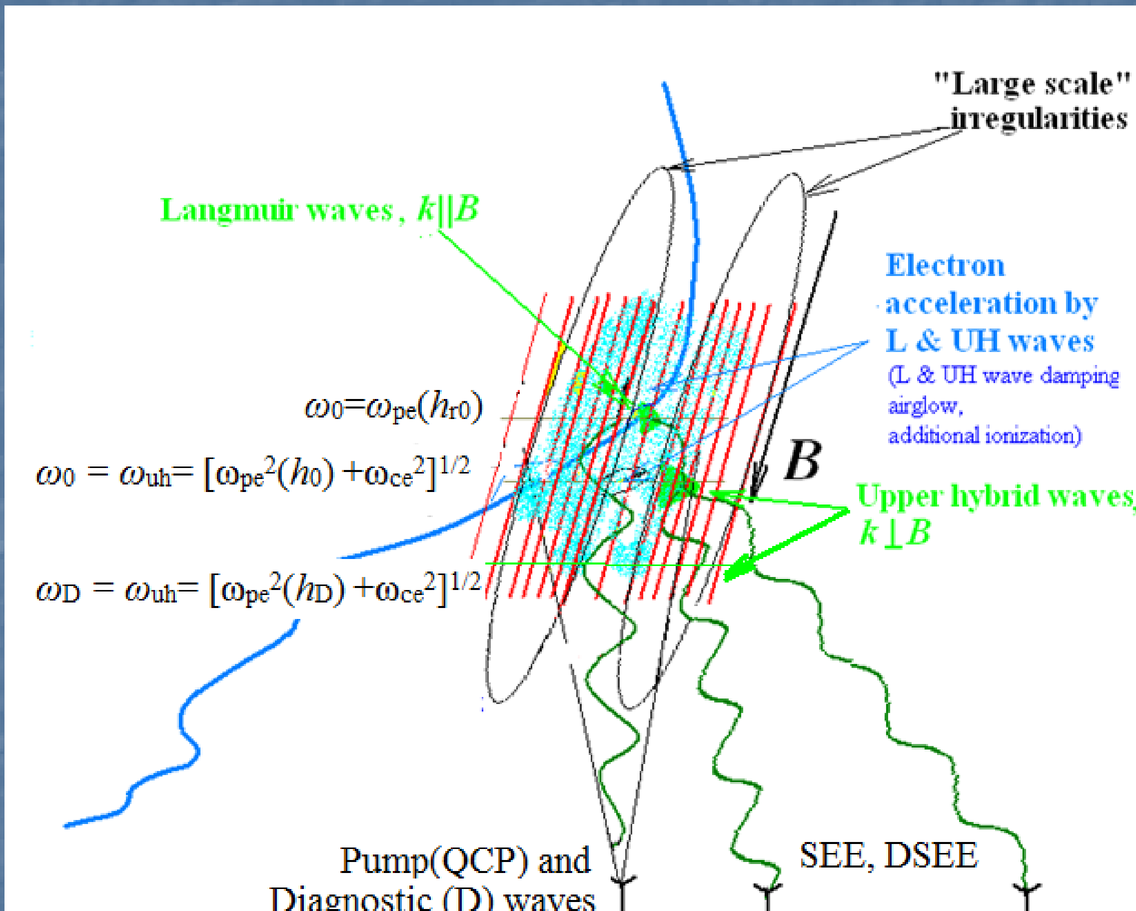
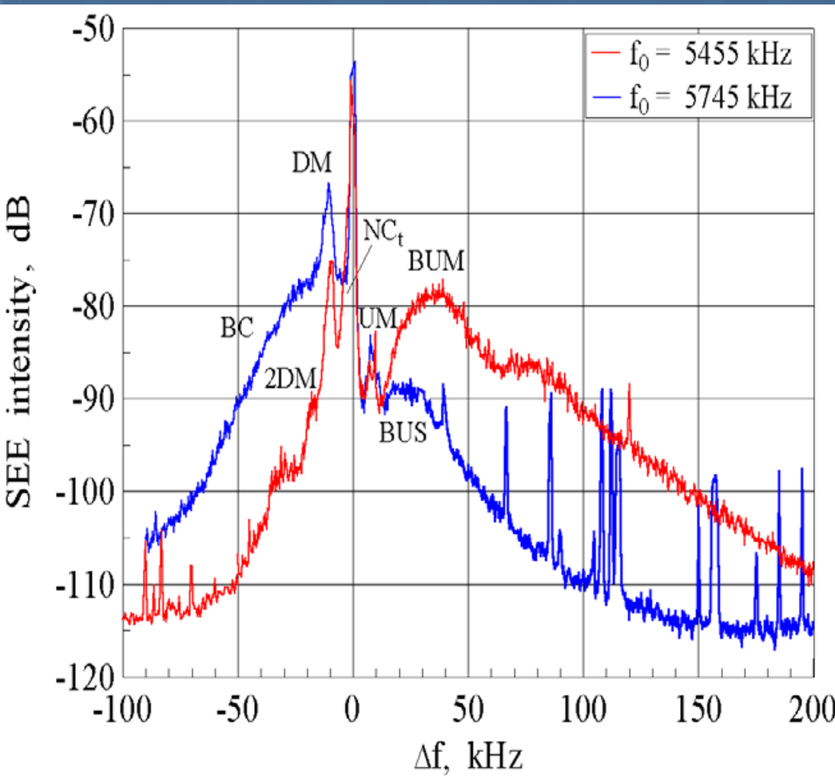
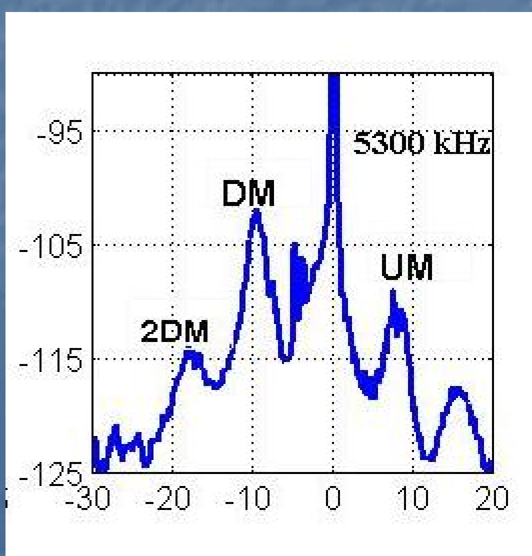
УНИВЕРСИТЕТ
ЛОБАЧЕВСКОГО

Very simple scheme of the processes occurring in the HF pumped volume of the *F*-region



A typical dimension of the excited striations along ***B***, $l_{||}$ ~ 5-30 km, is close to the altitudinal extent of the heated region and the F-region thickness at the Sura, HAARP, and EISCAT facilities with χ = 18.5°, 14.5°, and 12°.The altitudes of the upper-hybrid resonances (h_D) for the diagnostic waves at frequencies f_D and the pump wave (h_0) at the frequency f_0 ($f_D \neq f_0$) significantly differ from each other. Measuring the diagnostic SEE (DSEE) generated by a short-pulse diagnostic wave (DW) will specify the DW-related Z/UH modes as well as the QCP related striations near h_D. Applying different frequencies f_D will provide the relevant information at different altitudes in the perturbed region. Additional information on the striation intensity can be revealed from measurements of anomalous absorption (AA) of the sounding (S) waves.





For furthur statement let me remind most prominent SEE spectral features for long pumping (spectra obtained at Sura):

- Downshifted maximum (DM), is situated at the frequency shifts $\Delta f_{DM}<0$, $|\Delta f_{DM}|> f_{LH}$, DM desappears at $f_{DM} \approx nf_c \approx f_{uh}$
- Broad upshifted maximum BUM), at

$$\Delta f_{BUM} \sim f_0 - nf_c + \delta f \quad (1)$$

exists for $f_0 \geq nf_{ce}$, δf=15-20 kHz

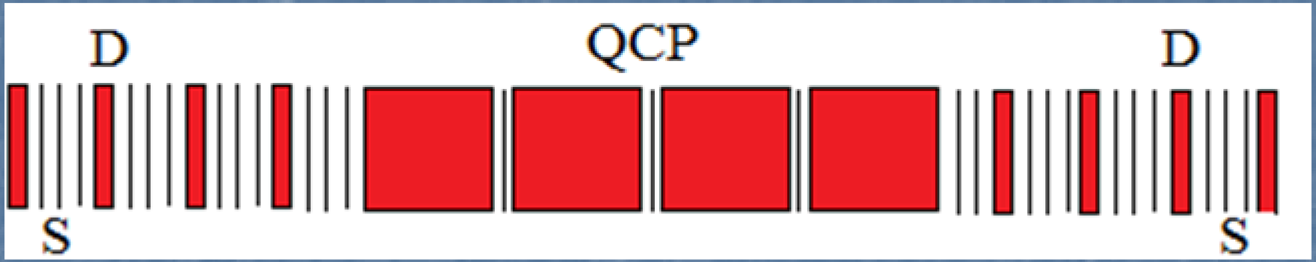
- DM family (UM, 2DM, 2UM)
- Broad continuum (BC): Broad Upshifted Structure (BUS)

Top: $f_0 > nf_c$,

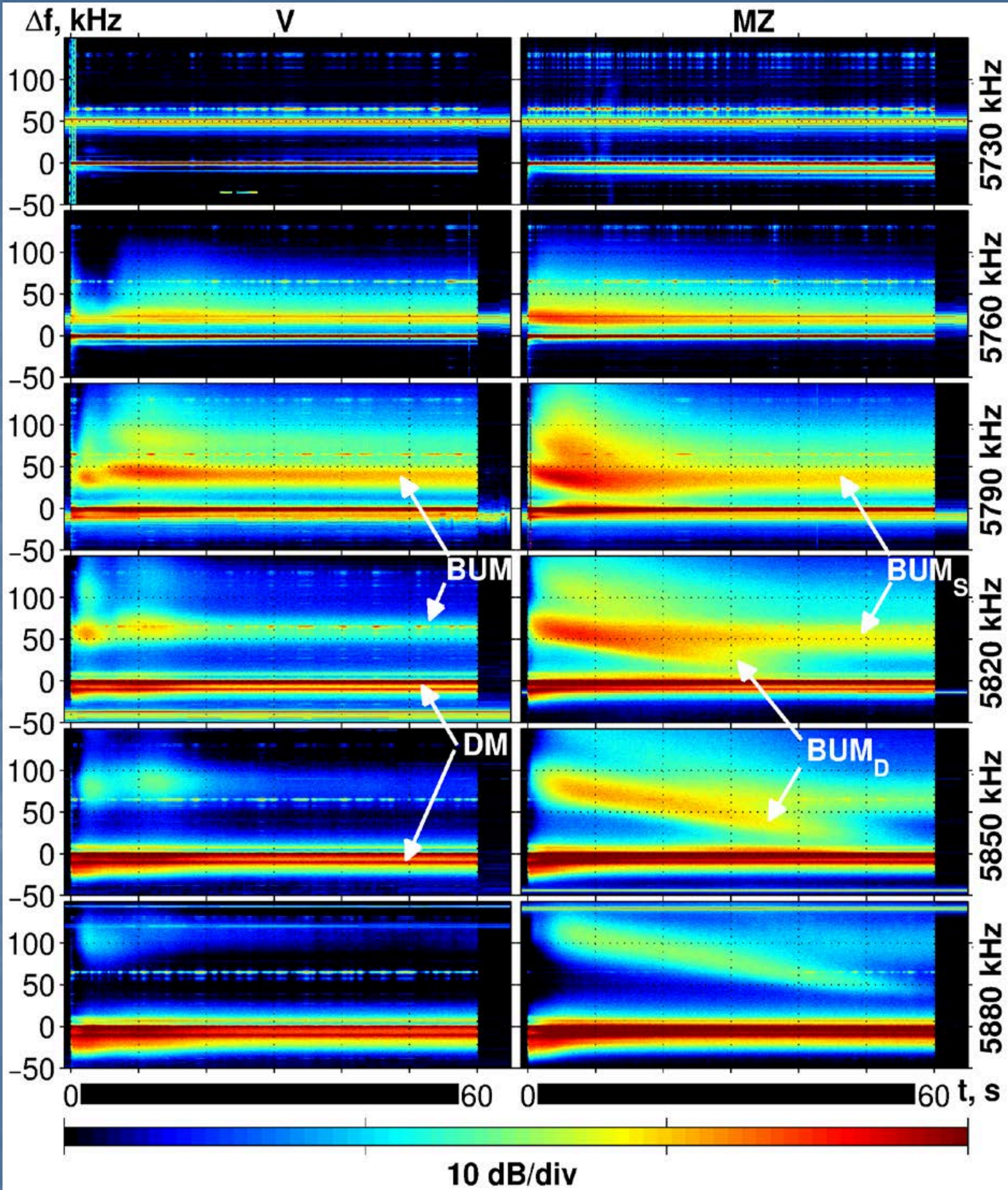
Bottom: $f_0 < nf_c$

Descending layers of articial ionization during high-duty cycle injections at MZ (PRL, 2013).

Radiation scheme: an alternation of quasi-continuous pump wave (QCP) radiation (70-180 ms “on”, 20 -30 ms “off”) during 1 minute and the low duty cycle pulse pumping (τ_1 , IPP_2). For sounding heated volume we used also short pulses of the pump wave (τ_2 , IPP_2), the radiation scheme is shown in the figure



Low duty cycle: τ_1= 5...50 ms, IPP_1=1...10 s
Low (diagnostic) duty cycle τ_2 = 100 µs, IPP_2 = 100...200 ms
High duty cycle: τ = 160 ms, IPP=200 ms
Low (diagnostic) duty cycle τ_2 = 100 µs, IPP_2 = 200 ms, τ_{delay} = 180 ms

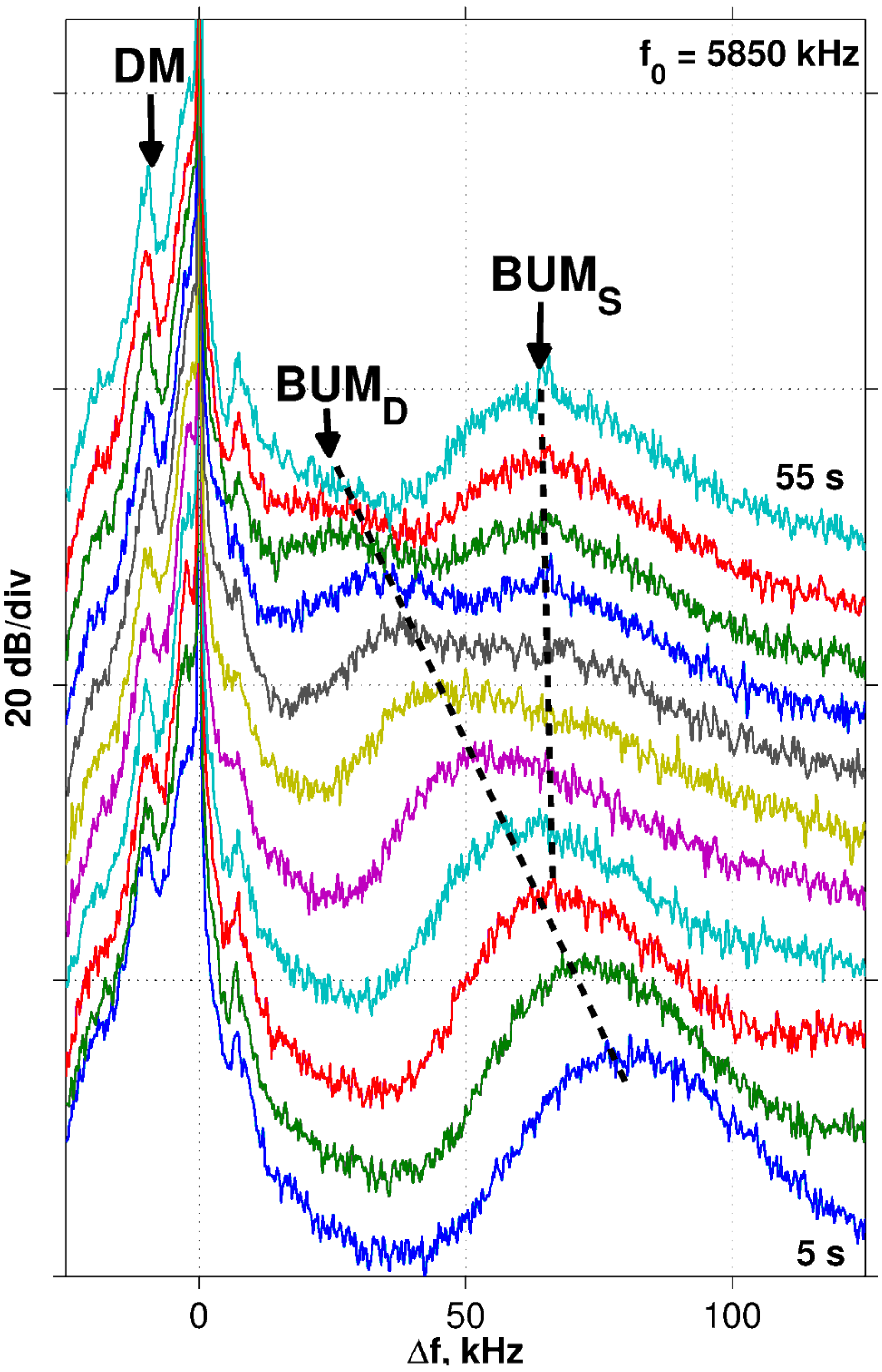


28.03.2011,

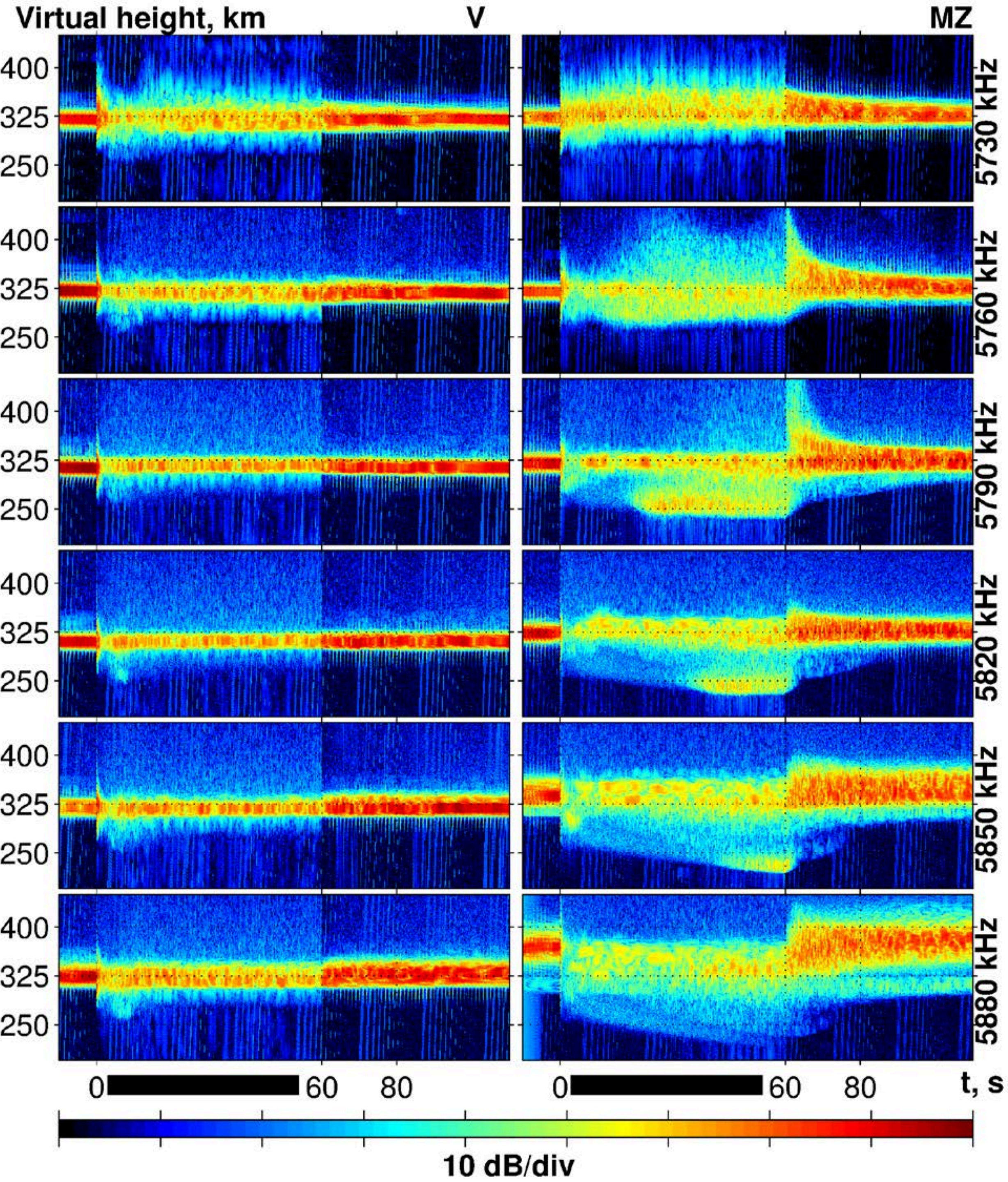
P_{ef} = 1,7 GW

SEE spectrograms for Vertical (V) and magnetic Zenith (MZ) pumping

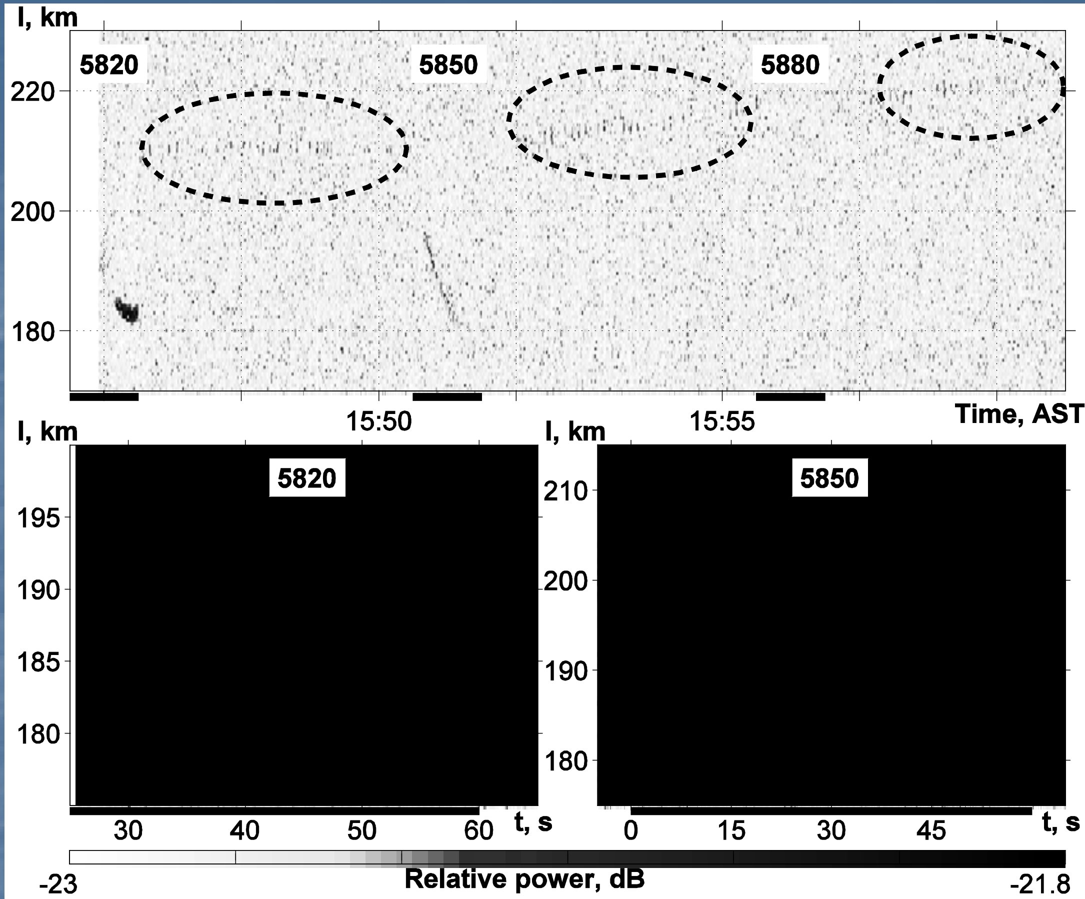
The DM absence at f_0=5760 kHz means that $f_{DM}=4f_c(h_d)=f_{uh}(h_d)\approx$ 5750 kHz



A sequence of the SEE spectra during 1 minute of the quasi-continuous pumping at f_0=5850 kHz with a 5 sec. step.



Virtual reflection heights of diagnostic 100-μs long pulses for vertical and MZ pumping vs time. Black bars – quasi-continuous pumping.



(top) Relative power of PL echoes from the MUIR vs range *l*≈ h/cos(14.2º) during the last three intervals of HDC at MZ.
(bottom) Zoomed images for f0 5820 (left) and 5850 (right) kHz. Black bars indicate period HDC. Dashed lines encircle the enhanced PL echoes during LDC periods near the reflection height h_r and at the onset of the HDS. The radar was turned on about 20 s after the start of HDC for 5820 kHz.

Similar and even more impressive results were obtained by Watkins and Fallen in March 2013.

CONCLUSIONS

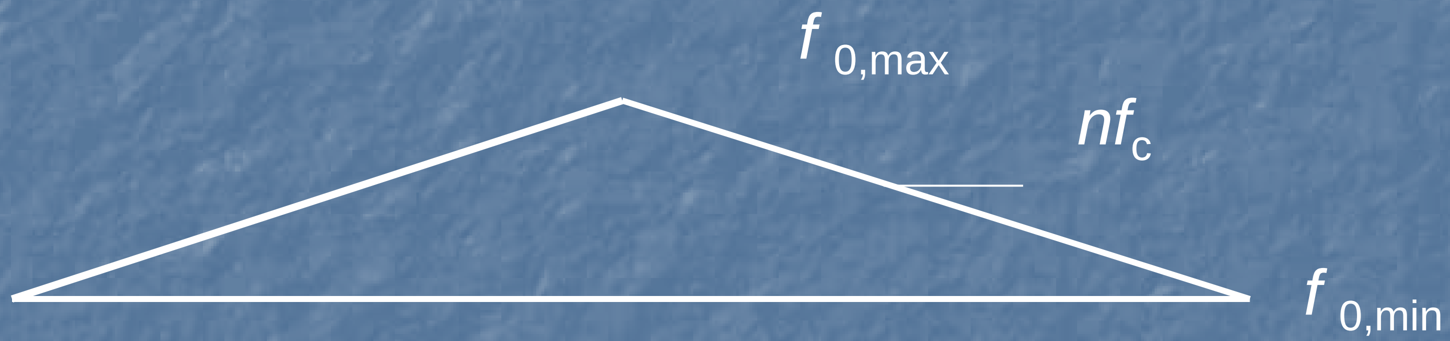
1. All three effects: BUM approaching to the pump wave in the SEE spectrum, a decrease of the diagnostic wave virtual reflections height and a range of the PL echo go together and shall be attributed to the artificial ionization layer! The speed od the layer descent can be estimated as V_L **≈450-600 m/sec**

2. The descending ionization layer appeared only if $f_0 > nf_c$ and at pumping to the magnetic zenith!

3. The descent of the artificial layer terminated at the height where $f_0 \approx 4f_c\,(h_d)$, or at the double resonance where

$$f_0 \approx 4f_c(h_d) \approx f_{uh}(h_d) = (f_p{}^2 + f_c{}^2)^{1/2}$$

Fast frequency sweep near fourth electron electron gyroharmonic $4f_c$ in case of preliminary created density striations.

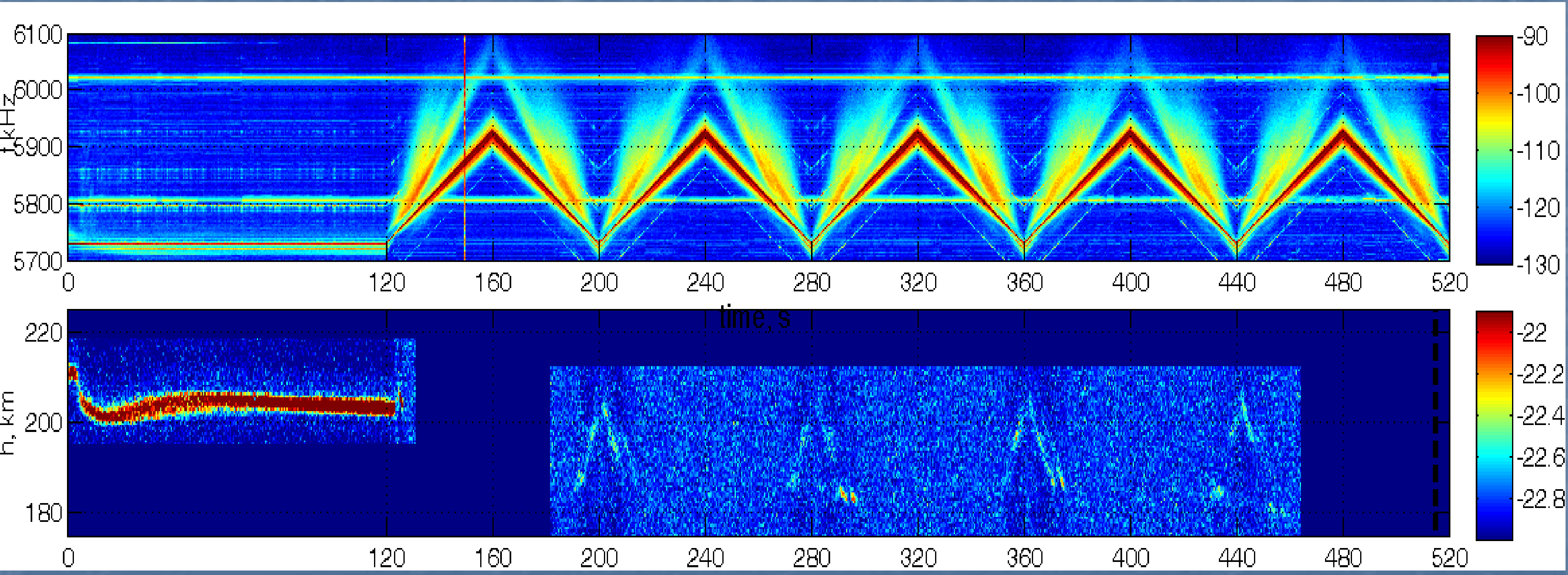


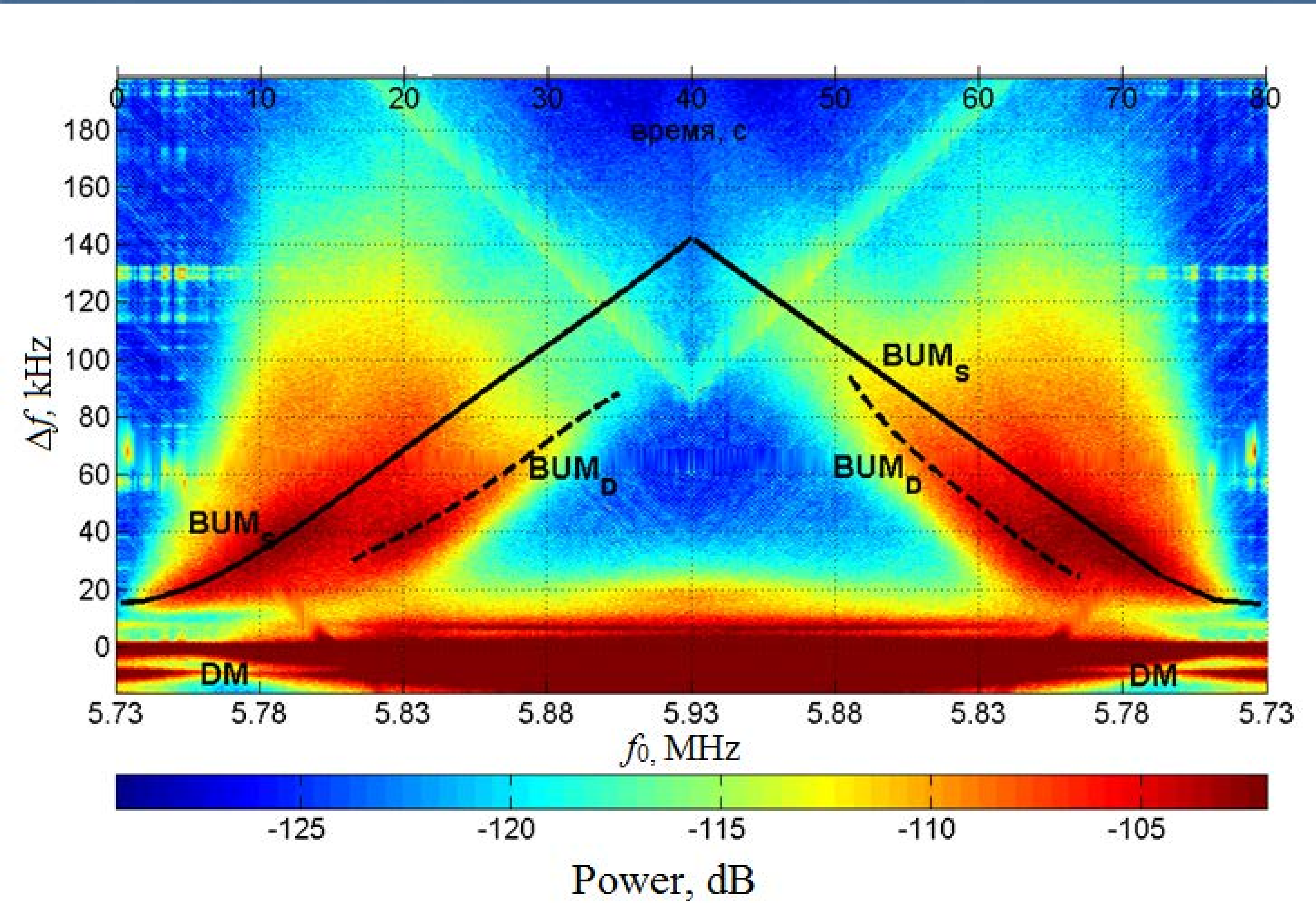
PW frequency was varied with a step of 1 kHz every 0.2 s, i.e., at the rate r_{f0} = 5 kHz/s within the range of 5730 → 5930 → 5730 kHz. The rate r_{f0} corresponds the displacement of the multiple (fourth) cyclotron resonance height, where $f_0=4f_c$, with a velocity $\boldsymbol{V_{4cr}\approx 1.9}$ **km/s>**V_L.

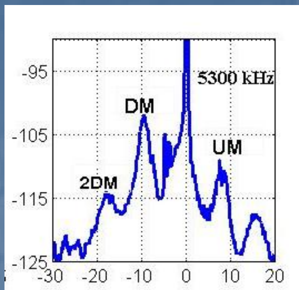
5730→5930→5730 kHz. Prior to sweeping, PW was transmitted continuously (CW) during 2 min at f_0 = 5730 kHz < $4f_c$

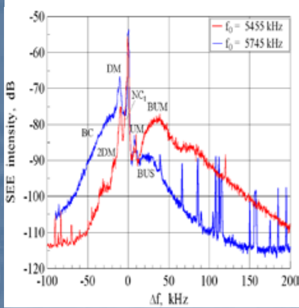
MZ pumping ($\mathbf{k}_0||\mathbf{k}_r||\mathbf{k}_s||\mathbf{B}$)

Top: SEE spectrogram. Bottom: MUIR radar Plasma Line (PL) echo. Bragg conditions: $f_s = f_r + f_L$; $\mathbf{k_s} = \mathbf{k_r} + \mathbf{k}_L$, $k_s \approx -k_r \approx -k_L/2$

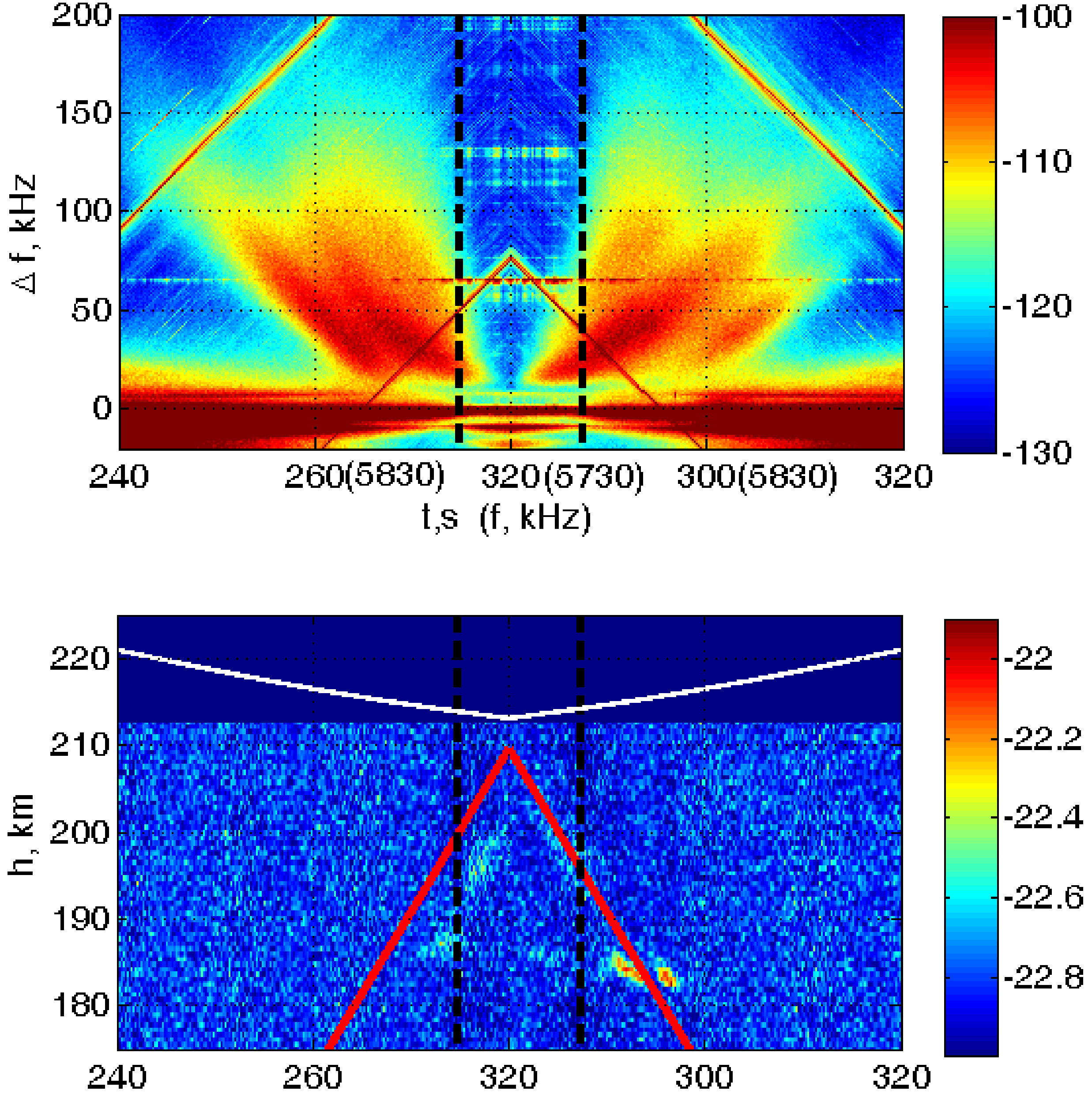




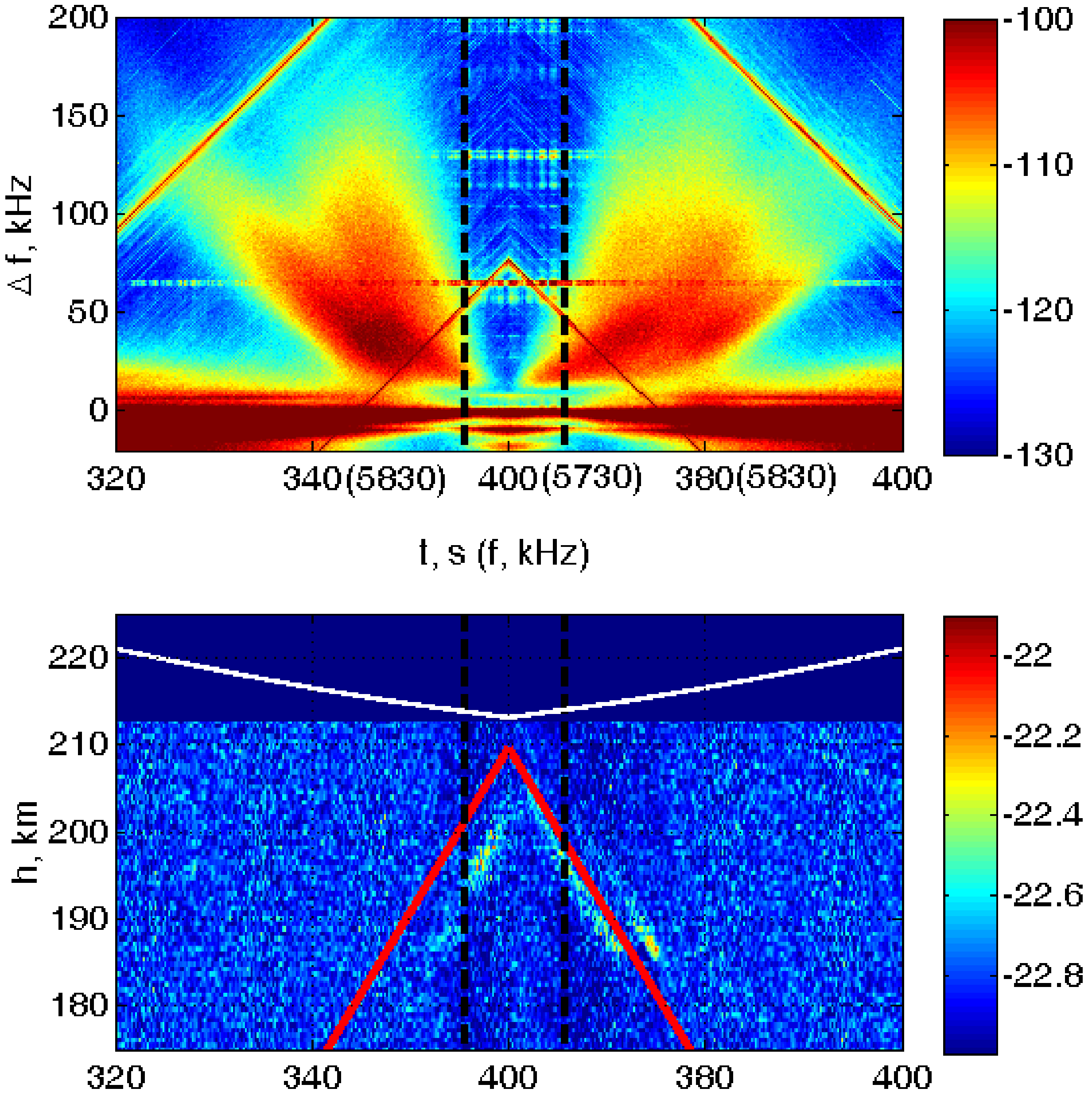




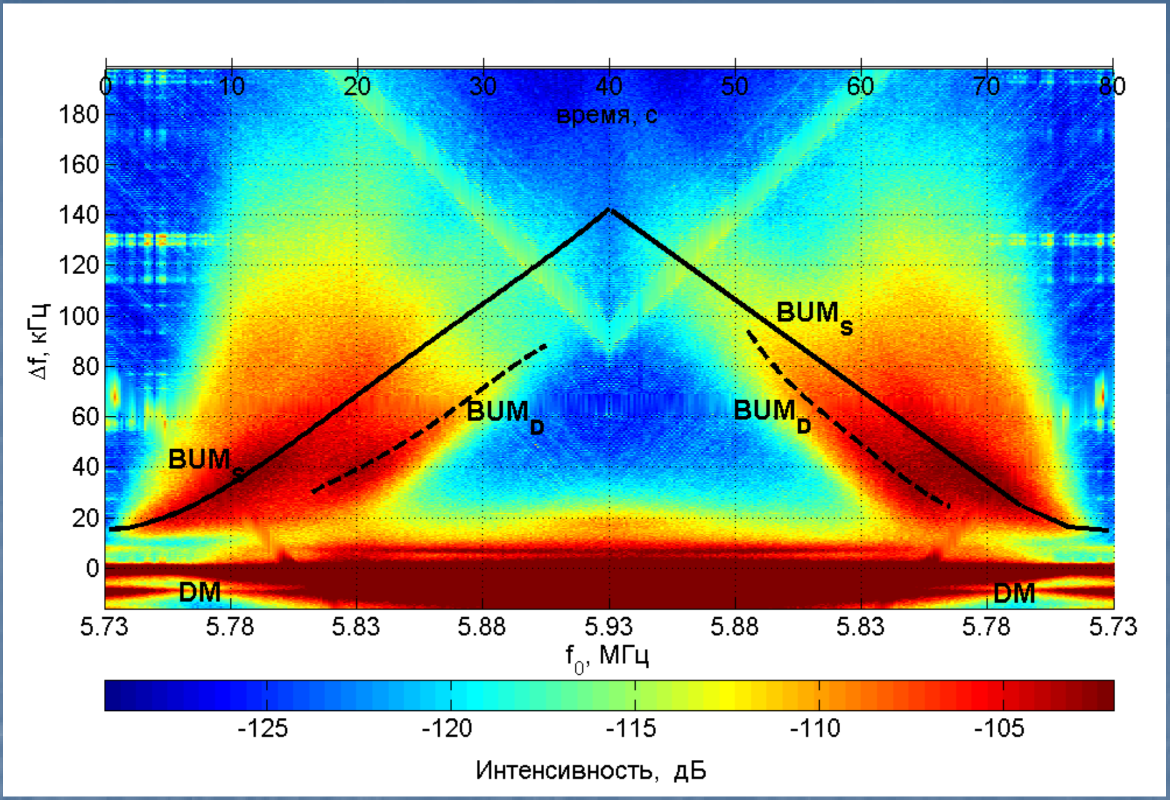
SEE spectrogram from 200th по 280th seconds (2nd sweep in the range 5730→5930→5730 kHz).



Pump frequency sweep in the range 5930→5730→5930 kHz.
(top):
SEE spectrogram,
(bottom): MUIR radar Plasma Line echo.
White line:
$f_0 = f_p(h)$,
red line: $f_0 = 4 f_c(h)$,
black dashed line: pump frequency at which the DM is minimum ($f_{DM} = f_d$)



Next sweep. During the sweep at $f_0 > 4f_c$ in the SEE spectrum together with “traditional” BUM_s (stationary broad upshifted maximum) at the shift of the peak $\Delta f_{BUMs} \approx f_0 - nf_c(d) + 15\text{-}20$ kHz, dynamic BUM_D is generated for $f_0 > f^*$.

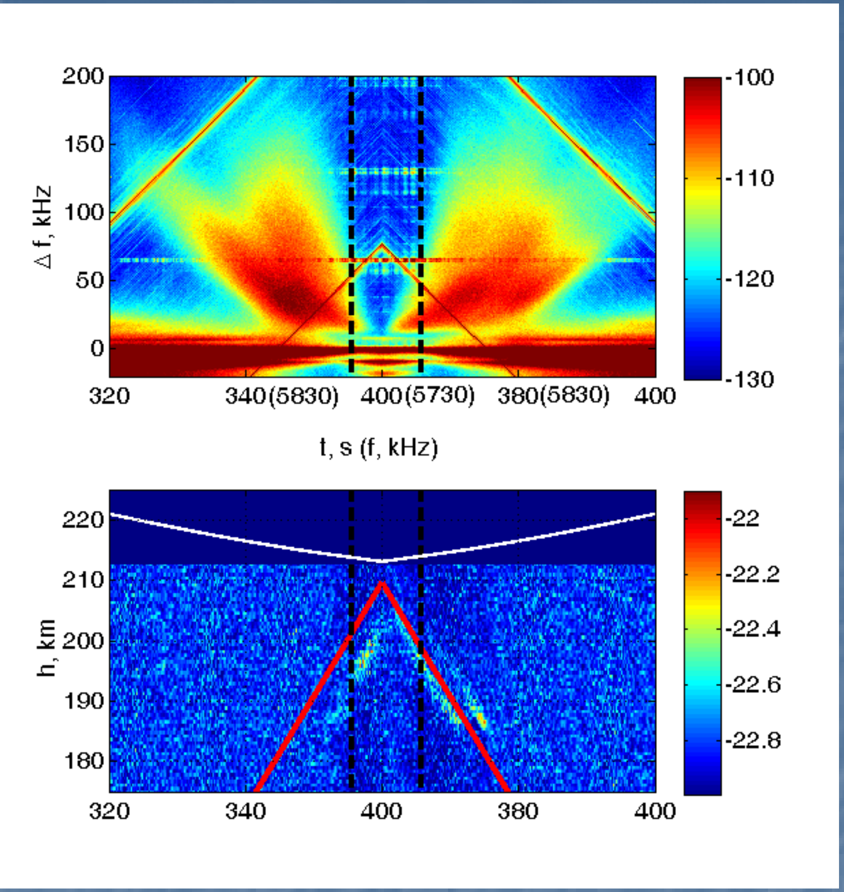


BUM_D was present at smaller Δf for $f_0 > f^* \sim 5800$ кГц (somewhat larger f^* and smaller BUM_D intensity occur during up-sweep). Assuming (1)

$$\boldsymbol{\Delta f_{\mathrm{BUM}} \sim f_0 - n f_c(h) + \delta f} \qquad \textbf{(1)}$$

to be valid, we can estimate that BUM_D is generated in the artificial ionization layer, 8-10 km below the background F-layer.

The minimum DM during the sweeps, which indicated the double resonance condition that $f_0 \approx f_d \approx 4f_c(h_d) \approx 4f_{uh}(h_d)$ (f_{uh} is the upper hybrid frequency, h_d – is the double resonance altitude) in the background ionospheric plasma, occurred at 5759 -5764 kHz.



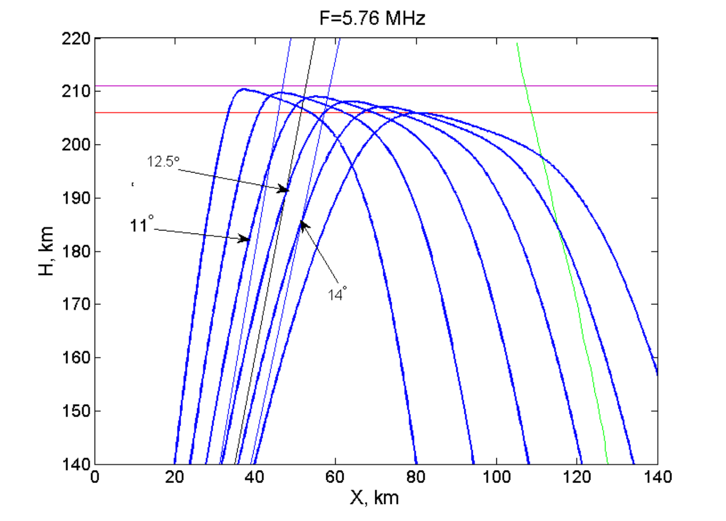
The PL signal was observed form the ranges *d* (altitudes *h*), whare $f_0 < 4f_c$, The altitude *h* decreased against growing f_0 in accordance with the altitude dependence $4f_c(h)$. The difference $\Delta f_g = f_0 - 4f_c$ was kept constant during either sweeping up [-(4-8 kHz)] or sweeping down [-(18-22 kHz)]. This corresponds to the difference between the altitude where $f_0 = 4f_c$ and the PL generation altitude by Δh ~ 1.5-3 km and 7-8 km, respectively. During the down-sweep, the PL was observed only for 5730 kHz $< f_0 < f_d$ + 10 kHz, at $f_0 \approx f_d$ PL dropped till the noise level.

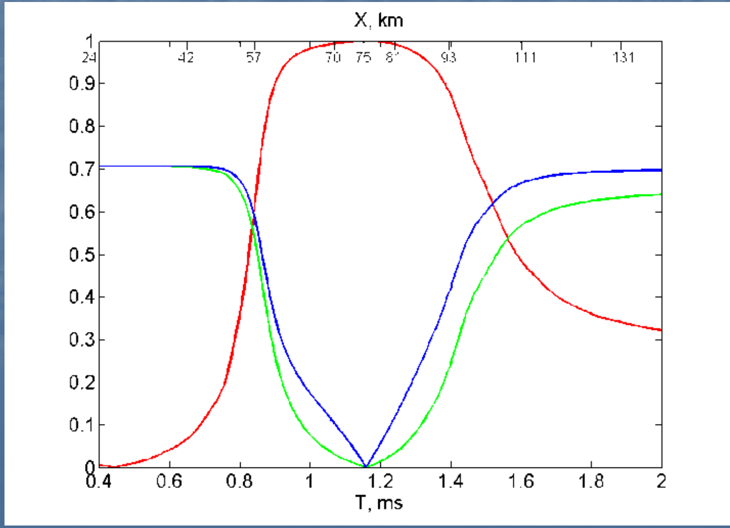
During stepping up the upper limit of the PL generation (over f_0) was observed for larger f_0 and the PL intensity drop at $f_0 \approx f_d$ was observed not in all sessions. Besides, the PL was observed also from the ranges where $f_0 > 4f_c$. In this case Δf_g was 8-13 kHz corresponding to Δh ~ -4 km. The PL has never been observed for $f_0 > f^*$.

CONCLUSIONS

During long-term pumping (>5 s), the energy is pumped into plasma waves propagating across geomagnetic field *B* near local upper hybrid resonance. This follows from

1) the presence of the UH-related DM and BUM in the SEE spectra;
2) the PL generation height (range) gluing to the 4th CR height;
3) weakening of the PL at $f_0 \sim f_d$;
4) PL generation height (range) is considerably less than PW plasma resonance and PW reflection heights. At former height, PW is polarized mainly across the magnetic field *B*.





Excitation of the Langmuir waves propagating along ***B*** occurs, most likely, due to plasma wave energy transfer from “transversal” UH to “longitudinal” Langmuir waves over angles. For $f_0 > 4f_c$ ($f > f^*$), the energy transfer is less effective due to presence of the other energy “consumers”, such as electron acceleration and additional ionization. Therefore, the plasma UH waves excited by PW do not have enough energy to achieve longitudinal direction under the transfer.

QUESTIONS:

1) Why the PL generation is glued to the 4CR?
2) Why during the up-sweep the PL is generated for both $f_0>4f_c$ and $f_0<4f_c$, but at the different frequency offsets $|\Delta f_g|$?
3) Is the result general or belongs only to the experiment described?

Thank you for attention