Studies of the Ionospheric Turbulence Excited by the Fourth Gyroharmonic at HAARP

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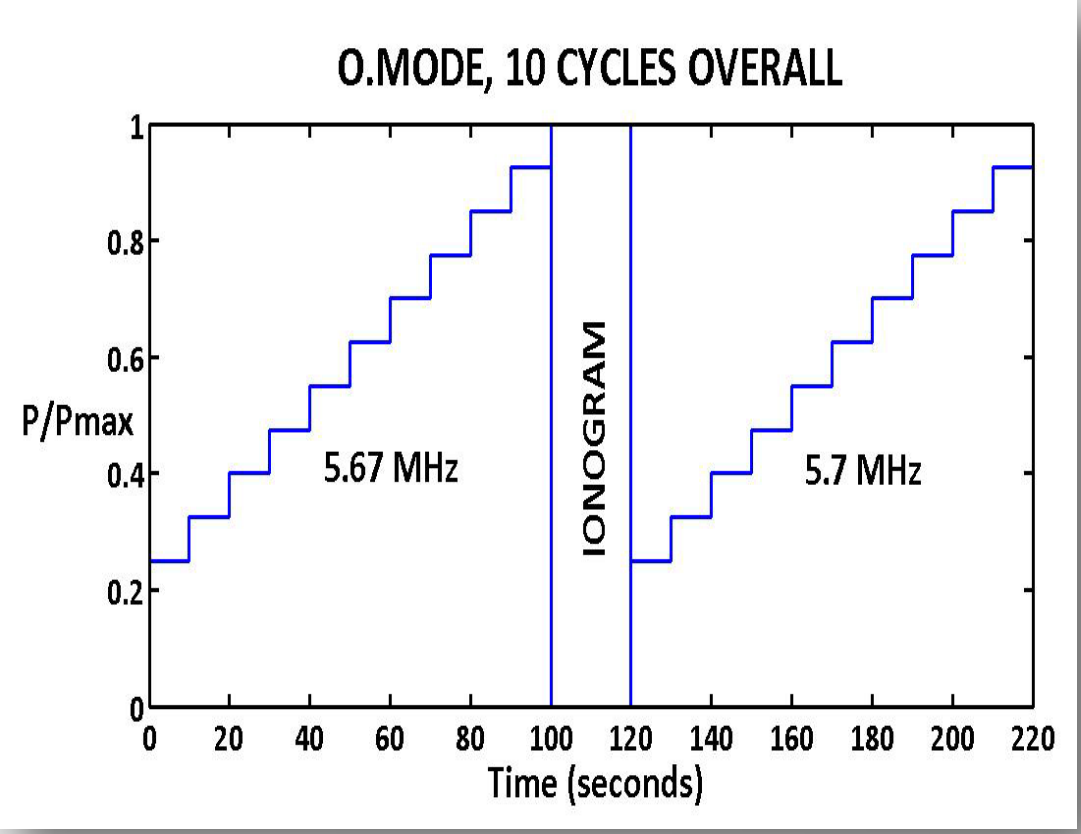
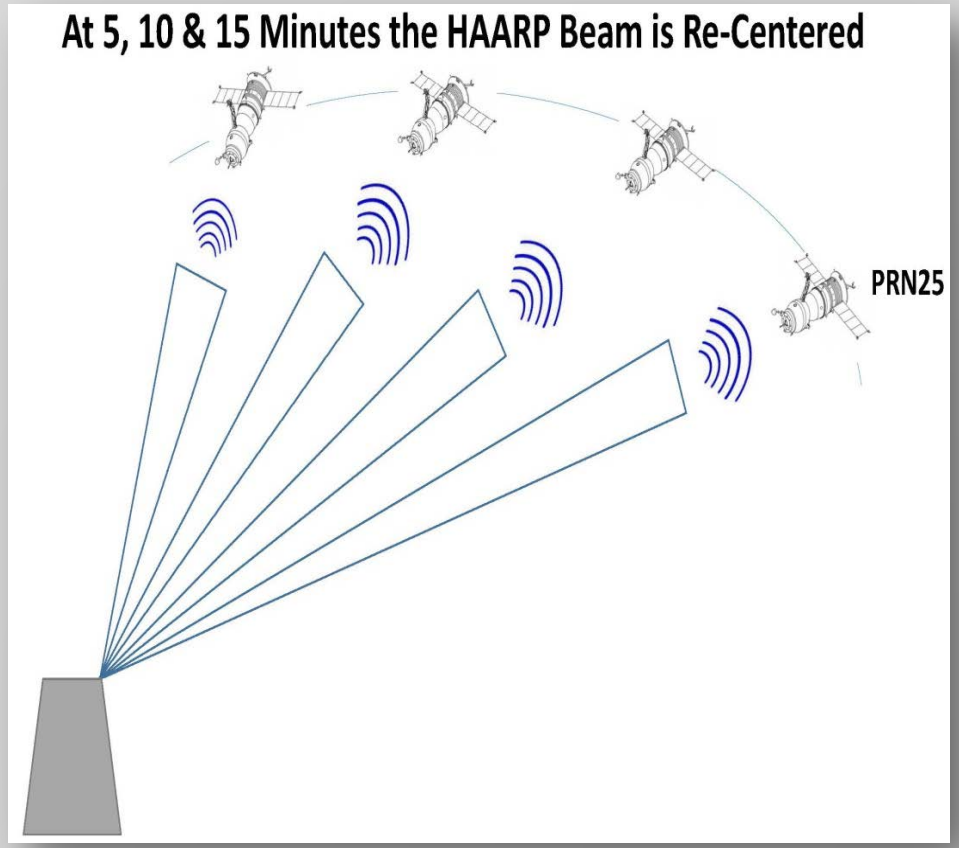
Objectives

- **Artificial ionospheric turbulence was studied during the HAARP June 2014 campaign. The data collected from the different diagnostic tools were analyzed, the main features detected in the experiments are discussed.**

- **The diagnostics included:**
- **measurements of phase-derived Slant Total Electron Content using the L1/L2 GPS;**
- **measurements of Stimulated Electromagnetic Emission (SEE);**
- **ionograms from HAARP's digisonde and reflectance data from Kodiak radar;**
- **detection of the HAARP HF radiation at Antarctica Peninsula.**

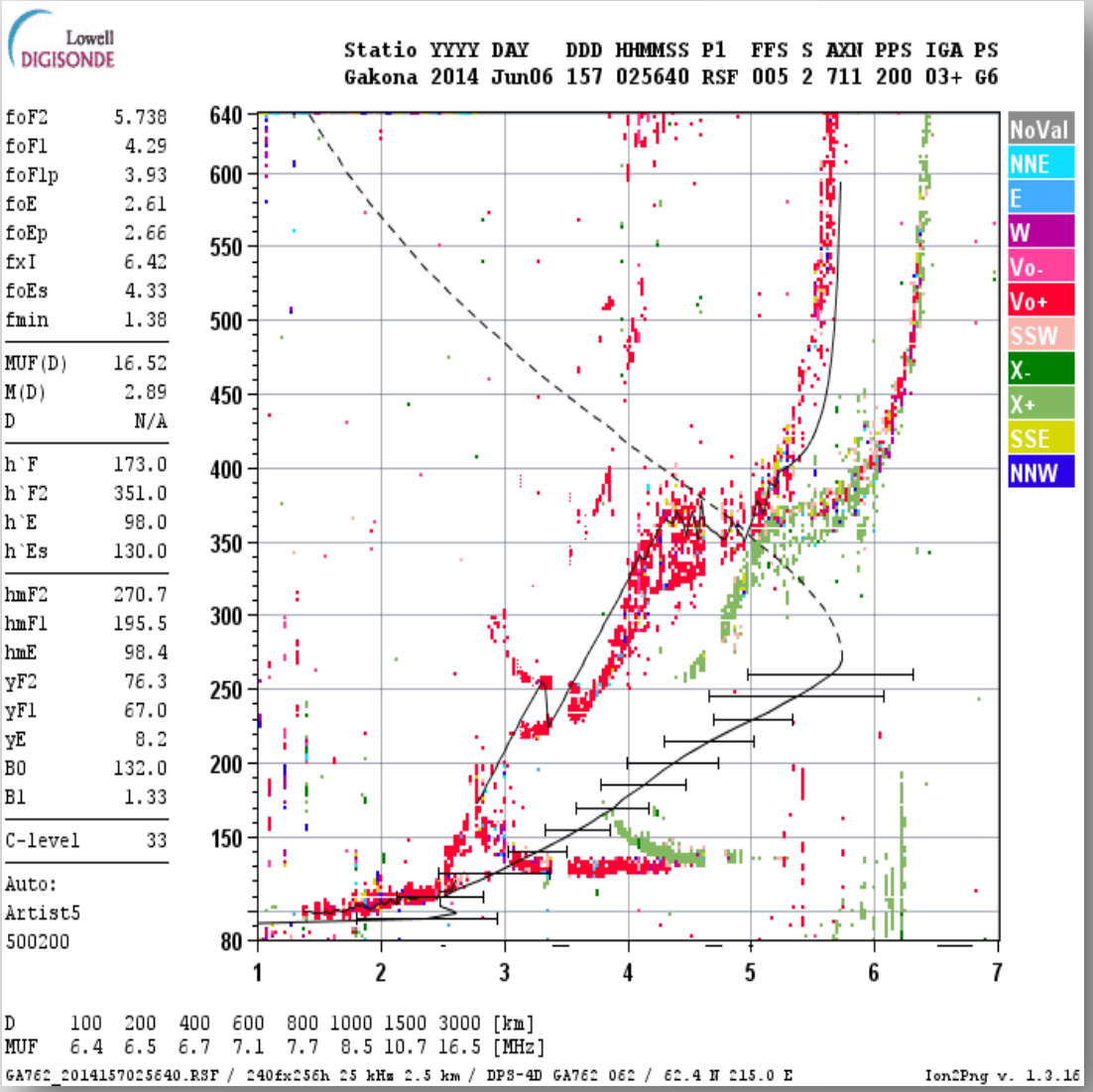
Schematic of the Experiment





Three experiments were conducted on June 6-8, 2014. We will focus on 06/06 experiment. The frequency was stepped up from 5.67 to 5.94 MHz in 30 kHz increments.

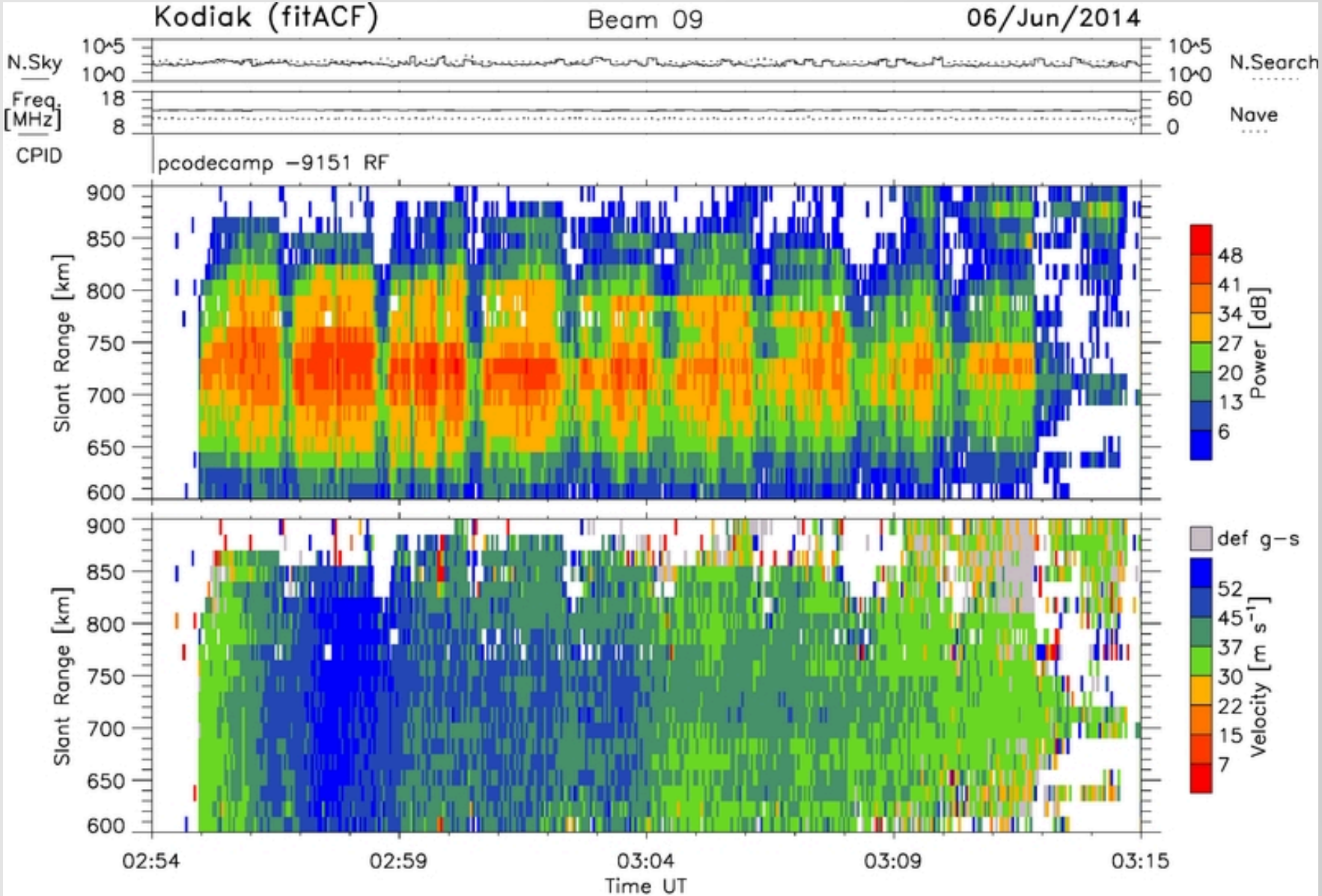
The ionospheric conditions on 6/6/2014



The local time was 7 p.m., the ionosphere was slightly disturbed with Es present.

The heating frequency was 5.67-5.94 MHz and the 4th gyro resonance estimated at 5.6 MHz.

SNR & velocity of plasma irregularities from Kodiak

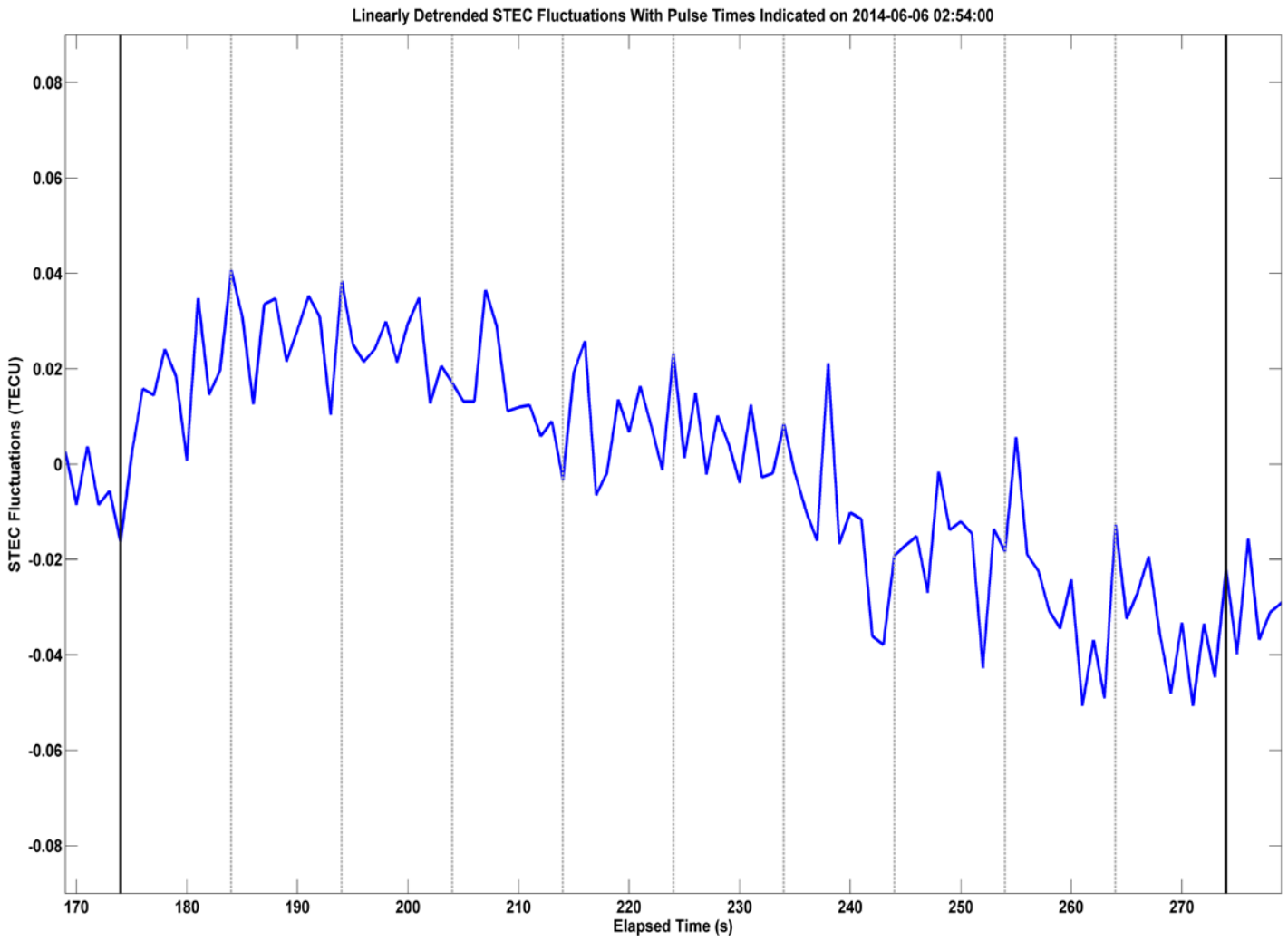


The HF heating was switched on at 02:55, a strong radar reflection Appeared 20s later.

The strongest backscatter at 5.7-5.8 MHz.

Velocity of the artificial irregularities reached 50m/s.

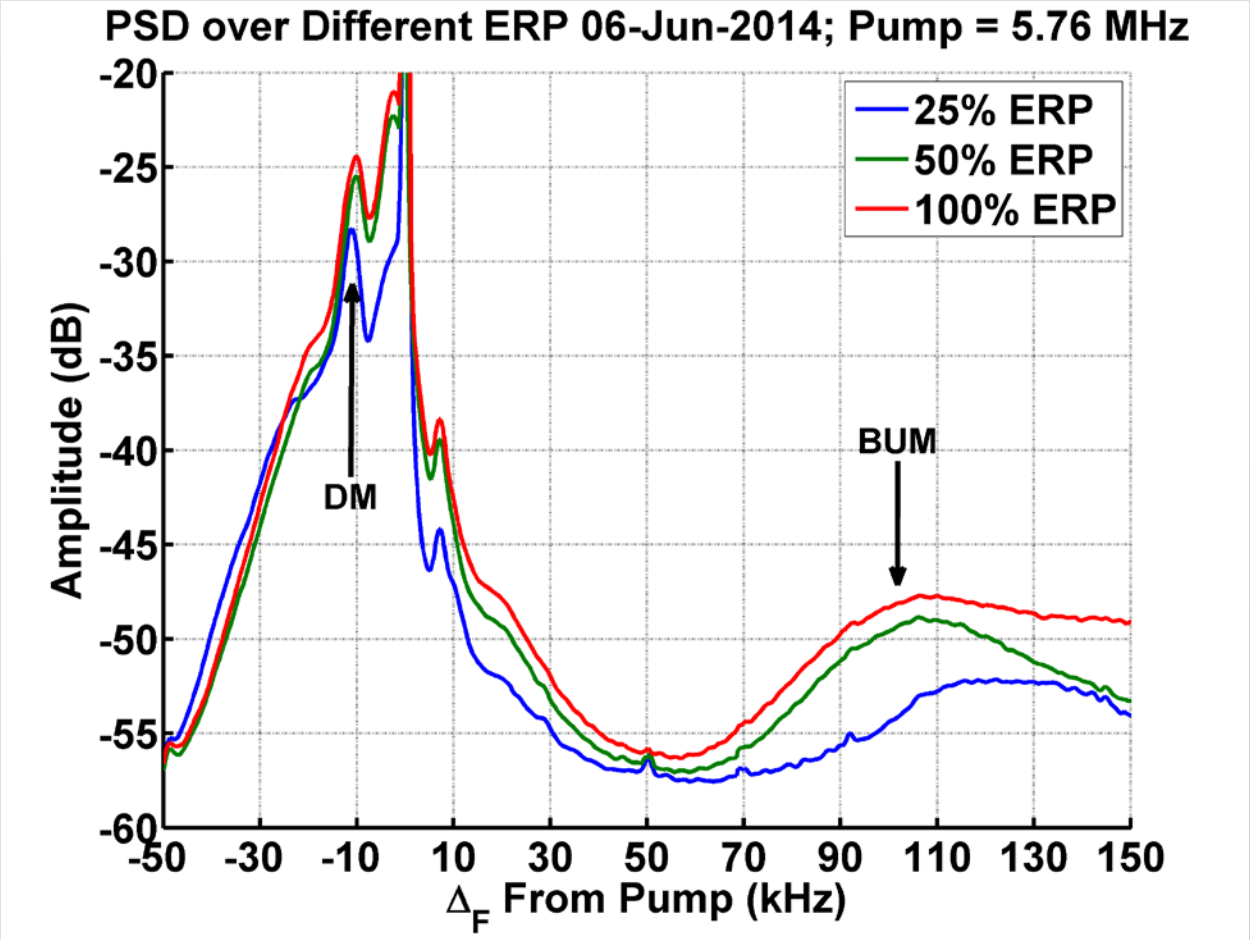
STEC data detected at HAARP



STEC vs. elapsed time

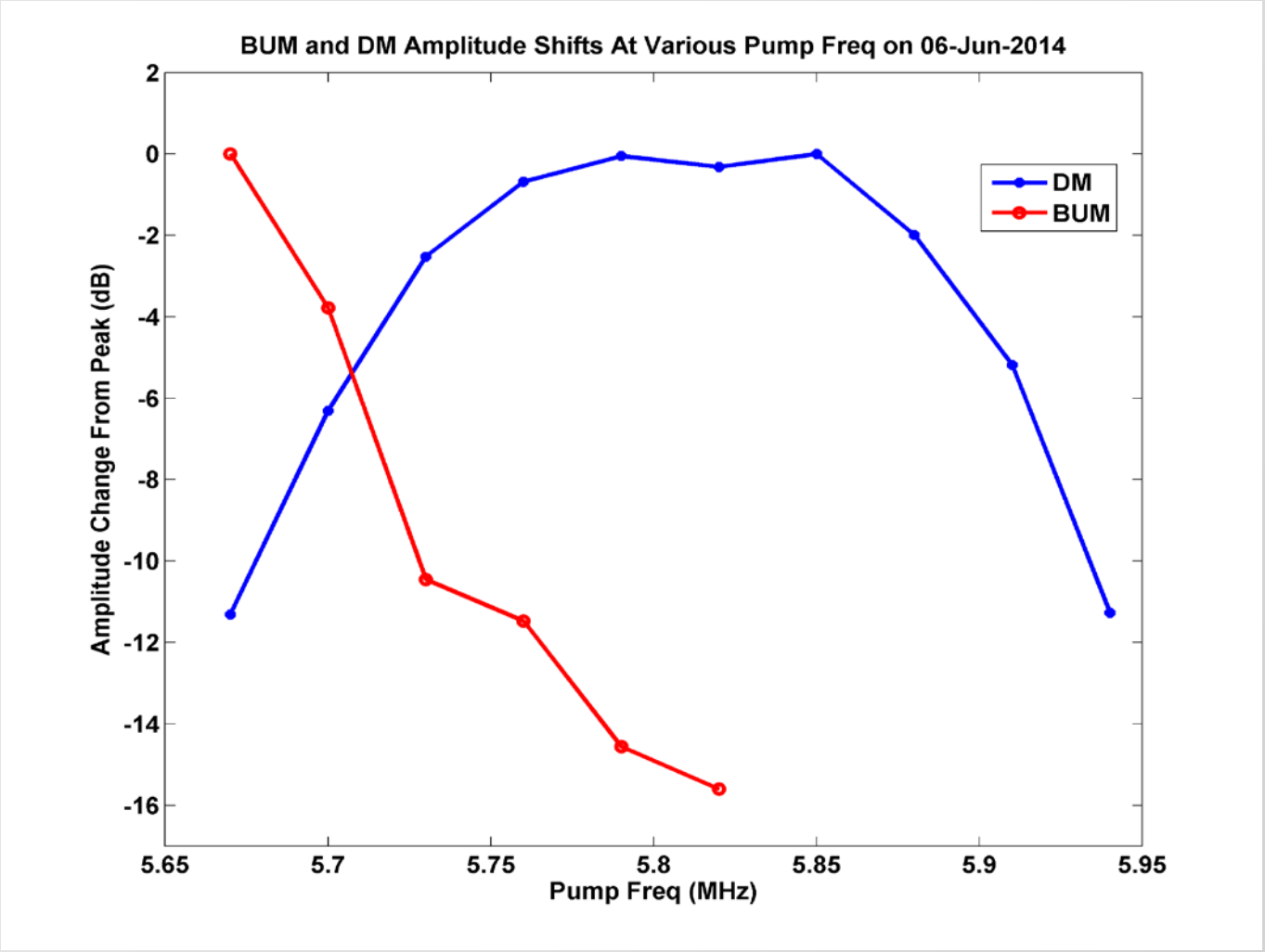
f=5.70 MHz, stepping up ERP each 10 s

Power spectral densities (PSD) of broadband SEE



The traces are averaged over a 10s portion of the heating period with constant effective radiated power (ERP). *SEE signals were measured by the Naval Research Lab. Detector 15 km away from HAARP.*

Amplitudes of DM & BUM

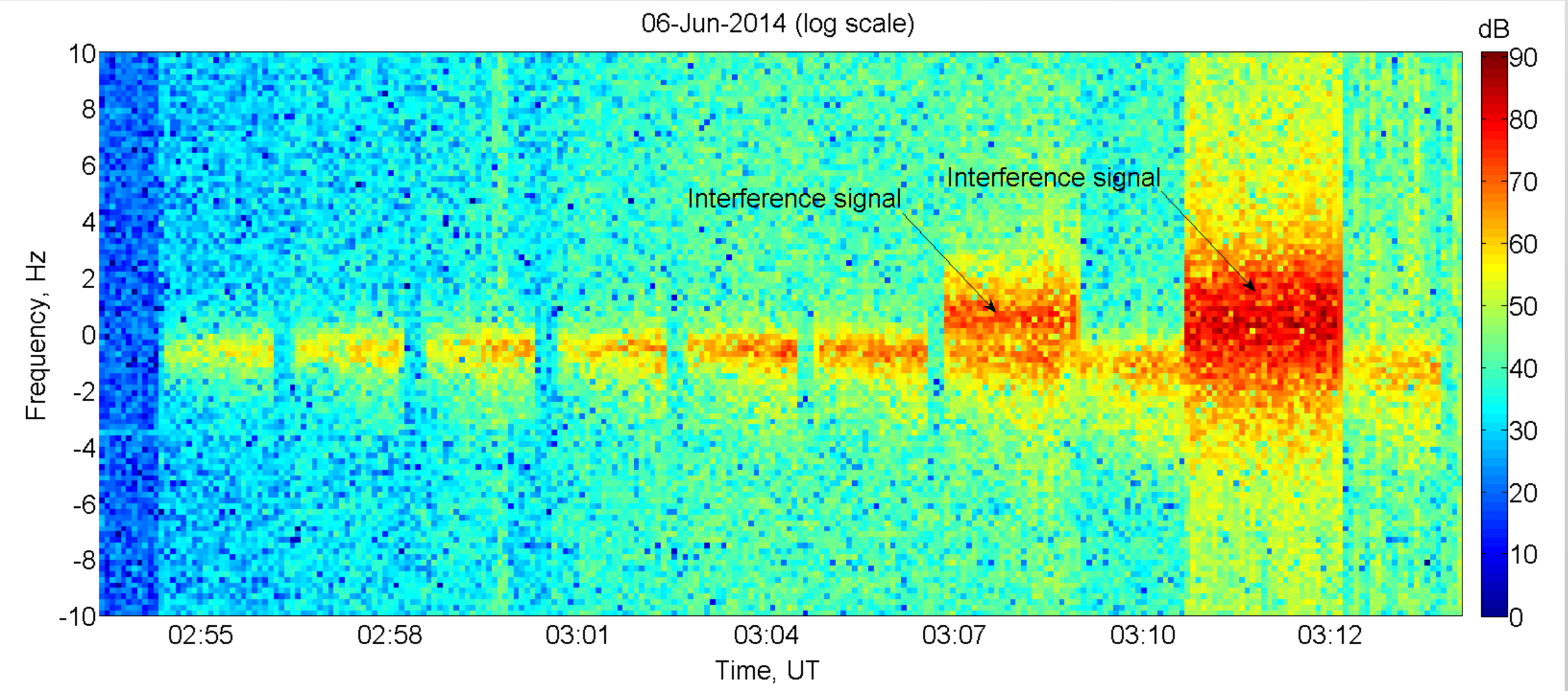


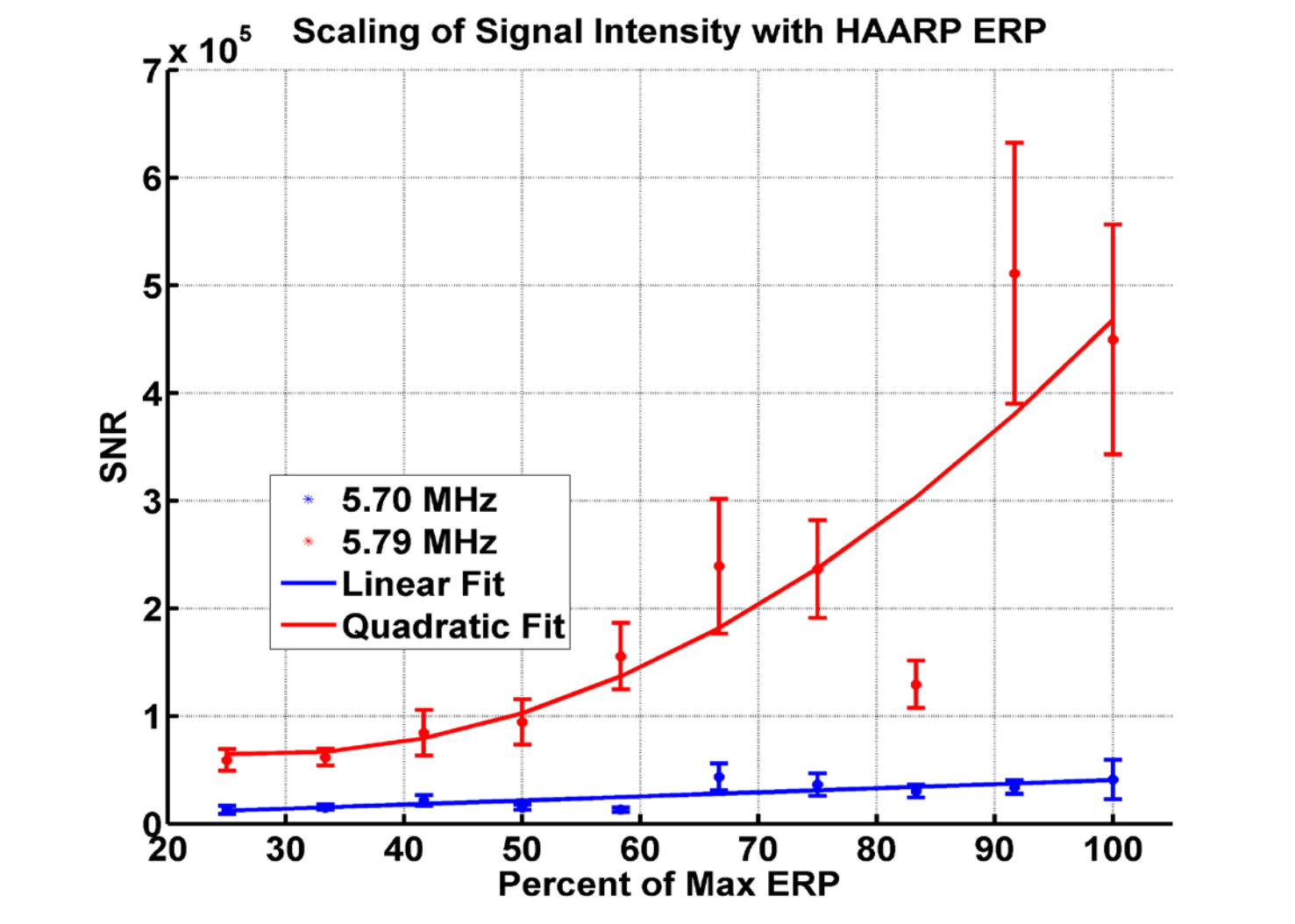
Amplitudes of DM & BUM, both normalized by their peak values, versus the heating frequency.

HAARP signals detected at UAS

- **HF waves from HAARP were scattered by the AIT into the ionospheric waveguide oriented along Earth's terminator, and were subsequently detected at Ukrainian Antarctic Station (UAS) (coordinates 65.25 S, 64.25 W) at 15.6 Mm from HAARP.**
- **Simultaneous attempts to measure the scattered HF signal in Ukraine and Scandinavia were unsuccessful showing the critical role played by the terminator.**

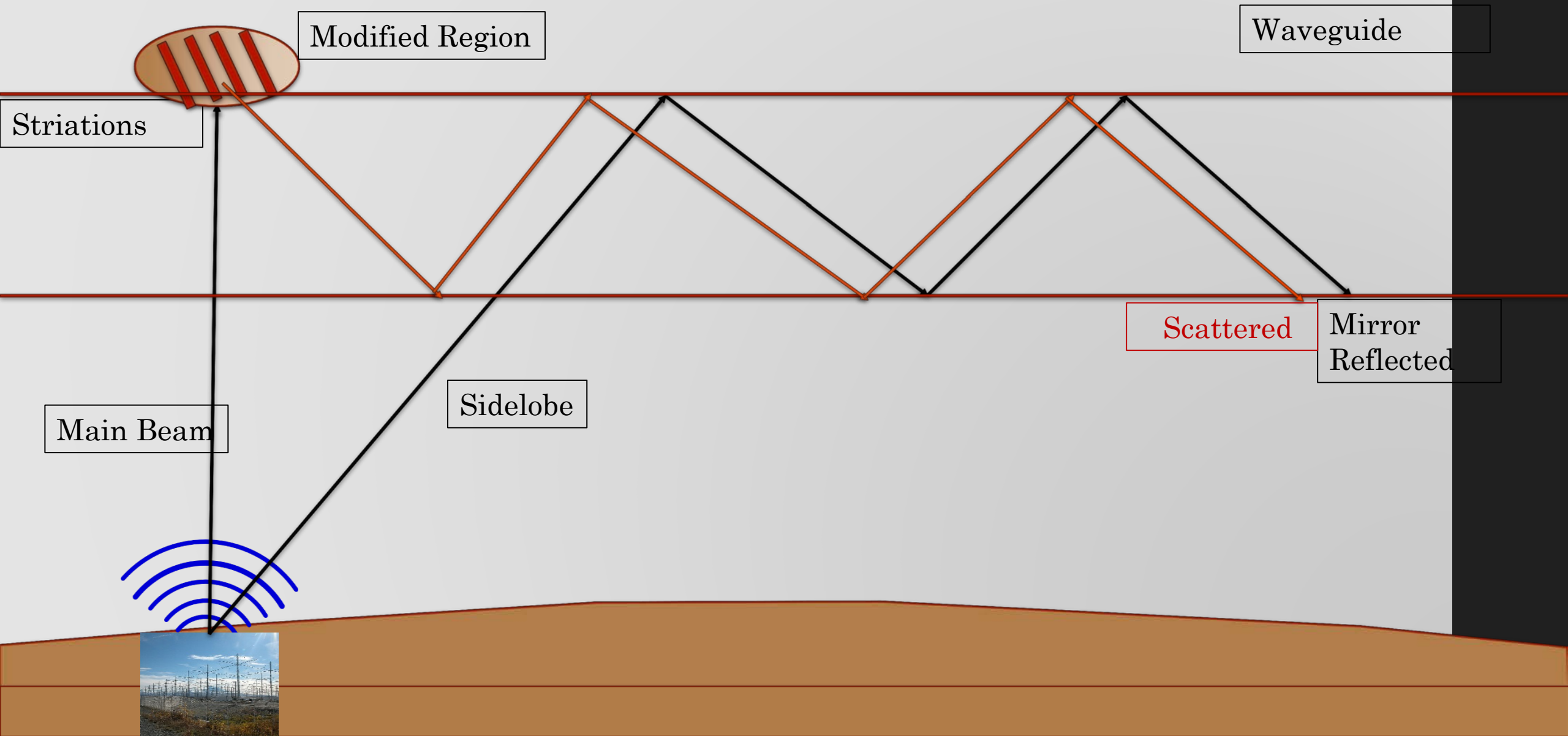
Spectrogram of the HF signal at UAS





Scaling of the Signal-to-noise-ratio at UAS with ERP for two different pump frequencies. 5.79 MHz is non-linear in HAARP's ERP.

Schematic of HF Signal Formation

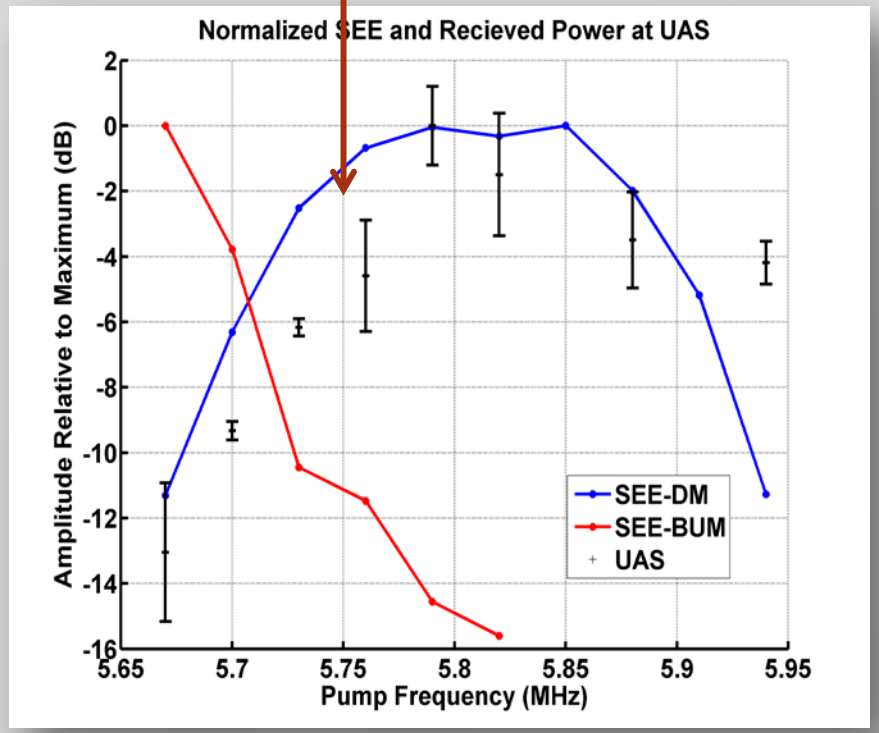


The peak of the amplitude of the HF signals detected by UAS correlates with the peak of DM

The BUM is associated with 10 cm scale striations, called super small striations (SSS) while the DM is associated with decameter scale striations.

SSS are inefficient scatters of the HF waves compare to the decameter scale striations.

The mirror reflection does not play an important role.



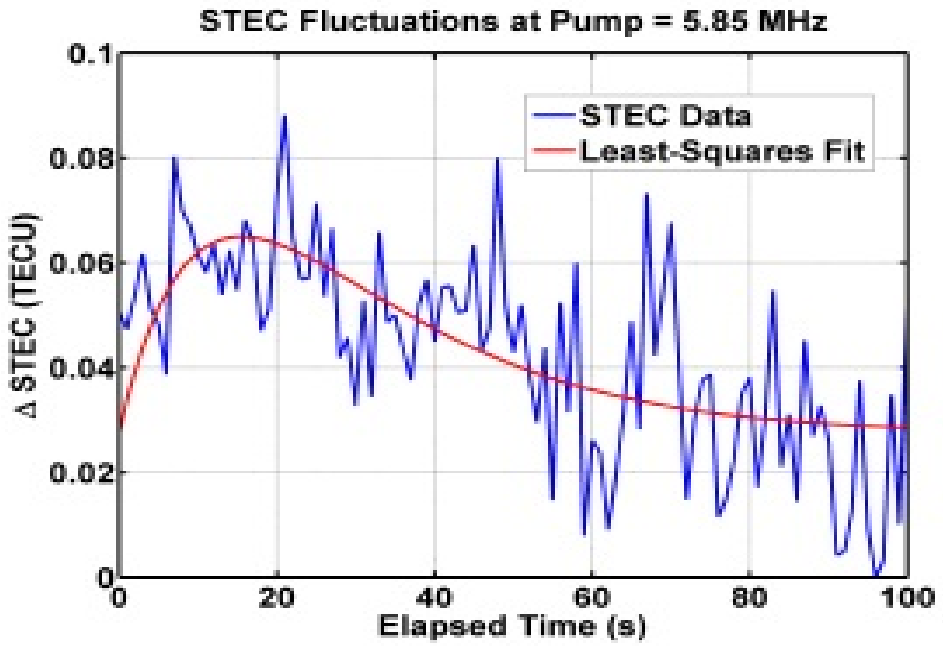
The shape of STEC may be caused by competition between SSS which are responsible for the scattering GPS signals, and decameter scale striations which control the anomalous absorption.

$$\mathrm{STEC} \propto \left(\frac{\delta n_e}{n_e}\right)^{SSS} \propto P e^{-\mathrm{abs}}$$

$$\mathrm{abs} \propto P$$

$$\mathrm{STEC} \propto (P/P_{max})\, e^{-\frac{\alpha P}{P_{max}}}$$

$$\alpha = P_{max}/P_{peak}$$



Conclusions

- **The AIT induced at HAARP by the frequencies swept around $4f_{ce}$ was studied by a set of diagnostic tools. That include STEC, SEE, the HAARP ionozonde, and Kodiak radar. We added the novel diagnostic of received signal at the Ukrainian Antarctic Station (UAS) 15.6Mm away.**
- **HF waves from HAARP were scattered by the AIT into the ionospheric waveguide oriented along Earth's terminator, analogous to a whispering gallery mode, and were subsequently detected at UAS. Simultaneous attempts to measure the scattered HF signal in Ukraine and Scandinavia were unsuccessful demonstrating the critical role played by the terminator.**
- **The intensity of the received signal at UAS also has a frequency dependence, with the maximum occurring at the same frequency as the DM peak in the SEE and the minimum correlating with the BUM peak in the SEE**
- **The Doppler broadening was Δf_D=1.15-1.40 Hz. This corresponds to the velocity of ionospheric irregularities 30-35 m/s, which is consistent with the our direct measurements from the Kodiak radar.**
- **The STEC and SEE probing of AIT reveal nonlinear effects caused by the variations of the intensity and frequency of the pumping wave.**

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Extra Slides

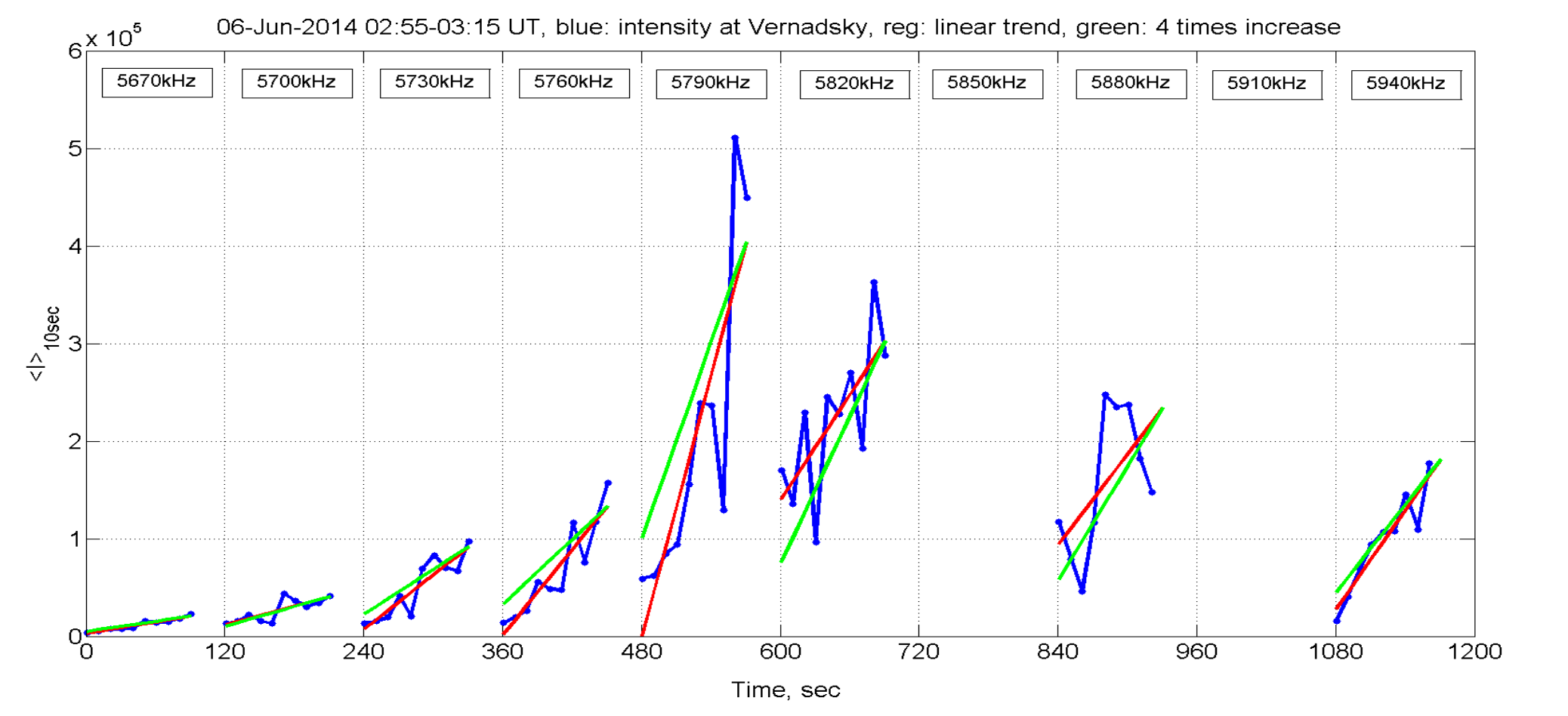
HAARP signals detected at UAS

- **The scattering HAARP signals were detected on the ground at Ukrainian Antarctic Station (UAS) (coordinates 65.25 S, 64.25 W) at 15.6 Mm from HAARP.**

- **The HF signals were recorded within frequency band 500 Hz centered at the carrier frequency of the HAARP pumped signal.**

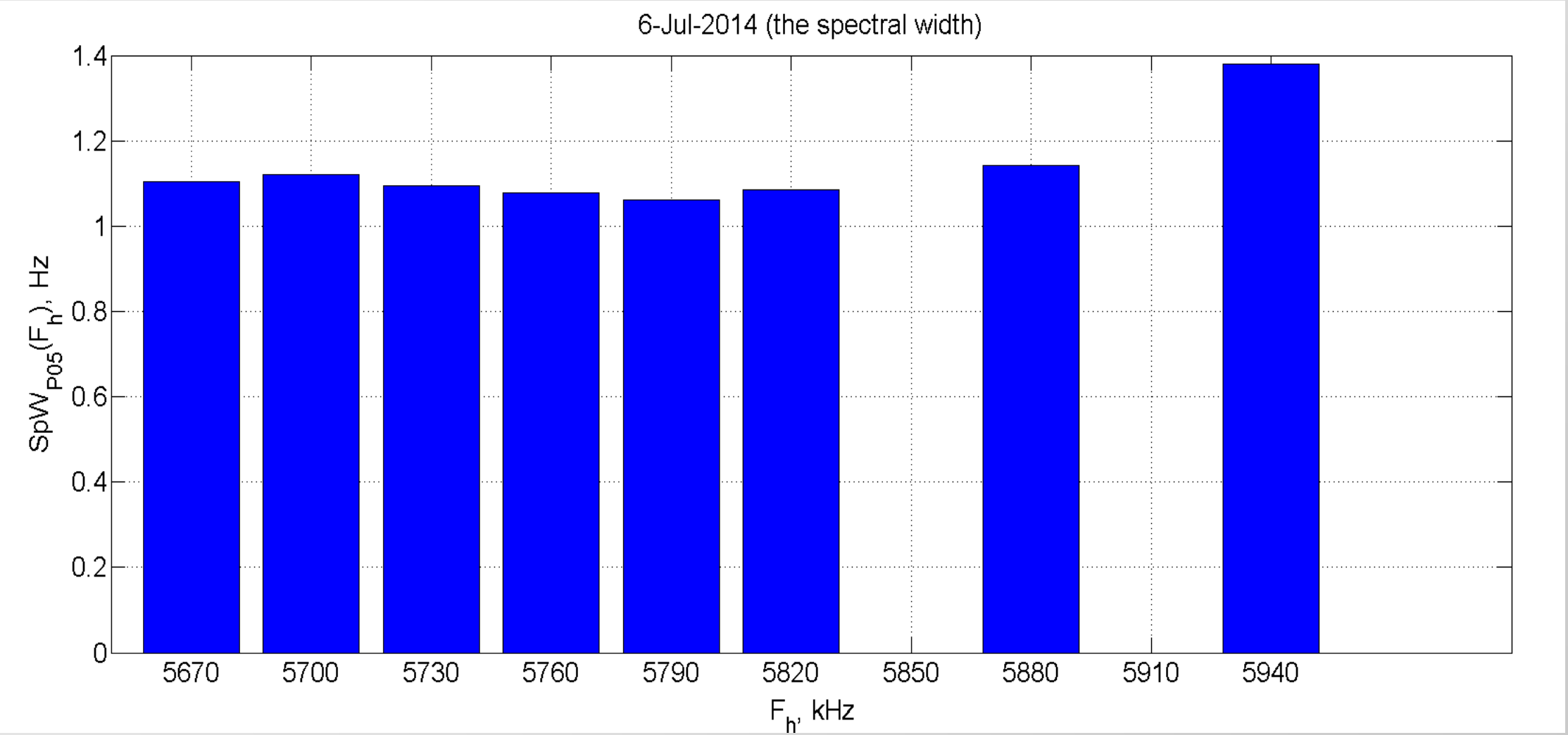
- **The data acquisition system collected records of the intensity and the Doppler spectra of the signal with time resolution 1.0 and 10.0 sec.**

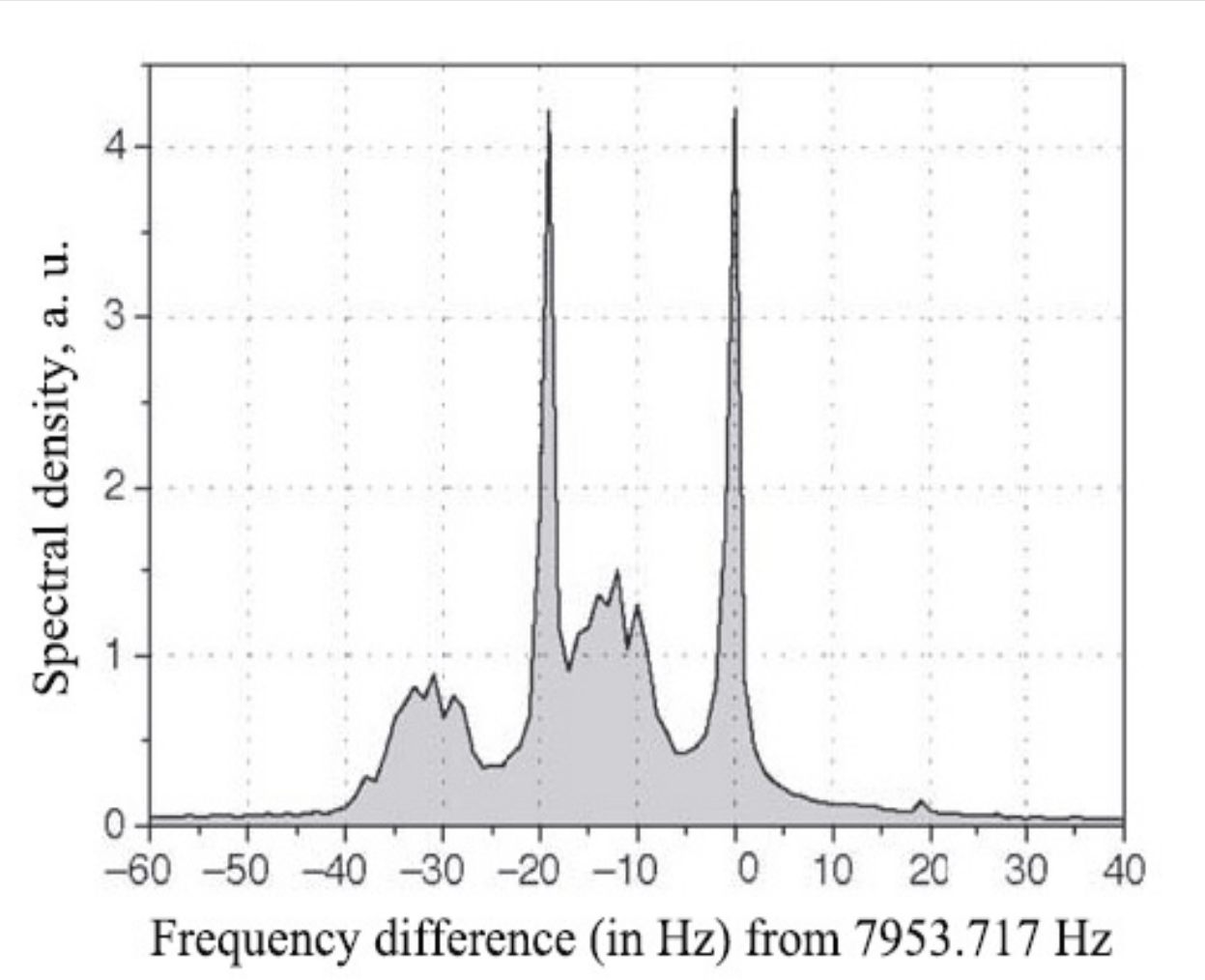
Scaling of Received Power at UAS with ERP. Linear scaling shown for reference



The blue line is the signal intensity vs. ERP; the green lines correspond to 4 times increase of ERP; the linear interpolation is shown by the red lines.

Spectral width of received signal at half-max power at UAS





Zalizovski et al. [2009] detected HF signals from EISCAT facility at UAS 16.3 Mm from the heater. The HF signal revealed:
a narrowband “mirror-reflected” and broadband “scattered” components.