New Method of Ionospheric Diagnostics Using Artificial Periodic Irregularities with Different Spatial Scales

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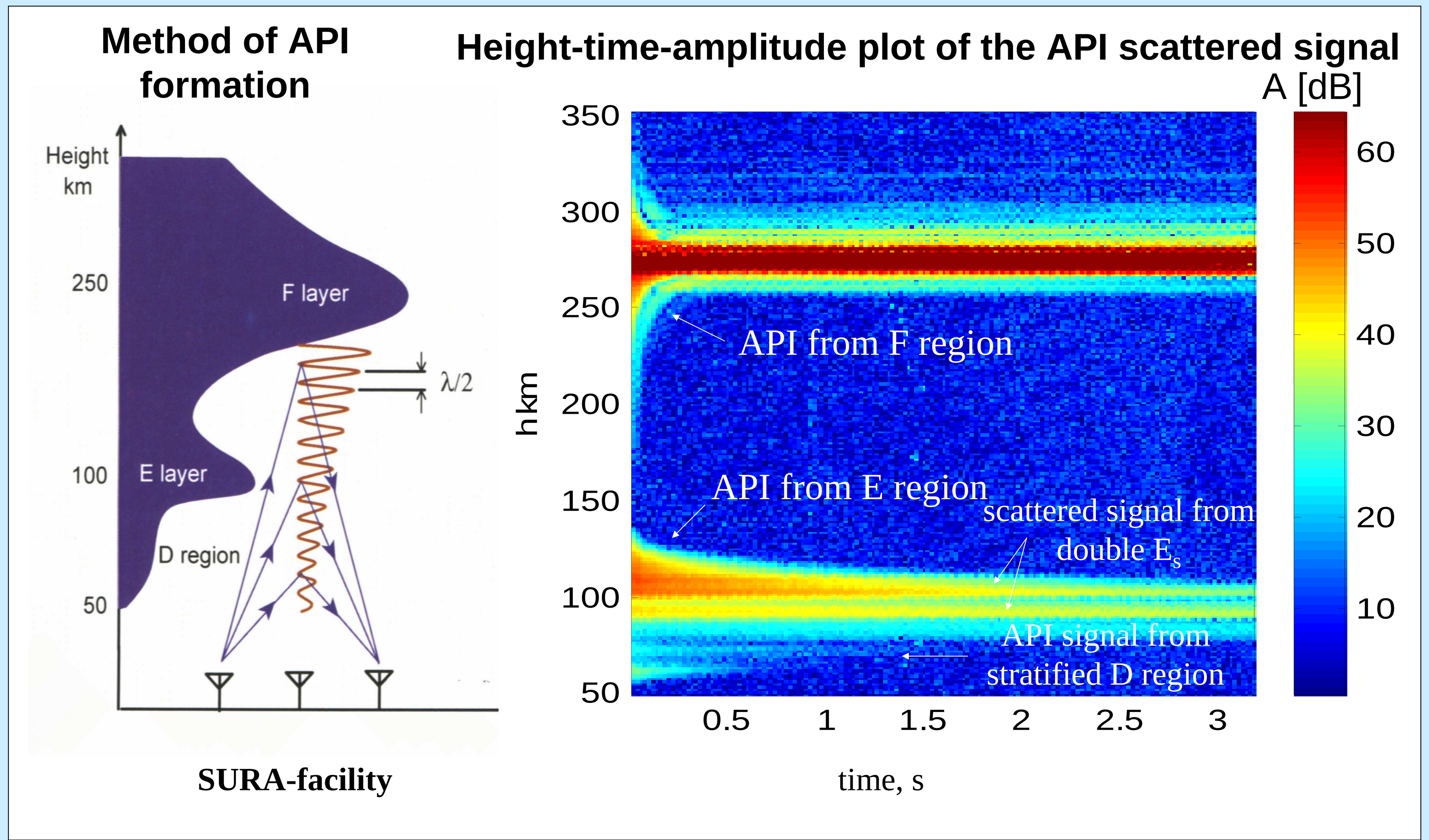
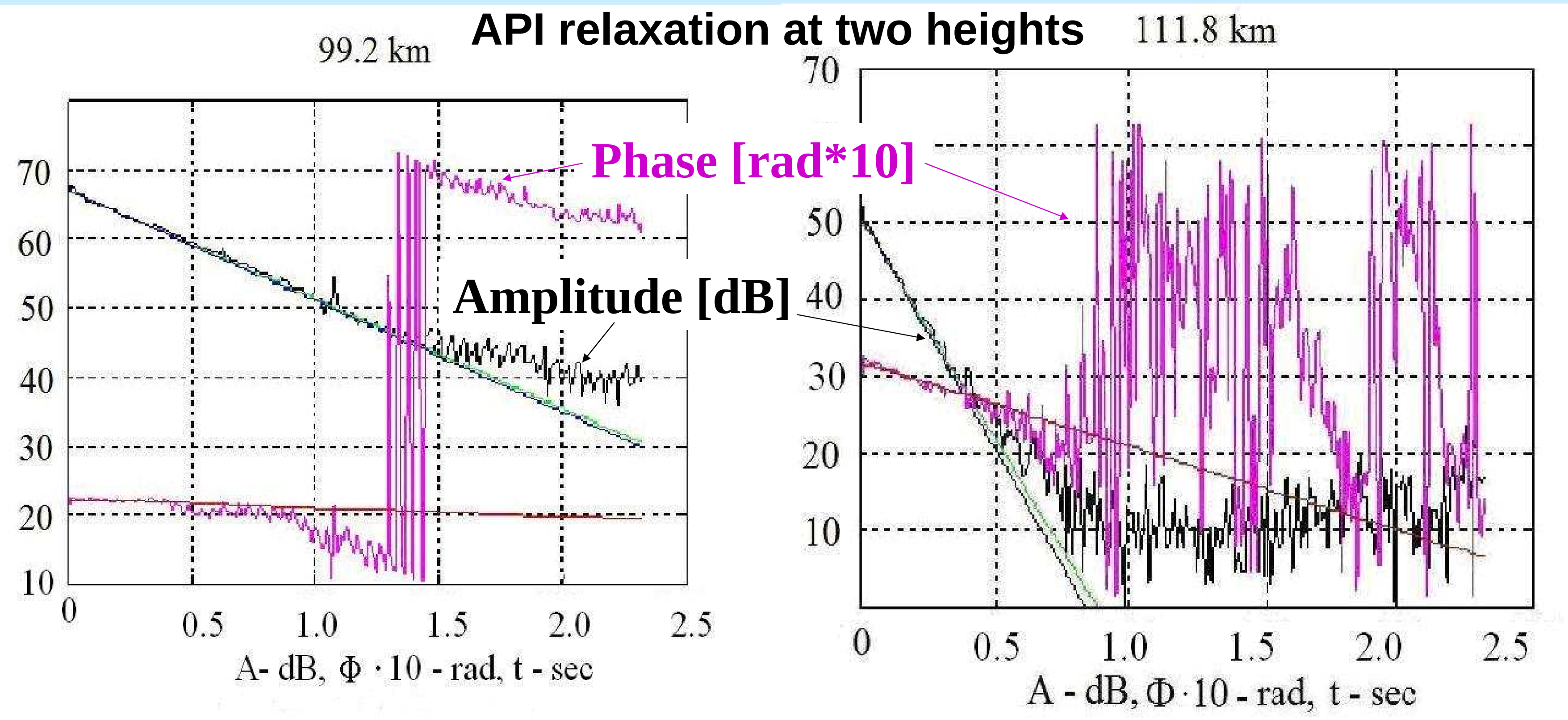
Abstract

We present a new way to determine the electron density in the ionospheric *E*-region using artificial periodic irregularities (API) formed by powerful radio waves. The results are from October 2006 using the SURA heating facility at 4.7 and 5.6 MHz. API with two different spatial scales were formed. The height profile of electron density was determined from the ratio of the API relaxation times at the two frequencies. The method allows studying fine structure in the electron density profile.

Introduction to API

The artificial periodic irregularities (API) are created in the electric field of a powerful standing wave formed by the interference of an incident HF wave and its ionospheric reflection. The spatial period of the irregularity is the standing wavelength, Λ or half the HF pump wavelength $\lambda/2$. Physical processes dominant at each ionospheric height determine the API decay processes after the pump turn off. In the E-region, it is ambipolar diffusion.





Temporal dependence of the backscattered amplitude and phase signals from API after the pump turn off. The relaxation time τ is determined by the e-folding decrease in the amplitude: $\ln A(t) = \ln A_0 - t/\tau$.

Successful API measurements from both F, E and D regions have also been made with the **EISCAT heating facility** [2, 3]. The upgrade of the heating control system which is underway will also allow one of the antenna arrays to be used for reception. The whole upgrade should allow more advanced API experiments, like the two-frequency experiments reported here, to be made more easily and more often.

API may be used as a diagnostic of the ionospheric plasma and the upper atmosphere. After formation the API they are sounded by pulsed probe radio waves. From the amplitudes and phases of Bragg backscattered signals (resonance scattering) off the API, the parameters of interest are determined. The electron density profiles, the vertical velocity, the vertical component of the turbulent velocity and the temperature and density of the neutral atmosphere may be obtained by the API technique [1].

The main results of the ionosphere studies carried out in 2006–2007 with aid the API are presented in [4]. The **most important development was the realization of a new two-frequency API technique:⇒**

Two-frequency method of API

This is based upon the scattering of the probe waves from API formed by the powerful radiation at two frequencies with different spatial periods. In the ionospheric E-region the API are formed by plasma diffusion. The relaxation process of the periodic structure after SURA switches off is controlled by ambipolar diffusion and the scattered signal relaxation time τ is proportional to the ambipolar diffusion coefficient D_a : $\tau = (K^2 D_a)^{-1}$, and $K=2\pi/\Lambda$ is the wave vector of the standing wave.

Hence after turning the pump off, API having different spatial scales decay with different relaxation times τ. The API spatial scale depends on the refractive index n and the electron density N. The ratio of API relaxation times θ at two frequencies f_1 and f_2, measured at the same heights, is related to the frequency ratio and the refractive index ratio by equation:

$$\theta = \frac{\tau_1}{\tau_2} = \frac{k_2^2}{k_1^2} = \frac{\lambda_1^2}{\lambda_2^2} = \frac{f_2^2}{f_1^2}\cdot\frac{n_2^2}{n_1^2}$$

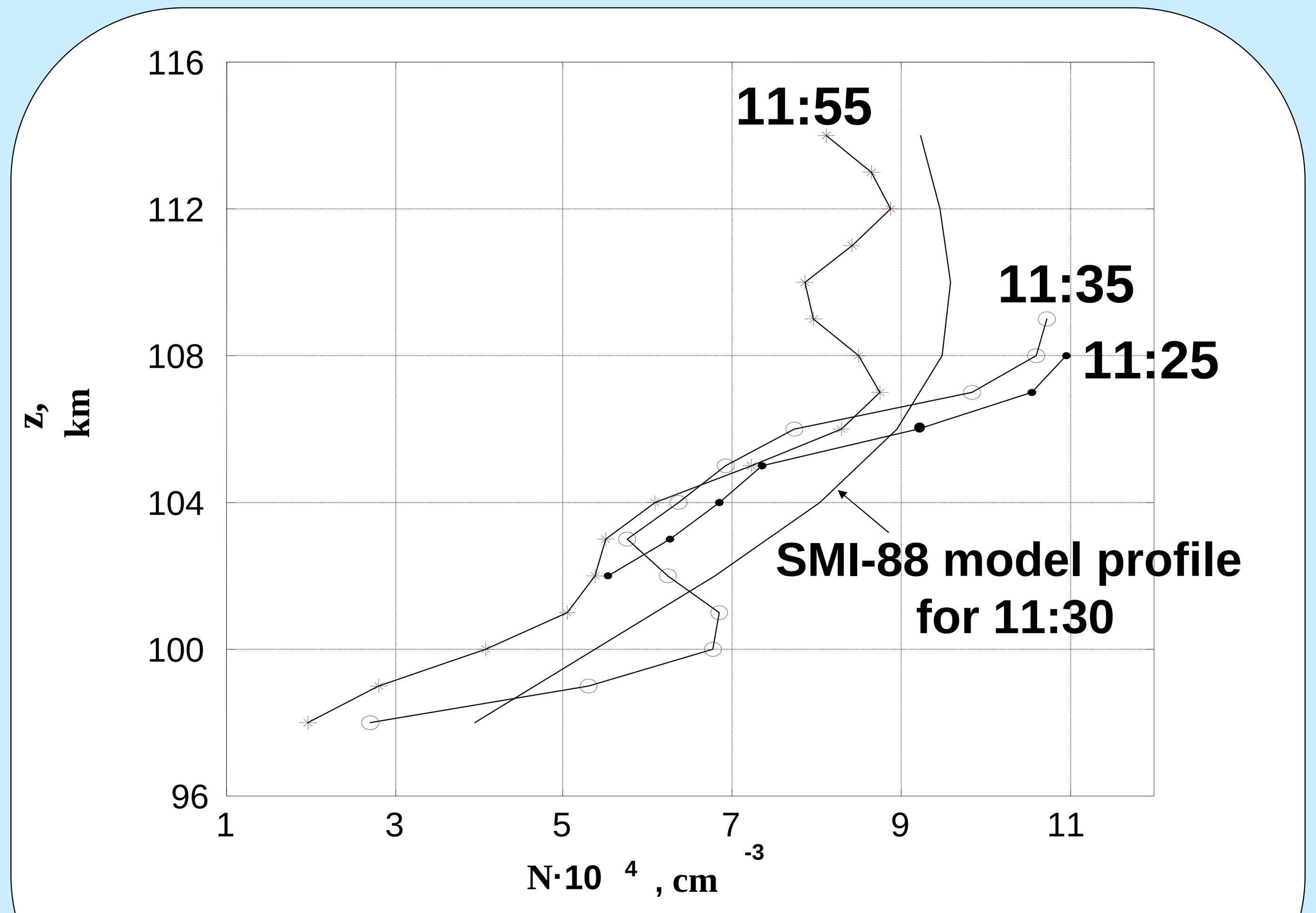
At E-region heights, the quasi-longitudinal approximation can be used for n. In this case, the ratio of the relaxation times at two frequencies is equal to:

$$\theta = \frac{f_2}{f_1}\cdot\frac{(f_1-f_L)}{(f_2-f_L)}\cdot\frac{[f_2(f_2-f_L)-f_0^2]}{[f_1(f_1-f_L)-f_0^2]},$$

where plasma frequency f_0 can be expressed in terms of the electron density N. The ratio θ allow us to determine $n=n(\theta)$ and $N= N(\theta)$ profiles.

The measured dependence $\theta(z)$ makes it possible to determine the electron density profile N(z). Note that the formulas are true only when the relaxation times for the different frequency are measured at the same real height z. However, the registration of the backscattered signals from API was performed in dependence on the virtual heights h. This factor can be taken into account with equation:

$$h = \int_0^z \frac{d\left(f\,n\,(f,z)\right)}{df}\,dz.$$



N(z)-profiles obtained between 11 and 12 LT on 4 October, 2006.

New electron density results in the lower ionosphere using two frequencies

The two-frequency method was tried in 2006, 2007 using the **SURA facility** (56.13ºN, 46.15ºE). The API formation and their sounding by probe radio waves of X-polarization were carried out alternately at frequencies of f_1=4.7 MHz and f_2=5.6 MHz. The effective radiated power was about 70 MW at f_1 and 15 MW at f_2. The measurement interval of the API relaxation time τ for each frequency was 15 s. During one minute two intervals of pumping at each frequency were carried out. During the first 3 s the ionosphere was pumped by an X-polarized powerful radio wave and API were formed. The heating period was followed by 12-s during which probing pulses with the same frequency, 30-μs duration, and a 50 Hz repetition rate were radiated. The scattered signals from the virtual height range 50–750 km were recorded. To reduce the measurement errors the relaxation times τ_1(hi) at the frequency f_1 and τ_2(hi) at the frequency f_2 were averaged over 10-minute intervals on each height hi and the ratio θ(h) was calculated. The initial N (z)-profile was taken from the ionosphere model in order to find the initial virtual heights on each of the frequencies. Further actual N (z)-profile was determined from the ratio θ by iteration. The error of the N (z)-profile from the API two-frequency method should not exceed 10%.

References:

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