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Control of spectral characteristics of artificial low-frequency ionosphere turbulence

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Abstract. A way to control the spectral characteristics of artificial low-frequency ionosphere turbulence ($\mathrm{AIT_{LF}}$) in high frequency (HF) heating experiments is suggested. It is based on the experimentally established dependence of $\mathrm{AIT_{LF}}$ properties on the pump wave power, frequency, and polarization; on duration of powerful wave radiation; and on turbulence gyrofeatures. Creation of $\mathrm{AIT_{LF}}$ with given properties can be used in studies of such problems as radio wave propagation under various ionosphere conditions, influence of ionosphere disturbances on plasma–wave interactions, plasma dynamics in the upper ionosphere, generation of plasma density perturbations, and electromagnetic emissions in magnetized plasmas, etc.

1. Introduction

For almost three decades, extensive experimental and theoretical studies have been performed in the area of ionospheric plasma modification by high frequency (HF) powerful radio waves launched vertically from ground-based transmitters. A fairly good understanding of various plasma processes, leading to artificial ionospheric turbulence (AIT) generation, was achieved. Among them, nonlinear coupling of high- and low-frequency waves defines the AIT spectrum. Its high-frequency part comprises Langmuir, upper-hybrid, and Bernstain plasma waves. Low-hybrid and ion acoustic waves, plasma density and temperature perturbations, and fluctuations of background electric and magnetic fields are basic contributors to the low-frequency turbulence spectrum. In AIT spectrum, artificial ionospheric irregularities (AII) has been the subject of much study. On the basis of features of plasma density perturbations, small ($l_\perp < 50$ m), middle ($50 < l_\perp < 500$ m), and large ($l_\perp > 500$ m) scale irregularities can be distinguished in AII spectrum, taking into account different mechanisms of their generation. Here $l_\perp$ is the irregularity scale length in the direction perpendicular to the geomagnetic field line. It has been stated that AII characteristics depend strongly on both ionosphere and pump wave parameters.

The AIT features have been studied at several purposefully built heating facilities located at low (Arecibo, Puerto-Rico, USA; Gissar, Tadzhikistan, former SU), middle (Boulder, USA; Zimenki and Sura, Russia), and high (EISCAT, Norway; HAARP and HIPAS, Alaska, USA) latitudes. The experimental and theoretical results obtained in these studies have been published in numerous reviews and original papers (see, for example, special issues: Radio Sci., 9(12), 1974; J. Atmos. Terr. Phys., 44(12), 1982; J. Atmos. Terr. Phys., 47(12), 1985; Radiophys. Quant. Electron. (Engl. Transl.), 37(5), 1994; J. Atmos. Sol.-Terr. Phys., 59(18), 1997; Radiophys. Quant. Electron. (Engl. Transl.), 42(7–8), 1999, and references therein). They have provided a deeper insight into the physics of nonlinear processes in magnetized plasmas. By now, such nonlinear phenomena as the parametric decay instability (PDI), thermal (resonance) parametric instabilities, and self-focusing instability of powerful electromagnetic waves in magnetized plasma have been studied in great details. Among the observed non-local AIT components, probably the most attractive are HF-accelerated suprathermal electrons [*Carlson et al.*, 1982], stimulated electromagnetic emissions (SEEs) [*Frolov et al.*, 2001; *Leyser,* 2001; *Stubbe et*

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al., 1984, 1994], and AII which are excited in a wide range of length scales $l_\perp$ from a few centimeters to a few kilometers [*Basu et al.*, 1997; *Belenov et al.*, 1977; *Fialer*, 1974; *Frolov et al.,* 1997b, 2000; *Myasnikov et al.,* 2001; *Nasyrov*, 1991].

A new stage in development of ionosphere heating experiments is to make use of the ionosphere as a natural plasma laboratory where various processes observed in magnetized plasmas can be studied in detail. In this way, the ability of generation of a controllable and repeatable AIT with given properties is of a great practical importance. Suffice it to say that generation of such turbulence is a critical requirement for devising new diagnostic methods that can be used for AIT remote sounding and modeling by AIT a set of natural processes observed in magnetized plasmas.

Consideration of some opportunities to produce $\mathrm{AIT_{LF}}$ with required characteristics is the prime purpose of this paper. Such a consideration is mainly based on the experimental results obtained in heating experiments at the middle latitude facilities (at the Zimenki and Sura facilities, first of all).

2. Experimental Facts Providing a Basis for the AIT Control

Results, obtained in numerous heating experiments, have shown that many factors exert a rather strong influence on AIT features. Some of them, bearing regular character, can be used for the control of turbulence characteristics. Below we present their dependence on pump wave parameters and on the scheme of pump wave radiation.

2.1. Polarization of the Pump Wave

In F region modification experiments, HF powerful radio waves (pump wave, PW) with o-mode polarization are almost always used. This is because of the fact that in the vicinity of the plasma resonance these waves effectively interact with the ionospheric plasma. As a result of such an interaction, the growth of the parametric decay instability (PDI), which is developed near and somewhat below the PW reflection height within a few milliseconds after PW switch-on in the plasma is observed [*Gurevich*, 1978; *Perkins et al.*, 1974; *Vas'kov and Gurevich*, 1973]. A few seconds later, the thermal (resonance) parametric instability is developed in a region of about 1–5 km below the PW reflection height [*Das and Fejer*, 1979; *Grach et al.,* 1977; *Gurevich*, 1978; *Vas'kov and Gurevich*, 1975]. These instabilities determine generation of intense AIT of both high- and low-frequency origins. In the case of pumping by means of x-mode waves, the lack of the resonant interaction between the x-mode PW and the plasma significantly limits possible mechanisms of AIT generation. Among of such mechanisms we can point out the plasma heating caused by the collision absorption of the wave energy [*Gurevich*, 1978] and generation of irregularities due to the self-focusing instability of powerful waves in plasma [*Gurevich,* 1978; *Perkins and Goldman*, 1981; *Perkins and Valeo*, 1974; *Vas'kov and Gurevich*, 1976]. Evidently, these effects occur for o-mode pumping also but they are masked, as a rule, by stronger HF-induced turbulence due to more active (resonant) wave–plasma interactions. Nevertheless, they can clearly manifest themselves for vertical underdense heating when the PW frequency is higher than the peak plasma frequency in the $F2$ layer. It is confirmed by the experiments [*Frolov et al.*, 1999, 2000] which have demonstrated that in the cases of x-mode pumping or o-mode underdense heating the AIT intensity is relatively week and generation of the large-scale AII with $l_\perp \geq 0.5$–1 km is only observed under such conditions.

In addition to the aforesaid, we have to note that independent of PW polarization, HF modification of the E and $F1$ regions in the daytime ionosphere could provide here an increase of the electron plasma density resulting in formation of a defocusing lens at heights *happrox*130–150 km. Such a lens is responsible for a decrease in the PW intensity in the upper ionosphere and, consequently, for weakening of the PW–plasma interaction [*Boiko et al.*, 1985]. At the same time, on some occasions the use of the x-mode pumping can be more preferable when, for example, investigation of influence of the ionosphere D and E regions on features of AIT induced by HF powerful waves in the F region.

2.2. AIT Steady State Spectral Characteristics at *o*-Mode Pumping. Temporal Evolution of the AII Spectrum

As it has been mentioned above, the o-mode pumping leads to growth of the parametric instabilities, development of which is accompanied by generation of strong AIT. Under steady state conditions which are reached after rather long-term pumping, longer than a few tens of seconds at the effective radiated power (ERP) of $P_{\mathrm{eff}} \geq 20$ MW, generation of AII is observed in a wide range of length scales $l_\perp$ from a few centimeters to a few kilometers. The small-scale part of AII for $l_\perp \leq 50$ m (known as striations) arises due to development of the thermal (resonance) parametric instability. The middle-scale artificial irregularities with $l_\perp \approx 50$–500 m appear with growth of the self-focusing instability, and it is assumed that the large-scale irregularities with $l_\perp > 0.5$–1 km occur by enhancement of natural plasma density perturbations usually presented in the upper ionosphere.

The AII spectral features were experimentally studied by *Basu et al.* [1997], *Erukhimov et al.* [1987], *Fialer* [1974], *Frolov* [1996], *Frolov et al.* [1997b, 2000], *Kelley et al.* [1995], *Minkoff et al.* [1974], *Myasnikov et al.* [2001], and *Nasyrov* [1991]]. On the basis of these experimental data, the steady state transverse spatial spectrum for plasma density fluctuations, $\Phi_{\mathrm{N}}(l_\perp)$, obtained under optimum conditions can be presented in a power low form $\Phi_{\mathrm{N}}(l_\perp) \propto l_{\perp}{}_{0}^{p}$. By the optimum conditions are meant that experiments are conducted in evening or night hours under quite ionosphere conditions, the ionosphere is modified at $P_{\mathrm{eff}} \geq 20$ MW ERP, and the PW frequency is both slightly below of the $F2$-peak frequency and far from a gyroharmonic frequency. In this case the power index p_0 is of about 4–5 for $l_\perp \approx 1$–3 m, of about 2–3 in two scale ranges $l_\perp \approx 3$–30 m and $l_\perp \approx 100$–300 m, and of about 3–4 for $l_\perp \approx$ 1–4 km. In the experiments it has been also found that in the AII spectrum, $\Phi_{\rm N}(l_\perp)$, three maxima can be distinguished between the regions with the power-law dependence [*Erukhimov et al.*, 1987]. The first maximum is observed at $l_\perp \approx$ 30–50 m the value of which is close to the PW wavelength. This maximum is determined by development of the thermal (resonance) parametric instability. The second maximum is located at $l_\perp \approx$ 300–500 m and determined by growth of the self-focusing instability. The third maximum is developed at $l_\perp \approx$ 5–10 km as a result of enhancement of natural ionospheric irregularities by HF ionosphere heating.

The steady state spectrum for the small-scale AII ($l_\perp \approx$ 1–30 m) obtained under the optimum ionospheric conditions at $P_{\rm eff} \approx 50$ MW ERP and normalized to $\Phi_{\rm N}$ ($l_\perp = 30$ m; $t = 60$ s) is shown in Figure 1 (bold line). Naturally, its form can somewhat vary depending on ionospheric conditions, PW frequency and power [*Alimov et al.,* 1986; *Erukhimov et al.*, 1987; *Frolov*, 1996; *Frolov et al.,* 1997b].

According to our recent experiments [*Frolov et al.*, 2000], the generation of the small-scale irregularities (striations) exerts a strong influence on features of the middle-scale AII. The latter are responsible for the anomalous attenuation of HF radio waves in the ionosphere disturbed volume due to the wave multiple scattering effect [*Erukhimov et al.*, 1980; *Zabotin et al.,* 2002]. As a result of this effect a decrease in the PW intensity is observed near the PW reflection level. On the other hand, the large-scale irregularities, acting as focusing lenses, also cause the PW intensity to strong variations in this region. Both of these effects change conditions for wave–plasma interactions and exert an influence on striation features. By this means the interrelation between artificial irregularities with different length scales manifests itself in AIT generation.

Erukhimov et al. [1987], *Fialer* [1974], *Frolov* [1996], and *Frolov et al.* [1997b, 2000] found that over a wide scale range $l_\perp \approx 1$ m to 3 km the dependence of the typical time of AII growth up to its stationary state, $\tau_{\rm gr}$, on $l_\perp$ can be represented in a power low form: $\tau_{\rm gr} \propto l_\perp^\alpha$, where $\alpha \approx 0.5$; at $P_{\rm eff} \approx 20$ MW ERP $\tau_{\rm gr} \approx 1$ s for $l_\perp \approx 3$ m and $\approx$ 1–1.5 min for $l_\perp \approx 1$ km. In turn, the dependence $\tau_{\rm gr}(P_{\rm eff})$ can be also represented in a power low form $\tau_{\rm gr} \propto P_{\rm eff}^{-\beta}$ with $\beta \approx$ 0.5–1, where higher magnitudes of β are related to smaller $l_\perp$ [*Frolov et al.*, 1997b]. Another key feature of the small-scale AII (or striations) is the existence of a delay time between PW switch-on in the plasma and the beginning of striation growth. The delay time, τ_d, increases with increasing in the striation length scale $l_\perp$ being of about 30–50 ms for $l_\perp \approx$ 2–3 m and $\tau_d \approx$ 100–200 ms for $l_\perp \approx$ 10–20 m [*Frolov*, 1996; *Frolov et al.*, 1997b; *Nasyrov,* 1991]. It has been also found that at sufficiently high PW power $P_{\rm eff} \geq$ 10–20 MW ERP the meter-scale striations have a maximum of their intensity during a few first seconds of pumping and a lower intensity at the steady state of the AII development [*Frolov*, 1996; *Frolov et al.*, 1997b]. This phenomenon is more pronounced for smaller-scale striations and at higher PW power. It is significant that the striation intensity in this maximum can be up to higher by a value of about 3–10 dB (being higher for smaller $l_\perp$) than for its steady state. From the all above reasoning the striation generation can be significantly enhanced when a short-pulse pumping (shorter than a few seconds) is used in ionosphere modification experiments [*Belenov et al.*, 1991; *Frolov*, 1996; *Frolov et al.*, 1997b].

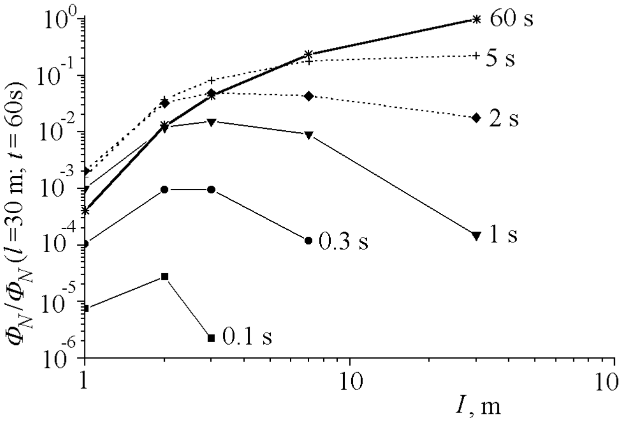

Figure 1. The temporal evolution of the normalized AII spectrum in its small-scale range.

Figure 1 shows the temporal evolution of the normalized AII spectrum in its small-scale range, which is calculated using the empirical model for the striation temporal evolution presented by *Frolov et al.* [1997b] and briefly considered above. The existence of the maximum of the intensity for the meter-scale striations with $l_\perp \geq 5$ m at the initial stage of pumping (at $t \leq 5$ s) is clearly seen here.

In addition to the aforesaid, it has been also found that radiation of the PW with square wave modulation (when the pulse duration is equal to a half of its repetition period) leads to the decrease in intensity of decameter-scale striations by a value of about 6–10 dB when the modulation frequency is of about 0.1–0.5 Hz. It should be noted that the striation intensity averaged over the disturbed volume is directly related to the cross section of scattering volume in field-aligned scattering measurements [*Minkoff et al.*, 1974]. The dependence of the value of the cross section, σ, on the PW modulation frequency, $F_{\rm mod}$, for $l_\perp \approx$ 10–20 m is shown in Figure 2 taken from [*Frolov,* 1996]. Because this effect does not occur for the meter-scale striations [*Nasyrov*, 1991], such AII properties can be used for the preferable generation of the meter-scale striations.

All aforesaid can be summarized as follows. During the first few seconds of pumping at $P_{\rm eff} \geq 20$ MW ERP the meter-scale striations dominate in the AII spectrum. Somewhat later the decameter-scale striations are of stronger intensity compared to meter-scale ones but they can be suppressed by the square wave modulation of the PW. The middle-scale irregularities, which are more intensive than striations, reach itself steady state within 10–20 s after PW switch-on, and the growth of the large-scale irregularities, which are the most intensive part of the AII spectrum, lasts longer than 1–2 min. Such AII temporal evolution makes it possible to change the AIT spectral characteristics varying both pump pulse duration and pulse repetition period. Evidently, the choice of concrete timing for PW radiation

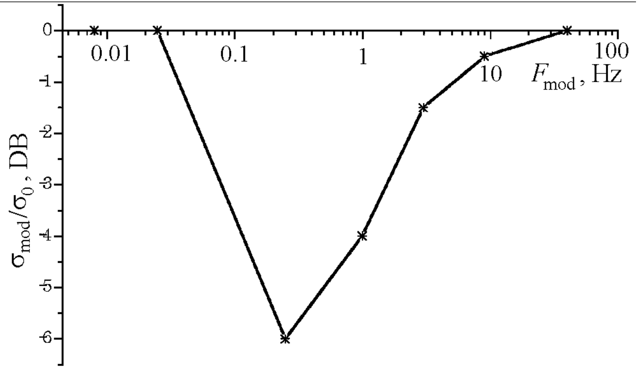

Figure 2. The dependence of the value of the cross section, σ, on the PW modulation frequency, $F_{\rm mod}$, for $l_\perp \approx 10$–20 m.

depends strongly on such factors as ionospheric conditions, PW power, and frequency, as well as on the PW reflection height and a value of plasma density gradient in the wave–plasma interaction region.

2.3. Modification of the Ionospheric Plasma When the PW Frequency is Close to the Gyroharmonic Frequency, $f_o \cong nf_{ce}$

Such experiments are very attractive since the interaction of the *o*-mode pump wave with the magnetized plasma when $f_o \cong nf_{ce}$ is strongly suppressed due to the dispersion properties of the upper-hybrid and Bernstain plasma waves [*Grach et al.*, 1994]. If this is the case, the striation generation is also strongly suppressed and AII features therewith undergo substantial variations in a narrow frequency range near a gyroharmonic frequency showing asymmetric behavior relative to nf_{ce} [*Honary et al.*, 1999; *Ponomarenko et al.*, 1999; *Stubbe et al.*, 1994]. It has been also stated by *Frolov et al.* [2000] that together with the striations the middle-scale irregularities are also suppressed when $f_o \cong nf_{ce}$, but the large-scale irregularities develop as in the case of $f_o \neq nf_{ce}$. These systematic AIT gyro-features can be successfully used for turbulence generation in a wide range of AIT characteristics when the PW frequency f_o is slightly changed near a gyroharmonic frequency nf_{ce}.

2.4. Scheme of Additional Pumping [*Frolov*, 1996]

This scheme comprises two different powerful waves. An *o*-mode pump wave, having diagnostic properties (diagnostic wave, DW), is used to simulate SEEs, which in turn is used for AIT diagnostics. In the measurements, the DW power is chosen so as to induce an unsaturated turbulence at a rather low level, which flexibly responds to any additional external actions. The second powerful radio wave (pump wave, PW) can have the *o*- or *x*-mode polarization. This wave is used to create additional ionospheric disturbances whose influence on the DW-induced turbulence manifests in changes in SEE features. The scheme of additional pumping makes it possible to distinguish between the influence of different factors on the AIT generation and evolution by varying PW parameters. Choice of the PW polarization makes it possible to change type and intensity of the AIT. The PW power determines the AIT intensity and efficiency of electron acceleration up to suprathermal energy in the ionosphere disturbed volume. Choice of the PW frequency determines the distance between DW and PW reflection heights and influences on AIT gyrofeatures. At last, the AII spectral characteristics can be changed through the timing for PW radiation.

As an illustration of the use of the additional pumping scheme we can refer to recent experiments conducted by *Frolov et al.* [2002]. Results obtained in this paper have demonstrated that in many cases, variations in the DW-induced plasma turbulence intensity are determined by the influence of thermal and HF-accelerated suprathermal electrons. On the basis of these measurements and experiments performed by *Frolov et al.* [1997a] and *Sergeev et al.* [1998], we can safely assume that the SEE provides a rather sensitive method to study the influence of the suprathermal electrons on AIT generation.

3. Schemes of AIT Remote Sounding

The problem of the control of the AII spectral characteristics is intimately related to their on-line testing. For this purpose, a combination of SEE and anomalous absorption measurements with sounding of the disturbed volume by the *x*-mode probe waves and chirp-sound signals can be used. In such measurements the anomalous absorption effect makes it possible to study temporal evolution of the small-scale striations, which are HF-induced by the *o*-mode PW near its reflection level due to the thermal (resonance) parametric instability development. The *o*-mode probe waves at frequencies close to the PW frequency are also employed for anomalous absorption measurements [*Erukhimov et al.* 1987; *Frolov et al.*, 1997b]. The effect of multiple scattering of the *x*-mode probe waves from the middle-scale irregularities [*Erukhimov et al.*, 1980; *Zabotin et al.*, 2002] is used to study evolution of these irregularities as well as spread of the HF-disturbed ionosphere volume along geomagnetic field lines. Both the *x*-mode probe wave sounding and testing of the disturbed volume by chirp-sound signals provide a way to measure the AII characteristics in their large-scale range through the analysis of fluctuations and spread of probe wave signals reflected from the ionosphere [*Frolov et al.*, 2000]. In addition to the methods noted above, the field-aligned scattering measurements and scintillation observations with satellite beacons can be also used for remote testing of the AII, but they are not as flexible for the on-line control during experiments. It should be mentioned that all above-listed methods of ionosphere sounding have been successively used in studies of AII features recently performed by *Frolov et al.* [2000, 2002], *Myasnikov et al.* [2001], *Sergeev et al.* [1999], and *Zabotin et al.* [2002].

After investigation of the fundamental SEE features, which were summarized by *Frolov* [1996], *Frolov et al.* [2001], *Leyser* [2001], *Stubbe and Hagfors* [1997], and *Stubbe et al.* [1984, 1994], the SEE has become a very useful tool to study HF-induced nonlinear processes in the ionospheric plasma. It is important that SEE measurements are carrying out directly without a need for additional electromagnetic waves for probing, such as the probing used in radars. It became possible because both short-time ponderomotive nonlinearities, giving rise to high-frequency plasma turbulence, and long-time thermal nonlinearities, leading to the excitation of both plasma waves and small-scale striations, are involved in the SEE generation. The SEE spectra show the existence of many emission components: currently, more than 15 SEE structures have been already revealed and investigated [*Frolov*, 1996; *Leyser*, 2001; *Stubbe et al.*, 1984]. It demonstrates a contribution of many processes to the AIT generation going simultaneously in the HF modified plasma. Dramatic modifications occur in SEE features under small changes of the PW frequency around the gyroharmonic [*Frolov et al.*, 2001; *Leyser*, 2001; *Stubbe et al.*, 1994; *Stubbe and Hagfors,* 1997]. It makes possible to find by means of SEE a gyroharmonic resonance frequency in the ionosphere with high precision and thus to determine a PW frequency offset from nfce during experiments and for experimental data processing.

On the basis of the SEE, a diagnostic SEE technique (DSEE) has been devised for testing of the AIT [*Frolov et al.*, 1994]. It employs short ($\leq$ **20** ms) pump pulses with their repetition period of about 1 s. These pulses are radiated during a few minutes before and after long-term pumping, which lasts from a few dozens of seconds to a few minutes in order to create turbulence with required properties. During the periods of the PW pulse, radiation averaged pulse power is rather small, so that it does not exert any additional influence on the ionospheric plasma and plasma turbulence. As it has been demonstrated by *Frolov et al.* [1994], *Frolov* [1996], and *Sergeev et al.* [1998], this technique allows study of temporal evolution of the high-frequency and low-frequency turbulence induced in the ionosphere by the HF powerful wave. In our DSEE measurements we often use also the scheme of additional pumping which is described in subsection 2.4. It is very important that the SEE-based technique can be easily combined with other diagnostic methods usually applied to ionospheric studies. Wide opportunities of the SEE for AIT diagnostics have been demonstrated in experiments performed during recent years, in which many different tools were combined for the study of AIT features [*Frolov et al.*, 1994, 1997a, 1999, 2000, 2002; *Kagan and Frolov*, 1996; *Sergeev et al.*, 1998, 1999].

4. Closing Remarks

In the paper some abilities to control of spectral characteristics of the artificial low-frequency ionosphere turbulence have been demonstrated on the basis of the data obtained in comprehensive ionosphere modification experiments which have allowed to elaborate the empirical model for AII evolution. The performed studies have opened up wide possibilities for creating repeatedly the ionospheric turbulence with required properties. It is an important step toward using the ionosphere as a natural wall-less plasma laboratory where various plasma processes and instabilities related to magnetized plasmas can be successfully studied in detail.

Among many studies performed during a few recent years at the Sura heating facility, in which the AIT was purposefully used to highlight specific plasma processes, we would like to note the following:

1. The empirical model of AIT evolution elaborated by *Frolov et al.* [1997b] has been used by *Grach et al.* [1998] to calculate temporal evolution of the broad continuum (BC) emission component in the SEE spectrum and evolution of DSEE after a long-term pumping. The results obtained are fairly well consistent with experimental data on the number of counts and demonstrate a correctness of the proposed model. The model has been also used by *Sergeev et al.* [1999] to explain dependence of the SEE features on the PW power and frequency. In one's turn, SEE measurements can be easily used for the study some features of small-scale irregularities (striations) [*Kagan and Frolov*, 1996; *Sergeev et al.*, 1999].

2. The experiments with $\boldsymbol{x}$-mode additional pumping performed by *Frolov et al.* [1999] have shown that the $\boldsymbol{x}$-mode pump wave affects distinctly characteristics of the AIT, excited by the $\boldsymbol{o}$-mode pump wave, and leads to a decrease in the intensity of turbulence of both ponderomotive and thermal origins. The data obtained have shown a great complexity and multiplicity of observed phenomena, which have not been well understood yet. It is clear that similar effects occur in the $\boldsymbol{o}$-mode pumping experiments, and their investigation is of a great importance for deeper understanding features of wave–plasma interactions in magnetized plasmas.

3. Recently, the creation of AIT by the additional pumping has been successfully used in pioneering studies of the transport processes in the upper ionosphere performed by means of the SEE [*Frolov et al.*, 2002]. In these experiments it has been found that for HF-induced disturbances the velocity of their spread along the geomagnetic field lines is, as a rule, much higher than the ion thermal velocity, $\boldsymbol{v_{Ti}}$, and sometimes it is even higher than the electron thermal velocity, $\boldsymbol{v_{Te}}$. It unambiguously shows that in the HF-modified ionosphere, thermal and suprathermal electrons, and consequently electric fields and currents HF-induced in the ionosphere disturbed volume, exert an important influence on plasma dynamics. It is worth noticing that the suprathermal electrons affect the decay properties of the high-frequency turbulence [*Sergeev et al.,* 1998] and on the BUM generation (BUM, broad up-shifted maximum emission component in the SEE spectrum) [*Frolov et al.*, 1997a].

The experimental data described above represent our efforts aimed at devising new radiophysical methods of ionospheric remote sounding in which creation of AIT by means of HF powerful radiowaves has a dominant role in measurements. Experience, which has been accumulated over a number of experiments performed during recent years, leads us to conclude that these methods can be successfully employed for the study of various instabilities and dynamic processes observed in magnetized plasmas.

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