Key Ideas for Heightening the Informativeness of Plasma Physical Theorizing

Vasily I. EROFEEV

Laboratory of Nonlinear Physics, Institute of Automation & Electrometry of the Siberian Branch of Russian Academy of Sciences, Novosibirsk 630090, Russian Federation

(Received: 26 August 2008 / Accepted: 19 December 2008)

It is pointed that approaches of traditional plasma theory cannot provide sufficient *reliability* of final theoretical deductions: The recipes of the theory yield equally rigorous justifications to incompatible versions of the same physical phenomenon. This general property stems from two mutually intertwined reasons. First, the asymptotic convergence of intermediate iterative calculations: It supposes that variations in the leading order of perturbation expansion yield diversity of derivable scenarios of the plasma physical evolution and also imply some restrictions on appropriateness of specific computing methods in intermediate kinetic calculations. (Thus, intermediate transition from time originals to Fourier (Laplace) transforms is fraught with substantial loss in the *informativeness* of final results.) Second, common substitution of real plasmas by plasma ensembles: *The laws of evolution of the ensemble statistics cannot be independent on the ensemble content.* For gaining the informativeness of plasma kinetic considerations with account for these reasons, a specific correlation analysis is created. It can be characterized as some technique of reducing full plasma description to more simplified kinetic one. The current results are discussed of its application to studies of a homogeneous weakly turbulent plasma. Some comments are formulated regarding possible other informative plasma research.

Keywords: informativeness of plasma theoretical description, correlation analysis of plasma kinetics, weakly turbulent collisionless plasma, Coulomb collisions in a quiet weakly nonideal plasma

1. Introduction

One of basic branches of plasma physics is the plasma turbulence theory. Factually, from the very moment when Langmuir and Tonks observed electronic oscillations in a fully ionized gas and proposed term "plasma" [1], physicists began theoretical studies of turbulent plasma phenomena. We shall omit discussion of the story of theory development: plasma physicists do know it rather well. We note only that activities of 60–70-th in lapsed XX-th century resulted in appear of the *weak plasma turbulence theory.* One of most important of its beginnings was the idea of conservation of Langmuir wave quanta in nonlinear processes [2] that complied with former semi-empiric deductions [3]. This property yielded wave transfer to low wave numbers through the wave scattering by plasma particles. With this, a high level of turbulence was believed to build up at the long-wavelength region of the spectrum, due to the inefficiency of wave dissipation there in comparison with the wave energy supply. The corresponding piece of the turbulence spectrum was called a Langmuir condensate. The puzzle of its dissipation had stimulated studies that can be characterized as the creation of strong plasma turbulence theory. The most important of them was the development of concept of Langmuir wave collapse [4]. Since the appear of the latter, many of plasma physicists rendered the collapse as a real physical phenomenon that provides back transfer of wave energy to short-wavelength region of the spectrum. In view of this, a large number of reports have been collected in history of plasma natural experiments about observations of various evidences for Langmuir wave collapses. The most recognized of them were developed in series of beam-plasma experiments by Wong and his colleagues (University of California, Los Angeles) [5–8]. They observed formation of a solitary spatially localized field structure and its subsequent evolution that resembled the Langmuir wave collapse. The collapse theory was discussed also in connection with beam-plasma experiments by group of Vyacheslavov (BudkerINP) [9–11], and by Benford *et al.* [12–14]. We have mentioned here only the most important of respective plasma observations: More expanded review of the collapse-related activity was given by Robinson [15].

Having posed the laboratory plasma observations of above three groups to an extra scrutiny, we have shown that they evidence more explicitly against the Langmuir wave collapse rather then in its favor [16–18]. (Particularly, in experiments by Wong *et al.* the characteristic time of observed "wave collapse" constitutes about 20 inverse growth rates of original Zakharov's instability with respect to short-wavelength modulations in plasma density [4]. The growth rate of the given instability depicted

author's e-mail: yerofeyev@iae.nsk.su

the granted rate of the most slow initial stage of Langmuir collapse: With extra reasons of the collapse initiation the very collapse would have developed on a shorter time scales.). We stress that in all three series of experiments the necessary conditions for the collapse were well satisfied (see details in Refs. [16–18]). Note that it is only via a sufficiently intense decay of Langmuir wave quanta that the development of collapse scenarios might have been precluded there. We supposed that the reason of wave dissipation is the transfer of wave energy to plasma electrons during their nonresonant diffusion in momentums. We discovered that consideration of this phenomenon within tradition of plasma theory implies equally rigorous substantiations both for the commonly accepted concept of Langmuir wave quanta conservation and one of their intense energetic decay. The incompatibility of these two conclusions demonstrates that the plasma turbulence theory *fails* in its main destination of *modelling realities of plasma physical evolution*. To put it more correctly, the commonly accepted principles of plasma theoretical studies cannot yield appropriate reliability of respective final deductions.

The above conclusion has helped us to uncover basic false cornerstone of plasma theory: The substitution of real plasmas by plasma ensembles. After the Gibbs's success with erecting the statistical thermodynamics [19], the practice of ensemble averaging was widely rendered as the only appropriate one in many of specific physical theories. Particularly, the idea of the ensemble method had exerted a key influence on formation of the most basic of plasma physical theoretical notions and approaches. The method underlies the plasma kinetics after Bogoliubov [20] — Born — Green [21] — Kirkwood [22] — Yvon [23] (that is collectively known as the BBGKY kinetics), it is hidden behind any hydrodynamic plasma modelling, behind the wave phase averaging, etc. In short, plasma theorists did always freely substituted real plasmas by plasma ensembles, either deliberately or unintentionally, whereas *the ensemble averaging generally veils the picture of the plasma physical evolution*. We have thus stated that the *nonequilibrium statistical mechanics* is *useless* for physical studies of evolving plasmas. More generally, our results have disclosed that the existing common belief in virtues of the given theoretical discipline has no scientifically sound foundation.

An expanded discussion of history of ensemble studies and their trend in modern physics was given in paper [18]. For illustration, we expose here only the most evident visualization of senselessness of plasma ensemble considerations.

Following the most easy common sense, laws of evolution of the ensemble statistics should strongly depend on the ensemble content[1]. Studying some plasma ensemble, one never can be sure that evolution of the ensemble statistics repeats macroscopic evolution of the given single plasma. Naturally, for each of single plasmas one can compose plenty of ensembles that follow some period of time the macroscopic behavior of a given plasma in dynamics of their statistics, but many others demonstrate quite different evolution of their statistics from the very beginning. To have a possibility to select a “proper” ensemble, one should perform preliminary study of macroscopic evolution of the single plasma itself, because otherwise he cannot judge whether certain ensemble adequately models behavior of his plasma or not. From the viewpoint of common sense, *after* learning the physics of a single plasma the search for the “proper ensemble” becomes a senseless enterprise[2].

Thus, plasma experimental realities have helped us to affirm *an absolute truth* of an inappropriateness of plasma ensemble studies that does not even need in any experimental checking: Our argumentation against the ensemble method is cogent in itself.

An important comment on inappropriateness of plasma ensemble substitutions can be advanced from the viewpoint of the information theory. Note that none of constructive plasma descriptions can give a picture of a certain plasma evolution that does not diverge over time from the real plasma macrophysical evolution. The reason is an incompleteness of data on positions and momentums of individual plasma particles. (On the one side, they are never known to the full extent. On the other, their full -scale account is technically unfeasible.) With this, the general problem of a theorist is *to reduce the* nonconstructive *full plasma description*[3] *to a more simplified one that models as better as possible the current plasma macrophysical evolution*. This implies *an extremely careful separation of the theory informational basis from the full plasma information*. The ensemble substitution has no correlation with the given principle. It can be said that generally with implementing the ensemble averaging the researcher manually lessens *the informativeness* of final plasma macrophysical scenario and thus looses lots in the scientific soundness of final conclusions.

In usual plasma considerations the ensemble

[1] We have pointed above that traditional theory permit equally rigorous substantiations to conclusions of Langmuir wave quanta conservation and that of their intense energetic decay. We have commented in Ref. [18] that respective reasonings oriented on differing plasma ensembles.

[2] The reader is reminded that substitution of physical system by system ensemble was proposed by J.W. Gibbs after L. Boltsmann [24] exclusively for simplification of the system physical study.

[3] For a classical ionized plasma, the full description is given by simultaneous Klimontovich [25]–Dupree [26] and Maxwell equations.

substitution is strongly intertwined with *second* reason of losses in theory informativeness: *The ignore of asymptotic nature of the theory convergence.* This thesis can be developed as follows. When theorist reduces full plasma description to a simplified one, he(she) inevitably generates some nonlinear successive perturbations. Regardless the essence of corresponding iterations, they will converge at best *asymptotically* only: *While heightening the expansion order one gets a factorial growth in number of terms to be taken account of.* We stress that the asymptotic convergence of the theory suppose absence of any unique limit even for converging orders of the expansion: The conditional limit for those orders depends on the choice of the lowest order approximation. The differing conditional limits of the theory imply the varying scenarios of the plasma evolution. Hence, *final results of kinetic calculation depend essentially on the choice of the lowest order approximation in respective perturbation expansion.* Correspondingly, a problem arises of a rational choice of this approximation: its variations predetermine the physical content of basic notions of the theory. This position can be exemplified by the notion *wave*: above mentioned deductions of Langmuir wave quanta conservation and of their intense dissipation stemmed from delta-functional and Lorentzian approximations of wave frequency line, respectively (see details in Refs. [16, 17]). Undoubtedly, the problem of thorough choice of basic theoretical notions is important for many of branches of plasma theory and, respectively, for many activities in plasma studies[4].

The asymptotic nature of perturbation convergence impose also some restrictions on appropriateness of specific computational techniques for intermediate kinetic calculations. For instance, the ordinary transition from time originals of particle distributions and electromagnetic field to their frequency Fourie (Laplace) transforms leads to lessening of the theory informativeness[5].

It should be stressed that the above two reasons of theory non-informativeness cannot be separated: one implies another and vice versa. Really, had the picture of ensemble evolution not depended on the ensemble content, one may have substantiated by ensemble variations the diversity of lowest order approximations. Equally, variations of lowest order approximation within the practice of ensemble studies suppose appeals to differing ensembles; absence of dependence of plasma evolution picture on the theory leading order would have meant then the independence of the picture of the ensemble evolution on the ensemble content.

In view of above stated, it is necessary to gain existing practice of plasma physical theorizing, in order of maximal heightening the informativeness of final theoretical results, by creating new approaches with both refraining from traditional plasma ensemble substitutions and proper accounting for the asymptotic nature of successive iterations. Below we exhibit basic principles of such an approach for the case of a weakly turbulent homogeneous plasma.

The narration is constructed as follows. The beginnings of our plasma kinetic approach are given in Section 2. The current results on the high-informative kinetics of a homogeneous plasma with a weak Langmuir turbulence are listed in Section 3. Section 4 contain comments on informative studies for alternative plasma physical situations. We comment here also the top level of informativeness of respective plasma macrophysical scenario.

2. Logics of informative kinetic study for a homogeneous turbulent plasma

The most logical reasoning in plasma kinetic studies was developed through our former researches, and its diverse aspects were enlightened rather well in papers [31, 32, 34] (see also Refs. [16, 17, 33, 35]). We formulate below only its milestones.

The basis of full plasma description is the Klimontovich -Dupree equation:

$$\frac{\partial N_\alpha}{\partial t} + \left(\boldsymbol{v}\cdot\frac{\partial N_\alpha}{\partial \boldsymbol{r}}\right) + e_\alpha\left(\boldsymbol{E} + \frac{1}{c}\left[\boldsymbol{v}\times\boldsymbol{B}\right]\right)\cdot\frac{\partial N_\alpha}{\partial \boldsymbol{p}} = 0. \qquad (1)$$

It represents in a cumulative form the motion equations of all the individual charged plasma particles: The trajectories of charged particles are the characteristics of this partial differential equation.

For the nonmagnetized plasma with Langmuir turbulence, the terms with magnetic fields can be omitted. Then the electric field $\boldsymbol{E}$ is governed by equation $\partial\boldsymbol{E}/\partial t = -4\pi\boldsymbol{j}$, with current density $\boldsymbol{j}(\boldsymbol{r},t)$ being the standard integral of *microdistributions* $N_\alpha = \sum_i \delta^3(\boldsymbol{r}-\boldsymbol{r}_i(t))\delta^3(\boldsymbol{p}-\boldsymbol{p}_i(t))$.

The microdistribution cannot be rendered as a constructive notion of the theory: it depends substantially on the positions and momenta of all plasma particles that are never known to a full extent. Besides, the integration of full plasma description is technically infeasible, because of large numbers of the particles. For eliminating dependencies on positions and momenta of individual particles, the necessary *statistic* of the microdistribution, known as *a distribution function* $f_\alpha = \langle N_\alpha(\boldsymbol{r},\boldsymbol{p},t)\rangle$, was

[4] Particularly, the reconsideration of theory fundamentals might have been useful for diverse items of nuclear fusion research, e.g. for studies on the magnetized target fusion [27, 28] and for studies on the inertial confinement fusion [29, 30].

[5] See details in Ref. [17].

traditionally developed by the plasma ensemble averaging. With refraining from the latter, one is forced to substitute it by a contextually oriented *averaging in phase space*: An appropriate arrangement of the averaging depends essentially on the plasma physical problem under consideration. Thus, for a *homogeneous* plasma with Langmuir turbulence one can average over 6-dimensional parallelepipeds with extended spatial dimensions: At the expense of them one can reach appropriate small momentum gradations of a *statistically reliable* particle distribution $f_\alpha(\boldsymbol{p}, t)$.

Function f_α evolves according to equation

$$\frac{\partial f_\alpha}{\partial t} = -e_\alpha \frac{\partial}{\partial \boldsymbol{p}} \langle \boldsymbol{E}(\boldsymbol{r}, t) N_\alpha(\boldsymbol{r}, \boldsymbol{p}, t)\rangle . \quad (2)$$

That is, the distrubution f_α is advanced in time by function $[NE]_\alpha(\boldsymbol{R}, \boldsymbol{p}, t, t') = \langle N_\alpha(\boldsymbol{r}, \boldsymbol{p}, t)\boldsymbol{E}(\boldsymbol{r}+\boldsymbol{R}, t')\rangle$ that we call *a two-point correlation function*. The latter is advanced in time by *a three-point correlation function* $[NEE]_\alpha(\boldsymbol{R}, \boldsymbol{R}', \boldsymbol{p}, t, t', t'') = \langle N_\alpha(\boldsymbol{r}, \boldsymbol{p}, t)\ \boldsymbol{E}(\boldsymbol{r}+\boldsymbol{R}, t') \otimes \boldsymbol{E}(\boldsymbol{r}+\boldsymbol{R}', t'')\rangle$, *etc.* (Sign $\otimes$ symbolizes the direct tensor product.) The corresponding chain of evolution equations is infinite. It can be truncated in the case of a weakly turbulent plasma at any reasonable order, and then one reduces the problem to a study of coordinated evolution of the distributions $f_{e,i}(\boldsymbol{p}, t)$ and the *two-time* correlation function $\widehat{\boldsymbol{\Phi}}(\boldsymbol{R}, t, t') = \langle \boldsymbol{E}(\boldsymbol{r}, t) \otimes \boldsymbol{E}(\boldsymbol{r}+\boldsymbol{R}, t')\rangle$. Note that the latter is conceptually the solution to Maxwell equations whereat the charges and charge currents are respective integrals of the two-point correlation functions. In our case of potential Langmuir wave field,

$$\frac{\partial \widehat{\boldsymbol{\Phi}}}{\partial t} = -4\pi \sum_\alpha e_\alpha \int \boldsymbol{v}_\alpha(\boldsymbol{p}) \otimes [NE]_\alpha(\boldsymbol{R}, \boldsymbol{p}, t, t') d^3\boldsymbol{p} \quad (3)$$

(here $\boldsymbol{v}_\alpha(\boldsymbol{p})$ is the particle nonrelativistic velocity). We comment that within above truncated plasma description, the integrand of two-point correlation function can be iteratively expressed in terms of the two-time correlation function itself. The corresponding calculations were properly described in Ref. [31] and afterwards reconsidered in Ref. [34] for gaining the accuracy of plasma consideration. We note that the calculations generate equations that resemble the canonical redaction of Wyld diagram technique [36] in its two-time reading.

The remaining path to informative description of the plasma evolution consists of selecting the leading order of the two-time correlation function, of the iterative expressing the two-time correlation function through its cumulant of a wave spectral density $n_{\boldsymbol{k}}$ (a characteristic of the leading order of the function), and of final expressing the RHS of Eq. (2) and $\partial n_{\boldsymbol{k}}/\partial t$ in terms of wave spectral density and distribution functions. The choice of the leading order of two-time correlation function is the key problem here. Let us comment it a bit.

As we have formerly stated, the only consistent goal of any plasma calculation is to approximate as better as possible the current tendency of plasma macrophysical evolution. The corresponding computing should use predominantly the features of the plasma state at the current moment and at the relatively recent past. (Really, the further back in time the plasma state one considers, the less definite is the influence of that state on the current plasma evolution. This is a consequence of the lack of detailed information on positions and momenta of individual plasma particles.) Meanwhile, the customary frequency harmonics of electromagnetic field and distribution functions suppose weighting of particle distributions and electromagnetic field at all time axis $-\infty < t < \infty$ (semi-axis $0 < t - t' < \infty$ in the case of Laplace transformation) without any discrimination of the time remote states. Note also that the period of the plasma existence is rather often a finite one, especially in laboratory installations, and then the appeals to Fourier transforms imply the supplementing of real plasma history by nonexistent plasma states. Figuratively speaking, the researcher manually introduces extra entropy into the plasma description when he operates by temporal Fourier (Laplace) transforms of electromagnetic field and particle distributions.

Thus, it is more natural to develop the lowest order approximation of correlation function $\widehat{\boldsymbol{\Phi}}_{\boldsymbol{k}}(t, t')$ stemming from the original two-time representation of this function rather than from its frequency spectrum. (Note that it is both convenient and well appropriate to perform the transition to spatial Fourier transform of the two-time correlation function, $\widehat{\boldsymbol{\Phi}}(t, t') = \int \widehat{\boldsymbol{\Phi}}(\boldsymbol{R}, t, t') \exp(-i\boldsymbol{k} \cdot \boldsymbol{R}) d^3\boldsymbol{R}$. In view of final correlation radius of the turbulent wave field, this function is defined unambiguously at any moment.) In the case of stationary plasma the representation of certain plasma natural oscillation in $\widehat{\boldsymbol{\Phi}}_{\boldsymbol{k}}(t, t')$ should obey harmonic oscillations following the wave dispersion law $\omega_{\boldsymbol{k}}$ (a nonlinear one generally):

$$\widehat{\boldsymbol{\Phi}}^{(0)}_{\boldsymbol{k}}(t, t') \equiv \widehat{\boldsymbol{\Phi}}^{(0)}_{\boldsymbol{k}}(t - t') = \sum_{s=\pm} \widetilde{\boldsymbol{E}}_{s\boldsymbol{k}} \otimes \widetilde{\boldsymbol{E}}^*_{s\boldsymbol{k}} \times$$
$$\times \exp(-is\omega_{s\boldsymbol{k}}(t - t') - \gamma_{s\boldsymbol{k}}(t - t')).$$

(Here $\widetilde{\boldsymbol{E}}_{\boldsymbol{k}}$ is the amplitude of the wave, and $\gamma_{\boldsymbol{k}}$ is its damping rate.) A natural generalization of above form for the common case of evolving plasma is

$$\widehat{\boldsymbol{\Phi}}^{(0)}_{\boldsymbol{k}}(t, t') = \frac{\boldsymbol{k} \otimes \boldsymbol{k}}{k^2} \sum_{s=\pm} \times$$

$$\begin{cases} n_{s\boldsymbol{k}}(t')\exp\left(-is\int\limits_{t'}^{t}\omega_{s\boldsymbol{k}}(\tau)d\tau-\int\limits_{t'}^{t}\gamma_{s\boldsymbol{k}}(\tau)d\tau\right), \\ t>t', \\ n_{s\boldsymbol{k}}(t)\exp\left(is\int\limits_{t}^{t'}\omega_{s\boldsymbol{k}}(\tau)d\tau-\int\limits_{t}^{t'}\gamma_{s\boldsymbol{k}}(\tau)d\tau\right), \\ t<t'. \end{cases} \tag{4}$$

The notation $n_{\boldsymbol{k}}(t)$ stands for the wave spectral density. Note that structure (4) of the solution is dictated by the evolution equation of $\widehat{\boldsymbol{\Phi}}_{\boldsymbol{k}}(t,t')$, and it complies with the causality principle. In more details we discussed this in Ref. [31].

3. Final deductions developed with novel correlation analysis of plasma kinetics

The beginnings of above approach were first exemplified on a problem of three-wave interactions for a drift wave turbulence [31, 32]. In corresponding research, the usual understanding of three-wave phenomena was confirmed [32].

Papers [16–18] unroll the physics of Langmuir wave dissipation in a turbulent plasma due to the nonresonant electron diffusion in momentums, and uncover the most important consequences of this phenomenon. Let us specify this in a more expanded manner. In Ref. [16], we have shown that respective wave dissipation is intense enough for precluding the formation of Langmuir wave condensate, especially at intense pumping of weakly turbulent short-wavelength Langmuir turbulence. Ref. [18] was devoted to demonstration of impossibility of Vedenov-Rudakov's long-wavelength modulational instability of a plasma with intense Langmuir turbulence [37]. Besides, paper [18] supplements the study of Ref. [17] in showing impossibility of Zakharov's short-wavelength plasma modulational instability in a turbulent plasma. Together, these two papers state the impossibility of Langmuir wave collapses in a turbulent plasma and thus explain the non-occurrence of Langmuir collapses in above cited beam-plasma experiments of Wong's, Vyacheslavov's and Benford's teams.

In paper [33], we reconsidered the physics of Langmuir wave scattering induced by plasma electrons. We shall correct a bit the final result of the study. In terms of our $n_{\boldsymbol{k}}$, the rate of wave scatter is

$$\frac{\partial n_{\boldsymbol{k}}}{\partial t}=\frac{2\pi\omega n_{\boldsymbol{k}}}{\mathrm{Re}\ \partial(\omega\epsilon(\boldsymbol{k},\omega))/\partial\omega}\Bigg|_{\omega=\omega_{\boldsymbol{k}}}\frac{4\pi e^4}{m_e^3}\int d^3\boldsymbol{k}_1\times$$

$$d^3\boldsymbol{k}_2\delta^3(\boldsymbol{k}-\boldsymbol{k}_1-\boldsymbol{k}_2)\frac{(\boldsymbol{k}\cdot\boldsymbol{k}_1)^2}{k^2k_1^2}\frac{n_{\boldsymbol{k}_1}}{\omega_{\boldsymbol{k}}^4}\int d^3\boldsymbol{v}\times$$

$$\delta(\omega''-(\boldsymbol{k}_2\cdot\boldsymbol{v}))\left\{\frac{|1+\varepsilon_i(\boldsymbol{k}_2,\omega'')|^2}{|\varepsilon(\boldsymbol{k}_2,\omega'')|^2}+4\frac{(\boldsymbol{k}\cdot\boldsymbol{v})}{\omega_{\boldsymbol{k}}}+\right.$$

$$\left.10\frac{(\boldsymbol{k}\cdot\boldsymbol{v})^2}{\omega_{\boldsymbol{k}}^2}\right\}\Bigg|_{\omega''=\omega_{\boldsymbol{k}}-\omega_{\boldsymbol{k}_1}}\left(\boldsymbol{k}_2\cdot\frac{\partial f_e}{\partial\boldsymbol{v}}\right). \tag{5}$$

Note that the traditional analog of this equation differs with the given one in content of braces: Former images of the phenomenon assumed it to be

$$\left|\frac{2(\boldsymbol{k}\cdot\boldsymbol{v})}{\omega_{\boldsymbol{k}}}+\frac{1+\epsilon_i(\boldsymbol{k}_2,\omega'')}{\epsilon(\boldsymbol{k}_2,\omega'')}\right|^2 \tag{6}$$

(see, e.g., Refs. [38, 39]).

Regarding the very picture of the phenomenon as compared to its traditional analog, we shall say the following. The fair quantitative coincidence of traditional and new images of the scatter takes place for long waves ($\lambda \gg (m_i/m_e)^{2/5}r_D$). Further, intensities of two scatters for short Langmuir waves ($r_D \ll \lambda \ll r_D(m_i/m_e)^{1/3}$) *have the same scaling* in the case of maxwellian isotropic plasma electron distribution. But new scatter of short Langmuir waves, unlike to former one, yields here the Langmuir quanta decay: In some elementary scatters *both the scattering and the scattered wave quanta help each other to deliver a piece of their energy to bulk plasma electrons.* Finally, the intensity of traditional scatter of above specified short Langmuir waves in a plasma with a fairly nonisotropic electron distribution constitutes a piece of the order r_D/λ of new (real) wave scatter intensity. That is, at this case traditional approaches veil the bulk of the short wave scatter.

In paper [35], the physics was considered of electron redistribution in momentums during related scatter of Langmuir waves. We have shown there that traditional theory undervalues rate of change of electron distribution in all possible situations.

4. General comments on informative plasma theoretical studies

Narration of Sections 2,3 was oriented on the easiest problem of an evolving homogeneous weakly turbulent plasma. Meanwhile, the very homogeneous plasma turbulence is nothing but an abstraction that hardly can be evoked in real plasmas by any external influence. Say, when one tries to heat a plasma by an electron beam, he(she) observes spatially inhomogeneous beam-plasma interaction. Besides, the latter process depends essentially on dynamics of the beam injection. On the other side, the weakly turbulent plasma phenomena are not the only ones that yield obtaining of any informative final theoretical conclusions. In general, the revealing of plasma contexts that possess this property, and the developing of theoretical means for inferring respective final deductions, should constitute an extremely important component of plasma research. We stress that *there are no any universal calculation* *technique*: each of plasma problems dictate its own logics of obtaining informative final conclusions. The easiest illustration to this thesis constitute the problem of thermodynamic relaxation of a weakly nonideal nonequilibrium homogeneous plasma. In such a plasma, the particles exercise Coulomb collisions, which lead to the plasma thermalization. Similarly to phenomena in a collisionless weakly turbulent plasma, this process permits developing of its somewhat informative scenario. At the same time, the above concept of plasma natural oscillation (the leading solution (4)) and respective fashion of its treating are useless here. The consideration of Coulomb collisions requires differing lowest order approximation of $\widehat{\mathbf{\Phi}}(\boldsymbol{R}, t, t')$, which supposes respective change in further calculation organization. One more illustration is the plasma leakage from a tokamak: Toroidal geometry of plasma volume dictates respective fashion of the phase space averaging.

Finally, the possibility of developing informative conclusions depends essentially on the order of expansion parameter in the perturbation expansion: *No informative final deductions can be developed without smallness of that parameter.* (Really, successive iterations diverge then from the very beginning.) With expansion parameter ε, the most optimal order of the expansion is about $1/\varepsilon$. Up to this top level, the adding of extra orders leads to enlarging the time interval of reliability of the respective plasma scenario. In the plasma turbulence case, the expansion parameter is the ratio of nonlinear damping rate γ^{nl} to the turbulence dispersion in natural frequencies $\Delta\omega$, then conclusions on current plasma evolution up to n-th order are reliable up to time delays $\sim$ $(\Delta\omega^{n-1})/(\gamma^{nl})^n$. Similarly, in other cases the parameter ε constitutes a ratio of two characteristic inverse times, with analogous estimation of the period of the scenario reliability.

[1] I. Langmuir and L. Tonks, Phys. Rev. **33**, 195 (1929).
[2] L. M. Gorbunov, V. P. Silin, Sov. Phys. JETP **20**, 135 (1965).
[3] A.S Kompaneyets, Zh. Eksp. Teor. Fiz. **31**, 876 (1956).
[4] V.E. Zakharov, Sov. Phys. JETP **35**, 908 (1972).
[5] A.Y. Wong and P.Y. Cheung, Phys. Rev. Lett. **52**, 1222 (1984).
[6] P.Y. Cheung and A.Y. Wong, Phys. Rev. Lett. **55**, 1880 (1985).
[7] M.D. McFarland and A.Y. Wong, Phys. Plasmas **4**, 945 (1997).
[8] M.D. McFarland and A.Y. Wong, Phys. Rev. Lett. **84**, 666 (2000).
[9] L.N. Vyacheslavov et al., Proc. of the IV-th International Workshop "Strong Microwaves in Plasmas," Nizhny Novgorod, Inst. of Applied Physics, 1999, edited by A.G. Litvak (Nauka, Moscow, 2000) Vol. 2, p. 405.
[10] L.N. Vyacheslavov et al., JETP Letters **75**, 41 (2002).
[11] L.N. Vyacheslavov *et al.*, PPCF **44** (12), B279 (2002).
[12] D. Levron, G. Benford and D. Tzach, Phys. Rev. Lett. **58**, 1336 (1987).
[13] G. Benford, X. Zhai and D. Levron, Phys. Fluids B **3**, 560 (1991).
[14] G. Benford and X.L. Zhai, Phys. Fluids B **5**, 1914 (1993).
[15] P.A. Robinson, Rev. Mod. Phys. **69**, 507 (1997).
[16] V.I. Erofeev, Physics of Plasmas **9**, 1137 (2002).
[17] V.I. Erofeev, J. Plasma Phys. **68**, 1 (2002).
[18] V.I. Erofeev, Physics of Plasmas **11**, 3284 (2004).
[19] J.W. Gibbs, *Elementary principles in statistical mechanics, developed with especial reference to the rational foundation of thermodynamics* (Yale Univ. Press, New York, 1902).
[20] N.N. Bogoliubov, *Problems of a Dynamical Theory in a Statistical Physics* — In *Studies in Statistical Mechanics,* edited by J. deBoer and G.E. Uhlenbeck, (North-Holland Publ., Amsterdam, 1962), Vol. 1.
[21] M. Born, and H.S. Green, *A General Kinetic Theory of Liquids* (Cambridge University Press, London, 1949).
[22] J.G. Kirkwood Journ. Chem. Phys. **14**, 180 (1946).
[23] J. Yvon, *La théorie des fluids et l'équation d'état: actualités, scirntifigues et industrielles* (Hermann and Cie, Paris, 1935).
[24] L. Boltzmann, *Lectures on Gas Theory*, translated by S. Brush (Univ. California Press, Berkeley, 1964).
[25] Yu.L. Klimontovich, Zh. Exp. Teor. Fiz. **33**, 982 (1957); *The Statistical Theory of Nonequilibrium Processes in a Plasma.* (MIT Press, Cambridge (Mass.), 1967).
[26] T.H. Dupree, Phys. Fluids **6**, 1714 (1963).
[27] R.C. Kirkpatrick, I.R. Lindemuth and M.S. Ward, Fusion Technology **20**, 843 (1991).
[28] D.D. Ryutov, D.C. Barnes, B.S. Bauer et al., Magnetized Target Fusion, Proceedings of 19th IAEA Fusion Energy Conference (Lyon, France, 2002) IAEA-CN-94/IF/P12, pp. 1-6.
[29] H. Hora, G.H. Miley, F. Osman et al., Journ. Plasma Phys. **69**, 413 (2003).
[30] H. Hora, C. Yu, H. Xiantu, et al., Plasma Science and Technology, **69**, 2173 (2004).
[31] V.I. Erofeev, J. Plasma Phys. **57**, 273 (1997).
[32] V.I. Erofeev, Australian Journ. Phys. **51** (5), 843 (1998).
[33] V.I. Erofeev, Journal of Fusion Energy **19**, 99 (2000).
[34] V.I. Erofeev, J. Plasma Phys. **70**, 251 (2004).
[35] V.I. Erofeev, Journal of Fusion Energy **22**, 259 (2003).
[36] Zakharov, V. E. and L'vov, V. S., Izv. Vyssh. Uchebn. Zaved., Radiofiz. **18**, 1470 (1975).
[37] A.A. Vedenov and L.I. Rudakov, Sov. Phys. Dokl. **9**, 1073 (1965).
[38] V.N. Tsytovich, Sov. Phis. Uspekhi **9**, 805 (1967).
[39] V.N. Tsytovich, Nonlinear effects in plasma (Plenum, New York, 1970).