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RESEARCH REPORT
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From Dressed Particle to Dressed Mode in Plasmas

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A theoretical method to analyze the strong turbulence in far-nonequilibrium plasmas is discussed. In this approach, a test mode is treated being dressed with interactions with other modes. Nonlinear dispersion relation of the dressed mode and statistical treatment of turbulence is briefly explained. Analogue to the method of dressed particle, which has given Balescu-Lenard collision operator for inter-particle collisions, is mentioned.

Keywords: method of dressed mode, turbulence, dressed particle, renormalized dispersion relation, statistical theory

I. Introduction

Plasmas have been one of the main subjects of modern physics. This is because that almost all the matter, the presence of which is known to mankind, is in the plasma state and the understanding of the physics of plasmas constitutes foundations for our perception of the nature. In addition, plasmas have revealed challenging problems. One important issue is that the charged particles in plasmas interact with others through the long-range interaction of electromagnetic fields which are at the same time governed by the motion of plasma particles. This feature is known as the collective interactions. The other stimulating issue is that the plasmas are often far-away from the thermodynamical equilibrium.*) Fluctuating electromagnetic fields or fluctuating component of plasma parameters are far from those predicted for the thermodynamical fluctuations and do not at all satisfy the equi-partition law. The strong non-equilibrium nature of fluctuations comes from instabilities and turbulence, and influences the nature of plasmas.

The collective nature of plasmas influences the collisions of charged particles. The analysis of collisional process in plasmas is essential: this is because the inter-particle collisions are the origin of irreversibility and dissipations. The rate of dissipation has a basic importance for the analysis of the transport processes. This collective nature was successfully formulated by Balescu [1] and Lenard [2], which is now known as Balescu-Lenard collision operator. It has been clearly demonstrated that charged particles are "not alone" in plasmas. When one particle encounters with the other, it is not a collision of "bare" particles. In stead, each particle is dressed with interactions between many other particles through electromagnetic fields. The interaction between two "bare" particles are screened by many other particles, and the collision is formulated as those between "dressed" particles. The inter-particle collision is an origin of the transport processes and this formula has been a foundation of the analysis of transport coefficients. For instance, the collisional transport is basic to the cross-field transport in strongly-magnetized plasmas, which have been intensively investigated for the motivation to realize controlled thermonuclear fusion. The cross-field transport owing to the binary collision of charged particle is called "classical transport" (or "neoclassical transport" in toroidal configurations) and has been subject to long and intensive investigations. For this transport coefficient, the monograph by Balescu [3] provides a systematic deduction, and forms a firm basis of plasma transport processes, together with other literature [4].

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*) In a standard terminology, one may use the words "thermal equilibrium" and "thermal fluctuations" to describe the state which is equilibrated at a given temperature. The fluctuation of thermal energy (or temperature) is an important element for plasma turbulence in nonequilibrium state. In order to avoid the confusion of the fluctuation of thermal energy and fluctuations at thermal equilibrium, the words "thermodynamical equilibrium" and "fluctuations at thermodynamical equilibrium" are employed here.

Far-nonequilibrium property of plasmas has required a breakthrough in understanding the fluctuations. Instabilities, which are caused by inhomogeneities, boundaries, or anisotropy of distribution function, drive fluctuations into the level which is much higher than the thermodynamical equilibrium fluctuations. The subject of strong turbulence has been a main issue in the plasma theory. In strong turbulence, the growth of a mode that is labelled among a large number of excited modes is different from what has been predicted by linear stability. Proper theoretical treatment of the interaction of excited mode with other fluctuations has been (and will be) a central theme. (See [5] for an illustrative description of the problem.) A method of dressed test mode in a strongly-turbulent magnetized plasmas is reported briefly.

II. Model

2.1 Example for the case of reduced set of equations

The method of dressed mode is illustrated by use of an example of a reduced set of equations. The reduced set of equations has the form

$$\frac{\partial}{\partial t} f + \mathcal{L}^{(0)} f = \mathcal{N}(f, f) + \tilde{S}_{\mathrm{th}} \tag{1}$$

where f denotes the set of fluctuating field variables. (See [6] for a survey.) For instance, $f^{\mathrm{T}} = (\phi, n)$ for Hasegawa-Wakatani model [7], $f^{\mathrm{T}} = (\phi, J, p)$ for three-field model [8], or $f^{\mathrm{T}} = (n, \phi, \Phi, v_{\parallel}, p_e, p_i, A_{\parallel})$ for Yagi-Horton model [9]. (ϕ : electrostatic potential, J : current along the strong magnetic field, p : pressure, n : density, etc.) These have been used for the study of nonlinear dynamics of resistive drift mode turbulence, current-diffusive mode turbulence, and for a comprehensive study of many instabilities, respectively. The linear operator $\mathcal{L}^{(0)}$ is an $N \times N$ matrix for the $N-$ field model and controls the linear modes. $\mathcal{N}(f, f)$ is the nonlinear terms, e.g., $\mathcal{N}(f, f) = -\left(\nabla_\perp^{-2}[\phi, \nabla_\perp^2 \phi], [\phi, J], [\phi, p]\right)^{\mathrm{T}}$, for the case of $f^{\mathrm{T}} = (\phi, J, p)$. The term $\tilde{S}_{\mathrm{th}}$ stands for the thermodynamical excitations induced by the interaction with a heat bath.

Theoretical models have been developed to separate the nonlinear interaction term into two terms:

$$\mathcal{N}(f, f) = \mathcal{N}_{\mathrm{coherent}}(f, f) + \tilde{S} \, , \tag{2}$$

where $\mathcal{N}_{\mathrm{coherent}}(f, f)$ is the coherent part, which changes with the phase of the test mode, f_k, and $\tilde{S}$ is the incoherent part (noise part). Explicit forms of $\mathcal{N}_{\mathrm{coherent}}(f, f)$

and $\tilde{S}$ are given by modelling. Various models for the coherent and incoherent parts have been analyzed. For detailed discussion, see e.g. [6, 10]. In the method of dressed test mode, a test mode $\boldsymbol{f}_k$ is chosen, and a following modelling is taken: The term $\mathcal{N}_{\text{coherent}}(\boldsymbol{f}, \boldsymbol{f})$ is modelled as an effectively-linear term of $\boldsymbol{f}_k$ renormalizing nonlinear interactions with back-ground turbulent fluctuations, and $\tilde{\boldsymbol{S}}_k$ is a random noise.

In an actual application to plasma turbulence, a diagonalization approximation of $\mathcal{N}_{\text{coherent}}(\boldsymbol{f}, \boldsymbol{f})$ is often used for analytic insight. The diagonal terms in $\mathcal{N}_{\text{coherent}}(\boldsymbol{f}, \boldsymbol{f})$ are approximated by the diffusion terms with the turbulent viscosity (μ_N for ion viscosity, μ_{Ne} for electron viscosity, and χ_N for thermal diffusivity), or by the eddy-damping coefficients (γ_υ for ion momentum, γ_e for parallel electron momentum, and γ_p for thermal energy), as $\mathcal{N}_{\text{coherent}}(\boldsymbol{f}, \boldsymbol{f})_k = \left(\mu_N \nabla_\perp^2 f_1, \mu_{Ne} \nabla_\perp^2 f_2, \chi_N \nabla_\perp^2 f_3\right)^{\mathrm{T}}$ or $\mathcal{N}_{\text{coherent}}(\boldsymbol{f}, \boldsymbol{f})_k = -\left(\gamma_\upsilon f_1, \gamma_e f_2, \gamma_p f_3\right)_k^{\mathrm{T}}$. Within this diagonal approximation, the renormalized operator $\mathcal{L}$ is given by

$$\mathcal{L}_{ij} = \mathcal{L}_{ij}^{(0)} + \gamma_i \delta_{ij} \tag{3}$$

and one has a renormalized reduced set of equations (with a thermodynamical noise source) as

$$\frac{\partial}{\partial t} f_k + \mathcal{L} f_k = \tilde{\boldsymbol{S}}_k + \tilde{\boldsymbol{S}}_{\text{th}, k} \ , \tag{4}$$

where $\boldsymbol{k}$ denotes the test mode [11].

2.2 Dressed modes

Equation (4) shows that the amplitude of the fluctuation $|\boldsymbol{f}_k|$ becomes large in the vicinity of the pole of the renormalized operator $\mathcal{L}$. Thus the nonlinear dispersion relation

$$\det\left(\lambda \boldsymbol{I} + \mathcal{L}\right) = 0 \tag{5}$$

describes the characteristic feature of the turbulence, where $\boldsymbol{I}$ is a unit tensor, and $-\lambda$ is the eigenvalue of the operator $\mathcal{L}$. The sign of λ is defined so that $\Re e \lambda$ is positive when the test mode perturbation does not increase. The decorrelation rate is given by $\Re e \lambda$. This dispersion relation includes the (coherent part of) nonlinear interactions with back ground fluctuations, and the eigenmode corresponding to the nonlinear eigenvalue is called dressed mode.

In order to solve the Langevin equation (4), an ansatz for a large number of degrees of freedom in the random modes, N, is introduced. The renormalized term γ_j in $\mathcal{L}$ arises from the statistical sum from N components, so that its variation in time becomes $O(N^{-1/2})$ less than that of f_k. Therefore, in solving f_k, $\mathcal{L}$ is approximated to be constant in time in the limit of $N \to \infty$. The general solution is formally given as

$$f(t) = \sum_m \exp\left(-\lambda_m t\right) f^{(m)}(0) + \int_0^t \exp\left[-\mathcal{L}(t-\tau)\right] \tilde{S}(\tau)\, d\tau \tag{6}$$

where $-\lambda_m$ ($m = 1, 2, 3 \cdots$ and $\Re e\, \lambda_1 < \Re e\, \lambda_2 < \Re e\, \lambda_3 < \cdots$) represent the eigenvalues of the renormalized matrix $\mathcal{L}$. ($f^{(m)}(0)$ represents the initial value which is transformed into a diagonal basis.)

2.3 Statistical theory

The incoherent part $\tilde{S}$ acts as a nonlinear noise. Taking an example of three-field model, the statistical analysis is explained [11, 12]. The matrix $\exp[-\mathcal{L}(t-\tau)]$ in equation (6) are decomposed as

$$\left\{\exp\left[-\mathcal{L}(t-\tau)\right]\right\}_{ij} = A_{ij}^{(1)} \exp\left[-\lambda_1(t-\tau)\right] + A_{ij}^{(2)} \exp\left[-\lambda_2(t-\tau)\right] + A_{ij}^{(3)} \exp\left[-\lambda_3(t-\tau)\right] ,$$

where explicit forms of $\boldsymbol{A}^{(m)}$ are given in [12]. By introducing a projected noise source, $\mathcal{S}^{(m)}(\tau) = \left(1, -i\, k_\parallel k_\perp^{-2}(\gamma_e - \lambda_m)^{-1}, -i\, k_y \kappa k_\perp^{-2}(\gamma_p - \lambda_m)^{-1}\right) \cdot \left\{\tilde{S}(\tau) + \tilde{S}_{th}(\tau)\right\}$, where κ is the magnetic field gradient and the superscript (m) denotes m-th eigenmode, one can estimate the noise source as $\left\langle \mathcal{S}^{(1)*} \mathcal{S}^{(1)} \right\rangle \simeq C_0 \gamma_v A_{11}^{-2} \left\langle f_{1,k}^{(1)*} f_{1,k}^{(1)} \right\rangle$ + thermal excitations , where C_0 is a numerical factor of the order of unity [11]. With this estimate, the long time average of the fluctuation amplitude is given as

$$\left\langle f_{1,k}^{(1)*} f_{1,k}^{(1)} \right\rangle = \frac{C_0 \gamma_v}{2 \Re\, \lambda_1} \left\langle f_{1,k}^{(1)*} f_{1,k}^{(1)} \right\rangle + \text{thermal excitations} . \tag{7}$$

This is one form of *extended fluctuation dissipation relation* for the non-equilibrium plasmas. In this formula, the effects of turbulence are renormalized in γ_v and λ. The formula $\Re\, \lambda_1 = C_0 \gamma_v / 2$ describes the stationary state of strong turbulence.

III Applications

3.1 Nonlinear instability and subcritical excitation

The method of dressed mode has been applied to interchange mode turbulence [8]. When there is a dissipation that impedes the free electron motion along the magnetic field line, the interchange mode becomes unstable. This mechanism allows the nonlinear instability. When the electrons respond to the test mode (interchange mode) in the presence of the back-ground turbulent fluctuations, electrons are dressed with reactions from back-ground fluctuations. Electrons are 'heavy' owing to the presence of turbulence, and electrons do no longer freely cancel the charge separation associated with the mode. There arises a nonlinear link of mechanisms that excites fluctuations: (1) fluctuations impede the free motion of electrons through cross-field diffusion, (2) this electron diffusion increases the growth rate (3) the increased growth rate further enhances the fluctuation level. An explosive growth of fluctuations takes place until the fluctuation level becomes high enough so that the ion viscosity stabilizes the mode. Plasma turbulence is self-sustained, not necessarily being driven by linear instability [13].

By use of this method, a subcritical excitation and anomalous transport in plasma can be analyzed. A nonlinear marginal stability condition has been derived for current diffusive interchange mode (CDIM) as [14]

$$\frac{G_0}{s^{4/3}} \frac{\left(\mu_{eN} + \mu_{ec}\right)^{2/3} \left(c/a\omega_p\right)^{4/3}}{\left(\chi_N + \chi_c\right)\left(\mu_N + \mu_c\right)^{1/3}} = \Im_c \tag{8}$$

where G_0 is a normalized pressure gradient $G_0 = a^2 \nabla \ln p_0 \cdot \nabla \ln B$ and s is a magnetic shear parameter, and the length, time, and the scalar and vector potentials are normalized to the plasma radius a, poloidal Alfven transit time $\tau_{Ap} = a/v_{Ap} = R/v_A$, Ba^2/R and $Bv_A a^2/R$, respectively. A critical Itoh number $\Im_c$, is of the order of unity. (Suffix c for μ, μ_e and χ indicates the collisional transport process.) This formula shows that the turbulence is self-sustained even in a linearly stabile region $G_0 < G_c$. At the critical pressure gradient G_*, the turbulent transport coefficient is subject to a subcritical excitation. Figure 1 illustrates a theoretical prediction of fluctuation level as a function of pressure gradient, G_0. Explicit multifold form of electrostatic potential perturbation $\tilde{\phi}(G_0)$ is seen. A subcritical excitation of turbulence is predicted to occur if G_0 exceeds the critical value G_*. The subcritical excitation and self-sustaining of turbulence are confirmed by direct numerical simulations [15].

3.2 Turbulence transition and transition probability

The result of the current-diffusive turbulence shows that the fluctuations have cusp catastrophe owing to the two excitation mechanisms (i.e., inhomogeneity that induces instability and thermodynamical excitations). The statistical transition can take place among the turbulent states and the transition probability can be calculated.

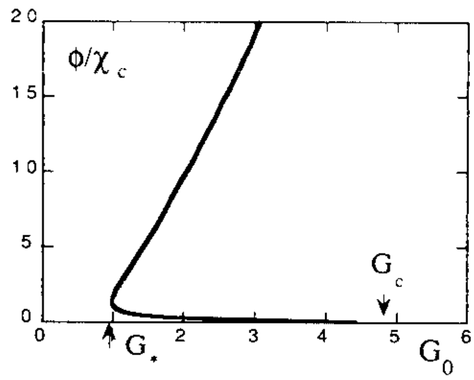

Fig.1 Fluctuation level as a function of the pressure gradient. Strong turbulence exists below the critical pressure gradient against the linear instability, $G_0 < G_c$. Transition to the turbulent state takes place at $G_0 = G_*$. On horizontal axis, G_0, G_* and G_c are divided by $s^{4/3} a^{2/3} \delta^{-2/3} \chi_c^{2/3}$, $\delta = c/\omega_p$ [14].

The renormalized Langevin equation is reduced to the one for a course-grained quantity [11]. The total fluctuating energy, which is the quantity integrated over some finite-size volume of size L, $\mathcal{E} \equiv \frac{1}{2} \sum_k k_\perp^2 \phi_k^2$ is taken as an examples. By introducing an average dissipation rate, $\Lambda \equiv 2 \sum_k \lambda_{1,k} k_\perp^2 \phi_k^2 / \mathcal{E}$, the Langevin equation for the total fluctuating energy is given as

$$\frac{\partial}{\partial t} \mathcal{E} + 2\Lambda \mathcal{E} = g\, w(t) , \tag{9}$$

where $w(t)$ denotes the white noise and $g^2 = 4\hat{T}\gamma_m \mathcal{E} + \sum_k \left(\sum_{j=1}^{3} A_{1j} g_{j,k} \right)^2 k_\perp^4 \phi_k^2$. ($g_{j,k}$: the amplitude of $\tilde{S}_k$, $\tilde{S}_{j,k} = g_{j,k}\, w(t)$, and $\hat{T} = 2\mu_0 B_p^{-2} k_B T$: the normalized temperature, γ_m : the mean decorrelation rate at thermodynamical equilibrium.) The associated effective potential $S(\mathcal{E})$

$$S(\mathcal{E}) = \int^{\mathcal{E}} \frac{4\Lambda \mathcal{E}}{g^2} \mathrm{d}\mathcal{E} , \tag{10}$$

is introduced. This renormalized potential plays a central role in the statistical property of fluctuations. First, the probability density function (PDF) of fluctuation energy in a stationary state is given by $P_{st}(\mathcal{E}) = \bar{P} g^{-1} \exp\{-S(\mathcal{E})\}$. The minima of $S(\mathcal{E})$ denote the probable states. In the case that a hysteresis exists, $S(\mathcal{E})$ has multiple minima, separated by local maximum. Thermodynamical fluctuation state (horizontal axis of Fig.1) and turbulent state (upper branch of Fig.1) are denoted by A and B; the lower branch of Fig.1 that is an unstable marginal state is denoted by C. Second, the transition probability between different turbulent state can be given by $S(\mathcal{E})$ [16].

The transition probability from the thermodynamical branch to the turbulent state is given as

$$r_{A \to B} = \frac{\sqrt{\Lambda_C \gamma_m}}{\sqrt{\pi}} \exp\left\{ -S(\mathcal{E}_C) \right\} \tag{11}$$

$\Lambda_C = \mathcal{E} \, \mathrm{d}\Lambda / \mathrm{d}\mathcal{E}$ at $\mathcal{E} = \mathcal{E}_C$. This is an extension of the *Arrhenius law* to the system far from thermodynamical equilibrium. For the case of CDIM turbulence, the probability of transition from thermodynamical fluctuation to the turbulent fluctuation is given, near the critical gradient $G_0 \simeq G_c$, as

$$r_{A \to B} \sim \frac{\gamma_m}{\sqrt{\pi}} \left(\frac{\mu_{ec}}{2} \right)^{-2b_1} k_0^{-4b_1/3} \left(\hat{T} \gamma_m \frac{3}{16 C_0} \right)^{2b_1/3} \left(1 - \frac{G_0}{G_c} \right)^{-b_1} \tag{12}$$

where $b_1 \simeq \left(k_0 \gamma_m / \sqrt{3}\, 16 C_0 \right)^{2/3} \hat{T}^{-1/3} (L/a)^2$. Important feature is that the probability is expressed in terms of the power law $r_{A \to B} \propto \left(1 - G_0 / G_c \right)^{-b_1}$.

The phase boundary for the ensemble average is given by the formula

$$S(\mathcal{E}_A) = S(\mathcal{E}_B) \, . \tag{13}$$

This is an extension of the *Maxwell's construction.*

IV Summary

In this article, a brief description is made for a recent development of the theory of plasma turbulence. Property of turbulent plasma is formulated by a method of dressed modes. The coherent part of nonlinear interactions is included in a nonlinear dispersion relation, which allows analyses of subcritical turbulence or nonlinear saturation states. The incoherent part contributes to the stochastic noise term, and a statistical theory is constituted. Two fundamental issues of plasmas, i.e., the collective phenomena and non-equilibrium property, are investigated by this method.

This method can be applied to various problems. Extensions to the cases with many kinds of instabilities are presented in [17, 18]. Statistical excitation of stable and long-wavelength fluctuations has also been discussed, in conjunction with the nonlocal transport processes [17]. In this article, the plasma inhomogeneity is treated as a given control parameter. In reality, it evolves with turbulence. The structural formation and turbulent transport are discussed in literature and monograph [6, 8].

Starting from the dressed particle, research of far-nonequilibrium plasmas now includes the method of dressed modes. This direction will provide a prosperous path to explore the further progress of modern physics.

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Dedication

This article is dedicated to Prof. R. Balescu on occasion of his 70th birthday, with cordial thanks for his elucidating comments and discussions in the course of research which is presented here.

References

[1] Balescu R 1960 Phys. Fluids **3** 52

[2] Lenard A 1960 Ann. Phys. (N. Y.) **3** 390

[3] Balescu R 1988 *Transport Processes in Plasmas 2. Neoclassical transport theory* (North-Holland, Amsterdam)

[4] Rosenbluth M N, Hinton F L, Hazeltine R D 1972 *Phys. Fluids* **15** 116; Galeev A A and Sagdeev R Z 1973 in Reviews of Plasma Physics (ed. M. A. Leontovich, Consultants Bureau, New York) Vol.7, Hirshman S P and Sigmar D J 1981 Nucl. Fusion **21** 1079; Kovrizhnykh L M 1984 Nucl. Fusion **24** 435

[5] Balescu R 1997 *Statistical Dynamics: Matter out of Equilibrium* (Imperial College Press, London)

[6] Yoshizawa A, Itoh S-I, Itoh K and Yokoi N 2001 Plasma Phys. Contr. Fusion **43** R1

[7] Hasegawa A and Wakatani M 1983 Phys. Rev. Lett. **50** 682

[8] Itoh K, Itoh S-I and Fukuyama A 1999 *Transport and Structural Formation in Plasmas* (IOP, Bristol,)

[9] Yagi M and Horton C W 1994 Phys. Plasmas **1** 2135

[10] Krommes J A: "Fundamental statistical theories of plasma turbulence in magnetic fields" Phys. Reports in press (2002)

[11] Itoh S-I and Itoh K 1999 J. Phys. Soc. Jpn. **68** 1891; 2611; 2001 J. Phys. Soc. Jpn. **69** 408.

[12] Itoh S-I and Itoh K 2001 J. Phys. Soc. Jpn. **69** 3253.

[13] Itoh K, Itoh S-I and Fukuyama A 1992 Phys. Rev. Lett. **69** 1050.

[14] Itoh K, Itoh S-I, Yagi M and Fukuyama A 1996 *J. Phys. Soc. Jpn.* **65** 2749.

[15] Yagi M, Itoh S-I, Itoh K, Fukuyama A and Azumi M 1995 *Phys. Plasmas* **2** 4140

[16] Itoh S-I and Itoh K 2000 J. Phys. Soc. Jpn. **69** 427

[17] Itoh S-I and Itoh K 2001 Plasma Phys. Contr. Fusion **43** 1055

[18] S.-I. Itoh, K. Itoh, M. Yagi, M. Kawasaki, A. Kitazawa 2002 "Transition in multiple-scale-lengths turbulence in plasmas" Phys. Plasmas **9** in press

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