§16. Kinetic Description of Nonlinear Plasma Turbulence

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The development of the statistical theory for the strongly turbulent plasma has been one of the main subjects in the plasma physics. Theories have been developed by use of various methods. Previous theories often assume, at least at the final stage of the theoretical scheme, the presence of an eddy viscosity type drag and employ the Markovian approximation. One direction of the recent progress is to investigate the basis of this analysis. Namely, the basic nonlinear equations are time-reversal in the absence of the dissipation due to molecular viscosities. When turbulent interactions are renormalized, the renormalized terms have non-Marikovian from [1,2]. The induction of irreversibility in the stochastic evolution equations is related to the approximations. Another key issue in progresses is the recognition that treating the coherent part and incoherent part (nonlinear noise) of nonlinear effects in an equal-footing manner is essential in theory of plasma turbulence. The incoherent part has influences in dynamics such as subcritical excitation and self-sustaining [3-5], enhanced transport near stability boundary [6], acceleration of relaxation, access to nonlinear stationary state [2], excitation of global modes [7], etc. Driven by the progress of direct nonlinear simulations for kinetic plasmas, importance of nonlinear fluctuating force has also been recognized [8]. Nevertheless, the research in this direction is still limited. For instance, refs. 2-5 are based upon fluid approximation. Kinetic description of plasma turbulence has been examined by Kadomtsev by a heuristic model approach [9].

In this work, we extend the previous analysis on the line of Mori's method [10]. A set of basic kinetic equations to describe the plasma strong turbulence is derived introducing the memory functions and the fluctuating force. Explicit formalisms of memory functions for electron/ion distribution functions and for the fluctuating potential are obtained within three wave interaction approximation. Nonlinear dispersion equation including the self-noise scattering term is derived. Nonlinear dispersion relation equation contains the kinetic description of the drag terms which include the wave-particle interactions. The self-noise scattering term for the case of strong turbulence also includes the wave-particle interactions. The terms naturally reduce to the quasilinear diffusion terms as well as the collision terms of thermal fluctuation in the limiting cases.

Roles of coherent and incoherent nonlinear terms are discussed. First, the access to nonlinear stationary state is discussed. Then, two mechanisms in the dynamical development of wave spectrum are considered. One corresponds to the resonance broadening, and the other is the non-modal wave excitation due to the strong self-noise scattering. Both include the kinetic description of wave-particle interactions. Non-modal wave excitation is the current topic as well as the long lasting problem problem of spectrum cascade [11].

As an example, we illustrate here the accumulation of quasi-modes. It is shown that the incoherent emission leads to an accumulation of quasi-mode at the frequency of

$$\omega(k) = 2\,\omega'(k/2)$$

where $\omega'(k')$ indicates the dispersion relation of mode. Figure 1 shows an example, where accumulation of the incoherent quasi-modes is demonstrated. The incoherent emission near $\omega \simeq 0$ constitutes another accumulation frequency of quasi-modes. This accumulated emission is important in the study of zonal flows and streamers. Here we focus to the local representation, even though the non-local disparate scale interactions are important [12].

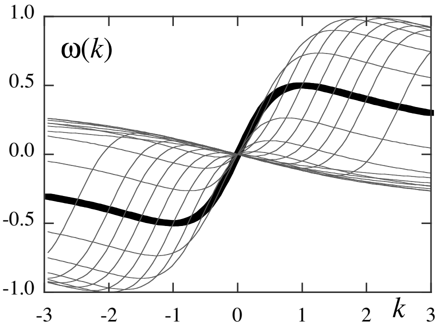

Fig.1: Frequencies of the modes and induced quasi-modes. Thick solid line denotes the eigenmode, and thin lines indicate examples of quasi-mode. In this figure, each line for quasi-mode $\omega(k) = \omega'(k') + \omega''(k'')$ is drawn by varying k' and keeping k'' constant.

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