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Spatio-temporal dynamics of turbulence based on wave-kinetic formalisms

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Transport of particles and heat in magnetically confined plasmas is dominated by turbulence, which is driven by the spatially gradients of temperature and density [1]. The drift wave type turbulence nonlinearly generates the meso-scale structures such as zonal flows, streamers, and others [2]. These meso-scale structures has significant impact on turbulence dynamics. As a consequence of the interaction between turbulence and meso-scale structures or the self-interaction of turbulence, the ballistic propagation of turbulence, which is called turbulence spreading or avalanche, often appears [3, 4], and/or the spatial localization of turbulence and profile corrugation, which is the staircase formation, are observed [5, 6]. The selection rule of such turbulence states should be understood.

In order to obtain the physical picture of the turbulence bifurcation, reduced simple models are useful. Wave-kinetic theory is the simple turbulence model, which treats the turbulence distribution function in the phase space, where the phase space consists of real space and the wavenumber space. In this theory, the phase random approximation is used, so that only the intensity of the turbulence is considered. The interaction between the turbulence and large scale flows can be described by this theory. The evolution equation for the turbulence distribution function has a same mathematical structure as the Boltzmann equation. A mechanism of the particle trapping by electrostatic potentials exists for the Boltzmann equation, and the typical vortex structure called BGK vortex exits in the phase space. Similarly, the turbulence trapping occurs for the wave-kinetics. When the certain condition is satisfied, the turbulence clump is trapped in the large scale flows, such as zonal flows or streamers [7]. The physical mechanism of the turbulence trapping is as follows. The turbulence eddy deforms in the presence of the sheared flows, so that the wavenumber of the turbulence is changed, which influences the propagation direction through the linear dispersion relation. In this study, the turbulence trapping in the phase space is focused on, and the resulting turbulence dynamics is discussed.

The interaction between the turbulence and the zonal flows/streamers is considered by performing the direct numerical simulation of the wave-kinetics. The zonal flows have the shear in the radial direction, so that the turbulence eddy suffers the stretching effect, and the turbulence trapping occurs [5-7]. Figure 1 illustrates the phase space pattern of the turbulence distribution function. The island type structures are formed, which is close to the BGK vortex in the kinetic theory. On the

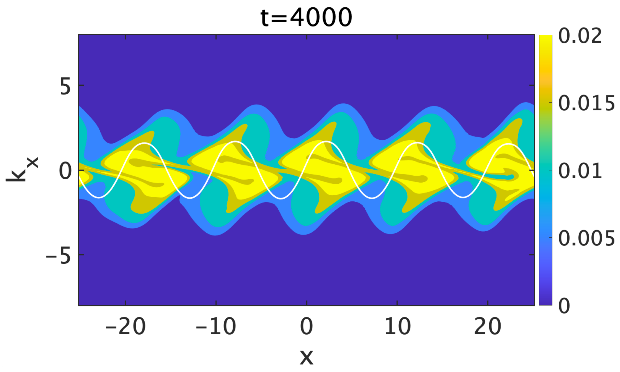

Fig. 1: Phase space structure of turbulence distribution

other hand, the streamer has the shear in the azimuthal direction, the turbulence azimuthal propagation is significantly affected, and the radial propagation of the turbulence is possible [8]. If the streamer is dominant, the turbulence forms clumps in the azimuthal direction, and freely propagate radially. This state corresponds to the avalanche or turbulence spreading, and the propagation speed is the radial group velocity which is comparable to the diamagnetic drift speed. If one considers the toroidal plasmas, zonal flows have two branches; one is the stationary zonal flow, and another is the geodesic acoustic modes (GAMs). GAMs have finite radial phase velocity, so the trapped turbulence clump ballistically propagate radially with the phase velocity of the GAMs. While the zonal flow dominant state, the localization of turbulence is realized, and the profile corrugation occurs (staircase formation). In this way, depending on which meso-scale structure is formed, the turbulence dynamics drastically changes.

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