§13. Selective Formation of Turbulent Structures in Cylindrical Plasmas

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Turbulent plasmas form a variety of meso-scale structures such as a zonal flow and a streamer 1). A streamer, which is a localized vortex in the azimuthal direction, is generated by nonlinear wave coupling, and is sustained for a much longer duration than the oscillation period of micro instability. The turbulent structure affects the level of the anomalous transport in fusion plasmas by regulating micro-scale fluctuations, therefore, the formation and self-regulated mechanism of the turbulent structures should be taken into consideration to understand the transport processes. The structural formation mechanism and their selection rule have been studied by numerical simulations of resistive drift wave turbulence in magnetized cylindrical plasmas 2).

We have been developing a 3-D numerical simulation code called 'Numerical Linear Device' (NLD), which describes the resistive drift wave turbulence in a linear device 3). The three-field (density, potential and parallel velocity of electrons) reduced fluid model is adopted. The plasma has a simple cylindrical shape, and the magnetic field has only the component in the axial direction with the uniform intensity. According to experiments, high density ($n_e > 1\times10^{19}$[m^{-3}]) and low temperature ($T_e < 5$ [eV]) plasmas in an argon discharge are analyzed. The density of neutral particles is high even in the plasma core region, so the effect of neutral particles is taken into consideration.

A nonlinear simulation has been performed to examine the saturation mechanism of the resistive drift wave turbulence. The electron collisions destabilize and the ion-neutral collisions stabilize the resistive drift wave 3). The calculation with a fixed particle source has been carried out. In the nonlinear saturation states, two kinds of turbulent structures have been obtained 2); a zonal flow and a streamer. Selective formation of the turbulent structure can be identified by changing ion-neutral collision frequency ν_{in}, which represents the strength of the damping force of the zonal flow and the driving force of the drift wave instability. Figure 1 shows the dependencies of fluctuation energies of the potential on ν_{in} in nonlinear steady states. The energy components of (0, 0) mode, which is the zonal flow, and the sum of (4, 1) and (5, 1) modes, which form the streamer, are shown. The zonal flow amplitude is small and the streamer modes are excited when ν_{in} is smaller than the critical value. As ν_{in} is decreased, the zonal flow begins to be excited.

In the cases discussed here, there are two dominant energy exchange paths from $m \neq 0$ mode by mode coupling. One is that to (0, 0) mode to form the zonal flow, and the other is that to the mediator mode ((1, 2) in this case) to form the streamer. These two kinds of structural formation mechanisms are involved, but only one of the structures can appear in stationary states from their competitive nature. When the zonal flow is formed, the E × B shearing of the zonal flow breaks the phase locking of the modes, so the streamer is not formed, even though amplitudes of the modes are large.

The important role of the (1, 2) mode for the streamer formation is illuminated by controlling possible energy exchange paths. If the mediate mode (1, 2) is artificially removed after the saturation, the streamer is not sustained and only a single mode becomes dominant 2). Another calculation including modes with $m \neq 0$ and $n = 0$ also shows the selective formation of the streamer. Modes with $(m, n) = (\pm3, \pm1)$ and $(\pm4, \pm1)$ are dominant in this case, which form a streamer. To confirm which mode couplings are dominant in nonlinear energy transfer, the rate of energy exchange for (4, 1) mode is calculated. Among the couplings with $m \neq \pm4$ modes, couplings with neighbouring modes, such as $(4, 1) \leftarrow (3, -1) + (1, 2)$ or $(5, -1) + (-1, 2)$, are dominant for nonlinear mode excitation, as is the same in the case without $(m, 0)$ modes. The couplings mediated by $(m, 0)$ modes affect as damping of the mode, whose rate of energy exchange has the negative sign. It is found that the couplings mediated by (1, 2) mode is still most important for streamer formation. The streamer is sustained with balance of some nonlinear mode couplings, and is selectively formed with ν_{in} larger than the critical value, in spite of the other possible energy exchange paths.

Plasma experiments in a simple linear configuration have been carried out for quantitative understandings of the structural formation mechanism by turbulence 4). Our numerical simulations show spatio-temporal structures of the streamer, and have guided the experimental discovery of the streamer on LMD-U 5). In this way, our minimal model for analyzing the turbulent structural formation mechanism by mode coupling represents the selection rule of the structure.

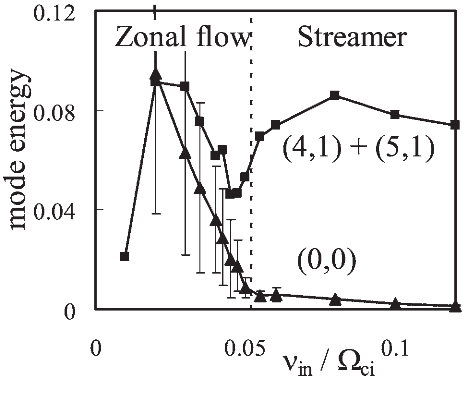

Fig.1: Dependencies of the fluctuation energies of the electrostatic potential on ν_{in} in nonlinear steady states.

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