§20. Global Simulation and Diagnostics of Plasma Turbulence

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It is important to clarify the role of turbulence structures for understanding transport mechanism in magnetized plasmas [1]. Global simulations, which solve entire plasmas including both core and edge regions, become possible by using recent high-performance computers. A turbulence diagnostic simulator (TDS) is combination of turbulence codes for global simulations and numerical diagnostic modules to simulate experimental measurements of plasma turbulence [2]. Numerical simulations can give three-dimensional turbulent fields, which represent fundamental phenomena in plasmas. In this research, we have been carrying out evaluations of the structural formation in plasmas, and here report results in this year using the global simulation codes for the torus and cylindrical configuration.

For the analysis in a torus plasma, drift-interchange modes are analyzed, using a reduced MHD model in helical plasmas [3]. To clarify the role of nonlinear couplings for evolution of mean profiles and fluctuations, details of the energy balance are analyzed [4]. Flux driven simulations with a fixed pressure source are carried out, which can study competition of formation of global modes, microscopic instabilities, nonlinear coupling with Reynolds stress, and collisional diffusion process. Analyses in both linear and nonlinear phases of the simulation are carried out. The following characteristics of the structural formation are identified. The evolution of the mean component (homogeneous in the poloidal and toroidal direction) includes an oscillation with rather smaller frequency compared to the turbulent time-scale. This oscillation is generated by coupling of $m = \pm 1$ modes (m is the poloidal mode-number), and accompanies with variation of the position of the magnetic axis. The global mode, which spreads widely in the radial direction, is linearly unstable, and its mode structure is modified by drive by nonlinear energy transfer between the other unstable modes. Figure 1 shows the radial profile of the energy balance of the global mode in the nonlinear saturated state. The nonlinear contribution is larger at r = 0.5 - 0.8, where several modes are excited to give the strong nonlinear effect [3]. In this region, the global mode does not generate the heat flux by itself. The microscopic instability is driven quasi-linearly, and the change of the fluctuation intensity and its turbulent heat flux follows the change of the pressure gradient. In this way, the structural formation mechanisms with the competition of multiple time-scales are clarified by the global simulation.

Nonlinear MHD simulations are also carried out taking account of 3-D magnetic configurations of helical plasmas [5]. Dependency of the nonlinear couplings for a relaxation process of high β plasmas is investigated by changing the magnitude of the heat diffusivity. The wavenumber spectrum and combination of mode couplings depends on the heat diffusivity to change the pressure profile in the saturated state.

For the analysis in a cylindrical plasma, the resistive drift wave turbulence is analyzed with the extended Hasegawa-Wakatani model [6]. In this year, understanding of the formation mechanism of solitary drift waves is progressing. A solitary drift wave is a nonlinear wave with a steep gradient. It is predicted theoretically that index Ξ, which represents the difference between the radial profile of the density and potential, is important to determine the shape of the nonlinear wave [7]. In the case with $\Xi > 0$, the steep gradient exists forward in the propagation direction, and vice versa. We have confirmed the relation between this criterion and solutions of numerical simulations, and have obtained both forward and backward bunching drift waves in accordance with the sign of Ξ [8]. More detailed parameter scans for the wave bunching is carried out in this year [9]. Linear analyses show the parameter dependencies on the magnetic field, length of the device, collisional diffusion coefficient and density gradient length of the resistive drift wave instability to give the condition for the solitary drift wave observed in the PANTA experiments. The background density profile is important to determine the position of the wave bunching. When the density profile has a large gradient in outer region, Ξ can become negative to give backward bunching in the region where the fluctuation has large amplitude as in the experiment. Systematic nonlinear simulations will reveal the structural formation mechanism including self-consistent nonlinear processes.

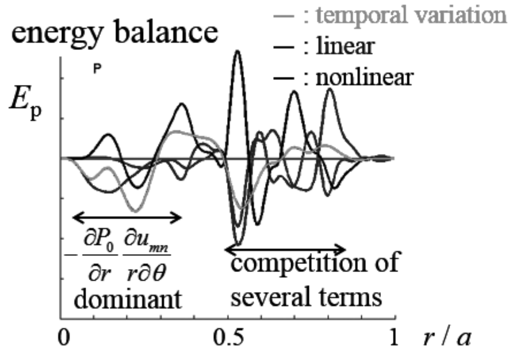

Fig.1: Radial profile of the internal energy balance of the global mode in the nonlinear saturated state of drift-interchange turbulence.

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