§28. Simulation Research of Plasma Turbulence and Diagnostics

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Turbulence in toroidal plasmas forms meso-scale structures, such as a zonal flow and streamer, and it is important to clarify the role of the turbulence structures on anomalous transport [1]. High resolution measurements of fluctuations have been carried out in experimental devices to make quantitative estimation of turbulent transport. Numerical simulations can give three-dimensional turbulent fields, which represent fundamental phenomena in plasmas, so the simulation data are suitable as a test field to carry out detailed analyses for comparison with experimental results. A turbulence diagnostic simulator (TDS) is combination of fluid turbulence codes and numerical diagnostic modules to simulate experimental measurements of plasma turbulence for that purpose [2]. We have been carrying out evaluations of the structural formation and turbulent transport, and here report results in this year using the simulation code for the helical, tokamak and cylindrical configuration.

For the analysis in a helical plasma, drift-interchange modes are analyzed, using a reduced MHD model [3]. To clarify the transport dynamics, response to active control with additional modulation is studied [4]. Characteristic response to the modulation is extracted by the conditional averaging. Rapid propagation of heat modulation and a hysteresis in the gradient-flux relation are found in a global nonlinear simulation. Figure 1 shows the relationship between the pressure gradient and heat flux at one radius. In the nonlinear saturated state, modes spreading broadly in the radial direction (global mode) and localized near their rational surfaces are both excited. The global mode is excited nonlinearly, and induces the turbulence flux in a limited radial region. The nonlinear couplings take a finite temporal duration for redistributing the energy. The mode also has a seesaw effect: increase of the amplitude of the global mode, at the other radii, works to absorb the energy form microscopic modes to suppress the turbulence. Successive excitations of microscopic modes cause the accelerated propagation of change of the heat flux like turbulence spreading after the onset of modulation. Owing to these processes, the hysteresis appears in the gradient-flux relation in the counter-clockwise, which is opposite to the experimental observation. Turbulence analyses using simulation data can give the insight for the physical mechanism in plasmas, so in future experiments, one can identify the radial profiles of the flux by the global mode itself and of the energy transfer from microscopic modes to the global mode revealed by the simulation.

For the analysis in a cylindrical plasma, the resistive drift wave turbulence is analyzed with the extended Hasegawa-Wakatani model [5]. In this year, the formation mechanism of solitary drift waves is the main object. 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 [6]. In the case with $\Xi > 0$, the steep gradient exists forward in the propagation direction, and vice versa. The relation between this criterion and the solutions of the numerical simulations is investigated [7]. Linear analyses show the parameter dependencies on the magnetic field, 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. It was found that the sign of Ξ can be changed with variation of the background density profile. When the density profile has a large gradient in outer region, Ξ can become negative. Then nonlinear simulations using NLD were carried out with that condition to obtain nonlinear wave bunching. The solitary drift wave is formed in the nonlinear simulations. In the simulation, a fixed particle source term is supplied to form the mean density profile self-consistently. From the linear analysis, the source profile is selected to shift the steep gradient of the background density to outer for wave bunching backward in the propagation direction. The forward and backward bunching is obtained in accordance with the sign of Ξ. The radial distribution of the bunching position is also observed in accordance with the radial profile of Ξ. Temporal variation is related to the nonlinear dynamics, which should be investigated in future.

Nonlinear gyrokinetic, bounce-averaged simulations have been performed to investigate the impact of granulations, which are clusters of particles correlated via precession resonance. The characteristic scales of granulation were obtained for the first time in a simulation. In addition, reduced simulations with a 1D model of an energetic particle-driven geodesic acoustic mode have been performed in the LHD. These simulations allow elucidating the mechanism of subcritical instability.

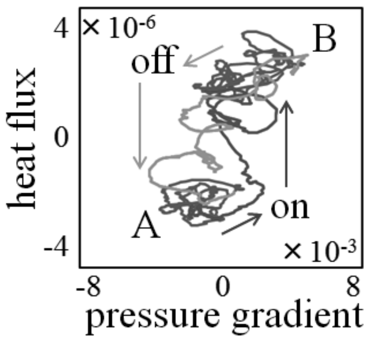

Fig.1: Hysteresis in local parameters. Relationship between the pressure gradient and heat flux at $r = 0.6$ is shown.

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