§15. Simulation Research of Plasma Turbulence and Diagnostics

Kasuya, N., Sasaki, M., Lesur, M., Kosuga, Y. (Kyushu Univ.), Sugita, S. (Chubu Univ.), Toda, S.

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. We have been developing a turbulence diagnostic simulator (TDS), which is the combination of fluid turbulence codes and numerical diagnostic modules to simulate experimental measurements of plasma turbulence [2]. In this year, evaluations of the structural formation and turbulent transport were carried out 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 are studied. A pressure source forms the profile peaked at the center and global simulations give long time series of three-dimensional turbulent fields. In the nonlinear saturated state, modes spreading broadly in the radial direction and localized near their rational surfaces are both excited. There is an experimental observation of global structures that spreads broadly in torus plasmas [4], which is one of the candidates to cause immediate transfer to separated positions. Owing to overlapping by the spreading modes, mutual couplings with several modes are possible. Pressure source modulation is applied on the nonlinear saturated state. Characteristic response to the modulation is extracted by the conditional averaging. It is found that fluctuations in wide range of frequency and heat fluxes show the immediate response at different radii. The response time is determined by the characteristic time of the turbulence, which is much shorter than that of the diffusion time. Nonlinear energy transfer rate is evaluated to show multiple interactions of excited modes in the case with radially-spread modes [3]. The dynamics of their radial profiles reveal the mechanism of propagation to separated radial locations. In this way, turbulence analyses using simulation data can give the insight for the physical mechanism in plasmas.

For the analysis in a cylindrical plasma, the resistive drift wave turbulence is analyzed with the extended Hasegawa-Wakatani model [5]. The selection rule of formation of several turbulent states, as the zonal flow, streamer, flute structure and solitary vortex, has been studied [6]. The streamers are characterized to be formed by nonlinear processes, and localized in the poloidal direction and elongated in the radial direction. In this case, linearly unstable drift waves show the coherent peaks in the spectrum. The instantaneous frequency is evaluated to identify the role of the modes. Dominant drift waves are coherent, and have frequency with small variances. They propagate in the electron diamagnetic direction. The mediator mode has small but finite frequencies, which satisfies the frequency matching condition with the unstable drift waves. The deviation of the frequency matching is shown in Fig. 1. The frequency of the mediator satisfies the frequency matching, when the streamer is formed. In the smaller collision frequency cases, the frequency matching is broken, where the zonal flow and the flute type structure dominate the system, and the streamer does not exist. In this way, the frequency matching of the mediator with the drift waves characterizes the streamer state. Dynamical response of the streamer near a critical condition where the streamer disappears is investigated. The gradual change of the global control parameter is given to the plasma. When the control parameter approaches the critical condition, the phase mismatch between the drift waves (which form the streamer) and the mediator mode increases abruptly, finally loosing the nonlinear matching condition. The eigenmode is also modified after the transition from streamer to the other state occurs. The phase relation is much sensitive compared to the change of amplitude, and could be observed even by a one-point measurement.

The development of a new code for the trapped-ion-mode, which is driven by resonance with the precession motion of trapped ions, has been also carried out to study kinetic nonlinearities and phase-space structures in toroidal plasmas. The conservation properties and parallelization performances of the code were checked, and the linear growthrate is verified against theory.

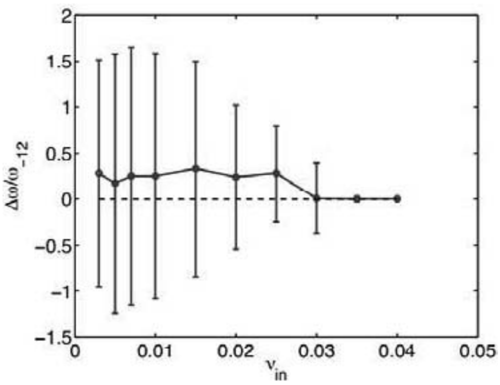

Fig.1: Dependency of the frequency matching in three-wave coupling on the collision frequency. This value is zero, when the frequency matching is satisfied.

1) Diamond, P. H. et al.: Plasma Phys. Control. Fusion **47** (2005) R35.
2) Kasuya, N. et al.: Plasma Sci. Technol. **13** (2011) 326.
3) Kasuya, N. et al.: Plasma Fusion Res. **8** (2013) 2403070.
4) Inagaki, S. et al.: Phys. Rev. Lett. **107** (2011) 115001.
5) Kasuya, N. et al.: Phys. Plasmas **15** (2008) 052302.
6) Sasaki, M. et al.: J. Phys. Soc. Conf. Proc. **1** (2014) 015011.