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Gyrokinetic simulation study on ITG turbulent transport in LHD experiment
LHD実験におけるITG乱流輸送のジャイロ運動論的シミュレーション研究

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Gyrokinetic simulations are applied for ion temperature gradient (ITG) turbulent transport in the discharge of Large Helical Device (LHD) experiment with high ion temperature. In the discharge, the microturbulence spatial profiles are precisely measured by phase contrast imaging (PCI) method where the measured fluctuations show some characteristics of the ITG instabilities. In the gyrokinetic nonlinear simulations for the investigation of the turbulent transport triggered by the ITG modes and zonal flow generations in the LHD experiment, we applied the GKV-X code which incorporates full geometrical effects of non-axisymmetric field configuration corresponding to the discharge. The simulation results can reproduce the turbulent transport levels comparable to the experimental results. Furthermore, the resultant transport levels at different flux surfaces are expressed in terms of a simple relation between the transport coefficient and the ratio of the squared turbulent potential fluctuation to the averaged zonal flow amplitude.

1. Introduction

In the last decade, large number of gyrokinetic simulation studies has presented many significant results for the anomalous transport which is one of critical issues in fusion plasma researches. In order to improve plasma confinement, it is very important to reduce the resultant transport levels that are caused by competitive effect of zonal flows and microinstabilities such as the ion temperature gradient (ITG) modes. Nowadays, direct comparison of numerical results of gyrokinetic simulations with experimental data is strongly demanded. For non-axisymmetric systems such as Large Helical Device (LHD) [1], however, there are not many studies for validation of gyrokinetic simulation, although studies in tokamaks have been extensively done to investigate turbulent transport (for example, Ref. [2]). The present study is devoted to apply the gyrokinetic simulations to evaluate the saturation levels of the turbulent fluctuations, zonal flows, and ion heat transport in the LHD discharge.

2. Ion heat transport and fluctuation spectra

In the LHD high ion temperature discharge #88343 [3], the density fluctuations measured by phase contrast imaging (PCI) method [4] have large amplitudes for the radial positions and the poloidal wavenumbers which correspond to ITG modes having large growth rates obtained from the linear gyrokinetic simulations [5]. Applying the gyrokinetic Vlasov flux-tube code GKV-X [6], in

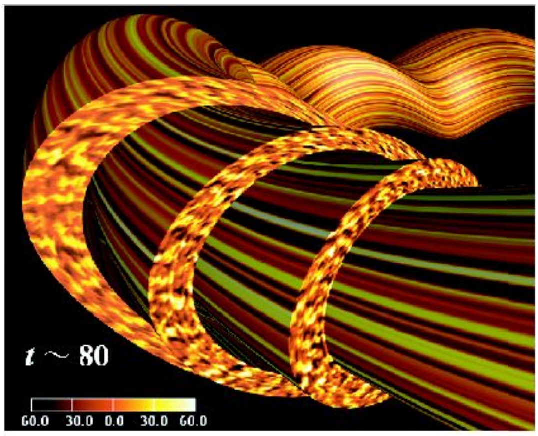

Fig.1 Color contours of the perturbed electrostatic potentials obtained from GKV-X simulations in the LHD high ion temperature discharge at three different flux-surfaces. The plots show the snapshots at $t = 80\ R_0/v_{ti}(\rho=0.65)$.

present work, nonlinear flux-tube ITG turbulence simulations are performed at different three flux-surfaces in the discharge as shown in Fig.1. Figure 2 shows the comparison results of the ion heat flux obtained from the simulations and the LHD experimental observation. The simulation results are 15–50 % lower than that in the experimental values which include both the anomalous and neoclassical contributions to the transport. If the neoclassical part is subtracted from the experimental values, the simulation results agree well with the anomalous part of experimental results. The wavenumber spectra of the turbulent

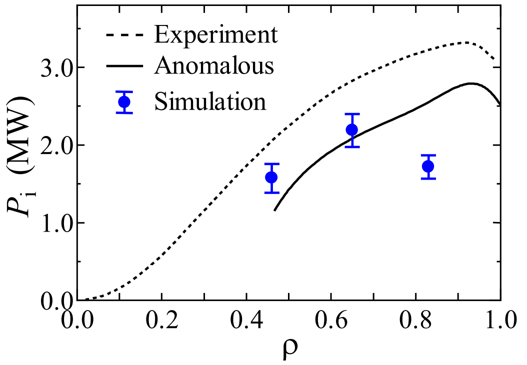

Fig.2 Ion heat flux obtained from the LHD experiment (dotted curve) and the GKV-X simulations (open squares). The solid line represents the anomalous part of the experimental result.

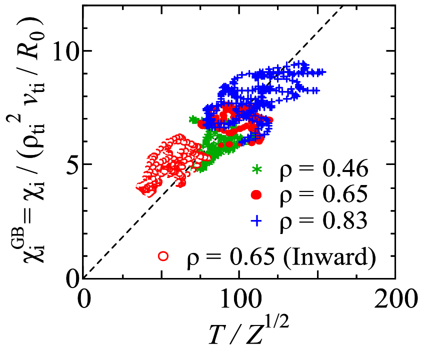

Fig.4 Lissajous plots of the ITG turbulence simulations of the saturated phase in ($T/Z^{1/2}$, χ_i) space for the experimental case at three different flux-surfaces and the inward-shifted LHD case.

density fluctuation obtained from the PCI measurement and the simulations are shown in Fig.3. Both spectra have a peak in a low wavenumber region and similar shape in a high wavenumber region. The reasonable agreements between the LHD experiment and the simulations strongly encourage us to pursue the gyrokinetic simulation studies for the anomalous transport in non-axisymmetric systems.

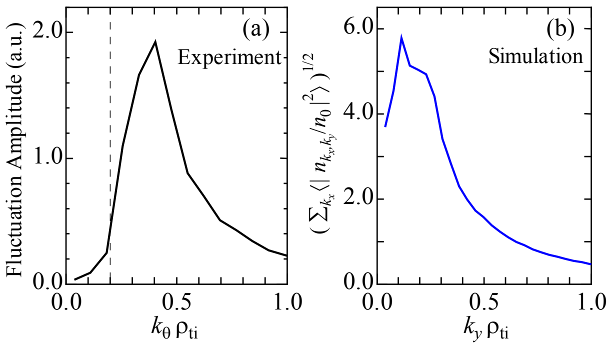

Fig.3 Wavenumber spectra for the fluctuation amplitude obtained from (a) the experiment and (b) the GKV-X simulation. The dashed line in (a) represents the cutoff of the PCI measurement.

3. Relation between transport level, turbulent fluctuation and zonal flow amplitude

The ITG turbulent transport is considered to be determined by the interaction between turbulence and zonal flows. Figure 4 shows the Lissajous plots of the ITG turbulence simulations for the ion heat diffusivity χ_i^{GB} in the gyro-Bohm unit and the ratio of the squared turbulent potential T to the zonal flow amplitude $Z^{1/2}$. In the plots, we also show the simulation result in the vacuum field configuration with more inward shifted magnetic axis than the experimental case, which is one of the optimized configurations to reduce neoclassical transport [7].

While the transport level in the inward-shifted case is lower than the experimental case, which is consistent with our previous work [8], all plots including the case of inward-shifted configuration are well represented by a simple relation $\chi_i^{GB} \propto T/Z^{1/2}$ despite of the fact that a wide range of conditions for the different flux-surfaces and the inward-shifted case are included here. Therefore, we expect that this newly obtained result can contribute to anomalous transport modeling in helical plasmas.

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References

[1] A. Komori *et al.*, Fusion Sci. Technol. **58** (2010), 1.
[2] T. L. Rhodes *et al.*, Nucl. Fusion **51** (2011), 063022.
[3] K. Tanaka *et al.*, Plasma Fusion Res. **5** (2010), S2053.
[4] K. Tanaka *et al.*, Rev. Sci. Instrum. **79** (2008), 10E702.
[5] M. Nunami *et al.*, Plasma Fusion Res. **6** (2011), 1403001.
[6] M. Nunami *et al.*, Plasma Fusion Res. **5** (2010), 016.
[7] S. Murakami *et al.*, Nucl. Fusion **42** (2002), L19.
[8] T.-H. Watanabe *et al.*, Phys. Rev. Lett. **100** (2008) 195002.