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ヘリカル・プラズマにおけるイオン温度勾配乱流輸送
Ion Temperature Gradient Turbulent Transport in Helical Plasmas

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The anomalous transport has been considered to be one of the most critical issues in magnetically confined fusion plasma researches. In the last decades, large number of gyrokinetic simulation studies has presented many significant results for the anomalous transport physics. In order to improve plasma confinement, it is very important to reduce the resultant levels of the turbulent transport that are mainly caused by the micro-instabilities such as the ion temperature gradient (ITG) instability. Nowadays, according to great progress of the computational resources, direct comparisons of numerical simulation results by the gyrokinetic approaches with experimental data are strongly demanded. While the studies in tokamaks have been extensively done to analyze turbulent transport (for example, Ref. [1]), there are not many studies for non-axisymmetric systems such as the Large Helical Device (LHD) [2] to validate the gyrokinetic simulation with the experimental results.

To demonstrate the comparisons between the simulations and experiments in non-axisymmetric systems, we focus on the LHD high ion temperature discharge #88343 [3] and we employ the gyrokinetic Vlasov flux-tube code GKV-X [4] which is applicable to treat three-dimensional field configurations. In the experiment, the density fluctuations measured by two-dimensional phase contrast imaging (2D-PCI) method [5] have large amplitudes for the radial positions and the poloidal wavenumbers which correspond to the linear ITG instabilities having large growth rates obtained from the linear gyrokinetic analysis [6]. Applying the GKV-X to the discharge, nonlinear ITG turbulent transport simulations are performed [7]. Figure 1 shows a snapshot of the perturbed electrostatic potentials obtained from the GKV-X simulations in the discharge. The comparison results of the ion heat flux obtained from the simulations and the LHD experimental observation

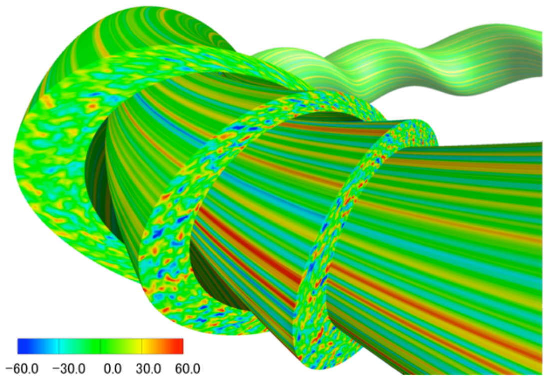

Fig. 1 Color contours of the perturbed electrostatic potentials obtained from GKV-X simulations in the LHD high ion temperature discharge at three different flux-surfaces, ρ=0.46, 0.65 and 0.83. The plots show the snapshots at $t = 60R_0 / v_{ti}$ (ρ=0.65).

are plotted in Fig. 2. The simulation results are about 15–50% lower than the experimental results that includes not only the anomalous part but also neoclassical contribution part to the total transport. If the neoclassical part of the contributions is subtracted from the total experimental observations, it can be confirmed that the simulation results agree well with the anomalous part of experimental results. The wavenumber spectra of the turbulent density fluctuation obtained from the PCI measurement and the simulations are also compared. Both spectra have a peak in a low wavenumber region and similar shape in a high wavenumber region. These reasonable agreements about the heat flux and the turbulent spectrum between the LHD experiment and the GKV-X simulations strongly encourage us to pursue the gyrokinetic simulation studies for the anomalous transport phenomena in the helical or non-axisymmetric systems.

In general, the resultant turbulent transport is determined by the interaction between turbulence fluctuations and zonal flows. In our simulations, it

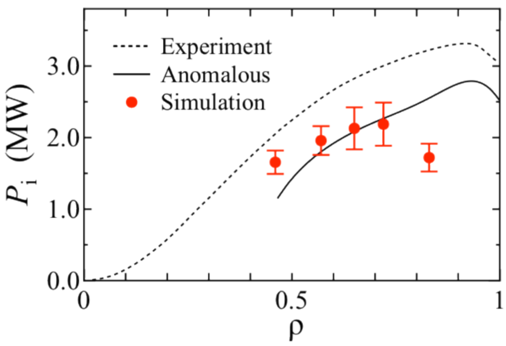

Fig. 2 Ion heat flux obtained from the LHD experiment (dotted curve) and the GKV-X simulations (open squares). The solid line represents the anomalous part of the experimental result.

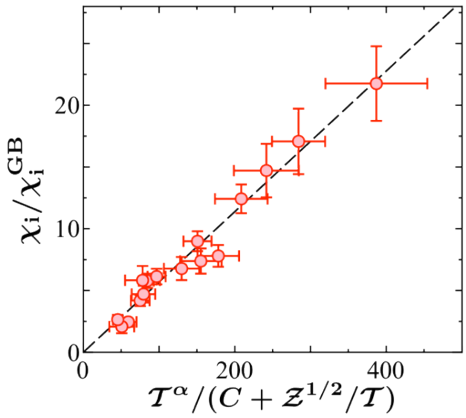

Fig. 3 Ion heat diffusivity in the gyro-Bohm unit χ_i/χ_i^{GB} versus the function of the squared turbulent potential $\mathcal{T}$ and the squared zonal flow potential $\mathcal{Z}$.

is confirmed the spectral transfer of the fluctuations into higher radial wavenumber region which is considered to be induced through the interaction between the zonal flow and the turbulence as discussed in Ref. [8]. In Fig. 3, by means of many GKV-X simulation data, the correlations of the ITG turbulent transport levels on the function of the squared turbulent potential fluctuation $\mathcal{T} \equiv (1/2)\sum_{k_x,k_y\neq 0}\langle|\tilde{\phi}_{k_x,k_y}|^2\rangle$, and the squared zonal flow potential, $\mathcal{Z} \equiv (1/2)\sum_{k_x}\langle|\tilde{\phi}_{k_x,0}|^2\rangle$, are examined. Here, average along the field line is denoted by $\langle\cdots\rangle$. One finds that the normalized ion hear diffusivity, χ_i/χ_i^{GB}, has strong correlation with $\mathcal{Z}$ and $\mathcal{T}$. In the plots, we also include the simulation results 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 [9]. Thus, all plots including the case of inward-shifted configuration are well represented by the simple relation despite of the fact that a wide range of conditions for the different flux surfaces, different field configurations, and different temperature/density gradient lengths are included here. Therefore, we expect that this obtained result can contribute to anomalous transport modeling in helical plasmas. In fact, the nonlinear variables $\mathcal{T}$ and $\mathcal{Z}$ are correlated with the linear growth rates of the ITG mode and the linear response function of the zonal flow potential. Using the linear analyses, we can construct the ITG turbulent transport model in the helical plasmas. The details of the numerical modeling and current issues of the turbulent transport simulations will be reported at the meeting.

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