§12. Development of Gyrokinetic Turbulent Transport Simulation with Realistic Tokamak MHD Equilibrium and its Application to JT-60U Plasma

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Exploring physics behind turbulent transport and predicting quantitatively the resultant transport levels are central issues for the establishment of self-ignited steady burning plasmas in future fusion devices such as ITER/JT-60SA and DEMO. First-principle based gyrokinetic simulation is a promising method for such issues, and the local-model approach is applicable to the future large devices of which a local limit condition ($a/\rho_i >> 300$, a: plasma size, ρ_i: ion thermal gyroradius) is well satisfied.

In this study, a realistic tokamak equilibrium is incorporated to a local fluxtube gyrokinetic code GKV[1] using a newly developed interface code IGS[2], and then the prediction capability on turbulent transport levels is examined through quantitative comparisons with existing tokamak experiments.

The realistic MHD equilibria including up-down asymmetry is produced by a free-boundary 2D Grad-Shafranov equation solver MEUDAS or by an integrated transport code TOPICS. By using IGS code, two dimensional rectangular equilibrium data is, then, converted to the straight-field-line flux coordinates such as Hamada, Boozer, and axisymmetric coordinates, which are useful for gyrokinetic micro-instability and turbulent transport analyses. The extended codes have been verified by a cross-code benchmark test using Cyclone-base-case like MHD equilibrium, where good agreement in the dispersion relation of ITG driven mode has been confirmed[2].

The extended GKV is applied to JT-60U tokamak experiments. In view of validations towards future large devices, an L-mode plasma[3] [Figs. 1] with near-local-limit normalized plasma size $a/\rho_i \sim 500$ is considered, where global profile shear effects are negligibly small. The inclusion of fully gyrokinetic ions and electrons beyond the conventional adiabatic approximation reveals a transition of micro-instability from ITGs (inner core region) to TEMs (outer core region) depending on radial positions, and the resultant heat and particle transport levels are examined[Figs. 2]. As shown in Figs. 3, the ITG-TEM turbulence simulations with GKV show good agreement against the experimental results on the ion and electron heat diffusivities in the core region, where a gyrofluid-based transport model TGLF shows relatively larger deviations. Also, different nonlinear dependences of the zonal flow energy on the ion/electron heat and particle transport levels are identified, i.e., weaker impact on the electron heat and particle transport compared to the ion heat one. These findings on the quantitative agreement among turbulence simulations and experimental results, as well as on the related zonal flow dynamics, contribute to an improvement of the prediction capability of gyrokinetic simulations and to a more accurate heat and particle transport modeling.

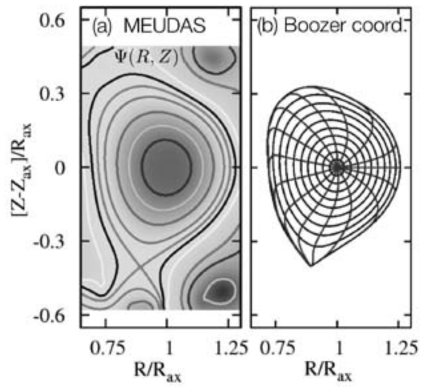

Fig. 1 (a)JT-60U L-mode equilibrium(shot# E45072). (b) Corresponding Boozer coordinates produced by IGS.

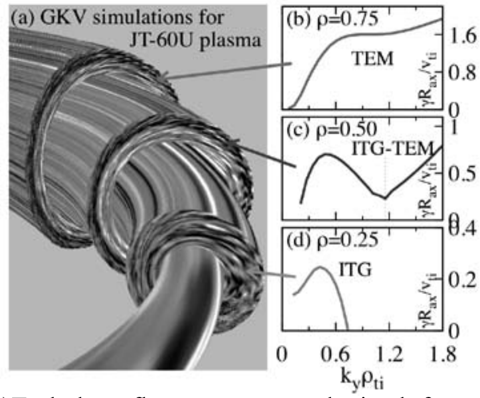

Fig. 2 (a)Turbulent flow structures obtained from GKV simulations with JT-60U equilibrium. [(b), (c), (d)] TEM/ITG-TEM/ITG mode growth rates on ρ=r/a=0.75, 0.50, 0.25, respectively.

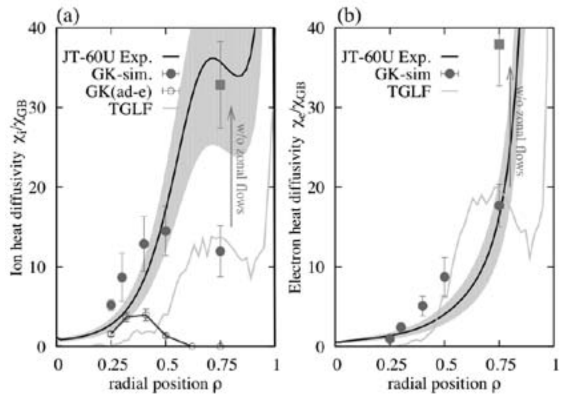

Fig. 3 Comparison between turbulence simulations and experimental measurements on (a)ion and (b)electron heat diffusivities.

1) Watanabe, T. -H. et al.: Nucl. Fusion **46** (2006) 24.
2) Nakara, M. et al.: Plasma Fusion Res. **9** (2014) 1403029.
3) Yoshida, M. et al.: Plasma Phys. Control. Fusion **48** (2006) 1673