§32. Numerical Simulation of Turbulent Transport and Structure Dominated by Multi-scale Interaction in Fusion Plasma

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Turbulent transport in magnetically confined fusion plasmas exhibits various prominent features characterized by different time and spatial scales. Zonal modes, such as zonal flow and pressure, which are poloidally and toroidally symmetric macro-scale structures nonlinearly generated from micro-scale turbulence, are found to play an important role, regulating turbulent transport and structure.

In order to investigate such dynamics, we extend the entropy balance equation [1-2] by keeping the dynamics in radial direction given as

$$\frac{\partial}{\partial t}\int s^{(2)} dZ^3 + \frac{\partial}{\partial x}\int\left(-\frac{\partial \Phi}{\partial y}\right) s^{(2)} d^3Z + \frac{\delta U_{(0,0)}}{2L_T} - \frac{\delta Q_{(0,0)}}{2TL_T} = 0\,, \tag{1}$$

where $d^3Z = dydzdv_{\|}$, $L_T(x) = -\partial_x \ln T(x)$ and the periodic boundary conditions are employed in y and z directions. Phase space entropy $s^{(2)}$ are defined by $s^{(2)} \equiv -\delta f^2 / 2f_0$, where f_0 and $\delta f = f - f_0$ are the Maxwellian distribution function and its perturbed part, respectively. $\delta U_{(0,0)}$ and $\delta Q_{(0,0)}$ represent the density and heat flux. It should be noted that $\delta Q_{(0,0)}$ corresponds to the entropy source, and $\delta U_{(0,0)}$ is equivalent to the production rate of zonal flow.

We have investigated the entropy dynamics in ion temperature gradient (ITG) and electron temperature gradient (ETG) driven turbulence by using the global gyrokinetic Vlasov simulation in slab geometry. Figure 1 shows the spatial profiles of the first (EP2), second (EC2), third (DF2) and fourth (HF2) terms in the right hand of Eq. (1) in the cases with (a) $L_T = 37$ and (b) $L_T = 148$ in ITG turbulence and (c) $L_T = 148$ in ETG turbulence, respectively. The temperature profile is also illustrated.

It is found that the relaxation is dominated by avalanche-like front propagation in the ITG turbulence with steep temperature gradient (Fig. 1 (A)). The perturbed entropy convection, which corresponds to turbulent spreading, plays an important role. On the other hand, in the ITG case with gentle gradient, the second order heat flux shows a strong correlation with the zonal flow production and then a self-organized relaxed state is established, which is characterized by a spatially corrugated short wavelength zonal pressure (Fig. 1 (B)). We found that the wave number and phase of the zonal pressure are regulated by the zonal flow shear. The contribution of the zonal flow becomes weak in the ETG case, as can be seen from Fig. 1 (C), and the global profile relaxation can take place.

Thus, the zonal flow plays an important role to regulate the turbulent transport in the ITG turbulence, depending on the temperature scale length. The global scale length may be determined by source and sink terms, which needs to be further investigation in future.

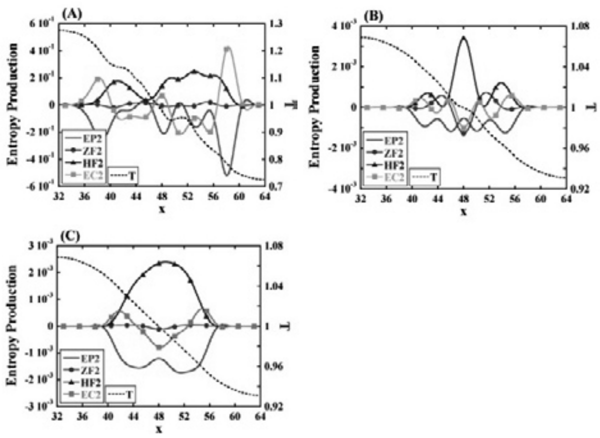

Fig. 1: Spatial profile of each term of Eq. (1) in the cases with (a) $L_T(x) = 37$ and (b) $L_T(x) = 148$ in ITG turbulence and (c) $L_T(x) = 148$ in ETG turbulence. The temperature profile is also illustrated.

[1] K. Imadera, Y. Kishimoto and J. Q. Li, J. Plasma Fusion Res. **5** (2010) 019.
[2] K. Imadera, Y. Kishimoto, J. Q. Li and T. Utsumi, J. Plasma Fusion Res. **5** (2010) S2050.