Gyrokinetic study of the local entropy dynamics in turbulent plasmas with zonal flow

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It has been recognized that turbulent driven heat flux balances with entropy production in both transient and quasi-steady state [1, 2]. On the other hand, the effect of zonal flows which play an important role for turbulent transport is not explicitly appeared in the entropy balance equation, since the entropy is a scalar quantity integrated over whole phase space. In order to investigate the relation between turbulent transport and zonal flows from the view point of entropy production, we have introduced the local entropy balance equation given as

$$\int \left\{ \frac{\partial \delta s}{\partial t} - \frac{\partial}{\partial x}\left(\frac{\partial \Phi}{\partial y}\delta s \right) - \frac{\partial \Phi}{\partial y}\frac{v_{\parallel}^2}{T}\delta f + \frac{\partial \Phi}{\partial y}\delta f + \frac{\partial \Phi}{\partial z}\frac{v_{\parallel}}{T}\delta f + \frac{\partial \Phi}{\partial z}\frac{v_{\parallel}}{T}\delta s \right\} d^3 Z = 0 \quad (1)$$

where $\delta s = \delta f^2 / 2 f_0$ is the local entropy perturbation and $\int d^3 Z = \int_{-\infty}^{\infty}\int_0^{L_z}\int_0^{L_y} dydzdv_{\parallel}$. The first and second terms in Eq. (1) denote the local entropy production and its convection, respectively. The third term is the heat flux, and the fourth one describes the vorticity flow, which directly relates to the zonal flow production via the Gyrokinetic Poisson and the Hasegawa-Mima equations.

We have performed the gyrokinetic full-f Vlasov simulation of the slab ITG turbulence and investigated the local entropy dynamics based on Eq. (1). Here, we have divided Eq. (1) into two parts as $\int d^3 Z = \int d^3 Z^L + \int d^3 Z^H$, where $\int d^3 Z^L = \int_{-1}^{1}\int_0^{L_z}\int_0^{L_y} dydzdv_{\parallel}$ and $\int d^3 Z^H = \int_{-\infty}^{-1}\int_0^{L_z}\int_0^{L_y} dydzdv_{\parallel} + \int_1^{\infty}\int_0^{L_z}\int_0^{L_y} dydzdv_{\parallel}$ are the integration over low-velocity and high-velocity regions, respectively.

Fig. 1 shows the profile of the Lagrange derivative of local entropy perturbation, zonal flow production and heat flux in (a)low-velocity and (b)high-velocity regions. It is found that the above three components balance with each other in both regions. From Fig. 1 (a), the local entropy with low velocity induces the zonal flow, whereas the local entropy with high velocity triggers the heat flux and suppress the zonal flow, as shown in Fig. 1 (b).

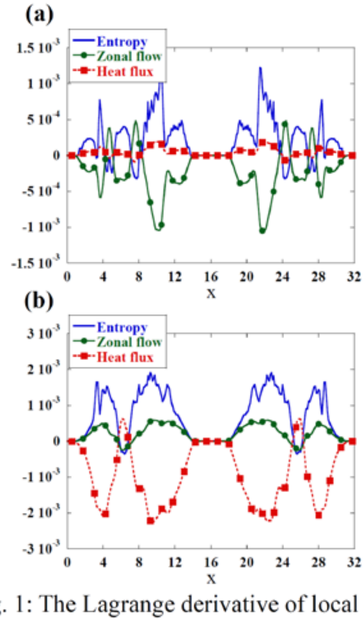

Fig. 1: The Lagrange derivative of local entropy perturbation, zonal flow production and heat flux in (a) low velocity and (b) high velocity regions.

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