§14. Effects of TEM-driven Zonal Flow on ETG Turbulence

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Turbulent transport caused by electron temperature gradient (ETG) modes was investigated by means of gyrokinetic simulations. It was found that the ETG turbulence can be regulated by meso-scale zonal flows driven by trapped electron modes (TEMs) which are excited with much smaller growth rates than those of ETG modes. The zonal flows of which radial wavelengths are in between the ion and electron banana widths are not shielded by trapped ions nor electrons, and hence they are effectively driven by the TEMs. It was also shown that an $\mathbf{E} \times \mathbf{B}$ shearing rate of the TEM-driven zonal flows is larger than or comparable to the growth rates of long-wavelength ETG modes and TEMs which make a main contribution to the turbulent transport before excitation of the zonal flows. [1).]

To clarify the effect of TEMs on ETG turbulence, we performed gyrokinetic simulations employing the adiabatic and kinetic ion models. The adiabatic ion model gives the pure ETG turbulence, whereas the kinetic ion model produces the ETG-TEM turbulence. Simulation results from the kinetic and adiabatic ion models would reflect the effects of trapped electron modes.

Figure 1 shows time-histories of the energy flux obtained by the adiabatic and kinetic ion models. The initial increase in the energy transport caused by the linear growth of ETG modes is almost the same for the two cases as well as their saturation levels $\left[Q_{\mathrm{e}} \sim 40 v_{\mathrm{te}} T_{\mathrm{e}} \left(\rho_{\mathrm{te}}/L_n\right)^2\right]$ until $t = 900\,(L_n/v_{\mathrm{te}})$. After $t = 1050\,(L_n/v_{\mathrm{te}})$, one finds a significant drop in the energy transport in the kinetic ion case, where the energy flux is reduced to $\left[Q_{\mathrm{e}} \sim 10 v_{\mathrm{te}} T_{\mathrm{e}} \left(\rho_{\mathrm{te}}/L_n\right)^2\right]$ which is a quarter of the early saturation level. In contrast, the transport level in the adiabatic ion case remains high $\left[Q_{\mathrm{e}} \sim 30 v_{\mathrm{te}} T_{\mathrm{e}} \left(\rho_{\mathrm{te}}/L_n\right)^2\right]$ during the whole simulation time, although the transport level slowly decrease with time due to the weak zonal flow generation. However, the transport reduction in the adiabatic ion case is quite limited compared to the kinetic ion case. The lower transport level in the kinetic ion case can be explained by the stronger zonal flow generation after $t = 1050\,(L_n/v_{\mathrm{te}})$ as shown in Fig. 2.

Through the analysis of mode structure of the electrostatic potential, it turns out that the strong zonal flow in the kinetic ion case is driven by the TEM whose growth rate is much smaller than a typical ETG mode. Then, the zonal flow driven by TEM regulates long-wavelength ETG modes in addition to TEMs, leading to the reduction of the electron energy transport (Fig. 1). By contrast, in the adiabatic ion case, the linearly stable TEM dose not grow and thus zonal flows are not strongly produced. As a consequence, the transport level in the adiabatic ion case remains high compared to the kinetic ion case.

It also turned out that the $\mathbf{E}\times\mathbf{B}$ shearing rate of the TEM-driven zonal flow is comparable with the growth rates of long-wavelength ETG modes and TEMs which are responsible for the electron energy transport in the nonlinear simulations. These estimations are consistent with the nonlinear simulations, wherein the TEM-driven zonal flows regulate the long-wavelength ETG and TEM fluctuations and lead to the reduction of turbulent electron energy transport.

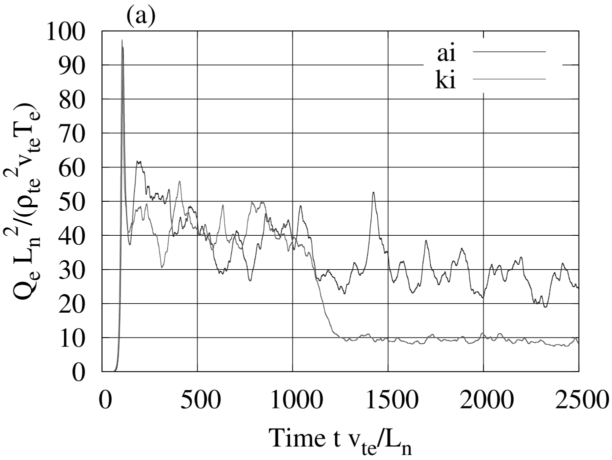

Fig. 1: The time evolution of electron energy flux, estimated by adiabatic ion model (blue dashed line) and kinetic ion model (red line)

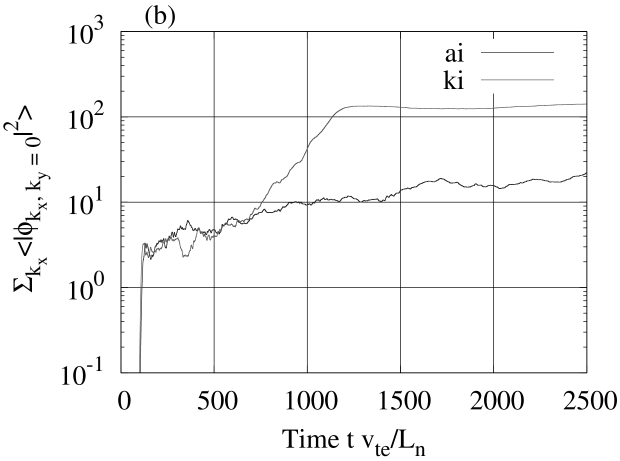

Fig. 2: The time evolution of the zonal flow amplitude, estimated by adiabatic ion model (blue dashed line) and kinetic ion model (red line)

1) Y. Asahi, A. Ishizawa, T.-H. Watanabe, et.al., Physics of Plasmas **21**, 055905 (2014).