§17. Gyrokinetic Simulations of Ion Temperature Gradient Turbulence with Kinetic Electrons

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Ion temperature gradient (ITG) driven turbulence is investigated by means of gyrokinetic simulations which include both kinetic ions and electrons in slab geometry with uniform equilibrium magnetic field. The entropy variable is transferred from ions to electrons through the perturbation of electrostatic potential, and the transferred fluctuation is diffused by the electron collision dissipation. In the ITG turbulence with kinetic electrons ion heat diffusion is larger than that with adiabatic electrons. The former is close to the latter when the ion mass is comparable to or larger than the hydrogen one.

We have constructed a gyrokinetic simulation code including both kinetic ions and electrons in slab geometry and studied the effects of kinetic electrons on slab ITG driven turbulence. Figure 1 shows time evolution of each term in the entropy balance equation for the mass ratio $m_i/m_e = 1836$. Since the turbulence is driven by ITG, the terms from the equation of ion distribution function are much larger than those from the electron equation. The ion heat flux Q_i nearly balances with ion collision diffusion D_i in the quasi-steady state $t > 500$. We remark that the particle flux Γ_i is finite because of kinetic electrons, but it is small. The electron particle flux Γ_e is also small and similar to Γ_i, and does not balance with the electron collision diffusion D_e. Thus, the electron entropy variable exchange $R_e = d\delta S_e/dt - \eta_e Q_e - \Gamma_e - D_e$ is positive. This R_e balances with the ion entropy variable exchange $R_i = d\delta S_i/dt - \eta_i Q_i - \Gamma_i - D_i$ which is negative. The sum of them $\sum_s R_s$ and the potential energy term dW/dt completely balances, and hence the entropy balance equation is satisfied. The balance between R_i and R_e implies that the perturbation of electrostatic potential due to ITG fluctuates the electron distribution, and thus the entropy variable is transferred from ions to electrons. The transferred fluctuation is almost dissipated by the electron collision diffusion, $R_e - D_e \approx 0$, because fine-scale structures of electron distribution function in the velocity space are generated by the convection in the phase space. Figure 2 shows the mass ratio dependence of the time-averaged ion heat transport coefficient in the radial direction $\chi_i = Q_i/\eta_i$ which is normalized by the gyro-Bohm coefficient. The coefficients χ_i with the kinetic electrons are larger than that with the adiabatic electrons, but is close to the latter when the mass ratio is large.

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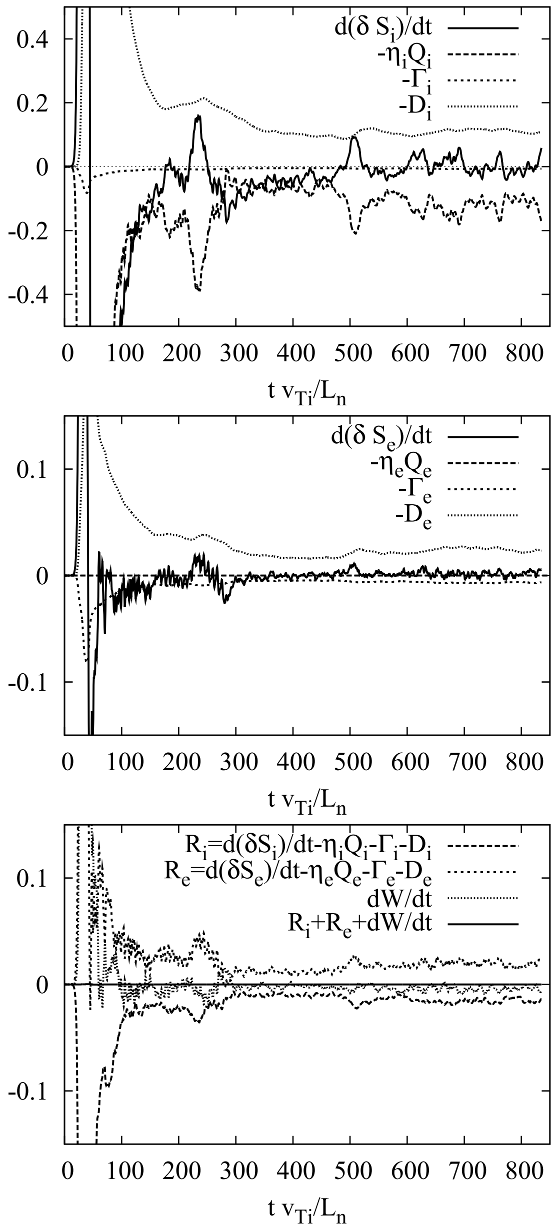

Fig. 1: Time evolution of each term in the entropy balance equation for the mass ratio $m_i/m_e = 1836$.

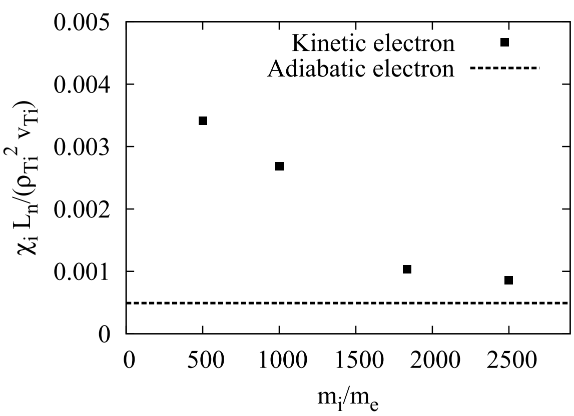

Fig. 2: Time-averaged thermal transport coefficient as a function of the mass ratio m_i/m_e.