§17. Application of the Kinetic-Fluid Model to ITG- and ETG-Mode-Driven Zonal Flows

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The kinetic-fluid model is used to study time evolution of zonal flows driven by either ion or electron temperature gradient (ITG or ETG) turbulence [1].

We first consider the wave-number region $k_\perp a_i < 1$ ($a_i \equiv \sqrt{T_i/m_i}/\Omega_i$). In order to determine the zonal flow driven by the ITG turbulence source, we use the ion kinetic-fluid equations for ions and the quasineutrality condition which is given by

$$e^{-b_i/2}\left(\frac{\delta n^{(\mathrm{g})}_{i\mathbf{k}_\perp}}{n_0} - \frac{b_i}{2}\frac{\delta T_{i\perp\mathbf{k}_\perp}}{T_i}\right) - \frac{e\phi_{\mathbf{k}_\perp}}{T_i}\left[1-\Gamma_0(b_i)\right] = \frac{e}{T_e}\left(\phi_{\mathbf{k}_\perp} - \langle\phi_{\mathbf{k}_\perp}\rangle\right).$$

Here, we consider large-aspect-ratio tokamaks, in which flux surfaces have concentric circular cross sections. The magnetic-field strength is written as $B = B_0(1-\epsilon\cos\theta)$ with $\epsilon \equiv r/R_0 \ll 1$, where R_0 denotes the distance from the toroidal major axis to the magnetic axis, r is the minor radius, and θ is the poloidal angle. Time evolution of the zonal-flow potential is shown in Fig. 1(a) for $q = 1.5$, $\tau_e \equiv T_e/T_i = 1$, $\epsilon = 0.1$, and $k_r a_i = 0.131$. Here, solid circular symbols and solid curves correspond to results from the gyrokinetic simulation and those from the fluid simulation, respectively, and the horizontal dashed line represents the residual zonal-flow level predicted by Rosenbluth and Hinton [2],

$$\frac{\phi_{\mathbf{k}}(t)}{\phi_{\mathbf{k}}(0)} = \frac{1}{1+1.6q^2/\epsilon^{1/2}}.$$

The initial condition is given by $\delta f^{(\mathrm{g})}_{i\mathbf{k}_\perp}(0) = (\delta n^{(\mathrm{g})}_{i\mathbf{k}_\perp}(0)/n_0)F_{e0}$ with $\delta n^{(\mathrm{g})}_{i\mathbf{k}_\perp}(0)/n_0 = [1-\Gamma_0(b_i)]e\phi_{\mathbf{k}_\perp}(0)/T_i$. We see a good agreement between the gyrokinetic and fluid simulation results in that both of them show the convergence to the Rosenbluth-Hinton zonal-flow level as well as nearly the same frequency of the GAM oscillations.

Next, we take the wave-number regions $a_i^{-1} \ll k_\perp < a_e^{-1}$ ($a_e \equiv \sqrt{T_e/m_e}/|\Omega_e|$)relevant to zonal flows in the ETG turbulence. Then, we use the kinetic-fluid equations for electrons and Poisson's equation which is written as

$$e^{-b_e/2}\left(\frac{\delta n^{(\mathrm{g})}_{e\mathbf{k}_\perp}}{n_0} - \frac{b_e}{2}\frac{\delta T_{e\perp\mathbf{k}_\perp}}{T_e}\right) + \frac{e\phi_{\mathbf{k}_\perp}}{T_e}\left(\frac{T_e}{T_i} + 1 - \Gamma_0(b_e) + k_\perp^2\lambda_{De}^2\right) = 0.$$

The gyrokinetic and fluid simulation results for $k_r a_e = 0.1715$ are shown by solid circular symbols and solid curves, respectively, in Fig. 1(b), where the horizontal dashed line represents the residual zonal-flow level given by the theoretical prediction,

$$\frac{\phi_{\mathbf{k}_\perp}(t)}{\phi_{\mathbf{k}_\perp}(0)} = \frac{T_e/T_i + \langle k_\perp^2(a_e^2+\lambda_{De}^2)\rangle}{T_e/T_i + \langle k_\perp^2 a_e^2\rangle[1+1.6(1+T_e/T_i)q^2/\epsilon^{1/2}] + \langle k_\perp^2\lambda_{De}^2\rangle}.$$

In Fig. 1(b), $q = 1.4$, $\tau_e = T_e/T_i = 1$, $\epsilon = 0.18$, and $k_r\lambda_{De} = 0$ are used, and the initial condition is given by $\delta f^{(\mathrm{g})}_{e\mathbf{k}_\perp}(0) = (\delta n^{(\mathrm{g})}_{e\mathbf{k}_\perp}(0)/n_0)F_{e0}$ with $e^{-b_e/2}\delta n^{(\mathrm{g})}_{e\mathbf{k}_\perp}(0)/n_0 = [T_e/T_i + 1 - \Gamma_0(b_e)]e\phi_{\mathbf{k}_\perp}(0)/T_e$ The gyrokinetic and fluid simulation results both show a good agreement with the predicted zonal-flow level.

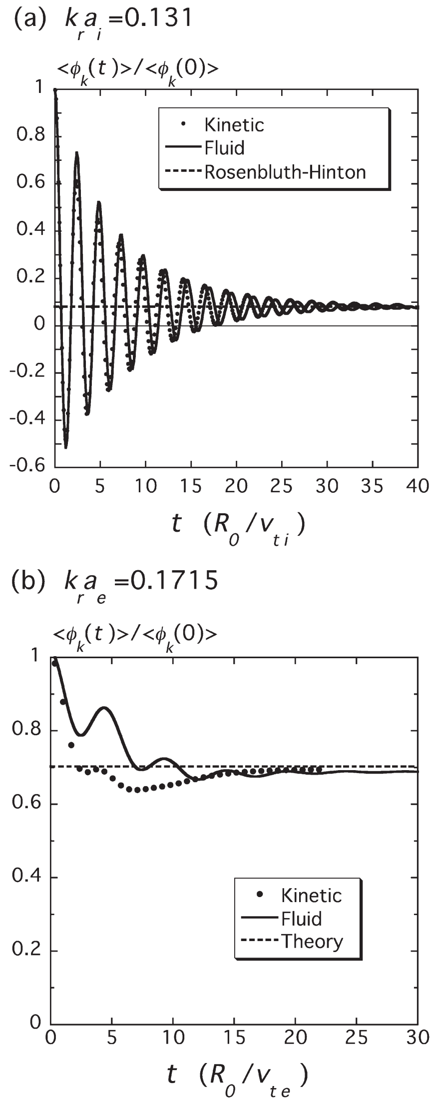

Fig.1. Time evolution of the zonal-flow potential for $k_r a_i = 0.131$ (a) and for $k_r a_e = 0.1715$ (b).

References

1) H. Sugama, T.-H. Watanabe, and W. Horton, Phys. Plasmas **14**, 022502 (2007).

2) M. N. Rosenbluth and F. L. Hinton, Phys. Rev. Lett. **80**, 724 (1998).