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Comparison of reduced sets of a gyro-fluid model for ion-temperature-gradient instabilities in cylindrical plasmas

Naohiro Kasuya[1], Tomotsugu Ohno[2], Makoto Sasaki[1] and Masatoshi Yagi[3]
[1] Research Institute for Applied Mechanics, Kyushu University, [2] Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, [3] National Institutes for Quantum and Radiological Science and Technology
e-mail: kasuya@riam.kyushu-u.ac.jp

In order to understand turbulent transport phenomena in magnetized plasmas, an excitation condition of the ion-temperature-gradient (ITG) instability has been investigated in linear devices [1-4]. Fluid models are convenient for analyzing global mode structures in collisional plasmas. The finite Larmor radius (FLR) effects must be taken into account [3], because a mode with the wave length comparable to the effective ion Larmor radius can become unstable even in low ion temperature plasmas [2]. Numerical analyses using a global gyro-fluid code in cylindrical plasmas have been performed to obtain mode structures and parameter dependences of the ITG instability [4]. Here we show the comparison of reduced sets of a gyro-fluid model for ITG instabilities to identify influence of the FLR effect.

The following set of linearized gyro-fluid equations [5] is used, where the magnetic curvature terms can be eliminated for the analysis of the cylindrical configuration;

$$\frac{dn}{dt}+\nabla_{//}u_{//}+\left(1+\eta_{\perp}\frac{\hat{\nabla}_{\perp}^{2}}{2}\right)\frac{1}{L_n}\frac{\partial\Psi}{\partial y}=0, \quad (1)$$

$$\frac{du_{//}}{dt}+\nabla_{//}\left(\tau n+T_{//}+\Psi\right)=0, \quad (2)$$

$$\frac{1}{\tau}\frac{dT_{//}}{dt}+\nabla_{//}\left(2u_{//}+\frac{q_{//}}{\tau}\right)+\eta_{//}\frac{1}{L_n}\frac{\partial\Psi}{\partial y}=-\frac{2\nu_{ii}}{3\tau}\left(T_{//}-T_{\perp}\right), \quad (3)$$

$$\frac{1}{\tau}\frac{dT_{\perp}}{dt}+\nabla_{//}\frac{q_{\perp}}{\tau}+\left[\frac{\hat{\nabla}_{\perp}^{2}}{2}+\eta_{\perp}\left(1+\hat{\hat{\nabla}}^{2}\right)\right]\frac{1}{L_n}\frac{\partial\Psi}{\partial y}=\frac{\nu_{ii}}{3\tau}\left(T_{//}-T_{\perp}\right), \quad (4)$$

where n is the ion density, $u_{//}$ is the ion velocity, T is the ion temperature, τ is the ratio between ion and electron temperature at the plasma center, and the subscripts // and $\perp$ represent the quantities in the parallel and perpendicular directions to the magnetic field, respectively. The other definitions of the parameters are described in Ref. [4]. The gyro-averaged potential Ψ is represented as $\Psi \equiv \Gamma_0^{1/2}\Phi$ with operators $\Gamma_0^{1/2}=\left(1+b\tau/2\right)^{-1}$ and $b=-\nabla_{\perp}^{2}$. Operator b gives the square of the perpendicular wavenumber $k_{\perp}^2$, which corresponds to the magnitude of the FLR effect. Two modified Laplacian operators $\hat{\nabla}_{\perp}^{2}$ and $\hat{\hat{\nabla}}^{2}$ are introduced to include the FLR effects. The quasi -neutrality relation is given to be

$$\Gamma_0\left(n-\frac{b/2}{1+b\tau/2}T_{\perp}\right)-\left(1-\Gamma_0\right)\frac{\Psi}{\tau}=\Psi \quad (5)$$

to determine the relation between the density and potential. The global analysis using this set of equations considers the boundary condition to determines the radial mode structure, which gives the values of the perpendicular wavenumber. The local analysis confirms to reproduce the global analysis result by adjusting the wavenumber to that obtained from the global analysis [4]. Therefore, the local model is used to obtain the analytical form of the dispersion relation here. The set of 4+1 field model equations consists of Eqs. (1-5), and some reduced sets of it are considered for comparison.

The ITG instability is unstable when the ratio of the ion temperature gradient to the density gradient η exceeds the threshold value near the unity. Figure 1 shows the dependency of the growth rate on τ and η. For the calculation, the experimental parameters in the PANTA device [6] are used. The critical value η_c for the ITG instability changes depending on the magnitude of τ. This dependency is related to the FLR effect. The comparison of the results from the original 4+1 field model, and its reduced 3 field model can make clear the mechanism. In the case of the resistive drift wave instability, break of the Boltzmann relation $n \neq \Psi$ is important for the destabilization. In this model, the FLR effect can break the Boltzmann relation, as Eq. (5), which affects the instability, but is not strong enough, so this effect alone cannot make the mode unstable.

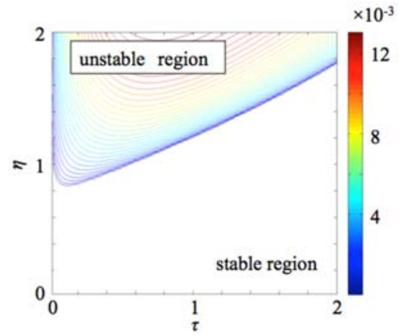

Fig. 1: Dependency of the growth rate of the ITG instability on τ and η. The mode with azimuthal mode number 2 and axial mode number 1 is calculated with the experimental parameters in the PANTA device.

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