§6. Comparison of Linear Growth Rate of Multiple Drift Wave Instabilities at $k_\theta \rho_{thi} \sim 1$

Yamagishi, O., Sugama, H., Watanabe, T.-H., Nakajima, N., Nakamura, Y. (Kyoto Univ.)

When we solve the linear gyrokinetic mode equation, we can find multiple drift waves to be driven unstable. Representative instabilities in the electrostatic assumption are ion temperature gradient modes (ITG), trapped electron modes (TEM) and electron temperature gradient modes (ETG). It is often the case that the only ITG modes are considered with the wavelength comparable to the ion Larmor radius, $k_\theta \rho_{thi} \sim 1$, because (i) the treatment of trapped particles is somewhat difficult compared to the circulating one, and (ii) the ETG modes are dominant at $k_\theta \rho_{the} \sim 1$, not at $k_\theta \rho_{thi} \sim 1$. We developed a linear gyrokinetic eigenvalue code, following Ref.[1], which is free from the order of wavelength or eigen frequencies (proper for any spatial and temporal scale). Thus the code works for the detail study of the different linear eigen modes.

The purpose of this report is to compare the linear growth rate of these modes in detail. Here we consider a s-α model tokamak known as the cyclone base case[2]. The parameters are: s=0.78, α=0(zero β thus electrostatic limit), R/L_n=2.2, R/L_T=6.9, $\eta = L_n/L_T$=3.114, m_i/m_e=3670, T_e/T_i=1, q=1.4, $\varepsilon_t = r/R_0$=0.18, and the ballooning angle θ_k=0.

The linear growth rates and real frequencies as a function of $k_\theta \rho_{thi}$ are shown in Fig.1. Here ITG, TEM, and ETG modes can be seen, for which we can confirm that they are surely ITG/TEM/ETG by doing some parameter scans. It can be seen that the ITG modes are typically stabilized at $k_\theta \rho_{thi} \sim 1$, while the TEMs remain unstable for higher $k_\theta \rho_{thi}$. Thus the TEMs is often considered to cause the electron transport with the fluctuation of $k_\theta \rho_{thi} \sim 1$. They are also stabilized at $k_\theta \rho_{thi} \sim 3$, which can be interpreted such that the real frequency becomes so high that the resonance between the wave and the electron bounce motion disappears. It should be remarked that the ETG modes are also unstable for $k_\theta \rho_{thi} \sim 1$ with sufficient growth rate. The eigenfunction is also shown in Fig.2 for for $k_\theta \rho_{thi}$=0.8. We can see that the ITG and TEM eigenfunction is usual ballooning type while the ETG is very broad function along a field line (The θ scale (x-axis) is $\pm 10\pi$ for ITG/TEM, and $\pm 80\pi$ for ETG).

The ETG growth rate should peaks at $k_\theta \rho_{the} \sim 0.5$, as the ITG growth rate does at $k_\theta \rho_{thi} \sim 0.5$ because they are isomorphism. Thus the ETG shown in Fig.1 can be considered to be rather weak, nearly marginal modes. In fact, for our case of m_i/m_e=3670, $k_\theta \rho_{thi}$=1 corresponds to $k_\theta \rho_{the} \sim 0.0165$ which is very long wavelength for the ETG. However, the ETG is mainly driven by the resonance between the wave and circulating electrons, and electron thermal velocity is $(m_i/m_e)^{1/2}$ times larger than ion's. This fast temporal scale of the ETG can over come their weakness due to the long wavelength, and their growth rate are even larger than the ITG or TEM growth rate, as in Fig.1.

It is noted that the linear growth rate itself is considered insufficient to explain the physics of nonlinearly saturated state, although the quasi-linear fluxes are proportional to that. The direct simulation will be needed in order to discuss the relevant transport formally.

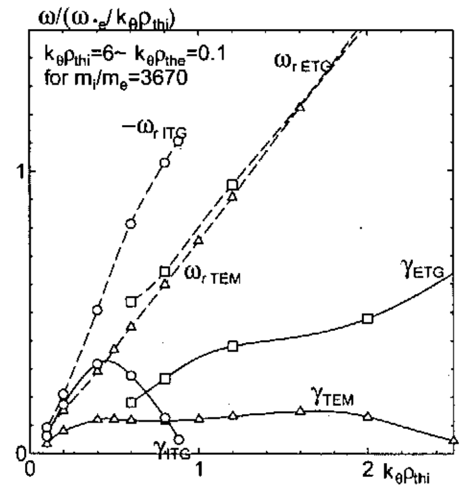

Fig. 1. Frequencies of ITG(circles), TEM(triangles), and ETG(squares) as a function of $k_\theta \rho_{thi}$.

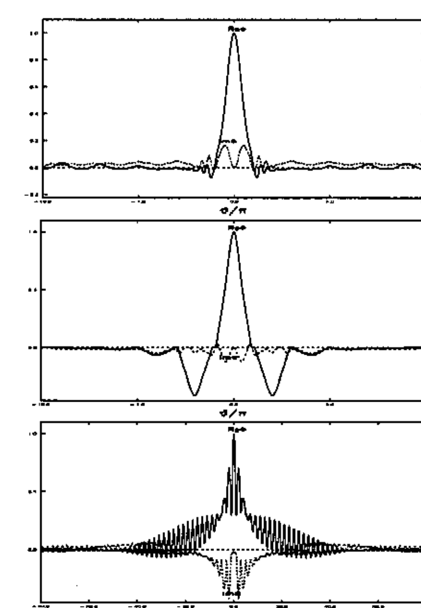

Fig. 2. Eigenfunction of ITG(top), TEM(middle) and ETG(bottom) for cyclone base case at $k_\theta \rho_{thi}$=0.8.

Reference

[1] Rewoldt. G., et. al., Phys. Fluids **25**, (1982) 480

[2] Dimits. A. M., et. al., Phys. Plasmas 7, (2000) 969

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