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Gyrokinetic simulation for the nonlinear interaction of electron temperature gradient mode and trapped electron mode

ジャイロ運動論的シミュレーションによる電子温度勾配モードと捕捉電子モードの相互作用解析

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Nonlinear interaction of electron temperature gradient (ETG) mode and trapped electron mode (TEM) was investigated by gyrokinetic simulations. Through linear analysis, we found that both ETG modes and TEMs are quite sensitive to density gradient: the growth rates of ETG modes decrease with density gradient while the growth rates of TEMs increase with density gradient. Two nonlinear simulations for the ETG-TEM turbulence were carried out with low and high density gradient cases, presenting the ETG dominant and TEM dominant cases, respectively. We found that the TEM driven zonal flow effectively regulate the ETG-scale fluctuations for both cases. For the TEM dominant case, the TEM-scale fluctuations are not fully regulated, while they are regulated in the ETG dominant case.

1. Introduction

Anomalous electron heat transport can be important in future fusion reactors where electrons absorb a large fraction of energy carried by fast alpha particles. It is generally recognized that the electron temperature gradient (ETG) turbulence can provide the large electron heat transport [1]. Another possible candidate is the trapped electron mode (TEM) turbulence which is destabilized by the trapped electrons at bad curvature region [2].

For a better understanding of anomalous electron heat transport, gyrokinetic simulations of the ETG turbulence and the TEM turbulence have intensively been carried out (see Review [3]). However, most of these are limited to the idealized ones, where the ETG modes and TEMs are not unstable at the same time. In our previous work, we performed the ETG-TEM turbulence simulation including both unstable ETG modes and TEMs [4]. We found that the ETG turbulence can be regulated by the TEM-driven zonal flow. In accordance, we perform the parameter scan for the density gradient to investigate the influence of the TEM-driven zonal flows on ETG-TEM turbulence.

2. Numerical settings

Our simulation results are obtained from GKV+ code [5], where electromagnetic effects are neglected in this work. Physical parameters used in this work are the Cyclon case parameters [6] except for the weaker magnetic shear. The density gradient is the scan parameter within $2.22 < R/L_n < 6.92$, while we only show $R/L_n = 2.22$ and 6.92 cases in this proceedings. The results from $R/L_n = 3.46$ and 5.0 cases are presented in the conference.

Through linear analysis, it turned out that the ETG modes (TEMs) are most unstable in R/L_n = 2.22 (6.92) case. This result implies that the dominant turbulence drive in the ETG-TEM turbulence can vary with the density gradient. Through the density gradient scan, we examine the nonlinear interaction of the ETG modes and TEMs for both ETG dominant ($R/L_n = 2.22$) and TEM dominant ($R/L_n = 6.92$) cases, respectively.

3. Simulation Results

We carried out the ETG-TEM simulations with $R/L_n = 2.22$ and $R/L_n = 6.92$ cases to evaluate the electron energy and particle flux. Figure 1 shows the time evolution of electron energy flux Q_e and particle flux Γ_e for ETG dominant ($R/L_n = 2.22$) and TEM dominant ($R/L_n = 6.92$) cases.

The initial increase in the energy flux for both cases stems from the linear growth of ETG modes. In the $R/L_n = 2.22$ case, the energy flux is reduced at $t \sim 600$ by the TEM-induced zonal flow. After $t > 800$, the statistically steady state is achieved with dominant zonal flow. Both the ETG modes and the TEMs are regulated in this case (See Figure 2.). It is also found that the particle flux is negligible compared with the energy flux.

The energy flux for the $R/L_n = 6.92$ case is largely enhanced at around $t = 200$ by TEMs (See Figure 3). The TEMs induce the zonal flows which suppress ETG modes but not TEMs. After $t > 500$ where statistically steady state is achieved, the

TEMs have large amplitude nevertheless the zonal flows are dominant. As a consequence, the energy and particle fluxes are mostly attributed to TEMs where the particle flux is no longer negligible compared with the energy flux.

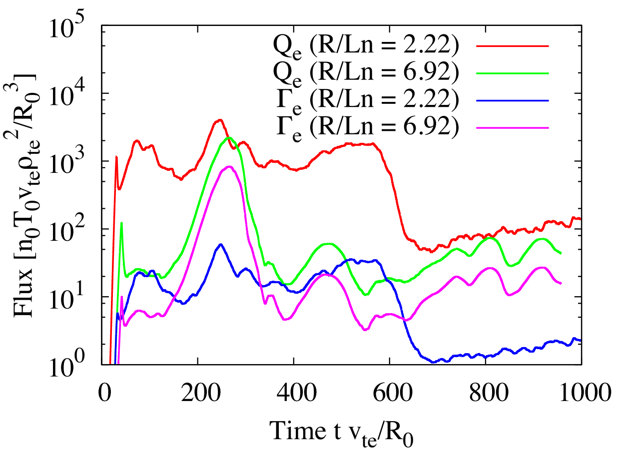

Figure 1. The time evolution of electron energy and particle flux for R/L_n = 2.22 (red and blue curves) and R/L_n = 6.92 (green and pink curves) cases.

The results from R/L_n = 6.92 case may in part reflect the characteristic of TEM-driven zonal flows in TEM turbulence, that is, TEM-driven zonal flows are not always essential for nonlinear saturation [7]. The regulation of TEMs by TEM-driven zonal flow seems to be non-trivial even in the ETG-TEM turbulence. More comprehensive analysis remains as a future work. In contrast, the ETG modes are effectively suppressed by the TEM-driven zonal flow both in R/L_n = 2.22 and R/L_n = 6.92 cases. It can be concluded that the regulation of the ETG modes by the TEM-driven zonal flow is robust as long as the TEMs are unstable.

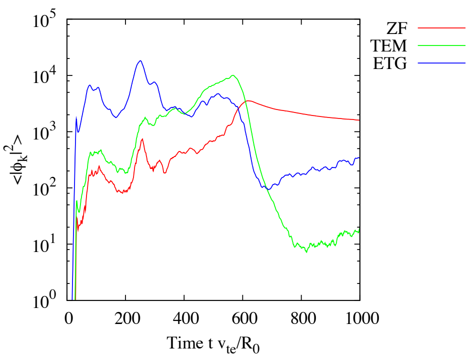

Fig. 2: The time evolution of the squared amplitude of zonal flow potential $\sum_{k_x}\langle|\phi_{k_x,\,k_y}|^2\rangle$ for R/L_n = 2.22 case, including the zonal mode with $k_y\rho_{te}$ = 0, the TEM with $k_y\rho_{te}$ = 0.035, and the sum of ETG modes with $0.07 \le k_y\rho_{te} \le 1.12$.

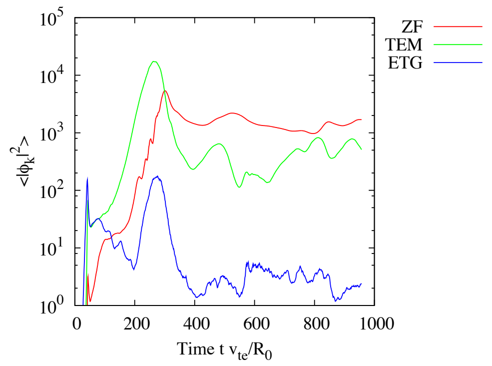

Fig. 3: The time evolution of the squared amplitude of zonal flow potential $\sum_{k_x}\langle|\phi_{k_x,\,k_y}|^2\rangle$ for R/L_n = 6.92 case, including the zonal mode with $k_y\rho_{te}$ = 0, the TEM with $0.035 \le k_y\rho_{te} \le 0.35$, and the sum of ETG modes with $0.385 \le k_y\rho_{te} \le 1.12$.

4. Conclusion

The density gradient scan for ETG-TEM turbulence was carried out by gyrokinetic simulations. It turned out that the TEM-driven zonal flow effectively regulate ETG modes for both ETG dominant and TEM dominant cases. However, the TEMs are not fully regulated by the TEM-driven zonal flow in the TEM dominant case.

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