

## **Short wavelength ion temperature gradient mode in tokamak plasmas with hollow density profile**

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The shape of density profile (peaked, flat, or hollow) in magnetic fusion operations is expected to play important roles in microinstability, magnetohydrodynamical (MHD) instability, as well as plasma performance. The importance of understanding transport processes in the region with hollow density profile is particularly accentuated when pellet injection is utilized during the H-mode operation, such as in the ITER reference scenario. In recent years, modelling and simulations of experimental scenarios of hollow density profile plasmas has been performed for FTU, MAST, ASDEX Upgrade, and JET. The impacts of pellets on the anomalous transport driven by microinstabilities, for example, ion temperature gradient (ITG) mode, electron temperature gradient (ETG) mode, and trapped electron mode (TEM) are investigated. Using experimentally measured profiles, the mode growth rates are found to be quite sensitive to the rapid and large excursions of the density gradient, temperature gradient, and collisionality affected by the pellet injection. In addition, a thorough scan of crucial local parameters has been carried out, the conditions for coexistence of the ITG mode and the TEM and the transition between those two modes in a certain parameter regime are also discussed[1, 2].

On the other hand, experimental evidence shows that the anomalous electron transport is governed by short wavelength turbulence after the stabilization of long wavelength turbulence[3, 4]. This mode is found to be driven by the ion temperature gradient in the presence of the Landau resonance/inverse resonance in slab geometry and by the toroidal drift resonance in toroidal geometry, in combination with the non-monotonic behavior of the mode frequency with respect to the perpendicular wave number. In earlier works, although the SWITG mode in tokamak plasmas with normal density profile has been investigated and the physical mechanism is discussed, for the properties of the SWITG mode with hollow density profile, relatively limited knowledge is available from some previous publications. To this end, the SWITG mode in tokamak plasmas with hollow density profile are numerically investigated using the local HD7 code to solve

the gyrokinetic integral eigenmode equation[5]. The kinetic effects of ions, including transit motion, finite ion Larmor radius, magnetic gradient and curvature drifts, and finite-orbit-width, are retained. The ballooning representation is used so that the linear mode coupling due to the toroidal magnetic configuration of tokamak is taken into account. Dependences of the growth rate, real frequency, mode structure, wave spectrum as well as the instability threshold on local plasma parameters are analyzed in detail.

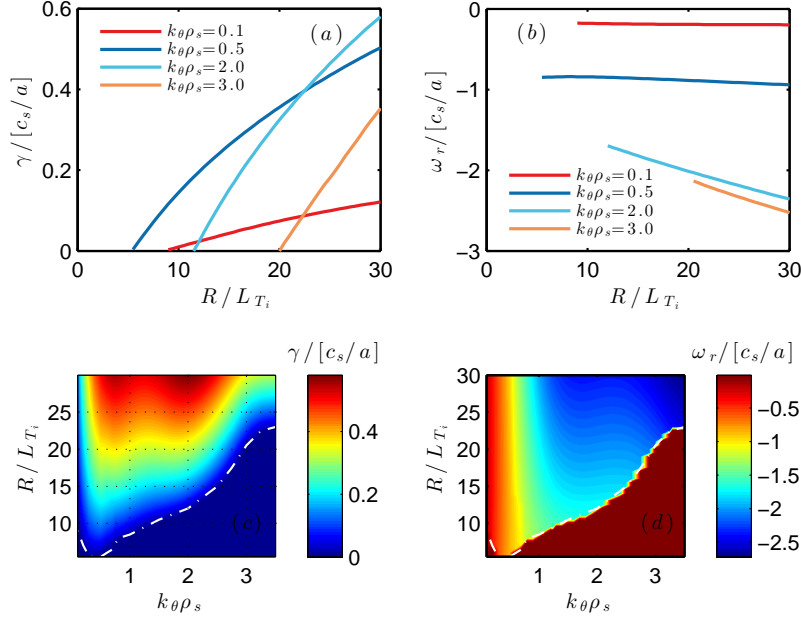


Figure 1: Normalized growth rate (a) and real frequency (b) of the ITG mode versus the normalized ion temperature gradient  $R/L_{Ti}$  for different poloidal wave number  $k_\theta \rho_s$ . Contour plots of the normalized growth rate (c) and real frequency (d) of the ITG mode in  $(k_\theta \rho_s, R/L_{Ti})$  plane. The white dashed lines correspond to the SWITG threshold. Other parameters are  $R/L_n = -5.0$ ,  $T_e/T_i = 1.0$ ,  $\varepsilon = 0.0$ ,  $s = 1.0$ , and  $q = 2.0$ .  $\gamma/[c_s/a] \sim 10^{-3}$  has been used as a threshold value defining the boundary lines in the figure.

It is demonstrated in Fig. 1 that the SWITG mode is an ITG driven mode in the higher  $k_\perp \rho_{Li}$  regime exhibiting a threshold in  $R/L_{Ti}$ . The required ion temperature gradient threshold  $R/L_{TiC}$  of the SWITG mode for negative  $R/L_n$  is somewhat lower than that for positive  $R/L_n$ , though far away from the threshold, the mode in the later case features larger growth rate, as shown in Fig. 2. A particularly property for the hollow  $n_e$  profile case is that the SWITG mode growth rate  $\gamma$  is much smaller than the real frequency  $\omega_r$ , this differs considerably from the peaked  $n_e$  profile case, where  $\gamma \ll \omega_r$  is satisfied only near the threshold. Generally speaking, a large absolute value of  $R/L_n$  leads to low growth rate, large  $R/L_{TiC}$  and narrow  $k_\theta \rho_s$  spectrum, which implies the more hollow density profile, the stronger stabilizing effect on the SWITG mode, and

thus more peaked ion temperature profile is required to excite the mode.

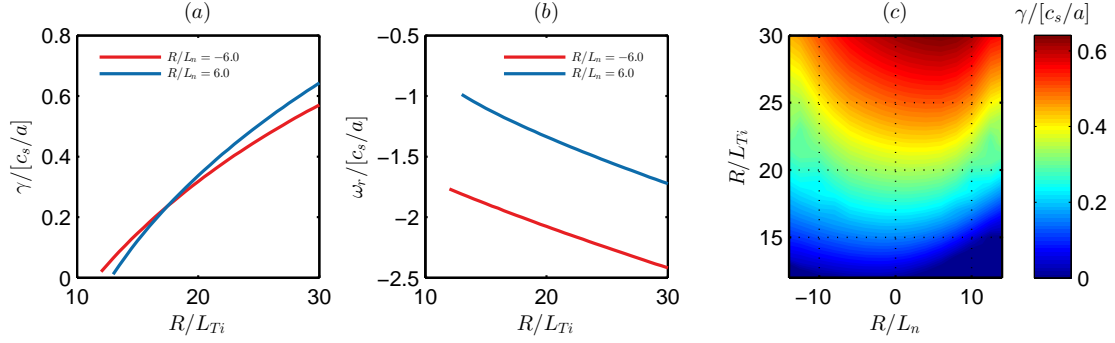


Figure 2: Normalized growth rate (a) and real frequency (b) of the SWITG mode versus the normalized ion temperature gradient  $R/L_{Ti}$  for different normalized density gradient  $R/L_n$ . Contour plots of the normalized growth rate (c) and real frequency (d) of the ITG mode in  $(R/L_n, R/L_{Ti})$  plane. Other parameters are  $T_e/T_i = 1$ ,  $\varepsilon = 0.0$ ,  $k_\theta \rho_s = 2.0$ ,  $s = 1.0$ , and  $q = 2.0$ .

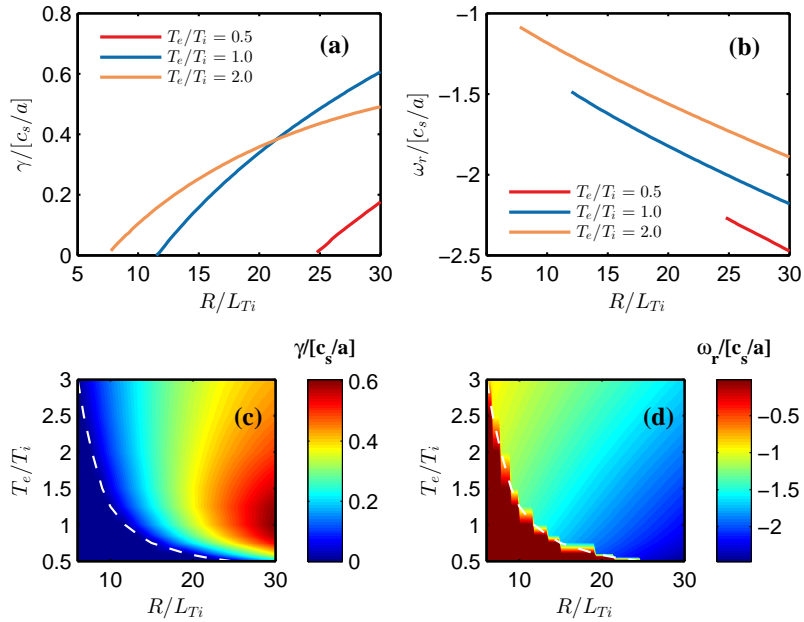


Figure 3: Normalized growth rate (a) and real frequency (b) of the SWITG mode versus the normalized ion temperature gradient  $R/L_{Ti}$  for different temperature ratio  $\tau_i = T_e/T_i$ . Contour plot of the normalized growth rate (c) of the SWITG mode in  $(R/L_{Ti}, T_e/T_i)$  plane. The dashed line for the threshold for SWITG modes versus temperature ratio  $\tau_i = T_e/T_i$  for various ion temperature gradients.

Besides, a new finding of this work is that the trapped electron effects on the SWITG mode is stabilizing or destabilizing, depending on the gradients of electron temperature and density.

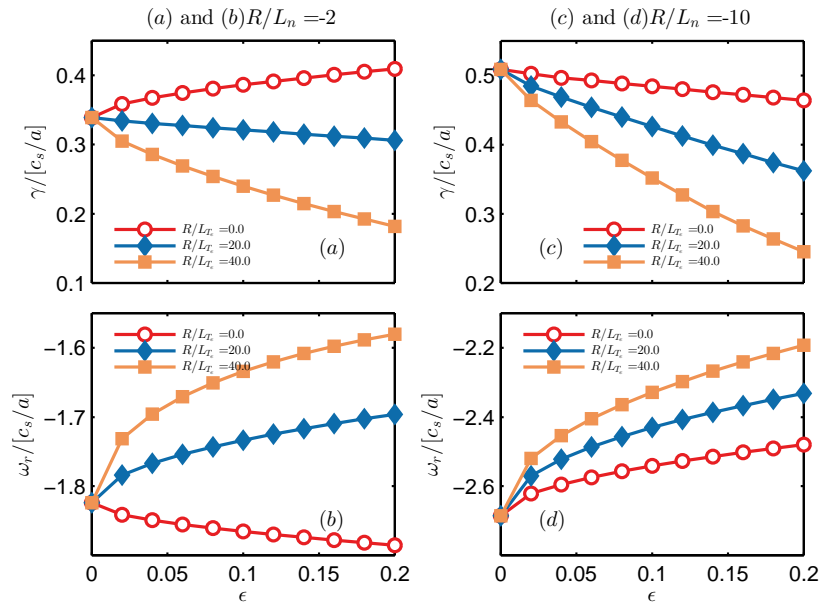


Figure 4: Normalized growth rate and real frequency of the SWITG mode versus the fraction of trapped electrons  $\epsilon$  for different normalized electron temperature gradient  $R/L_{Te}$ . (a) and (b) for  $R/L_n = -2.0$  and  $R/L_{Ti} = 20.0$ ; (c) and (d) for  $R/L_n = -10.0$  and  $R/L_{Ti} = 30.0$ .

It is found in Fig. 4 that for the moderate density gradients in tokamak plasmas ( $R/L_n \sim -2.0$ ), the trapped electrons with flat electron temperature profile ( $\nabla T_e \sim 0$ ) increase the SWITG mode growth rate. However, finite  $T_e$  gradient has a stabilizing effect on the SWITG instability so that the mode growth rate decreases when the  $R/L_{Te}$  value becomes larger. For a steep hollow density profile e.g.,  $R/L_n \sim -10.0$ , the trapped electron response stabilize the SWITG instability, and larger values of  $R/L_{Te}$  enhance such a mechanism, reducing the growth rate substantially and thus the mode threshold value is raised. In addition, it is found that a decrease in electron to ion temperature ratio  $T_e/T_i$  leads to a high threshold of  $R/L_{TiC}$ , indicating ion heating favors the suppression of the SWITG mode, thus the mode is more harder to be excited in hot ion plasmas than in hot electron ones.

## References

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