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Gyrokinetic simulation study of impurity effects on turbulence in tokamak

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Impurity ions in tokamak plasma can play a major role in the transport and stability. While the main issue related to impurities is the particle transport which affects the dilution of main fuel and radiation cooling, impurities can have an effect on the stability of micro-turbulence and the anomalous heat transport[1]. To address the impact of impurities on the anomalous transport in tokamak, a number of linear and nonlinear simulation studies were performed previously[2,3].

Recently, the gyrokinetic global delta-f code gKPSP[4] is extended to include the multi-species kinetic ion module. Gyrokinetic Poisson equation is modified to include the polarization charge of multi-species ions and a collision module based on the previous analytic work[5] is implemented. Basic benchmark tests, including Rosenbluth-Hinton residual flow, ITG (ion temperature gradient) linear growth rates[2] show a good agreement with previous results.

Although impurities are well known to have an impact on the linear stability of drift waves, their roles on the nonlinear transport of micro-instabilities are not well understood yet. Therefore, we performed a few of nonlinear simulations to investigate nonlinear effect of impurities on ITG and TEM(Trapped electron mode). Pure and impure cases with same linear growth rates are compared to isolate nonlinear effects from the linear one. Carbon (C^{6+}) is used as the impurity species and $Z_C n_C/n_e = 0.2$. The linear growth rates of ITG modes with adiabatic electrons are shown in Fig. 1. While main ion density and temperature profiles are identical for both cases, the impurity density profile is used as a parameter to match the linear growth rates.

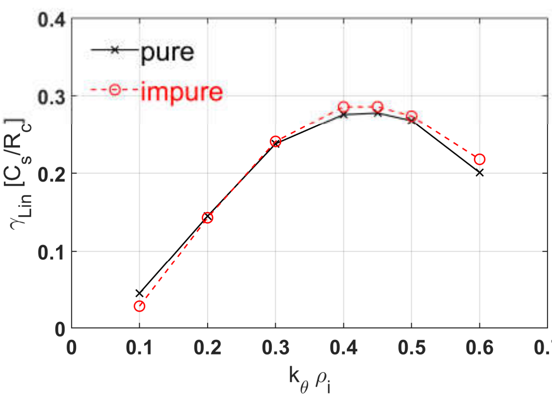

Fig. 1. Linear growth rate for ITG

For ITG, a modest increase of heat flux is observed in the impure case, compared to the pure case. Time averaged heat diffusivity profiles are shown in Fig. 2. The intensity profile of fluctuating potential also shows a similar level of increase for the impure case. Although the turbulence is stronger in the impure case, the zonal flow intensity is weaker in the impure case. In Ref [6], it was shown that the zonal flow is damped more in impure plasmas due to the stronger neoclassical polarization of impurity species. In Fig. 3, the residual zonal flow is shown for gKPSP simulation and predicted value from theory[6], which shows the reduced level of zonal flows in impure plasmas. Therefore, the nonlinear simulation results from gKPSP are consistent to the prediction of enhanced zonal flow shielding due to the neoclassical polarization of impurities.

For TEM case, the nonlinear effect of impurities is much weaker, despite of the decreased zonal flow. This seems to be related to the weaker connection between TEM saturation mechanism and the zonal flow, compared to ITG[7].

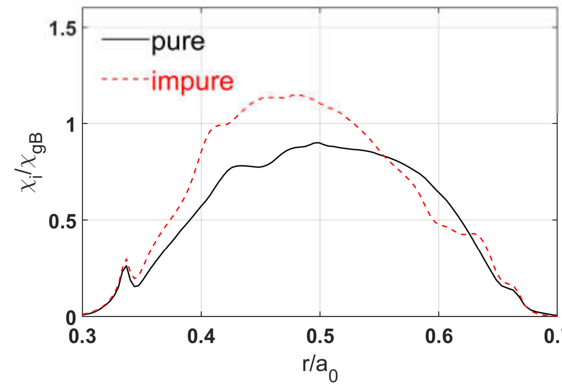

Fig. 2. Time averaged heat diffusivity profiles

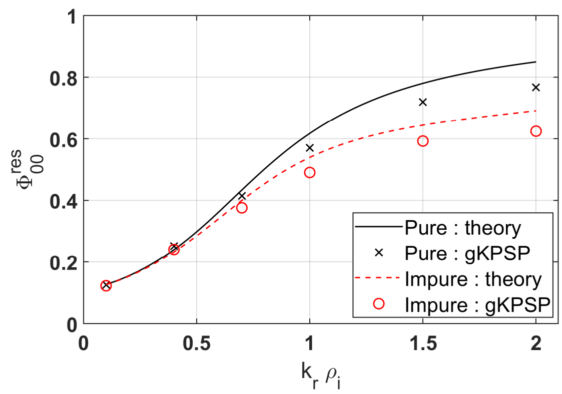

Fig. 3. Residual zonal flow from the theory[6] and gKPSP

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