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Gyro-Landau-fluid simulations of impurity effects on ion temperature gradient driven turbulence transport

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Microturbulence caused by drift wave instabilities, e.g., the ion temperature gradient (ITG) mode, is a leading candidate to explain the transport [1-4]. Suppressing the turbulence and controlling the transport are of importance for achievement of high-performance plasmas and realizing fusion energy. External impurity injection is observed to lead to ion thermal diffusivity reduction and confinement improvement in various experiments [5-7]. Some theoretical analyses and numerical simulations found that low or medium-Z impurities can destabilize or stabilize micro-instabilities in certain conditions. Therefore, impurity injection is a promising way to control the turbulence transport, and the impurity effects on the microturbulence deserve in-depth study.

In this work, the impurity effects on ITG driven turbulence transport in tokamak core plasmas are investigated numerically via global simulations of microturbulence with carbon impurities and adiabatic electrons using extended fluid code (ExFC) based on a four-field gyro Landau-fluid (GLF) model [8]. A number of simulations with parametric profiles of the cyclone base case (CBC) and different initial carbon impurity profiles are performed to investigate the impurity effects mainly in two aspects.

First, note that the ITG turbulence could be regulated by zonal flows and quenched in low temperature gradient, a higher critical temperature gradient than the linear prediction has been observed, i.e., the so-called Dimits shift. In fact, the impurity effects on the critical temperature gradient are also of interest. Simulations in Fig. 1(a) show that the critical temperature gradient can be influenced obviously by impurities with different profiles. The sign of impurity density gradient parameter R/L_{nz} corresponds to the different peaking directions of impurity density profile, and f_z represents the impurity fraction at the reference surface. Without considering the radiation effect, the inwardly peaked impurity density profile can improve the confinement.

Second, considering that the heat flux mainly results from bulk ions on account of small fraction of impurity, we focus on the impurity effects on χ_i in the ITG turbulence near critical temperature gradient. Fig. 1(b) presents a more complete picture of the impurity effects on the confinement, it shows the improved confinement by inwardly peaked impurity and deteriorated confinement by outwardly peaked impurity near the critical temperature gradient, but the transport level is instead reduced by impurity at higher temperature gradient. It may be ascribed to that the steep density gradient of both ions and impurities have relaxed quickly (within the magnitude of 1ms) to a flatter one by particle transport induced by impurities. Fast relaxation indicates that the destabilization of the outwardly peaked impurity profile is a transient state response. Moreover, in the region where turbulence excited by impurity effect, the unquenched turbulence with the thermal diffusivity in neoclassical transport level (about $0.1\rho_{s0}^2 c_{s0}/a_0$) is found near the linear critical gradient of ITG without impurity ($R/L_T \approx 4$).

These results may evidence the plasma confinement improvement by the impurities probably through adjusting both heat diffusivity and critical temperature gradient.

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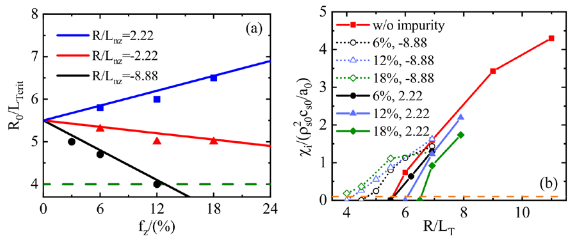

Figure 1: (a) Quenched points and fit lines of critical temperature gradient versus impurity fraction f_z with different R/L_{nz}; (b) Heat diffusivity χ_{i} of turbulence without impurity and with impurity near critical temperature gradient, lines are labeled by the values of parameters (f_z, R/L_{nz}).

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