4th Asia-Pacific Conference on Plasma Physics, 26-31Oct, 2020, Remote e-conference

Gyrokinetic Simulation of Isotope Effect on Turbulent Transport in Burning Plasmas

Yong Xiao, Shengming Li
Department of physics, Institute for Fusion Theory and Simulation, Zhejiang University, China
e-mail: yxiao@zju.edu.cn

Isotope effect on the turbulent transport has become an important issue as the burning plasmas operation of ITER is approaching. The scaling of the confinement with the isotope mass A_i have been studied experimentally on many devices. The Gyro-Bohm scaling as shown by some simulations [1] predicts that the turbulent diffusivity of ion energy flux increases with $\sqrt{A_i}$, which is inconsistent with experiments [2].

In this work, nonlinear simulations using Gyrokinetic Toroidal Code (GTC) are carried out to study isotopic dependence of hydrogen isotope (H, D and T) on typical electrostatic turbulence driven by ion temperature gradient (ITG) mode and trapped electron mode (TEM). Simulations show that in linear growth stage, the short wavelength dominated TEM instability has a stronger isotope dependence than the long wavelength dominated ITG instability. The isotope effect on zonal flow response is verified by analytic theory [3,4]. It is found that the growth rate for energy flux increases with A_i in TEM but decreases in ITG. In nonlinear stage, both TEM and ITG turbulences saturate at long wavelength and the saturation level has a strong isotope dependence when kinetic electrons are retained in the simulation. The average radial wave vector of the zonal flow and radial correlation length of the turbulence increase with A_i for both ITG and TEM, which implies that the significant isotope effect is not caused by the zonal flow that regulates turbulence. In addition, it is found that the turbulence magnitude modified by the electron-to-ion mass ratio may cause the isotope effect of turbulent energy transport. With the gyroradius increasing from H to T, the mixed ITG-TEM driven turbulent transport is significantly reduced, which is consistent with current experimental observations and favors burning plasmas operation.

References

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