Gyro-fluid simulation on the response of micro-scale fluctuation to the MHD island dynamics in fusion plasma turbulence

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Micro-instabilities, for instance the ion temperature gradient (ITG) mode at the ion-scale in magnetic fusion plasmas, are generally excited in an ideal MHD equilibrium. Various instabilities with different driving force have been intensively investigated in a stationary MHD equilibrium to build the plasma stability theory so far. Here we address the property of the micro-instabilities and their nonlinearity in a dynamical MHD equilibrium, for example, typically with a magnetic island in the Rutherford stage of the nonlinear tearing mode.

Direct simulations based on a gyro-fluid model which consistently involves both micro-scale ITG mode and macro-scale resistive tearing mode are performed to understand the response of micro-scale fluctuation and ion transport to the magnetic island dynamics in an initial ideal MHD equilibrium. The results reveal the breakdown of magnetic frozen-in law due to the vanishing of ion temperature profile flattening inside the magnetic island. As a result, a new short wave-length micro-instability with a substantially lower stability threshold is induced by the magnetic island (referred to as the MITG[1]) in multi-scale turbulence. Most interestingly, different from usual instability occurring in a stationary equilibrium, this novel one results from the multi-scale nonlinear interaction in which all zonal modes (the zonal field/current for the island formation, zonal temperature and density for profile modification and the zonal flow for fluctuation stabilization.) are involved dynamically. A critical width of magnetic island is observed for the excitation of the MITG. The quasi-steady-state turbulence behaves with intermittent ion transport in the case with steeper temperature gradient and the transport is enhanced by the MITG instability. The results may helpfully understand the complex nonlinear interaction processes and the response of micro-scale fluctuations to the MHD activities with magnetic islands.

[1] Z.X. Wang, Jiquan Li, Y. Kishimoto, J.Q. Dong, Phys. Plasmas 16, 060703(2009)