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Gyrokinetic simulation study on the role of 3-dimensional helical magnetic island in tokamak toroidal ITG modes

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Magnetic island is a typical structure relevant to the MHD modes (for example, the tearing modes) and/or external magnetic fluctuations (such as the resonant magnetic perturbation) in toroidal plasmas. It cannot only cause various MHD activities including magnetic reconnection as well as plasma disruption, but may also interplay with the micro-scale fluctuations, then influence turbulent transport accordingly. The latter is related to the so-called multi-scale interaction problem. In this work, we focus on exploring the role of 3D helical magnetic island in toroidal micro-turbulence and transport based on a toroidal gyrokinetic full-f code GKNET (GyroKinetic Numerical Experimental Tokamak). As an initial trial, we investigate the effect of a static 3D magnetic island on the toroidal ion temperature gradient (ITG) instability to understand the island dynamics in the equilibrium, turbulence and associated transport.

In current work, the GK Vlasov modeling with an embedded 3D static island is proposed with the conservation of density and energy. The quasilinear profile flattening effect due to the magnetic island is elucidated based on global simulations. The role of the helical magnetic island in toroidal ITG instabilities is elaborated with the analysis of mode structures. Then, the GAM damping in the presence of helical island will be discussed.

We observed that thin 3D helical magnetic islands e.g. with $(m, n)=(1, 1)$ can stabilize the toroidal ITG mode efficiently, while thick islands may play a destabilization role, as shown in Fig.1. Here *m* and *n* are the poloidal and toroidal mode number, respectively. As the poloidal mode number *m* increases, the destabilization effect is weakened. It is found that the stabilization mainly results from two mechanisms. One is the quasi-linear profile flattening effect inside the 3D island, which reduces the ITG drive force. Such a geometric effect is clearly evidenced in the bad curvature region. The other is the mode coupling with different toroidal mode number, namely toroidal *n*-coupling, due to the existence of the 3D island, as shown in Fig.2. The *n*-spectrum is broadened so that the free energy is dissipated in the high-*n* region. On the other hand, the destabilization may result from the enhanced mode coupling with different poloidal mode number, namely poloidal *m*-coupling. This is the same as the usual so-called toroidal coupling. This mechanism is evidenced by the up-shift of the *m*-spectrum peak. In addition, we found that the GAM damping in toroidal plasma is enhanced by the 3D helical magnetic island while the GAM frequency is increased with increasing island width. As a result, residual level of the zonal flow is remarkably reduced.

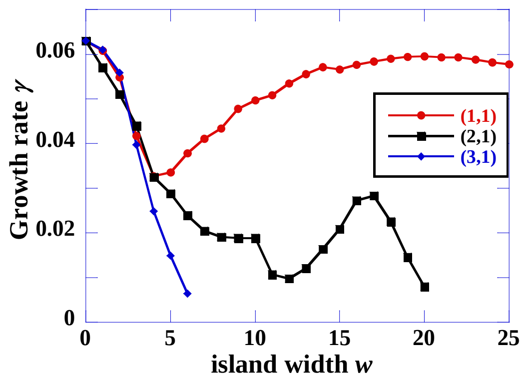

Fig.1 The growth rate of toroidal ITG mode versus the magnetic island width *w* normalized by ion gyro-radius for different helical islands.

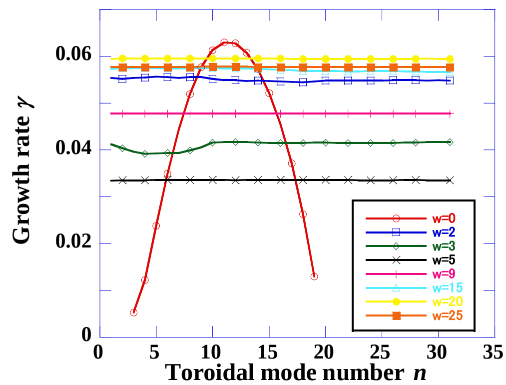

Fig.2 The growth rate of toroidal ITG mode versus the toroidal mode number n in the case with (1, 1) helical magnetic islands. The magnetic island width *w* is normalized by ion gyro-radius.