The impact of secondary instability and associated large scale structures in multi-scale non-linear dynamics in magnetic fusion plasmas

Y. Kishimoto*[a], M. Janvier [a], Z. X. Wang [b], K. Imadera [a], J. Q. Li [a],
[a] Graduate School of Energy Science, Kyoto University, Uji, Kyoto 611-0011, Japan
[b] Dalian University of Technology, Dalian 116024, China
* kishimoto@energy.kyoto-u.ac.jp

The study of macro-scale magneto-hydrodynamic (MHD) and micro-scale turbulence phenomena is always a central topic in the magnetically confined fusion (MCF) plasmas. This is because fusion plasma is generally subject to various kinds of instabilities at differing spatio-temporal scales due to varied magnetic configurations and plasma profiles. Nonlinear interaction among such different scale fluctuations has been widely interested since such process can be new free energy source for secondary instability and cause new complex phenomena. Large scale structure such as zonal modes (zonal flow, field and pressure) and generalized Kelvin-Helmholtz modes generated from micro-turbulence are the examples and found to play an essential role in understanding turbulent transport. These secondary and sometimes tertiary instabilities are believed to ascribe to the modulational process which transfers fluctuation energy among different scales [1]. Motivated by the impact of such nonlinear process, we extend the study to the electromagnetic fluctuation accompanied by large scale magnetic island. Here, we investigate two problems.

The first one is the pure MHD related to the double tearing mode (DTM) leading to abrupt/sudden growth and subsequent full reconnection which has attracted attention as a crucial problem restricting high performance revised magnetic shear plasma in tokamaks. Similar magnetic configuration can be established where a shear reversal in the magnetic field is responsible for the trigger of the flare dynamics in the solar corona [2,3]. Based on the simulation of two field reduced MHD equation, we found a possible process of the nonlinear destabilization characterized by two distinct but coupled secondary instabilities with two different time scales, i.e., 1) *a secondary instability* which triggers the growth of potential flows with faster time scale, and 2) *a zonal field driven tearing instability* which triggers that of the magnetic flux with slower time scale. The first one originates from the 2D magnetic islands deformation during the quasi steady-state nonlinear regime, which may result from modulational process, whereas the latter emerges from the current corrugations, i.e. the zonal field, generated by the coupling between destabilized flows and slowly evolving magnetic flux. These two mechanisms are subsequently coupled, leading to the full reconnection/collapse.

The second one is the system where large scale MHD mode and micro-turbulence at ion gyro-radius scale coexists. There are experimental evidences that MHD activities are diagnosed accompanying wit suddenly occurring small-scale fluctuation, showing the secondary mode excitation. Such phenomena are speculated as a consequence of nonlinear interaction among macroscopic MHD activities and micro-scale drift waves. Based on the five field gyro-fluid simulation including kind/tearing MHD modes and ion temperature gradient (ITG), we investigated the nonlinear evolution of a dynamically interacting system involving all zonal mode components [4,5]. Here, we found two remarkable processes, i.e. 3) *a short wavelength ITG instability induced by a MHD magnetic island* as a consequence of the breakdown of the frozen-in law, and 2) *a magnetic island oscillation due to the interaction with micro-turbulence*. The underlying mechanism of the island oscillation is identified as a cross-scale dynamo generation by the micro-turbulence through a minimal modeling analysis.

The above two MHD phenomena essentially originate from the modulational type interaction which offer new insights in understanding complex nonlinear interaction among multi-scale multi-mode fluctuations in fusion plasmas.

References

1. L. Chen et al., Phys. Plasmas 7, 3129 (2000).
2. Y.Ishii *et al.*, PRL **89**, 205002 (2002), and ZX.Wang *et al*, Phys. Plasmas **15**, 082109 (2008).
3. M. Janvier et al.,23rd IAEA Fusion Energy Conference, THS/P5-09, October 13(2010).
4. J.Q. Li, *et al.*, Phys. Plasmas **11**, 1439(2004).
5. J.Q. Li, *et al.*, Nucl. Fusion **49**, 095007(2009).