§10. Multi-Scale-Nonlinear Interactions among Micro-Turbulence, Magnetic Islands, and Zonal Flows

Ishizawa, A., Nakajima, N., Okamoto, M., Ramos, J.J. (MIT)

We investigate multi-scale-nonlinear interactions among micro-instabilities, macro-scale tearing instabilities and zonal flows, by solving reduced two-fluid equations numerically. We find that the nonlinear interactions of these instabilities lead to fast breaking of magnetic surfaces then this breaking spreads the micro-turbulence over the plasma. These multi-scale-nonlinear interactions can explain complicated evolution of fluctuation observed in torus plasma experiments because micro-turbulence and MHD instabilities usually appear in the plasma at the same time, in spite of the fact that effects of micro-turbulence and MHD instabilities on plasma confinement have been investigated separately. For instance, MHD activities are observed in reversed shear plasmas with a transport barrier related to zonal flows and micro-turbulence (1), and micro-turbulence is observed in Large Helical Device plasmas that usually exhibit MHD activities (2).

We carry out three-dimensional simulations with a reduced set of two-fluid equations that extends the standard reduced two-fluid equations (3), by including temperature gradient effects. By solving this set of equations, we can describe the nonlinear evolution of tearing modes, interchange modes, ballooning modes and ion temperature gradient modes. We examine the multi-scale-nonlinear interaction among these instabilities in a reversed shear plasma with beta=1%, a/R=0.25, Ln=8a, LT=a and qmin=2.2. In the linear phase, a ballooning structure of toroidal micro-instability appears in the bad curvature and positive shear region, as represented by the electric potential profile in the first frame of Fig.1. A tearing mode is also unstable, but its growth rate is small compared to that of the micro-instability. We start the nonlinear simulation at t=0 by taking the result of the linear calculation as the initial condition.

We have found that the multi-scale nonlinear interaction among micro-turbulence, macro-scale tearing modes and zonal flows leads to fast breaking of magnetic surfaces, then this breaking spreads the micro-turbulence due to the micro-instability over the plasma. The mechanism of these interactions is as follows. The micro-instability induces zonal flows which attempt to suppress the tearing mode. However, the nonlinear-mode-coupling due to the micro-instability overcomes this suppression and accelerates the growth of the tearing mode. This tearing mode breaks the magnetic surfaces, and thus the tearing mode spreads the turbulence over the plasma. These nonlinear interactions can explain the evolution of n=1 fluctuation observed before the disruption of reversed shear tokamak plasmas (1). These multi-scale-nonlinear simulations call to mind the importance of the choice of initial perturbations. To complement the simulation presented here, based on a linear mode initial condition, we will investigate the result of a turbulent initial perturbation. Besides, the present simulation adopted an initial equilibrium without any flow. The effects of a flow due to a radial electric field in the initial equilibrium on the multi-scale-nonlinear interaction will be investigated as well.

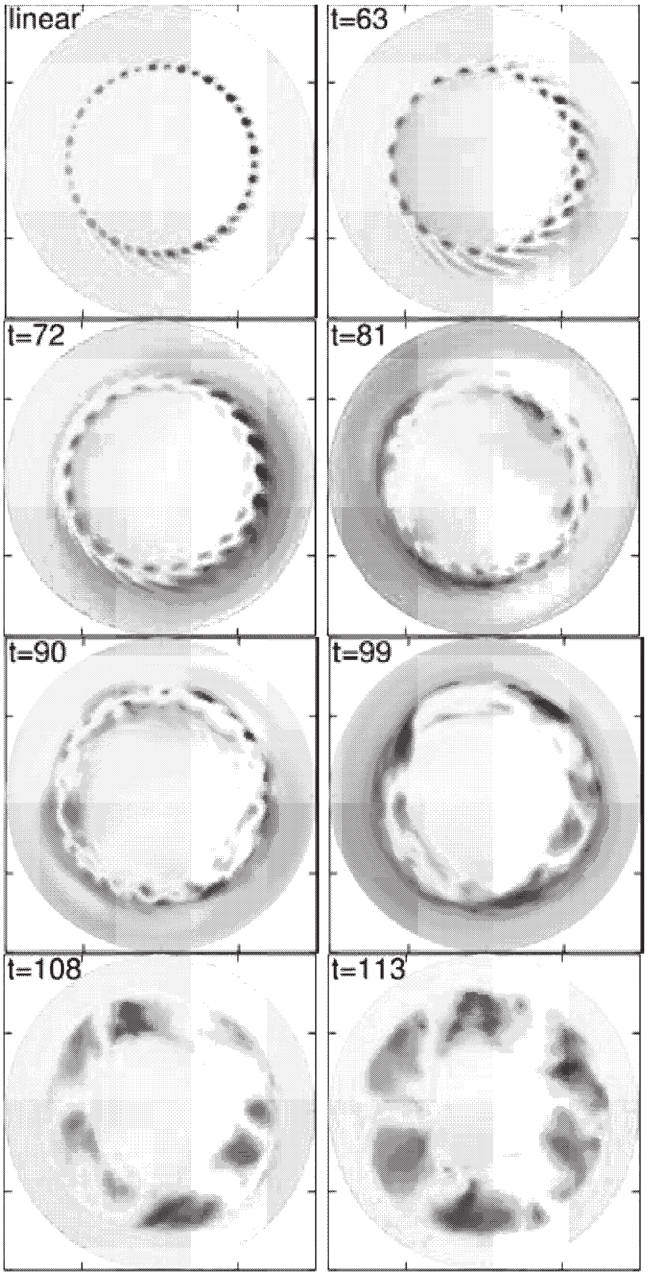

Fig.1. Time evolution of the electric potential on a poloidal section, where the time is normalized by the ion thermal transit time. The micro-instability dominates the linear evolution, then its ballooning structure is deformed by the zonal flow at t=72 and the instability is suppressed by the flow. Next, the m=3 tearing mode arises at t=99, finally the turbulence due to micro-instability expands over the plasma at t=113.

Reference
1) S. Takeji, et al., Nuclear Fusion 42, 5 (2002).
2) K. Tanaka, et al., Nuclear Fusion 46, 110 (2006).
3) R. D. Hazeltine, et al, Phys. Fluids 30, 320 (1987).