§31. A Model of Cross-Scale Dynamo Action in Multi-scale MHD and Micro-turbulence

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Turbulence driven by different instability sources such as the non-ideal MHD and the drift wave micro-instabilities may coexist in laboratory and natural plasmas. The nonlinear interaction among electrostatic (ES) and electromagnetic (EM) fluctuations and structures over a wide scale is a common but intractable issue. The exchange channels between the magnetic and kinetic energy and also among different scales are rather complex and ambiguous, but important to understand the underlying mechanisms of structure formation and anomalous transport in MCF plasmas. In this work, taking the resistive tearing mode and the ion temperature gradient (ITG) driven drift wave instability as the example of the EM MHD and ES micro-turbulence, respectively, the multi-scale multi-mode nonlinear simulation is performed based on a 5-field gyrofluid model to study the energy exchange mechanism between ES and EM turbulence in a tokamak plasma as follows.

$$d_t n = -\partial_y \phi - \nabla_{//} \upsilon_{//} + \nabla_{//} j_{//} + D_n \nabla_\perp^2 n \quad , \tag{1}$$

$$d_t \nabla_\perp^2 \phi = (1+\eta_i) \partial_y \nabla_\perp^2 \phi + \nabla_{//} j_{//} + \mu_\perp \nabla_\perp^4 \phi \quad , \tag{2}$$

$$\beta \partial_t A_{//} = -\nabla_{//} (\phi - n) - \beta \partial_y A_{//} - \eta j_{//} \quad , \tag{3}$$

$$d_t \upsilon_{//} = -\nabla_{//} (2n + T)_i + \beta (2+\eta_i) \partial_y A_{//} + \eta_\perp \nabla_\perp^2 \upsilon_{//} \quad , \tag{4}$$

$$d_t T_i = -\eta_i \partial_y \phi - \tfrac{2}{3} \nabla_{//} \upsilon_{//} - \tfrac{2}{3} \sqrt{\tfrac{8}{\pi}} \left| \nabla_{//} \right| T_i + \chi_T \nabla_\perp^2 T_i \quad . \tag{5}$$

with $j_{//} = -\nabla_\perp^2 A_{//}$, $\beta = 8\pi n_0 T_{i0} / B^2$, $\eta_i = d \ln T_i / d \ln n$. The operators $\nabla_\perp^2 = \partial_x^2 + \partial_y^2$, $d_t = \partial_t + \hat{e}_z \times \nabla_\perp \phi \cdot \nabla_\perp$, and $\nabla_{//} = \partial_z + \hat{e}_z \times \nabla (A_{//0} + A_{//}) \cdot \nabla_\perp$ are expressed in slab geometry $\vec{B} = B_0 \hat{e}_z - \beta \nabla A_{//0}(x) \times \hat{e}_z$ with constant B_0 . An equilibrium model $B_y \propto \tanh(x/\lambda) / \cosh^2(x/\lambda)$ for the poloidal field is employed, probably corresponding to local q profiles in tokamak plasmas. Here x is the distance deviated from the singular surface, λ is the gradient length of axial equilibrium current. Note that near the singular surface, namely the rational surface $x = 0$, both models are reduced to the usual slab model in tokamak plasmas.

The simulation can be performed using an initial value code, which solves the nonlinear evolution equations (1)-(5) in a 2-dimensional (x, y) plane perpendicular to the equilibrium magnetic field along the z direction. The details of the physical model and simulation setting have been described in [1]. Here, we focus mainly on the island dynamics. A prominent magnetic island oscillation is commonly observed in the final nonlinear stage with a fully reconnected island (namely, with larger tearing instability parameter Δ'), showing a dynamic quasi-steady state. A typical simulation with ion temperature gradient parameter $\eta_i = 2.0$ and resistivity $\eta = 5 \times 10^{-4}$ is specified. The island oscillation is visualized by a movie of island evolution, and much more clearly, by snapshots of the dominant flux component $m = 1$. The oscillation occurs as pivoting along the singular surface like a seesaw (referred to hereafter as an *island seesaw*). The averaged EM torque [2)]

$$T_{EMy} \hat{z} = \iint_{xy} x \hat{x} \times (\vec{j} \times \vec{B})_y \, dxdy / L_x L_y \tag{6}$$

exerted on the island by the fluctuating EM force in the y direction increases dramatically and tends to oscillate in time in the quasi-steady state synchronizing with the island seesaw.

This proposes a new concept of *cross-scale dynamo action* induced by micro-turbulence, which is shown to be responsible for an island seesaw oscillation pivoting around the singular surface in multi-scale ES and EM turbulence. Fig.1 shows a turbulent cross-scale dynamo action excited due to the micro-scale ES turbulence in a nonlinearly interacting MHD and ITG turbulence. The turbulent dynamos are evidenced by an oscillatory magnetic island dynamics, which is referred to as the island seesaw [2)]. It is found that the threshold of the dynamo action depends on the intensity of micro-turbulence. This mechanism offers a new energy exchange channel between multi-scale MHD and ES micro-fluctuations in an EM plasma environment.

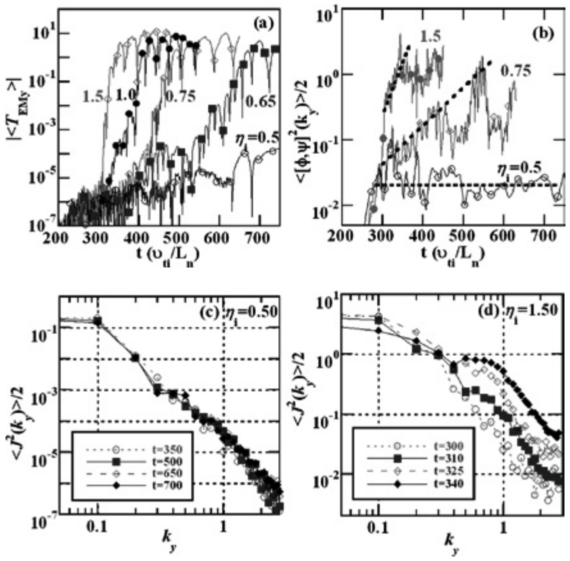

Fig. 1. Evolution of the cross-scale dynamo action versus ITG turbulence intensity. (a)-(d) corresponds to the averaged EM torque amplitude $|T_{EMy}|$; dynamo driving intensity $<[\phi,\psi]^2(k_y)>/2$ for a representative of $k_y = 0.7$; and the k_y spectra of fluctuating current for different ITG driving force.

1) Li, Jiquan, Kishimoto, Y., et al.: Nucl. Fusion **49**, 095007(2009),
2) Li, Jiquan, Kishimoto, Y.: Plasma and Fusion Resaerch **5**, 031 (2010).