§19. Numerical Simulation of Turbulent Transport and Structure Dominated by Multi-scale Interaction in Fusion Plasma *Origin of the Structure Driven Non-linear Instability*

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Multiple current sheet configurations can be found in simple models of space and stellar plasmas, as well as in tokamaks with reversed magnetic shear profiles [1]. Recently, the striking phenomenon of the sudden kinetic energy onset in the double tearing mode (DTM) evolution and subsequent explosive behaviors has been found in resistive MHD simulations in cylindrical geometry [2]. The DTM consists of the development of plasmoids in two nearby current sheets, and their associated nonlinear dynamics are of specific importance in reaching a full understanding of fast dynamics related to magnetic reconnection. Interestingly, the time scale of DTMs weakly depends on the resistivity η once the onset takes place. The phenomenon is crucial since the long-standing trigger problem leading to fast magnetic reconnection in collisional plasmas can be reproduced in a simple resistive MHD framework. Here, we identify a *new type of secondary nonlinear instability* as the key role for the onset of fast reconnection [3,4,5]. The free energy of the instability is found to be related to the two-dimensional asymmetry of the magnetic islands, so that the growth rate becomes weakly dependent on the resistivity.

First, DTM simulations are numerically performed, based on the reduced MHD equations in slab geometry. Figure 1 shows the nonlinear evolution of the magnetic and kinetic energies of DTMs for different system size L_y in poloidal direction which determine the linear instability. The typical type time leading to the explosive dynamics is prolonged as L_y decreased down to L_y=0.76 which saturated as L_y is further decreased. Figure 2 illustrates the snapshots of the magnetic flux contour for (a) Ly=0.75 and (b) Ly=0.76 hich corresponds to the saturated case and that exhibiting explosive dynamics. From these observations, it is considered that the system becomes nonlinearly (secondary) unstable once the magnetic islands evolve to a certain level.

To confirm this idea, a new methodology is proposed: we perform a linear stability analysis of equilibria with the magnetic islands obtained from the previous nonlinear simulations to disclose the secondary instability associated

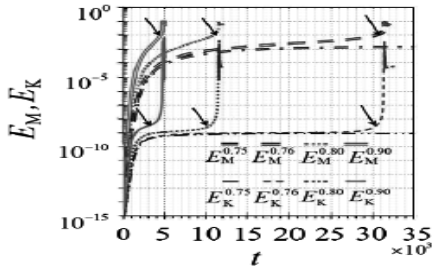

Fig. 1: Time evolution of magnetic (double line) and kinetic (single line) for the case exhibiting an explosive DTM dynamics for different value of Ly. As Ly is decreased down to Ly-0.76, the DTM lead is saturated.

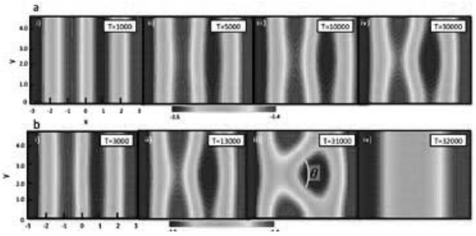

Fig. 2: Two-dimensional contour plot of the magnetic flux for Ly= 0.75 [(a), saturated DTM] and 0.76 [(b), nonlinearly destabilized DTM.

with the two-dimensional deformation of the islands. As the magnetic islands evolve on a long time scale during the Rutherford regime, we can define quasiequilibria from those structures. The variables associated with such equilibria are expressed as ψ_{eq} and ϕ_{eq} which have 2D structure. To characterize thestructural deformation of the quasi-equilibrium magnetic islands, the couple of parameters (*w*, θ) is chosen, corresponding to the width or angle rating the triangularization (shown in Fig. 2).

Figures 3(a) and 3(b) present the evolution of γ_S in function of *w* and θ for L_y=0.75→ 0:90. In the case of L_y=0.76, as *w* (and θ) increase (decrease), γ_S is decreased as expected from the linear DTM growth rate and then stabilized. However, crossing a stability window, γ_S is found to increase again around (*w*, θ) =(1.1; 155°) as the islands grow bigger. This is a strong evidence of the emergence of a new type of instability, different from linear DTM: since the instability appears while the free energy associated with the current sheets is minimal and cannot drive current instabilities, we can conclude that the new growth results from the 2D asymmetric island deformation and we refer to it as a *structure-driven nonlinearity*. Considering that the instability is induced intrinsically from the slow time scale evolution of the system, this structure-driven nonlinear instability is expected to play a key role in understanding the physical mechanism of the onset of sudden and fast magnetic reconnection events.

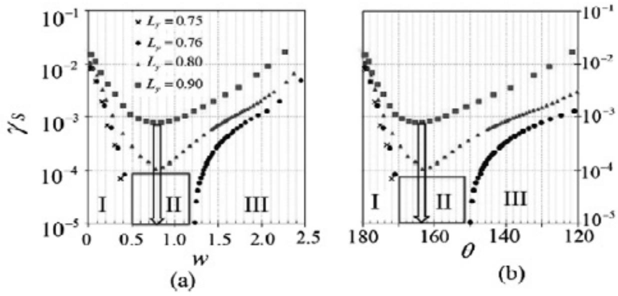

Fig. 3: Linear growth rate γ_S of instabilities in function of (a) the equilibria island width *w* and (b) the deformation angle θ for different wave numbers L_y

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