Nonlinear Dynamics of Toroidal Alfvén Eigenmode in HL-2A H-mode Plasmas

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The nonlinear dynamics of shear Alfvénic wave fluctuations have become a major concern in magnetically confined fusion, since they can be driven unstable by energetic particles (EPs). There are two routes for the Alfvénic fluctuation nonlinear dynamic evolution, with one corresponding to wave-particle phase space nonlinear dynamics dominated by resonant particles, while the other, dubbed as nonlinear wave-wave interactions, describing nonlinear spectrum evolution due to the nonlinear couplings among modes[1]. The former route can be described by the bump-on-tail paradigm or fishbone paradigm[2][3]. The latter route may take place via Compton scattering of the bulk ions and magnetohydrodynamic (MHD) nonlinearities effects as well as zonal structure generation[4]. Those theoretical predictions had been shown to be relevant in realistic fusion plasmas. On experiments, many nonlinear dynamics phenomena of shear Alfvénic wave fluctuations occur and are identified in laboratory and space plasmas.

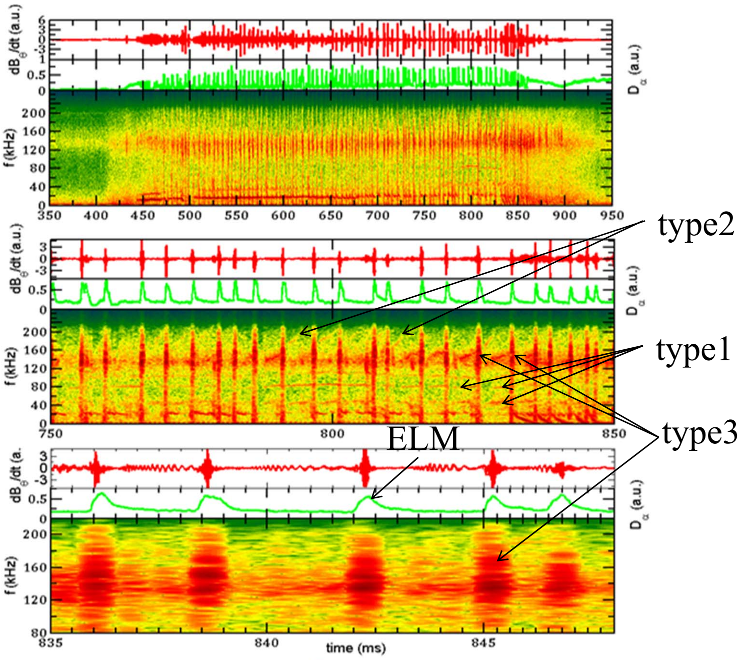

Figure 1: A typical H-mode discharge on HL-2A. dB_θ/dt, Mirnov signal (red line); D_α signal in the divertor (green line); Spectrogram of dB_θ/dt (2D pattern) (Partially enlarged view.).

In the present paper, the nonlinear dynamics of toroidal Alfvén eigenmodes (TAEs), including nonlinear wave-particle and wave-wave interactions, have been observed in HL-2A NBI H-mode plasmas. Figure 1 shows a typical H-mode discharge on HL-2A. At least, there are three type high-frequency coherent modes during inter-ELM period[5][6]. Here, we focus on the type 3. It is found that the pitch-fork phenomena of TAEs with $m = 7 - 10$ and $n = 3$ can occur continuously and become an explosive instability. The corresponding result is present in the Figure 2. These TAE modes localize in outer regions of the plasma, i.e. $\rho > 0.5$, and the simulation suggests that they are composed by multiple poloidal harmonics. There are also strong nonlinear mode couplings (NMCs) between TAEs and low frequency MHD mode (kink or fishbone) with n=1.

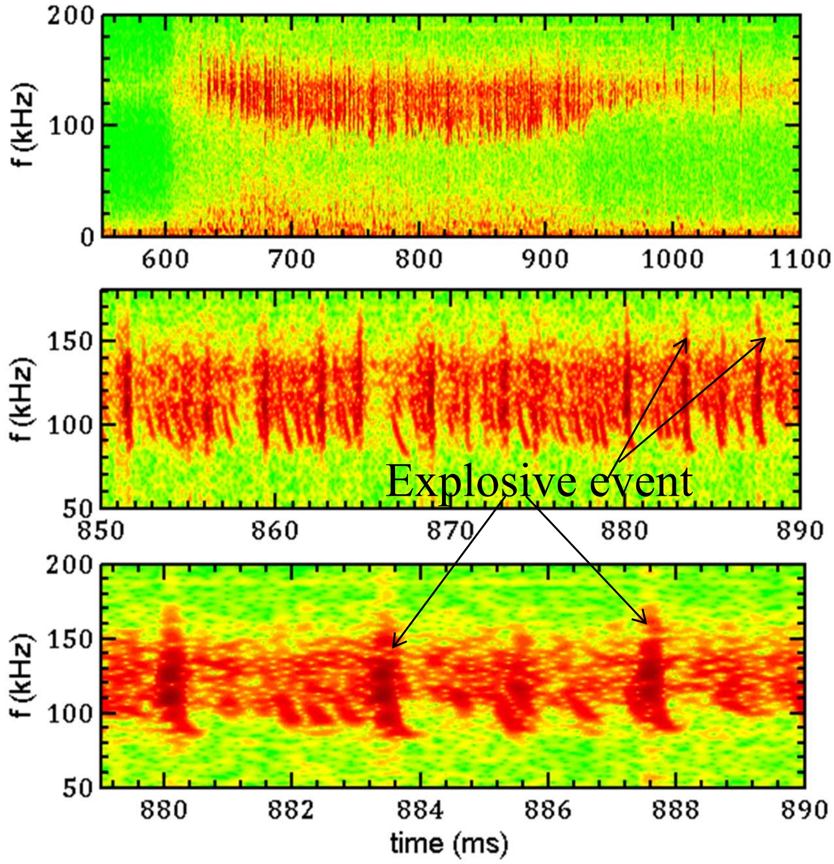

Figure 2: Nonlinear evolution of TAEs and explosive events. The 2D pattern is spectrogram of Mirnov signal (Partially enlarged view).

The explosive events have two kind fine structures, i.e., multi-modes and pitch-fork. The two kind structures can coexist, but the strong nonlinear mode coupling induces that the pitch-fork weakens or vanishes and the modes blow-up in finite-time (figure 3), and this indicates that the nonlinear mode coupling may redistribute energetic-ions, destroy hole-clump pairs in the phase-space, and induce three-wave mixing nonlinearly. As a consequence, the TAE nonlinear

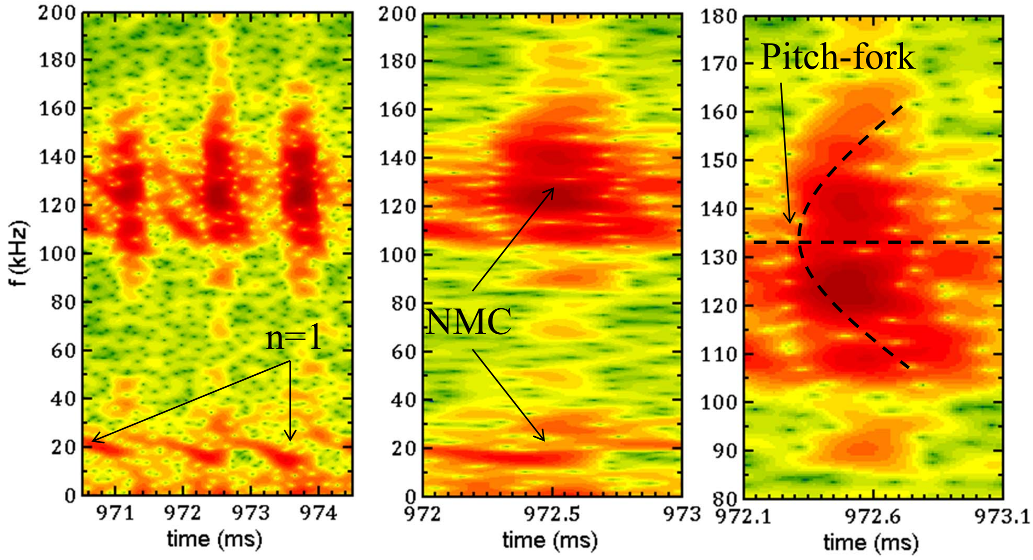

Figure 3: Two kind fine structures (i.e., mode coupling and pitch-fork) of explosive events.

dynamics can trigger the onset of ELMs and pedestal collapse within several hundred Alfvén times (figure 4-5). The experimental results also suggest that the related nonlinear dynamics can affect the ELM features, such as double-ELM or wide-ELM.

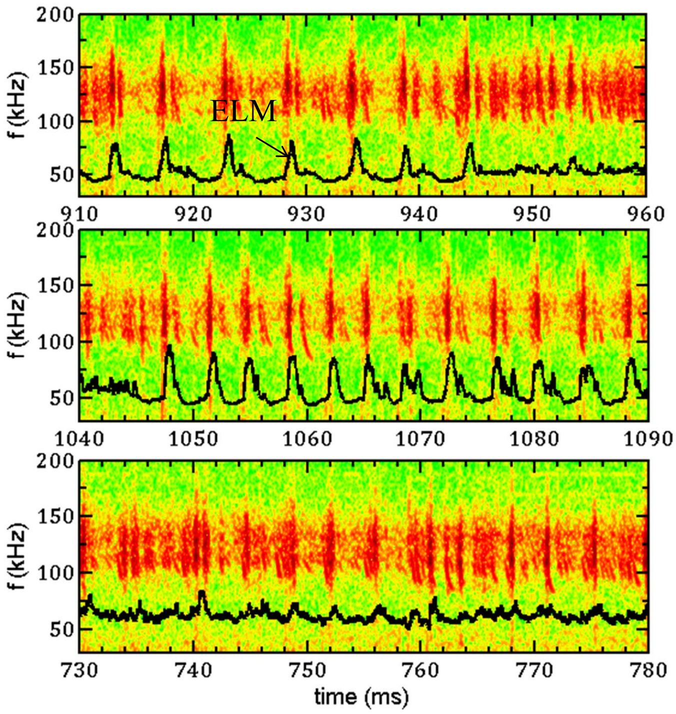

Figure 4: The onset of ELMs triggered by explosive events. Three different discharges.

The experimental result manifests that the nonlinear dynamics of Alfvén fluctuations may furnish an additional perturbation of the energetic-particle pressure in the pedestal, and this pressure perturbation can move closer to MHD limit, so that the ELM trigger is determined

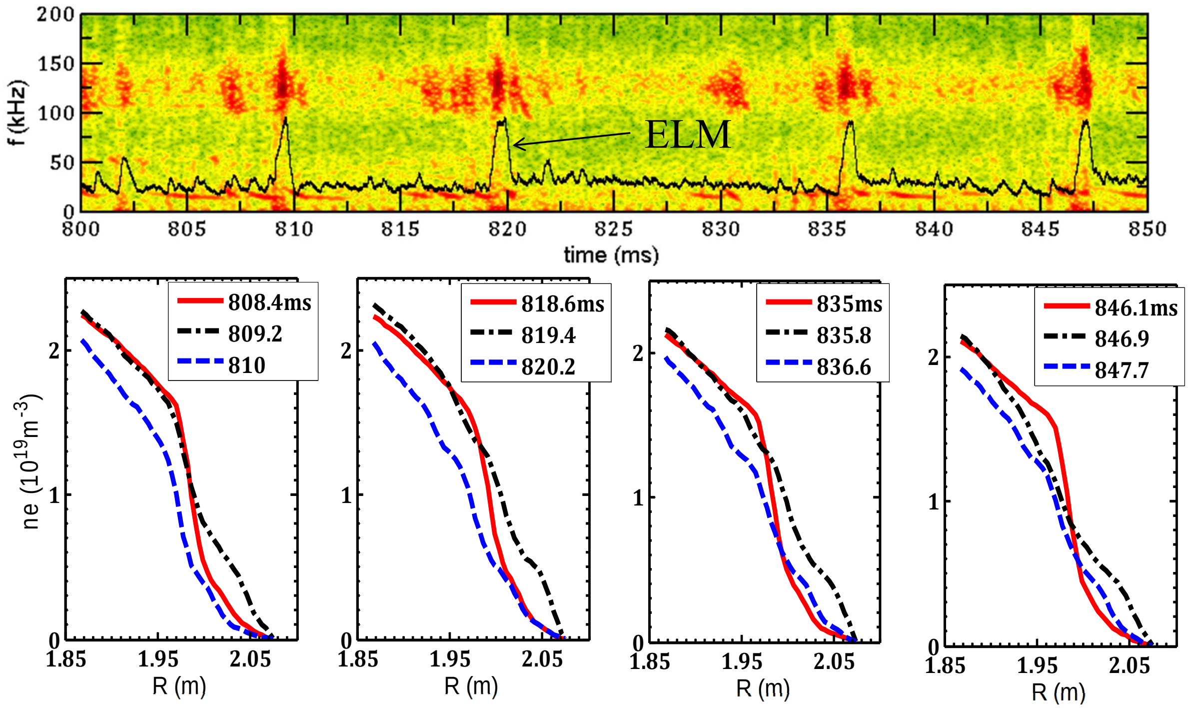

Figure 5: The pedestal collapse induced by nonlinear mode couplings. Before ELMs (red line), and ascending/descending (black/blue line) stages of ELMs.

by the nonlinear mode coupling and edge stability. These findings can help to understand the triggering mechanism of an ELM event. Moreover, following the continuous appearances of rich nonlinear dynamics phenomena, more attentions should be paid to understand the underlying mechanisms, as experimental verification of numerical simulations and analytical theory, that are developed for the predictive ability for future burning plasma scenarios.

References

[1] L. Chen and F. Zonca, *Rev. Mod. Phys.* **88**, 015008 (2016).

[2] H.L. Berk and B.N. Breizman, *Phys. Fluids B* **2**, 2226&2235&2246 (1990).

[3] F. Zonca *et al.*, *New J. Phys.* **17**, 013052 (2015).

[4] Z.Y. Qiu *et al.*, *Phys. Rev. Lett.* **120**, 135001 (2018).

[5] W.L. Zhong *et al.*, *Plasma Phys. Control. Fusion* **58**, 065001 (2016).

[6] F.M. Laggner *et al.*, *Nuclear Mater. Energy* **19**, 479 (2019).