Reconsideration of ELMs

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The Edge Localized Modes (ELMs) have been observed in the H-mode [1]. The type-I ELMs could be a substantial obstacle in realizing the fusion reactor.

Classification of ELMs was given phenomenologically, and is not necessarily based on the mechanisms. The ELM bursts have been conventionally imagined as MHD activiries (except 'dither', which is considered as limit cycles of turbulence and meso-mean plasma parameters [2,3]). A majority line of thought on the type-I ELMs employs the peeling-ballooning (P-B) mode as a central player (See, e.g., a review [4]). Nevertheless, a few essential problems remain, i.e., the identification of P-B mode in the trigger, the reason why the so-called 'resonant magnetic (RM) field' [5] is effective in suppression, etc.

Driven by these motivations, precise studies of trigger mechanisms have been made on type-III ELMs (HL-2A plasma) [6] and on type-I ELMs (JT-60U plasma) [7]. Here we report new discoveries that could rewrite the conventional picture of trigger mechanisms of ELMs.

The first example is the study of type-III ELM on HL-2A. As was reported in [6], the experimental measurement (by use of the Langumuir probe) was made in the region of transport barrier of the H-mode. Before the onset of ELM bursts, fluctuations at several tens of kHz emerge, and then turn into the streamer. The streamer is also observed on the ECEI data, and extend into the core region with the perturbation of the electron temperature (which is a few % of the mean temperature). At the sudden onset of the streamer, the burst of plasma energy occurs. The magnitude of the streamer was strong enough to induce the observed loss of energy [8].

This study rewrites the picture of the type-III ELMs, which has been thought to be results of some kind of MHD instabilities. Rather, (at least in the case that was studied) it is a transition from a localized strong radial electric field structure to the streamer. In the transport barrier, the strong radial electric field induces poloidal and toroidal flows [9]. Both flows are inhomogeneous: while the former can suppress gradient-driven turbulence so as to establish transport barrier, the latter can drive parallel velocity gradient (PVG) instability. The PVD turbulence can generate a streamer. One can propose the transition from zonal flow to streamer as a new mechanism that triggers the onset of type-III ELM.

The next example is the detailed study of type-I ELM on JT-60U [7]. As a basis for this study, Kamiya and collaborators have succeeded in identifying the P-B mode in the H-mode plasma [10]. The P-B mode was identified in the edge-harmonic oscillation, and confirmed predicted characteristics (medium poloidal mode number, parity of displacement, etc.). This observation was employed as a touchstone to identify what happens in the triggering of the type-I burst in JT-60U. As has been ubiquitously observed in 'abrupt events' in laboratory and astrophysical plasmas, in the instance of triggering bursts, '*the abrupt increment of the growth rate*' was also observed in the type-I ELMs. The property of the trigger mode was identified unambiguously that the poloidal and toroidal mode numbers are $(m, n) = (4,1)$. This implies that the mode has a resonance surface in the transport barrier region, and that it could be the tearing mode (not the P-B mode). The tearing parity of the temperature perturbation was confirmed in the precursor phase and until the real trigger happens. In addition, the strong nonthermal emission in the ECE is detected in the phase of rapid growth of the (4,1) mode, suggesting a fast reconnection.

The mechanism of trigger was studied. The onset condition of the magnetic stochasticity was analyzed based on the observed magnitude of the (4,1) mode, and was found to agree, semi-quantitatively, with the onset time of the trigger. If magnetic stochasticity takes place, the anomalous current diffusivity is switched-on, and explosive growth can happen [11]. The time scale of the explosive growth also shows semi-quantitative agreements with measurements.

These two examples urge us to reconsider the trigger mechanisms of ELMs. Results here provide a perspective to classify ELMs based on the triggering mechanisms, as well as a hope to formulate a dependable guideline to control them.

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References:
[1] ASDEX Team: Nucl. Fusion **29** (1989) 1959
[2] S.-I. Itoh, et al.: Phys. Rev. Lett. **67** (1991) 2485
[3] E. J. Kim, et al.: Phys. Rev. Lett. **90** (2003) 185006
[4] H. R. Wilson, et al.: Plasma Phys. Contr. Fus. **48** (2006) A71
[5] T. Evans, et al.: Nature Physics **2** (2006) 419
[6] J. Cheng, et al.: Nuclear Fusion **60** (2020) 086014
[7] K. Kamiya, et al.: submitted (2023)
[8] K. Itoh: J. Phys. Soc. Jpn. **90** (2021) 034502
[9] K. Itoh, et al.: Plasma Phys. Contr. Fus. **38** (1996) 1
[10] K. Kamiya, et al.: Commun. Physics (2021) 4:141
[11] P. K. Kaw, et al.: Phys. Rev. Lett.s **43** (1979) 1398