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A reduced model for pedestal dynamics and edge localized mode control in tokamak

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Edge localized modes (ELMs) control is one of the most important task to be achieved for successful ITER operation and fusion ignition. Extensive theoretical and experimental studies on ELM physics are carried to develop reliable ELM control methods. Fueling methods, supersonic molecular beam injection (SMBI) and pellet injection (PI), are employed to control ELMs. To study the dynamics of H-mode pedestal with ELMs, and their control by SMBI and PI, we develop a diffusive, bistable, tri-unstable cellular automata (CA) model.[1]

It is found that the extended CA model does recover the key features of the H-mode pedestal with Type-I ELMs. When the number of fueling grains N_F exceeds a certain threshold, H-mode pedestal is generated. Avalanche transport events triggered by ballooning instabilities appear and regulate the pedestal. If N_F is increased further, Type-I ELMs triggered by peeling instabilities appear periodically. The avalanche transports triggered by ballooning instabilities also appear in between the Type-I ELMs. The frequency of Type-I ELMs increases as N_F increases, which is analogous to the increase in Type-I ELM frequency in H-mode experiments with an increasing input power.

SMBI and PI are modeled as additional grain injections into pedestal with varying degrees of injected materials and profiles. It was found that global transport avalanches triggered by ballooning instabilities are enhanced if SMBI is applied on the H-model pedestal with Type-I ELMs. The enhanced transports prevent the total current in the pedestal from reaching the peeling criterion. Then, Type-I ELMs disappear and big periodic collapses of the pedestal by the ELMs are replaced with more irregular and smaller transport events. It was noted that SMBI induces different structural changes in the distribution of transport avalanches depending on the baseline fueling N_F. If the fueling N_F is large enough to allow Type-I ELM, SMBI makes transport avalanches bigger. The resulting transport enhancement leads to the disappearance of Type-I ELM. On the other hand, if the fueling N_F is low enough to avoid Type-I ELM, SMBI enhances small scale avalanches. Then, these local avalanches regulate the pedestal from growing globally unstable to pressure gradient driven ballooning instabilities, which leads to the mitigation of Type-II/III ELMs.

The CA modellings of PI showed that the pellet pacing of Type-IELM can be achieved if the injections are made with sufficient strength near the top of H-mode pedestal. If PIs successfully trigger Type-I ELMs, the height and gradient of H-mode pedestal are found to follow different evolution paths to reduce the ELM sizes from those of the natural Type-I ELMs. However, it was also found that the efficiency of pellet pacing decreases as the injection frequency increases. It is because multiple PIs can be made without proper time intervals to allow the growth of H-mode pedestal from previous collapses by Type-I ELMs. When PIs fail to trigger ELMs, they increase the pedestal pressure like additional fueling. Later, bigger ELMs triggered by either PIs or spontaneous processes follow. Scanning the frequency of pellet injection, it is found that a maximum efficiency of pellet pacing is achieved when the injection frequency is approximately the ten times of the natural frequency of Type-I ELM.

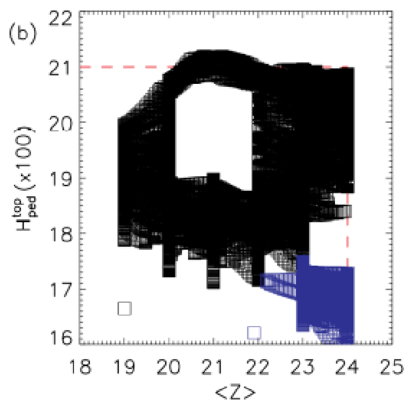

Figure 1. Simulated result of the evolution of pedestal top (H_{ped}^{top} meaning total bootstrap current) vs averaged pedestal gradient ($\langle Z \rangle$ meaning averaged ∇P) during ELM cycles. Black and blue squares represent the phase space evolutions of type-I and type-II/III ELM, respectively.

Reference
[1] T. Rhee, J.-M. Kwon, P.H. Diamond, Phys. Plasmas **27**, 072503 (2020)