Comparison of small ELM characteristics and regimes in Alcator C-Mod, MAST, and NSTX

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We report on a set of ITPA-endorsed experiments among the Alcator C-Mod, MAST and NSTX devices to compare the characteristics of small edge-localized modes (ELMs) and the conditions in which they can be obtained. Specifically small ELM discharges were developed in each of the machines, and common features were identified, both in terms of ELM structure and operational windows. A common observation is an apparent β_{ped} threshold for small ELM access, although the threshold value varied widely between the devices.

The urgency for development of small and no ELM scenarios has increased with the recent revision of the allowable ELM size in ITER to 1 MJ, representing about 0.3% of the 350 MJ plasma stored energy. Two approaches to mitigate large Type I ELMs being tested in the community include the use of Resonant Magnetic Perturbations (RMP)[1] and pellet pace-making[2]. In Alcator C-Mod, the Enhanced D_α (EDA) regime has been shown[3] to have individual small ELMs at sufficiently high pedestal temperature and/or β. In MAST small ELMs have been observed in specific circumstances, described in detail below. Finally in NSTX a small ELM regime, termed Type V ELMs, has been shown to have a wide operating window with unique ELM structure[4]. The poloidal cross-sections were matched approximately in discharges in the three devices, with a minor radius scale factor of 2.9. An electron collisionality ν_e^* and pedestal β scan were obtained in each machine to determine the threshold conditions under which small ELMs were observed.

In the Alcator C-Mod device, the small ELM regime was observed in a lower-single null boundary shape (κ=1.7, δ=0.5, δ_r^{sep} ~ -5mm). An apparent rf power threshold of ~ 3 MW is required to access small ELMs, and these ELMs are still present at the highest rf power level of 4.5 MW. There is thus an apparent lower β_{ped} threshold ~ 0.25% (Figure 1), with no sign of an upper value up to β_{ped} ~ 0.5%. The pedestal top ν_e^* range is between 0.5 and 4. These ELMs are visible on the edge soft X-ray emission, fast magnetics, and gas puff imaging diagnostic, although their individual impact on stored energy is indiscernible from the statistical noise on equilibrium reconstructions.

In the MAST device, small ELMs have been obtained in double-null boundary shapes (κ=1.9, δ=0.43, δ_r^{sep} ~ 0mm). The small ELMs occur over a wide collisionality range: $1.5 < \nu_e^* < 20$ (Figure 1), inter-mixed with Type III ELMs in the upper range while completely disappearing at the lower range as Type I ELMs appeared at high β_{ped}. The small ELMs have a high-n structure, with more filaments than the 10-20 typically observed[5] during Type I ELMs. The dynamics differ also: most of the filaments do not detach from the plasma, and the dynamic evolution of the filaments is observed with a fast visible camera.

In the NSTX device, two distinct classes of small ELMs have been identified. In near double-null boundary shapes that slightly favor the lower divertor and are otherwise similar to the MAST device shapes (κ=1.8, δ=0.5, -2mm < δ_r^{sep} < -6mm), an intermediate-n small ELM has been identified in a narrow β_{ped} window. In discharges that more strongly favor the lower divertor (δ_r^{sep} ~ -15mm), the classic type V ELM regime with single or double filaments in a broad β_{ped} window is recovered. At the upper end of the β_{ped} operational space in Figure 1, a return to a mixed Type I ELM and Type V ELM regime was observed.

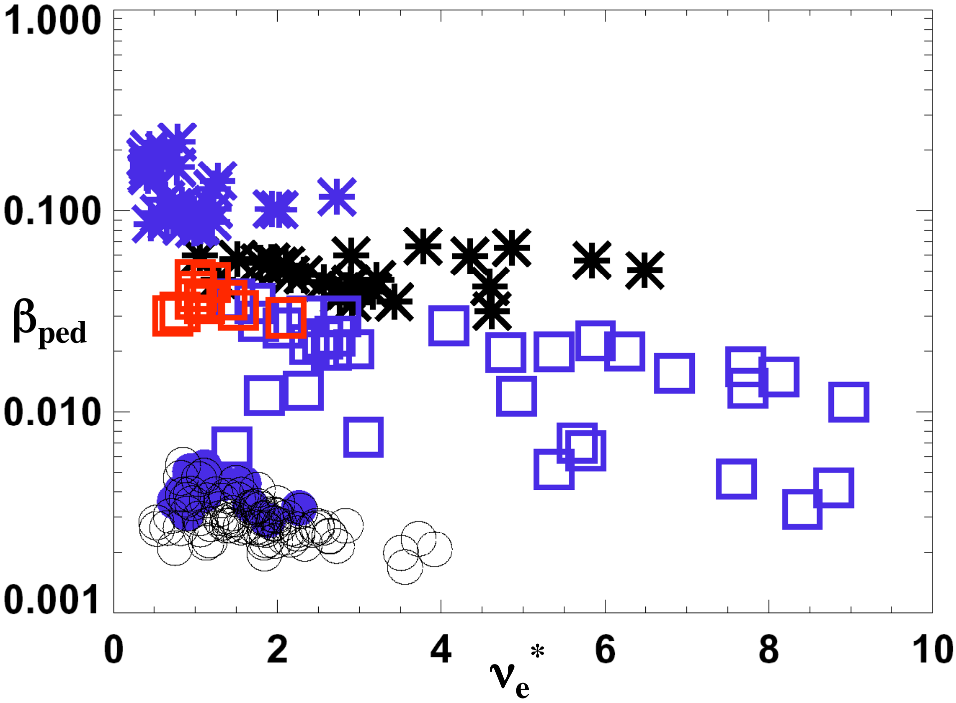

Figure 1: Small ELM edge operational space in Alcator C-Mod (circles), MAST (squares), and NSTX (stars). The color BLACK signifies no small ELMs, BLUE signifies that small ELMs were observed, and RED signifies large ELMs only, i.e. no small ELMs.

One straightforward conclusion from these studies is that small ELMs can indeed have different toroidal mode structure and operational windows, even within a single device. Thus there may be multiple scenarios by which small ELMs could be achieved naturally in ITER. All of these scenarios have apparent β_{ped} windows, although the details differ between the devices. Stability analysis of these ELMs is complicated by the fact that the resulting profile relaxation is quite subtle. Ideal MHD calculations of the NSTX discharges indicated stability to low-n and high-n ideal modes, possibly pointing to the need for resistive MHD calculations.

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