ELM Mitigation by Supersonic Molecular Beam Injection: KSTAR and HL-2A Experiments and Theory


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Abstract: We report recent experimental results on ELM mitigation by Supersonic Molecular Beam Injection (SMBI) on HL-2A and KSTAR. Cold particle deposition by SMBI within the pedestal is verified in both machines. The signatures of ELM mitigation by SMBI are an ELM frequency increase and ELM amplitude decrease which persist for an SMBI influence time \( \tau_I \) (\( \tau_I \) duration for the SMBI influenced pedestal profile to refill). An increase in \( f_{\text{ELM}} \), i.e., a decrease of the energy loss per ELM \( \Delta W_{\text{ELM}} \) were achieved in both machines. Physical insight was gleaned from studies of density and \( v_T \) evolution, particle flux and turbulence spectra, divertor heat load and ELM filament structures. The characteristic gradients of the pedestal density soften and a change of \( v_T \) was observed during a \( \tau_I \) time. The spectrum of edge particle flux \( \Gamma \sim <v_T^2> \) with and without SMBI was observed in HL-2A. A clear phenomenon observed is a divertor heat load decrease during the \( \tau_I \) time in HL-2A. A similar result is the profile of saturation current density \( I_{\text{sat}} \) with and without SMBI in KSTAR. A reduction of the filament amplitude is apparent during a \( \tau_I \) time. We note that \( \tau_I/L_T \) (particle confinement time) is close to \( \sim 1 \), although there is a large difference in individual \( \tau_I \) between the two machines. This suggests that \( \tau_I \) is strongly related to particle transport events during ELM mitigation by SMBI. Experiments and theory support the important conclusion that ELM mitigation by SMBI results from an increase in high frequency fluctuations and transport events in the pedestal, and inhibits the occurrence of large transport events which span the entire pedestal width.

1. Introduction

H-mode is characterized by an edge pedestal or edge transport barrier (ETB) as it is manifested on the profiles of the plasma density, temperature. In ELMy H-mode, the plasma edge is a region of crucial importance due to its influence on plasma confinement and performance. ELMy H-mode exhibits fast, quasiperiodic short bursts called edge localized modes (ELMs), which eject particles and energy from plasma. ELM losses will have a significant negative impact on the net thermal generation efficiency and involves the interaction of the large energy impulses released by each ELM with the plasma facing surfaces (PFCs). Depending on the interaction area of the ELMs with divertor and main chamber PFCs, material erosion limits require that this energy must be reduced to prevent an accelerated degradation of the divertors and wall surfaces [1]. A central question for ITER [2] is whether external control tools can be developed to reduce the ELM size to acceptable values while maintaining good confinement. An effective control scheme should show an increase in the actual ELM frequency relative to the intrinsic ELM frequency in \( f_{\text{ELM}} \). Since the relation \( f_{\text{ELM}} \Delta W_{\text{ELM}} \approx \text{const.} \), with \( W_{\text{ELM}} \) the energy loss per ELM [3], holds for intrinsic ELMs on many diverted tokamaks, increasing the frequency should decrease \( W_{\text{ELM}} \), as we desire. Some techniques are
reported in [4]. Both such physics problems require tuning the macroscopic relaxation oscillations of a self-organized criticality which can manifest spatiotemporal chaos and cyclic bursts. In particular, the aim of ELM control is to eliminate the largest transport events, which cause the largest impulsive heat loads on the divertor.

In this work we describe an experimental demonstration of ELM mitigation by SMBI in HL-2A and KSTAR, and elucidate the physics of this result. The organization of this article is as follows: i) the SMBI system were introduced in second section, the third section gives the particle source deposition and the optimized parameters of SMBI pulses. The fourth part presents the basic experimental results, then a simple model is discussed in sixth section, the importance of \( \tau_e/\tau_p \) is discussed in seventh part, and the last is the conclusions and discussions.

2. History of SMBI and its application in HL-2A and KSTAR

SMBI system was performed in HL-1M to be used on the plasma fuelling for the first time since 1998 [5]. On HL-2A tokamak [6], there are two SMBI systems in LFS and HFS after some upgrade of the SMBI systems [7]. LFS SMBI system was reported in this paper on the ELM mitigation for the first time in 2010. For the SMBI system in LFS, the backing pressure could high to 60 bars, and the duration is >0.5 ms. Also, a turbo-molecular pump with the capacity of 450 L/s was applied to maintain a low background neutral gas pressure during the injection [7]. 4 ms SMBI pulse duration was used for the ELM mitigation experiment in HL-2A [8]. In the KSTAR tokamak, successful experiments of the SMBI fuelling and ELM mitigation have been operated in 2011 [9]. The SMBI system was newly installed at a median port of the vacuum vessel to explore the ELM mitigation by SMBI. The characteristic of the pulse valve of the SMBI system could be performed at the room temperature and at 105K. The gas pressure range of SMBI system in KSTAR is from 0.4 to 2.2 MPa. 8 ms SMBI pulse duration was used for ELM mitigation experiment in KSTAR [9, 10].

3. Characteristics of the SMBI system for the ELM mitigation

3.1 Penetration and particle source position in pedestal region

As a fuelling tool, SMBI has superior characteristics, such as good local particle source, good fuelling direction, high gas speed and high fueling efficiency. The typical difference is that the recycling of SMBI is lower than normal gas puffing [7]. These characteristics support trying the experiment of ELM mitigation by SMBI. Local deposition of particle close to the pedestal foot is a key point in this experiment. The local particle source can be determined by the maximum of the derivative of the density in time at the beginning of the density modulation [11], when density evolution is dominated by the particle source. The cold particle source position for one SMBI pulse can be confirmed using the rate of density increase with time \( \partial_t n_e \).

In same way, deposition of neutral gas into the pedestal is achieved in H-mode discharges. The particle source position is confirmed as shown in figure 1, which shows the experimental results for the particle source position and pedestal structure.

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\begin{align*}
\text{Fig. 1: (a) is the local particle source position. (b) is the pedestal density profiles with and without SMBI. The red arrow indicates the particle source position in HL-2A.}
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Figure 1 (a) is the \( \partial n_e \) and the square curve is a signal of the SMBI electron magnet valve. The arrow shows the local particle source position at \( R \sim 2.01-2.02 \). The pedestal structure was measured by microwave reflectometry [12]. The density pedestal is about \( 1.26 \times 10^{19} \text{m}^{-3} \) and the pedestal width is about 3.3 cm. The separatrix position is \( \sim 2.03 \) m as shown by the dash line in figure 1 (b). Third arrow indicates the particle source position corresponding to (a) the white arrow. It indicates that the injected cold particles are indeed deposited just inside of the separatrix, as shown in the white ellipse in figure 1 (a) and the red arrow in figure 1 (b). It is very clear that the particle source position is shallow and just inside of the separatrix.

3.2 Optimized parameter of SMBI pulses

In order to find a set of suitable parameters for the SMBI pulses in ELM mitigation experiments, comparative experiments have been performed in HL-2A. Optimized SMBI duration in the ELM mitigation experiments has been successfully conducted as shown by figure 2, which presents the relation between individual SMBI pulse duration \( \tau_{\text{pulse}} \) and \( \tau_I \), the SMBI persistence influence time. For the gas pressure of 1.1 MPa in figure 2 (a), there is no effect of ELM mitigation for 2 ms SMBI duration as shown by the star, while ELM mitigation results appear for 4 ms and 6 ms SMBI duration. However, for gas pressure of 2.0 MPa shown in figure 2 (b), the ELM mitigation effect with 4 ms SMBI duration is more striking than that for 2 ms SMBI duration. For the ELM mitigation by SMBI, the optimized parameters of the SMBI are the gas pressure of 2 MPa and the pulse duration \( \tau_{\text{pulse}} \) of 4 ms for the HL-2A tokamak. In KSTAR, the gas pressure range of SMBI system is 1.0 MPa and the SMBI pulse duration is 8 ms for the ELM mitigation experiment. These parameters show that the particle source (neutral gas) local position is necessary to perform ELM mitigation by SMBI.

4. Experiments of ELM mitigation by SMBI in HL-2A and KSTAR

4.1 Density and rotation evolution with and without SMBI

A pioneering experiment on ELM mitigation by SMBI was performed on HL-2A [8]. We observed an ELM frequency increase and an ELM amplitude decrease during an SMBI influence time \( \tau_I \) for the type III ELMs [6]. Increases in frequency of \( f_{\text{ELM}}^{\text{SMBI}}/f_{\text{ELM}}^0 \sim 2-3.5 \) were achieved. In particular, the pedestal density gradient scale length is changed during \( \tau_I \). The ELM mitigation by SMBI in KSTAR for the large ELMs and HL-2A for the type III ELMs is shown in figure 3. Here, (a) is the ELM monitor signal of ELM in KSTAR, (b) the \( D_a \) ELM monitor and (c) the density profiles at different times 701ms, 722ms, 731ms and 737ms in HL-2A. Density profile analysis indicates a distinct difference in pedestal density gradient steepness upon comparison of the profiles with and without SMBI. The density gradient softens immediately following SMBI, while the density gradient without SMBI is steeper than that with SMBI. These correspond to the times indicated in (b) by the arrows. It shows that the density gradient softens (becomes less steep) immediately following SMBI. After a \( \tau_I \), the steep density gradient state is recovered. Similar density profiles evolution also were observed for shot 19425 in figure 1 (b). These observations suggest that the pedestal particle...
confinement is degraded by SMBI. More dramatic results in ELM mitigation by SMBI were achieved in KSTAR[5]. Not only an increase in frequency of $f_{ELM}^{SMBI}/f_{ELM}^{0} \sim 2-3.5$ was observed, but also the ELM amplitude decreased for a $\tau_{I}$ time, which is several hundred $ms$ in figure 3 (a). An experimental indication of ELM mitigation by SMBI is shown by the fact that ELM frequency increased from 28Hz to 68Hz and ELM amplitude dropped by half after an SMBI for the large ELMs in KSTAR. The SMBI influence time $\tau_{I}$ is about 400ms and about 8% of the stored energy is lost with slight confinement degradation. The core toroidal rotation (by XICS) is also observed to drop from~150km/s to~132km/s during $\tau_{I}$, then slowly recover to~143km/s. A novel physics result of this work is the observation that the plasma toroidal rotation $v_{\phi}$ changes. The duration of the change of $v_{\phi}$ can be comparable to the SMBI influence time $\tau_{I}$ as shown in figure 4 for shots 6376 and 6353 (both shots have same discharge parameters) in KSTAR. The ELM amplitude decreases and ELM frequency increases during a $\tau_{I}$ (~300 ms) time, as shown in figure 4 (a). The key point is that after SMBI, the core plasma toroidal rotation decreases sharply, and then slowly recovers to $v_{\phi0} \sim 143$km/s at the end of $\tau_{I}$, as shown in figure 4 (b) by the red bar. Before the SMBI, $v_{\phi}$ is larger than $v_{\phi0}$, while after SMBI, $v_{\phi} < v_{\phi0}$ during a $\tau_{I}$ time, then the core plasma toroidal rotation increases and reaches or exceeds the $v_{\phi0}$ value at the end of $\tau_{I}$. The difference in the core plasma toroidal rotation is shown by the gap between the level dashed lines in figure 4 (b), and it can be repeated for the same discharge conditions in KSTAR, shots 6376 and 6353. An approach to a possible explanation has been presented in [8, 13]. The key point of this result is that SMBI deposition in the pedestal inhibits the formation of the largest, most extended transport events and ELMs, which span the full width of the pedestal. This indicates that during ELM mitigation by SMBI, core toroidal rotation is changed because the SMBI softens the edge pressure gradient and consequently the ETB electric field shear thus reduces the ETB momentum confinement as well as intrinsic rotation drive. It is consistent with the suggestion that the density gradient scale length in the pedestal region softens in response to an SMBI pulse injection as observed in HL-2A.

### 4.2 Fluctuation induced particle flux

Particle flux was measured by Langmuir probe (LP) [14] with and without SMBI at the plasma edge and close to the pedestal foot in HL-2A. A change in the spectrum of edge particle flux $<\tilde{v}, \tilde{v}>$ during

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**Fig. 3**: (a) is the $D_{0}$ of ELM mitigation by SMBI in KSTAR. (b) is the $D_{0}$ ELM monitor and (c) is the density profiles at different times in HL-2A.

**Fig. 4**: A change of core plasma toroidal rotation during a $\tau_{I}$ time in KSTAR.
ELM mitigation by SMBI was observed, as shown in figure 5 for shot 16248. Here, \(\bar{v}_r\) is the radial velocity perturbation, \(\bar{n}_e\) is the density perturbation. The red square is after SMBI and blue circle is before SMBI. It is clear that with SMBI, the low frequency (\(<10kHz\), grey bar left) content of the edge particle flux spectrum decreases, while there is some indication that the higher frequency (\(>10kHz\), grey bar right) content increases. The changes in the edge particle flux suggests that ELM mitigation results from an increase in higher frequency fluctuations and transport events in the pedestal [8]. This is consistent with the idea that SMBI inhibits the formation of large (low frequency) avalanches or transport events, while triggering more small (high frequency) avalanches [13, 15].

4.3 Divertor signatures in ELM mitigation by SMBI

The divertor plate is the part of the in-vessel components exposed to the highest heat load. A critical issue for the plasma facing components in tokamaks is the high transient heat loads associated with the type I ELMs, which can lead to rapid erosion of the divertor plates if not addressed. So, a main goal of ELM mitigation is to strongly reduce the ELM energy losses while maintaining adequate confinement. Basic signatures in divertor of the ELM mitigation by SMBI were observed on the saturation current density profiles and the evolution of the heat loading in divertor.

The effect of ELM mitigation by SMBI was also investigated by through the profiles of the ion saturation current density \(J_{sat}\), which was measured by LP [16] in the inner and outer divertor plates. The profiles of the \(J_{sat}\) are shown in figure 6 (a). Here, \(J_{sat} \sim Cn_eT_e^{0.5}\) for \(T_e>>T_i\) (\(C\) is a constant, \(n_e\) is density and \(T_e\) is electron temperature). Since \(n_e=\langle n_e \rangle + \bar{n}_e\), this means there is a relation between \(J_{sat}\) and particle flux \(\Gamma \sim \langle \bar{v}_r \bar{n}_e \rangle\). Figure 6 (a) shows the \(J_{sat}\) profiles in the outer divertor (There is no distinct change of the particle flux with and without SMBI in the inner divertor of KSTAR, similar to JET’s results [17]). The particle flux drops strongly (almost fallen by half) with SMBI, in comparison to without SMBI. Thus is the main aim to mitigate the energy load on the divertor or share heating load of the divertor via ELM mitigation by SMBI. Figure 6 (b), the spectrum analysis of \(J_{sat}\) was observed in ELM mitigation experiments. The chosen data of the LP are marked using the dash line arrow in figure 6 (a). A comparison of amplitude of the \(J_{sat}\) is shown in figure 6 (b) in both cases, as the red curve and the blue curve. It suggests that with SMBI, the spectrum of the low frequency content (\(<10kHz\), grey bar left) decreases clearly, while there is some indication that the higher frequency content (\(>10kHz\), grey bar right) increases. Information on the high frequency content of \(J_{sat}\) is limited by the probe sampling frequency. The results of the spectrum analysis of \(J_{sat}\) suggest the conclusion that the main contribution of drop of the particle flux in figure

![Fig. 5: Particle flux measurement for the ELM mitigation by SMBI in HL-2A.](image)

![Fig. 6: (a) is the measurement results by LP in outer divertor with and without SMBI for shot 6352. (b) is the spectrum analysis of \(J_{sat}\) in KSTAR.](image)
6 (a) is from the decrease in the low frequency region in figure 5 (b). It is similar to the results for the edge particle flux in HL-2A, as shown in figure 5.

The power handled by the divertor depends on the input power and the amount of radiated power. The life time of the divertor targets in future fusion devices depends on our capability of controlling the heat load on the divertor target. Divertor heat load has been successfully reduced in HL-2A, as shown in figure 7. The heat load during ELM mitigation by SMBI was measured by LP. This result shows the heat load evolution with time, with and without SMBI. Figure 7 (a) is the Da ELM minitor and (b) is the heat load evolution with time. An SMBI pulse was injected at 500 ms. The ELM frequency increases and amplitude decreases during a $\tau_I$ ($\sim 25$ ms), as shown in figure 7 (a). During the $\tau_I$ time, the heat load on the divertor was reduced and recovered slowly at the end of $\tau_I$ (The color bar means the heat power intensity). A reduction in the ELM peak heat flux as the ELM size decreases is observed. It is consistent with the change of the $J_{sat}$ with and without SMBI in figure 6 (a). Thus means the divertor target material could be prevented from eroding by the larger ELMs. This is also the main goal of the ELM mitigation. These result illustrates directly that it is possible to mitigate the ELMs to prevent target.

4.4 Change of filaments

Figure 8 shows clear experimental indication of ELM mitigation by SMBI from ECEI measurements. (a) is the history of the $D_a$ ELM monitor. (b), (c) and (d) are ECEI [11, 12] images for shot 6352. After the SMBI, the ELM frequency increases from 28Hz to 68Hz and the ELM amplitude drops by more than half. The $\tau_I$ is about 400ms. Three special times are chosen to analyze 2-D filament structures by ECEI, before SMBI, during $\tau_I$ and after $\tau_I$. Before SMBI, large filament structures are shown. During $\tau_I$, just after about 0.1s of the SMBI, a reduction of the filament amplitude after the SMBI is apparent. After $\tau_I$, at ~ 3.1s, the filament structures are similar to before SMBI. The arrows show the poloidal rotation at plasma edge. The direction of the poloidal rotation is in the electron diamagnetic direction. In (b), (c) and (d) boxes, the maximum distance between filaments is marked using $L_1$, $L_2$ and $L_3$. Evidently, $L_1 > L_3 > L_2$, it shows that the filament scale decreases during $\tau_I$ because of SMBI pulse injection and the filament structures recover slowly after $\tau_I$, as shown in (d).

Intuitively, based on the evolutions of the filament distances, the change in distance of the filaments indicates SMBI inhibits the formation of large transport events, while inducing more small transport events during $\tau_I$. 

Fig. 7: Heat load evolution with and without SMBI for shot 16246 in HL-2A

Fig. 8: (a) is the history of the ELM monitor for shot 6352. (b), (c) and (d) are 2-D filament structures by ECEI at the corresponding times as the arrows.
5. Theory model of the ELM mitigation by SMBI

A simplified model study using a bi-stable cellular automata model was used to understand the shallow particle deposition effect of SMBI on ELM mitigation. Through the sand-pile model study, it was shown that shallow particle deposition induced frequent small ejection which prevented formation of large crashes. For the deep particle deposition, the mitigation effect of large crashes was rarely observed. The basic model is described in [15] and consists of a sand pile with an ejecting boundary on one side, a bi-stable toppling rule, noise-driven scattering to emulate collision diffusion, and an ultimate upper hard threshold on the occupation density for relaxation of the gradient, to emulate the trigger for ELM events. Here, the bi-stable toppling rule for the pile incorporates basic aspects of L and H phase turbulent transport. The hard threshold models an upper limit on profile steepness, as in a \((\nabla p)_{\text{crit}}\) for MHD instabilities, frequently associated with ELMs. ELMs occur when the entire edge pedal region is populated up to the hard threshold limit, and appear as ejection events driven by avalanches, which span the full pedestal cross-section. The trends indicated by this simplified model study are all qualitatively consistent with the experimentally observed trends, and suggests that shallow SMBI deposition into the pedestal mitigates ELMs by reducing the population of large avalanche transport events, while increasing the number of smaller events. Also, pedestal gradients flatten at the deposition position. The experiments, in section 4 on the ELM mitigation by SMBI in HL-2A and KSTAR, support the prediction of the sand-pile model in explaining the possible physical mechanism of the ELM mitigation by SMBI.

6. Importance of \(\tau_f/\tau_p\) in ELM mitigation by SMBI

In the ELM mitigation by SMBI, it was observed that the \(\tau_i\) is about 15-25 ms in HL-2A and about 250-400ms in KSTAR, respectively. It is quite different in both machines. \(\tau_i\) is close to the \(\tau_E\) in HL-2A (\(\tau_E \approx 20-30\)ms) but much larger than the \(\tau_E\) in KSTAR (\(\tau_E \approx 110-140\) ms [19]). Ohmic particle confinement improvement is described by an \(H_p\) factor (\(H_p = \tau_p/\tau_E\)) and the \(\tau_p\) has been defined by some theoretical analysis [20]. While for the H-mode case, the relationship between the \(\tau_p\) and the \(\tau_E\) was examined based on experiments. The ratio of \(\tau_p\) to \(\tau_E\) is about 1 in the low density regime (linear correlation region), but for the high line averaged density regime, this ratio is about larger than 2 [21]. It was shown that \(\tau_p\) depends strongly on the line averaged density, while the dependence of \(\tau_E\) on density is weaker [21]. In order to understand the property of \(\tau_f/\tau_p\) in ELM mitigation by SMBI, we distinguish this experiment with low line averaged density regime and high line averaged density regime corresponding to HL-2A (about 1.5-2×10^{19} m^{-3}) and KSTAR (about 3.3-3.8×10^{19} m^{-3}). It is useful to understand the physics of \(\tau_f/\tau_p\): whether the long or short \(\tau_i\) results from particle confinement, in other words, whether there is a approximate constant ratio of \(\tau_f/\tau_p\). An estimated ratio of \(\tau_f/\tau_E\) is about 1 in 1.8×10^{19} m^{-3} in HL-2A, and the ratio of \(\tau_f/\tau_E\) is about 2.4 in 3.5×10^{19} m^{-3} in KSTAR. We can get the ratio of \(\tau_f/\tau_p\approx 1\) with a averaged \(\tau_f\) of 20 ms in HL-2A (\(\tau_p/\tau_E\approx 1\)), and also get the ratio of \(\tau_f/\tau_p\approx 1\) with a averaged \(\tau_f\) of 300 ms in KSTAR (\(\tau_p/\tau_E\approx 2.4\)). That means the there would be an approximate constant ratio of \(\tau_f/\tau_p\) in both machines, i.e. \(\tau_f/\tau_p\approx 1\). It indicates that the contributions of the SMBI persistence influence time \(\tau_i\) is dominated by the particle confinement, thus the particle transport events play important roles in the ELM mitigation by SMBI. SMBI (into the pedestal) breaks the pre-existing transport process and induces a new transport state, i.e. SMBI inhibits the formation of large transport events, while triggering more small avalanches [8, 9, 13, 15].
7. Conclusions and discussions

ELM mitigation by SMBI pulse injection into the pedestal region was achieved in two different machines, HL-2A and KSTAR. An increase in \( f_{ELM}^{SMBI} / f_{ELM}^{0} \sim 2-3.5 \) and a decrease of the energy loss per ELM \( \Delta W_{ELM} \) were achieved in both machines. These experimental results show that the frequency and the amplitude of ELMs can be actively controlled by SMBI using an optimized duration SMBI pulse and achieving a good local particle deposition (close to the pedestal foot, shallow penetration depth).

Physical interpretation was presented: i) The characteristic slopes of the pedestal density are softened during a \( \tau_f \) time and the \( v_{\phi} \) drops at the injection time of SMBI and then recovers at then end of \( \tau_f \). ii) The spectra of edge particle flux was measured by Langmuir probe with and without SMBI in HL-2A. It is clear that with SMBI, the low frequency (\(<10kHz\)) content of the edge particle flux spectrum decreases, while there is some indication that the higher frequency (\(>10kHz\)) content increases. The changes in the edge particle flux suggests that ELM mitigation results from an increase in higher frequency fluctuations and transport events in the pedestal. A similar result on the comparison of the amplitude of the \( J_{sat} \) in divertor was observed in KSTAR. It shows that with SMBI, the low frequency content of the spectrum (\(<10kHz\)) decreases, while there is some indication that the higher frequency content (\(>10kHz\)) increases. One conclusion of the change of \( J_{sat} \) indicates the main contribution of the drop of the particle flux is from the decrease in the low frequency region. iii) Clearly, the divertor heat load decreased during a \( \tau_f \) time, as measured in HL-2A, and it is consistent with the profiles of saturation current density \( J_{sat} \) with and without SMBI in KSTAR. Also a reduction of the filament amplitude in KSTAR is apparent during a \( \tau_f \) time.

An interesting observation is that the ratio \( \tau_f/\tau_p \) is close to 1. It suggests that \( \tau_f \) is strongly related to the transport events during ELM mitigation by SMBI. Experiments and theory support the important conclusion that ELM mitigation by SMBI results from an increase in higher frequency fluctuations and transport events in the pedestal, while inhibiting the occurrence of large transport events which span the entire pedestal width. It also indicates that there would be an approximately constant (\( \tau_f/\tau_p \sim 1 \)) on the ratio \( \tau_f/\tau_p \) in both machines, i.e., the contributions of \( \tau_f \) is set by the particle transport events, which regulate pedestal building and refilling after SMBI.

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