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The effects of triangularity and main ion species on the inter-ELM profile evolution in ASDEX Upgrade

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In high confinement mode (H-mode) plasmas the steep gradients at the plasma edge (called pedestal) are quasi-periodically destabilised by edge localised modes (ELMs). Since the pedestal strongly affects the global plasma performance, further understanding of the temporal approach of the pedestal stability limit (also known as pedestal recovery) is needed to optimise plasma scenarios. Previous studies have shown different recovery timescales of the electron density n_e and temperature T_e pedestal in between ELM crashes [1]. In these experiments the n_e pedestal recovered first, while the T_e pedestal started to recover after the n_e pedestal was established. Gyrokinetic modelling attributed the recovery timescales to the domination of different turbulent modes [2]. In the phase of the n_e recovery trapped electron modes were found in the pedestal, whereas in the pre-ELM pedestal after the T_e recovery, especially on large scales, microtearing modes and kinetic-ballooning modes were dominant.

Experiments recently conducted at ASDEX Upgrade extended the investigated parameter space in plasma triangularity δ, since this parameter strongly influences the edge stability. Additionally, to quantitatively compare the temporal development of the pedestal in plasmas with different main ion species and to test edge stability codes, a pedestal top n_e, T_e-match in deuterium (D) and hydrogen (H) was performed. All presented discharges were conducted at a plasma current of 1 MA, -2.5 T toroidal magnetic field in lower single null configuration. A medium $\delta \sim 0.23$ and a low $\delta \sim 0.19$ shape was established. Characteristic pre-ELM edge profiles, evaluated by integrated data analysis [3], for the two shapes (heating power $P_\mathrm{Heat} \sim 5.25$ MW

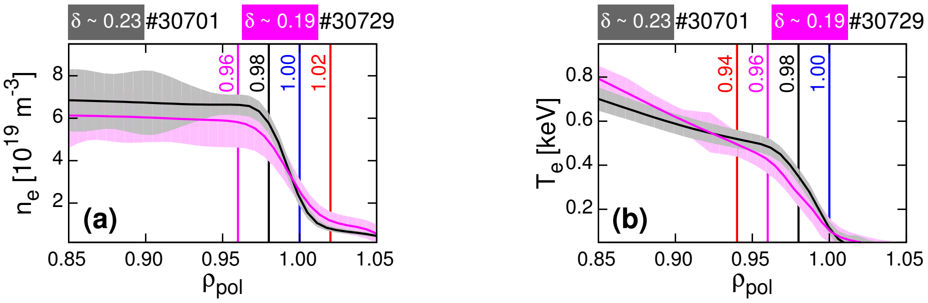

Figure 1: Pre-ELM (averaged between -2 and -1 ms before the ELM onset) pedestal profiles of n_e (a) and T_e (b) for medium ($\delta \sim 0.23$, black) and low ($\delta \sim 0.19$, magenta) triangularity. Owing to the different plasma shape the pedestal gradients of n_e and T_e are shallower at low δ compared to medium δ.

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* See http://www.euro-fusionscipub.org/mst1.

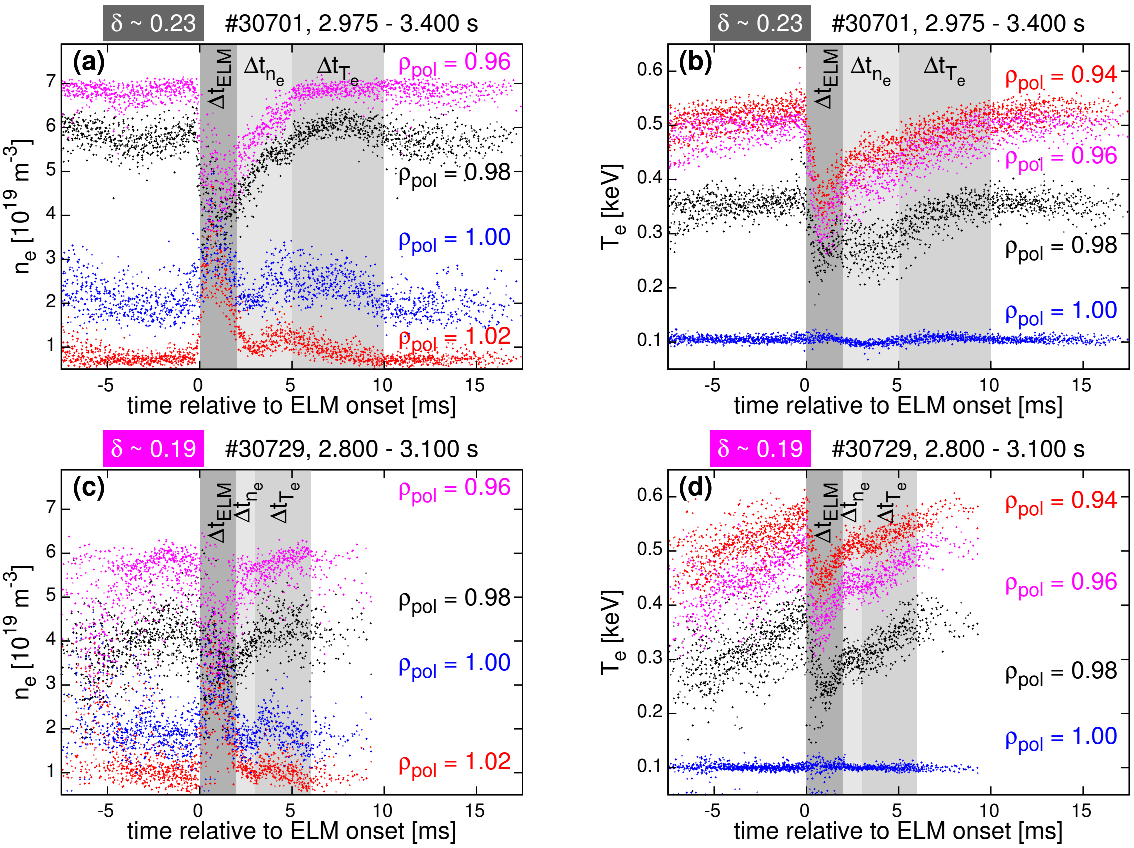

Figure 2: Temporal evolution of the ELM synchronised n_e and T_e at certain radial locations (ρ_{pol}) for medium $\delta \sim 0.23$ (a,b) and low $\delta \sim 0.19$ (c,d). In the low δ case f_ELM is roughly a factor 2.5 larger, the pedestal T_e gradient recovers faster and does not saturate in comparison to medium δ.

at medium δ, $P_\mathrm{Heat} \sim 8.20\,\mathrm{MW}$ at low δ) are presented in figure 1. The low δ discharge (magenta) has shallower pedestal gradients at similar pedestal width compared to the medium δ discharge (black), which is consistent with previous observations [4]. Several steps of heating power were applied to both low and medium triangularity discharges. In all cases the recovery of the pedestal after the ELM crash exhibited the same phases for both plasma shapes. As examples, figure 2 compares the inter-ELM evolution of ELM synchronised n_e and T_e profiles for medium (a,b) and low (c,d) δ. The ELM frequency f_ELM in the low δ discharge is $\sim 180\,\mathrm{Hz}$, which is ~ 2.5 times larger than in the medium δ discharge ($\sim 70\,\mathrm{Hz}$), a change which can be partially attributed to the higher P_Heat. The ELM duration (Δt_ELM), here defined as the period with enhanced transport, visible in the divertor shunt current measurements (c.f. figure 3, black curve), is $\sim 2\,\mathrm{ms}$ for both discharges. In the low δ scenario two types of ELM cycles (data of both included in figure 2c,d) were observed (with similar Δt_ELM), in which the ‘fast’ ELM crashes occurred immediately after the n_e pedestal recovery and before the full T_e pedestal recovery (compared to the ‘slow’ ELM cycle). For both δ cases the n_e pedestal recovers faster than the T_e pedestal. The n_e pedestal reaches its pre-ELM state faster (see/compare Δt_{n_e}) in the low δ than in the medium δ discharge. Additionally, a second n_e peak in the scrape off layer ($1.00 < \rho_{pol} < 1.02$) at 3 to 4 ms after the ELM onset is observed in both shapes. Its occurrence is correlated with the divertor neutral pressure. During the phase of the n_e recovery the pedestal

∇T_e (between $\rho_{pol} = 0.98$ and $\rho_{pol} = 1.00$) does not evolve (see figure 2b,d). The T_e pedestal recovery time (Δt_{T_e}) at low δ is faster ($\sim 3\,\mathrm{ms}$) than at medium δ ($\sim 5\,\mathrm{ms}$), but this might be caused by the larger P_Heat in the low δ discharge. Nevertheless, the pedestal ∇T_e (between $\rho_{pol} = 0.98$ and $\rho_{pol} = 1.00$) recovery saturates approximately 10 ms after the ELM onset in the medium δ discharge. This saturation is accompanied by the onset of radial magnetic fluctuations ($\partial B_r/\partial t$) with frequencies $\sim 240\,\mathrm{kHz}$ (figure 3) measured at the low field side midplane. This behaviour may be connected to the onset of a pedestal limiting instability as described in [5]. Because these fluctuations disappear with each ELM and set on as soon as the ∇T_e is recovered, it is very likely that the modes are located in the steep gradient region.

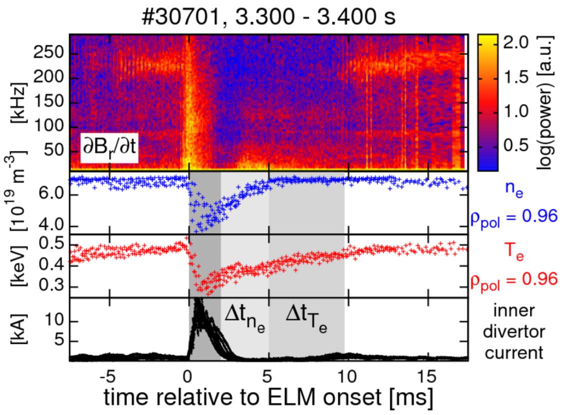

Figure 3: ELM synchronised spectrogram of radial magnetic fluctuations ($\partial B_r/\partial t$). When a certain pedestal top T_e (red) is reached frequencies of $\sim 240\,\mathrm{kHz}$ get dominant, correlating with a saturation of the pedestal ∇T_e (c.f. figure 2b).

The isotope pedestal top n_e, T_e-match required roughly a factor of 2 higher heating power as well as a factor of almost 10 higher fuelling rates in the H plasma to achieve similar pedestal top parameters. The pre-ELM n_e and T_e profiles of both plasmas are presented in figure 4. The pedestal top values agree well, however, the pedestal top ion temperature T_i is noticeably higher in the H plasma. The comparison of the n_e profiles (figure 4a) reveals shallower pedestal gradients in H plasmas. These are probably caused by the change of particle confinement for different main ion species, since a different ionisation source, further inside the plasma in H (at similar particle confinement), would lead to higher pedestal top n_e. Figure 5 compares the inter-ELM recovery of n_e (a,c) and T_e (b,d) for both main ion species. Both plasmas show qualitatively similar recovery phases, i.e. the pedestal n_e recovers on faster timescales than the pedestal T_e. Δt_ELM is in the range of $\sim 1.5\,\mathrm{ms}$ for both main ion species. The n_e pedestal takes longer to recover in the D plasma ($\Delta t_{n_\mathrm{e}} \sim 6.5\,\mathrm{ms}$) in comparison to the H plasma ($\Delta t_{n_\mathrm{e}} \sim 3.5\,\mathrm{ms}$), which possibly has a connection to the 10 times higher fuelling rate in H. In the H plasma a significantly higher f_ELM ($\sim 100\,\mathrm{Hz}$) is observed than in

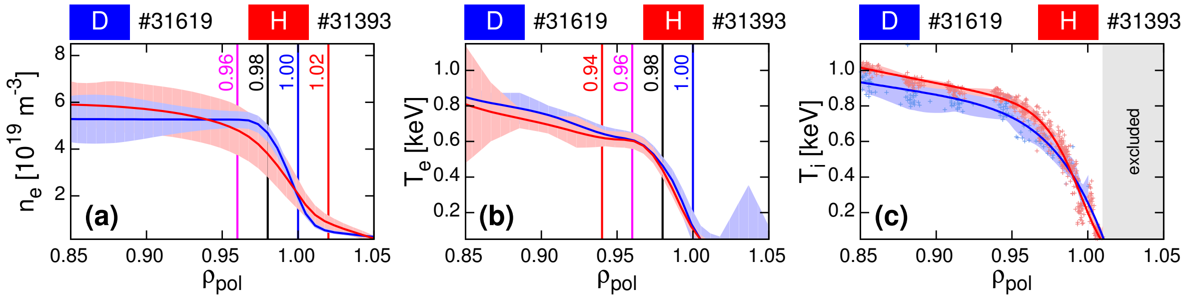

Figure 4: Pre-ELM (averaged between -2 and -1 ms before the ELM onset) profiles of n_e (a), T_e (b) and T_i (c) for D (blue) and H (red). The gradient of the n_e profile in H is shallower than in D, leading to a wider pedestal and a reduction of the achievable pressure gradient.

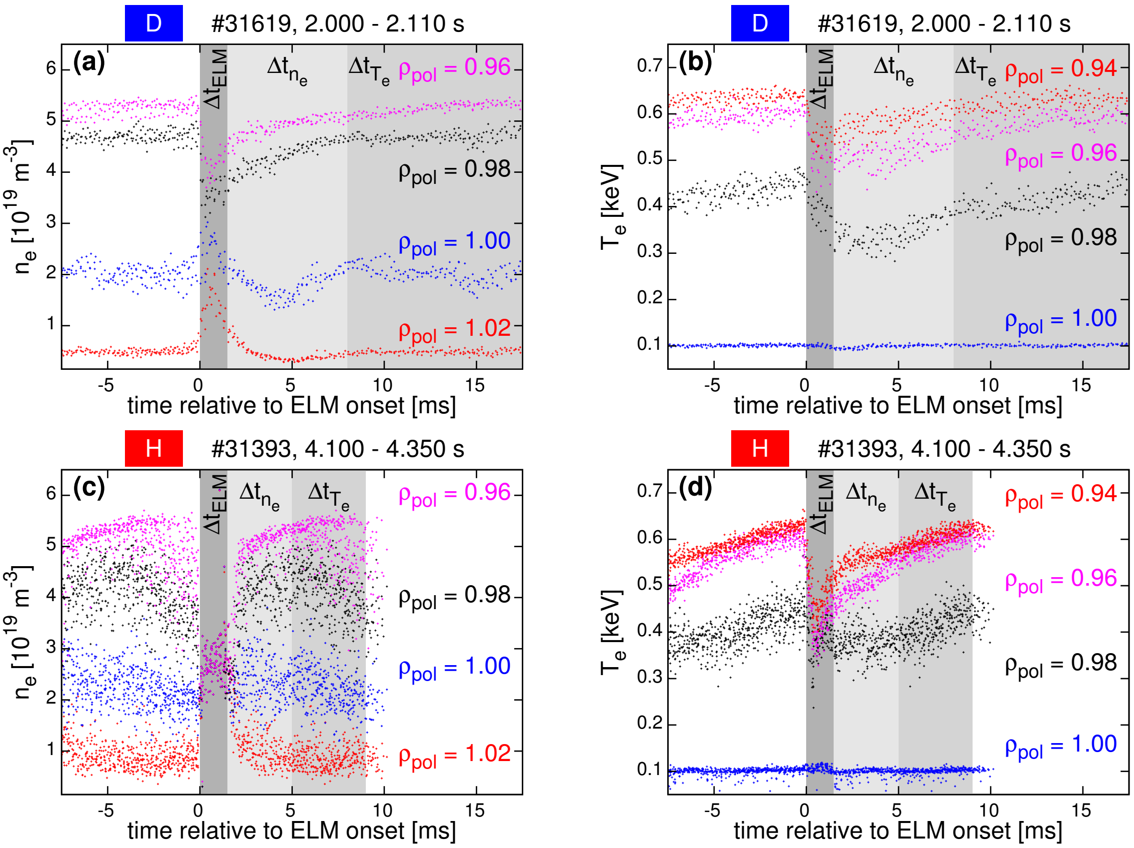

Figure 5: Evolution of n_e (a,c) and T_e (b,d) at certain positions (ρ_{pol}) for the D (a,b) and H (c,d) plasma. The T_e pedestal in H recovers faster than in D owing to the higher P_{Heat}.

D ($\sim$ 50 Hz). The ELM energy and particle losses are higher in the H plasma, but the fraction of power losses caused by ELMs $P_{ELM}/(P_{Heat} - P_{rad,core})$ is approximately similar in both plasmas. Linear MHD stability analyses indicate that the pre-ELM pedestals are peeling-ballooning limited for both main ion species. Nevertheless, the operational point of the H plasma is at shallower pressure gradients caused by the shallower pedestal ∇n_e.

From the presented observations following conclusions can be drawn: The different inter-ELM recovery timescales for the n_e and T_e pedestal (n_e pedestal recovers faster than the T_e pedestal) are robust and observed at different δ and in plasmas with different main ion species. In cases when the pedestal ∇T_e saturates the onset of radial magnetic fluctuations with frequencies larger then 200 kHz is found, which are probably the signature of a pedestal gradient limiting instability. The D and H plasma comparison found much shallower gradients in the H n_e pedestal, which might be related to different particle confinement.

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