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Effect of magnetic perturbations on pedestal, SOL and divertor in high collisionality plasmas at ASDEX Upgrade

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Edge localized modes (ELMs) appear in plasmas with steep pressure gradients in the edge transport barrier. These ELMs lead to high heat loads onto the divertor. Magnetic perturbations (MPs) are applied in order to achieve a reduction in the ELM energy fluence to the target. At the same time MPs affect radial transport in the scrape-off layer due to the additional magnetic field component in radial direction. In high collisionality discharges at ASDEX Upgrade application of MPs lead to the disappearance of large type-I ELMs as soon as a critical density is achieved [1]. The critical density is higher in plasmas with high heating power, indicating a dependence on collisionality [2]. New experiments were carried out with n=2 MPs in discharges with three different plasma currents, 600 kA, 800 kA and 1 MA, in which the density was raised continuously to span Greenwald fractions (f_GW) from 0.5 to 0.75. While at the lower densities both ELM types, large type-I and small ones, are found simultaneously, the large ELMs disappear at high f_GW. The influence of the density ramp on ELM behaviour, the structure of the midplane kinetic profiles from the pedestal top into the scrape-off layer (SOL), the thermographic footprint in the divertor as well as on the fluctuations in the SOL are presented exemplarily for the 600 kA case.

In figure 1 time traces are presented of ASDEX Upgrade (AUG) discharge #30590, which was run at -2.5 T and 600 kA. The top panel shows the total heating power, the stored energy (W_mhd), the radiated power (P_rad) and the current through the MP coils (I_coil). W_mhd drops from 0.38 to 0.32 MJ during the first MP interval and from 0.41 to 0.40 MJ during the second one. In the second panel the gas fuelling ramps (green) as well as the reaction of the core and edge interferometry channels are plotted. The bottom panel shows the shunt current measurements at the divertor plates which is used as ELM indicator.

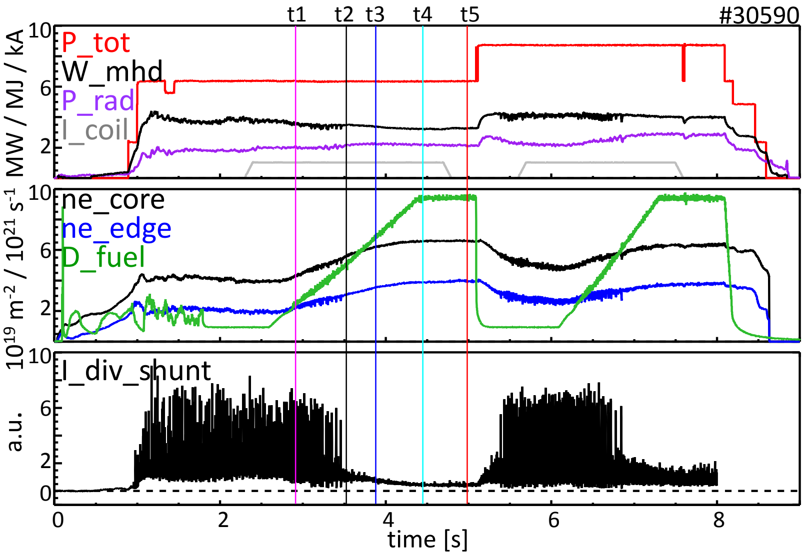

Figure 1: Time traces of #30590. Gas fuelling ramps are applied at two different heating powers. At the time points t1-t5 kinetic profiles are shown in figure 2 and outer divertor heat flux profiles in figure 3.

Several typical features for this kind of discharges can be observed from the time traces: (i) In the two phases with differing heating power the large type-I ELMs disappear during the density rise. A higher transition density can be observed with the higher heating power, indicating that collisionality might play a role. (ii) The small ELMs persist even after the MP coils are switched off (compare t4 and t5). No significant difference in the ELM appearance in the divertor current measurements can be seen, when MP coils are switched off. This observation is not true in the discharges with higher current: both in the 800 kA as well as in the 1 MA discharge the density drops slightly when the MP coils are switched off and a few type-I ELMs appear amongst the small ELMs. As has been shown in a previous study of high density discharges with and without MP [3] this might be due to the additional fuelling effect connected to the high density front at the HFS [4]. Infrared data of this 600 kA discharge is used to compare the footprint of small ELMs with and without MPs as well as the change of the footprint with rising density. Figure 2 shows the lobe structures of the heat flux on the outer target plate, where the measurements are time averaged during phases with small ELMs only or inter-ELM (t1). With increasing density the outer lobes are more and more pronounced, while the lobe closest to the separatrix shows a lower heat flux. The outer lobes also become wider. The change of the measured lobe pattern might be attributed to rotation of the lobe pattern caused by an altered plasma current near the separatrix. Another possible explanation for the widening of the lobes could be increased perpendicular transport. Also shown is a comparison of the heat flux structure of the small ELMs without the application of MPs for the highest density value (t5). Without MPs the lobe structure disappears and is replaced by a single wide feature. While single small ELMs also sometimes show a lobe-like structure, the position of these lobes is not locked, so that integration leads to the broad heat flux deposition profile.

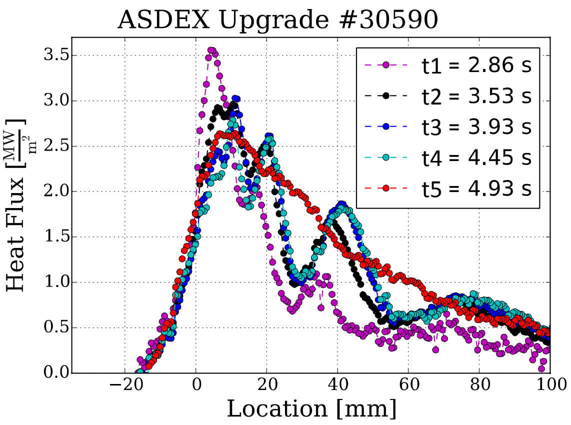

Figure 2: Heat flux profiles at time points indicated in figure 1. t1-t4 with MP, t5 without MP.

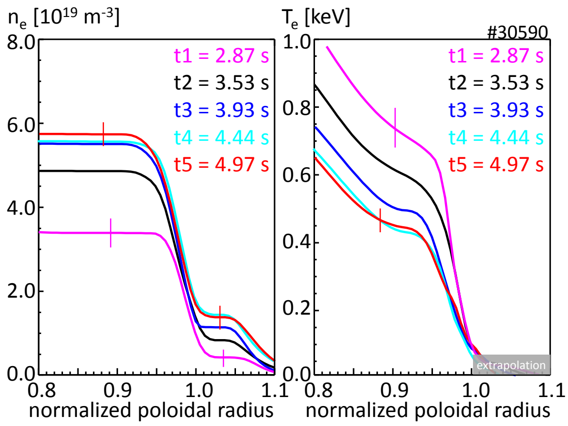

Figure 3: Edge electron density and temperature profiles of time points t1-t5. SOL T_e values are only extrapolated (grey shaded). The n_e SOL 'shoulder' increases with gas fuelling rate.

In figure 3 the corresponding edge electron density (n_e) and temperature (T_e) profiles are shown for the selected time points with increasing density. The data are derived from Lithium beam and DCN diagnostics for n_e and from ECE for T_e via integrated data analysis [5]. The n_e pedestal gradient does not change within the error bars. With the rising density the pedestal top temperature is reduced from 700 eV to 400 eV. From time point t2 on ($T_{e,ped}$ = 600 eV) only mitigated ELMs appear, which is at remarkably high pedestal temperatures. If collisionality is the determining factor, then this could be explained by the high q_{95} value for this 600 kA discharge. In the SOL n_e increases with rising fuelling levels. The typical long n_e fall-off lengths associated with increased filamentary transport, connected to high collisionalities in the divertor [6], are observed. When the MP coils are switched off in the high density period, no significant changes in the pedestal profiles can be observed (compare t4 and t5). The T_e values in the SOL are greyed out, as ECE data carry no information about the local T_e in this area. An analysis of the near SOL decay lengths from Thomson scattering data reveals a widening of both, T_e and n_e, with increasing collisionality (not shown).

The filamentary transport was measured with Langmuir probes on the mid-plane manipulator. Figure 4 shows filaments measured at the position R = 2.167 m, z = 0.313 m, corresponding to ρ_{pol} = 1.09, i.e. well in the limiter shadow of the inner heat shield. The bottom trace shows the ion saturation current, while the top two panels show T_e and n_e. All values are normalized to their mean. At time point t1 a period without type-I ELMs is chosen, so that the small filaments occurring between type-I ELMs can be compared with the small ELMs in the mitigated phase, which appear as large filaments at time t4. While the average T_e of both phases is very similar with 14 and 16 eV, the average n_e increases by a factor of 2. The values are consistent with the densities of the SOL shoulder shown in figure 3 and reflect the fact that the formation of the SOL n_e shoulder coincides with increased filament activity across the whole SOL.

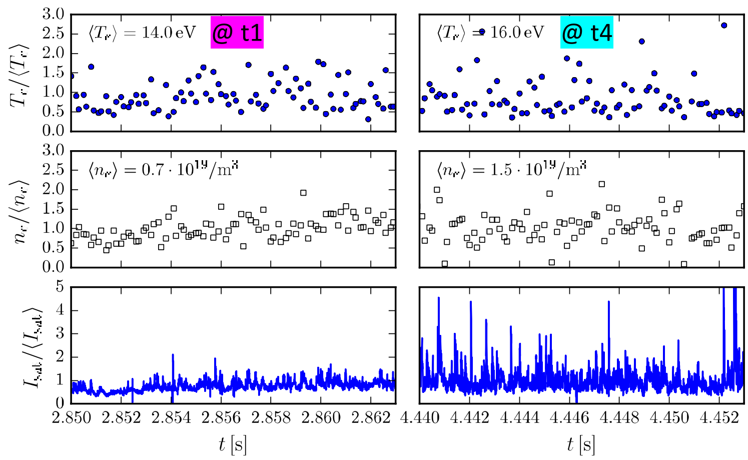

Figure 4: Langmuir probe data, T_e (top), n_e (middle) and I_{sat} (bottom), from two different time periods: left, time point t1 but without type-I ELMs, right: t4 is a mitigated phase at high fuelling level. All values are normalized to their mean.

Taken all observations together the following picture of the effect of increasing density on SOL and divertor can be drawn: Filaments are born near the separatrix and expelled into the SOL. With increasing collisionality these filaments become larger and contribute to the n_e shoulder in the SOL [6]. From a certain density or collisionality threshold on no type-I ELMs are triggered anymore. Magnetic perturbation coils create a pattern in the SOL magnetic field, giving rise to a lobe structure on the divertor surface. The larger filaments occur together with a wider near SOL T_e decay length at the midplane. This cross field transport could populate the lobes which are positioned further away from the nominal undisturbed strike line, so that these lobes carry more heat flux and become wider. At the same time the lobe closest to the nominal strike line carries less heat flux. This reduction of the temperature causes an increase in collisionality in front of the LFS divertor, which has been linked to the onset of the SOL n_e shoulder.

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