

Pedestal formation after L-H transition in ASDEX Upgrade

M. Willensdorfer¹, E. Wolfrum², F. Aumayr¹, R. Fischer², B. Nold³, P. Sauter²,
A. Scarabosio², P. A. Schneider², B. Sieglin² and the ASDEX Upgrade Team

¹*Institut für Angewandte Physik, Technische Universität Wien, Association EURATOM-ÖAW,
A-1040 Vienna, Austria*

²*Max-Planck-Institut für Plasmaphysik, EURATOM Ass., D-85748 Garching, Germany*

³*Institut für Plasmaforschung, Universität Stuttgart, D-70569 Stuttgart, Germany*

Introduction

The H-mode is the foreseen standard scenario for ITER. The initially installed heating power of ITER is expected to be around the H-mode power threshold of the initial H_2 or He plasma operation [1]. Therefore, the achievement of a sustained H-mode will be very sensitive to the development of the pedestal for heating powers close to the power threshold ($P_{Heat}/P_{Thres} \simeq 1$).

The ASDEX Upgrade tokamak is well equipped with plasma edge diagnostics, which deliver routinely detailed electron density and temperature measurements with a high spatial and temporal resolution. Within the available heating scenarios, it is even possible to achieve H-mode using electron cyclotron resonance heating (ECRH) only. In contrast to neutral beam heating (NBI), ECRH is not accompanied with a particle source in the confined plasma.

Discharges

We studied the L-H transitions and the following development of the H-mode pedestal. The core electron densities (n_e) at the L-H transition are near the L-H power threshold minimum ($n_e = 4 \cdot 10^{19} \text{ m}^{-3}$) [2]. Figure 1 shows an overview plot of two discharges (#25438 & #25440). For reproducibility several H-modes were induced by an ECRH power of 1.4 MW during each discharge ($P_{Heat}/P_{Thres} \simeq 1.25$). In Figure 1 the H-mode phases are indicated by red shaded areas. In both discharges the deuterium (D)

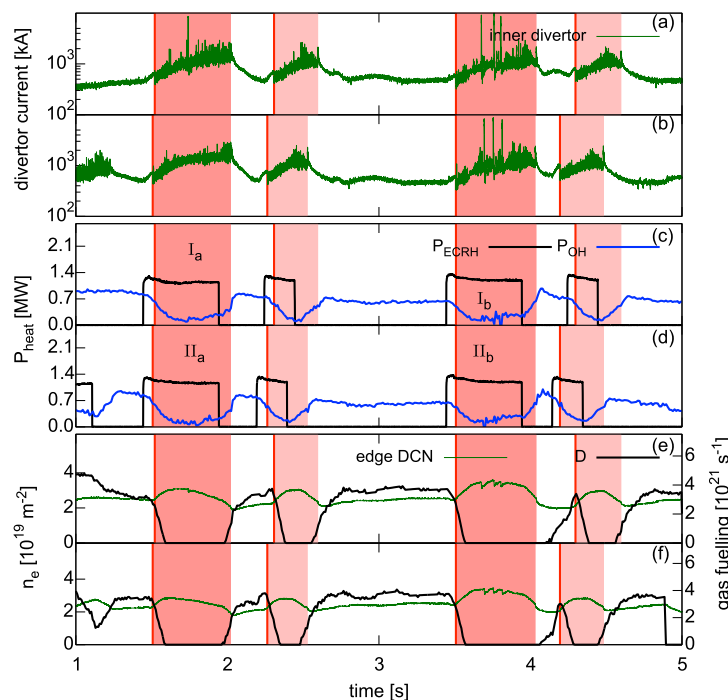


Figure 1: The plasma and divertor current (a & b), the heating power (c & d), the gas fuelling and the line integrated density (e & f) for both discharges (#25438 & #25440) are shown. Red shaded areas indicate H-mode phases.

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gas fueling was regulated via feedback control of the line integrated density measured by interferometry (DCN). This results in a closing of the gas valves after the L-H transition, due to the increasing electron density in H-mode. We distinguish between *long* H-modes (dark-red shaded areas) and *short* H modes (light-red shaded areas) using the divertor current to identify the L-H and H-L transitions. In the following sections, we analyze the pedestal formation of the *long* H-modes labelled by: Ia, Ib, IIa and IIb.

Deuterium inventory

Figure 2 illustrates various plasma parameters synchronized to the L-H transition ($t = 0$ s, black line). The ECRH power is about the same for all H-modes (Figure 2b) and the electron temperature (T_e) profiles develop similar (Figure 2c). The feedback control ensures similarly L-mode densities and gas fueling rates prior to the L-H transition (Figure 2d). However, differences in the edge DCN channel in every H-mode can be observed (Figure 2e). Gauges measure the neutral D flux density and show differences in the D inventory prior to the L-H transition, due to different L-mode durations and without steady state conditions. Figure 2f shows local measurements of neutral flux density (Γ) in the divertor, which indicate a clear connection between the neutral flux density prior to the L-H transition and the H-mode density.

After the L-H transition the edge transport barrier (ETB) is established and the particle diffusion coefficient (D_n) is reduced. In combination with the closure of the valve and the lower recycling flux, because of the ETB, the D inventory decreases and the D atoms are either pumped out by the cyro pump or are ionized within the separatrix. Without any additional source, e.g. NBI, the D inventory is the only source to fuel the plasma. Therefore we observe no significant increase in density, after the the D inventory has reached a minimum value (Figure 2f, $t \sim 100$ ms).

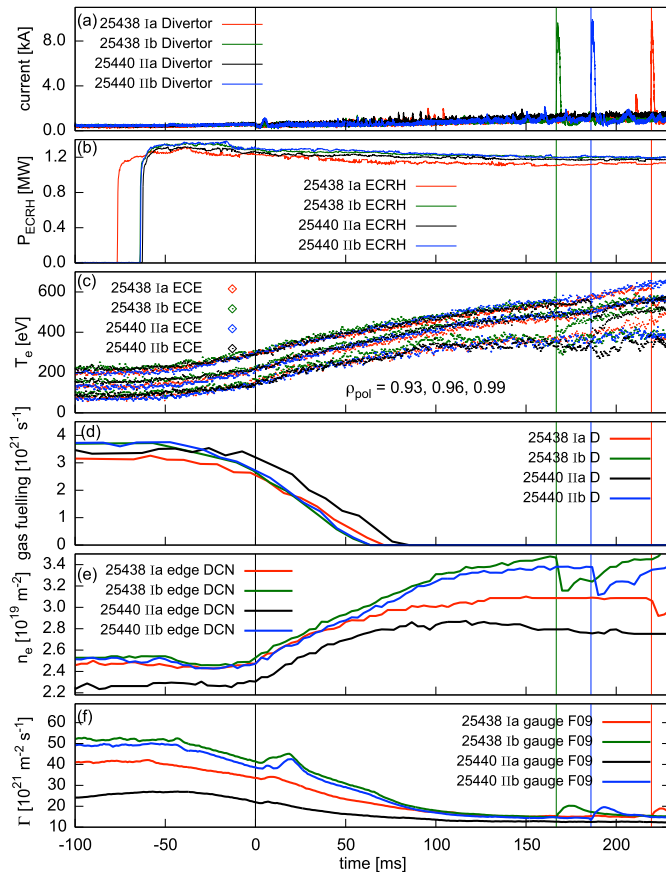


Figure 2: The divertor current (a), the ECRH power (b), ECE measurements at ρ_{pol} of 0.93, 0.96 and 0.99 (c), gas fueling rate (d), edge DCN measurements (e) relative to the L-H transition are shown. (f) illustrates the gauge measurements of the neutral flux density (Γ) in the divertor and the gas fueling rate of deuterium.

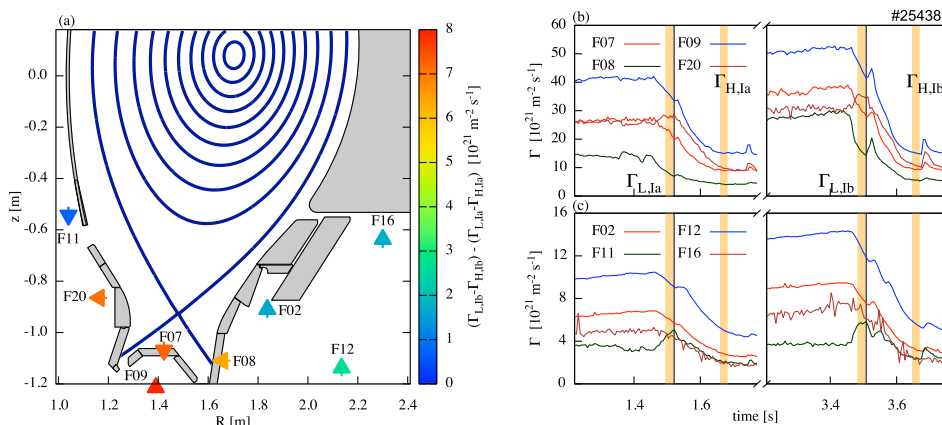


Figure 3: (a) shows the poloidal positions of the gauges F_i . The time traces of these gauge measurements during the onset of the phases Ia and Ib of #25438 are shown in (b) and (c).

Due to lack of a diagnostic, which routinely delivers the neutral density in the scrape off layer (SOL), we are not able to determine the exact location of the deuterium source, which is responsible for the fueling. But several gauge pressure measurements at different poloidal positions in the divertor region allow us to assess the poloidal distribution of the source (Figure 3a). Figure 3b and 3c show time traces of corresponding gauge measurements in H-modes Ia and Ib. The vertical black line indicates the L-H transition. To illustrate the local dependence of the neutral flux density (Γ) the color scaling in Figure 3a corresponds to the difference between the neutral flux density difference of H- and L- mode ($\Delta\Gamma_i = \Gamma_{L,i} - \Gamma_{H,i}$) in phase Ia and Ib. The time windows to determine $\Gamma_{L,i}$ and $\Gamma_{H,i}$ are indicated by yellow shaded areas. Figure 3a shows that the neutral gas inventory in the divertor plays an important role for the density profile build up in ECRH induced H-modes, which was already observed in [3].

Pedestal formation

In the previous section we already noticed differences in the edge line integrated n_e between the H-mode phases. In this section we investigate the time evolution of the kinetic profiles. For electron density (n_e) profiles we used DCN in combination with the lithium beam (LIB) and Thomson scattering (TS) diagnostic. Electron cyclotron emission (ECE) and TS contribute data for electron temperature (T_e) profiles. To characterize the edge pedestal and its evolution we used the modified hyperbolic tangent function (*mtanh*) and the two line (*two-line*) method. A comparison of the two methods is given in [4]. Due to systematic large uncertainties of the ECE diagnostic at low densities, i.e. at the plasma edge, we only consider data points, which are within $\rho_{pol} = 0.995$. Because of this ECE data cut and the low sampling rate of TS, the electron temperature in the SOL and its evolution are not well determined. Therefore, we only use the *two-line* method to fit the T_e profiles. For n_e profiles the SOL density is measured with accuracy, but not the pedestal top, therefore we use the *mtanh* fit to get n_e pedestal parameters. The time window for every fit amounts to 15 ms, which assures enough data points. The maximum n_e gradient (∇n_e) in Figure 4a shows the same tendency as the edge DCN channel (Figure 2e).

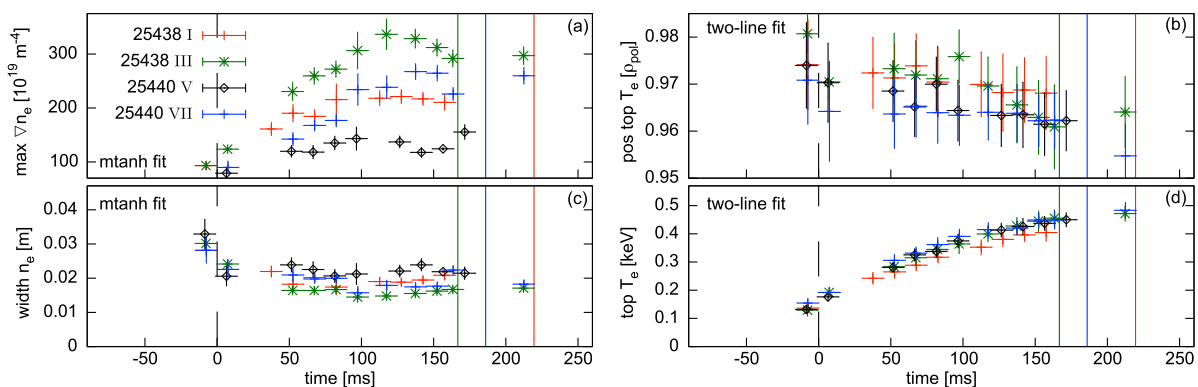


Figure 4: (a) Maximum n_e gradient determined from a modified tanh fit. (b) Position of the pedestal top in ρ_{pol} of the *two-line* fit of T_e . (c) Width from *mtanh* mapped onto the midplane. (d) Pedestal top value of the *two-line* fit of T_e . The vertical lines are the ELM onset of Figure 2.

Although the maximum gradient increases with time, the n_e pedestal width does not change significantly after 50 ms (Figure 4c). The position of the T_e pedestal knee moves inwards with time (Figure 4b), but the effect is not very pronounced within the uncertainties. Additionally due to the large uncertainties of T_e in the SOL, one cannot conclude that this is due to an increase in width. Similar behavior was reported in [5]. The pedestal top values of T_e confirms the earlier statement that the temporal evolution of T_e is about the same in all four cases (Figure 4d).

Conclusion

A clear relation between the neutral flux density in the divertor prior to the L-H transition and the electron density profile build up and its maximum gradient afterwards was found. With increasing D pressure in the divertor region an increased H-mode density and a concomitant earlier occurrence of the first type-I ELM is observed. The data suggest that the width of the n_e profile approaches its final value within 50 ms after the L-H transition and does not change afterwards, even if the maximum gradient of n_e is still increasing.

Acknowledgement

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