On the Fluctuating Detachment State at ASDEX Upgrade

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Introduction

In order to be able to handle the total power and particle fluxes to the target material, the ITER divertor has to be operated in the partially detached regime. Thus, understanding the physics of detachment is crucial for making predictions for the ITER divertor performance.

It has been observed on ASDEX Upgrade that, while increasing the plasma density, the detachment process can be divided into different distinct states [1]. During one of these states, where the inner divertor is partially detached and the outer divertor remains still attached, strong fluctuations in the radiated power signal appear in the SOL of the inner divertor close to the X-point (Fig. 1a). The origin of these fluctuations is still under investigation. During this *Fluctuating Deachment State* (FDS), a high electron density, n_e, appears at the X-point, measured by a Stark broadening diagnostic (SBD) (Fig. 1b). In addition, there is an increase of the ion flux, Γ_{D^+}, at the inner target at a distance of ≈ 4 cm from the strike point (Fig. 1c). Although this work focuses on L-mode discharges only, the X-point fluctuations appear also in H-modes with detached inner divertor [2] and are thus independent of the confinement regime.

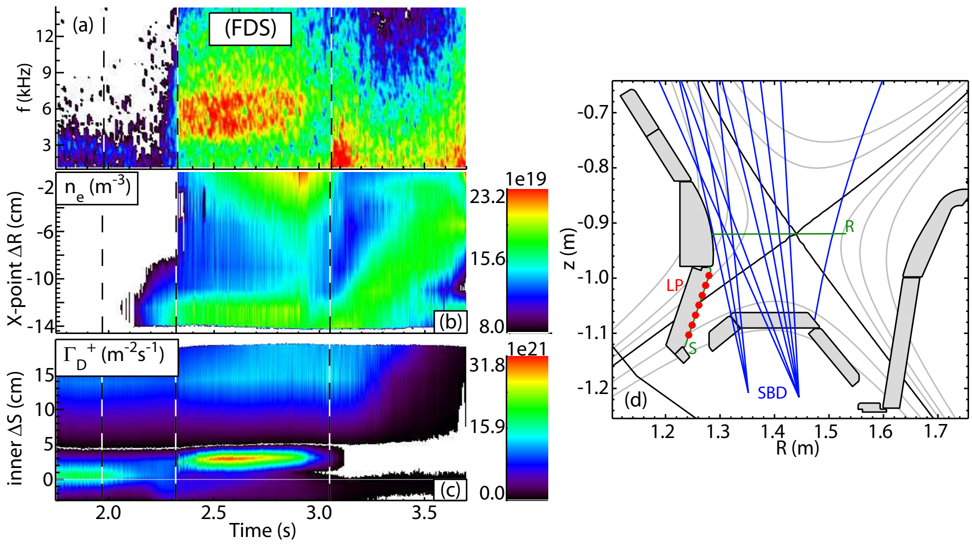

Figure 1: (a) Spectrogram of the radiated power measured by an AXUV diode close to the X-point. Profile of n_e (b) and Γ_{D^+} (c) measured by SBD and LP, respectively. The according SBD lines of sight (blue), Langmuir probes (red) and the *R* and *S* coordinate are shown in (d).

This work investigates the influence of the heating scheme, the connection length L_c and the X-point position on the detachment fluctuations throughout parameter scans. All scans are based on a reference discharge with a plasma current $I_P = 1$ MA, a toroidal magnetic field $B_t = 2.5$ T, a total heating power (ohmic plus electron cyclotron resonance (ECRH) heating) of 1.2 MW and a X-point position shown in Figure 1. An identical fueling ramp was applied to each discharge in order to trigger the divertor detachment.

FDS onset scaling

The occurrence of the X-point fluctuations is always associated with a high electron density at the X-point (Fig. 1b), which implies that the ionization front in the inner divertor expands to the X-point. Thus, we assume a similar critical temperature T_{crit} in the divertor when the fluctuations start. According to the Two-Point-Model (TPM), the divertor temperature scales as $T_{crit} \propto q^{10/7} L_c^{-4/14} n_{e,sep}^{-2}$ [4]. The power density in the SOL, q, and the separatrix density, $n_{e,sep}$, are proportional to the heating power $q = P/A \propto P$ (as the plasma surface area A is about constant) and the line integrated edge density, $n_{e,sep} \propto \bar{n}_{e,edge}$ [5], respectively. In the following, we determine the edge density at the fluctuation onset, $\bar{n}_{e,edge}^{FDS}$, for the various parameter scans and verify the assumption of a fixed T_{crit}.

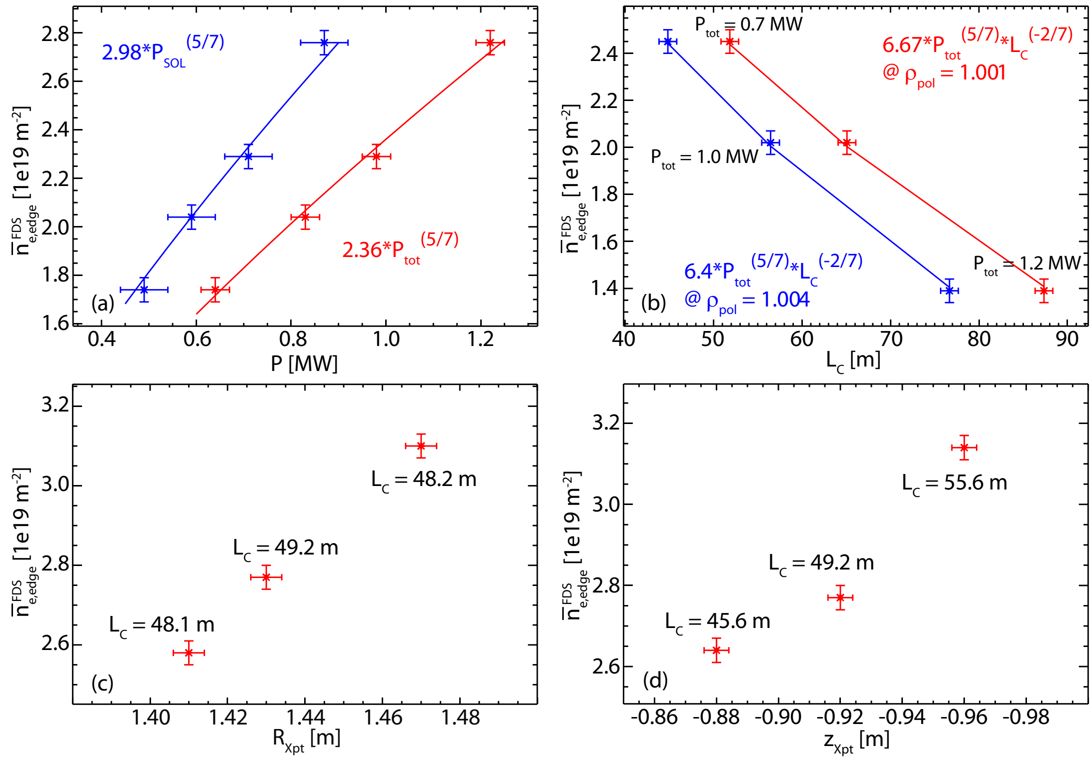

Figure 2: Edge density at the fluctuation onset as a function of: (a) total heating power (red) and power entering the SOL (blue), the lines show the TPM scaling; (b) connection length for two values of ρ_{pol}, the lines show the TPM scaling; (c) the vertical and (d) the horizontal X-point position.

Figure 2a shows $\bar{n}_{e,edge}^{FDS}$ versus the total heating power, P_{tot}, and the power entering the SOL, P_{SOL} (P_{tot} minus in the main chamber radiated power). It can be seen that $\bar{n}_{e,edge}^{FDS}$ scales positively with P_{tot} and the TPM scaling, assuming a fixed T_{crit}, fits very well to the measured data for both P_{tot} and P_{SOL}. As expected from the TPM scaling, $\bar{n}_{e,edge}^{FDS}$ scales negatively with L_c (Fig. 2b). The distance from the outer midplane to the inner target at a normalized flux ρ_{pol} of 1.0005 and 1.004 has been taken as L_c. The L_c variation was achieved by changing the plasma current I_P. This alters the ohmic heating power and thus P_{tot}. Taking the P_{tot} variation into account, the TPM scaling fits again very well to the measured data. This, together with the above power scaling, proves the existence of a similar T_{crit} in the divertor at the FDS onset.

In addition, we investigated geometric effects, which are not included in the TPM, on the detachment process via X-point scans. The X-point position was varied within 8 cm in $R_{X\,pt}$ and 6 cm in $z_{X\,pt}$ direction (Fig. 3) and was found to have a strong influence on $\bar{n}^{FDS}_{e,edge}$. Namely, $\bar{n}^{FDS}_{e,edge}$ scales positively with the distance from the inner target (Fig. 2c) and positively with the X-point height (Fig. 2d). The $z_{X\,pt}$ scan also implies a scan of L_c (Fig. 2d), but the L_c dependence (lowest $\bar{n}^{FDS}_{e,edge}$ at lowest L_c) is opposite to the above derived scaling. This means that the $\bar{n}^{FDS}_{e,edge}$ variation here is a pure geometric effect. Moreover, the dependence of the $z_{X\,pt}$ scan is counter intuitive, since a higher $\bar{n}^{FDS}_{e,edge}$ is needed with a closer divertor (Fig. 2d & 3b).

A simultaneous scan of I_p and B_t keeping L_c constant was also performed. Here, only a marginal influence on $\bar{n}^{FDS}_{e,edge}$ was found which can be attributed to the change of the ohmic heating due to the I_p variation. An exchange of the ECRH by neutral beam heating does not show any influence on $\bar{n}^{FDS}_{e,edge}$. In a freshly boronized machine, thus having less impurity content, $\bar{n}^{FDS}_{e,edge}$ is similar to the one of the reference discharge, although a 30 % higher gas fueling is needed.

Influence of the X-point position on the FDS

In this section, the influence of the various scans on the X-point fluctuations is investigated. The vertical and horizontal X-point scans reveal that the region of the fluctuations is connected to the X-point position. Figure 3a shows color-coded the three separatrix positions for the $R_{X\,pt}$ scan and the set of vertical AXUV diodes shaded in gray. The diode measuring the highest fluctuation strength is highlighted for each discharge in the respective color. The fluctuations clearly follow the horizontal movement of the X-point. The same behavior is observed in the $z_{X\,pt}$ scan (Fig. 3b), which reveals the movement of the fluctuations with the X-point. Figure 4a depicts the n_e profile along the R coordinate (Fig. 1d) at the X-point height. Each color corresponds to one discharge of the $R_{X\,pt}$ scan (Fig 3a) and the vertical dashed lines show the corresponding X-point positions. It can bee seen that the density profile always peaks at the X-point, which shows that the high n_e during the FDS is clearly connected to the X-point region and hence to the fluctuations. The X-point scans also imply a scan of the strike point (SP) position (Fig 3) and a change of the inner target Γ_{D^+} profile is observed in this scans. Figure 4b compares the Γ_{D^+} profiles during the FDS of the three discharges with the lowest SP positions (Fig. 3). The maxima of the Γ_{D^+} profiles are normalized. With a lower SP, the region close to the separatrix where pressure is lost (low Γ_{D^+}) is broader and the peak Γ_{D^+} position is further away from the strike point. Moreover, the lower the SP, the broader is the profile.

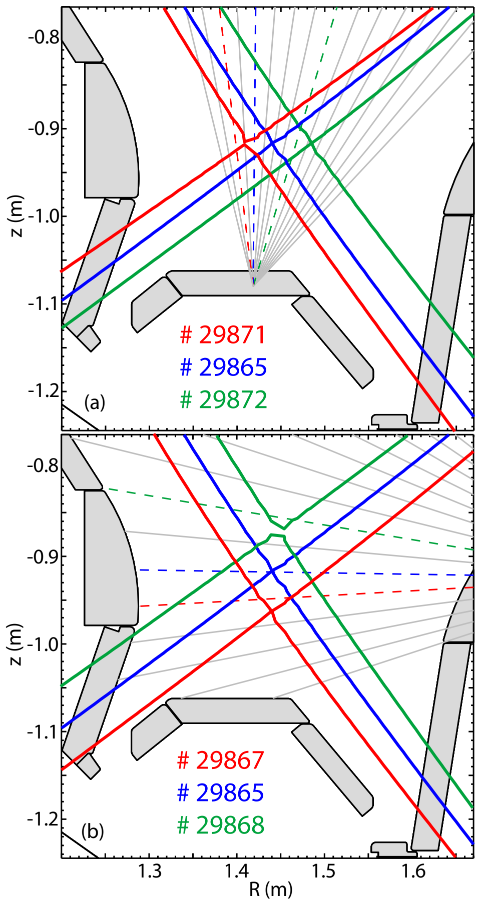

Figure 3: Separatrix positions of the $R_{X\,pt}$ (a) and $z_{X\,pt}$ (b) scan. The respective AXUV diodes measuring the strongest fluctuations are dashed colored.

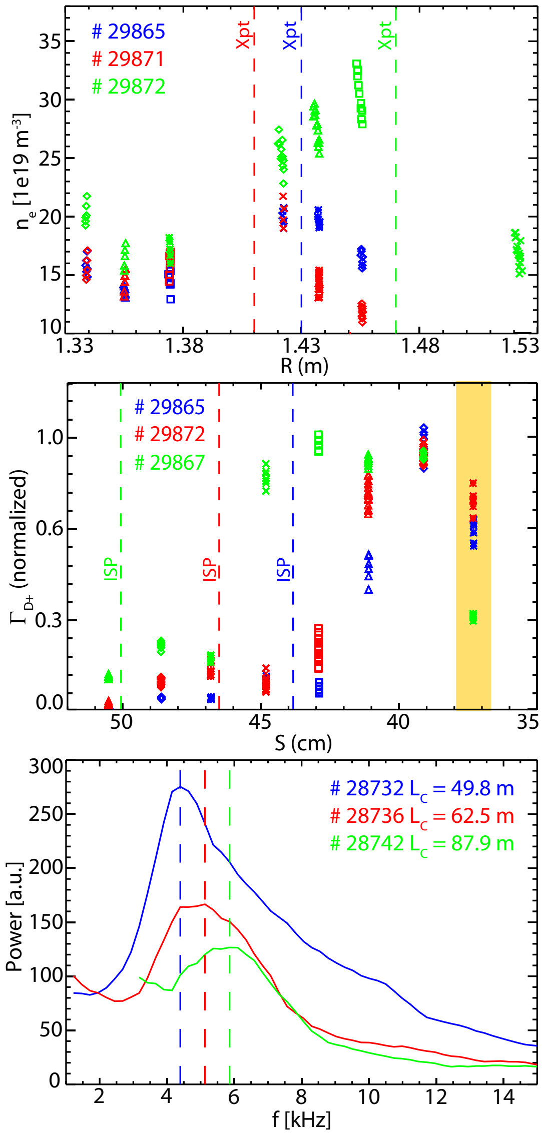

Figure 4: (a) n_e profiles for the three discharges of the R_{Xpt} scan. (b) Γ_{D^+} profiles for three discharges with an ISP scan. (c) Spectral power vs. frequency for the three discharges of the L_c scan.

One would expect, in contrast, a broader profile in the blue, high SP case, as $\bar{n}_{e,edge}^{FDS}$ and L_c is higher than in the red case at similar heating power. In all cases, however, the drop of Γ_{D^+} in the far SOL (orange region in Fig. 4b) is at the same location below the divertor nose (see uppermost probe in Fig. 1c). This, together with the higher $\bar{n}_{e,edge}^{FDS}$ with a closer divertor (Fig. 2d), suggests that the geometry of the inner divertor, namely the change from tilted towards the separatrix to tilted away, has an influence on the detachment process.

Influence of L_c on the FDS

Figure 4c shows for the L_c scan the spectral power versus the frequency, averaged over the duration of the X-point fluctuations, measured by the same AXUV diode. It can be seen that the peak position increases moderately with L_c, i.e. $\approx 40\,\%$ L_c variation causes a frequency change of $\approx 25\,\%$. In addition, the amplitude and the width of the frequency band, namely the high frequency wing, decrease with increasing L_c.

Summary

It has been proven that the occurrence of radiative fluctuations together with a high electron density in the inner SOL close to the X-point is a robust feature of the detachment process at AUG, i.e it is independent of the heating power, heating method, connection length, magnetic field, wall conditioning and X-point position. The plasma density at the fluctuation onset scales positively with P and negatively with L_c. A very good agreement with the TPM scaling is obtained for both scans, which reveals that a similar critical temperature in the divertor is necessary to trigger the fluctuations. In addition, the X-point position was found to have a strong influence on $\bar{n}_{e,edge}^{FDS}$. Finally, the peak position and the width of the frequency band scales weakly positive with the connection length.

References

[1] S. Potzel, et al., J. Nucl. Mater., **285-290**, 438 (2013)

[2] M. Bernert, et al., **P5.163** *This Conference*

[3] S. Potzel, et al., EPS Strassbourg, **O2.303**, (2011)

[4] P.C. Stangeby, *The Plasma Boundary of Magnetic Fusion Devices*

[5] G.D. Porter, et al., J. Nucl. Mater., **266-269**, 917 (1999)