Edge profile and MHD characterization of the type-II ELMy regime in ASDEX Upgrade

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1. Introduction

Plasma regimes which combine high global confinement, high pedestal pressure and small ELMs are especially interesting for ITER in view of the limited power load estimated for the divertor target plates [1]. Such small ELM regimes have previously been found in several machines (for an overview see. e.g. [2].). In particular the question of whether there is a significant difference between grassy ELMs observed at JT60-U, JET and AUG at low collisionalities and type-II ELMs observed at JET and AUG at high collisionalities [3] has triggered the experiments reported here.

Current type-II ELM models connect the occurrence of type-II ELMs with the narrower radial eigenfunction of the unstable mode [4], which could be shown to occur with increasing triangularity and edge safety factor, as well as with approaching closeness to double null (DN) configuration. Moreover, the reduction of the edge bootstrap current with increased collisionality is suggested to play a role in the occurrence of type-II ELMs. Another model [5] predicts that type-II ELMs appear if the first stability limit for ideal ballooning modes applies only to the outermost edge of the edge transport barrier. As stability analysis relies on the gradients of kinetic profiles, a strong emphasis of this work lies on the accurate characterisation of the kinetic edge profiles, i.e. electron densities and temperatures with high temporal and spatial resolution, as well as pedestal top ion temperatures. A characteristic feature of type-II ELMy regimes in several machines is the appearance of a broad fluctuation band between 20 and 50 kHz in the magnetic signals [6]. Data taken with the recently installed fast ECE [7] allow the localisation of these fluctuations radially.

2. Discharges

Following previous discharges in AUG, high triangularity shaping was chosen (upper triangularity δ_u=0.33, lower triangularity δ_l=0.45), which was built up first in single null with a lower x-point and then slowly shifted upwards (z-shift) so that the second separatrix came close to the first one. In all discharges presented here, the plasma current I_p was 800 kA, at a magnetic field of B_T=-2.5T with q_{95}=5.5. The z-shift stops at t=3s, and the position is kept constant for the rest of the pulse. Figure 1 shows time traces of three discharges with heating power, z-position, fuelling rate, line averaged edge density, H98y,2 factor and beta poloidal on the left hand side and the divertor currents as well as the integrated power densities for the outer divertor plates on the right hand side. Start and end times of the type II ELM phases are indicated with dotted lines. The plasmas were heated with 5 MW NBI (blue, #25740), 7.5 MW NBI (red, #25738) and 10 MW NBI (black, #25741) with an additional 0.7 MW central ECRH in all discharges. Strong fuelling was applied with a rate of 9 10^{21} e s^{-1} up to t=3s. After t=3s the fuelling was ramped down with different rates, in order to reach lower collisionality. Type–II ELMs appeared in all shots before the final z-position was reached, i.e. t<3s, later with higher heating power. The edge density increases until the final shape at t=3s is reached. The first larger ELMs can be seen when the density has decreased to the level of type-II onset. For higher heating powers a higher density is necessary, indicating that edge collisionality is the critical factor to obtain type-II ELMs. While peak power densities on the divertor plates of 10 MW m^{-2} are measured during type-I ELMs, the power densities are reduced to continuous values around 2-3 MW m^{-2} in the type-II ELM phase.

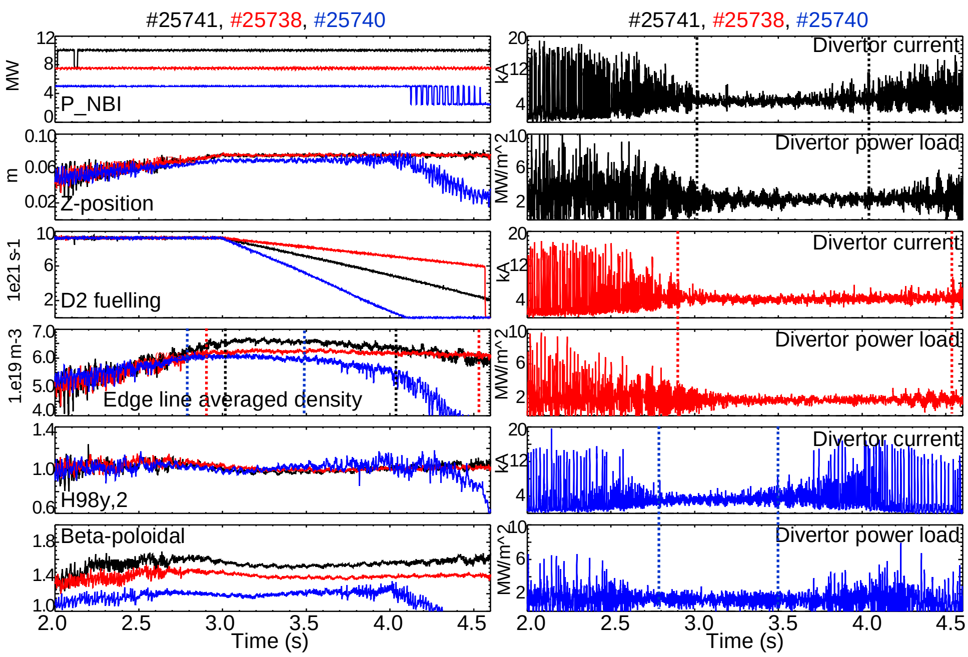

Figure 1: Time traces of (left top to bottom): NB heating power, Z-position, fuelling rate, edge channel of DCN interferometer, H98y,2 factor, beta poloidal. Right: Divertor current and divertor power densities for the three discharges. Start and end times of the type II ELMy phases are indicated with dotted vertical lines.

3. MHD

The magnetic signature previously found with type-II ELMs [3,6] was observed again: a wide band between 30 and 50 kHz. With the recently installed fast ECE diagnostic (up to 1 MHz) [7] it is now possible to spatially localise this feature. As shown in figure 2, the same wide 30-50 kHz band is seen in the spectrogram of some ECE channels during the type-II ELMy phase (2.7-3.7s), and disappears with the first type-I ELMs.

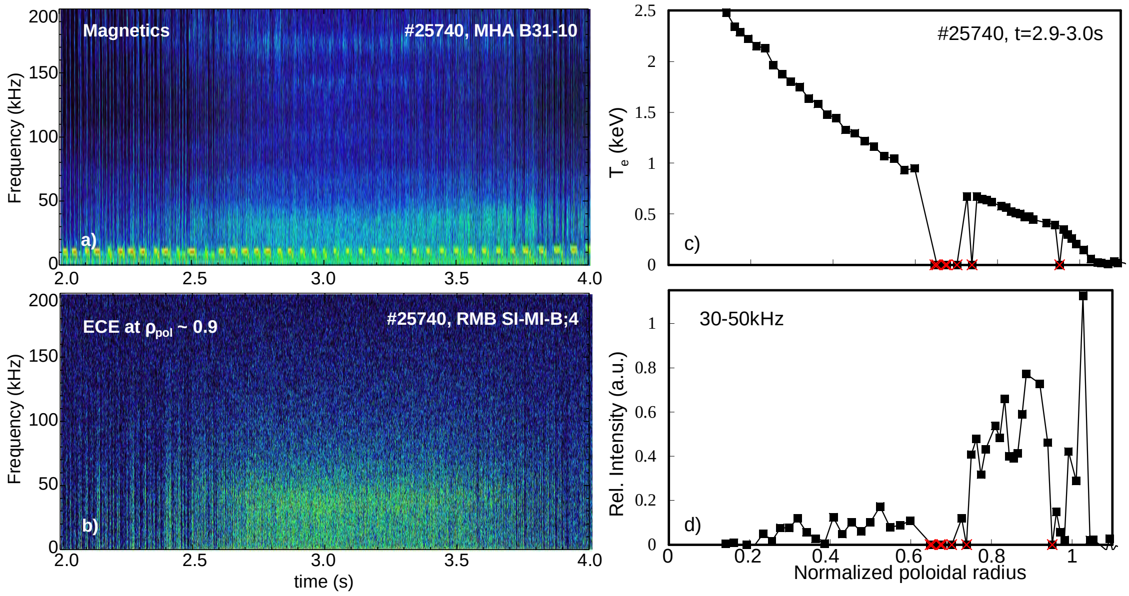

Figure 2: a) Spectrogram of an in vessel magnetic pick up coil, b) spectrogram of one ECE channel located at ρ_{pol} ~ 0.9, c) T_e profile and d) normalized intensity of the 30-50 kHz region (see text). Bad channels are marked with red crosses.

In order to determine where these T_e fluctuations occur, the ECE Fourier spectra of each channel are normalized to their average value at 250-300 kHz (proportional to T_e). The average intensity of the normalized Fourier spectra between 30-50 kHz is background corrected with a linear fit of the neighbouring lower and higher frequency regions. Figure 2c shows the ECE T_e profile together with such relative intensities of the 30-50 kHz region (2d).

Interestingly, a strong peak can be seen just outside the separatrix, where the density is so low, that the plasma is not optically thick to ECE radiation. It is believed that the corresponding radiation originates from inside the last closed flux surface. This assumption is confirmed by reflectometry data, which are available for the region outside the separatrix only, and do not show the characteristic fluctuations.

In the ECE channels located in the edge transport barrier region ($0.95<\rho_{pol}<1.0$), no fluctuations can be seen. They start sharply at the top of the pedestal and then decrease towards smaller radii and disappear for $\rho_{pol} < 0.75$.

4. Kinetic profiles and their edge gradients

The kinetic profiles are shown for #25740 in figure 3 together with maximal edge gradients of n_e, T_e and p_e. The profile data for type-I ELMy H-mode (black) are ELM synchronized to t=-3.5 - -1.0 ms before an ELM, while the type-II ELM data (red) are averaged over 100 ms. It can clearly be seen that in the region of $0.7<\rho_{pol}<0.95$ T_e is reduced, while the density profiles agree within their uncertainties. Also T_i is reduced in the same region, which is where the 30-50 kHz fluctuations were shown to exist.

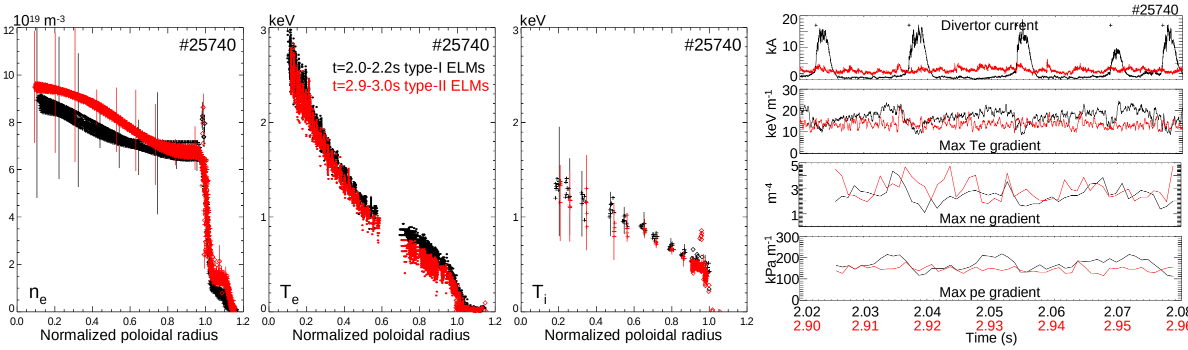

Figure 3: Kinetic profiles for type-I (black) and type-II ELM phase (red) for a) n_e, b) T_e and c) T_i. The divertor current as ELM indicator is shown in d) together with the maximal edge gradients of T_e, n_e and p_e.

Analysis of the edge gradients reveals, that for type-II ELMs T_e gradients are reduced in comparison with type-I ELMs (see figure 3d), n_e gradients stay the same and p_e gradients are around 150 kPa m^{-1}, while values of 230 kPa m^{-1} are reached before type-I ELMs. At the same time, the position of the maximum pressure gradients moves further out, i.e. close to the separatrix.

In summary we can state that type-II ELMs occur together with MHD fluctuations. These fluctuations lead to a reduction of T_e and T_i in the region of $0.7<\rho_{pol}<0.95$. At the same time, edge electron pressure gradients are reduced and located further out very close to the separatrix. A possible hypothesis might be that the fluctuations do not exist in type-I ELMy phases, because the bootstrap current leads to increased shear just inside the pedestal. The reduction of the bootstrap current during type-II ELMs changes the q profile such, that fluctuations are not suppressed any longer in the region $0.7<\rho_{pol}<0.95$. Stability studies based on these data are in progress.

References

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