

Study of the interplay between the core and edge regions in ITB plasmas using microwave reflectometry on ASDEX Upgrade

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1. Introduction

The edge and core transport barriers have many similar characteristics: steep pressure gradients, large gradients in the radial electric field, local reduction in plasma fluctuations. It has been suggested that the improvement of confinement at both regions might have a common underlying physics /1/ and therefore it is important to investigate the links between the formation and sustainment of edge and core barriers. With this aim we studied stationary discharges with improved core confinement and H-mode edge in ASDEX Upgrade /2/ using microwave reflectometry.

2. Density fluctuations at the core and edge regions

For the discharges under study the ASDEX Upgrade plasma was probed with four reflectometry channels [18 - 70 GHz] corresponding to densities [$0.4 - 6.5 \times 10^{19} \text{ m}^{-3}$] /3/. With fixed frequency operation we probe density layers at a rate of 1 μs (1 MHz sampling frequency). The radial turbulence wavenumber selected at the cut-off layer is $< 1-2 \text{ cm}^{-1}$ (spatial width of the cutoff : 2-3 cm), and the poloidal turbulence wavenumber is $\sim 1.5 < k < 8.5 \text{ cm}^{-1}$. Fig.1 shows the temporal evolution of: (a) neutral beam power; (b) central T_i ; (c) central T_e ; (d) integrated power spectra from reflectometry at a layer with $n_e \sim 2.8 \times 10^{19} \text{ m}^{-3}$; the power spectra of reflectometry (from contour plots of sliding FFT), at (e) $n_e \sim 2.8 \times 10^{19} \text{ m}^{-3}$ and (f) $n_e \sim 0.8 \times 10^{19} \text{ m}^{-3}$, located respectively at $r/a \sim 0.6$ and close to the separatrix. At the inner layer, the fluctuation level decreases abruptly at $t \sim 1.07 \text{ s}$, before the 2nd beam starts, coinciding with the increase of T_e and the confinement factor, and preceding (by $\sim 50 \text{ ms}$) the reduction at the edge at the L-H transition, occurring at $t \sim 1.12 \text{ s}$. This indicates that an internal transport barrier develops during the current ramp phase (with moderate NBI), before the edge H-mode barrier is formed. After 1.18 s the observed oscillations at the outer layer are correlated with the turbulence due to ELMs.

Prior to the improvement in the core, a shift of the turbulence spectrum to higher frequencies is observed indicating an increase of the plasma rotation. This is also seen at the edge prior to the L-H transition and it is a typical feature found in H-mode regimes with or without ITBs. At the formation of the edge barrier, the power integrated spectra attains a minimum level which may be explained by a further increase of plasma core rotation due to the formation of the edge barrier.

In a set of similar discharges (#12091 to 12095), the probing frequencies (one per channel) were varied from discharge to discharge covering the range n_e : $0.4-4 \times 10^{19} \text{ m}^{-3}$. The radial location of the probed layers is inferred from the density profile depicted in Fig.2a, obtained from DCN + Li-beam. The temporal evolution of the integrated power spectra at the probed density layers is shown in Fig.2b. Two regions where the fluctuations are reduced can be identified: the first is formed at plasma core ($t \sim 1.07 \text{ s}$), between 10 and 20 cm inside the separatrix, and the second one at $t \sim 1.12 \text{ s}$ close to the separatrix and extending to $\sim 5-7 \text{ cm}$ inside. No re-

duction is observed in the layer further inside the plasma (30 cm from the separatrix). The evolution of the regions with reduced fluctuations during the whole discharge shall be inferred from broadband measurements used also for density profile evaluation.

3. Density profiles and evolution of core and edge regions

Density profiles (with temporal resolution 20 μ s) were measured (#10516) by operating simultaneously four reflectometry channels in broadband swept mode (Figs. 3a and b). At $t \sim 0.865$ s the profile has the parabolic shape typical of L mode. After the central T_e starts to increase, a shoulder forms at the edge and the density profile peaks at the core, as observed at $t \sim 1.074$ s. The edge pedestal further develops after the L-H transition and the density gradient at the core steepens (seen at $t = 1.277$ s). The detailed evolution of the edge pedestal in a discharge with similar characteristics (#12041) can be seen in Fig.4. It is also formed before the L-H transition, when central T_e and T_i starts to increase, and develops in correlation with the evolution of the central T_i , which make evident the strong link between the core and edge barriers.

The power spectrum of the broadband signals (obtained with a sliding FFT) exhibits a main peak corresponding to the distance (group delay) between the antenna and the reflecting layer. When fluctuations are present, the energy of the main peak decreases and the spectrum broadens. In order to characterize the level of fluctuations at the discrete sweeping intervals, we define a parameter $P = 1 - \alpha$, where α is the ratio between the power spectra (of each time window used for FFT analysis) integrated around the main spectral component due to distance and the total power spectra. In Fig.5 we plot the P parameter in the density range [0.4-3.8 $\times 10^{19}$ m⁻³] and time interval [0.9-1.9 s]. The hot colours should correspond to higher level of fluctuations and the minimum level to the white regions.

In the L-phase fluctuations are found at all density regions. The pedestal can be clearly identified by the line separating the peaked edge region (with lower level of fluctuations) and the region beyond the density shoulder, where the fluctuations are enhanced due to the flatness of the profile (see Fig.4). A first transient drop of fluctuations in the core is observed [3.1-3.4 $\times 10^{19}$ m⁻³] for $t \sim 1.02$ s when the plasma changes from limiter to X-point configuration. This is in agreement with the evolution of the integrated power spectra shown in Fig.2b. However, the detailed temporal evolution cannot be obtained from the P-mapping because in this discharge the measuring windows were spaced by 15 ms, whereas the temporal resolution with fixed frequency is 0.5 ms. With this limitation, we observe that fluctuations are reduced at $t \sim 1.07$ s, when central T_e starts to grow, after increase and are reduced only at short time windows. This may be associated with the local plasma movements occurring during the ITB formation phase. When the density profile is stabilized, after the full development of the edge pedestal, at $t \sim 1.33$ s a clear region with reduced fluctuations is seen (n_e : 3.1-3.4 $\times 10^{19}$ m⁻³), located at the foot of the steep gradient core region (see density profiles in Fig.3b). This zone moves radially inward and outward and at some short intervals invades the edge region. These radial movements can be correlated with a relaxation oscillation associated with (1,1) fishbone activity that is triggered exactly at $t \sim 1.33$ s and is considered to provide a mechanism to expel particles and energy and in this way sustain the ITB [1]. With the reduction of beam power (at $t \sim 4.0$ s) central T_i drops, and the density gradient in the core is reduced (see profiles at 3.941 and 4.141 s) indicating a degradation of the internal transport barrier; a significant modification of the edge pedestal is also observed, with the density dropping from 2.5 to 1.7 $\times 10^{19}$. However, a steep edge gradient can still be observed, during the last part of the ELMy H-phase. At 4.55 s the edge barrier has also been destroyed: the edge gradient is greatly reduced and the broadband turbulence characteristic of the L-phase is present. This behaviour of turbulence is also clearly seen from fixed frequency measurements.

4. Concluding remarks

We analysed in a consistent way the evolution of density profiles and density fluctuations in plasmas with improved core confinement and H-mode edge. The localized measurements of reflectometry permitted to study continuously in time (with fixed frequency operation) and space (with broadband measurements) the formation, sustainment and destruction phases of both the core and edge barriers. The main findings common to both barriers are: the increase of the plasma rotation prior to the barrier formation, the abrupt decrease of plasma fluctuations, the peaking of the density profile. Also, the confinement improves first at the core and the core barrier is destroyed before the confinement degrades at the edge. The above results are in agreement with previous observations in DIII-D (from coherent Thomson scattering) during negative central shear discharges /4/.

We found that the internal barrier, located at the foot of the core region where the density profile is steep, is separated from the edge barrier (close and inside the separatrix) by a flat region in the density profile where the fluctuations are not suppressed. A strong interplay was discovered between the improvement of transport in the core and edge regions. Many open questions still remain that will be further investigated, namely if it is possible to infer from reflectometry measurements what is the role of the radial electric field shear in the ITB formation.

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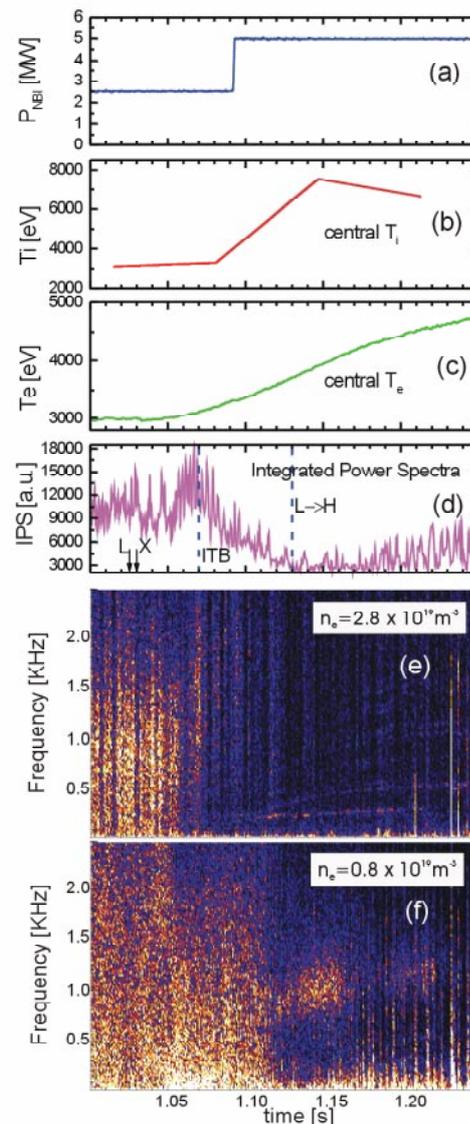


Fig.1

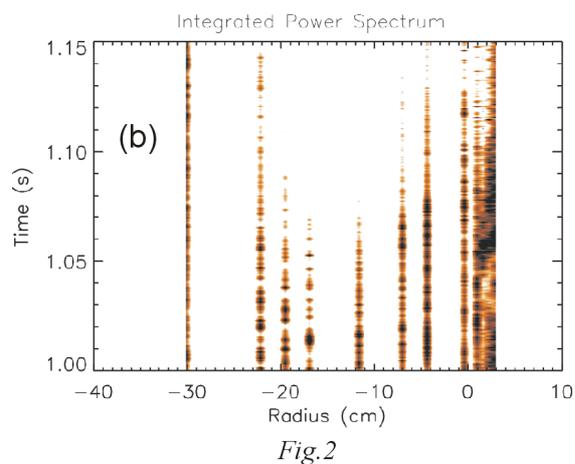
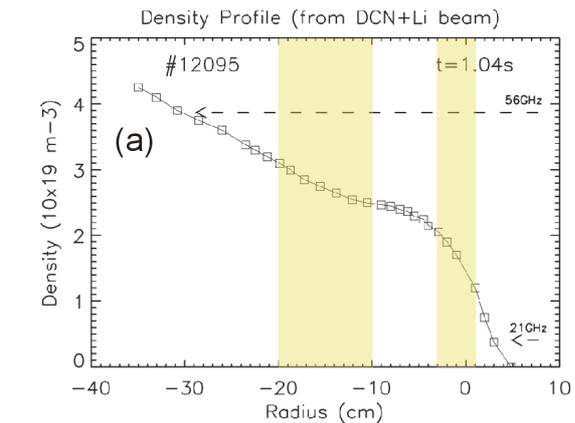


Fig.2

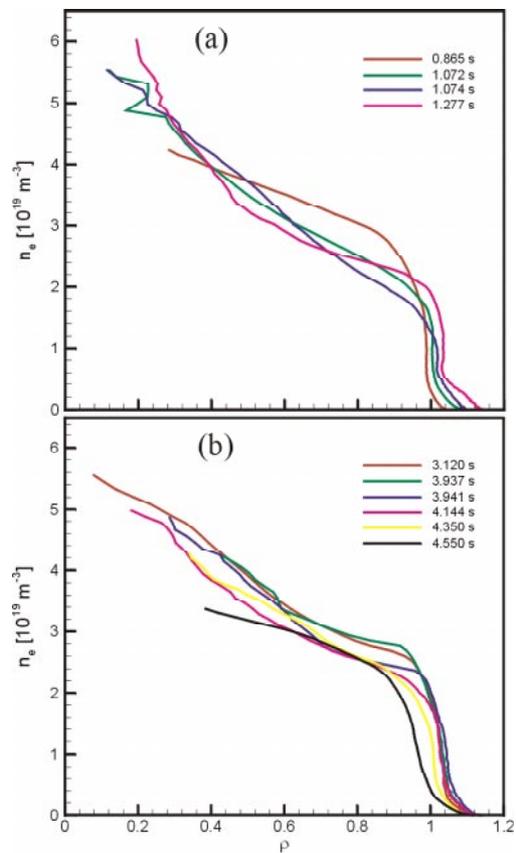


Fig.3

