Dynamics of the Electron Density Profile and Plasma Turbulence during the L-H transition and ELMs in TEXTOR

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Limiter H-mode on TEXTOR

An H-mode appears under certain conditions in NBI heated circular TEXTOR plasmas limited on the inner wall[1,2]. It is characterized by a density pedestal, a modest improvement in confinement and high frequency (~ kHz) ELMs. Although this regime might not be directly relevant for divertor tokamaks its detailed study could deliver information on H-mode and ELM physics due to some excellent diagnostics on TEXTOR. A previous study[3] using a high-frequency (5 kHz) Thomson scattering diagnostic and correlation reflectometry revealed the behaviour of turbulence and poloidal flow changes during the L-H transition and the ELM cycle and showed the existence of intermittent quasi-coherent MHD modes in the pedestal region. However, their relation to ELMs was not clearly understood. This study looks into the phenomena using highly efficient Li-beam diagnostic capable of turbulence and density profile measurement with a few microsecond time resolution. Discharges in 2009 and 2011 with I_p=230 kA, B_t=1.3T, one or two NBI heating beams (P_{NBI}=1.3-2 MW) with a clear L-H transition and quasi-periodic ELMs have been selected while avoiding dithering transitions and irregular ELM regimes. The results presented in this paper are valid for all discharges, it is the ELM frequency which depends on heating power.

Li-beam diagnostic

The density profile in the SOL and edge region of TEXTOR discharges is measured with a 35 keV Lithium Beam Emission Spectroscopy (Li-BES) diagnostic using direct imaging optics and highly efficient APD detectors. It is optimized for fast measurements, with 500 kHz signal bandwidth and only 1-5% RMS statistical noise on the 14 signals. The beam diameter sets the measureable $k_{pol} \le 2cm^{-1}$. Atomic physics effects in the Li-beam create about 2 cm radial smearing in the measurement, which is partly unfolded by the Bayesian density reconstruction method. The 14 measurement points are spaced by 1 cm radially (r=30-45 cm in the analyzed discharges) and enable measurement of fluctuations and density profile in the pedestal and SOL region (r=35-45 cm). An additional feature enables switching the beam on and off (chopping) with up to 250 kHz frequency, thus the background light (believed to be dominated by edge radiation from the bottom of the plasma) and Lithium beam intensity (and thus edge density profile) can be precisely calculated on a few microsecond timescale. A 400 kHz, 1-2 cm poloidal beam hopping capability provides some two-point poloidal resolution.

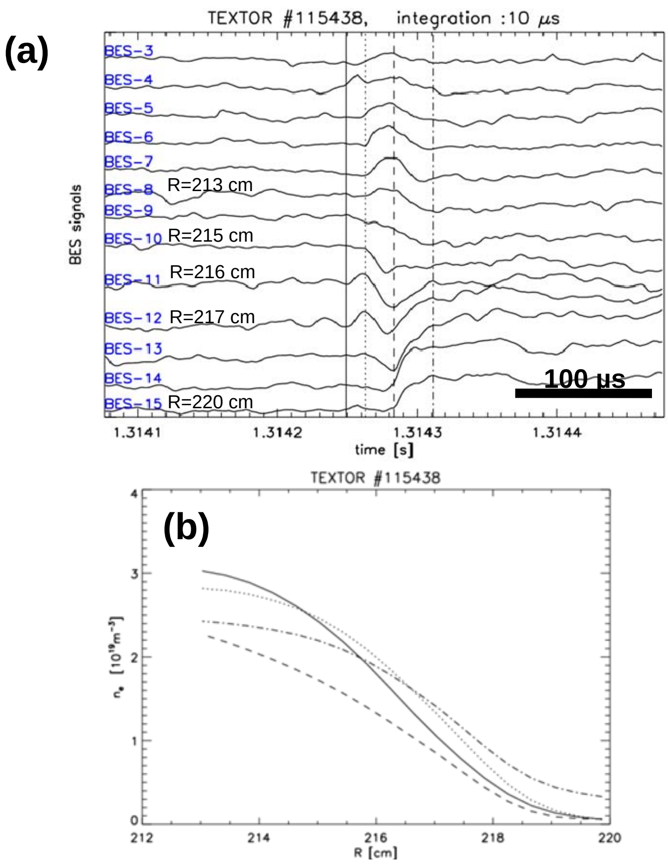
Density and turbulence dynamics at the L-H transition and during the ELM cycle.

Turbulence is dominated already in the NBI heated L-mode phase by ELM-like transient flattenings of the density profile. Larger events reach out to the edge and modulate the background light of the Li-beam diagnostic as well. This situation is in strong contrast to the Ohmic phase when the radial correlation length of turbulence is only 1-3 cm. Although usually present in lower density Ohmic TEXTOR measurements Geodesic Acoustic Modes (GAMs) are not observed in these discharges. At the L-H transition the low frequency (<30kHz) turbulence switches off in about 100 μs followed by gradual formation of the density pedestal on a ms timescale. No change in higher-frequency turbulence is seen, which is in contrast to reflectometry results[3]. The turbulence spectrum integrated over ELMs is quite similar to the L-mode phase, the inter-ELM phases exhibiting a drop at low-frequencies similarly to the L-H transition. During ELMs the density gradient drops and subsequently recovers also on a ms timescale, similarly to the L-H transition.

Density change during individual ELMs

Li-BES resolves the density profile dynamics during ELMs as well as shown in *Fig. 1.* For this analysis fast chopping measurements are used with 180-250 kHz chopping period, therefore a precise background correction is done on about a 5 μs timescale. Although individual ELMs are different some clear tendencies can be observed in their early period by a systematic analysis of Li-BES signals which, in the pedestal and SOL region (R>214 cm), are nearly proportional to the electron density. The electron density profile change is calculated only for certain ELMs using a Bayesian technique, an example is shown in *Fig. 1.*

For the statistical analysis a reference signal is constructed by summing all 14 Li-BES background signals. For each ELM the time is determined when the reference signal grows above a fixed level at about 5-10% of the highest pulse, this is marked by relative time 0 on *Fig. 1c-f.* In the [-20, 10] μs relative time range the reference signal of individual ELMs



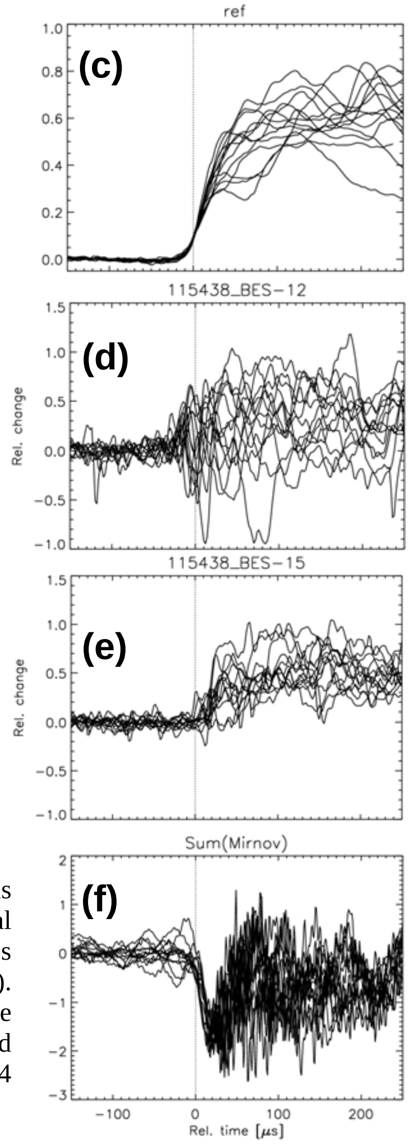


Fig. 1. (a) Time evolution of background corrected Li-BES signals during an ELM. The plasma edge is towards the bottom. The pedestal middle is at about channel 11-12. (b) Electron density profiles calculated from the Li-BES signals at the 4 timepoints indicated in (a). (c) ELM reference signal for 13 ELMs, the dotted line marks the reference time. (d)-(e) change of Li-BES signals at the middle and bottom of the pedestal relative to the mid-pedestal value. (f) Sum of 4 Mirnov coil signals in one poloidal quadrant for the same ELMs.

follows the same curve except about 10 % of the cases which appear to be triggered in a different (slower) way.

The ELM starts as a perturbation of the Li-BES signal at the steepest part of the pedestal *Fig. 1d* either as a few period of a quickly growing 30-50 kHz oscillation or a sudden inward or outward radial shift of the profile on a 10 μs timescale. The appearance of this "trigger" mode is limited to a 1-2 cm radial region (1-2 channels) in the middle of the pedestal. This mode is not seen with constant or slowly growing amplitude, it is always growing on a time scale comparable to its period time. Some information can be obtained for the poloidal wavelength of this mode from fast poloidal deflection Li-BES measurements which give an approximate poloidal phase delay. From this the poloidal wavelength is expected to be roughly 10 cm, that is m~30. In some cases a ~10 kHz sinusoidal oscillation is seen before or after the ELM as described in Ref. [3], but it is not limited to such a narrow radial extent and it is changing its amplitude on a much slower timescale, therefore not considered to be related to the trigger of the ELM. This initial trigger phase is followed within 30-40 μs by flattening of the density profile and a sudden jump in the Li-beam signal, and therefore the density, outside the pedestal, as shown in *Fig. 1e.* It is important to note that the background signals rise gradually *already* during the initial perturbation in the pedestal, while the sudden density rise outside the pedestal follows with a clear time delay. Neither the background signals nor Mirnov coil signals show signature of the trigger mode. Finally the sum of 4 Mirnov signals in the upper LFS quadrant are plotted for the same ELMs in *Fig. 2f.* There is a systematic change into negative direction corresponding to a drop in the poloidal field. In some cases a clear 10 kHz mode is observed in the Mirnov signals before or after the ELM. This initial ELM trigger period is followed by the bulk of the ELM which lasts for 300-500 μs. It is characterised by multiple ejection events and differs very much for each individual ELM for all signals.

Discussion

The detailed measurements revealed a quickly growing trigger mode with m~30 at the steepest part of the pedestal *(Fig. 1d)* as the earliest signature of an ELM. In its last cycle it evolves into a strong shift of the density profile *(Fig. 1b)*. In some cases 2-3 periods are seen, in other cases only the final shift, therefore we consider it as a toroidally localized mode growing on the steep pressure gradient. A sudden density jump follows outside the pedestal *(Fig. 1e)* within 20-30 μs, such a short time which is not sufficient for a density perturbation travelling with ion sound speed to distribute plasma along a flux surface. This way the plasma should be ejected by the MHD mode locally. A gradual increase of the background light in the early phase of the ELM everywhere in the Li-beam diagnostic indicates a change in edge plasma conditions even before the density wave arrival outside the pedestal. This might be the result of the trigger mode transporting hot electron fluid from the pedestal to the edge.

The trigger mode is not seen by the Mirnov coils as they are probably too large and distant to pick up the intermediate m perturbation. Other modes (mostly around 10 kHz) are seen by both the Mirnov coils and the Li-beam before and/or after the ELM (see Ref. [3] as well), but they don't seem to be related to the ELM trigger. However, a gradual decrease in the poloidal magnetic field is seen in the earliest phase of the ELM indicating either a shift of the plasma or decrease of edge current.

References

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