Density profile and turbulence evolution during L-H transition studied with the Ultra-fast swept reflectometer on ASDEX Upgrade

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1. Introduction

The plasma confinement is limited by the plasma energy and particle transport, in which turbulence plays an important role. One of the most widely accepted theories concerning the transition from the Low (L) to High (H) confinement regime asserts that the plasma edge is stabilized by increased radial electric field gradients: the $E_r \times B$ shear stabilizes turbulence and decreases the radial size of turbulent structures. A transport barrier forms in the edge where density, temperature and their gradients increase [1]. In this contribution we investigate the turbulence behaviour using data on density fluctuations measured by an ultra-fast swept reflectometer. Between L- and H-mode an intermediate phase, called I-phase, occurs, where density fluctuations, density gradient and perpendicular flow velocity oscillate in the kilohertz range. The number of periods preceding an established H-mode varies with the heating power, but at least a few oscillations are always present in favorable magnetic configuration in the ASDEX Upgrade tokamak (AUG). The I-phase has been described by an interplay between the turbulence and turbulent zonal flows that creates limit-cycle oscillations [2]. But recently it was shown on AUG, that the background $E_r \times B$ flow plays the dominant role [3]. The aim of the present study is to provide a better understanding of the density and background $E_r \times B$ velocity shear dynamics during the I-phase.

2. Ultra-fast swept reflectometer at ASDEX Upgrade tokamak

The recent transfer of the Ultra-fast swept reflectometer (UFSR) from Tore Supra to AUG has provided electron density measurements with a time resolution of $1\mu s$ (less than the characteristic turbulence time scale). The system consists of heterodyne V and W band (50-105 GHz) frequency sweeping reflectometers [4]. The emitting and receiving antennas are installed on the mid plane of AUG on the low-field side with a line of sight in radial direction towards the centre of the plasma. Using a linear frequency sweep and an iterative Bottollier-Curtet procedure [5] a density profile can be obtained (Fig. 1). The plasma density turbulent fluctuations can be extracted from the fluctuations of the reflected signal [6]. The heterodyne receiver and IQ detection assure a separation of phase and amplitude of the reflected signal with a signal to noise ratio of about 40 dB, sufficient for fluctuation measurements. Fast and repetitive sweeps with 0.25 μs dead time between sweeps provide an equivalent sampling rate of 800 kHz at a given probing frequency and allow to calculate radial density fluctuation profiles, frequency and wave number spectra.

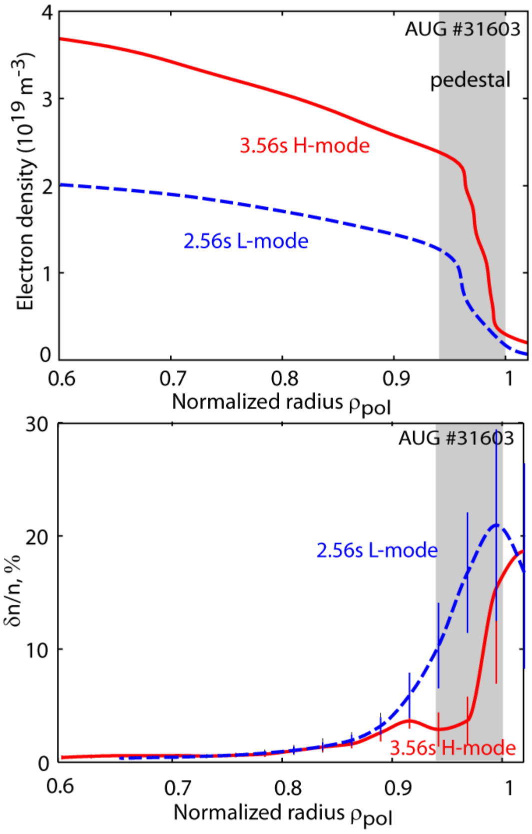

Figure 1: *Density and density fluctuation radial profiles from UFSR*

3. L-H transition

In order to understand the H-mode onset we have performed series of discharges where the L-H transition was triggered by an ECRH pulse close to the power threshold. The density fluctuations properties were compared in L- and H-mode using UFSR data. First, applying a closed-loop method and 1D-wave propagation simulation [6], the radial wave number spectra for each radial position have been found. Then, by a simple integration over small radial wave-numbers 1 cm^{-1} $< k_r <$ 10 cm^{-1} the absolute turbulence level profiles have been reconstructed (Fig. 1). The decrease in turbulence level during the L-H transition confirms the predicted suppression of large scale turbulent structures in the pedestal region, from the separatrix $\rho_{pol} = 1$ to the top of the density pedestal. To characterise the turbulence present in L- and H-mode the frequency spectra are first calculated for each probing frequency and then radially interpolated on the average density profile. A sharp transition from a broad turbulence spectrum to coherent modes around 100 kHz is observed in the early H-mode before the first ELM. The swept reflectometry can provide a precise radial localisation and extent of this coherent mode: $0.87 < \rho_{pol} < 1$. Toroidal mode numbers were deduced from magnetic pick-up coils. They vary between $n = -3, \ldots, -8$ for the lowest to uppermost branch (the negative sign corresponds to the electron diamagnetic direction). As the modes develop with the increase of the pressure gradient they might be related to a kinetic ballooning instability.

4. I-phase

During this study, I-phases for various plasma conditions were documented and the density gradient evolution is compared with the turbulence level. For the shot AUG#32723 a wide range of diagnostics was focused on a L-H transition produced by 1.2 MW ECRH. In AUG the I-phase can typically be identified in a poloidal Mirnov coil signal and in the divertor shunt current as low kHz range oscillations. The same kind of oscillations is clearly visible in the amplitude of the Doppler reflectometer signal which is proportional to the turbulence level at the position of about $\rho_{pol} = 0.98$ for a probing frequency of 50 GHz. Similar bursts were found with a high temporal resolution in the normalised density gradient $\frac{\nabla n_e}{n_e}$ evolution from UFSR data. Combining these data with the temperature measurements we could reconstruct pressure profiles and estimate the corresponding background E_r, in first approximation equal to the normalised electron pressure $E_{r0} = \nabla p_e/en_e$.

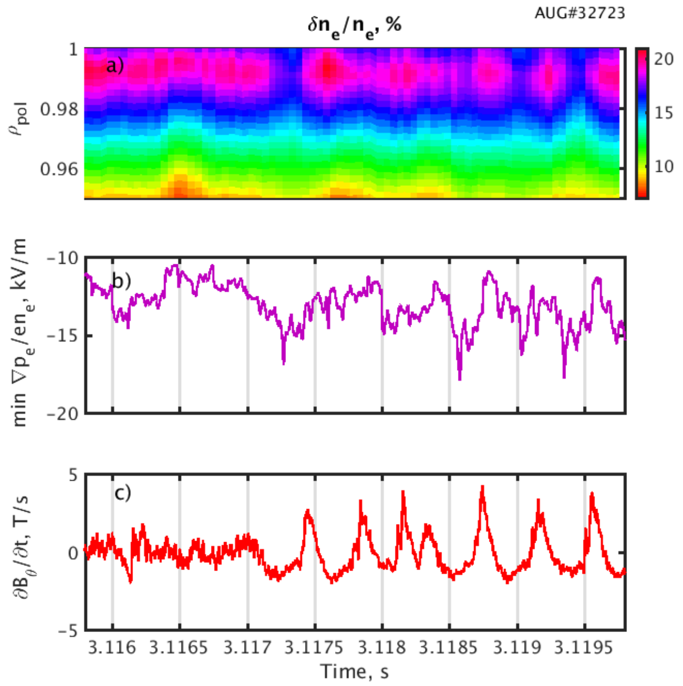

Figure 2: *Zoom on the L-I transition: a) density fluctuations from UFSR in the edge, b) normalised pressure gradient at* $\rho_{pol} = 0.98$ *compared to c) Mirnov coil signal*

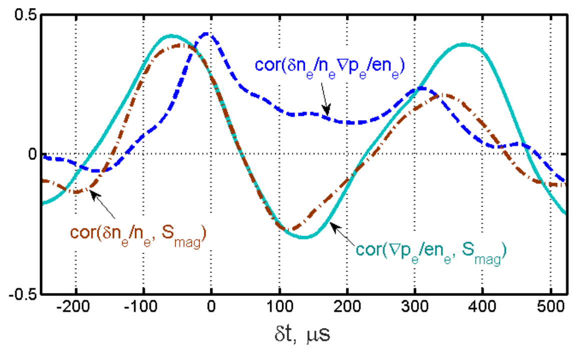

Figure 3: *Correlation functions between* $\nabla p_e/n_e$ *and* S_{mag} *(solid),* $\delta n_e/n_e$ *and* $\nabla p_e/n_e$ *(dash),* $\delta n_e/n_e$ *and* S_{mag} *(dot-dash) for the first 5 ms of the I-phase*

During the I-phase the average neoclassical radial electrical field E_{r0} deepens around $\rho_{pol} = 0.98$ with the smooth and continuous increase of the density. Estimated minimum values of E_{r0} are of the order of -10 kV/m in the late L-mode and reach -30 kV/m before the first ELM observed at $t = 3.246$ s. These values indicate that the I-phase confinement is close to that of an H-mode. A close zoom-in on the oscillations (Fig. 2, a-c) shows that during one period of the I-phase the E_{r0} minimum value changes by about 10 - 30 %, the crash to the lower absolute level being synchronised with magnetic signal $S_{mag} = \frac{\partial B_\theta}{\partial t}$ bursts and the increase of density fluctuations $\delta n_e / n_e$ measured by UFSR. Before the very first I-phase burst the turbulence level drops and the E_{r0} minimum crosses the typical threshold for L-H transition (around -15 kV/m), this stage will need further investigation to understand the triggering mechanisms of the transition. For an early I-phase, correlation functions were calculated between density fluctuations (Fig. 2, a), the electrical field estimate E_{r0} at $\rho_{pol} = 0.98$ (Fig. 2, b) and the pick-up coil signal S_{mag} (Fig. 3). The shift of the correlation function between the magnetic signal and the two others by $\Delta t = 50\mu s$ is probably due to the location of the Mirnov coil at different poloidal position. The absence of shift of the correlation function between E_{r0} and the turbulence level suggests that the I-phase bursts might be explained by edge instabilities appearing in the weak-E_r phase, while the turbulence is suppressed by the background electrical field shear during the strong-E_r phase.

5.Conclusion

After a successful installation of the Tore Supra reflectometers on AUG, first studies of the fast electron density dynamics during L-H transitions were performed. Evidence is presented that the level of low k_r density fluctuation decreases in the pedestal region after the transition to H-mode. An I-phase description based on the background E_r profile and edge instabilities is found to be the most suitable.

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