Flow dynamics approaching L-H transition

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The shear of the radial electric field at the edge is widely accepted to be responsible for turbulence reduction in edge transport barriers [1] and thought as a key ingredient of the improved confinement of H-mode plasmas [2]. While in H-mode, the radial electric field has been found to be neoclassical in the well measured just inside the separatrix [3, 4], contributions related to turbulence generated flows are reported to enter at play [5, 6, 7, 8] approaching the L-H transition. The present contribution focuses on the dynamics observed simultaneously in both the flow and the turbulence when approaching the L-H transition in the WEST tokamak. This dynamics is extracted from Doppler Backscattering system (DBS) signal via the velocity and the amplitude of the detected density fluctuations.

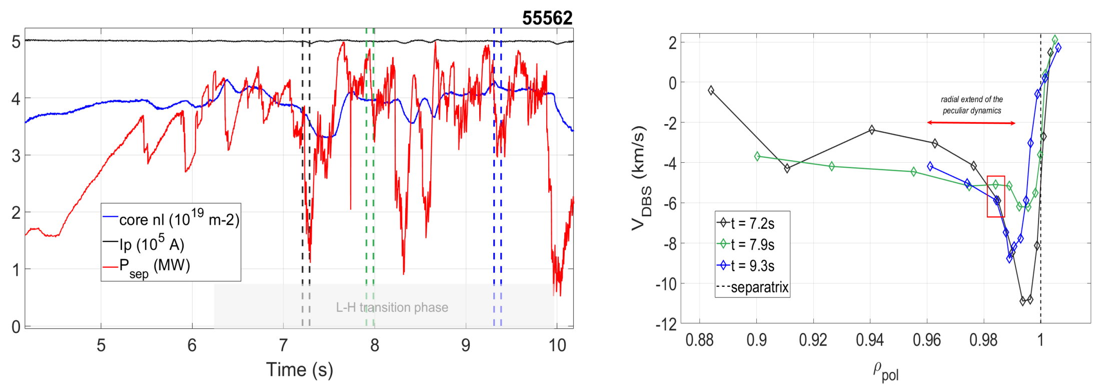

Figure 1: Time traces of density, plasma current and power crossing the separatrix P_{sep} (left). Radial profiles of the DBS velocity at corresponding times (right)

The WEST tokamak is an upgrade of Tore Supra from a limiter-based tokamak with carbon PFCs into an X-point divertor tokamak with full-tungsten armour while keeping its long pulse capability [9]. As a result, WEST is a large aspect ratio machine (A=5-6) with a magnetic ripple around 3% at the plasma outboard edge, lower than in Tore Supra (around 6%). Additional heating is based on RF systems (both Low Hybrid and Ion Cyclotron Resonance Heating systems); divertors are symmetric with active X-point either at the bottom or at the top and the $B \times \nabla B$ drift always pointing down. The velocity profiles presented and discussed in the following are obtained from Doppler BackScattering (DBS also called Doppler reflectometry) measurements in X-mode polarisation [10]. Two data analysis methods are used for determining both an average velocity of density fluctuations and an kind of 'instantaneous' velocity as a function of time. The first, commonly used to access to the radial profile of the velocity is based on Fast Fourier Transform (FFT). The second, introduced in the community to detect GAMs [11], uses the MUltiple SIgnal Classification (MUSIC) algorithm[12].

In WEST, L-H transitions have been observed both in Lower Single Null (LSN) and Upper Single Null (USN) configurations. While no sign of an established H-mode regime is visible (such as ELMs), transitions have been identified by simultaneously observing expected changes in both the confined and SOL plasmas [13]. The present contribution focuses on a discharge in USN which corresponds to so called 'unfavourable $B \times \nabla B$'. Time traces of this discharge are shown in Figure 1 (left). During this discharge, at $B_T = 3.7T$, $I_p = 0.5MA$ and $q_{95} = 4.5$, additional power is coming from both LHCD and ICRH, and L-H transition occurrs at $t = 6.2s$. During this transition, the radial profile of the velocity shows the deepest well observed so far in WEST plasmas (Fig. 1 right). The heating power is not stationary (P_{sep} changing between 2MW and 4.5MW) and this discharge is eventful. The velocity well reaches $-11km/s$ at $t = 7.2s$ while the weak improvement in the confinement is lost around $t = 7.3s$. When enough additional power is recovered ($t = 7.55s$), the density increases again and the velocity profile shows anew a well. As compared to the previous one, this velocity well appears weaker while P_{sep} is higher. Looking more in details into the DBS data, it is found that at this time the velocity has a particular dynamics.

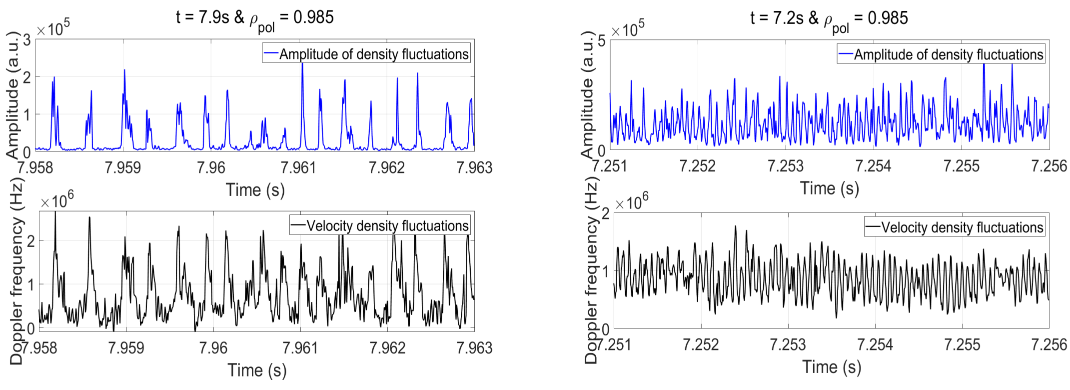

Figure 2: Dynamics of the amplitude and the flow around $\rho_{pol} = 0.985$ at $t = 7.9s$ (left) and at t = $7.2s$ (right), for density fluctuations selected at $k_\perp \simeq 9cm^{-1}$)

Figure 2 shows the dynamic of both amplitude and velocity of density fluctuations at a given radial position ($\rho_{pol} = 0.985$) for two different time sequences. At $t = 7.2s$ (Fig. 2 right), standard oscillations around a certain value are observed in the DBS velocity with a frequency around $15kHz$. While this behaviour appears similar to the presence of Geodesic Acoustic Modes (GAMs), the amplitude of the DBS appears also modulated. This feature is not expected for GAMs (i.e. perturbation in density such as m=0, n=0).

The particular behaviour mentioned above takes place at $t = 7.9s$ (Fig. 2 left). The amplitude of the DBS signal (corresponding to density fluctuations level at the selected wavenumber, here $k_\perp = 9cm^{-1}$) exhibits burst events with a frequency around $4kHz$ in a radial zone which extends across the well and inner branch. This bursty dynamics is associated with bursts of high (resp. low) Doppler velocities. Therefore, the averaged profile (Fig. 1 right, green profile) does not resolve properly the peculiar shape of the velocity profile at this time. This behaviour explains the less deep well.

This bursty dynamics, observed both in the velocity and in the amplitude of density fluctuations has strong similitude with observations made in ASDEX Upgrade [5, 14], TJ-II[7] and DIIID [6]. Note that however, in WEST, no sign of an I-phase dynamics has been detected so far in other signals (such as Dalpha or fast sweep reflectometry). In particular, it is important to mention that no oscillations are observed in density profiles (neither from density fluctuations at fixed probing frequency) from ultra-fast swept reflectometer (UFSR) while the time resolution is high enough to resolve such dynamics. This point is surprising since this system uses the same band frequency in X-mode polarisation and then probes the same radial location. The main difference between both systems (UFSR and DBS) should be the selected wavenumber density fluctuations. In the case of UFSR, it collects fluctuations between $1 < k_r < 20cm^{-1}$ with poloidal wavenumbers up to $k_\theta \simeq 10cm^{-1}$. In the case of DBS, only very small radial wavenumbers are included $k_r < 1cm^{-1}$ with a selected poloidal wavenumber, here $k_\theta \simeq 9cm^{-1}$. Others major differences, as compared to the previous observations cited above is that in WEST, first the observation is made in unfavourable configuration and secondly that the phase delay between amplitude and velocity is of opposite sign ; the velocity increases slightly before the fluctuation level. While the last characteristic may not appeared compatible when considering zonal flows and turbulence interaction, it should be noted that the expected timing may changed

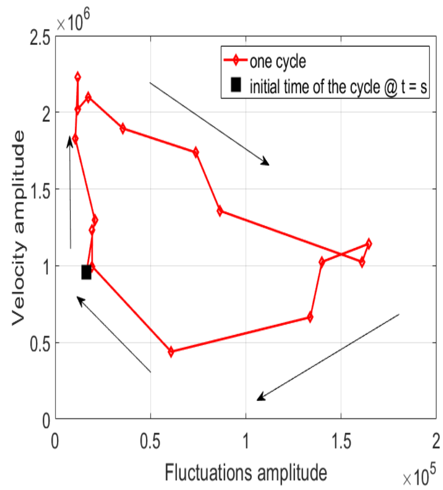

Figure 3: Relation between velocity and density fluctuations amplitude.

considering different spatial scales of fluctuations. This behaviour reamins compatible with a predator-prey model, as Volterra model [15], in which the phase shift depend on the parameters of the model (such as, in our case, flow damping and growth rate of turbulence). Concerning the fact that this dynamics takes place in the unfavourable configuration, one could think that this situation suggests an I-mode regime since this configuration is favorable to such mode. Especially, WEST operating at high B field, it is expected to have an-I mode significant operational window [16]. However, in addition to the increase in density, which is not expected during I-mode, no clear signs of a Weakly Coherent Mode typically, considered as the signature of I-mode, is reported on fast sweeping reflectometry. The peculiar behaviour appears over a radial zone which extends across the well and inner branch (between $\rho_{pol} = [0.96 - 0.99]$. Looking at the time delay between density fluctuations amplitude and velocity at different radius, no clear trend is found ; it varies from $\Delta t = 32\mu s$ at $\rho_{pol} = 0.985$ to $\Delta t = 19\mu s$ more outside.

At this stage, it remains not possible to conclude about the interpretation of the flow and density fluctuations coupled dynamics. However, since such behaviours is generally observed just before the establishment of an H-mode, its observation in WEST is encouraging for performing H-mode in the co-called "unfavourable configuration", i.e in USN configuation.

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