Evidence of Zonal Flows triggering the L-H transition and role of isotope mass in the TJII stellarator

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Introduction:

Understanding the impact of 3D fields and isotope mass on transport during the Low to High (L-H) transition is determinant for the development of ITER base-line scenarios with controlled Edge Localized Modes (ELMs) and reduced L-H power threshold.

In tokamaks, experimental studies have shown a reduction of the L-H power threshold by about 50% when using Deuterium and He instead of Hydrogen [1]. No full understanding of ELM suppression mechanisms is available yet [2], however the application of RMPs (Resonant Magnetic Perturbations) at a certain magnitude increases the power required to access H-mode as has been investigated experimentally in the MAST tokamak [3].

H-mode confined plasmas [4] are characterized by the suppression of turbulence and the formation of an edge negative radial electric field (E_r) well accompanied by the build-up of an edge transport barrier and the reduction in D-alpha emission [5]. At present there exists substantial evidence for the decorrelation of the turbulence by sheared flow during the development of the transport bifurcation [6]. The relation between turbulence driven flows (Zonal Flows) and pressure gradient driven flows in the triggering and evolution of the L-H transition is still under discussion [1, 7]. While the ion pressure gradient plays an important role in the fully developed H-mode in tokamaks, the ratio of the electric field to the diamagnetic contribution can be larger than one in the W7-AS stellarator [8]. In the TJ-II stellarator the diamagnetic term is close to the radial electric field obtained experimentaly during the L-mode but it changes only very slightly after the L-H transition [9]. Also in stellarators have been detected long-range correlations consistent with the theory of zonal flows (ZFs) occurring at L-H transition density threshold values [10] in addition to the study of the role of magnetic topology and rational surfaces [**¡Error! Marcador no definido.**, 11, 12] in the development of plasma bifurcations.

In this work is reported direct experimental evidence of the presence of low frequency fluctuating zonal flows and mean sheared flows during the L-H transition as well as during the H-mode plasma in the TJ-II stellarator for both Hydrogen and Deuterium plasmas. Also, the radial evolution of the LRC was assessed. No evidence of isotope mass affecting the dynamics of LRC and radial electric field was found.

Experimental set-up: plasma scenarios and diagnostics

The TJ-II heliac is a four period stellarator (magnetic field $B \sim 1\,T$, plasma minor radius $a \sim 0.20\,m$) with helical magnetic axis and with a bean shaped plasma. Experiments have been carried out in pure NBI heated regimes ($P_{NBI} \approx 500$ kW) with line averaged plasma density in the range 2 x 10^{19} m^{-3} and central electron temperature T_e = 300 - 400 eV. Hydrogen (100 %) and Deuterium dominated plasmas (up to 70%) were generated in the NBI heated regime. Experiments were done for the standard magnetic configuration of TJ-II, having the edge rotational transform value close to 1.6 (which corresponds to n/m = 8/5 rational surface).

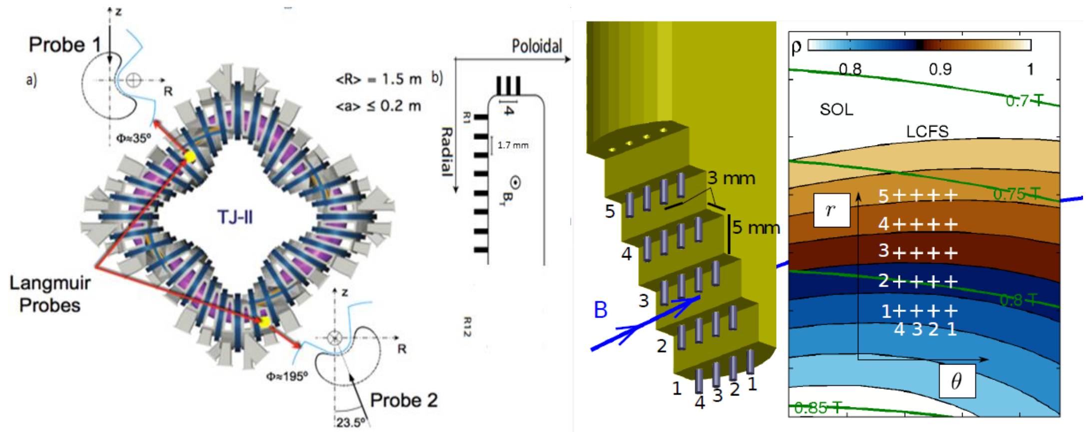

Figure 1. a) Schematic view of the location of the two Langmuir probe arrays (160º toroidally and 155º poloidally separated and b) a sketch of rake probe 1.

Mean radial electric fields (E_r) are characterized by a two-channel Doppler reflectometer (DR) that allows the measurement of the perpendicular rotation velocity of the turbulence and density fluctuations [13]. The radial range accessible by the DR is rho ≈ 0.6 to 0.9. Large-scale coherent structures in plasma potential (i.e. Zonal Flows [14,15]) were investigated using a dual system of Langmuir probe arrays, labelled as Probe 1 and Probe 2, located at two different toroidal/poloidal ports. The rake probe 1 is installed on a fast reciprocating drive at the top of the plasma. This probe consists of sixteen Langmuir probe tips, separated radially 5 mm and poloidally 3 mm (Figure 1.c). The second probe (probe 2) is also installed on a fast reciprocating drive and is located in a bottom port entering the plasma through a higher flux compression region than probe 1. This probe consists of eight probes separated 1.7 mm together with three poloidally separated tips at the top of the probe head (Figure 1.b). The sampling rate of probe signals was 2 MHz. The radial range accessible by the Langmuir probe arrays is rho $\approx$ 0.8 to 1. [See figure 1].

Results

The main results obtained in this work are the following: The radial electric field, measured by Doppler reflectometry, reaches values in the order of 5 kV/m in the L-mode plasmas before the L-H transition. During the H-mode the radial electric reaches values of about 10 kV/m.

The dual system of Langmuir probes allows the obtaining of floating potential signals at distant poloidal/toroidal positions. Cross-correlation and cross-coherence spectral techniques are applied to these signals in order to identify low frequency (1-20 kHz) global fluctuations, named as Long Range Correlations (LRC), considered as a proxy of Zonal Flows. LRC is computed between the radially outermost tip in probe 1 and all the radially disposed electrostatic tips in probe 2. The innermost tip in probe 1 shows the maximum LRC level and it radially decays, allowing a radial characterization of the outer part of LRC. The level of LRC increases during the preceding L-mode, reaching a maximum amplitude during the L-H transition and finally marginally decreases during the H-mode plasmas.

In addition, decoupling between floating potential and density fluctuations was found in the H-mode plasma. While the level of fluctuations is reduced in density for the whole frequency spectra, in the case of floating potential fluctuations, the reduction in the spectral power affects only to the higher frequencies, remaining the lower frequency band ($1<f<20$ kHz) fluctuations, which, in fact are the ones contributing to the Zonal Flows.

The amplitude of LRC and the radial electric field have similar values and evolve in a similar way for both cases of pure Hydrogen plasmas and Deuterium dominated plasmas. [See figure 2].

Conclusions and future work

The equilibrium radial electric field and the low frequency fluctuating radial electric field (Zonal Flows) were studied. The Zonal Flow activity was found to increase during the preceding L-mode, having a maximum during the L-H transition and remaining during the H-mode plasmas. This finding, together with previous results obtained at other stellarators suggest that the H-mode can be accessible through both ion pressure gradients and zonal flows.

In addition, there have not found evidence of the isotope mass affecting the radial electric field or LRC level during the transition in the explored magnetic configuration. Additional experiments exploring different magnetic configurations are needed to fully understand the role of isotope mass.

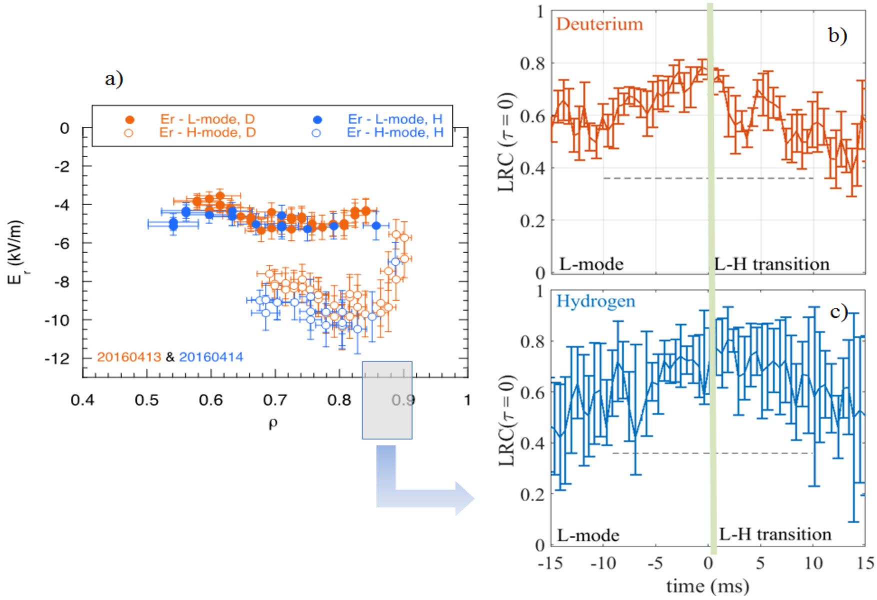

Figure 2. a) Radial profile of electric field during L-mode and H-mode plasmas. b) Time evolution of the LRC amplitude during the L-H transition. The figures show how the LRC amplitude is similar for both Hydrogen and Deuterium plasmas.

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