L-H transition experiments in the TJ-II stellarator

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Introduction

In the stellarator TJ-II, spontaneous L-H transitions are achieved in NBI heated plasmas [1]. H-mode transitions reproduce common features found in other devices: i.e. an increase in plasma density and plasma energy content, a reduction in H_α signal, the development of steep edge density gradients and a reduction in the turbulence level. To experimentally investigate radial electric field and turbulence dynamics a two-channel Doppler reflectometer [2] is used. This diagnostic technique allows the measurement of the perpendicular rotation velocity, radial electric field, E_r, and density fluctuations on various scales with good spatial and temporal resolution. At the L-H transition, an increase in E_r and E_r-shear is measured, and a significant reduction in the density fluctuation level is detected sincronized with the onset of a remarkable fluctuating E_r [1]. In the present work, the effect of the magnetic topology on the transition is reported. The low magnetic shear and high magnetic configuration flexibility of TJ-II allow controlling the position of low order rational values within the rotational transform profile and, therefore, the study of how the magnetic topology affects the L-H transition.

Experimental results

Previous L-H transition studies in TJ-II have shown a dependence of the H-mode quality on the rotational transform [3]. Different magnetic configurations were explored in plasmas heated with one NBI (co-injector). The differences found when comparing these configurations suggest a positive role of rational surfaces (8/5 or 5/3) on the transition. In order to proceed with these studies, the rotational transform scan has been extended covering vacuum $\iota/2\pi$ values at $\rho = 1$ between 1.5 and 1.71. It is worth mentioning that these experiments have been carried out at relative low NBI input power. The NBI absorbed power, P_{abs}, is close to that given by the tokamak H-mode power threshold scaling, P_{th} [4]; the ratio P_{abs}/P_{th} ranges from 1.0 to 1.3 In order to estimate the quality of the H-mode, both, the relative increase in the confinement enhancement factor, $H_{ISS04} = \tau_{E\ exp}/\tau_{E\ ISS04}$, over the L-mode value and the absolute value of the radial electric field well, have been selected and are shown in figure 1.a and 1.b, respectively, as a function of the edge rotational transform. Figure 1.b also displays the absolute value of the radial electric field measured right before the L-H transition in each magnetic configuration.

The shaded area in figure 1.a reflects the error in the diamagnetic energy measurement and gives the uncertainty in the H-factor determination. Both magnitudes, the H-factor and E_r field-well, show similar ι-dependence: higher values are obtained in configurations with a low order rational, either 8/5 or 5/3, close to the plasma edge $\rho \approx 0.8-0.9$. However, with $\iota/2\pi = 3/2$ the increase in the H-factor is marginal and the change in E_r less pronounced. By the comparison between the E_r field-well values measured in the H-mode and right before the L-H transition, it can be concluded that non special conditions regarding E_r are required prior to the transition for getting a good quality H-mode.

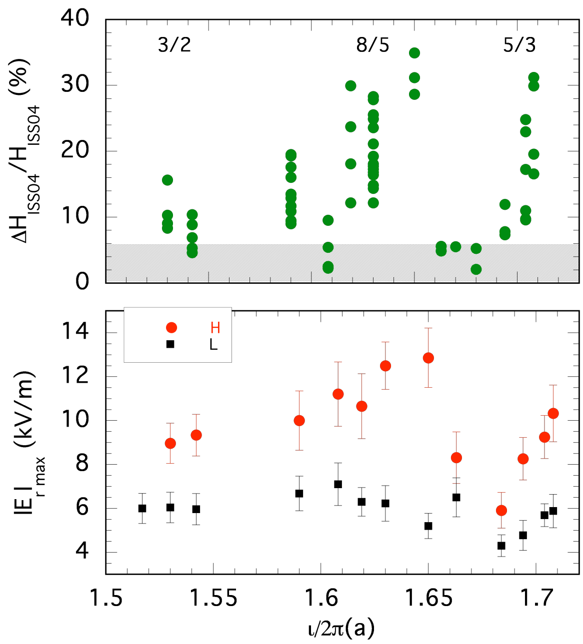

Figure 1: Increase of the H factor over the L-mode value (top) and radial electric field in L- (squares) and H-(circles) modes at $\rho \approx 0.75-0.8$ (bottom) as a function of edge $\iota/2\pi$

The dependence found in this fine magnetic configuration scan suggests a positive influence of low order rationals when located close to the plasma edge. In fact, the magnetic configurations with the rational 5/3 close to the plasma edge show that the L-H transition requires certain plasma current that depends on the magnetic configuration. Figure 2 shows the vacuum ι-profiles, the plasma current at which the L-H transition takes place and the E_r profiles measured in L and H modes in three magnetic configurations having the rational 5/3 close to the plasma edge. As the vacuum ι decreases, the plasma current required to trigger the transition increases which indicates a preferential radial position for the rational to ease the transition. Presently, we do not have a fair theoretical estimate of the bootstrap and NBI currents in these plasmas, but using a cylindrical estimate of $\Delta\iota(a)$ and stiff ι-profiles, the plasma current shown in figure 2.b would move the lower ι-profiles shown in 2.a to the higher one.

The mechanism to explain the shear flow generation in the vecinity of rational surfaces has not been identify yet; a theoretical analysis of a possible mechanism can be found in Ref. [5].

A the transition, pronounced oscillations in E_r are measured in the configurations with a low order rational close to the plasma edge. These oscillations represent local changes in E_r which may be induced by the rational surface facilitating the transition and giving rise to a higher confinement enhancement factor and a deeper radial electric field well.

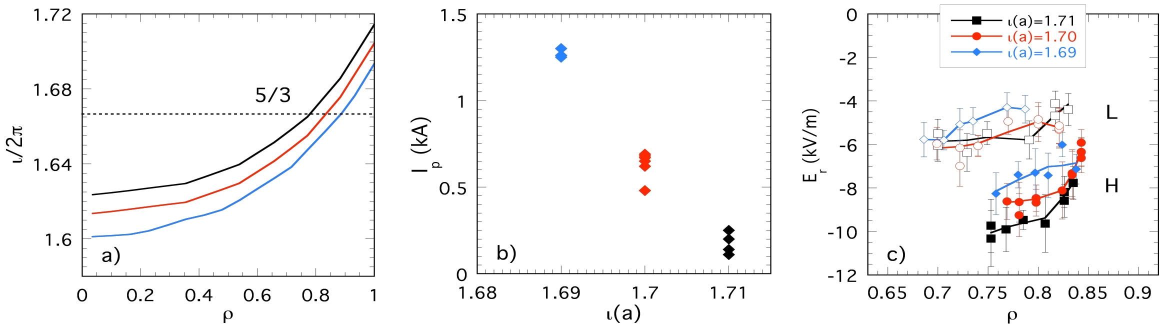

Figure 2: (a) Vacuum ι-profiles of three magnetic configurations with the rational $5/3$ close to the plasma edge, (b) plasma current at which the L-H transition takes place and (c) E_r profiles in L- and H-mode in these configurations.

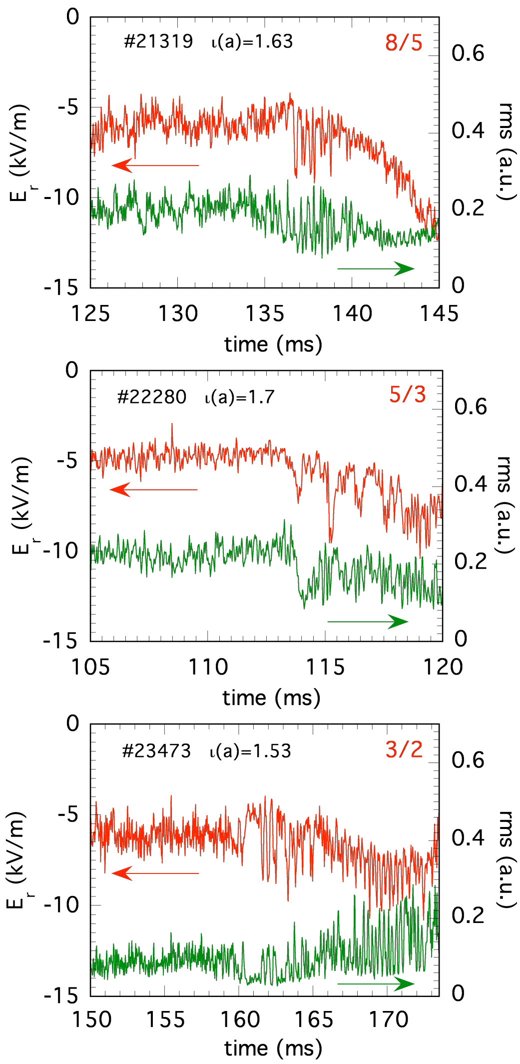

Figure 3: Time evolution of E_r (red) and density fluctuation level (green) measured at $\rho \approx 0.8$ in three magnetic configurations with rational surfaces 8/5 (top), 5/3 (mid) and 3/2 (bottom) close to the plasma edge.

Differences in the amplitude and duration of these oscillations are found associated to the order of the rational surface. They appear right at the L-H transition and vanish a few millseconds later, except in configurations with the rational 3/2 close to the plasma edge (see figure 3); in the latter case the oscillations often last all along the remaining plasma discharge precluding the subsequent radial electric field increase and turbulence reduction.

A closer look at the time evolution of both, E_r and density fluctuations, reveals a characteristic predator-prey behaviour, as shown in figures 4 and 5. The spectrogram of the Doppler reflectometer signal, displayed in figure 4, already shows the relation between E_r and turbulence level. The time evolution of the Doppler peak frequency ($\propto E_r$) and Doppler peak amplitude ($\propto$ density fluctuations) is shown in figure 5.left and two cycles are represented in figure 5.right. A periodic behaviour with E_r following the density fluctuation level with 90° phase difference can be clearly seen. The turbulence induced sheared flow is generated causing a reduction in the turbulent fluctuations (**1** in figure 5.right), the subsequent drop in the sheared flow (**2** in figure 5.right) and the posterior increase in the turbulence level (**3** in figure 5.right). The coupling between fluctuations and flows, described as a predator-prey evolution, is the basis for some L-H transition models [6].

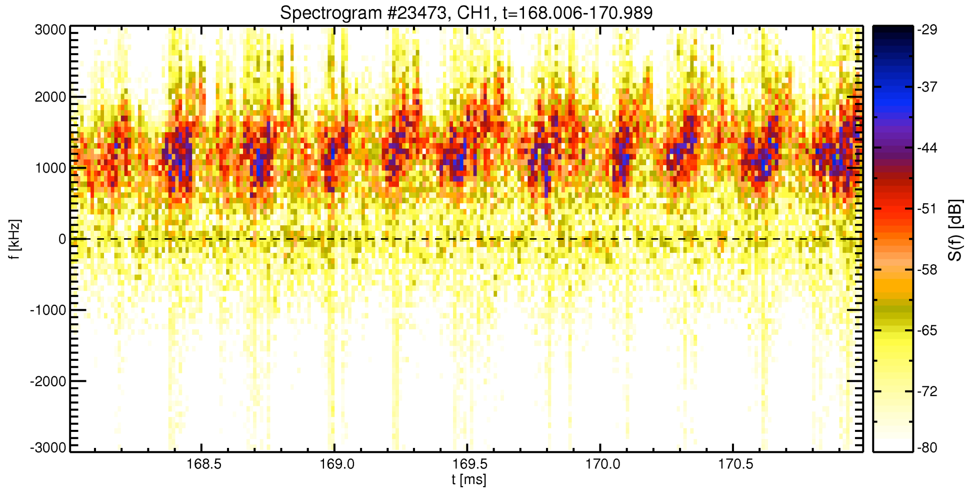

Figure 4: Doppler reflectometer spectrogram measured at $\rho \approx 0.8$ in a magnetic configuration with the rational 3/2 close to the plasma edge.

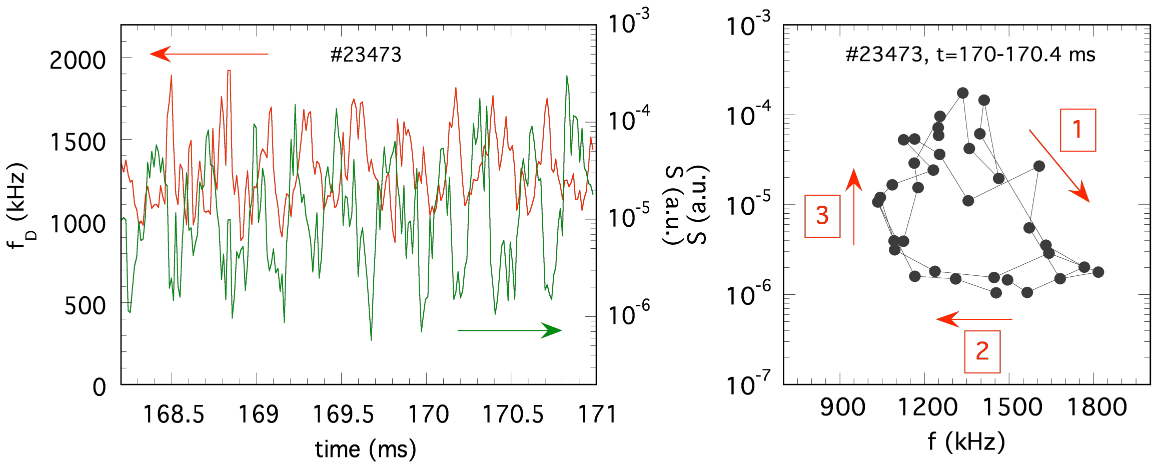

Figure 5: Left: Time evolution of Doppler peak frequency (red) and amplitude (green). Right: relation between Doppler peak amplitude ($\propto$ density fluctuations) and frequency ($\propto E_r$) during two cicles.

Summary

L-H transitions have been explored in different magnetic configurations. The impact of low order rational surfaces close to the plasma edge is experimentally demonstrated. At the transition, the dynamics of the radial electric field and density fluctuations reveals a characteristic predator-prey behaviour.

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