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Interaction between turbulence and shear flows during L-H transitions in TJ-II plasmas

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The interaction between plasma turbulence and flows has been measured during the L-H transition in TJ-II plasmas by means of Doppler reflectometry. The results show that mean sheared flow is not the unique element to explain the reduction of turbulence at the transition, oscillating sheared flows have to be also considered. Besides, close to the L-H transition threshold conditions turbulence and flows display an oscillatory behaviour with a characteristic predator-prey relationship. These results are consistent with models predicting L-H transition triggered by zonal flows. Finally, the characterization of the H-L back-transition has revealed signatures of spreading of the turbulence from the plasma core to the edge barrier.

1. Introduction

Spontaneous transitions from the Low to the High confinement mode (L-H transitions) are observed in fusion plasmas where a reduction in the density turbulence, $\tilde{n}_e$, is found linked to a pronounced shear in the radial electric field, E_r-shear. The Doppler reflectometry (DR) technique offers the possibility to measure these magnitudes simultaneously and with good spatiotemporal resolution allowing the investigation of the physical mechanisms involved in the transition. In particular, the Doppler reflectometer installed at the TJ-II stellarator was carefully designed to fulfil the optimization requirements for a good spectral resolution [1] and has been used to study the L-H transition physics in TJ-II plasmas.

In TJ-II, spontaneous L-H transitions are observed in pure NBI heated plasmas under Li coated wall conditions [2]. "Fast" as well as "gradual" L-H transitions are observed depending on the heating power level and/or magnetic configuration, facilitating a detailed study of the physical mechanisms involved in the L-H transition. Furthermore, impurity accumulation during the H-mode and the concomitant increase in the radiation losses occasionally bring the plasma into the H-L back-transition conditions, allowing its characterization and the comparison with the L-H transition.

2. Experimental Results

2.1 Turbulence and flows at L-H transition

L-H transitions show a pronounced reduction in $\tilde{n}_e$ in the edge plasma region where the E_r-shear develops. However, high temporal resolution measurements show that the reduction in $\tilde{n}_e$ precedes the increase in the mean E_r-shear. Furthermore, simultaneous with the reduction in turbulence, an increase in the E_r-shear low frequency oscillations is measured [3]. These observations indicate that mean sheared flow is not the unique element to explain the reduction of turbulence at the transition, oscillating sheared flows have to be also considered. These results are consistent with models predicting L-H transition triggered by zonal flows [4].

2.2 Turbulence and flows close to the L-H transition threshold conditions

Further experimental evidence supporting the central role of zonal flows has been observed close to the L-H transition threshold conditions. In these cases, pronounced oscillations in both, E_r-shear and fluctuation level are measured at the plasma edge. This oscillatory behaviour is displayed in fig. 1. It shows a characteristic predator-prey relationship between turbulence and flows, with the flow –the predator– following the turbulence –the prey– with a phase delay of 90º in a limit-cycle way (see fig. 2) [5]. The turbulence-flow oscillation-pattern repetition frequency decreases as the plasma density increases, and the E_r oscillation amplitude decreases while that of the turbulence level increases. These observations can be explained based on the collisional damping of flows, which eventually sets the turbulence level. The coupling found between turbulence and flows follows that found in the predator-prey theory model [4]. In this model the turbulence driven zonal flow triggers the transition by regulating the turbulence until the mean flow is high enough to suppress turbulence effectively. Due to the self-regulation between turbulence and flows, the transition is marked by an oscillatory behaviour with a characteristic predator-prey relationship between turbulence and zonal flows.

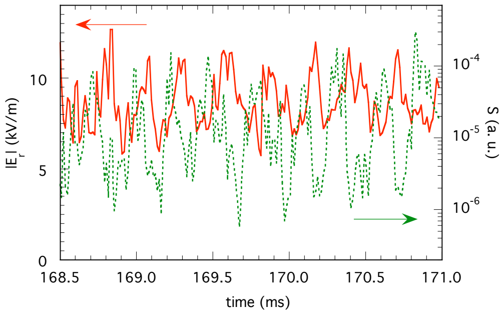

Fig. 1. The time evolution of E_r (solid line) and density fluctuation level (broken line) showing a predator-prey relationship.

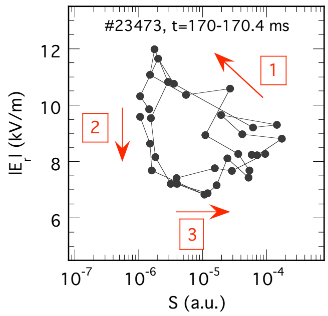

Fig. 2. Relation between E_r and density fluctuation level showing a limit-cycle behaviour. The time interval between consecutive points is 12.8 μs.

2.3 Turbulence and flows at the H-L back-transition

H-L back-transition experiments at TJ-II have revealed signatures of spatial spreading of plasma turbulence [6]. In these experiments, DR measurements show a gradual decrease in E_r and E_r-shear as the plasma approaches the back-transition and a fast drop in the E_r-shear right at the back-transition (see fig. 3.a). The turbulence level shows a distinct behaviour at both sides of the E_r-shear position. Outside the E_r-shear the turbulence level remains almost unchanged as the back-transition is approached and increases in a very fast time scale right at the transition. Contrary, the turbulence level measured at inner radial positions increases gradually, reaching values right before the back-transition comparable to those measured at the L-mode (see fig. 3.b). These experimental results suggest the following scenario: Radial spreading of the turbulence, braked during the H-mode by the high E_r-shear, becomes noticeable as E_r-shear declines and produces a gradual increase in the turbulence level at the internal radial positions, reaching the E_r-shear location right before the H-L back-transition. The consequence is a gradual retreat of the transport barrier quantified as the width of the turbulence reduction region. These experimental results resemble simulation studies reported in [7] –where the key quantity to the control of turbulence spreading was found to be the E_r-shearing rate– and point to the possible role of radial spreading of turbulence in determining the width of transport barriers.

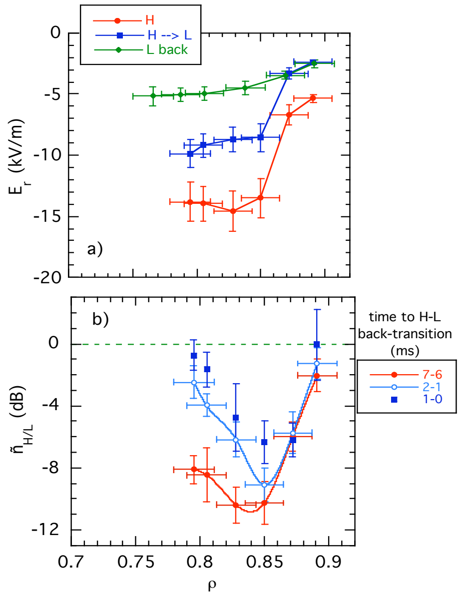

Fig. 3. Profiles of (a) E_r measured during the H-mode (red circles), right before the H–L back-transition (blue squares) and in the L-mode (green diamonds), and (b) turbulence reduction ($\tilde{n}_H/\tilde{n}_L$) measured 7, 2 and 1 ms before the back-transition.

3 Conclusions

The interaction between turbulence and flows measured in TJ-II plasmas, both, during the L-H transition and in plasma conditions close to the L-H transition threshold, is consistent with models predicting L-H transitions triggered by zonal flows. H-L back-transition results point to the possible role of radial spreading of turbulence in determining the width of transport barriers.

Acknowledgments

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References

[1] T. Happel *et al.*, Rev. Sci. Intrum. **80** (2009) 073502

[2] J. Sánchez *et al.*, Nuclear Fusion **49** (2009) 104018

[3] T. Estrada *et al.*, Plasma Phys. Control. Fusion **51** (2009) 124015

[4] E.-J. Kim and P.H. Diamond. Phys. Plasmas **10** (2003) 1698

[5] T. Estrada *et al.*, EPL (Europhysics Letters) **92** (2010) 25001

[6] T. Estrada *et al.*, Nuclear Fusion **51** (2011) 032001

[7] W.X. Wang *et al.*, Phys. Plasmas **14** (2007) 072306