Temporal and radial dynamics of long-range correlated structures in the TJ-II stellarator

M. A. Pedrosa, C. Hidalgo, C. Silva[1], M. A. Ochando, B. Carreras, D. Carralero,
D. López-Bruna, J. Romero, A. López-Fraguas, J. A. Alonso and the TJ-II team

Laboratorio Nacional de Fusión, Asociación EURATOM-CIEMAT, 28040 Madrid, Spain
(1) Associação EURATOM-IST, Instituto de Plasmas e Fusão Nuclear, Lisboa, Portugal

1.- INTRODUCTION

Heat and particle transport in fusion plasmas is generally due to turbulent processes associated with small-scale instabilities driven by the inhomogeneity in plasma profiles. The magnitude of turbulent transport is probably the dominant parameter affecting the global confinement properties and hence the understanding of turbulence is a fundamental issue for the success of magnetic nuclear fusion. At the same time, the development of inverse cascade of turbulent energy spectra and condensation of the spectrum can form meso-scale structures that can control turbulent radial diffusion. Among these structures zonal flows (ZFs) and geodesic acoustic modes (GAMs) are known to play a role in regulating plasma turbulence and consequently anomalous transport [1, 2 and references therein]. In addition, ZFs-like structures can also be generated by fast particles and MHD instabilities [3]. Also, it has been theoretically shown that zonal flows can be developed in the proximity of low order rational surfaces [4, 5]. The radial propagation of large-scale structures has been studied theoretically [6, 7]. However, experimental evidence of radial propagation of GAMs and ZFs is rather limited [8, 9, 10].

In TJ-II long-range toroidally correlated structures, with characteristics in agreement with the ones of the ZFs and/or GAMs have been observed during the development of the edge shear flows [11, 12, 13]. The influence of the magnetic configuration in the temporal and radial dynamics of the long-range correlated structures is now being studied.

2.- EXPERIMENTAL

Experiments were carried out in TJ-II in Electron Cyclotron Resonance Heated (ECRH) plasma ($P_{ECRH} \leq 400$ kW, $B_T = 1$ T, $\langle R \rangle = 1.5$ m, $\langle a \rangle \leq 0.22$ m, $\iota(a)/2\pi \approx 1.5 - 1.9$) and in pure Neutral Beam Injection (NBI) heated plasma (P_{NBI} port through $\approx$ 450 kW).

Modulation of the TJ-II current coils allows changing the magnetic configuration in a narrow iota range (5-10%). It should be noted that during the fine iota scan other plasma parameters, like plasma volume and plasma shape, remain basically unchanged.

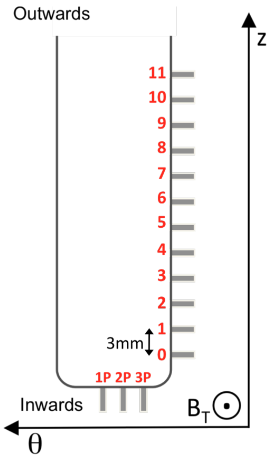

Fig. 1 Schematic view of the rake probe (Probe #1).

Two Langmuir probe arrays, named Probe #1 and Probe #2, located at two different toroidal positions about 160º apart have been used. Probe #1 includes a rake probe made of twelve Langmuir probes radially separated 3 mm with three tips at the probe front that allow the measurement of the turbulent particle flux (figure 1). This set-up permits the simultaneous investigation of the radial structure of plasma floating potential (whose gradients are linked to radial electric fields) and long-range correlated structures in the plasma boundary region of the TJ-II. During this experiments Probe #1 was located in the plasma edge region (1>r/a>0.75) whereas the Probe #2 was located at a fix position r/a≈0.85.

3.- EFFECTS OF MAGNETIC CONFIGURATION

The influence of the presence of different rational surfaces on the radial structure of floating potential as well as on long-range toroidal correlations has been investigated in the plasma edge of the TJ-II, during fine dynamical ι-scans in the magnetic configuration.

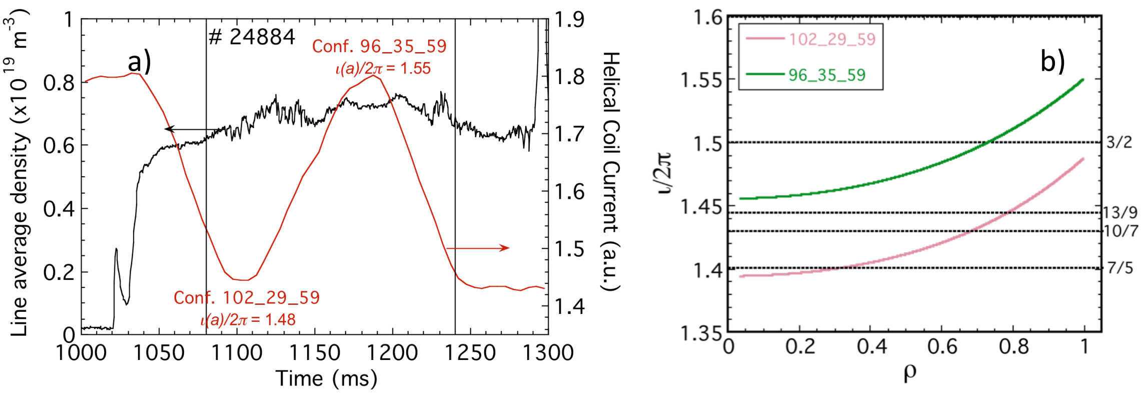

Fig. 2 a) Time evolution of line average density and modulation of TJ-II coil current. Vertical lines indicated the considered time interval, with density approximately constant. b) Vacuum iota profiles for the dynamic configuration scan in the proximity of the 3/2 rational surface. The two extreme configurations are indicated.

Figure 2.a shows the time evolution of the plasma density together with one of the TJ-II coils current that indicates the configuration modulation between two extreme configurations crossing the 3/2 rational surface. The vacuum extreme iota profiles for this experiment are shown in figure 2.b. Good density control was obtained during the dynamic configuration scan for plasma densities in the range of 0.6 x 10^{19} m^{-3} (i.e. below the plasma density at which edge sheared flows are spontaneously developed in the TJ-II stellarator).

Figure 3 shows the time evolution of the floating potential radial profiles (1 ms average) obtained with Probe #1 during the described dynamic magnetic configuration scan (see fig.

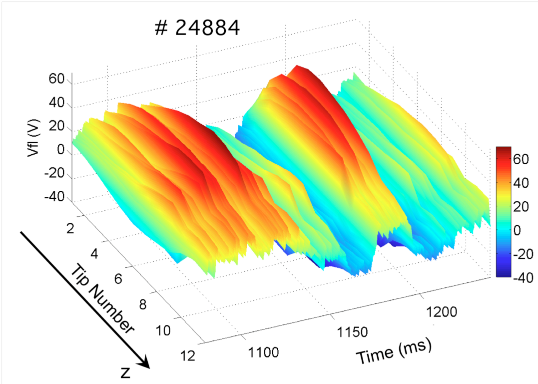

Fig. 3 Floating potential profiles during the dynamic scan configuration (ι/2π= 1.55 – 1.49) (see fig. 1). Probe position 0.85<r/a<1

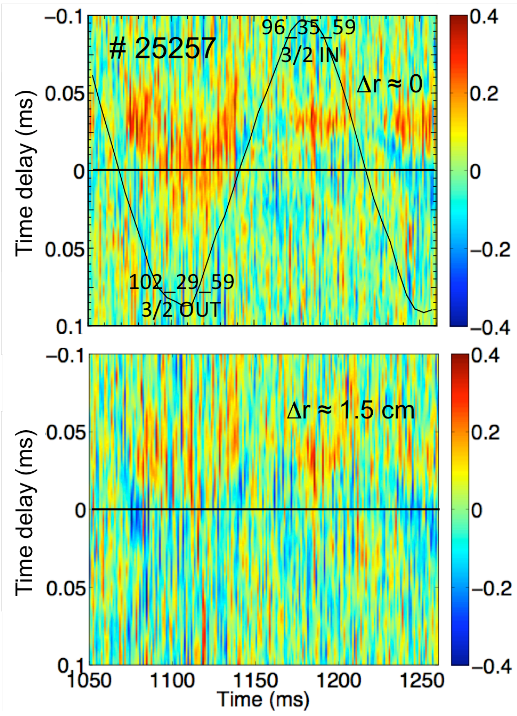

Fig. 4 Long-range correlation between one tip of Probe #2 (r/a≈0.85) and two different tips of Probe #1 (0.8<r/a<1).

2a). Minor changes in the iota value (in the order of 10 %) produce strong modification on the floating potential profiles (up to 100 V) and their gradients (in the order of 1 – 3 kV/m). Potential profiles are strongly coupled to the magnetic configurations in all studied configuration scans with different rational surfaces present at the plasma edge. In the presence of 3/2 rational, radial structures (≈3 cm) appear in time scales of tens of μs.

Figure 4 shows the time evolution of the long-range correlation of potential fluctuations during the described dynamical configuration scan. Long-range correlation shows a clear radial structure with a characteristic radial decay length in the order of 1 – 2 cm due to frequencies below ≈ 20 kHz [11]. This floating potential low frequency component that show long-range correlations (V_{fl}^{LR}, with rms ≈ 10 – 20 V) can be used to infer a shearing rate, estimated by V_{fl}^{LR}/ Δ_r^2 B, (where Δ_r is the typical radial scale of long-range correlations), resulting in the order of 10^5 s^{-1}, comparable to the decorrelation rate of fluctuations calculated as the inverse of autocorrelation time, suggesting that time-varying flows are important to stabilize turbulence.

4.- RADIAL PROPAGATION OF LARGE-SCALE STRUCTURES

The radial propagation of long-range correlated structures has been studied in NBI plasmas in TJ-II. Figure 5 shows the radiation profiles during the bursty phase that precedes the transition to improved confinement regime. Strong MHD events coming from the plasma bulk (see figure 5) are long-range correlated. Figure 6 shows the long-range toroidal correlation of low frequency (< 20 kHz) potential fluctuations signals measured in Probe #2 with the obtained in the six innermost tips (0.78<r/a<0.9) from the Probe #1. Experimental results show evidence of outwards (i.e. negative time delay) radial propagation of these low frequency events with velocities in the order of 100-200 m/s.

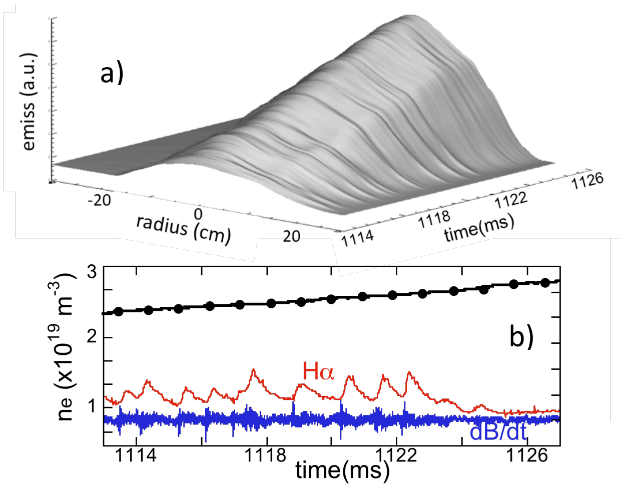

Fig. 5 a) Time evolution of the emissivity profile. b) Time history of electron density, Hα emission and magnetic field fluctuations in the vicinity of the confinement transition.

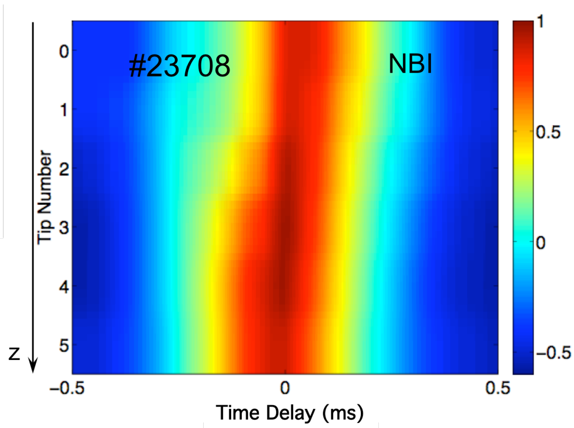

Fig. 6 Long-range toroidal correlation between potential fluctuations, below 20 kHz, measured in Probe #2 with the ones in the six innermost tips (0.78<r/a<0.95) of the rake probe (Probe #1) in NBI plasma (1121<t<1123).

5.- SUMMARY

Experimental evidence of the development of radial structures in the plasma potential and changes in the degree of long-range toroidal correlations, during fine dynamical scans in the magnetic configuration in the proximity of low order rational surfaces, has been obtained in TJ-II. These findings provide a direct evidence of the development of long-range toroidal correlations consistent with the theory of zonal flows and linked to the magnetic topology in low magnetic shear configurations.

Experimental evidence of radial propagation of low frequency fluctuations (MHD) showing long-range toroidal correlation, with velocities in the range of hundred m/s was obtained.

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