Unravelling zonal flows and fluctuations behaviour in TJ-II

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Introduction

Zonal flows (ZF) have been theoretically [1 and references therein] and experimentally [2 and references therein] studied in fusion plasmas and are considered an important mechanism to regulate transport caused by turbulence. The interest to unravel how ZF develop and how they interact with microturbulence is growing up in order to improve the prospects of confinement in ITER device.

The onset of the edge shear flow development has been investigated in TJ-II for different plasma conditions, in particular changing the magnetic configuration and heating power [3, 4]. In Electron Cyclotron Resonance Heated (ECRH) plasmas a transition to improved confinement regime has been observed for a given value of the plasma density gradient (for simplicity we have used the line average plasma density as a control knob). Close to the plasma transition to improved confinement regimes (ECRH low density, Neutral Beam Injection high density or biased plasmas) bursts of long-range correlated fluctuations have been observed [5, 6, 7]. These low frequency oscillating structures have been associated with ZF developed at the plasma edge [8].

Experimental

A rake system with 12 Langmuir probes radially separated 3 mm, installed in a fast reciprocating drive in a top port of the TJ-II chamber, has been used to obtain the detailed radial profile of the radial electric field (i.e. floating potential gradient). Three probes poloidally separated at the rake probe front allow measurements of the fluctuation-induced particle flux. Alternatively a bidimensional set of 20 Langmuir probes (5 poloidal rows x 4 radial columns) has been used in the same drive to measure the Reynolds stress. Another probe array, with 3 poloidally separated probes located at a different position of the torus, separated about 160° toroidally (more than 5 m) and 150° poloidally from the other drive, is used to measure simultaneously with one of the previously described systems.

Measurements have been obtained in TJ-II during ECRH plasmas ($P_{ECRH} \leq 400$ kW, $B_T = 1$ T, $\langle R \rangle = 1.5$ m, $\langle a \rangle \leq 0.22$ m, $\iota(a)/2\pi \approx 1.5\text{-}1.9$). Probes were located from the scrape-offlayer up to 30 mm inside the last closed flux surface (LCFS).

Zonal flows development at the plasma edge of the TJ-II

It has been previously reported than close to the development of the edge mean shear flow, long-range correlations between floating potential signals toroidally separated are amplified at the plasma edge. Once the mean shear flow is fully developed the level of long-range correlation decreases [7]. Long-range correlations are due to low frequency oscillations (typically bellow 20 kHz).

Figure 1a shows the time evolution of the long-range correlation at zero time delay between floating potential measured by the probes of the rake system and the one in the far away system. Measurements were obtained in a shot with constant line average density close to the critical value for edge sheared flows development ($n_e \approx 0.65 \times 10^{19}$ m^{-3}). The time evolution of the radial derivative of the floating potential (i.e. the radial electric field neglecting effects due to electron temperature gradients) obtained with the rake probe is shown in figure 1b for the same shot. Experimental results show the development of the edge sheared flow at t ≈ 1110 ms, concomitant with the reduction in the amplitude of long-range correlations (figure 1.a). Low frequency oscillations can be clearly seen (1070 ms < t < 1105 ms) before the development of the mean edge sheared flow.

Figure 2 shows the radial profile of the floating potential radial gradient during one of the above mentioned oscillations, together with the profile of long-range correlation in the plasma regime with high level of long-range correlation and before the development of mean shear flows. Radial gradients of the floating potential are strongly fluctuating showing a dynamical reversal from positive to negative gradients; this result is reflecting that

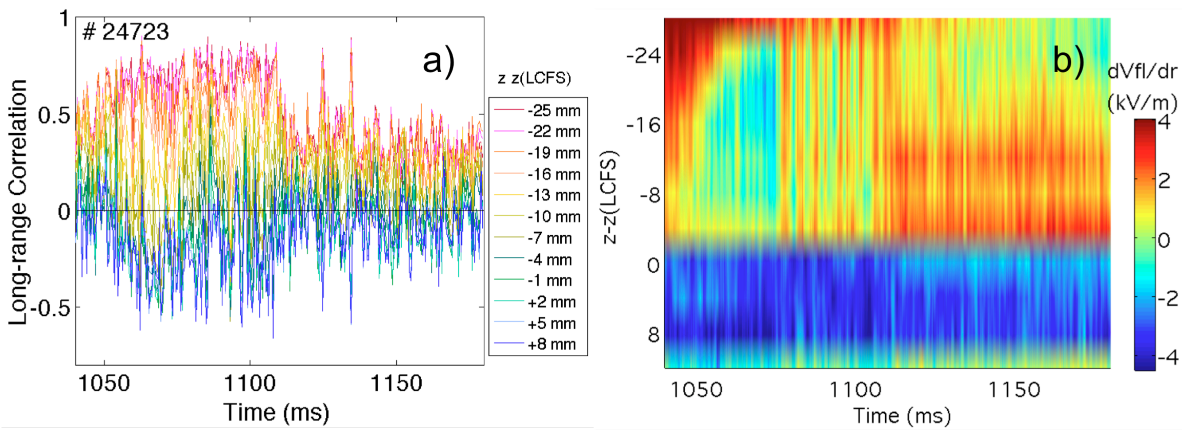

Fig. 1- a) Time evolution of level of long-range correlation at delay=0 between floating potential measured by the probes of the rake system (located at the indicated z-z(LCFS)) and the one in the far away probe (z-z(LCFS)≈-22 mm). b) Radial profile of the radial derivative of the floating potential measured by the rake probe, smoothed for frequencies below 5 kHz.

perpendicular velocities due to $E_r xB$ drifts are also dynamically changing even before the mean edge sheared flow is fully developed. The radial profile of the correlation indicates the presence of fluctuating structures in the edge radial electric field, with radial extension λ≈15 mm evolving in time scales of miliseconds. The characteristics of long-range correlated structures fluctuating at low frequencies, with radial scale length in the order of 1-2 cm and modulating global transport [9] are consistent with ZF developed at the plasma edge when the plasma is closed to the low-density ECRH transition. Recently the amplification of zonal flow like structure in the proximity of the critical plasma density, has been interpreted in terms of the reduction of the neoclassical viscosity near the transition from the ion to the electron neoclassical root [10].

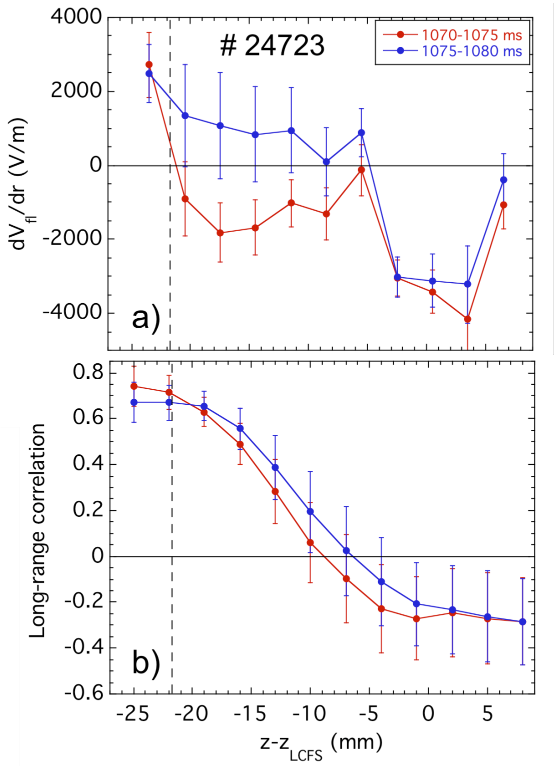

Fig. 2- (a) Radial profiles of the floating potential gradient and (b) the long-range correlation at delay=0 between floating potential measured by the probes of the rake system (located at the indicated z-z(LCFS)) and the one in the far away probe (z-z(LCFS)≈-22 mm, dotted vertical line) during one low frequency oscillation (continuous lines) and once the mean sheared flow was developed (green dotted line).

Reynolds stress measurements

Reynolds stress has been measured using the bidimensional system [9]. The electrostatic component of the Reynolds stress, proportional to $\langle \tilde{E}_r \tilde{E}_\theta \rangle$, has been computed considering the corresponding gradients of the floating potential in the radial and poloidal direction to measure the radial and poloidal fluctuating electric fields (i.e. neglecting electron temperature fluctuation effects) [11]. Figure 3 shows the time evolution of the the Reynolds stress measured at $z\text{-}z_{LCFS} \approx -20$ mm, the line average density, the maximum long range correlation, the root mean square (rms) value of the floating potential fluctuations and the phase difference between two probes poloidally apart (proportional to the poloidal velocity). The Reynolds stress increases just before the edge shear flow is developed (i.e. at plasma densities below the critical value), and concomitant with the develoment of long-range toroial correlations, and decreases as the edge shear in the poloidal velocity is fully developed (i.e. at densities above the critical value). The radial profile of the Reynolds

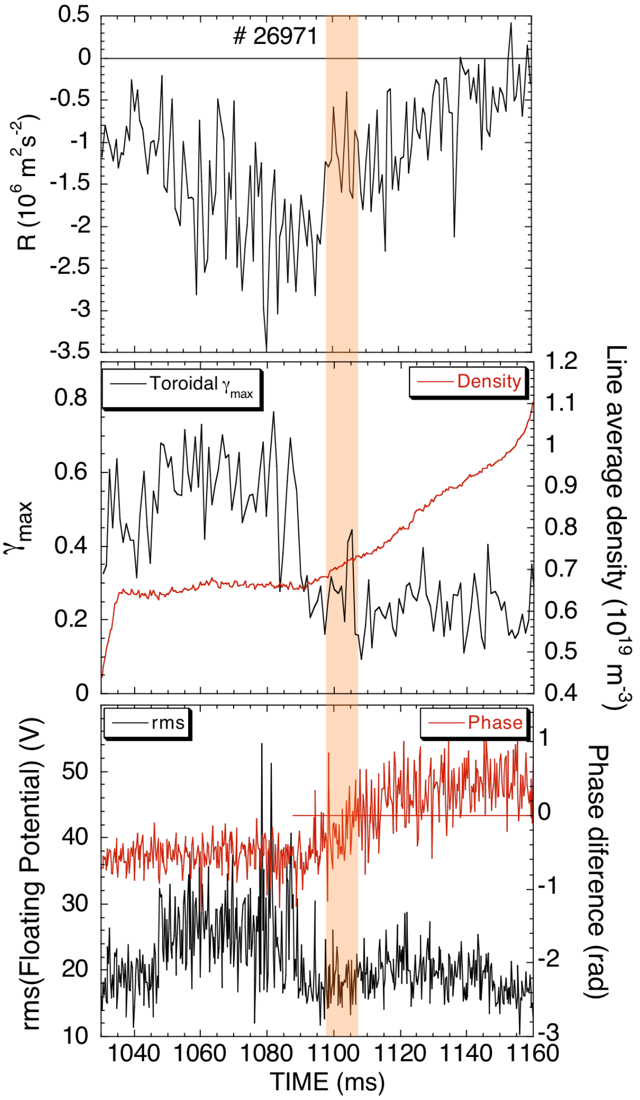

Fig. 3- Temporal evolution of (a) the Reynolds stress, (b) the line average density and the maximum long range correlation and (c) the floating potential fluctuations and the phase difference between two poloidally apart probes. Shadowed area indicates the time at which shear in the radial electric field develops.

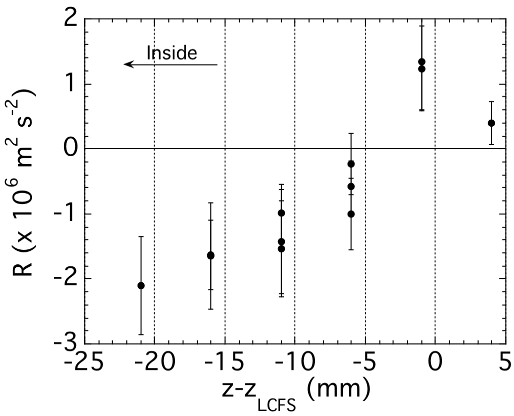

Fig. 4- Radial profile of the Reynolds stress have been determined in a shot to shot basis during high long-range correlation time ($n_e \approx 0.65 \times 10^{19}$ m^{-3}).

stress has been determined in a shot to shot basis in the plasma regime showing high level of long-range correlation (ZF). The radial derivative of the Reynolds stress can be estimated in the range of 10^8 m s^2, in agreement with previous results reported in tokamak plasmas [11]. Interestingly in these plasma conditions the radial gradient of the Reynolds stress is dominated by gradients in the potential rms value, this result suggets a proxy for Reynolds stress measurements in the plasma core.

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