

## Isotope effect on zonal flows and searching for asymmetries in potential profiles in the TJ-II stellarator

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### I.- Introduction

Recent developments of plasma diagnostics have allowed characterizing the properties of large (comparable to the machine) and small (comparable to the Larmor radius) plasma structures in fusion plasmas showing the importance of multi-scale mechanisms for describing the properties of transport in fusion plasmas [1, 2, 3]. In particular, experiments performed in the TJ-II stellarator have shown direct experimental evidence of long-range correlations (LRC) in potential fluctuations, consistent with zonal-flow like structures, which are amplified during the development of the edge shear flows (electron – ion root transition) [2], by externally imposed radial electric fields and when approaching the L-H confinement edge transition [4].

The focus of this paper is twofold. First we have investigated the influence of the isotope effect in the development of LRC (zonal flows). Second, using the amplitude of LRC to label magnetic flux surfaces, we report our searching for asymmetries in plasma potential profiles.

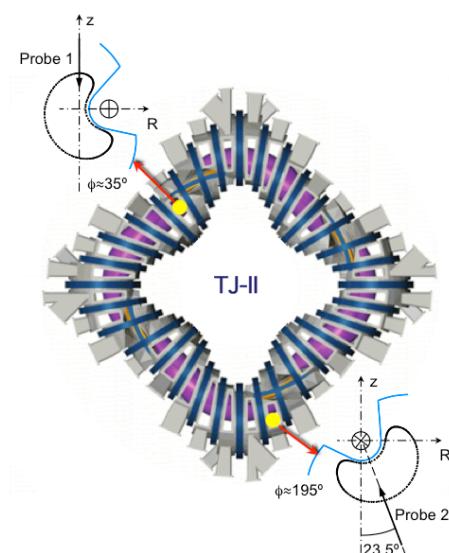


Fig. 1. Experimental set-up

### II. Experimental set-up

Experiments were carried out in the TJ-II stellarator in Electron Cyclotron Resonance Heated plasmas ( $P_{ECRH} \leq 400$  kW,  $B_T = 1$  T,  $\langle R \rangle = 1.5$  m,  $\langle a \rangle \leq 0.22$  m,  $\iota(a)/2\pi \approx 1.6$ ). The plasma density was modified in the range  $(0.34 - 1) \times 10^{19} \text{ m}^{-3}$ . Edge plasma parameters were simultaneously characterized in two different poloidal / toroidal positions using two similar multi-Langmuir probes (Fig. 1). One of them (Probe 1) is located in a top window entering vertically through one of the “corners” of its bean-shaped plasma and at

$\phi \approx 35^\circ$ , and the second one (Probe 2) is installed in a bottom window at  $\phi \approx 195^\circ$ , and enters into the plasma through a region with a higher density of flux surfaces (i.e. lower flux expansion) than probe 1. Measurements were obtained both in hydrogen and deuterium plasmas.

### III. Isotopic effect and Long Range Correlations in the TJ-II stellarator

Understanding the physics of the isotope effect in plasma transport and confinement remains as a fundamental open question with direct impact in the confinement properties of fusion DT reactors. Considering that the characteristic step-size of collisional transport and turbulent structures increase with the normalized gyro-radius  $\rho_s$ , increasing the mass of the isotope would imply a deleterious effect on transport. On the contrary, there is clear experimental evidence that at similar plasma parameters deuterium have improved confinement properties as compared with hydrogen plasmas in tokamaks [5, 6]. Interestingly the isotopic effect seems to be weaker in stellarators than in tokamaks. Thus, comparative studies in tokamak and stellarator devices would provide a guideline for further studies on

the impact of multi-scale physics to unravel the physics of the isotope effect in fusion plasmas.

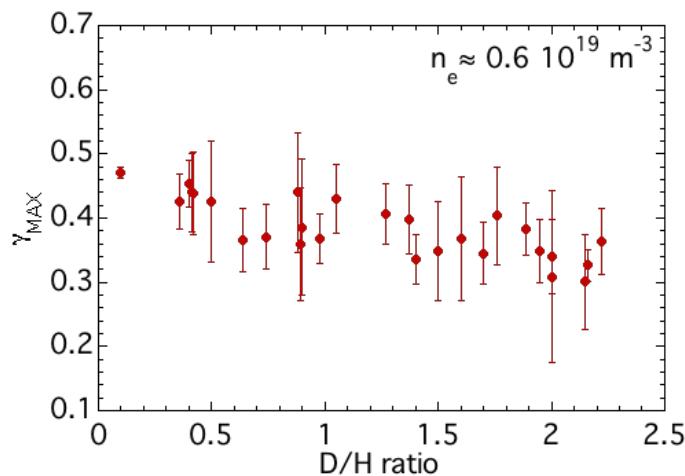


Fig. 2. Maximum LRC between floating potential signals as a function of D/H ratio concentration in plasma.

Figure 2 shows the behaviour of the maximum amplitude of LRC in floating potential signals as a function of the deuterium to hydrogen ratio concentration. Experimental findings show that the amplitude of LRC of potential fluctuations (i.e. the amplitude of

zonal flows) is, within the experimental uncertainties, constant during the transition from H to D dominated plasmas in the TJ-II stellarator, in contrast with recent findings in the TEXTOR tokamak [5, 6] showing a systematic increasing in the amplitude of LRC during the transition from H to D dominated plasmas. However, properties of local turbulence are affected during the transition in TJ-II; in particular, the radial correlation length of fluctuations slightly increases as the D/H ratio increases (i.e., as D Larmor radius becomes more dominant).

#### IV. Searching for plasma potential asymmetries in the TJ-II stellarator

Power exhaust issues and impurity accumulation should be recognized as potential showstoppers for the development of fusion energy. Core impurity accumulation has a negative impact on fusion performance whereas edge impurity radiation can affect the maximum attainable edge pedestal temperature with direct impact on global performance. In parallel, edge impurity radiation is a crucial ingredient to reduce power heat load in plasma facing components [7].

Efficient impurity control has been achieved in non-axisymmetric plasma regimes in the W7-AS stellarator [8] and in the so call impurity hole regime in the LHD helical device [9], whose underlying mechanisms remain unknown. Those experimental findings show that it is possible the simultaneous achievement of improved energy confinement with low impurity accumulation. The possible role of variations in plasma potential on magnetic flux surfaces on particle dynamics has been discussed long ago [10, 11], concluding that they can have a modest effect on ion transport. More recently the impact of potential variation on neoclassical impurity transport has been addressed, concluding that it is essential for describing impurity dynamics in stellarators [12].

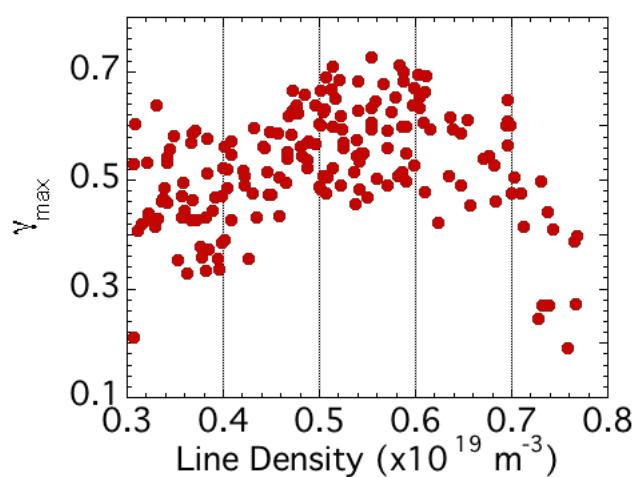


Fig. 3. Maximum LRC between floating potential signals as a function of line average plasma density.

Searching for asymmetries in plasma potential requires an experimental criterion to label magnetic flux surfaces at any toroidal and poloidal position. In the present work, we have labelled magnetic surfaces through the amplitude of LRC of floating potential signals measured by probe arrays 1 and 2. Figure 3 shows the maximum LRC between two floating potential signals, measured simultaneously at the toroidal / poloidal positions above described by

the multi-Langmuir probes, as a function of the line average plasma density; in agreement with previous results the amplitude of LRC increases in the proximity of the threshold density ( $n_e \approx 0.6 \times 10^{19} \text{ m}^{-3}$ ) where the radial electric field reverses from radially outwards (electron root) to radially inwards (ion root).

Reproducible plasmas with a ramping density allow obtaining radial profiles of the floating potential at different plasma densities. Figure 4 shows the radial profiles of floating potential measured simultaneously by probes 1 and 2 at three different values of the plasma density: in the electron root regime with radially outwards radial electric field ( $\approx 0.4 \times 10^{19} \text{ m}^{-3}$ ), in the proximity of the electron / ion root transition (plasma density threshold  $\approx 0.6 \times 10^{19} \text{ m}^{-3}$ ) and in the ion root regime with radially inwards radial electric field ( $\approx 0.8 \times 10^{19} \text{ m}^{-3}$ ). The shaded area shows the radial location with maximum LRC quantified in the proximity of the plasma threshold density for the electron to ion root transition.

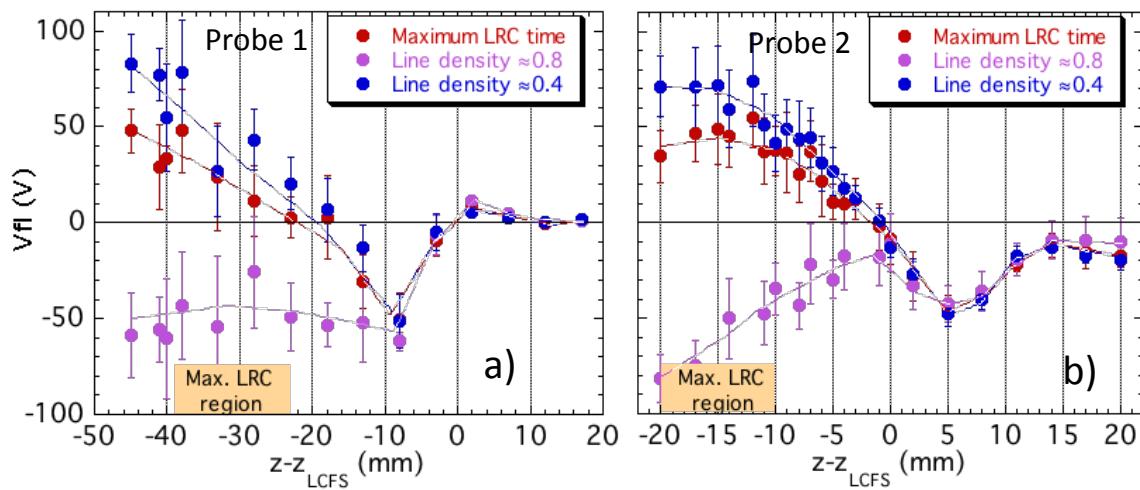


Fig. 4. Radial profiles of floating potential measured simultaneously by probe 1 (a) and probe 2 (b) at three different plasma densities obtained in two similar experiments.

Using the amplitude of LRC correlations to label the magnetic flux surfaces floating potential measurements in both probes have been compared. Asymmetries in the order of 10 – 30 V are measured when plasma is in the proximity of the electron / ion root transition. Assuming that electron temperatures have zero parallel gradients, these results are reflecting asymmetries (poloidal / toroidal) in plasma potential.

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- [1] Fujisawa et al., Phys. Rev. Lett. **93**, 165002 (2004)
- [2] M.A. Pedrosa et al., Phys. Rev. Lett. **100**, 215003 (2008)
- [3] T. Estrada et al., Plasma Phys. Controll. Fusion **54** 124024 (2012)
- [4] C. Hidalgo et al., EPL 87 55002 (2009)
- [5] Y. Xu et al., EPS Conference (2013)
- [6] Y. Xu et al., Phys. Rev. Lett (2013) in press
- [7] A. Loarte et al., Nucl. Fusion **47**, S203 (2007)
- [8] K. McCormick et al., Phys. Rev. Lett. **89**, 015001 (2002)
- [9] M. Yoshinuma et al., Nucl. Fusion **49**, 062002 (2009).
- [10] H. Minik, Phys. Fluids **27**, 2086 (1984)
- [11] D. Ho and R. M. Kulsrud, Phys. Fluids **30**, 442 (1987)
- [12] J. M. García-Regaña et al., Plasma Phys. Controll. Fusion **55**, 074008 (2013)