Radial electric field and density fluctuations measured by Doppler reflectometry during the post-pellet enhanced confinement phase in W7-X

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Abstract

Radial profiles of density fluctuations and radial electric field, E_r, have been measured using Doppler reflectometry (DR) during the post-pellet enhanced confinement phase [1] achieved along the 2018 W7-X experimental campaign [2]. A pronounced E_r-well is measured in the radial range ρ ~ 0.6 − 0.8 during the post-pellet enhanced confinement phase which agrees with simulations carried out using the neoclassical codes DKES and KNOSOS [3]. The density fluctuation level decreases in the same radial region, the decrease being more pronounced in the high iota magnetic configuration than in the standard one. In order to discriminate whether this difference is related to the differences in the plasma profiles or in the stability properties of the two configurations, gyrokinetic simulations have been carried out using the codes stella [4] and EUTERPE [5]. The simulation results point to the plasma profile evolution after the pellet injection and the stabilization effect of the radial electric field profile as the dominant players in the stabilization of the plasma turbulence.

Introduction

High core plasma densities will be essential in future fusion reactors in order to maximize fusion power. Presently, high central densities are achieved using intense high repetition rate pellet injection. In most experiments, a reduction of the ion transport and an increase in the core ion temperature are found associated to peaked density profiles.

In W7-X, a notable improvement in the plasma performance is observed after the injection of a series of frozen hydrogen pellets into ECH heated plasmas [2].

The present work [1] shows radially-resolved measurements of density fluctuations and radial electric field by **Doppler Reflectometry** (DR) during the post-pellet enhanced confinement phase in standard (EJM) and high iota (FTM) configurations, and the comparison with neoclassical and gyrokinetic simulations.

Experimental set-up: V-band Doppler Reflectometer (DR)

DR installed at AEA21 (φ = 72° bean shaped plane), out-board mid-plane

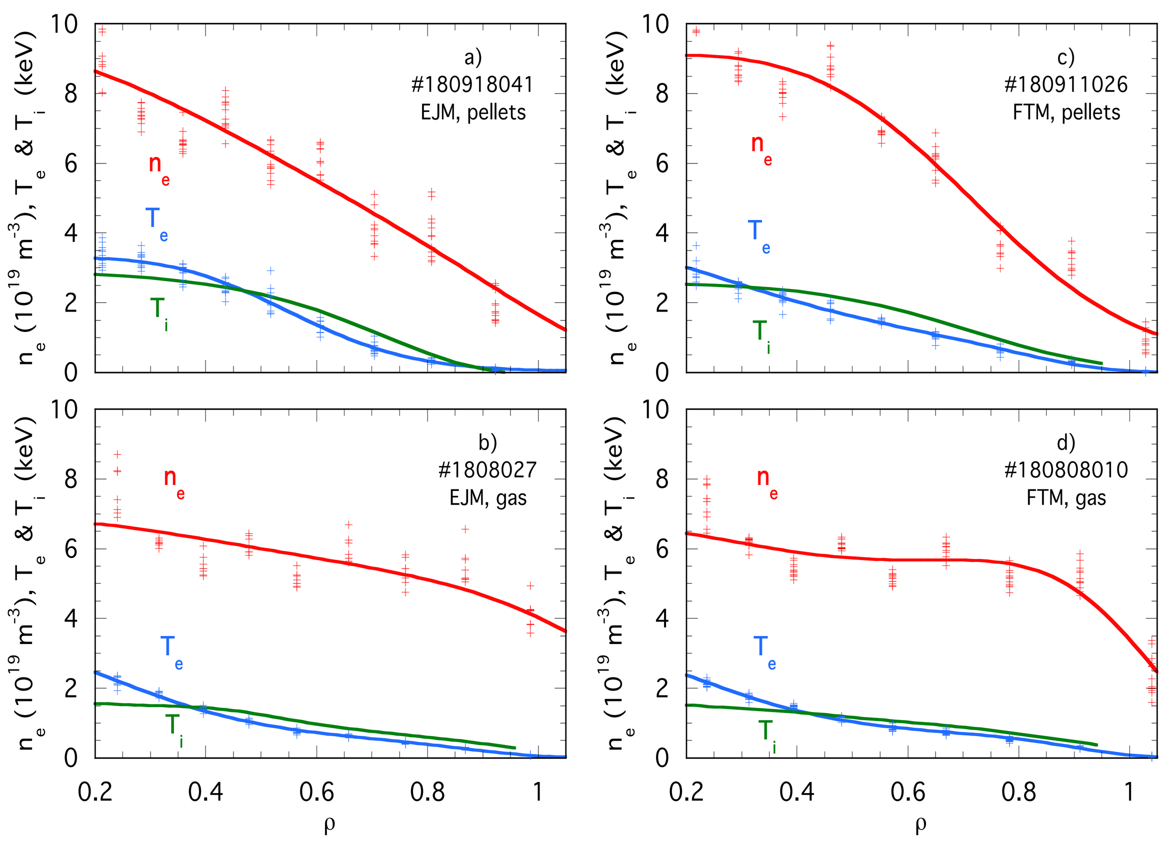
V-band (50-75 GHz), propagation in O-mode at fixed probing beam angle α = 18°

- local densities: 2.8 – 6.3 10^{19} m^{-3}
- perpendicular wavenumbers of the turbulence $k_\perp$ ~ 7 - 10 cm^{-1}

Probing frequency in hopping mode: 25 steps of 1 GHz, 10 ms each → one complete scan every 250 ms

3D ray-tracing code TRAVIS [6] (with VMEC equilibrium and n_e profile) → ρ and $k_\perp$

E_r profiles: comparison with NC simulations

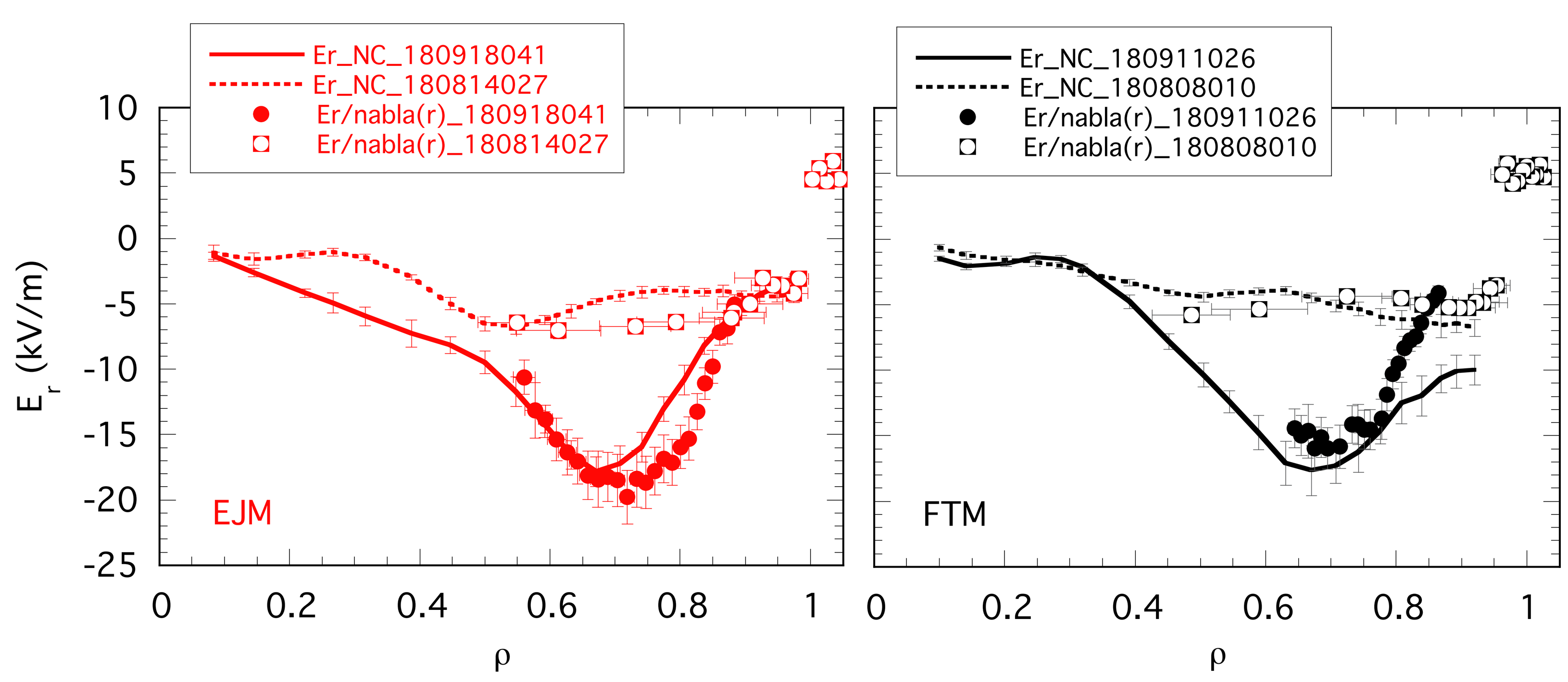


Density and temperature profiles of the selected experimental programs:

- post-pellet (top)
- gas fuelled (bottom)
- Standard EJM (left)
- High iota FTM (right)

n_e ~ 9×10^{19} m^{-2}
P_{ECH} ~ 5.5 - 6.0 MW

Comparison of experimental E_r profiles normalized with |∇r| (symbols) and neoclassical predictions obtained using the codes DKES and KNOSOS (lines) for the four experimental programs:

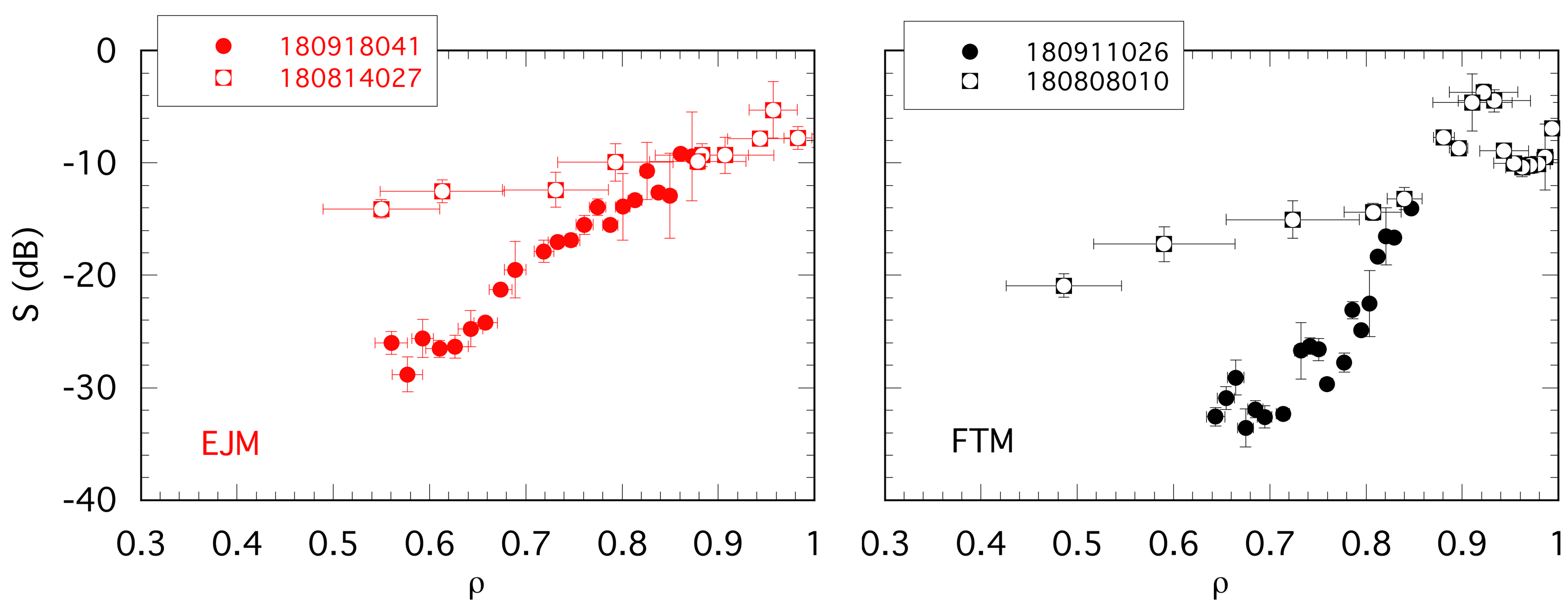


An E_r-well is measured in the radial range $\rho \approx$ 0.6 - 0.8 during the post-pellet enhanced confinement phase

Good agreement between the experimental E_r profiles and the neoclassical predictions

Density fluctuations

Density fluctuations measured during the post-pellet phase (solid symbols) and those measured in gas fuelled reference programs (open symbols), in standard EJM (left, in red) and in high iota FTM (right, in black) configuration

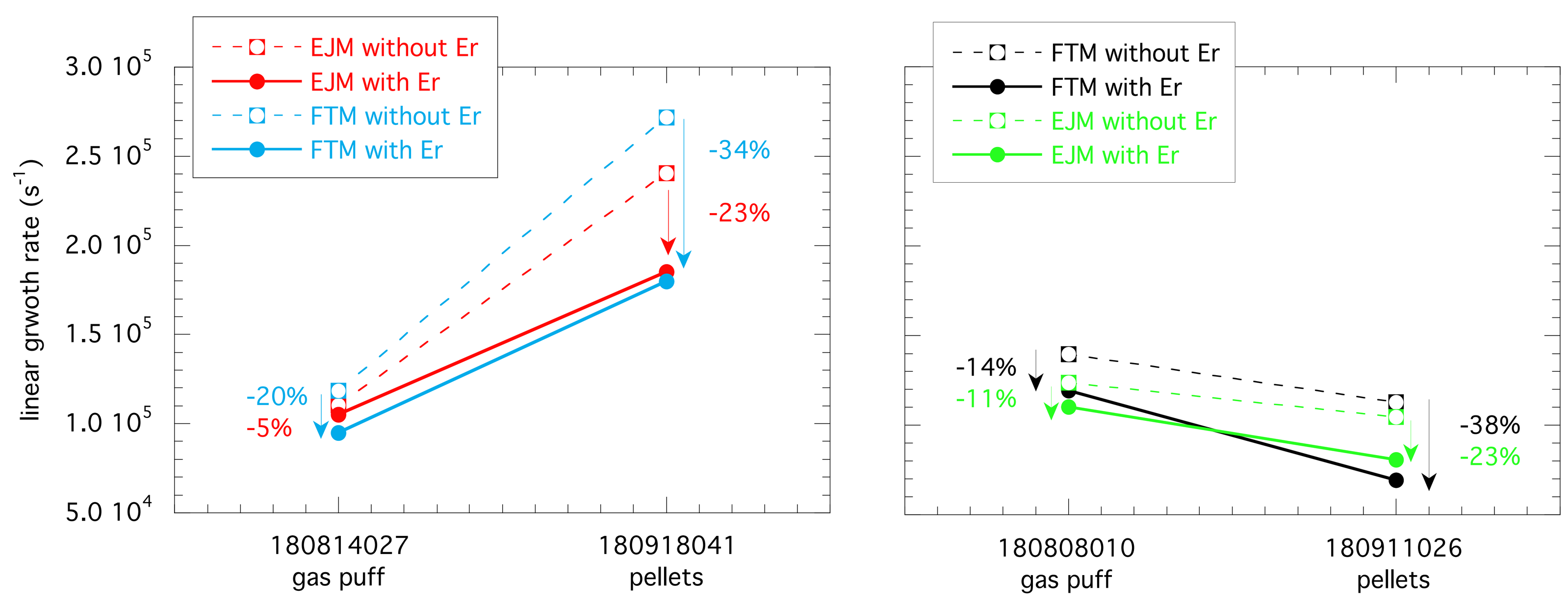


The density fluctuation level decreases from the plasma edge toward the core: the drop is more pronounced in the post-pellet phase than in reference puffing fuelled plasmas, and more in the high iota configuration than in the standard

Gyrokinetic simulations

EUTERPE: Linear global simulations; collisionless plasmas with adiabatic electrons; computational domain ρ = 0.65 – 0.85

Linear growth rates obtained for the four experimental programs: in EJM (left, in red) and in FTM (right, in black), without and with E_r (open and solid symbols, respectively). In blue and green, the growth rates obtained swapping the magnetic configurations. The reduction in the growth rate associated to E_r is indicated for each case



Post pellet phase: higher γ in EJM than in FTM; this difference however is not directly linked to the magnetic configuration itself but rather to the differences in the evolution of the plasma profiles after the pellet injection (higher $\eta = L_n/L_T$ in EJM than in FTM)

Stabilization effect linked to E_r: modest in the gas fuelled plasmas, but significant in the post-pellet plasmas

Summary

Density fluctuations and E_r profiles have been measured using DR during the post-pellet enhanced confinement phase achieved in W7-X

A pronounced E_r-well is measured at ρ: 0.7- 0.8. Good agreement is found with neoclassical simulations carried out using DKES and KNOSOS

The density fluctuation level is lower in the post-pellet phase than in gas fuelled plasmas, and is lower in FTM than in EJM

GK simulation results point to the plasma profile evolution after the pellet injection and the stabilization effect of E_r as the dominant players; the differences in the stability properties of the two configurations, however, have a minor impact

Non-linear simulations are foreseen which will allow for a quantitative comparison with the experimental results

[1] T. Estrada *et al.*, Nuclear Fusion **61**, 046008 (2021)
[2] S. Bozhenkov *et al.*, Nuclear Fusion **60**, 066011 (2020)
[3] J. Velasco *et al.*, Journal of Computational Physics **418**, 109512 (2020)
[4] M. Barnes, *et al.* Journal of Computational Physics 391, 365 (2019)
[5] E. Sánchez *et al.*, Journal of Plasma Physics **86**, 855860501 (2020)
[6] N. Marushchenko, et al. Computer Physics Communications **185**, 165 (2014)

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