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

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A notable improvement in the plasma performance has been observed after the injection of a series of frozen hydrogen pellets into ECH heated plasmas in the stellarator W7-X [1]. In these experiments, the pellet series rise the plasma density considerably and the central fuelling results in a peaked density profile. At the end of the pellet series, the ion and electron temperatures rise and almost equilibrate, and the plasma stored energy increases by more than 40\% reaching values above 1 MJ. This enhanced confinement phase lasts for several confinement times and terminates as the density and its peaking decay [2]. The stabilisation of this enhanced confinement will be of the utmost importance for exploring reactor-relevant scenarios in the device's next operational phase with an actively cooled divertor.

A candidate to explain these observations is the reduction of the turbulent transport due to both, the stabilization by centrally peaked density profile of the ion temperature gradient (ITG) driven instabilities, and the specific stability properties of the electron-density-gradient driven trapped electron mode (TEM) in the W7-X magnetic geometry [3, 4]. This theoretical description has been to some extent supported by the drop in the line-integrated density fluctuation level measured with a phase contrast imaging (PCI) system during the enhanced confinement phase [5]. The present work reports, for the first time, radially-resolved measurements of density fluctuations and radial electric field by Doppler reflectometry (DR) that can provide new insights into the nature of this transient suppression of turbulence. The study encompasses several high-performance phases, observed under different heating power levels and magnetic configurations, along the 2018 W7-X experimental campaign. A comparison with both, neoclassical and gyrokinetic simulations is also presented in an attempt to test the ability of our most sophisticated tools to reproduce these observations.

Measurements are obtained with a DR system working in the 50-75 GHz frequency range in O-mode polarization. The reflectometer front end uses a single antenna and a set of mirrors for launching and receiving the signal at fixed probing beam angle of $\theta = 18\circ$ [6]. Under these conditions, perpendicular wave-numbers of the turbulence in the range $k_\perp \sim 7 - 10$ cm^{-1} are measured at the accessible local densities in the range from 2.8 to 6.3 10^{19} m^{-3}.

Profiles of radial electric field, E_r, and density fluctuation level have been measured in discharges with different pellet sequence reaching different plasma densities and heated with different ECH power levels, in two magnetic configurations, one with low ripple (called standard) and one with high iota. A pronounced E_r-well is measured with local E_r values as high as -40 kV/m in the radial range $\rho \sim 0.7 - 0.8$ during the post-pellet enhanced confinement phase in both magnetic configurations. The maximum E_r intensity at the E_r-well scales with both density and ECH power level following a similar trend as the plasma energy content. For comparison, in plasmas with similar ECH heating power and density but fuelled by gas puffing, the E_r profile is rather flat with values close to -15 kV/m within the range $\rho \sim 0.5 - 0.9$. The density fluctuation level decreases from the plasma edge toward the plasma core in all plasma scenarios but the drop is more pronounced in the post-pellet enhanced confinement phase than in the puffing fuelled plasmas. In the post-pellet phase the fluctuation level decreases by about $15 - 20$ dB within the radial range from $\rho \sim 0.9$ to $\rho \sim 0.5$, while it decreases only by about 10 dB in the puffing fuelled plasmas. As an example, figure 1 shows the profiles measured in the standard magnetic configuration at two different ECH power levels and densities.

Despite the qualitative similarity of profiles in the two magnetic configurations, the fluctuation levels are found to be significantly lower in the high iota compared to the standard one. This dependence appears to be in agreement wit their linear stability properties [4]. Indeed, both configurations exhibit a reduction in the growth-rates of electrostatic instabilities for certain combinations of temperature and density scale-lengths, that are achieved during the post-pellet phase, but the predicted reduction is more pronounced in the high iota configuration.
Encouraged by these observations, neoclassical as well as gyrokinetic simulations are in progress to conduct a systematic comparison with the experimental results. First neoclassical simulations using DKES and KNOSOS [7] show changes in the E_r profile comparable to the experimental ones. Regarding the density fluctuations, gyrokinetic simulations using EUTERPE [8] and stella [9] are being carried out to disentangle the effects of E_r, plasmas profiles, and magnetic configuration on the fluctuation level. The effect of plasma profiles and magnetic configuration on the linear stability properties is studied using both EUTERPE and stella. The

specific effect of E_r is studied with EUTERPE while non-linear simulations with stella will provide information on saturated fluctuation levels under different plasma conditions.

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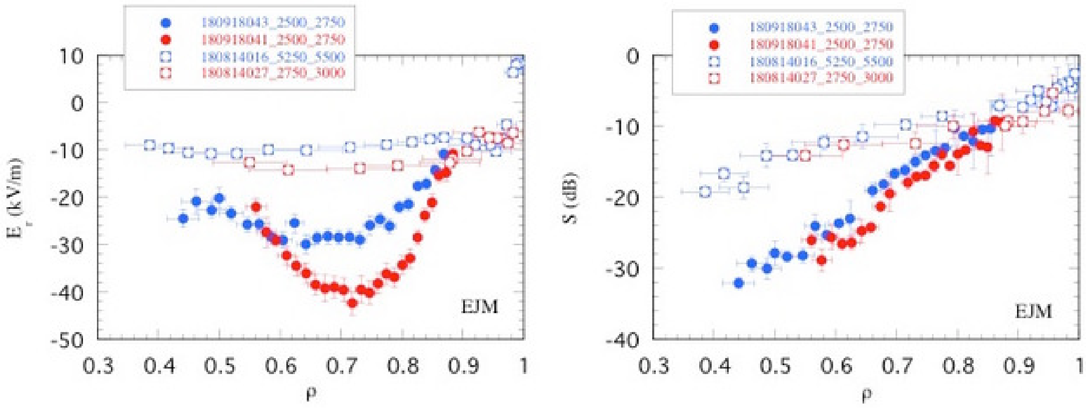

Figure 1: Radial profiles of E_r (left) and density fluctuations (right) measured during the post-pellet enhanced confinement phase (solid symbols) and those measured in puffing fuelled reference discharges (open symbols), with $n_e \sim 8\ 10^{19} m^{-2}$ and $P_{ECH} = 3$ MW (in blue), and $n_e \sim 9\ 10^{19} m^{-2}$ and $P_{ECH} = 5.5$ MW (in red).

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