Understanding the role of edge plasma physics in H-mode density limit on the JET-ILW

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For a dataset of JET-ILW plasma, reaching the ballooning limit leads to confinement degradation. However, unlike JET-C, the plasma stays in a marginal 'dithering' phase for a relatively long period, associated with a (≈20%) higher H-mode density limit (HDL) than that in JET-C[1][2]. Thus, another mechanism must cause the H-L transition and so the HDL This paper studies the edge-SOL physics of the HDL and the dithering phase.

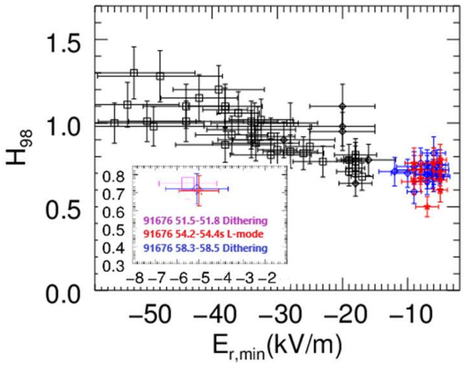

Figure 1: *The minimum radial E-field of the edge plasma well against normalised global confinement; Inset figure show L-mode and dithering phases of discharge #91676*

A new, reliable estimator for JET E_r profiles in the edge has been derived by combining high resolution Thomson scattering (HRTS) measures of edge-SOL decay lengths, with HRTS pedestal gradient measurements. As shown in figure 1, $E_{r,min}$ for the edge plasma well is observed to vary little between L-mode and dithering phases. The inset figure in figure 1 shows this also the case for a single discharge, #91676, which alternates from dithering phase to L-mode and back to dithering phase whilst input power and global plasma parameters remain relatively constant. Plasma potential can be used to determine the peak SOL E-field, $E_{r,SOL}$. $E_{r,SOL}$ is generally higher in the dithering phase, figure 2. The inset figure shows that the difference is more outstanding for the phases in #91676. The observed behaviour of $E_{r,min}$ and $E_{r,SOL}$ implies that the higher positive E_r gradient at the separatrix sustains the marginal phase and enables access to higher density. The weakening of this positive E_r shear gradient eventually triggers the final H-L back transition.
Across a dataset of JET-ILW L-mode, H-mode and dithering plasma, normalised SOL width is found to increase with increasing collisionality, consistent with previous observation[3] and studies [4][5]. A hypothesis for the dithering H-mode phase close to HDL is proposed with H-L-H-L- oscillations following:
n_e increases → $\nu_{*,SOL}$ increases → SOL broadens → E_r shear decreases → H-L transition;
n_e decreases → $\nu_{*,SOL}$ decreases → SOL narrows → E_r shear increases → L-H transition.

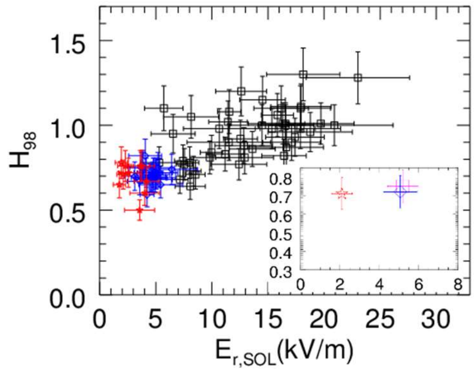

Figure 2: *radial E-field in the SOL against normalised global confinement for a set of JET-ILW L-mode, H-mode and dithering plasma; Inset figures show only the L-mode and dithering phases of discharge #91676*

The study has shown that, at high density, JET-ILW plasma reach the edge ballooning limit, α_{crit}, and their confinement reduces but without a transition to L-mode. Instead, the higher positive E_r gradient at the separatrix sustains a dithering phase, shown to be a bifurcation in plasma state. A hypothesis has been developed for the limit cycle during this phase.The observed JET-ILW results suggest ITER can operate in H-mode at higher density, which is beneficial for the power handling issue, but more likely in dithering phase with lower confinement and broader SOL. However, if the plasma exhaust can be handled at sufficiently low densities, operating just below the dithering phase would be a promising regime for maximising core density, global confinement and fusion performance.

*[1] A. Huber et al. Nucl. Fusion **57** (2017) 0860007; [2] HJ. Sun et al. Nucl. Fusion **61** (2021) 066009; [3] HJ. Sun et al. Plasma Phys. Contr. Fusion 57 (2015) 125011; [4]Eich et al. Nucl. Fusion 60 (2020) 056016; [5] RJ. Goldston, 2018, EPS, 'Generalization of the Heuristic Drift Model of the SOL for Finite Collisionality'*