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[REGULAR POSTER TWIN] L-H transition studies at JET: H, D,He and T

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Characterizing and understanding the power threshold conditions for ITER to achieve H-modes (P_{LH}) is a major goal of a series of L-H transition experiments undertaken at JET since the installation of the ITER-like-wall (JET-ILW), with Beryllium wall tiles and Tungsten divertor [1,2,3,4]. In this contribution we report on results from L-H transitions studies in H, D and new almost pure ^4Helium plasmas, and compare the results with ITER predictions. The most notable result is that the density at which P_{LH} is minimum, $n_{e,min}$, is considerably higher for ^4He than for D, and strongly influenced by shape.
A detailed analysis of the pre-transition E_r profiles across the ne scan in D and ^4He find matching qualitative changes in the E_r profile. In high field NBI heated D plasmas, we report on power balance analysis and its impact on $n_{e,min}$. Modelling of the plasma SOL does show differences in the heat flux required to drive a transition between H and D (in the high n_e branch), and ^4He plasmas are also being studied.

Characterizing the L-H transition power threshold for H, D, ^4He: $n_{e,min}$, ion heat flux, E_r
The interest on ^4He plasmas is not purely academic, and our data brings surprises. The ITER Research Plan includes a low toroidal field Pre-Fusion Operating Power phase with either Hydrogen or Helium plasmas in order to study H-modes as early as possible, before the nuclear phase that starts with D plasmas. A prediction of $n_{e,min}$, was made inspired on the studies of Ryter [5], who observed in AUG that a sufficient edge ion heat flux is necessary to achieve a sufficient radial electric field (shear). Assuming pure electron heating in ITER, $n_{e,min}$ has been evaluated on the basis of 1.5-D transport modelling as the density at which the ratio of edge ion power flux to total edge power flux starts to saturate with increasing density. The result of this modelling is that $n_{e,min}$~$0.4n_{GW}$, independent of the ion species [6]. The transition condition in that model is itself based on the assumption that the He power threshold, $P_{LH}(He)$, is 1.4 x $P_{LH}(D)$, while $P_{LH}(H)$=2x$P_{LH}(D)$ [7].

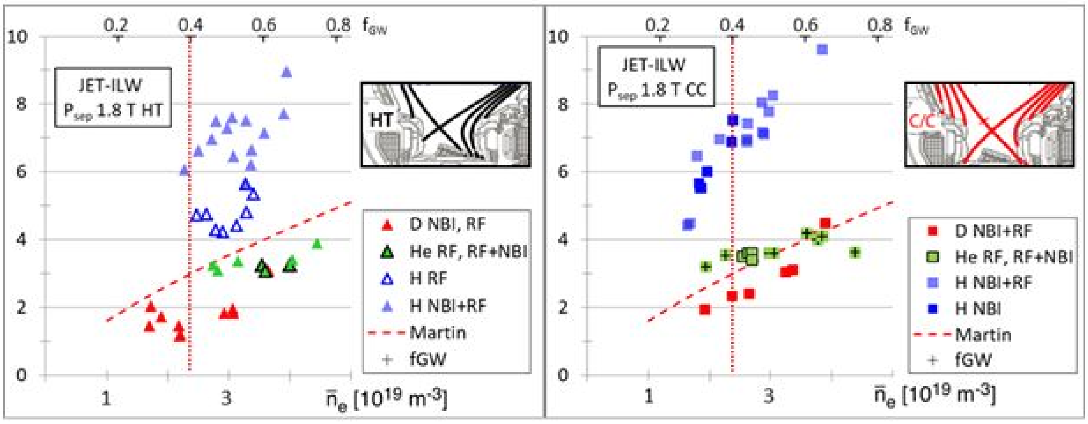

Figure 1: PLH(ne,av) for H, D, ^4He , for 1.8 T, 1.7 MA plasmas. Left plot: horizontal target configuration. Right plot: Corner configuration. Across the top is the corresponding Greenwald fraction.^4He points without an outline transitioned briefly during an NBI blip, P_{LH} could be higher.

We find that for Horizontal Target plasmas the estimate of $n_{e,min} \sim 0.4 \times n_{GW}$ is in agreement with the D data, but $n_{e,min}$ is closer to $0.5 \times n_{GW}$ for H, and to 0.6 for Helium. NBI heated H plasmas have higher P_{LH} than RF heated ones, the reasons are still being investigated. The data points with no black outline correspond to transitions during an NBI blip, so P_{LH} is probably higher. In fact radiation is considerably higher for the dominantly RF-heated Horizontal Target Helium plasmas at low density, so the auxiliary power required for the L-H transition to take place is lower for H than for He below 3.3×$10^{19}e/m^3$. Above $n_{e,min}$(He), D and He have similar P_{LH}, below the Martin scaling, while H has a much higher P_{LH}.
In the 1.8 T Corner dataset $n_{e,min}$ is not so easily identified. Above 0.4n_{GW}, P_{LH} in Corner is generally higher than in Horizontal Target for all species, approaching the Martin scaling for D and He, much higher for H.

The strong shape effect shown in all L-H transition datasets at JET is in apparent contradiction with the ion heat channel determining $n_{e,min}$. A detailed study of the relation between ion heat flux and $n_{e,min}$ in 3T, 2.5 MA D plasmas, now with T_i measurements, is underway [9]. We find the e-i exchange term is subdominant and unlikely to determine $n_{e,min}$.

In a dataset with Horizontal Target, 2.4 T, 2 MA, NBI-heated plasmas (not shown), we find that $n_{e,min}(He) \sim 0.7 \times n_{GW}$, while $n_{e,min}(D) \sim 0.4 \times n_{GW}$. Above $n_{e,min}(He)$, D and He have similar P_{LH}. In this case we are attempting to reproduce the ITER transport models and P_{LH} predictions and contrast them with the data. For these plasmas Doppler reflectometry shows that the E_r profile of the low ne branch for both D and He plasmas has a modest E_r well inboard of the separatrix and a sharp peak further out, while the high density branch has a clear E_r well, but no peak near the separatrix.

DIII-D results show a ~30% increase in $n_{e,min}$ of He plasmas relative to D [10], lower than our 50% shift. AUG studies show no difference in $n_{e,min}$ between H, D and He, and the same P_{LH} for D and He plasmas[11]. In AUG $H +^4 He$ mixtures [14], more than 20% $n_{He}/(n_{He} + n_D)$ is needed to see a change in P_{LH}(H), while <10% suffices in JET NBI heated plasmas [4]. C-Mod results [12] show He data in the low n_e branch for $n_e < 0.3 \times n_{GW}$, while in D P_{LH} increases with density, indicating a shift in $n_{e,min}$. Above $n_{e,min}(He)$, P_{LH} in JET-ILW is similar for D and He, therefore the increase in P_{LH} due to higher $n_{e,min}$ is compensated by the lower power required to access it, since ITER had assumed $P_{LH}(He)$=$1.4 \times P_{LH}$(D).

Simulations of L-H transitions for hydrogen isotopes with the HESEL[15] model find that P_{LH} decreases with increasing mass number like $A^{-1.2}$. Results in ^4He plasmas are expected soon.

Summary and Outlook:

Our results question the logic that supports He for access to H-mode in the early operating phase of ITER, but not necessarily the final power estimate. Detailed analysis is on-going, to provide better understanding of the mechanisms involved and produce an improved prediction. Novel E_r measurements will enable a more detailed understanding of L-H transitions in D and ^4He plasmas.

A Tritium campaign is planned at JET for summer 2020. We expect to obtain L-H transition data for pure Tritium, H+T and H+^4He mixtures. This should inform future experiments in JET and ITER.

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