Reducing the L-H Transition Power Threshold in ITER-Similar-Shape DIII-D Hydrogen Plasmas

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Recent experiments in electron-heat- dominated, low-torque, ITER-similar-shape (ISS) hydrogen plasmas (q_{95} ~3.6) show that the L-H transition power threshold P_{LH} can be reduced substantially (~25-30%) with moderate Helium trace injection (helium ion fraction $n_{He}/n_H \leq 25\%$ during the ensuing H-mode [Fig. 1(b)]. Without mitigation, the power threshold was higher by a factor of ~3 compared to reference deuterium ISS plasmas due to the significant edge electron heat flux [$Q_e(\rho=0.95)/Q_i(\rho=0.95)$ = 1.2-2] [Fig. 1(a)]. Hydrogen ISS plasmas with increased edge safety factor q_{95}~5 exhibited a significantly lower power threshold, an observation not accounted for by the commonly used multi-machine threshold scaling [1] (a dependence of P_{LH} on q_{95} was observed in deuterium ISS plasmas only at mid-density [2]). In co-injected plasmas, P_{LH} increased with neutral beam torque as previously observed in DIII-D deuterium plasmas.

Techniques for reducing P_{LH} are very important for ITER, in particular for hydrogen plasma operations during the PFPO-1 campaign with marginal auxiliary heating (20-30 MW of ECH). We report here also new observations that P_{LH} can be effectively reduced at low ion edge collisionality via applied n=3 Non-Resonant Magnetic Perturbations (NRMF), producing local edge counter-current torque via the Neoclassical Toroidal Viscosity (NTV) at the plasma edge, consistent with linear plasma response simulations.

These results contrast with the increased L-H power threshold observed with applied n=3 *Resonant* Magnetic Perturbations (RMP) in DIII-D, ascribed to edge stochastization due to island overlap [3], and reduced Reynolds stress [4].

Hydrogen fuel pellet injection of 1.7 mm diameter pellets did transiently increase the edge density gradient, but did not result in a robust reduction of P_{LH}, in contrast to earlier DIII-D deuterium experiments with larger 2.7 mm pellets, where the threshold was reduced by ~ 25%.

Control of L-mode $\boldsymbol{E}\times\boldsymbol{B}$ shear via Helium seeding [Fig. 1(b)], or applied NRMF/NTV via the DIII-D n=3 C-coil) can open up a path for reducing P_{LH} in ITER during the non-nuclear Pre-Fusion Power Operations (PFPO-1) phase. For example, the ITER 3-D internal coil set can be used to generate large NTV in the edge plasma layer, favored by the relatively low collisionality expected in the ITER L-mode edge.

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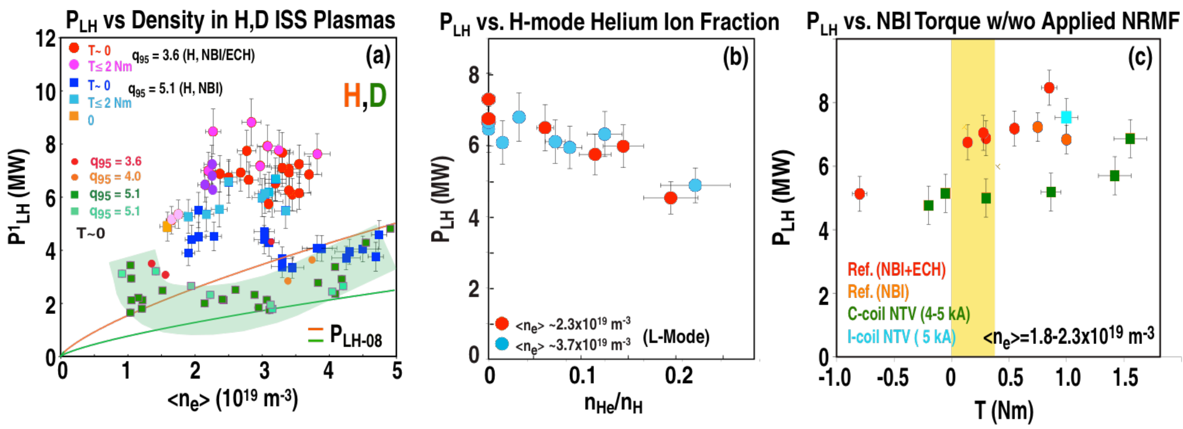

Fig. 1: (a) L-H transition power threshold in ISS hydrogen and deuterium plasmas vs. density, for different values of the edge safety factor q_{95} and NBI torque T; (b) L-H transition power threshold in DIII-D ISS plasmas with helium seeding vs. H-mode helium ion fraction n_{He}/n_{H}, for two different L-mode plasma densities; (c) L-H power threshold in ISS hydrogen plasmas vs. NBI torque w/wo applied n=3 NRMF (the equivalent range of expected intrinsic L-mode torque in ITER is indicated in yellow).