Physics of the Super H-Mode Regime: Record Performance on C-Mod and DIII-D, and Prospects for JET and ITER

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High fusion performance in tokamaks is enabled via the spontaneous formation of a transport barrier, or "pedestal." While many open issues remain, progress in gyrokinetic, neoclassical and MHD theory and simulation [eg 1] has enabled a significant degree of predictive capability for the pedestal height and width, embodied in models such as EPED [2], which have been compared to hundreds of observations on several tokamaks (σ~0.25) [eg 2,3]. Notably, EPED predicts that, at very strong shaping, above a critical density, the pedestal solution bifurcates into multiple roots, including the usual H-mode pedestal root, and a "Super H-mode" (SH) root at very high pedestal pressure [Fig 1a]. Guided by predictions, the SH regime was discovered on DIII-D [4]. More recently, in the final two weeks of Alcator C-Mod operations, SH experiments achieved world record pedestal pressure (~80 kPa) [5], finding, as predicted, ITER-like pedestal pressure at ITER-like toroidal and poloidal field. New DIII-D SH experiments in 2017-18 have achieved high pedestals [Fig 1a] and fusion performance [Fig 1b], including what appears to be the highest Q_{DD} (and Q_{DT_equiv}~0.5) ever achieved on a medium scale tokamak (R<2m). Sustained high performance operation at low and high separatrix density has been achieved, using 3D magnetic perturbations to control density and achieve stationary profiles. Normalized metrics of fusion performance such as Q/IaB, or <p>W/P_{heat}IaB, reach very high values in SH [Fig 1b]. Achieving similar levels of normalized performance could allow Q>1 in JET, or Q=10 in ITER at currents below 15MA. However, there are many challenges in achieving such performance, including methods for sustainment, impurity and ELM control, and compatibility of high triangularity shapes with nearby metal walls. We present SH theory compared to results on C-Mod and DIII-D, and predictions and challenges for SH on JET, ITER , JT-60SA and DEMO concepts.

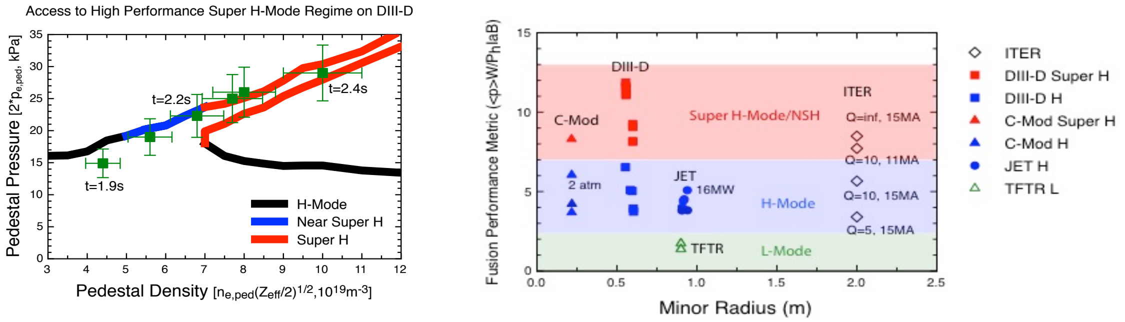

Figure 1: (a) Recent DIII-D experiments have achieved very high pedestal pressure, deep into the SH regime, simultaneously achieving high fusion performance. (b) A simple metric of normalized fusion performance (<p>W/P_hIaB) illustrates the fusion benefit of Super H (solid symbols are existing data from cases with <p> > 50kPa). Approximate required values of this metric for various levels of ITER performance are also shown.

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