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[REGULAR POSTER TWIN] Development of an integrated core-edge scenario using the Super H-mode

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An optimized pedestal regime called the Super-H Mode (SH-mode) is leveraged to simultaneously couple a fusion relevant core plasma with a scrape-off layer appropriate for realistic reactor exhaust solutions. Recent DIII-D experiments have expanded the operating space from previous studies of the SH regime and investigated optimization of impurity seeding, deuterium gas puffing, 3D magnetic perturbations, and plasma shape. Experiments demonstrate gas puffing and impurity seeding lead to a radiative mantle and low divertor temperatures (< 15eV) that are compatible with maintaining SH-mode and have marginal impact on pedestal and core pressure. An important recent result is that access to the SH-mode has been achieved in shapes matching JET plasmas with moderate plasma triangularity ($\delta_{avg} \sim 0.4$), providing a pathway for increased performance for the JET D-T campaign as well as increased confidence in the EPED predictions for SH-mode access in ITER.

Plasma shape is a key parameter impacting pedestal stability, and when SH-mode access is marginal, small changes in triangularity and aspect ratio can lead to an increase in global metrics like plasma stored energy through pedestal optimization. Previous experiments maximized plasma triangularity and volume in the SH regime in order to maximize pedestal and core performance; however, recent experiments show SH access can still be obtained at moderate plasma shaping. Figure 1 shows the pedestal electron pressure and density in two JET similar shapes, with one having an increased plasma triangularity from 0.3 (gray) to 0.4 (red). This change in triangularity opens access to the SH-mode channel, allowing a higher pedestal at the same density, and higher stored energy even with a slightly reduced plasma volume. The relatively modest plasma triangularity compared to the double null SH experiments leads to pedestal pressures which are farther from ideal β limits, allowing plasma trajectories deep in the SH channel to be maintained in a stationary state. Robust SH-mode access in lower single null shapes with intermediate levels of triangularity implies applicability for potential use as a target scenario in both JET and ITER. Figure 1 indicates that SH-mode is compatible with JET plasma shapes and could increase plasma stored energy in the upcoming D-T campaign at the same engineering parameters.

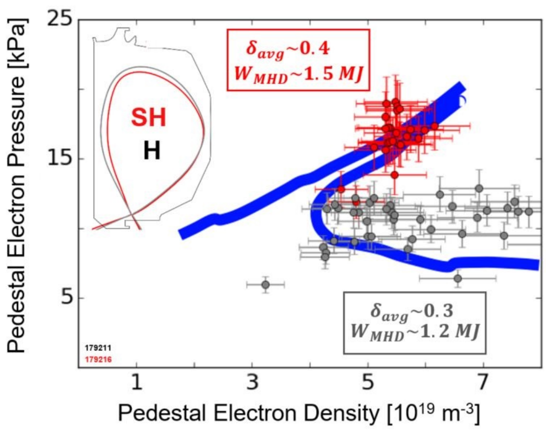

Figure 1: Density-pressure diagram showing Super H-mode channel access calculated from EPED for the $\delta \sim 0.4$ discharge compared to DIII-D experimental data in two JET similar shapes. The higher triangularity shape (red) exhibits SH-mode operation, but the lower plasma shaping case (gray) does not.

By employing a dynamic density trajectory and shape control, peeling and ballooning physics can be decoupled in the pedestal {1}. The peeling-limited pressure pedestal reaches ~20-30kPa on DIII-D and up to ~80kPa on C-Mod {2}, even with strong gas puffing. The pedestal maintains low collisionality with a high separatrix density {3}, which is important for achieving a low heat flux to the divertor plate without degradation of the pedestal pressure. Recent experiments on DIII-D have employed co-current beam injection at full magnetic field ($B_t = 2.1 - 2.2T$) and current ($I_p = 1.4 - 2.0MA$) in both closed and open divertor configurations. Initial indications show that a slightly larger divertor volume with a longer leg between the x-point and strike points allows more power to be radiated in the scrape off layer and pedestal regions, and to be excluded from the core more effectively. Advanced control algorithms {4,5} simultaneously optimize the line average density and divertor radiative power. Introducing 3D magnetic perturbations that pump out particles actively controls the line average density and allows the SH-mode plasmas to enter an extended stationary phase for 2s with sustained pedestal pressure and controlled impurity content. Dual seeding with deuterium and nitrogen radiate power near the separatrix and reduce the divertor heat flux and temperature to promote integration with requirements of plasma facing components, as shown in Fig. 2 for a lower biased double null ($\delta_{avg} \sim 0.57$). The SH-mode plasma has a pedestal electron temperature of ˜1keV with divertor temperature <15eV. Feedback control on the divertor radiation was employed for optimal nitrogen seeding to maintain a steady dissipation of ˜42% of injected power contained to the divertor and pedestal regions while maintaining a pedestal with β_N^{ped} 0.8 and core plasmas with $\beta_N^{core} = 2.2$ and $W_{MHD} \sim 2MJ$.

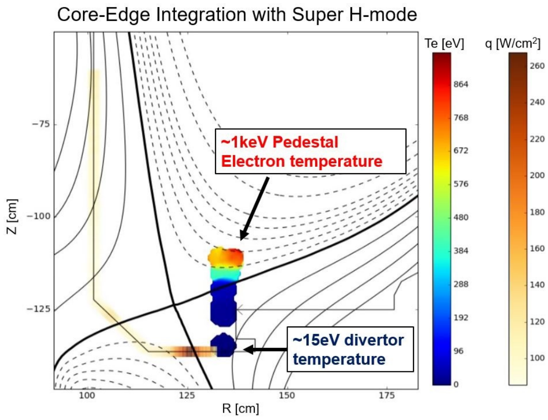

Figure 2: DIII-D divertor Thomson measurements in a Super H-mode with dual deuterium and nitrogen seeding. Pedestal temperatures are ˜1keV and divertor temperatures are <15eV. Infrared imaging heat flux measurements show reduced heat flux to the strike points due to N_2 and D_2 seeding.

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{2} J. Hughes, et. al., NF 58, 112003 (2018)
{3} P.B. Snyder, et. al., Nucl. Fusion 59, 086017 (2019)
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