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The Role of Drifts and Radiating Species in Detached Divertor Operation at DIII-D

EX-D

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A comprehensive experimental campaign at DIII-D has advanced understanding and modeling of the effects of drifts and radiating species in divertor discharges up to ITER-relevant collisionality. Unique diagnostic capabilities are employed to show directly that plasma drifts lead to in/out asymmetries as well as shifts in radial profiles throughout the divertor legs, and are a critical factor for predicting detachment onset, and particle and heat fluxes for a detached divertor. These results are reproduced by first-of-its-kind boundary modeling of H-mode discharges with a full physics description of drifts using UEDGE in both toroidal field directions, confirming that the interplay of radial and poloidal **E**×**B** drifts are primarily responsible for target asymmetries and localization of high density/low temperature plasma in the scrape-off layer. SOLPS modeling of L-mode Helium discharges with negligible carbon emission suggests that molecular contributions and atomic physics may play a role in explaining a consistent shortfall in divertor radiation observed in boundary modeling of multiple tokamaks. These and future planned studies of detachment provide valuable physics insight informing the implementation of high-Z plasma facing components at key locations poloidally in DIII-D in 2016.

For the first time fully 2D measurements of density and temperature throughout the inner and outer divertors are accomplished in H-mode using divertor Thomson scattering (DTS) with sub-eV measurement capability (Fig. 1) revealing that reversing the drift direction leads to target conditions with increased symmetry. Ion **B**x∇**B** is directed both into and out of the active lower divertor in

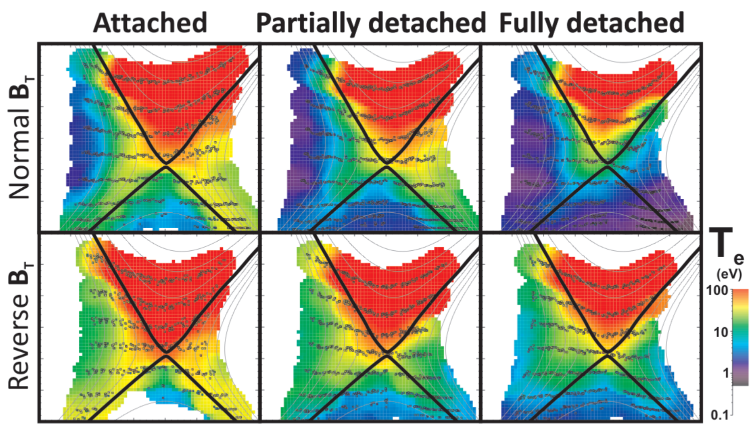

Figure 1: Electron temperature measured by DTS in forward (top) and reverse (bottom) B_T in the transition to divertor detachment.

matched discharges. H_{98} remained >1.0 and stored energy remained constant for all divertor regimes. A broad region of unexpectedly high density is seen in the SOL on the side in the direction of the $\mathbf{E}_r \times \mathbf{B}_T$ radial drift for all divertor regimes implying significant particle flux is present. While detachment flattens temperature gradients near the targets, those gradients remain strong just beyond the ionization front where baffle materials and design depend critically on heat flux. A rapid transition from 10-15 eV to <2 eV is observed as a function of density at the outer target in the normal $\mathbf{B}_T$ direction (ion $\mathbf{B}\mathrm{x}\nabla\mathbf{B}$ drift toward the X-point), while the transition is smooth at both targets in reverse $\mathbf{B}_T$.

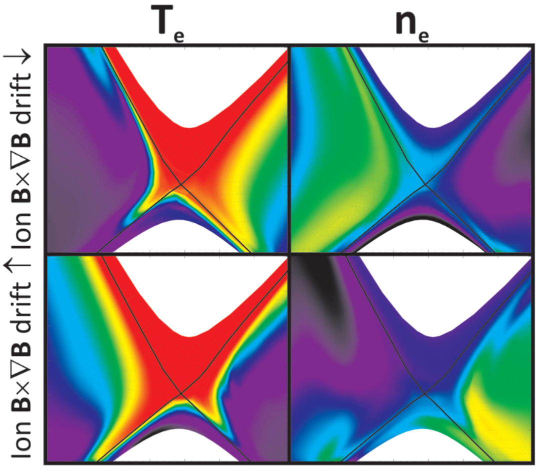

Figure 2: UEDGE modeling of low density H-mode in forward (top) and reverse (bottom) $\mathbf{B}_T$ in DIII-D.

For the first time, modeling of the H-mode boundary with a full physics drift model is achieved using UEDGE, successfully matching features of the data for in/out divertor-leg plasma asymmetries, with the normal $\mathbf{B}_T$ direction having higher n_e and lower T_e in the inner divertor leg than outer (Fig. 2). The reverse $\mathbf{B}_T$ case shows a decrease (increase) in the inner divertor n_e (T_e) with the opposite in the outer divertor. These plasma changes are traced to large $\mathbf{E}_r \times \mathbf{B}_T$ poloidal particle flow under the X-point coupled with large $\mathbf{E}_p \times \mathbf{B}_T$ radial flows in the divertor legs, where $\mathbf{E}_r$ and $\mathbf{E}_p$ are the radial and poloidal electric fields. The importance of such particle flow under the X-point confirms recent EDGE2D modeling of L-mode plasmas [1] and previous probe measurements at DIII-D [2], and reinforces the need to improve prediction of the ionization front location in partially/fully detached plasmas [3].

Helium discharges without chemical sputtering of carbon show that a radiation shortfall seen in modeling of deuterium discharges in multiple tokamaks can only be partially explained when atomic and molecular D contributions are negligible. Tangential imaging shows that CIII emission is reduced below the detection limit in the divertor. Modeling using SOLPS shows good agreement for He I/II emission at the targets, but radiated power, isolated to the X-point region (Fig. 3), remains insufficient to match experimental data [4]. Projection of modeling to H-mode suggest improved trapping of He neutrals relative to L-mode, and motivate a Helium H-mode campaign with He neutral beam injection planned for 2016.

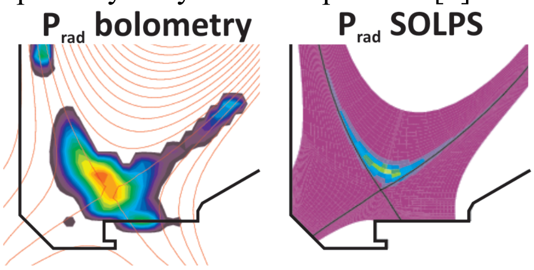

Figure 3: Modeling of radiated power in He plasma.

Overall these results provide increased confidence in interpretation and prediction of divertor detachment onset and control, and indicate that the physics of drifts and molecular impurities are critical ingredients for accurate boundary modeling. At DIII-D, these advancements will aid ongoing experiments aimed at understanding of detachment, and in high-Z erosion and transport from the divertor in the upcoming Tungsten metal tile campaign.

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