Experimental Inference and Modeling of Impurity Transport in Alcator C-Mod and DIII-D regimes without ELMs

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The achievement of core-edge integration in tokamaks depends crucially on our understanding of impurity and neutral particle dynamics. In this work, radial profiles of experimental impurity transport coefficients are inferred following laser blow-off (LBO) injections into both DIII-D and Alcator C-Mod, finding significant discrepancies with TGLF and (nonlinear) CGYRO in cases where hollow impurity profiles are experimentally observed. We make use of an advanced Bayesian framework, leveraging a range of spectroscopic diagnostics and recent development of the AURORA package*. Our investigation spans regimes without ELMs including Enhanced D-Alpha (EDA) H-mode and I-mode on C-Mod, and diverted negative-triangularity discharges on DIII-D. On C-Mod, a novel forward model for the entire K-alpha spectrum of calcium has been combined with VUV spectroscopy of multiple charge states. On DIII-D, analogous VUV measurements complement local CER density estimates. In all cases, the effect of charge exchange between background neutrals and impurities is found to be extremely important for charge state balance in the pedestal. This conclusion is supported by SOLPS-ITER predictions of neutral distributions, which are shown to compare favorably to Lyman-alpha measurements near the C-Mod midplane as well as high-n Rydberg series observations from x-ray imaging crystal spectroscopy. On DIII-D, we also examine the impact of fast and thermal NBI neutrals on impurities, finding these to be less important to charge state balance than edge neutrals. Neutral density estimates are an integral part of our Bayesian inferences of impurity transport; together with time-resolved LBO injections, this offers important advantages to understand atomic processes and sources for both devices. Comparison of the experimentally inferred impurity particle transport coefficients with NEO, TGLF and nonlinear CGYRO shows good agreement in diffusion but important differences in convection at mid-radius. This leads to incorrect predictions of peaking vs. hollowness of impurity density profiles, suggesting that turbulent transport models may be missing critical physics.

This work is supported by US DOE grants DE-SC0014264, DE-FC02-04ER54698, DE-AC05-00OR22725

* Public release and documentation: https://aurora-fusion.readthedocs.io