Understanding Electron Heat Loss and Profile Stiffness Through Direct Comparison of Multi-Scale Gyrokinetic Simulation with Experiment

N.T. Howard[1], C. Holland[2], A.E. White[1], M. Greenwald[1], J. Candy[3], and A. Creely[1]
[1] Massachusetts Institute of Technology (MIT), Cambridge MA 02139, USA.
[2] University of California – San Diego (UCSD), La Jolla, CA 92093, USA.
[3] General Atomics (GA), San Diego, CA 92121, USA.

Despite years of research and numerous advances in theory and simulation, disagreements between experimental electron heat flux and leading turbulence models remain common. It has been speculated that short wavelength, electron-scale turbulence may play an important role in electron thermal transport. However, simulation capturing both ion ($k_\theta\rho_s < 1.0$) and electron-scale ($k_\theta\rho_s > 1.0$) turbulence simultaneously was, until recently, computationally intractable and therefore had not been compared quantitatively against experiment. We report results from dedicated validation experiments on Alcator C-mod, designed to probe the origin of electron heat transport. These experiments were simulated using cutting-edge, multi-scale simulations which capture ITG/TEM/ETG turbulence up to $k_\theta\rho_s \sim 48.0$ using all experimental inputs, impurities, realistic electron mass ($(m_i/m_e)^{1/2} = 60$), ExB shear, and collisions. The simulations reveal that ion-scale turbulence likely coexists and couples with electron-scale, 'streamers' in the tokamak core. Direct comparison of multi-scale simulation with both experimental heat fluxes (Q_i and Q_e) and electron profile stiffness were made. Only by simultaneously capturing ion and electron-scales is simulation able to reproduce experiment – pointing to the likely origin of the anomalous electron heat loss and electron profile stiffness in tokamaks. Electron-scale turbulence and its cross-scale coupling with ion-scale turbulence is found to play a significant role in experimental plasma conditions, increasing electron heat fluxes by up to an order of magnitude of above standard, long wavelength simulation. A description of the experiments performed, the mechanisms of cross-scale coupling, implications for experimental interpretation, and the impact on modeling of ITER and beyond will be discussed.