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Demonstrating the Multi-scale Nature of Electron Transport Through Experimentally Validated Simulations

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New experimentally validated simulations demonstrate for the first time that the turbulent transport that sets tokamak confinement is robustly multiscale across a variety of reactor-relevant regimes, with significant nonlinear cross-scale couplings that must be accurately described to correctly predict ITER performance. These gyrokinetic and gyrofluid simulations of electron transport dominated experiments performed on the Alcator C-Mod and DIII-D tokamaks consistently find that over half of the electron thermal transport arises from short-wavelength electron-scale (k_theta rho_i > 1) fluctuations not resolved by conventional ion-scale (k_theta rho_i ≤ 1) microturbulence simulations. It is found that only by including these short-wavelength fluctuations can the turbulence simulations simultaneously match the measured temperature gradients, incremental electron thermal diffusivity, and independent power balance calculation energy fluxes within experimental uncertainties. Significant transport contributions from electron-scale streamers are found to persist even in discharges with low rotation and input torque, where they co-exist with non-negligible ion-scale eddies that drive the ion thermal transport. The multiscale simulations show complex nonlinear interactions between the electron- and ion-scale fluctuations, such that the intensity of electron-scale fluctuations can depend upon the ion-scale fluctuation intensity, and vice versa. Therefore, the resulting transport cannot be assumed to be a simple sum of separate ion- and electron-scale dynamics. Taken together, these simulations provide the clearest evidence to date that electron-scale turbulence will be prevalent in burning plasma conditions, and that the nonlinear multiscale dynamics and cross-scale couplings of this turbulence must be accurately described to confidently predict the performance of those regimes.

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