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The Role of ITG/TEM/ETG Cross-Scale Coupling in Explaining Experimental Electron Heat Flux and Profile Stiffness[1]

N.T. HOWARD, Oak Ridge Institute for Science Education (ORISE)

Anomalous electron thermal transport in tokamak plasmas is the "great unsolved problem of tokamak transport physics" [Batchelor Plasma Sci. Tec. 2007]. For years it has been speculated that short wavelength ETG turbulence plays a key role, but simulation capturing both ion and electron-scale turbulence simultaneously had never been tested quantitatively against experiment due to extreme computational requirements. Only recently have gyrokinetic codes and supercomputing resources together been able to capture the physics of cross-scale coupling between long wavelength ITG/TEM and short wavelength ETG turbulence. In C-Mod, long wavelength simulations often under-predict electron heat flux. As a result, dedicated experiments have been performed in L-mode plasmas to validate multi-scale nonlinear gyrokinetic simulations. In this talk, the first set of full-physics, multi-scale simulations of a tokamak plasma performed with the GYRO code are compared to experiment. The simulations include coupled ITG/TEM/ETG turbulence ($k_\theta \rho_s < 48.0$) at realistic mass ratio ($m_i/m_e = 3600$), with experimental inputs for impurities, geometry, ExB shear, and collisions. 100M CPU hours were required for six simulations to scan the ITG and ETG drive terms (a/L_{Ti} and a/L_{Te}) within experimental error bars. The multi-scale simulations show for the first time that ETG streamers coexist and nonlinearly couple with ITG and zonal flows. This nonlinear cross-scale coupling enhances both ion and electron heat fluxes by up to a factor of 10 above standard, long wavelength simulation, resulting in simulations that simultaneously match experimental ion and electron heat fluxes and electron profile stiffness. The new physics of ITG/ETG/zonal flow coupling has important implications for predictions of ITER performance and may be linked to phenomena such as confinement transitions and rotation reversals.

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