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Role of Trapped Electron Mode Turbulence in Density Profile Control with ICRH in Alcator C-Mod

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Abstract

Recent experiments[1] on Alcator C-Mod, using off-axis ICRH, have produced very peaked density profiles without core fueling, following the transition to EDA H-Mode. As the density peaks, the temperature profile remains relatively unaffected. Adding modest levels of central ICRH arrests the density peaking. Similar results are seen in DIII-D in the QDB regime, where off-axis ECH flattens peaked density profiles.[2] The degree of density peaking is set by adjusting the central heating power, demonstrating density profile control via external tools. This mode is produced without core fueling, reverse shear, large Shafranov shift, central auxiliary heating, or external torques. This provides a unique opportunity to study the fundamental turbulent and collisional processes underlying particle transport in an isolated context. The relevant electron continuity equation is simply $\partial_t n + \nabla \cdot (\Gamma_p^{neo} + \Gamma_{turb}) = 0$, where Γ_p^{neo} is the collisional neoclassical pinch, and Γ_{turb} is the particle flux due to TEM turbulence. This work aims to determine the basic processes controlling particle transport in the steep gradient region, making quantitative comparisons between experiments, neoclassical codes, and nonlinear GS2[3,4] gyrokinetic turbulence simulations.

Transport analysis shows the neoclassical (Ware) pinch exceeds the inflow required to peak the density profile. Early in time, when the temperature profile is peaked and the density profile is relatively flat, GS2 simulations show a turbulent pinch similar in magnitude to the neoclassical pinch. As the density profile peaks, this turbulent inflow reverses to become an outflow. Toroidal ion temperature gradient driven modes are suppressed inside the half-radius (nominally the "foot" of the internal transport barrier), and dominant in the outer half-radius. As the density gradient further steepens, non-resonant collisionless trapped electron modes (TEM) are driven unstable. Gyrokinetic stability analysis shows the modes are driven by the density gradient, have wavelengths of order twice the ion gyroradius, and are partially damped by collisions. After the TEM onset, the turbulent outflow strongly increases with the density gradient. This outflow balances the inward neoclassical pinch at the same time the density gradient scale length comes to steady state. Further, the turbulent particle diffusivity from nonlinear GS2 simulations comes close to the experimental value inferred from the continuity equation, using measured density profile data and the calculated neoclassical pinch. This turbulent diffusivity exhibits a strong unfavorable temperature dependence, enabling control with central heating.

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