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Understanding and Predicting Profile Structure and Parametric Scaling of Intrinsic Rotation[1]

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It is shown for the first time that turbulence-driven residual Reynolds stress can account for both the shape and magnitude of the observed intrinsic toroidal rotation profile. Nonlinear, global gyrokinetic simulations using GTS of DIII-D ECH plasmas indicate a substantial ITG fluctuation-induced non-diffusive momentum flux generated around a mid-radius-peaked intrinsic toroidal rotation profile. The non-diffusive momentum flux is dominated by the residual stress with a negligible contribution from the momentum pinch. The residual stress profile shows a robust anti-gradient, dipole structure in a set of ECH discharges with varying ECH power. Such interesting features of non-diffusive momentum fluxes, in connection with edge momentum sources and sinks, are found to be critical to drive the non-monotonic core rotation profiles in the experiments. Both turbulence intensity gradient and zonal flow ExB shear are identified as major contributors to the generation of the $k_{\|}$-asymmetry needed for the residual stress generation. By balancing the residual stress and the momentum diffusion, a self-organized, steady-state rotation profile is calculated. The predicted core rotation profiles agree well with the experimentally measured main-ion toroidal rotation. The validated model is further used to investigate the characteristic dependence of global rotation profile structure in the multi-dimensional parametric space covering turbulence type, q-profile structure and collisionality with the goal of developing physics understanding needed for rotation profile control and optimization. Interesting results obtained include intrinsic rotation reversal induced by ITG-TEM transition in flat-q profile regime and by change in q-profile from weak to normal shear.. Fluctuation-generated poloidal Reynolds stress is also shown to significantly modify the neoclassical poloidal rotation in a way consistent with experimental observations. Finally, the first-principles-based model is applied to studying the $\rho*$-scaling and predicting rotations in ITER regime.

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