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Theory and Simulation of Rotational Shear Stabilization of Turbulence[1]

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Stabilization of turbulence in tokamaks by E×B rotational shear is now thought to be a key mechanism leading to both L/H-edge and core transport barriers. Numerical simulations of ion temperature gradient (ITG) mode transport with gyrofluid flux tude codes first lead to the approximate rule that the critical E×B rotational shear rate $\gamma_{\rm E} = {\rm r/q}\,\partial({\rm q\,v_{E\times B}/r})/\partial{\rm r} \approx \gamma_{\rm max}$ the maximum of ballooning mode growth rates γ_0 in the absence of the E×B shear.[2] The present work revisits the ($\rho^* \to 0$) flux tube simulations reformulated terms in of Floquet ballooning modes which convect in the ballooning mode angle $\theta_0 \to \theta_0 + \gamma_{\rm E}/\hat{\rm s}\,{\rm t}$. This formulation avoids linearly unstable and spurious "box modes" which arise from discretizing in θ_0 and illustrates the true nonlinear nature of the stabilization in toroidal geometry. The eigenmodes can be linearly stable[3] at vanishingly small $\gamma_{\rm E}$ when θ_0-averaged $\gamma_0(\theta_0) \le 0$, yet Floquet mode convective amplification with nonlinear coupling allows turbulence to persists unless $\gamma_{\rm E} \approx \gamma_{\rm max}$. The rule seems to hold at vanishing magnetic shear $\hat{\rm s}$. Going to finite ρ^* with diamagnetic velocities comparable to $\rm v_{E\times B}$, likely requires the total mode phase velocity shear (not just the $\rm v_{E\times B}$ Doppler part) ${\rm r/q}\,\partial({\rm q\,v_{mode}/r})/\partial{\rm r} \ge \gamma_{\rm max}$. "Profile curvature" ($\rm x^2$ profile variations in γ_0) works against stabilization from "profile shear" (x-variation). From studies of global eigenmodes of the "ballooning-Schrödinger equation,"[4] the profile curvature is generally not important if ρ^* is typically small. Further studies of profile stabilization use the 2d full radius ITG code.[5]

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