Model for Nonlinear Upshift of TEM Critical Density Gradient and ITG Dimits Shift

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The effective critical density gradient for onset of TEM turbulent transport significantly exceeds the TEM linear stability threshold [1, 2]. This nonlinear upshift, as computed using nonlinear GS2 gyrokinetic simulations, increases strongly with collisionality [3, 4], and is associated with zonal flow dominated states. A simple dynamical model is developed to describe the energy exchange between zonal flows and primary instability, as driven by secondary instability [5, 6]. Despite its simplicity, the model reproduces the nonlinear upshift computed from nonlinear gyrokinetic simulations. Coefficients which significantly impact model predictions are calculated from first principles rather than fitting to nonlinear simulation results, making the model predictive. Interestingly, effects which are not well-quantified *a-priori* in the model, including tertiary instability and wavenumber diffusion, merely give rise to structural stability and mainly affect the rate of convergence.

For density gradients between the linear and effective nonlinear TEM critical gradients, periodic bursting is observed in nonlinear GS2 simulations. Analytic expressions are obtained for the flux, the period between bursts of flux, and other key quantities. The model reproduces the variation of this burst period with driving factor while matching the nonlinear upshift from GS2. The model predicts additional parametric scalings which can be used to optimize fusion performance, including a significant and favorable isotope scaling of the upshift. The approach readily simpilifies to describe the Dimits shift for ion temperature gradient (ITG) driven turbulence [7]. This model could find application in quasilinear transport models to include the effect of zonal flows near threshold, improving their accuracy for rapid estimates of transport when evolving profiles.

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[1] D. R. Ernst et al., Phys. Plasmas **11**, 2637 (2004).

[2] D. R. Ernst, K. H. Burrell, W. Guttenfelder, T. L. Rhodes, A. M. Dimits et al., Phys. Plasmas **23**, 056112 (2016).

[3] D. R. Ernst, "Nonlinear upshift of trapped electron mode critical density gradient: Simulation and experiment," APS-DPP Invited paper, Providence, Rhode Island (2012).

[4] D. R. Ernst et al., "Controlling H-Mode particle transport with modulated electron heating in DIII-D and Alcator C-Mod via TEM turbulence," in Proc. 2014 IAEA Fusion Energy Conference, St. Petersburg, Russia, IAEA-CN-221/EX/2-3.

[5] B. N. Rogers, W. Dorland, and M. Kotschenreuther, Phys. Rev. Lett. **85**, 5336 (2000).

[6] P. H. Diamond, S.-I. Itoh, K. Itoh, and T. S. Hahm, Plasma Phys. Contr. Fusion **47**, R35 (2005).

[7] A. Dimits et al., Phys. Plasmas **7**, 969 (2000).