Zonal Flow — Drift Wave Interactions in 2D 2-Fluid ITG

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It is believed that most of the heat transport in tokamak plasmas is caused by turbulence. Numerical simulations have shown that turbulence in tokamaks is regulated by the interaction of 3 different phenomena — shear of the mean plasma flow, zonal flows (ZF) and drift waves (DW) [1, 2]. The latter represent wave-like fluctuations in the plasma, driven by gradients in the background plasma parameters — density, temperature, etc. Zonal flows are Larmor-scale shear flows in the poloidal direction (around the smaller radius of the torus), which are generated nonlinearly by the drift-wave turbulence itself.

We aim to find an analytical description of the nonlinear interaction of ZFs and DWs and the phenomena resulting thereafter — the Dimits shift [1] and the recently discovered state dominated by coherent structures [3]. Our equations are obtained by taking density and temperature moments of the electrostatic gyrokinetic equation in an appropriate cold ion limit ($T_i \to 0$) and large collisionality expansion $\nu_i \gg \omega \sim \omega_* \sim \nu_i k_\perp^2 \rho_i^2$. The resulting system of two PDEs is shown to exhibit both a linear ion-temperature-gradient instability, driven by a background magnetic field and temperature gradients, a nonlinear (secondary) instability towards the development of strong zonal flows, as well as the break-up of the ZF-dominated state (tertiary instability). We present analytical results on both the linear and nonlinear behaviour of the system, together with numerical validations.

References

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