GYROFLUID MODELS OF TURBULENT TRANSPORT IN TOKAMAKS

Michael Alan Beer

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To Jason, with love.

Abstract

MICROINSTABILITY DRIVEN TURBULENCE IN TOKAMAKS is studied via numerical simulation of a comprehensive fluid model. For the ions, toroidal gyrofluid equations are derived which contain accurate models of the kinetic effects arising from toroidal ∇B and curvature drifts, parallel Landau damping and its inverse, finite Larmor radius effects, and trapped ion effects. For the electrons, sophisticated bounce averaged trapped electron fluid equations are derived which model the toroidal precession resonance and use a Lorentz collision operator for pitch angle scattering. These coupled ion and electron equations can simultaneously describe the nonlinear evolution of toroidal ion temperature gradient driven instabilities and trapped electron modes, and provide realistic nonlinear calculations of ion and electron heat fluxes and particle fluxes. These equations are solved in a reduced flux tube geometry, formulated in general magnetic coordinates. This technique exploits the elongated nature of microinstability driven turbulence, which has long parallel scales and short perpendicular scales. The reduced simulation volume allows high resolution simulations in realistic tokamak geometry, fully retaining important toroidal effects such as good and bad curvature. These toroidal simulations predict much larger thermal transport than found in simplified sheared slab geometry, bringing the predictions up to experimentally measured levels. The turbulent fluctuation spectrum is peaked at long wavelengths compared to the fastest growing linear modes, and the fluctuation spectrum is anisotropic in k_r and k_θ, as seen in experimental fluctuation measurements. The nonlinear generation of sheared $\mathbf{E} \times \mathbf{B}$ flows is found to play an important role in the development and saturation of this turbulence, and the damping of these flows is carefully investigated. Finally, the predicted transport from these simulations is compared with experiment. The simulations underestimate the transport near the plasma edge, but encouraging agreement is found between the predicted and measured ion and electron heat transport in the core.

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