A comprehensive look at saturation dynamics of trapped electron mode turbulence

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Abstract

Comprehensive spectral analysis of trapped electron mode turbulence reveals that it does not saturate according to the canonical picture of quasi homogeneous, unstable plasma turbulence. It does not saturate by spectral energy transfer from unstable to stable modes, as identified by linear stability theory, and fluctuations carrying the energy do not have a frequency given by the unstable root of the linear dispersion relation. Instead, saturation is achieved by energy transfer to fully damped eigenmodes, i.e., roots of the dispersion relation that are damped for all wavenumbers $- \quad < k < \quad$. The excitation of such eigenmodes to finite amplitude causes wavenumbers that are unstable in linear analysis to become robustly stable at finite amplitude, making the landscape of linear sources and sinks a non predictor of energy transfer. Energy transferred to the damped eigenmode cascades to long wavelengths, even when the only nonlinearity is electron density advection. Inverse transfer is the result of near-resonant wave triads and reflects the wave anisotropy, while violating the doctrine that cascade direction is determined by dynamical invariants. The anisotropy of the inverse energy transfer process favors the excitation of zonal modes, including those of the damped eigenmode spectrum, opening a potent finite-amplitude-induced sink. These results are established for the weakly collisional (collisionless) limit of a fluid model for trapped electron mode turbulence,[1] using bispectral analysis of simulation results, analysis of the basic symmetries of the model, and an analytical solution of the statistical closure equations in the strong-turbulence limit. The latter is made possible by an asymptotic expansion, and yields the nonlinear frequencies and saturation levels of density, potential, and density-potential cross power for both the turbulence spectrum and zonal modes. Like other systems with coupling to zonal modes, the system first saturates at a relatively high level, and then adjusts to a lower level as the zonal modes increase relative to non zonal modes. When zonal mode coupling is removed, the turbulence level increases by at least an order of magnitude. Analysis shows that this is caused by the removal of the saturation channel associated with anisotropic spectral transfer to the zonal modes of the damped eigenmode root, and has nothing to do with E□B shearing. Indeed, the E□B shearing rate cannot exceed the nonlinear correlation rate, consistent with recent observations from beam emission spectroscopy in DIII-D.[2]

[1]P.W. Terry, R. Gatto, and D.A. Baver, Phys. Rev. Lett. **89**, 205001 (2002).

[2]M. Jakubowski, Ph.D. Thesis, University of Wisconsin-Madison, 2003.

Work supported by USDOE.