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Zonal flow spectra and the reduction of collisionless trapped electron turbulence by nonlinear damping

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Abstract

Close analogs with quasigeostrophic turbulence and rotating 3D fluid turbulence indicate that plasma zonal flows in drift-wave-type turbulence are the condensate of an inverse spectral energy transfer process in which the spatial structure of the zonal flow is an expression of the anisotropy of the zero frequency wave.[1] This principle allows calculation and assessment of key properties of the system. In quasigeostrophic turbulence it yields the zonal flow spectrum.[2] We use it to derive two additional results: an expression for the timescale required for excitation of zonal flows in an inverse cascade driven by stirring at small scale, and a demonstration that in such a spectrum there is no suppression of turbulence by zonal flow shearing, because the shear suppression criterion is nowhere satisfied in the spectrum. We apply this type of analysis to collisionless trapped electron mode (CTEM) turbulence, first noting that systems with multiple fields must be transformed to the eigenmode decomposition, the analog of the helical decomposition employed in rotating 3D turbulence. Like rotating 3D turbulence, both eigenmodes are excited, even though in CTEM, one eigenmode is damped for all wavenumbers. The excitation of the damped eigenmode introduces a significant amount of finite-amplitude-induced dissipation, which saturates zonal flows and is a significant saturation mechanism for the smaller scale turbulence. A closure calculation yields the relative magnitudes of all fields, while spectral variation is obtained from the appropriate balance of wave frequency and nonlinearity. The power spectra go as k_x^{-3} for both the electron density and the potential. We find that in an inertial range there is no suppression of turbulence by zonal flow shearing. In the wavenumber range of unstable modes, suppression is possible provided the scale separation between zonal modes and turbulent modes $(\square_{zf}/\square_{turb})$ does not exceed the inverse nonadiabaticity parameter $\square^{-1}$ of the CTEM instability. However, the energy dissipation rate associated with the excitation of the damped eigenmode is much larger than the enhanced decorrelation associated with zonal flow shearing. The ratio goes as $\square^{-3/2}(\square_{zf}/\square_{turb})^{5/2}$. This indicates that the order of magnitude reduction in fluctuation level observed when zonal flows are included in CTEM simulations is a result primarily of the dissipation associated with the damped eigenmode, and not zonal flow shearing. The important role played by the damped eigenmode in CTEM turbulence is discussed in connection with the observation of geodesic acoustic mode excitation in DIII-D and TEXT.

[1]P.W. Terry, R. Gatto, and D.A. Baver, Phys. Rev. Lett. **89**, 205001 (2002).
[2]A. Chekhlov *et al.*, Physica D **98D**, 321 (1996).
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