Enhanced transport due to nonlinear coherent structures in stellarator TEM turbulence

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The stellarator offers a viable alternative to the tokamak as a magnetic confinement fusion device, thanks to the ease of steady-state operation, but much remains to be learned regarding its turbulent transport properties. Nonlinear gyrokinetic simulations of density-gradient-driven trapped-electron-mode (TEM) turbulence in the Helically Symmetric eXperiment predict integrated heat fluxes that are compatible with experimental observations in the corresponding density range [Faber et al., PoP 2015]. The development of the quasi-stationary turbulent state corresponds with the appearance of zonal flows in all simulations, consistent with density-gradient-driven TEM observations in tokamaks. However, the usual eddy-shearing mechanism, measured by the shearing rate, is too weak to account for flux suppression, suggesting the more powerful energy dissipation by zonal-flow-catalyzed transfer to stable modes.

An additional feature of the turbulence, a low-frequency, long-wavelength, radially localized coherent structure develops that significantly enhances flux levels at low wavenumbers. Following recent work on the contribution of subdominant ion-temperature-gradient modes to stellarator turbulence [Pueschel et al., PRL 2016], analysis of the subdominant TEM spectrum shows that the coherent structure is associated with nonlinearly destabilized ion-propagating modes. At sufficiently high density gradients, these stable ion modes appear to be excited to finite-amplitude fluctuations by zonal-flow-mediated energy transfer from the dominant TEM instability, thus simultaneously aiding in TEM saturation and causing additional heat and particle transport.