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Stable Modes in Saturation of Instability-Driven Plasma Turbulence[1]

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Saturation of instability-driven plasma turbulence, apart from cases with quasilinear flattening, has been treated almost universally as an energy-transfer or wavenumber scattering process, with the Kolmogorov cascade as the idealized paradigm. This view is being modified by the realization that for a broad parameter range wavenumber transfer is subjected to heavy damping at the same scales as the instability through transfer to a separate space of stable modes. The densely populated, nonlinearly driven stable-mode space can be represented by roots of the linear dielectric or empirically extracted modes of a singular value decomposition. This new understanding of instability-driven turbulence brings to light fluctuation characteristics, transport processes, and saturation mechanisms that cannot be anticipated solely from analysis of the linear instability or the related quasilinear transport approximation. This tutorial describes key aspects of the new paradigm, including characterization of stable modes, quantitative measures of the branching ratio between wavenumber transfer and transfer to stable modes, simultaneity of transfer to stable modes as contrasted to wavenumber cascades, equipartition of energy dissipation rate among stable modes, and zonal-flow regulation of ion temperature gradient (ITG) turbulence by catalyzing transfer to stable modes. It is shown that ballooning-parity ITG turbulence creates a stochastic magnetic field by exciting a stable microtearing mode and that zonal-flow catalyzed transfer to stable modes yields a turbulence level proportional to zonal flow damping. In stellarator trapped electron mode turbulence, stable ion modes become energy driving sources via cross correlations between non orthogonal modes. Stable mode effects are shown to arise for a range of fusion plasmas systems and for astrophysically relevant Kelvin-Helmholtz instability.

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