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A non-modal approach to formation of zonal flow patterns in drift wave turbulence

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Drift wave turbulence in magnetized plasmas can develop from various primary instabilities (PIs). The dominant mode structures of PIs are often recognized as radially elongated streamers. The primary modes then become unstable to secondary Kelvin-Helmholtz-like instabilities[1], typically with unstable wavenumber q_x comparable to the primary modes. It is well accepted that the primary-secondary instability paradigm explains the emergence of zonal flows in drift wave turbulence, as demonstrated in numerous numerical simulations. The linear theory of modulational instabilities (MIs) via four-mode truncation approach has been connected to the secondary instability (SI) calculations. However, the route from a linear stability analysis to the nonlinear dynamics of zonal flow pattern formation remains elusive.

In addition to linear eigenmode analysis, the wave interaction theory has been used to interpret mechanism of various instabilities of homogeneous and stratified shear flows. The Kelvin-Helmholtz instability (KHI), in particular, is shown to be induced by phase locking of two neutrally stable vorticity waves[2]. The wave interaction approach allows a non-modal stability analysis, thus capable of describing transient dynamics and spatial structures of instability growth, and can be readily extended to any potential vorticity (PV) conserved systems[3].

In this work, we propose a theory of secondary instabilities via non-modal wave interaction approach. The PV conserved system of primary streamer modes is translated into a spatially coupled system of N vorticity waves. We demonstrate the mechanism of zonal flow pattern formation via phase synchronization and poloidal coupling of primary modes. The role of beta-effect in formation of zonal flows is also discussed.

References
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