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The Maintenance of Coherent Vortices by Lagrangian Chaos in the Dimits Shift Regime of Plasma Edge Turbulence

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Understanding mechanisms for turbulence drive and saturation in the tokamak edge and scrape-off-layer is vital for predictive models of plasma confinement. These regions can experience large-amplitude, intermittent fluctuations that challenge assumptions of quasi-linearity and statistical homogeneity.[1-3]

Motivated by this, we study the Dimits shift regime of the flux-balanced Hasegawa-Wakatani (BHW) equations, which model a transitional regime of resistive drift-wave turbulence in the plasma edge. We show that turbulence in this regime is dominated by strong zonal flows and coherent drift-wave vortices which exhibit a form of "near-integrability" that qualitatively organizes the turbulent flows.

Using an exact stochastic Lagrangian representation of vorticity transport based on the Feynman-Kac formula, we demonstrate how these coherent flows influence ion polarization charge accumulation within the vortices through partial Lagrangian transport barriers linked to near-integrability. Drawing parallels with pattern formation in zonal flows, we argue that the resulting inhomogeneous mixing reinforces, rather than destroys, the large-amplitude vortex structures.

Finally, we discuss possible broader implications of this mechanism, dubbed the "potential vorticity bucket brigade", for structure formation in fluid and plasma systems beyond the studied model.

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References

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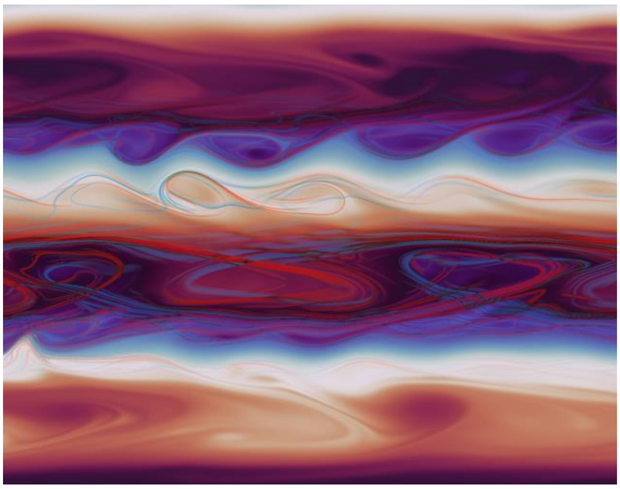

Figure 1: Plot of the potential vorticity field with "stable/unstable manifolds" overplotted in blue/red. These stable/unstable manifolds act as partial Lagrangian transport barriers that enclose the coherent vortex structures. Where the manifolds intersect, they form chaotic-tangle like structures that organize chaotic transport in the turbulent flow field.