Generation of Large-Scale Magnetic Fields by Shear-Flow-Instability-Induced Zonal Flows

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Abstract:
Dynamo action—the generation and sustenance of magnetic fields in magnetofluids and plasmas—is frequently described using turbulent helical fluid motions acting on an imposed mean field. While this fluid-helicity-based mean-field theory reproduces observed large-scale fields, the theory is challenged by first-principles studies; studies of turbulent flows report that the large-scale fields become tangled and are progressively folded and fragmented to small scales by shear flows. Here, considering a mean shear flow that is unstable and driven, we show a dynamo effect arising from mean vorticity [1]; this effect [2] generates—out of no initial mean field—a quasi-time-periodic, spatially reversed mean field (RMF) [1]. The RMF amplitude is controlled by inherently-three-dimensional zonal flows, which are induced by Kelvin–Helmholtz (KH) instability of the mean shear flow. The RMF polarity is regulated by long-time locking and short-time slipping of cross-phase (cross-helicity) between the zonal flows and fields. The zonal flows are coupled nonlinearly to the KH-stable and unstable eigenmodes at large scales [3,4], thus forming a near-resonant wavenumber triad, akin to that of ion-temperature-gradient-driven turbulence [5]. This zonal-flow-driven, cross-helicity dynamo may help explain the 2012 Madison dynamo experiment that measured turbulent electromotive force E to be orthogonal to the mean field B—a result unexplainable by fluid-helicity-driven dynamos, which require E to be parallel to B. Moreover, the dynamo-generated, signed, global mean magnetic flux is predicted and verified by using a reduced model whose only input is turbulence property at the shear-layer.

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