INERTIAL-RANGE DYNAMICS AND SCALING LAWS OF TWO-DIMENSIONAL MAGNETOHYDRODYNAMIC TURBULENCE IN THE STRONG ADVECTION REGIME

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Abstract We study inertial-range dynamics and scaling laws in unforced two-dimensional magnetohydrodynamic turbulence in the regime of small (and moderately small) magnetic-to-kinetic energy ratio r_0. This regime corresponds to strong advection (strong magnetic stretching), whereby the turbulence is characterized by an intense conversion of kinetic to magnetic energy (dynamo action in the three-dimensional context). This "dynamo" is an inertial-range phenomenon and, upon becoming quasi-saturated, deposits the converted energy within the inertial range rather than transferring it to the small scales. As a result, the magnetic energy spectrum $E_b(k)$ in the inertial range can become quite shallow and may not be adequately explained or understood in terms of conventional cascade theories. For fully developed turbulence, it is found by numerical simulations at high Reynolds numbers (and unity magnetic Prandtl number) that $E_b(k)$ scales as $k^{-\alpha}$, where $\alpha \lesssim 1$, including $\alpha < 0$. The extent of such a shallow spectrum is limited, becoming broader as r_0 is decreased. The slope α is found to decrease dramatically with r_0, achieving negative values for significantly small r_0. Meanwhile, the kinetic energy spectrum $E_u(k)$ is observed to scale as $k^{-\beta}$, where $\beta \gtrsim 1$. The total energy spectrum $E(k) = E_b(k) + E_u(k)$ appears to approximate the scaling k^{-1} (with a limited extent). This is reminiscent of the enstrophy spectrum of two-dimensional Navier–Stokes turbulence. We discuss the asymptotic behaviour of these spectra and of the energy dissipation on the basis of the present findings and in conjunction with recent results in the literature.