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Kolmogorov-like turbulence phenomenology in magnetohydrodynamics

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Understanding the scaling and intermittency in magnetohydrodynamic (MHD) turbulence remains a central challenge in plasma physics. Competing theories predict different spectral scalings: the Iroshnikov–Kraichnan (IK) model suggests a $k^{-3/2}$ spectrum, while Kolmogorov-like models by Marsch[1], Goldreich & Sridhar[2], and Verma et al.[3] support a $k^{-5/3}$ scaling. To investigate this, we perform high-resolution direct numerical simulations (DNS) using our GPU-accelerated pseudo-spectral solver, AITHON, achieving resolutions up to 1024^3 in 3D and 8192^2 in 2D. Our results show that the energy spectra of the Elsasser fields (z^+, z^-) follow a Kolmogorov-like scaling, with asymmetry in $E^+(k) \neq E^-(k)$ under unequal energy injection (ϵ^+, ϵ^-), in agreement with Marsch's[1] model.

In addition, the third-order structure functions $S_3^{\pm}(l)$ follows the predictions of Politano and Pouquet[4], which is consistent with Kolmogorov-like phenomenology. In addition, the intermittency exponents too follow scaling based on Kolmogorov theory. These results provide strong evidence for Kolmogorov-like scaling for MHD turbulence.

References:
[1] Marsch, "Turbulence in the solar wind", in *Reviews in Modren Astronomy*, p.145-156 (1991)
[2] Goldreich and Sridhar, The Astrophysical Journal 438, 763-65 (1995)
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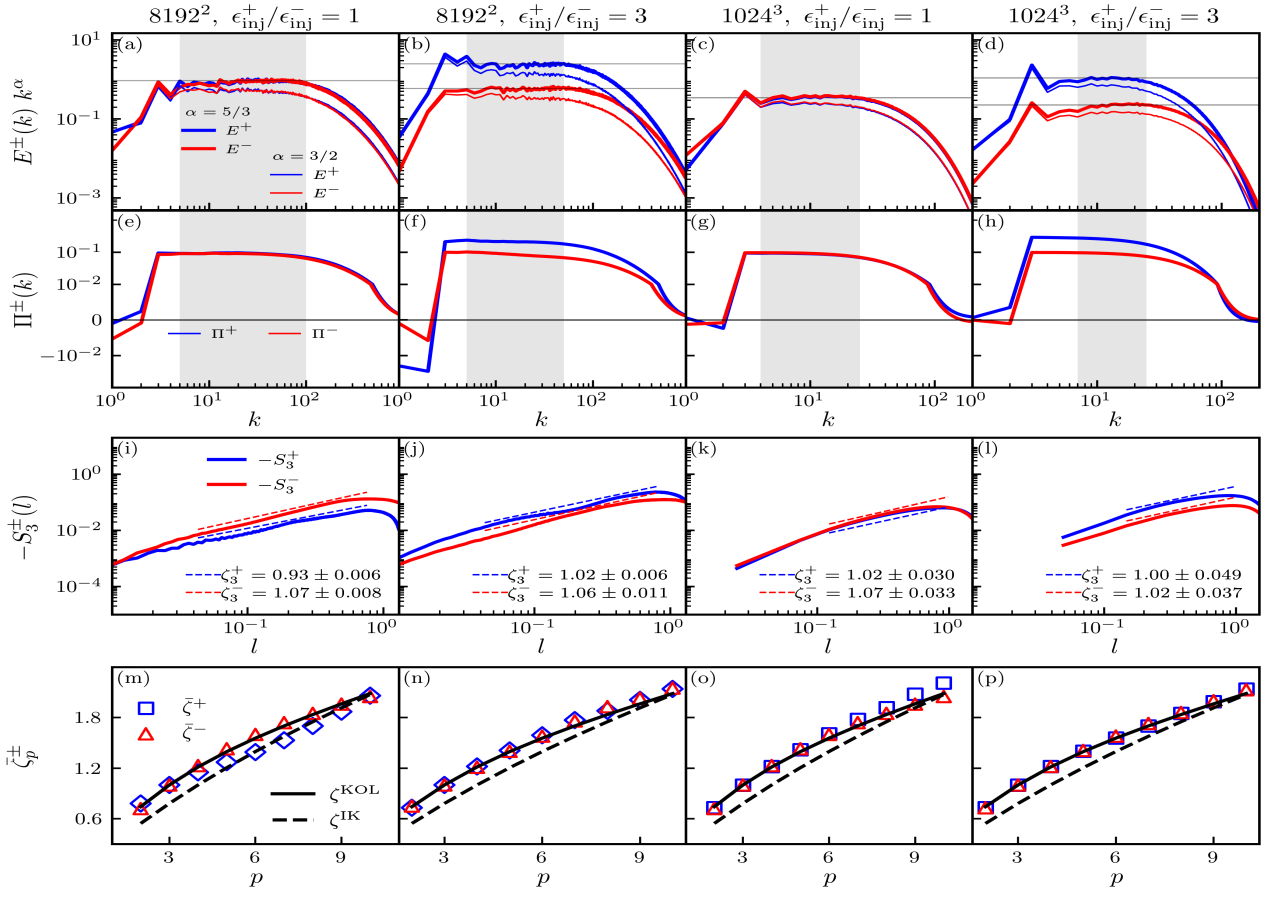

Figure 1. Numerical results of MHD turbulence simulations on 8192^2 and 1024^3 grids for $\epsilon^+_{\rm inj}/\epsilon^-_{\rm inj} = 1$ *and* 3. (a,b,c,d): Plots of the normalized energy spectra $E^{\pm}(k)k^{\alpha}, \alpha = 5/3$ (thick lines) and 3/2 (thin lines). (e,f,g,h): Plots of the energy fluxes $\Pi^{\pm}(k)$ for the above. (i,j,k,l): Plots of the structure function $-S_3^{\pm}(l)$ vs l. (m,n,o,p): Plots of the intermittency exponents $\zeta_p^{\pm}$, which are closer to She-Leveque extension based on Kolmogorov theory (solid lines). In all curves **blue** and **red** colors denotes z^+ and z^- fields respectively.