Moderate Magnetohydrodynamic Turbulence

Nonlinear Interactions in Incompressible Moderate Plasma Turbulence with Mean Magnetic Field

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In Short

- Numerical investigation of the moderately nonlinear regime of incompressible (deeply subsonic) turbulence in electrically conducting fluids (solar wind, stellar interiors, interstellar medium)
- Physical model: single fluid incompressible magnetohydrodynamics (MHD) subject to a mean magnetic field.
- Exploration of the complex nonlocal influence of the largest spatial scales of MHD turbulence on its smaller-scale fluctuations and their nonlinear dynamics in the inertial scaling range.

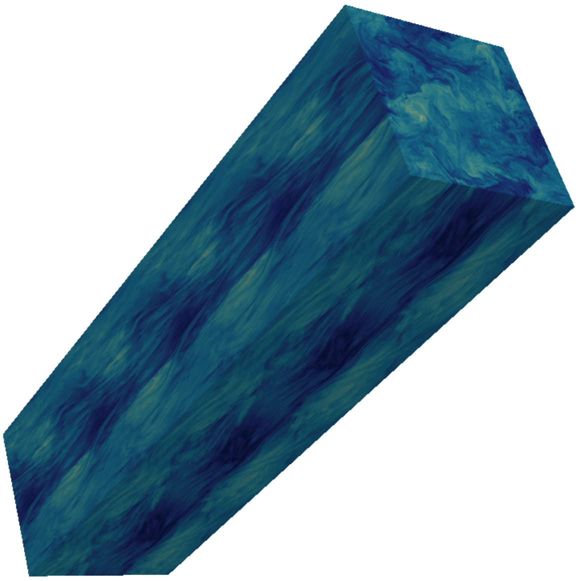

Figure 1: *Amplitude of magnetic field fluctuations in three-dimensional MHD turbulence subject to a strong mean magnetic field directed perpendicularly to the quadratic side of the volume.*

Turbulent flows of electrically conducting media, e.g. ionized gases or plasmas, are of fundamental importance for many systems throughout the universe. Turbulent plasmas interact with magnetic fields which can be of external origin or are self-induced by plasma currents via the turbulent dynamo effect. The nonlinear interaction of magnetic fields with the turbulent plasma flow results in complex structure-formation processes and energetic dynamics involving instabilities and waves. The large scope of plasma turbulence motivates theoretical and numerical investigations of this complex and difficult nonlinear phenomenon. In astrophysics understanding of the dynamics of the solar wind depends on insight gained from turbulence theory. Turbulence theory is also a key ingredient in the explanation of the accretion of matter onto a central gravitating object, the formation of stars in the interstellar medium, the generation of the magnetic fields of stars and planets, and the propagation of cosmic rays.

The nonlinearity of the underlying partial differential equations, renders magneto-hydrodynamic (MHD) turbulence a complex and mathematically difficult problem. The MHD approximation is a simplified one-fluid model of the dynamics of electrically conducting continua. A comprehensive MHD turbulence theory has not yet been formulated although much progress has been made recently. Insights gained from direct numerical simulations are essential to drive progress toward a better theoretical understanding of MHD turbulence.

This project investigates homogeneous incompressible (the limit of deeply subsonic) MHD turbulence subject to a homogeneous and constant mean magnetic field $\mathbf{B}_0$ using pseudospectral direct-numerical simulations at high-resolution. Simulations will have up to 1024^3 collocation points, producing MHD flows with Reynolds numbers $\gtrsim \mathcal{O}(10^3)$.

In systems which, like MHD turbulence, support strong nonlinear fluid interactions perpendicular to $\mathbf{B}_0$ as well as weakly nonlinear wave-wave dynamics along the mean field, the interplay of both processes allows to observe different dynamical regimes of MHD turbulence: strong and weak turbulence, governed by a respective strength of nonlinear interactions in the flow. A third regime, tentatively termed *moderate* turbulence has been found previously and various characteristics regarding similarity scaling, two-point statistics and nonlinear energy fluxes have been investigated in some detail by this group of researchers [1],[2],[3],[4]. Dynamically significant mean magnetic fields are common in astrophysical turbulence, e.g. in stellar winds, and, consequently, plasma turbulence with various levels of nonlinear strength is expected in nature. Thus, this project is relevant for astrophysics as well as for fundamental turbulence theory in systems which also support weakly nonlinear wave dynamics such as rotating turbulence or compressible turbulence.

Motivated by the experience and the previous work of the researchers involved here, this project focuses on the conditions required for the emergence of mod-

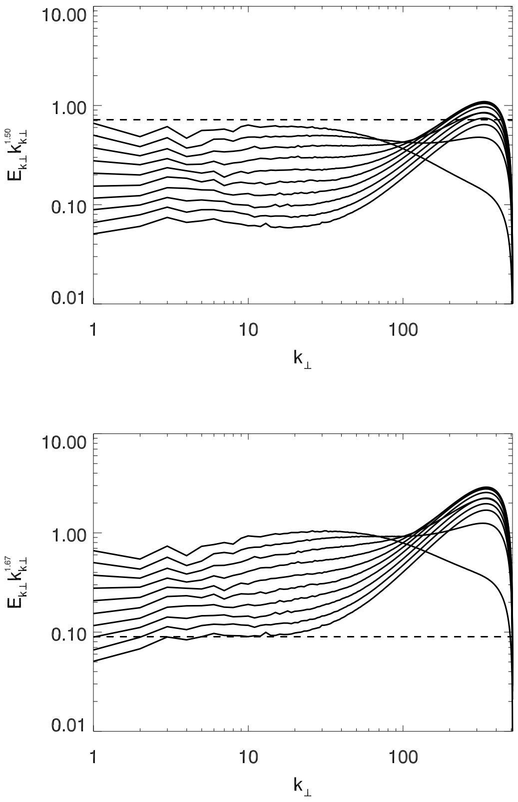

Figure 2: *Perpendicular total energy spectra in non-dissipative initially turbulent flow consecutively averaged over one large-eddy turnover time each and displaced along the vertical for better readability (time advances downwards). Compensation factor is* $k_\perp^{3/2}$ *(top),* $k_\perp^{5/3}$ *(bottom).*

erate turbulence. Direct numerical simulations of moderate turbulence in a periodic box threaded by a mean magnetic field (see Figure 1) serve as the main numerical tool for these investigations. To better understand the nonlinear dynamics of the flow, members of this group have conducted a suite of direct numerical simulations to characterize the statistical inertial-range properties of the regime of moderate MHD turbulence, in particular with regard to similarity scaling, two-point statistics and energy fluxes. In the course of these investigations it became clear that the largest spatial scales of the turbulent MHD flow whose evolution is governed by a process driving the turbulence play a key role for the existence of moderate MHD turbulence. After switching off this process the turbulent energy spectrum (taken perperndicular to $\mathbf{B}_0$) change its inertial-range scaling law from the signature of moderate turbulence, $k_\perp^{-3/2}$, to a Kolmogorov-like $k_\perp^{-5/3}$-scaling, a hallmark of strong turbulence (see figure 2). Identifying the yet unknown properties of the largest scales of MHD turbulence and the associated driving process that control this transition is the aim of the current project. These investigations allow turbulence theory to get a hold on the deterministic, multi-fractal chaos which underpins this system. The emergence of the necessary clear statistical signatures in turbulence simulations demands a broad dynamical range of spatial fluctuations. This translates into the requirement of high Reynolds numbers which necessitate large-scale direct numerical simulations based on commensurate computational resources.

WWW

http://www-astro.physik.tu-berlin.de/de/node/340

More Information

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Project Partners

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