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# Structures and statistics of Hall MHD turbulence

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Hall MHD model is a variation of MHD model extended to a microscopic scale (ion-skin-depth) of plasma motions. Hall MHD turbulence is extensively studied in contexts of solar wind observations as well as in the context of more fundamental framework of turbulence studies. We study spatial structures and statistics of Hall MHD turbulence by means of direct numerical simulations (DNS). The Hall term induces a transition of spatial structures from a vortex sheet to a vortex tube. We present detailed analysis of spatial structures and statistical quantities on intermittency in a large-scale Hall MHD simulation and highlight the Hall effects.

A typical influence of the Hall term can appear in a scale smaller than the ion skin depth $d_i$. We carry out DNS for some values of $d_i = 1/k_i$ where the symbol $k_i$ is the wave-number of the ion skin depth. This means the scale $k > k_i$ can be influenced by the Hall term strongly.

In Fig.1, the magnetic energy spectrum $E_M(k)$ and the kinetic energy spectrum $E_K(k)$ obtained by DNS of decaying homogeneous and isotropic turbulence with the number of grid points $N^3 = 1024^3$ for $d_i = 0.05$ and 0.0125 are shown. The wave-number k is normalized by $d_i$ so that the normalized wave-number becomes unity for the ion- skin-depth. The energy level of the two runs are scaled so that the two energy spectra becomes in the same level at $d_i k_i = 1$. A DNS of $d_i = 0.0125$ has a wide range of the wave number for $d_i k_i < 1$ (MHD scale), another DNS of $d_i = 0.05$ has a wide range for $d_i k_i > 1$ (sub-ion scale).

In Fig.1, $E_M(k)$ appears being scaled by $k^{-5/3}$ in the MHD scale, while the spectrum appears being scaled by $k^{-7/3}$ in the MHD scale. While this behavior is consistent with the earlier results (see [1-4] and references therein), we can show that another type of scaling, $E_M(k) \sim k^{-7/3}$ in a DNS of decaying turbulence which starts from a different initial condition [5]. The appearance of the new scaling is attributed to a preference of the initial condition to the chiral symmetry as has been studied in Refs.[6][7].

An aspect of the Hall effects can appear not only in the energy spectrum but also in local, coherent structures. As we have already reported in Refs.[1][4], the introduction of the Hall term can induce a transition of a vortex sheet to a vortex tube. In Fig.2, isosurfaces of the enstrophy density (the vorticity squared). While a vortex tube can be produce in single-fluid MHD turbulence too[8], the Hall term is considered to enhance magnetic reconnection and enhance structure transitions. The sheet/tube structure transition can change a qualitative change in turbulence statistics such as the phase-diagram (Q-R) plot of the magnetic field, structure functions of the magnetic and velocity fields, and others. We will present recent study of such statistical analysis.

References

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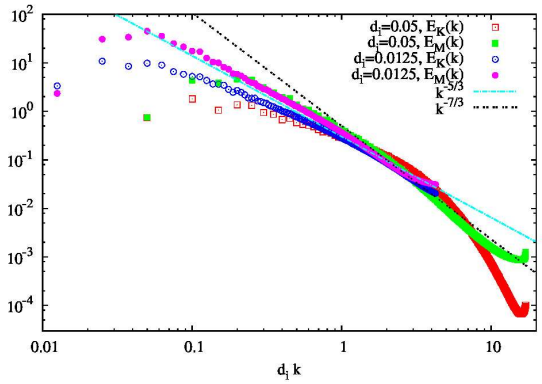


Figure 1: Magnetic energy spectrum and kinetic energy spectrum in decaying homogeneous and isotropic turbulence for $d_i = 0.05$ and 0.0125 ion skin depth.

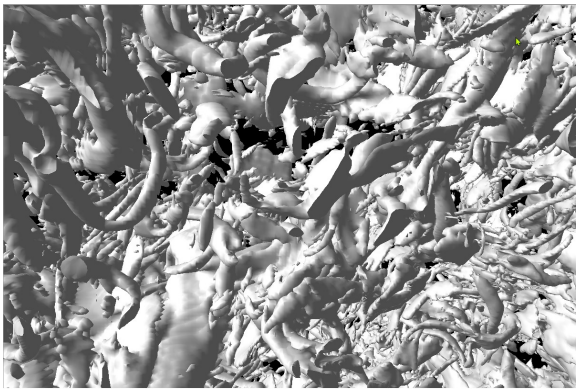

Figure 2: Isosurfaces of the enstrophy density (vorticity squared). Sheet-like and tubular structures can be observed in this figure.