7th Asia-Pacific Conference on Plasma Physics, 12-17 Nov, 2023 at Port Messe Nagoya

Statistical and structural properties of Hall MHD turbulence

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Hall magnetohydrodynamics (MHD) model is one of extended MHD models which incorporate effects of the ion skin-depth (or ion inertia scale) to the resistive MHD model. The Hall MHD model has three important parameters: ion skin-depth d_i, viscosity ν, and the current resistivity η. An important nature of the Hall MHD model is that the ion skin-depth (the Hall) effects divide the spatial scale into the macroscopy range (MHD scale) where the ion skin-depth effects are assumed being not very important, and a high wavenumber region (subionic scale) where the Hall effects are pronounced. Hall MHD turbulence is extensively studied in contexts of solar wind studies as well as in the context of more fundamental framework of turbulence studies.

We study homogeneous and isotropic Hall MHD turbulence by means of numerical simulations [1-7]. A typical influence of the Hall term can appear in a scale smaller than the ion skin depth d_i. We carry out simulations for some values of $d_i = 1/k_i$ where the symbol k_i is the wave- number of the ion skin depth. The numerical results are analyzed in views of the formation of energy flow in the wave-number space [1,2,6] as well as of coherent structures and their contributions statistical quantities [3-5,7]. More specifically, we are interested in the scale-to-scale interactions in the magnetic and velocity fields. To study the scale-to- scale interaction, we carry out numerical simulations of the magnetic Prandtl number $Pr_M = \nu/\eta$ unity as well as a high Pr_M and compare differences between them.

In Fig.1, structure function of the velocity field in Hall MHD turbulence with Pr_M=100 [7],

$$\begin{aligned} S_p(l) &= \langle \delta u_{\|}(l)^p \rangle \\ &= \langle |u_i(\mathbf{x}+l\mathbf{e}_i) - u_i(\mathbf{x})|^p \rangle \\ &\propto l^{\zeta_p} \end{aligned}$$

where u_i is the i-th component of the velocity field. The structure functions represent two-scaling regimes, characterizing its intermittent spatial structure. Structure functions, especially of the 3rd-order, are closely related with the von Karman-Howarth equation for homogeneous and isotropic turbulence in hydrodynamic turbulence, and with that for MHD and Hall MHD turbulence as well. We will present analysis of our numerical data (both Pr_M=1 and Pr_M=100) in the context of turbulence theory related with the vKH equation.

The intermittency nature of turbulence is considered to originate from localized spatial structures of both the magnetic and velocity fields. Spatial structures are compared among simulations of various Pr_M and ion skin depth d_i.

Spatial structure and intermittency in our numerical simulations are discussed in the context of studies of solar wind turbulence and other kind of turbulence.

References

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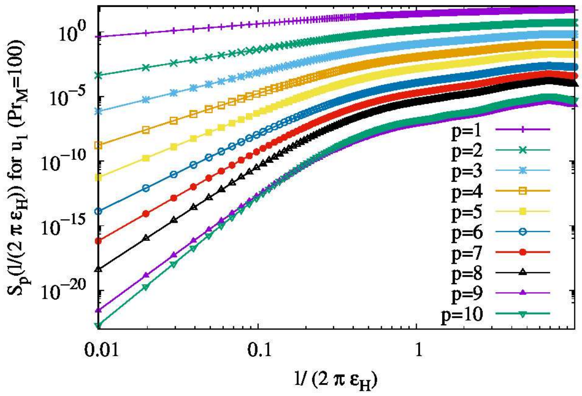

Figure 1: Structure function $S_p(l)$ of the velocity field in Hall MHD turbulence with Pr_M=100.

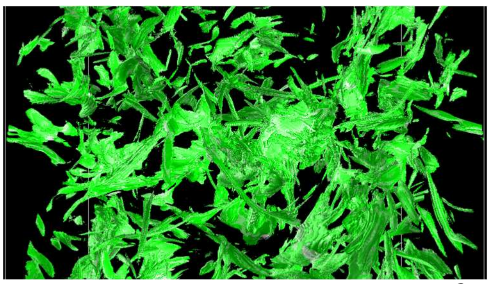

Figure 2: Isosurface of the enstrophy density $\omega_i^2/2$ in the Hall MHD simulation with Pr_M=1.