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Characterization of Hall MHD turbulence as wave turbulence

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Hall magnetohydrodynamic (MHD) turbulence provides a simple model to study plasma turbulence such as solar wind turbulence, interstellar medium, and others. Hall effects significantly modify turbulence characteristics, most notably the magnetic energy spectrum. Scaling laws such as $k^{-7/3}$ and $k^{-17/3}$ (k is the wave number) emerge in the sub-ion-scale range, which is typically associated with whistler and ion-cyclotron modes.

In this study, the influence of the Hall term on various characteristics of turbulence in the sub-ion scale regime is investigated through numerical simulations of homogeneous turbulence under a constant and finite background magnetic field, and those of homogeneous and isotropic turbulence. While the former is closely related to real phenomena, the latter is equipped with advantages of theoretical analysis. The introduction of the Hall term enhances wave-turbulence nature[1-5], while turbulence in the MHD scale can be either eddy- or wave-turbulence depending on the problem setting.

In Fig.1, isosurfaces of (a) enstrophy density and (b) current density in a freely decaying homogeneous and isotropic turbulence simulation are presented. On one hand, due to the separation of the velocity and magnetic fields at the sub-ion-scale, a vortex sheet often rolls into an array of thin vortices and forms vortex tubes as we can see its early stage in the lower-left corner of Fig.1(a).

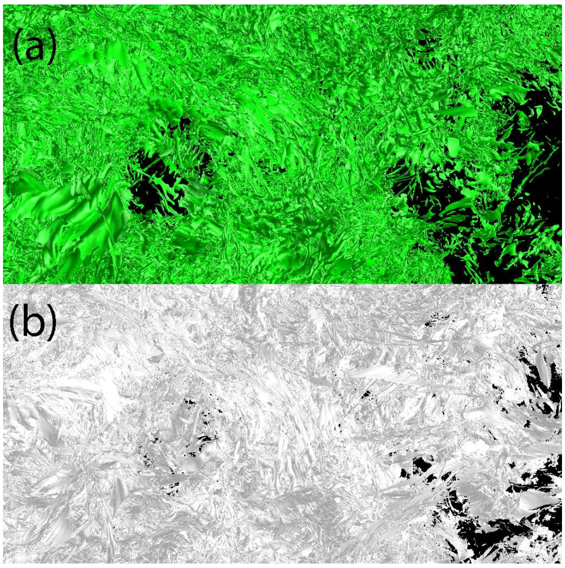

Fig.1: Isosurfaces of (a) enstrophy density and (b) current density in a homogeneous and isotropic turbulence simulation.

This observation suggests the dominance of vortex motion in the time evolution, at least in the area of the vortex roll-up.

On the other hand, in Fig.1(b), we observe many thin filaments of the current density. The thin filaments are basically aligned with a large-scale magnetic field vector (magnetic field lines are omitted from the figure). The sub-ion-scale properties can exhibit various scaling laws such as $k^{-7/3}$ or $k^{-17/3}$, depending on the range of the sub-ion-scale and/or the magnetic Prandtl number Pr_M, which is the ratio of the viscosity to the resistivity. This suggests that the magnetic field at the sub-ion-scale is fully characterized by wave-turbulence, which stands in contrast to the Kolmogorov-like eddy turbulence observed in the velocity field.

We characterize turbulence through statistical analysis of both the velocity and magnetic fields and try to develop phenomenology which is consistent with their respective behaviors. The analysis of homogeneous and isotropic turbulence is extended to cases with the background magnetic field.

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