# §14. DNS/LES of Magnetized Plasmas by an Extended MHD Model

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Large-scale Direct Numerical Simulations (DNSes) of Hall magnetohydrodynamic (MHD) simulations have been carried out in order to study effects of the Hall term on short-wave components. For the sake of developing a Sub-Grid-Scale (SGS) model of nonlinear terms in the Hall MHD equations, we need to know how the nonlinear terms are related with the short-wave components of the magnetic fields and the velocity fields. DNSes of Hall MHD turbulence have been carried out by our Fourier pseudo-spectral code with the number of grid points $1024^3$, for both freely decaying isotropic turbulence and forced magnetized homogeneous turbulence. DNSes of MHD turbulence (without the Hall term) have been also carried out in order to compare the results with Hall MHD DNSes.

In Fig.1, isosurfaces of the enstrophy density (half of square of the vorticity) and the current density in (a) homogeneous Hall MHD turbulence and (b) homogeneous MHD are shown. Because of a uniform and constant magnetic field $B_0$=5 imposed in simulations, both the enstrophy density and the current density are smooth in the direction of the magnetic field (perpendicular to the paper) both in Fig.1 (a) and (b). A crucial difference between Fig.1 (a) and (b) is that isosurface of the enstrophy density in Fig.1 (a) are tubular (vortex tubes) while those in Fig.1 (b) are sheets (vortex sheets). The former represents that fluid motions are governed by swirling motions of vortices, while the latter represents that the shearing motions dominate fluid motions. In Fig. 1(c), one-dimensional magnetic energy spectra $E_{M,ij}$ are shown where the first and the second index represents the vector components and the direction of Fourier transform, respectively. (The uniform magnetic field is in the third direction.) It is clearly observed that the magnetic energy spectrum is proportional to $k^{-7/3}$ .

Further analysis of two turbulent fields by the use of a low-pass filter shows difference in the hierarchy of the spatial structure of the enstrophy field. In case of Hall MHD turbulence, vortex tubes can appear in different places depending on the cut-off wave number of the low-pass filter. On the other hand, in case of MHD turbulence, the vortex sheets appear almost in the same place independent to the cut-off filter. These observations indicate that the plasma motions in MHD turbulence can be changed significantly by the introduction of the Hall term, even though the Hall term does not influence the velocity field but the magnetic field. Thus, alhough both Hall MHD and MHD turbulence show a power-law in their energy spectra and thus we can expect a kind of scale-hierarchy there, the nature of the scale-hierarchy should be quite difference between them. Further turbulent structures are going to be studied in order to provide basic knowledge to develop a SGS model of nonlinear terms in Hall MHD equations so that we can carry out Large Eddy Simulations (LESes) of magnetized plasmas.

More detailed results including our first LESes and SGS models are reported in Journal of Computational Physics[1)].

1) H. Miura, K.Araki, and F. Hamba: J.Comput.Phys. **316**, 385--395 (2016).

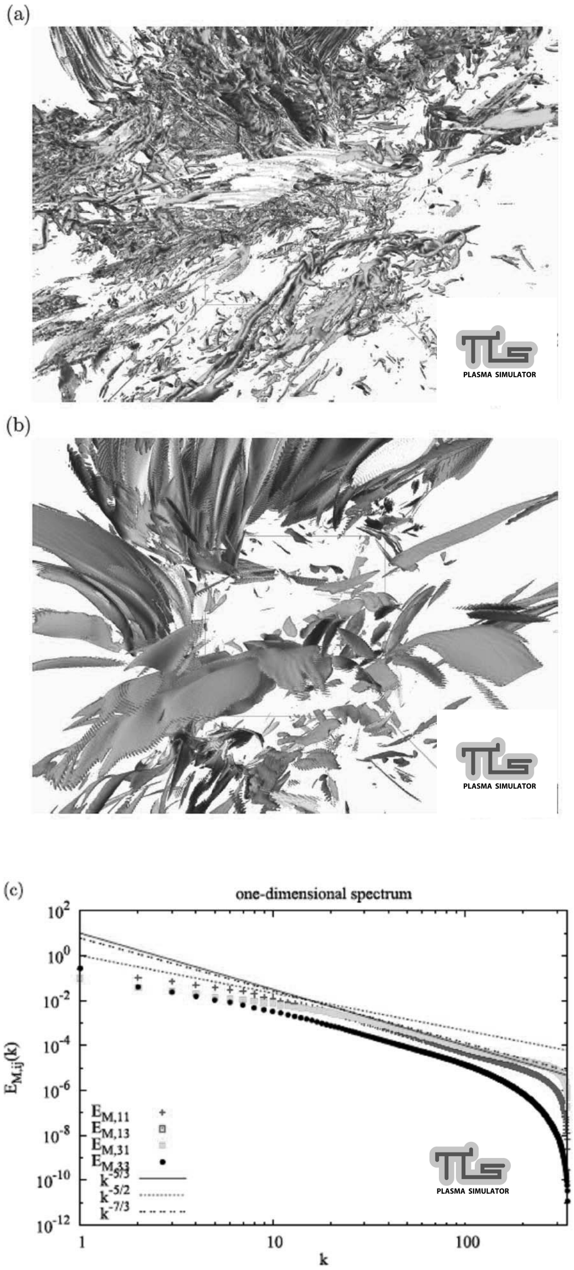


Fig. 1. Isosurfaces of the enstrophy density (half of square of the vorticity) and the current density in (a) homogeneous Hall MHD turbulence and (b) homomgeneous MHD. (c) One-dimensional energy spectrum $E_{M,ij}$ where the first and the second index represents the vector component and the direction of Fourier transfrom, respectively.