Two channels of energy transfer due to the Hall term in turbulent dynamos

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Hall magnetohydrodynamics (HMHD) is a single-fluid model of plasma that allows a finite difference between the electron and the ion velocities. Despite remaining a mono-fluid model, HMHD and the corresponding turbulence has been employed to study sub-ion scale dynamics of space and astrophysical plasmas. The Hall effect is introduced in the induction equation by adding a nonlinear term $-d_i \boldsymbol{\nabla} \times (\boldsymbol{j} \times \boldsymbol{b})$, where d_i is the ion inertial scale, $\boldsymbol{b}$ is the magnetic field (normalized to a velocity) and $\boldsymbol{j} = \boldsymbol{\nabla} \times \boldsymbol{b}$.

HMHD is found to have interesting consequences in turbulent dynamo mechanism which is essential to explain the development and energization of long-lasting magnetic fields in several astrophysical bodies. The role of Hall current in turbulent dynamos has been studied both analytically and numerically [1,2]. Numerically, it has been observed that Hall effect introduces a novel backscatter of magnetic energy leading to the enhancement of dynamo effect. However, the Hall contribution was calculated from the entire $-d_i \boldsymbol{\nabla} \times (\boldsymbol{j} \times \boldsymbol{b})$ term and the corresponding transfers was simply interpreted as a transfer between $\boldsymbol{b}$-fields. Inspired by the recent works in ordinary MHD[3], here we decompose the Hall term into two parts $-d_i\,(\boldsymbol{b} \cdot \boldsymbol{\nabla})\,\boldsymbol{j}$ and $d_i\,(\boldsymbol{j} \cdot \boldsymbol{\nabla})\,\boldsymbol{b}$ and investigate the contribution of the individual terms by means of a direct numerical simulation with 256^3 grid points. Moreover, the net transfer rate to the large-scale magnetic fields has been calculated using expressions for scale-separated flux rates[4]. Fig. 1 shows all scale-separated fluxes involved in the dynamo action, where $\Pi^{y>}_{x<}(k_0)$ is the net transfer rate of magnetic energy from all modes of y-field outside a sphere of radius k_0 to all modes of x-field inside.

Near the Hall-scale (HS), it is found that the small-scale magnetic as well as current fields are the primary contributors for the energization of large-scale magnetic fields (Fig. 1a and 1b) whereas the large-scale current fields tend to remove energy from the large-scale magnetic fields instead of energizing them (Fig. 1c). The sum of all these scale-separated transfer rates finally gives the net contribution of the Hall effect (Fig. 1d). Finally, our study also shows that the global nature of the dynamo action is also unaffected as one varies the HS.

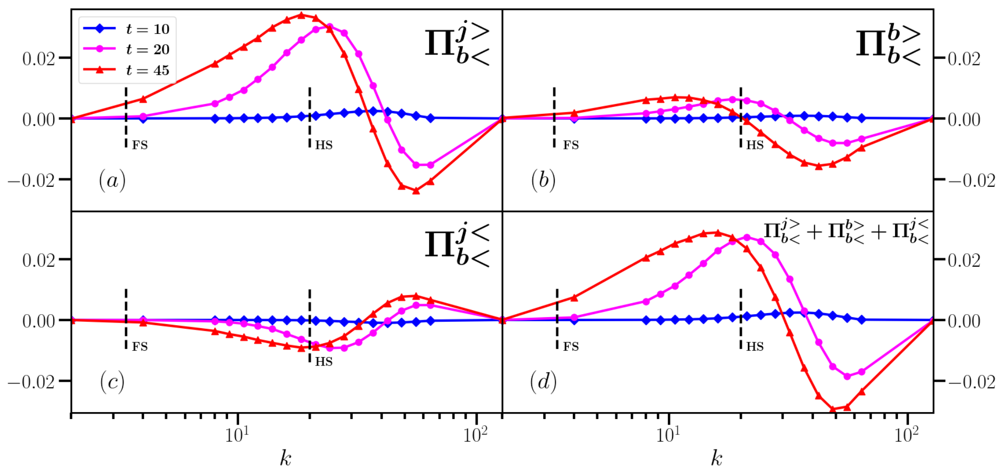

Figure 1: Various scale-separated fluxes involved in dynamo action. FS = Forcing scale, HS = Hall-scale.

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