On the diffusion-free regime in turbulent rapidly rotating convection and magnetoconvection

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How the heat transport scales with the control parameters in different systems is an outstanding problem in turbulent convection. In real geo- and astrophysical flows, convection is associated with rotation and magnetic field, in combination with extremely small viscosity and thermal diffusivity, suggesting the existence of a diffusion-free heat transfer scaling in both systems, where the heat flux is independent of viscosity and thermal diffusivity, resulting in the Nusselt vs Rayleigh and Ekman number scaling $Nu \propto Ra^{3/2}Ek^2$ in rotating convection, and the Nusselt vs Rayleigh and Chandrasekhar number scaling $Nu \propto RaQ$ in magnetoconvection. This diffusion-free heat transfer is usually associated with the ultimate regime of turbulence. In contrast to this view, here, by performing extensive direct numerical simulations with stress-free boundary conditions, we show that even though the heat transfer scaling behaves as in the ultimate turbulence, there is possibility that the kinetic energy dissipation rate can still deviate from Kolmogorov's energy cascade picture, indicating the system is not fully turbulent yet. We propose that a Reynolds number scaling and a convective length scaling have also both to be satisfied and the diffusion-free heat transfer scaling alone is not sufficient for demonstrating the ultimate turbulence.

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