Critical transitions in anisotropic turbulence

Abstract:

Turbulence may be defined as a chaotic, highly non-equilibrium state which occurs in many nonlinear physical systems, including nonlinear waves, plasmas and others in addition to the well-known example of fluid flow. Turbulent fluid flows are strongly affected by anisotropy. In astrophysical and geophysical settings, anisotropy can arise from rotation, gravity and density stratification, as well as anisotropic geometry, such as flow in thin layers. In isotropic three-dimensional (3-D) turbulence, energy injected at large scales is transferred to small scales by nonlinear interactions (*direct cascade*), where it is dissipated by viscosity. Due to additional inviscid invariants in two dimensions, isotropic two-dimensional (2-D) turbulence is constrained to cascade energy to scales larger than the forcing (*inverse cascade*). In a finite system, an inverse cascade saturates at the largest available scale where energy builds up to form a *turbulent condensate* after long times. As increasing anisotropy is introduced, one observes a *dimensional transition* from a purely direct cascade in the 3-D case towards an inverse cascade with an associated quasi-2D flow, typically at a threshold value of the anisotropy parameter (e.g. rotation rate, background stratification or domain anisotropy). These transitions are examples of non-equilibrium phase transitions, since the turbulent phases on either side of the transition are out of equilibrium, with non-vanishing energy fluxes through the system.

Since theoretical tools for analysing these transitions from first principles are not yet available, progress has relied on extensive and systematic numerical solutions of the Navier-Stokes equations, as well as modelling. In this talk, I will give examples of different possible scenarios for dimensional transitions in turbulence. I will specifically review recent results (including from my Master thesis work) on the properties of such dimensional transitions in rotating and stratified fluid turbulence, with particular emphasis on thin-layer turbulent condensates. The current knowledge about the phase diagram of rotating stratified turbulence will be briefly summarised and remaining open questions will be discussed.