Abstract

We study the properties of turbulence and nonequilibrium transitions in classical and quantum fluids. When driven out of equilibrium into a turbulent state, these flows organize in dimension-dependent ways and exhibit markedly different cascade behavior. We change the effective dimensionality by applying either rotation or stratification, and by varying the aspect ratio of the flow domain. The change in effective dimensionality often leads to a transition from one nonequilibrium state to another with distinct characteristics and serves as an interesting example of nonequilibrium transitions or bifurcations over a turbulent background. The background flow can exhibit not only strong vortical turbulence but also wave turbulence, the latter arising from the complex, nonlinear interactions among waves. We study the transition from strictly two-dimensional to quasi-two-dimensional rotating turbulence under confinement. By systematically varying the domain aspect ratio, Reynolds number, and large-scale friction, we identify two dominant destabilization mechanisms: parametric-type instabilities and centrifugal instabilities. The nonlinear saturation of three-dimensional perturbations is associated with a critical transition between these two states. We then explore the effect of stable stratification on a horizontally sheared flow driven by a two-dimensional Kolmogorov forcing. As the Froude number increases, the flow transitions from a regime dominated by buoyancy forces (strongly stratified flow), to an instability-prone regime characterized by Kelvin–Helmholtz instabilities, which is associated with an enhanced mixing and strongly stratified turbulence, and finally to a nearly isotropic regime. We also examine the role of vertically sheared horizontal flows in determining the characteristics of these regimes. Extending our studies of classical fluids, we study the influence of geometric confinement on the nonequilibrium dynamics of rotating Bose–Einstein condensates in a box trap. A reduction in the box-trap aspect ratio causes quasi-two-dimensional behaviour to emerge at moderate rotation rates, in contrast to what is observed in a cubic domain. Furthermore, analysis of the incompressible-kinetic-energy time series and spectra indicates an enhanced inverse-energy cascade at large scales. Finally, we study the nonequilibrium condensation dynamics of a two-dimensional, spin–orbit-coupled, two-component Bose gas. We find that condensation occurs at a finite-momentum state; spin–orbit coupling promotes phase separation (immiscibility) and can lead to the emergence of a striped pattern.

Keywords: Turbulence, Non-equilibrium transitions, Rotating turbulence, Stratified turbulence, Bose-Einstein condensates, Quantum turbulence, Rotating Quantum turbulence.