Multiscale Coherent States in canonical shear flows and Rayleigh-Bénard convection

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Fluid flows are typically observed in one of two states: `laminar' or `turbulent'. The ubiquitous turbulent flows are characterized by stochastic evolution on a multitude of spatial and temporal scales and turbulence folklore tells of a cascade of energy from large to homogeneous isotropic small scales. But turbulent flows are also characterized by increased transport of momentum and heat, for instance, and the emergence of coherent structures such as streaks and quasi-streamwise vortices in shear flows, and plumes in convection. Observations of such recurrent coherent structures have inspired a search for `exact coherent structures' that consist of equilibrium, traveling waves and periodic solutions of the Navier-Stokes equations. Many such solutions have been found in the last 20 years. The solutions are typically nonlinear, multi-scale and dynamically unstable, yet they capture the main structural and statistical characteristics of canonical turbulent flows. Since all those `exact coherent states' have been discovered through numerical computations, a challenge for nonlinear analysis is to prove existence of such solutions and derive their asymptotic characteristics.