Exact coherent superstructures in turbulent pipe flow

The extreme velocity fluctuations of turbulent flows play an important role in many industrial processes, and drive natural phenomena at planetary scale and beyond. These fluctuations are very difficult to model and predict because turbulence is highly chaotic in space and time. Consequently, turbulent flows are typically studied as a stochastic process and much progress has been done by assuming that flows are isotropic and homogeneous at sufficiently small scales. However, these assumptions do not apply to motions at large and very large scales because these are highly influenced by boundary conditions, geometry and driving mechanism. Such large-scale motions or superstructures are often coherent and typically carry a large part of the kinetic energy of the flow. Hence progress in predicting and modeling practical turbulent flows must build upon a good understanding of superstructures. In this proposal we will pursue this goal by focusing on turbulent flow through a circular pipe. Pipe flow gives a reasonable compromise between practical relevance and simple geometry, and features complex superstructures whose origins are still poorly understood. The figure below shows a snapshot of a superstructure at Reynolds number 15,000 displaying a superstructure in a 12,5 radii long pipe. The streamwise velocity fluctuation is plotted.

Our approach will be based on dynamical-systems theory and builds upon exact coherent solutions of the governing equations (for example time-periodic solutions in an appropriate reference frame). In recent years these solutions have been shown to organize the dynamics of turbulence transition in wall-bounded shear flows. Our hypothesis is that exact coherent structures form the skeleton of large- and very large-scale motions. We will test this hypothesis by using Direct numerical simulations (DNS) and Large eddy simulations (LES) up to Reynolds numbers of around 100,000. We will assess and quantify the transport properties of our exact coherent solutions using Lagrangian-Coherent-Structure methods developed by colleagues from Applied Mathematics. We expect that our results will elucidate the origin of superstructures in pipe flow and set the stage for reduced modeling approaches of superstructures in pipes and other wall-bounded shear flows.