Experimental Analysis of Turbulent Superstructures in Thermal Convection by Time-Resolved Lagrangian Particle Tracking up to Very High Rayleigh Numbers

We plan to adapt, combine and apply several innovative measurement techniques to capture turbulent superstructures, i.e. coherent structures in the velocity or temperature fields spanning several times of the characteristic length, in Rayleigh-Bénard convection (RBC) across the transition from the classical turbulent to the ultimate state. The generated data shall allow performing Lagrangian and Eulerian analysis of the observed large- and small-scale turbulent structures and help to significantly improve the understanding of the interactions between turbulent superstructures, large scale circulations, thermal plumes and turbulent background fluctuations by allowing directly observing and analyzing their dynamics interplay.

Herewith, the “Shake-The-Box” (STB) Lagrangian Particle Tracking (LPT) method for densely seeded flows, long-lived soap bubbles with dimensions of a few hundred microns and high power LED illumination will be employed to capture spatially and temporally resolved flow data in samples with variable aspect ratios. The data assimilation tool “FlowFit” will be used in order to maximize the spatial resolution and to calculate derived quantities. In addition, we will utilize Temperature Sensitive Paints to visualize the thermal fingerprints of the turbulent superstructures on the internal surfaces. A feasibility study involving temperature-sensitive tracer particles shall enable simultaneous measurements of velocity and temperature fields in LPT / STB of RBC.

Two different samples will be developed and set-up in the course of this proposal. The lower Ra ($< 2\cdot10^8$), will be provided by a convection cell with a quadratic cross section and a variable aspect ratio in the range of 4-10, which will be operated with water as working fluid (“QMC” - Quadratic horizontal section, Moderate Ra Cell). Larger Ra will be made accessible by a cuboidal convection cell with a longitudinal aspect ratio variable between 5 and 10 (“RHC” – Rectangular horizontal section, High Ra Cell), which is currently being developed at the Max-Planck Institute for Dynamics and Self-Organization in Göttingen (MPI-DS). The RHC will be operated inside the ‘U-Boot’ of Göttingen (at MPI-DS), employing pressurized SF_6 as working fluid, which allows to reach Rayleigh numbers up to $5\cdot10^{13}$.

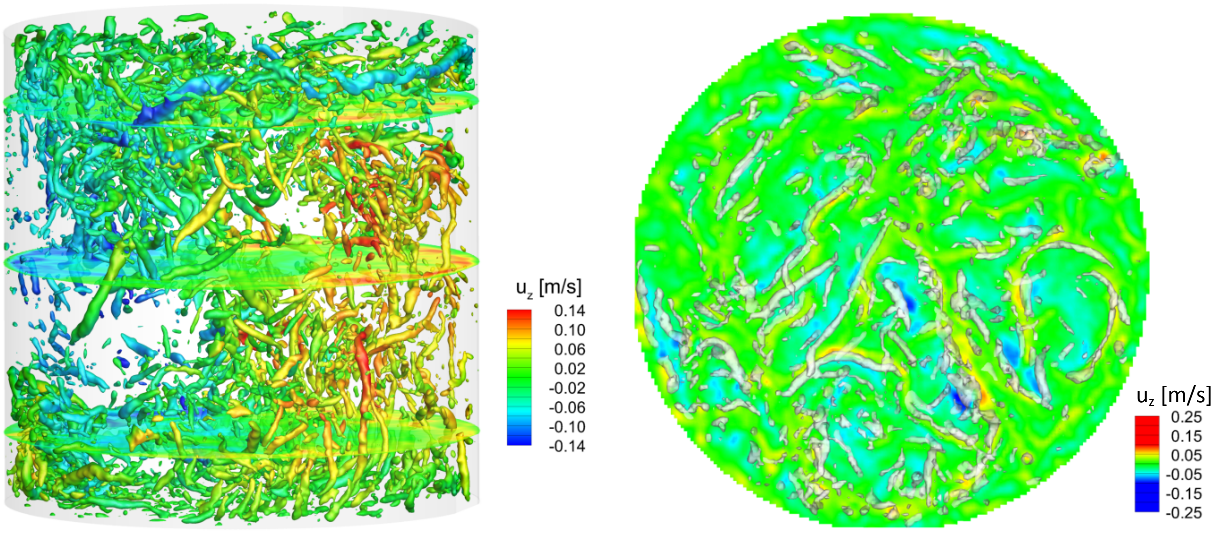

Figure 1: Turbulent flow structures in instantaneous flow fields of RBC at aspect ratio one from the first period of the SPP 1881, measured with STB / FlowFit and visualized by iso-surfaces of the Q-criterion. Left: global flow field, LSC and turbulent flow structures ($Ra = 5.4\cdot10^8$, $Q_{iso} = 5 / s^2$). Right: fingerprints of thermal plumes and turbulent structures at the edge of the thermal boundary layer ($Ra = 1.6\cdot10^9$, $Q_{iso} = 12 / s^2$).