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Otto LaPorte Lecture: Ultimate Rayleigh-Bénard and Taylor-Couette turbulence

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Rayleigh-Bénard flow — the flow in a box heated from below and cooled from above — and Taylor-Couette flow -- the flow between two coaxial co- or counter-rotating cylinders -- are the two paradigmatic systems in physics of fluids and many new concepts have been tested with them. They are mathematically well defined, namely by the Navier-Stokes equations and the respective boundary conditions, and share many features.

While the low Reynolds number regime (i.e., weakly driven systems) has been very well explored in the '80s and '90s of the last century, in the fully turbulent regime major research activity only developed in the last two decades. In this talk we will first briefly review this recent progress in our understanding of fully developed Rayleigh-Bénard (RB) and Taylor-Couette (TC) turbulence, from the experimental, theoretical, and numerical point of view. We will explain the parameter dependences of the global transport properties of the flow and the local flow organisation, including velocity profiles and boundary layers, which are closely connected to the global properties. Next, we will discuss transitions between different (turbulent) flow states. We will in particular focus on the so-called ultimate regime, in which the boundary layer has become turbulent, and which therefore has enhanced transport properties. In the mechanical driven TC flow this ultimate regime can also be achieved in our high-performance numerical simulations, showing excellent agreement with our experiments on the Twente Turbulent Taylor-Couette (T^3C) facility.

In the last part of the talk we will discuss RB and TC turbulence with rough walls. There the results can be expressed in terms of the skin-friction factor, revealing analogy to turbulent flow in rough pipes. Finally, we will present our results on RB and TC flow with bubbles, focusing on bubbly drag reduction and its origin.

This is joint work with many colleagues over the years, and I in particular would like to name Chao Sun, Roberto Verzicco, Siegfried Grossmann, Richard Stevens, Erwin van der Poel, Rodolfo Ostilla-Monico, Xiaojue Zhu, Dennis van Gils, Sander Huisman, Ruben Verschoof, and Gert-Wim Bruggert.