THE GÖTTINGEN ROTATING TURBULENT RAYLEIGH-BÉNARD CONVECTION FACILITY

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INTRODUCTION

Thermally driven turbulent convection under the influence of global rotation is ubiquitous in nature. Well known examples are the outer convective shell of our Sun and the outer liquid core of the Earth. Trying to understand the underlying dynamics of such flows is highly challenging, not only because of the enormous range in length- and time-scales that are involved with these geo/astrophysical cases and the complex interaction of hydrodynamics with electromagnetism, but also because direct measurements on these systems are most often impossible to carry out. We gain access to direct measurements by isolating part of the problem: We focus solely on the hydrodynamical aspects of turbulent convection by performing experiments in the lab and making comparisons with direct numerical simulations (DNS). The canonical system that we use to study such flows is Rayleigh-Bénard convection (RBC), the flow between a warm bottom plate and cold top plate, in a fluid-filled upright cylindrical cell that is rotating around its geometrical axis. This presentation will focus on the newly constructed rotating RBC facility at the Max Planck Institute for Dynamics and Self-Organization (MPIDS) in Göttingen.

NEW FACILITY AND ACCESSIBLE PHASE SPACE

The MPIDS has a general-purpose pressure vessel, called the "Uboot of Göttingen", which can house different RBC cells contained in High-Pressure-Convection Facilities (HPCF). By pressurizing the Uboot with sulfur hexafluoride (SF_6), nitrogen, or helium up to 19 bars one can obtain Rayleigh numbers spanning $10^9 \lesssim Ra \lesssim 10^{15}$, at nearly constant Prandtl numbers $0.6 \lesssim Pr \lesssim 0.8$. The Uboot has a volume of about 25 m^3, and it requires for instance about 2000 kg of SF_6 to fill it to 19 bars. This (non-rotating) facility is described in detail in [1, 2].

Recently, a rotating table was constructed that can operate outside as well as in the Uboot, on top of which the already existing HPCF-II containing a cell of aspect ratio $\Gamma \equiv \mathrm{diameter}/\mathrm{height} = 0.50$ can be installed, see figure 1. The table is able to rotate at 0.01 to 2.00 rad/s, can support loads up to 3000 kg, and has feedthroughs from the lab to the rotating frame for 12 temperature-controlled water cooling circuits and for the leads of up to 100 thermistors that probe the interior temperatures.

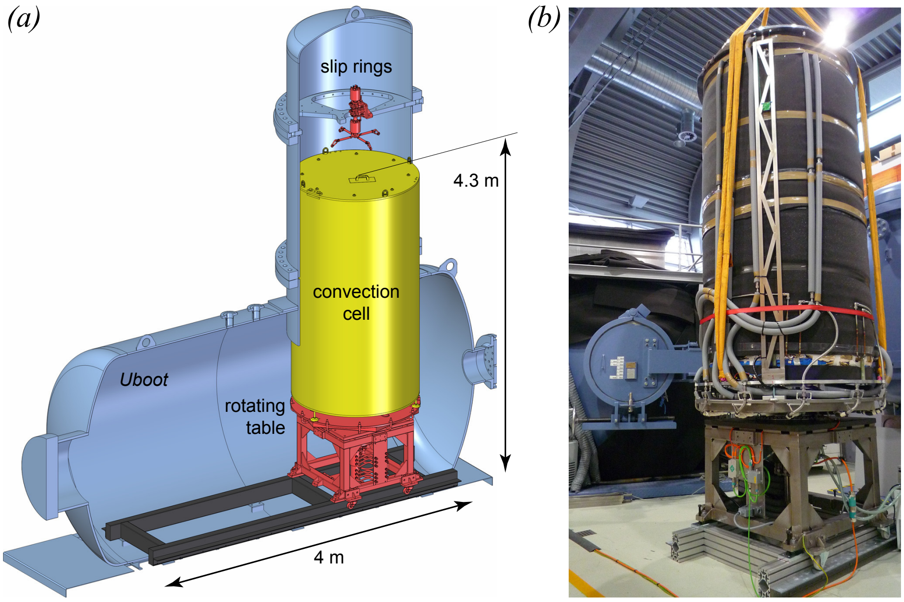

Figure 1. *(a)* Sketch of the Uboot (cut-through) with the rotating table and the convection cell on top. *(b)* Photo of the rotating table and the convection cell (HPCF-II) outside of the Uboot. The interior of HPCF-II is 2.24 m high and 1.12 m in diameter.

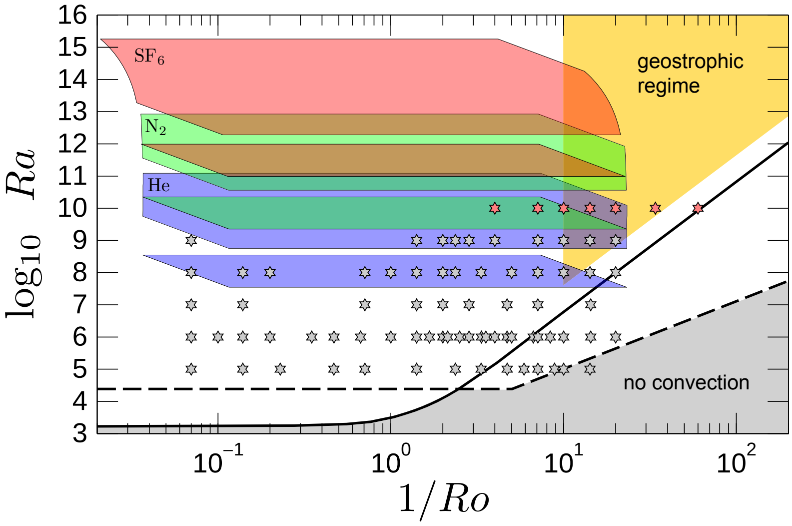

Figure 2. Phase diagram of the planned experimental investigations and direct numerical simulations on rotating turbulent Rayleigh-Bénard convection in terms of the Rayleigh number and inversed Rossby number. The black solid curve indicates Ra_c, the critical Rayleigh number for fixed top and bottom boundaries of infinite extend, below which there is no convection [3]. In experiments the sample is enclosed by sidewalls, giving rise to convective 'wall-modes' that precede the idealized criticality at fast rotation rates, shown here by the dashed line predicted by [4, 5, 6] for an aspect ratio 0.5 cell. The grey shaded area is hence the effective region where no convection exists. The red, green and blue shaded regions indicate the forthcoming experiments using, respectively, SF_6 with $Pr \approx 0.8$, N_2 with $Pr \approx 0.73$ and He with $Pr \approx 0.67$. The three colors each appear twice and correspond to the specific gas under either a pressure ranging from 4 to 19 bars when running the experiment inside the Uboot (top shaded regions), or at ambient pressure when running the experiment outside of the Uboot (bottom parallelogram regions). The temperature difference between the bottom and top plates will be from 2K to 20K and the rotation speed from 0.01 rad/s to 2.00 rad/s. Black stars correspond to the direct numerical simulations already studied by Horn *et al.* [7] and red stars indicate the cases to be studied in the near future. The yellow shaded area is an estimation for the geostrophic turbulent regime. Both DNS and experiments are able to probe this regime and are also overlapping with each other, promising more insight into geostrophic turbulence and the transition towards it.

The phase space that is accessible with this facility is shown in figure 2. The accessible inverse Rossby number (a ratio of the Coriolis and the buoyancy forces) spans $0.02 \lesssim Ro^{-1} \lesssim 20$. This range gives access to the transitions from the buoyancy dominated regime up to the rotation dominated regime. The accessible Ekman number (the ratio of the viscous to the Coriolis force) spans the range $10^{-8} \lesssim Ek \lesssim 10^{-3}$. The typical features that are associated with these flows are, in order of increasing rotation strength starting from rest, the buoyancy dominated thermal plumes, going onwards into the formation of Ekman vortices and chimney-like vortical structures that extract heat from the plates, towards rotation-dominated flows where turbulent fluctuations get suppressed along the rotation axis, giving rise to Taylor-Proudman columns. At strong rotation (small Ek) but still turbulent convection (large Ra) one enters the geostrophic turbulent regime. Both experiments and DNS are able to enter this regime and their parameter ranges overlap with each other, promising more insight into geostrophic turbulence and the transition towards it. We plan to present the first experimental results for measurements in the range of $2 \times 10^9 \lesssim Ra \lesssim 2 \times 10^{10}$ using N_2 with $Pr \approx 0.73$.

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