Experimental investigation on turbulent rotating thermal convection at large Rayleigh numbers

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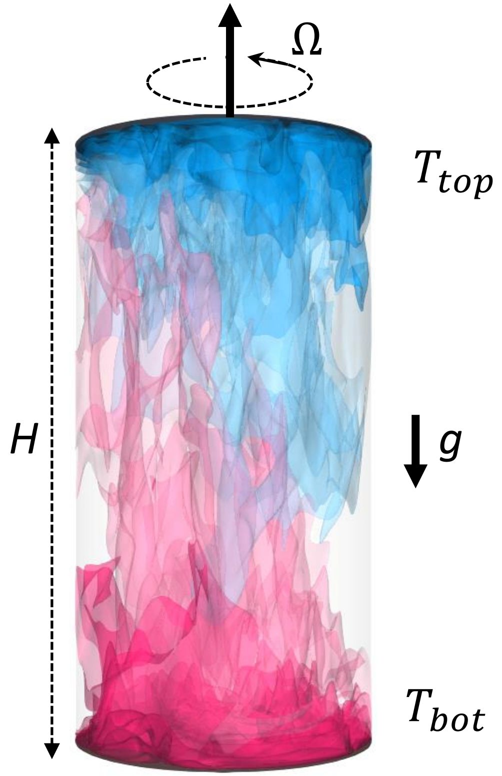
MAX-PLANCK-GESELLSCHAFT

Rayleigh-Bénard Convection (RBC)

- Heated from below, cooled from above: $\Delta = \mathrm{T}_{bot} - T_{top}$
- Turbulent convection
- Controlled by three parameters

$$Ra = \frac{g\alpha\Delta H^3}{\nu\kappa} \qquad Pr = \frac{\nu}{\kappa} \qquad \frac{1}{Ro} = \frac{2\Omega}{\sqrt{g\alpha\Delta/H}}$$

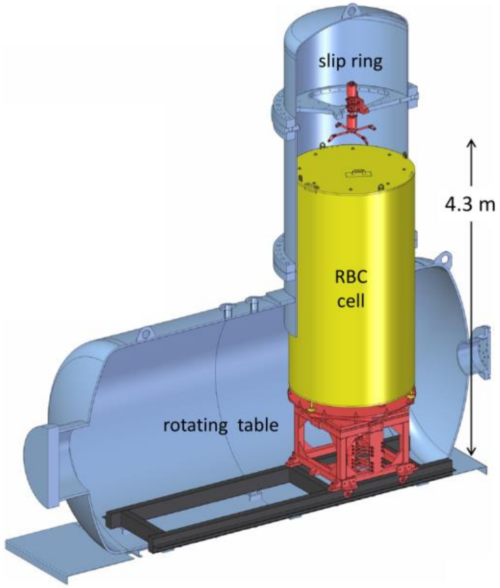
- Aspect ratio $\Gamma = \frac{D}{H} = 1/2$
- Heat transport $Nu = \frac{qH}{\lambda\Delta}$

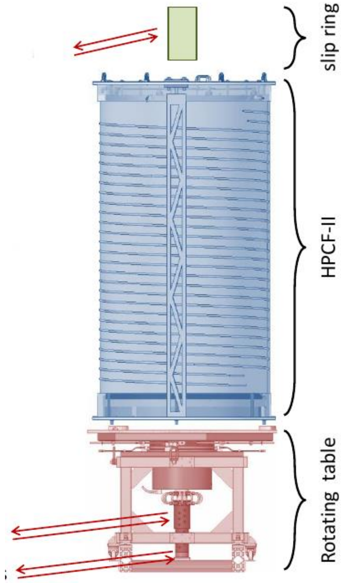


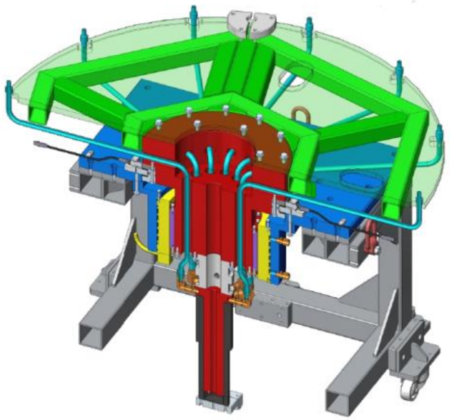
DNS by X. Zhang

ν kinematic viscosity
κ thermal diffusivity
α expansion coefficient
λ heat conductivity
q heat flux density

Experimental setup

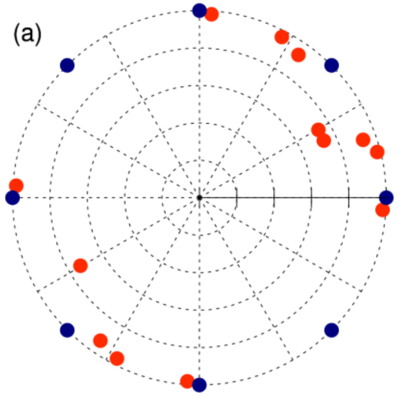


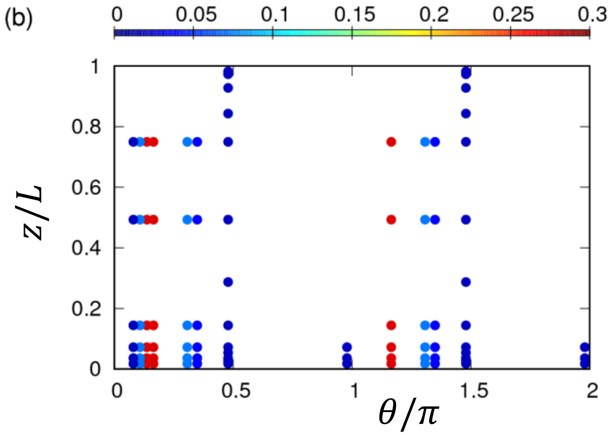




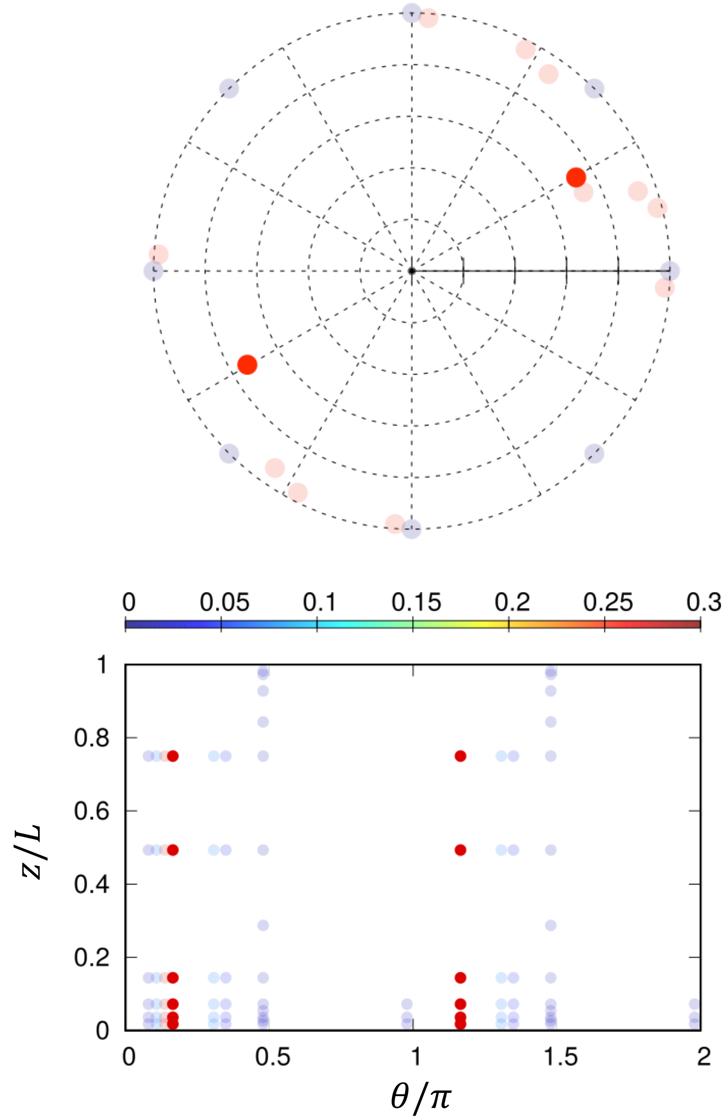
- $H = 2.24\text{m}$
- $0 \leq \Omega \leq 20$ rpm
- Working gas $\mathrm{SF_6}$ at high pressures (≤ 19 bar)
- $0.76 \leq Pr \leq 0.96$

$$Ra = \frac{g\alpha\Delta H^3}{\nu\kappa}$$

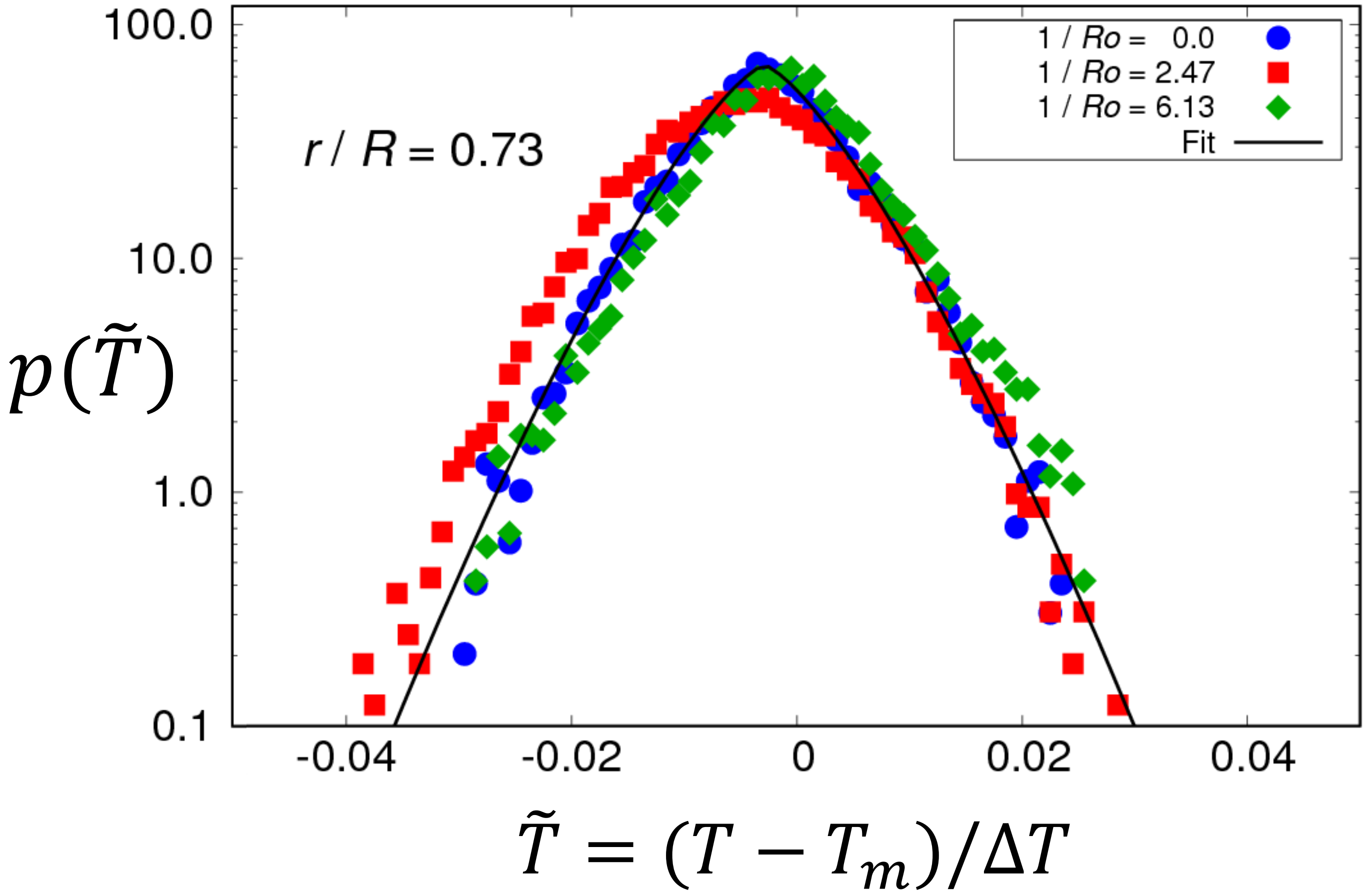




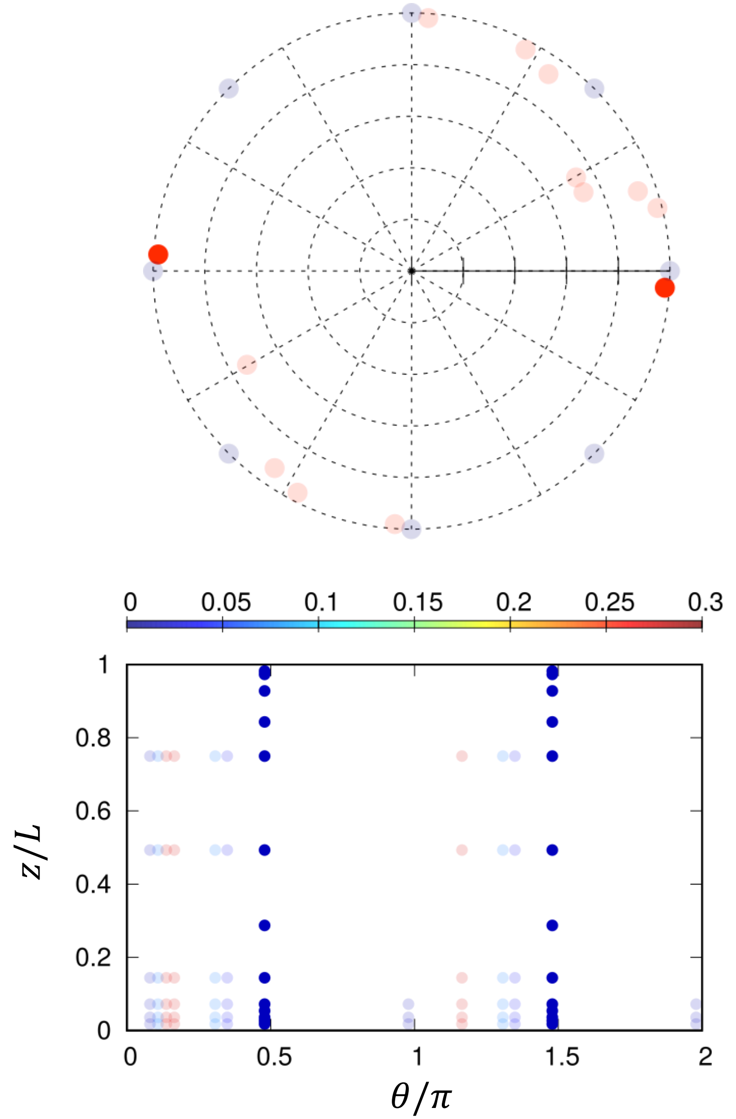
Temperature PDF in the bulk flow

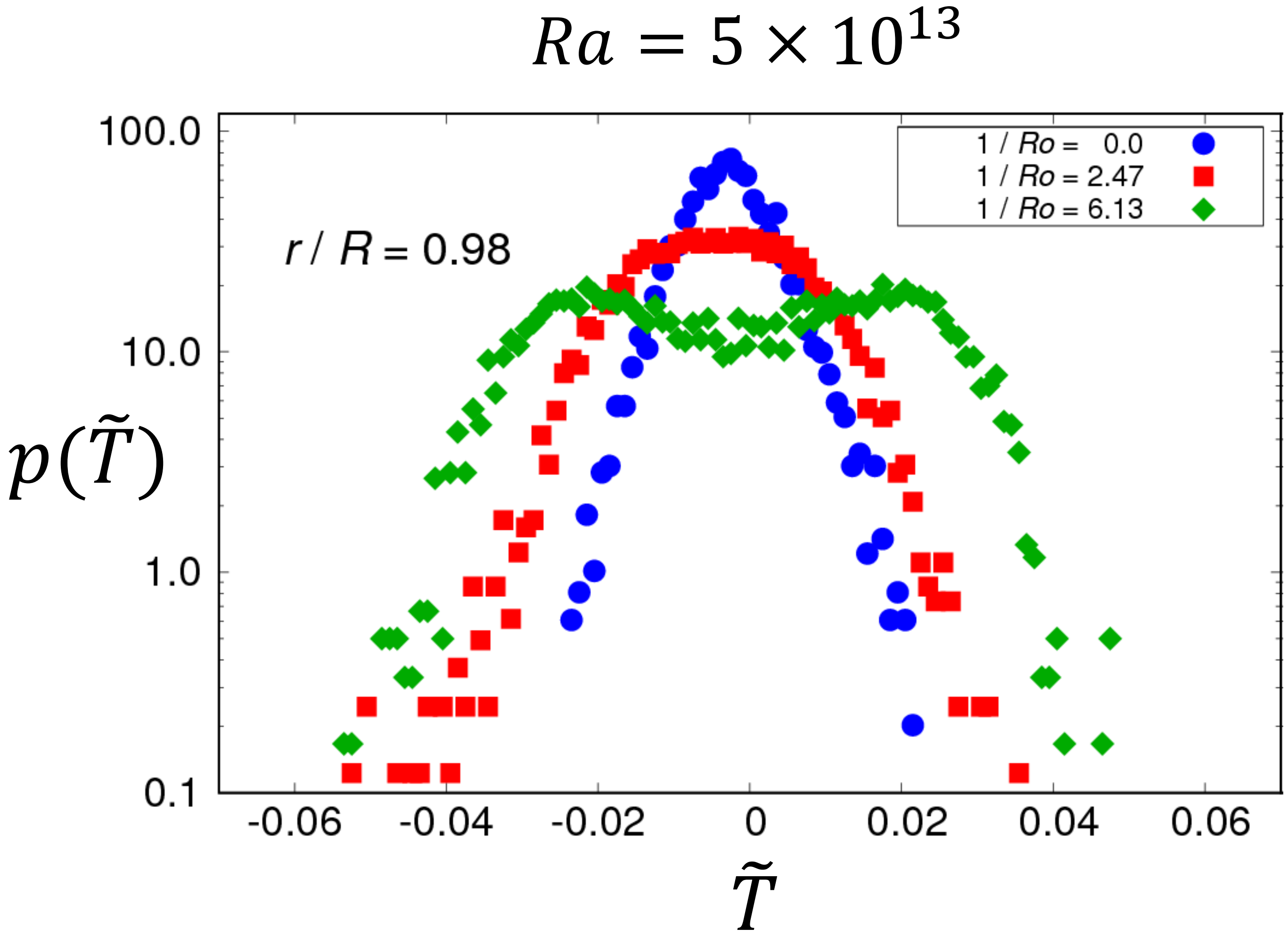


$Ra = 5 \times 10^{13}$



Temperature PDF close to the sidewall





Temperature PDF close to the sidewall

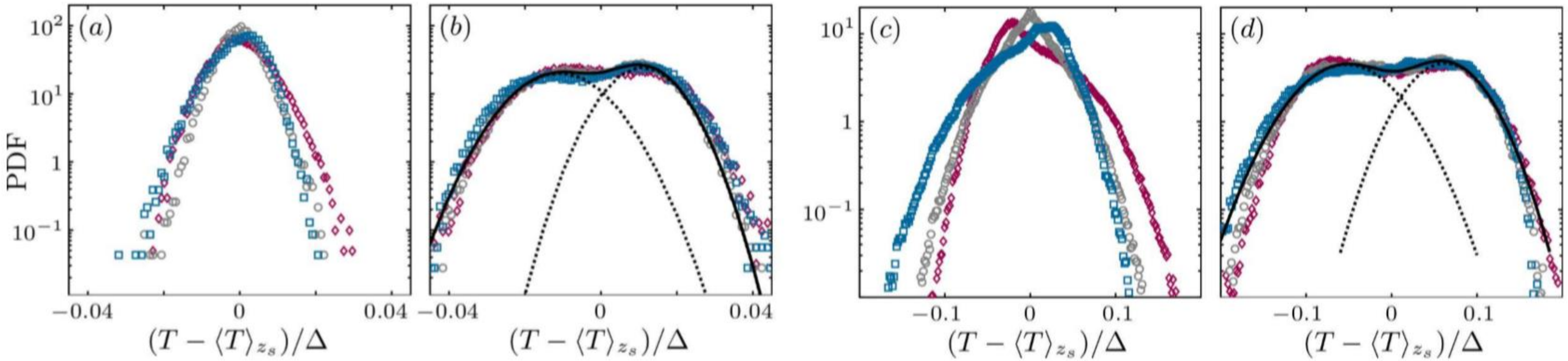
Experiment

$Ra = 8 \times 10^{12}$

DNS *Zhang et al. (2020) PRL*

$Ra = 10^{9}$

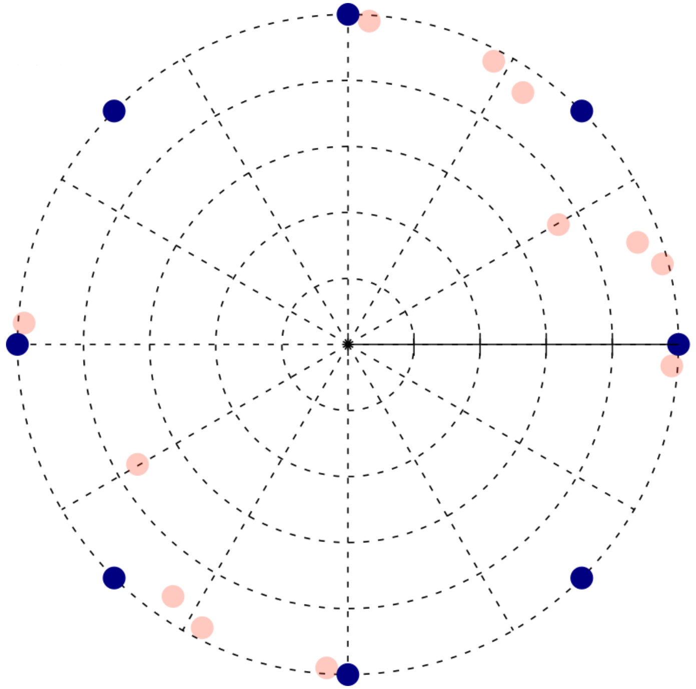
$1/Ro = 0$ $1/Ro = 10$ $1/Ro = 0$ $1/Ro = 10$



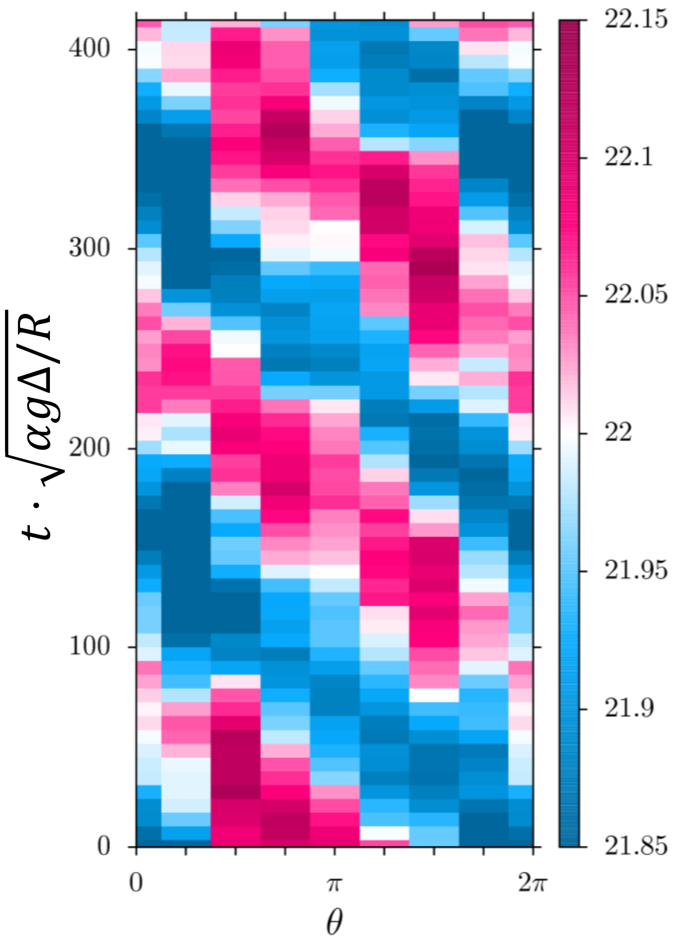
Boundary Zonal Flow (BZF)

Temperature measurements

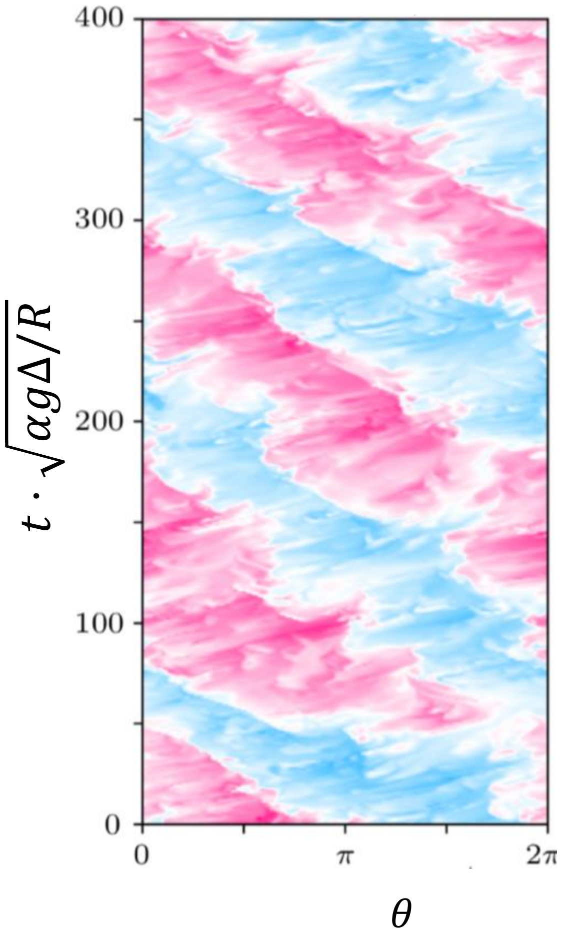
Temperature field along the sidewall reveals the mode 1 band structure of the BZF.



Experiment

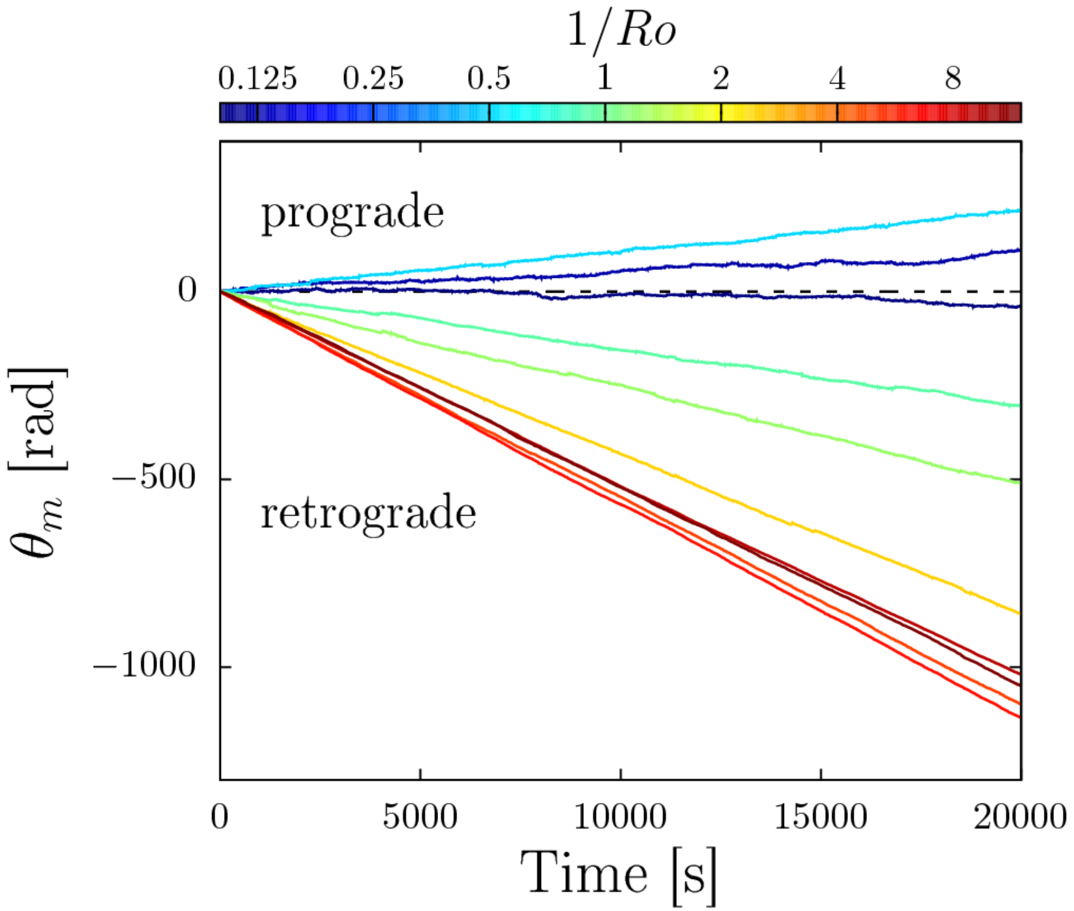


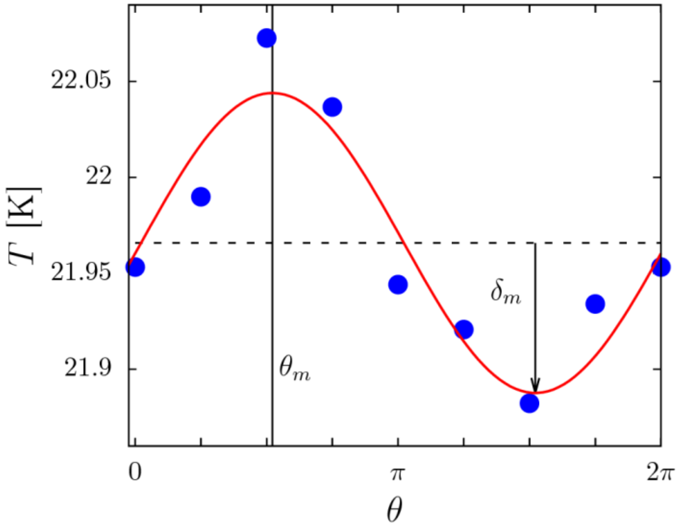
DNS

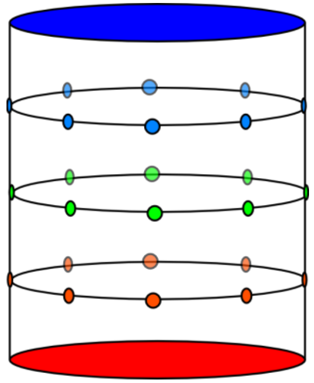


Drifting velocity of the temperature field

- current angle by fit $T = \bar{T} + \delta \cos(\frac{i\pi}{4} - \theta_\mathrm{m})$







Cioni et al. (1997) JFM

Summed angle over entire run

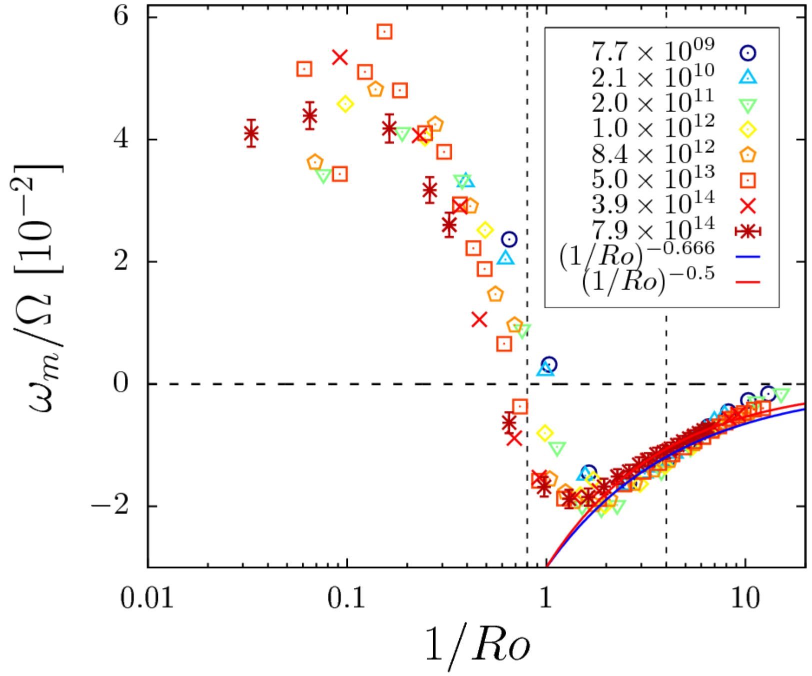
At constant Ra:

- Prograde for low $1/Ro$
- Retrograde for high $1/Ro$

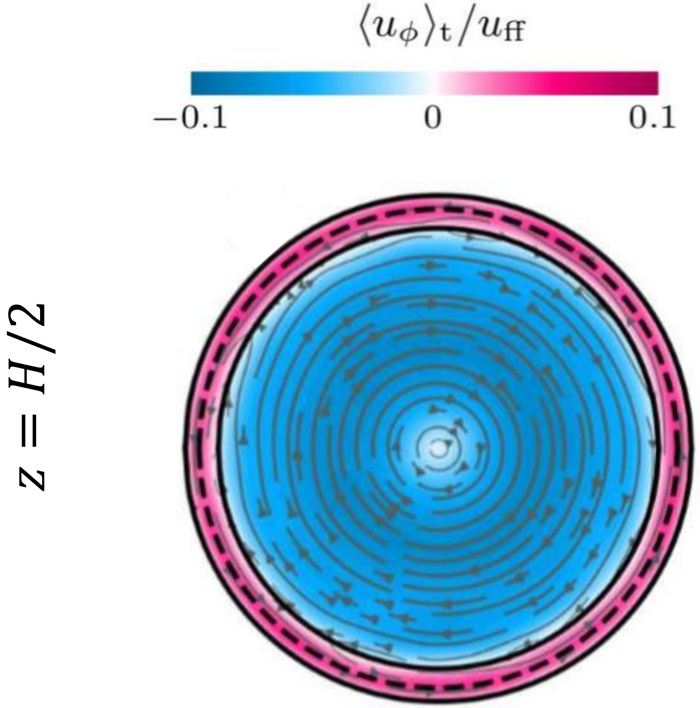
Drifting velocity

Behaviour similar at different Ra

- Transition point $1/Ro \approx 0.8$
- DNS suggests $\omega/\Omega \sim 1/Ro^{-5/3}$



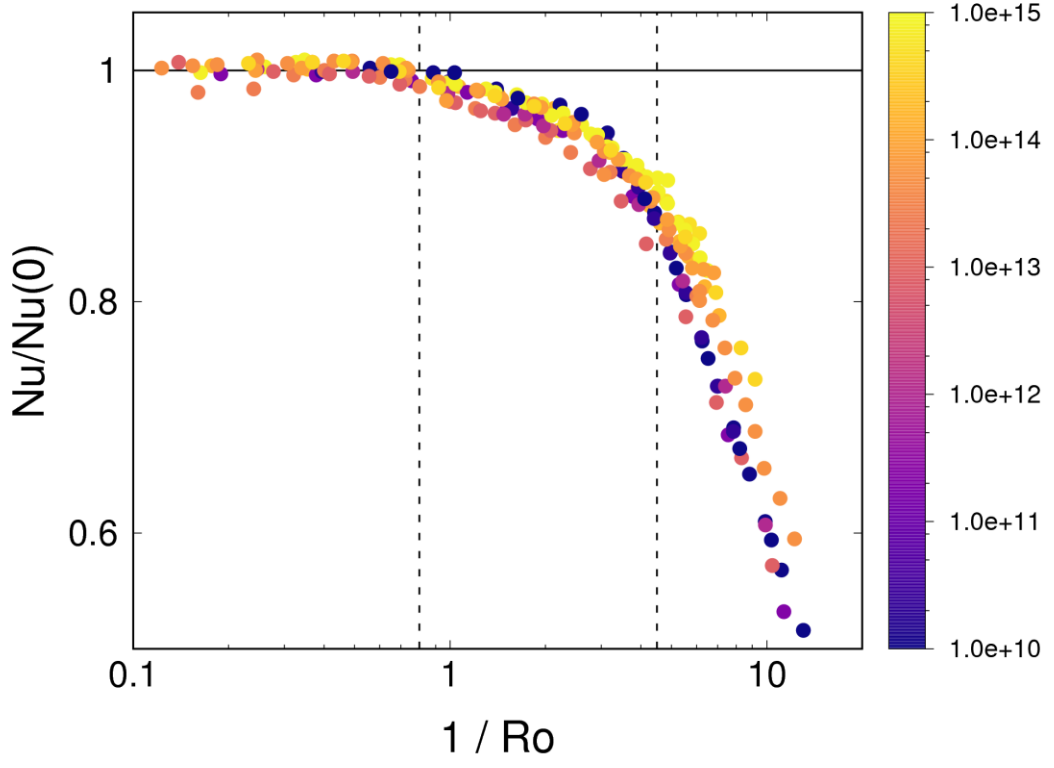
DNS:



Velocity field at the boundary always cyclonic

Nusselt number measurements

- No increase in Nu at intermediate Ro^{-1}
  - Contrast to large Pr, *e.g. Rossby (1969), Weiss et al. (2016)*



≈ 60% of heat flux within BZF