A new Taylor-Couette apparatus to study turbulence in stratified fluids

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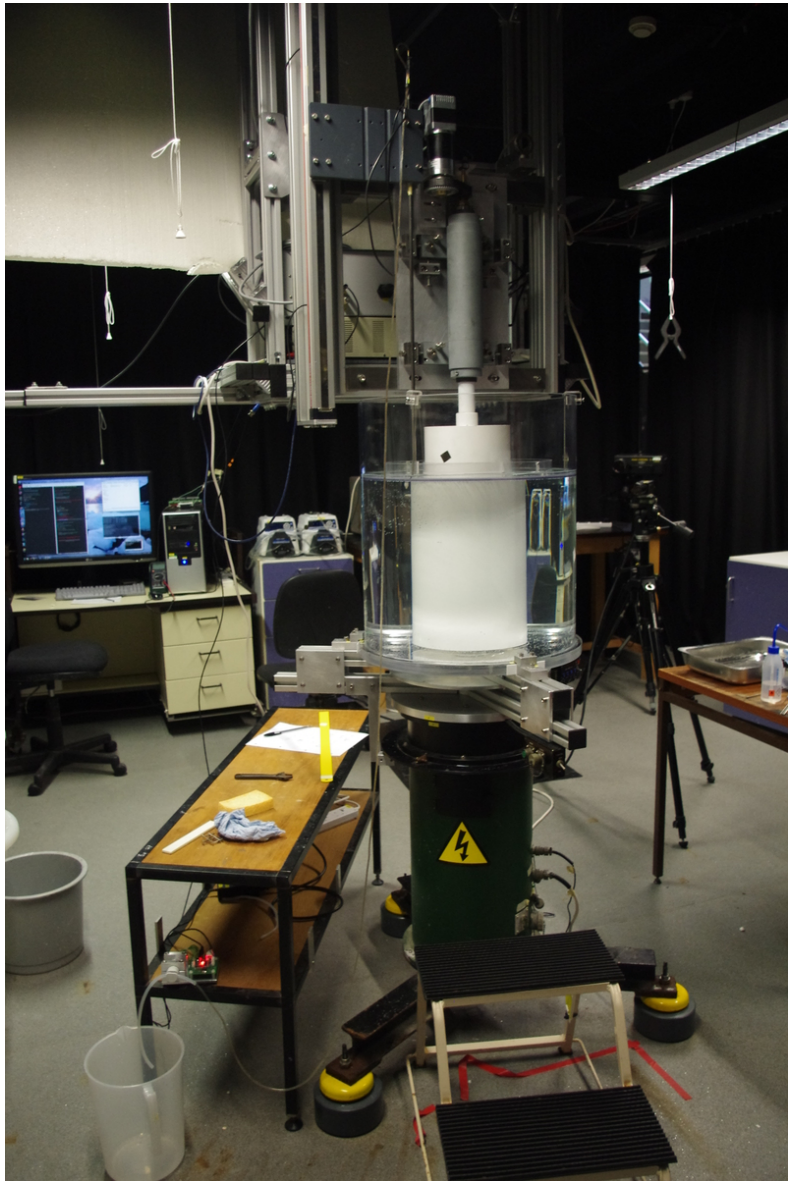
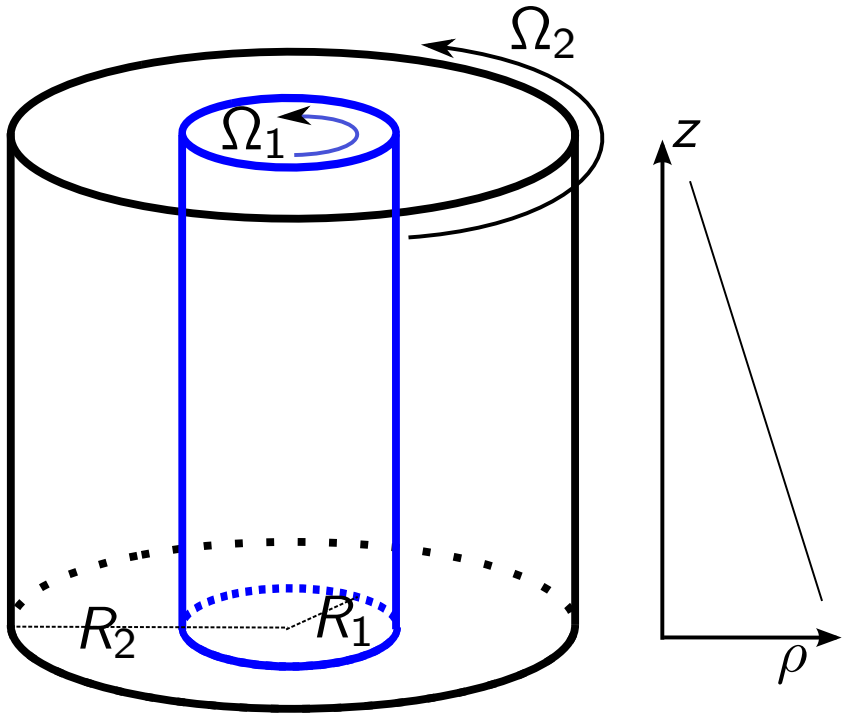
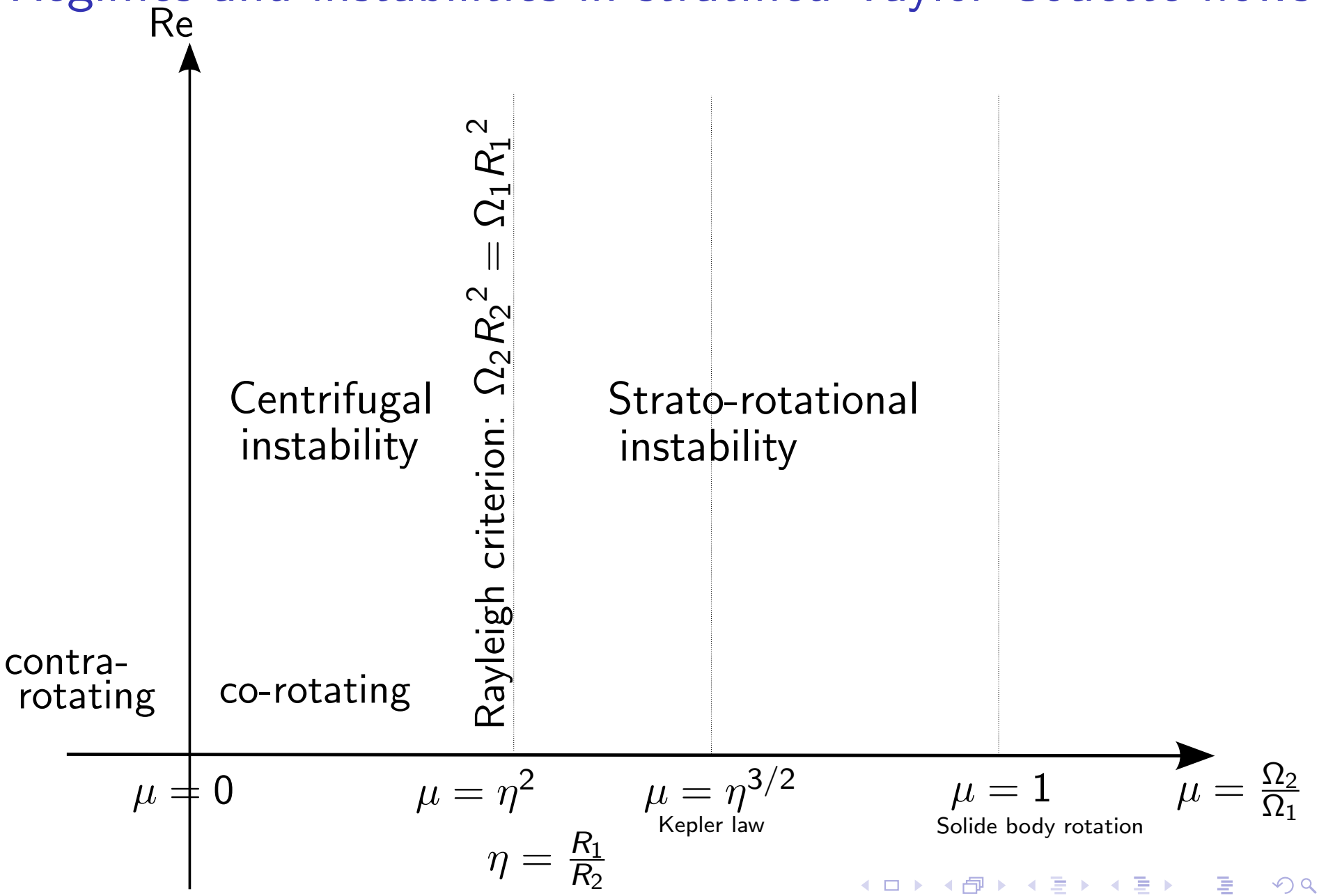
A new Taylor-Couette apparatus



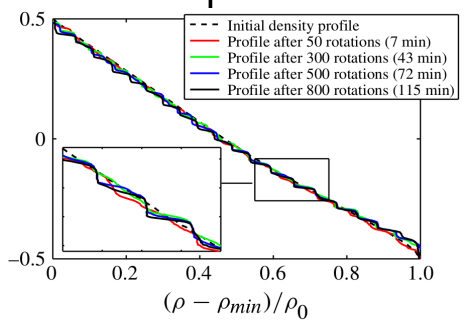


$$\mu = \frac{\Omega_2}{\Omega_1}, \qquad \eta = \frac{R_1}{R_2}.$$

Regimes and instabilities in stratified Taylor-Couette flows



Regimes and instabilities in stratified Taylor-Couette flows



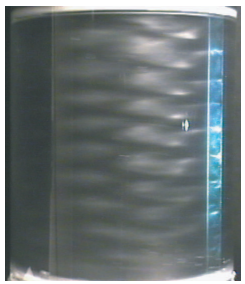
Oglethorpe et al 2013

Re

Centrifugal instability

Strato-rotational instability

Rayleigh criterion: $\Omega_2 R_2^2 = \Omega_1 R_1^2$



Le Bars and Le Gal 2007

contra-rotating

co-rotating

$\mu = 0$

$\mu = \eta^2$

$\mu = \eta^{3/2}$

Kepler law

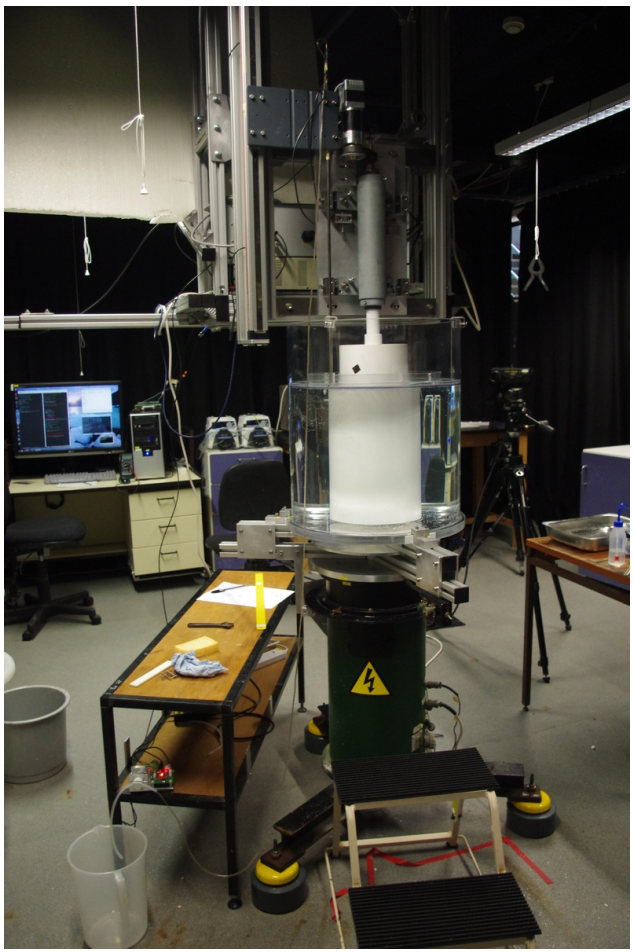
$\mu = 1$

Solide body rotation

$\mu = \frac{\Omega_2}{\Omega_1}$

$\eta = \frac{R_1}{R_2}$

A new Taylor-Couette apparatus

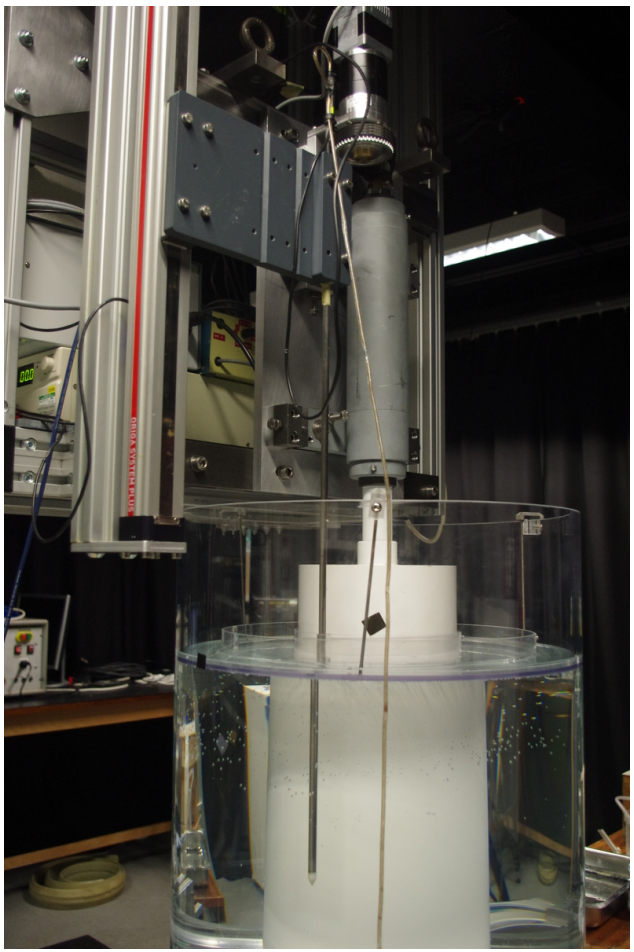


For the experiments, we

- adjust the alignment,
- control the rotation rates $\Omega_1(t)$ and $\Omega_2(t)$
- fill the tank with any stable density profiles

  using two peristaltic pumps controlled by computer,

A new Taylor-Couette apparatus

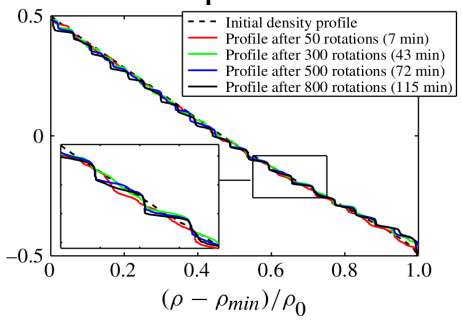


For the experiments, we

- adjust the alignment,
- control the rotation rates $\Omega_1(t)$ and $\Omega_2(t)$
- fill the tank with any stable density profiles using two peristaltic pumps controlled by computer,
- measure density profiles with a conductivity probe attached to a traverse; measurements at quite high speed (10 cm/s),
- optical measurements (shadowgraph, pearlescence, 2D PIV).

Case with the centrifugal instability ($\Omega_2 = 0$ rad/s)

Re



Oglethorpe, Caulfield and Woods 2013

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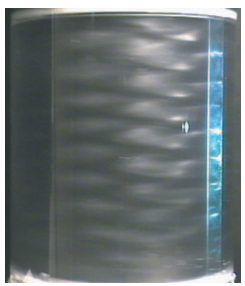

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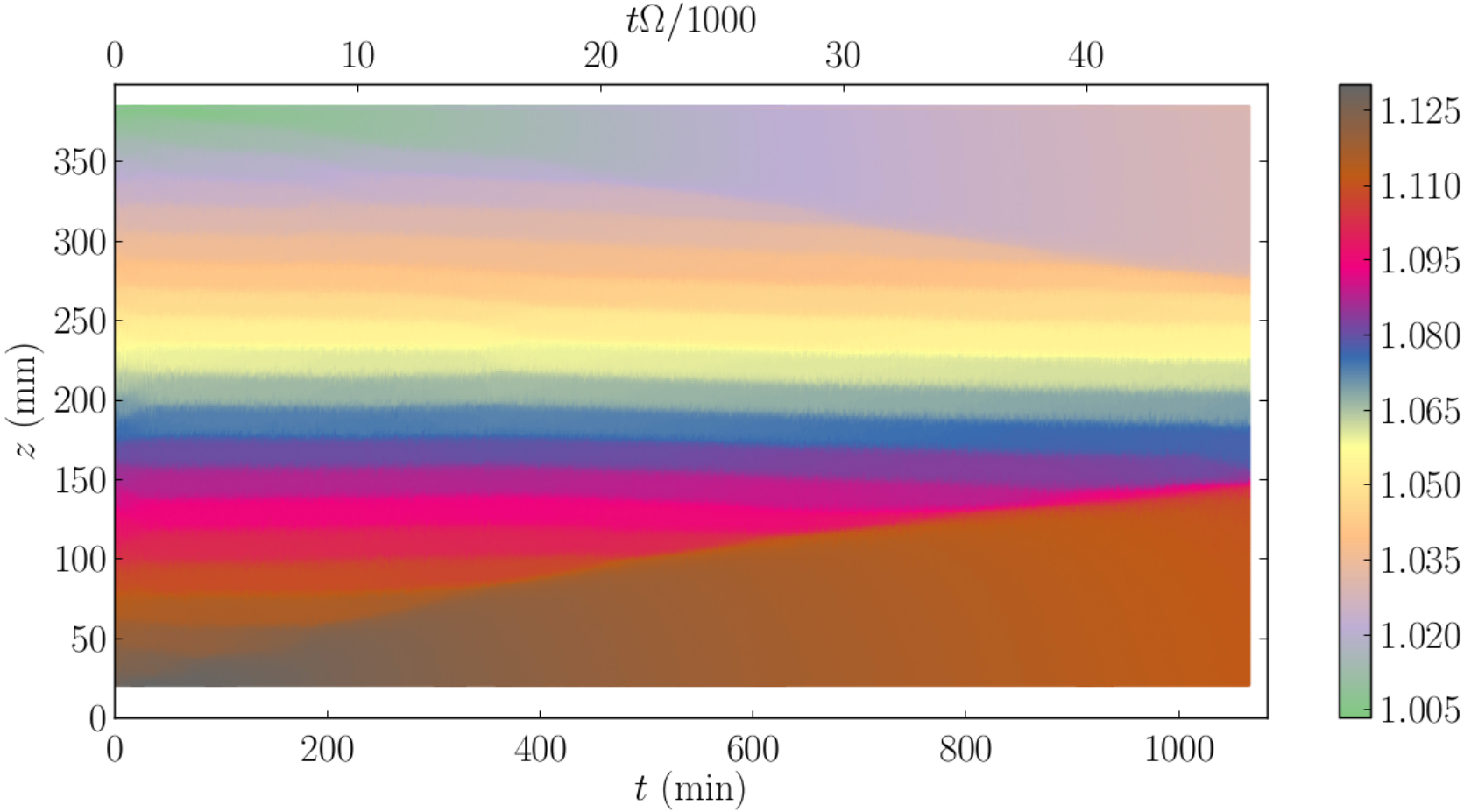
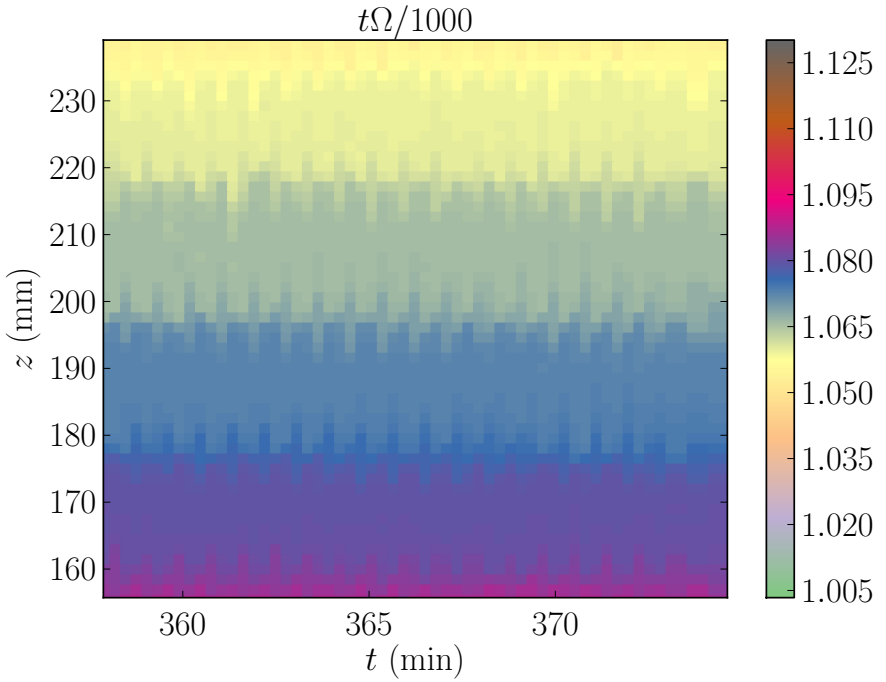
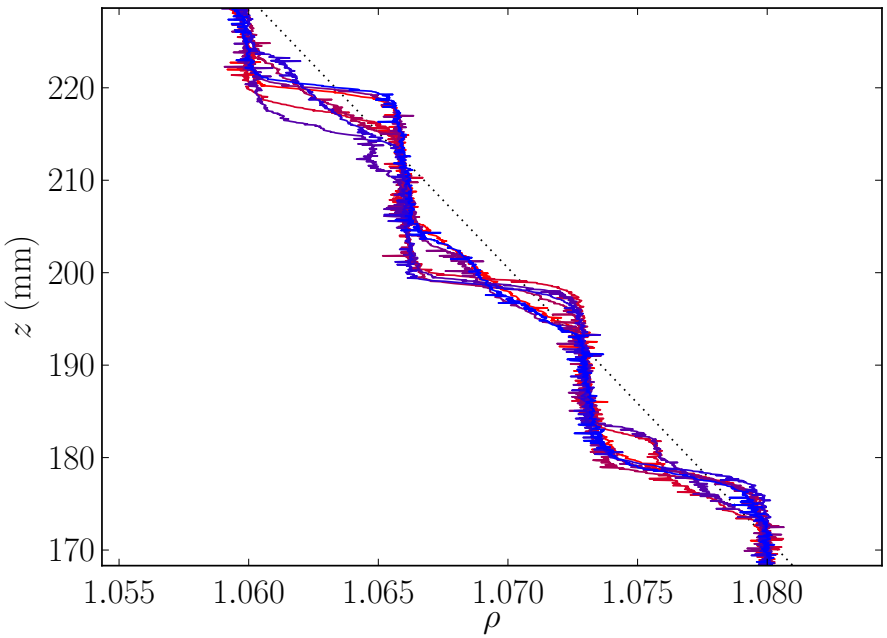
Layering, staircase density profiles



Fine temporal structure in the density profiles

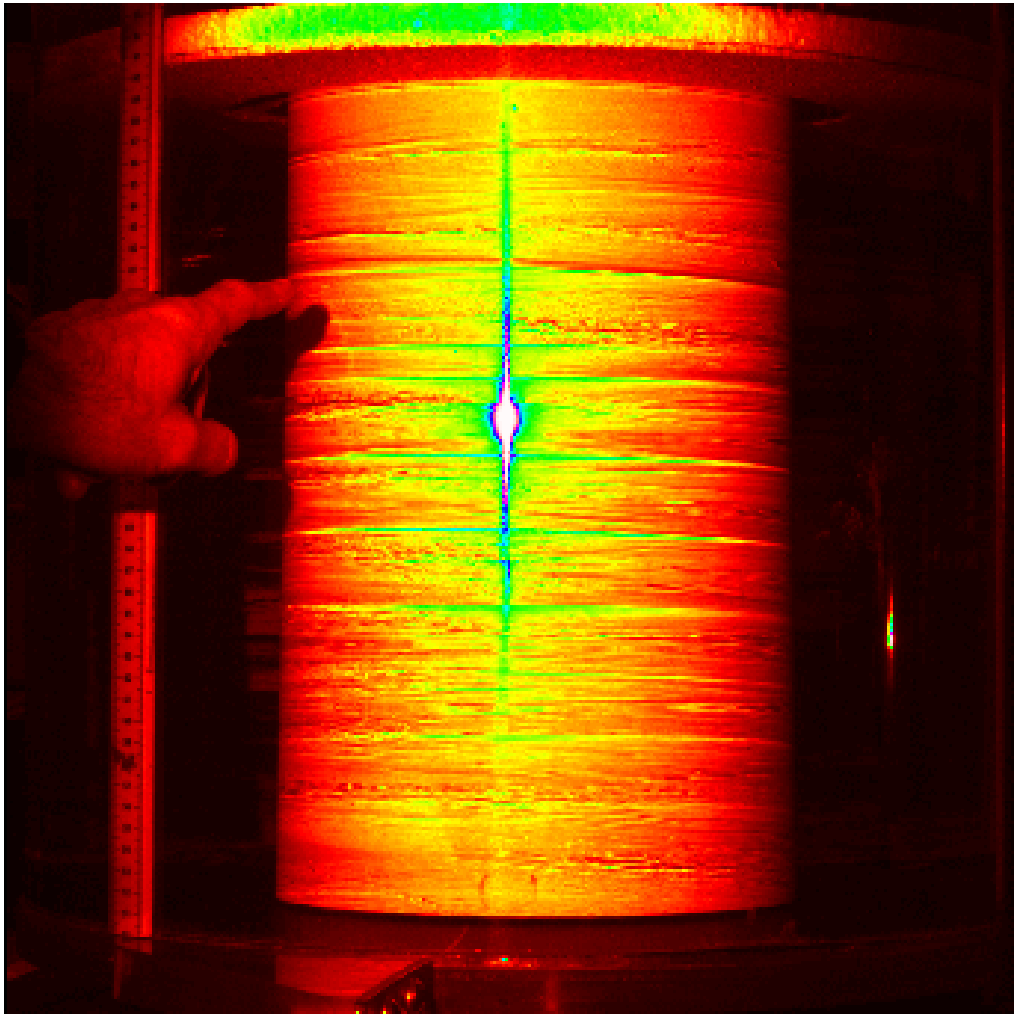




Period $\simeq$ 50 s (consistent with scaling law derived by Oglethorpe *et al. 2013)*

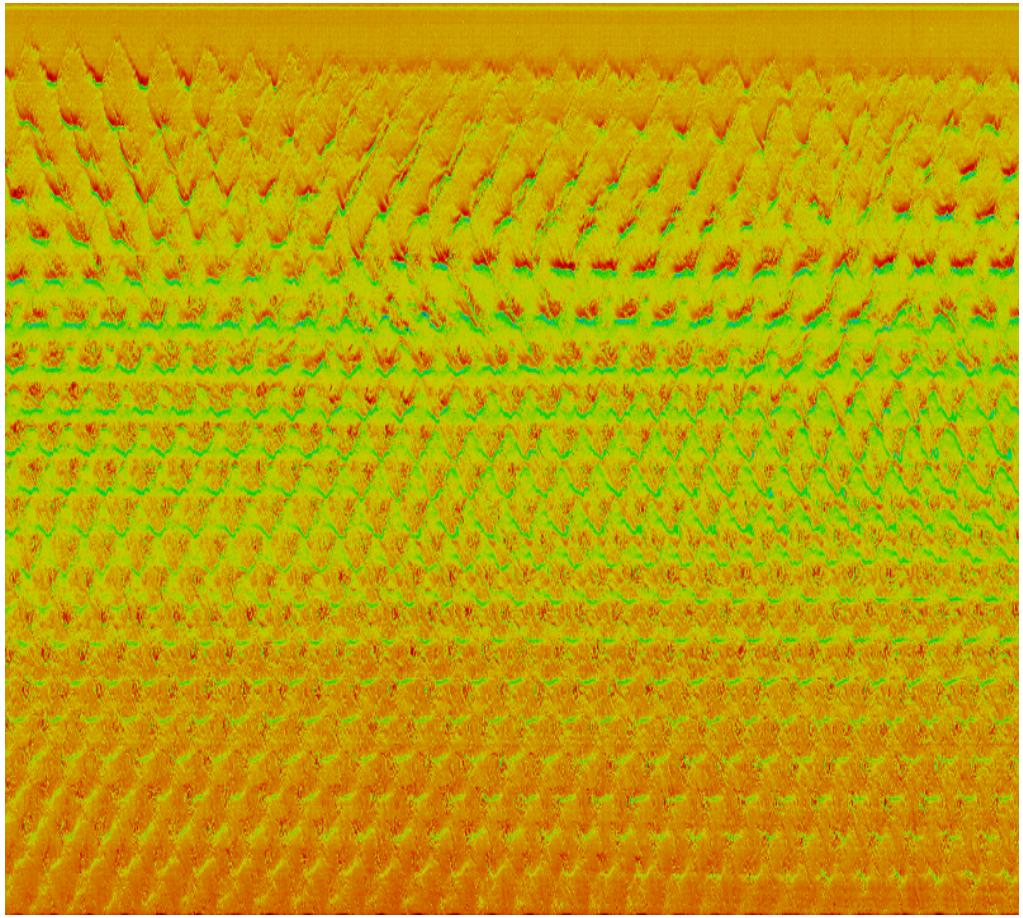
$2\pi/\Omega_1 \simeq 8.6$ s

Horizontal shadowgraph on the inner cylinder



Horizontal shadowgraph on the inner cylinder

Time series (intensity as a function of time and height)



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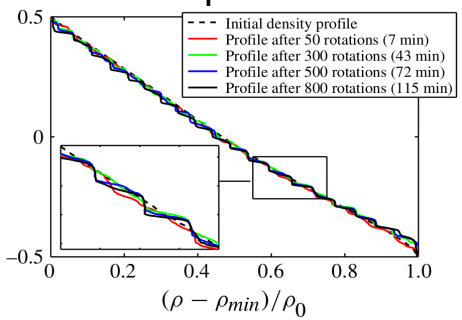
Case with the Strato-rotational instability ($\Omega_2 > 0$ rad/s)

Re



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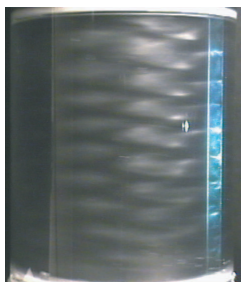

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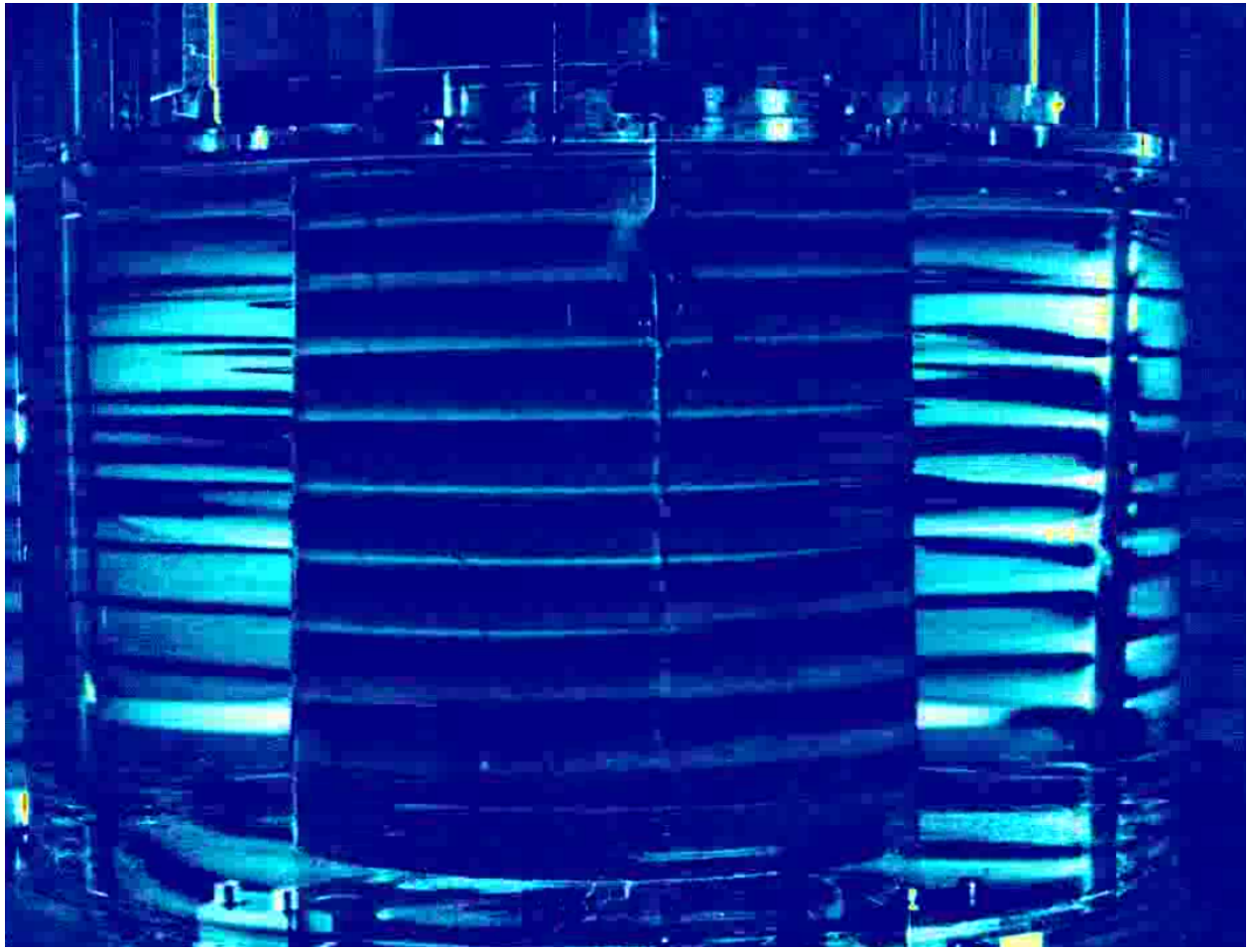
Case with the Strato-rotational instability ($\Omega_2 > 0$ rad/s)

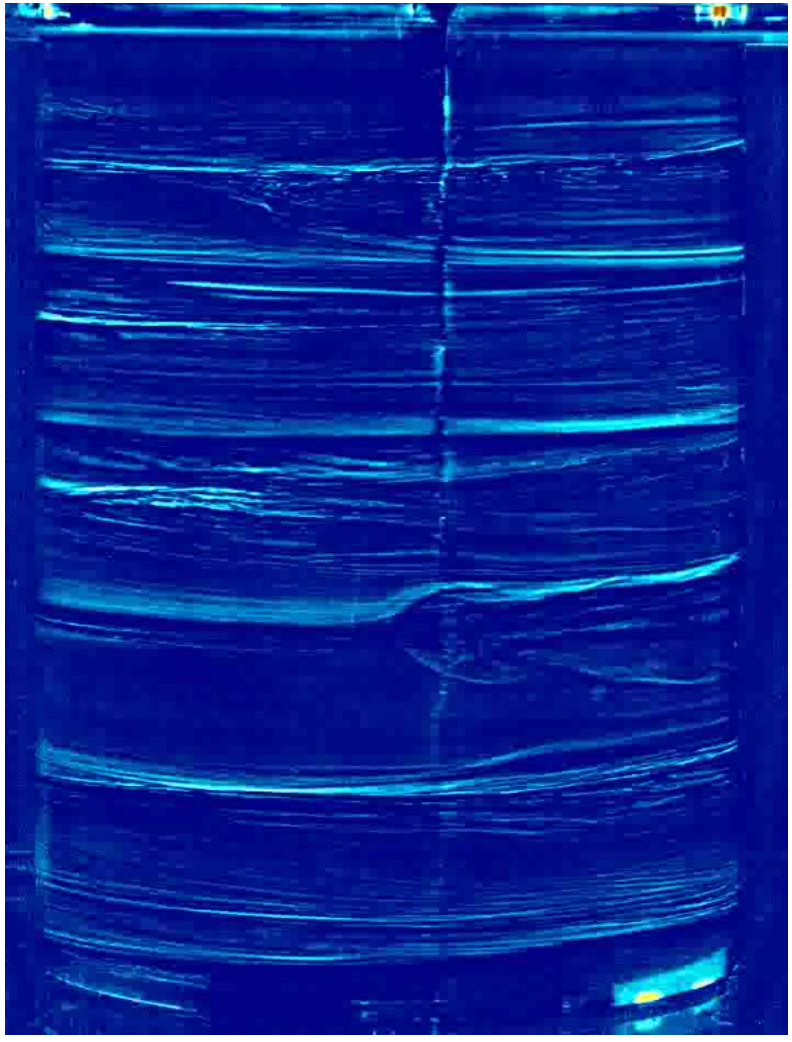
Shadowgraph



Speed-up: x20

Case with the Strato-rotational instability ($\Omega_2 > 0$ rad/s)

Shadowgraph (higher Reynolds number)



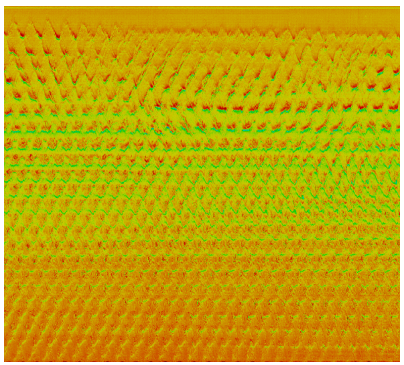
Speed-up: x10

Conclusions and perspectives

- New Taylor-Couette apparatus for studying stratified flows,
- Observation of turbulence produced by the centrifugal instability ($\Omega_2 = 0$) and the strato-rotational instability ($\Omega_2 > 0$),

$\Omega_2 = 0$

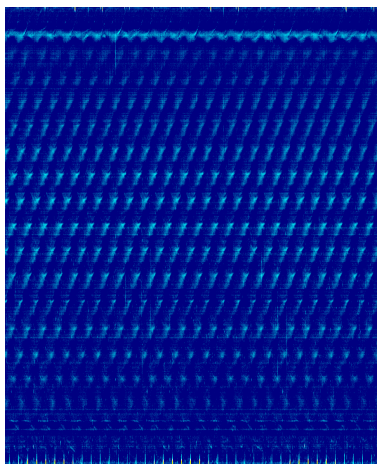
Turbulence in and between layers



periodic turbulent intrusions with coupling between adjacent layers.

$\Omega_2 > 0$

Turbulence in a linear stratification



spatio-temporal intermittency and coherent structures.

- We use Digiflow and FluidDyn.

FluidDyn

An open-source Python framework to study fluid dynamics

Goal: good-quality community-driven code

cross-platform, general object-oriented libraries, efficient, documented, good test suite.

Not yet ready but soon!

- Experiments
  - control of data acquisition boards, pumps, probes, motors, etc.
  - automatically organize the data,
  - post-analysis.
- Simulations (mostly pseudo-spectral)
  - Efficient (compiled parts, parallelized with MPI and OpenMP...),
  - 1D and 2D solvers, soon 3D solvers.

`http://pythonhosted.org/fluiddyn/`