Rayleigh-Bénard Convection in Liquid Metal under Influence of Vertical Magnetic Fields

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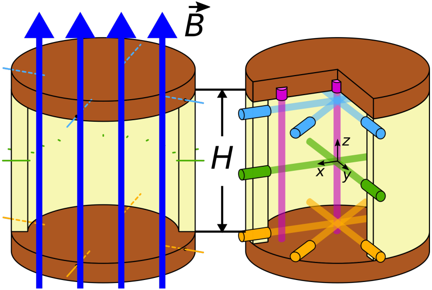
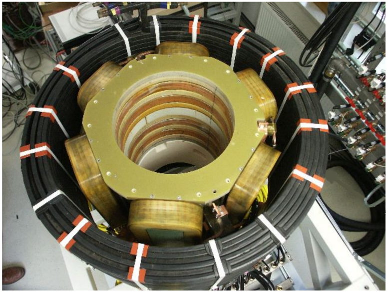
Setup





- $D = H = 180$ mm $\Rightarrow \Gamma = 1$
- GaInSn at Pr$= 0.029$
- electrical heating plate
- water cooling thermostat
- PEEK cylinder with thermal insolation
- sidewalls electrical isolating
- Ra$= 5 \times 10^6$ to 6×10^7
- vertical magnetic field applied by MULTIMAG facility
  - up to $B = 140$ mT
  - $\mathrm{Ha} = B \cdot H \cdot \sqrt{\frac{\sigma}{\rho\nu}} \leq 1000$

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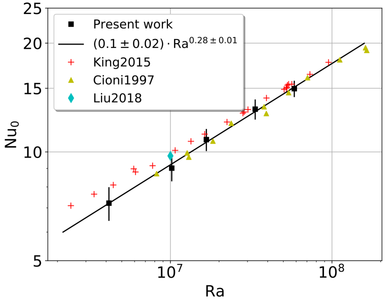
Liquid Metal Rayleigh-Bénard Convection ($B = 0$)



- temperature difference of cooling water
  $\Rightarrow$ heat transport through cell
- comparison with DNS and previous measurements in Hg and Ga to validate setup
- heat transport quantified:

$$Nu_0 = \frac{\text{total heat transport}}{\text{diffusive heat transport}}$$

- Rayleigh-Number:

$$Ra = \frac{\alpha \Delta T g H^3}{\kappa \nu} = Gr \times Pr = \frac{\text{buoyancy}}{\text{viscosity}} \times \frac{\text{momentum diffusivity}}{\text{thermal diffusivity}}$$

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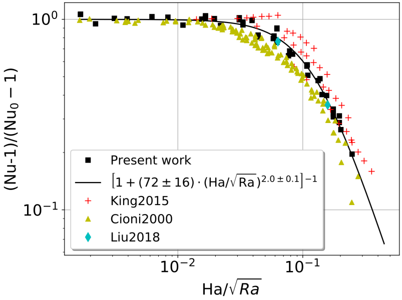
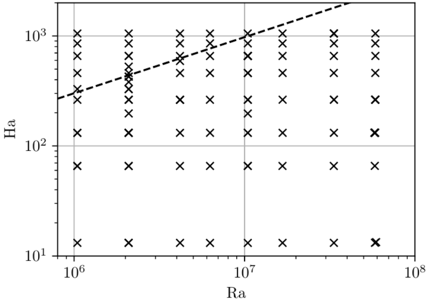
Convection in Vertical Magnetic Field ($B > 0$)



- onset of Convection: $\mathrm{Ra}_c \approx \pi^2 \mathrm{Ha}^2$
- Chandrasekhar limit: $\mathrm{Ha}_c \approx \frac{\sqrt{\mathrm{Ra}}}{\pi}$

- flow affected by magnetic field $\Rightarrow$ Lorentz Force $\Rightarrow$ convective part of heat transport collapses



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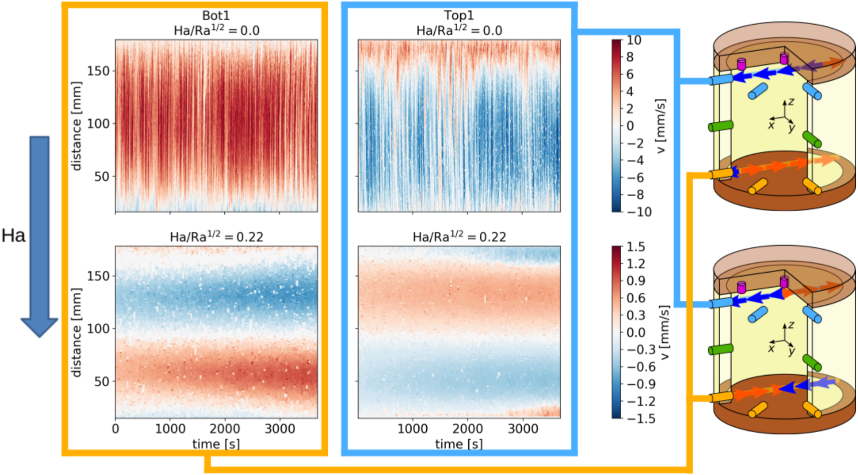
Results of Flow Measurements: Ultrasound



Linear profiles of the horizontal velocity

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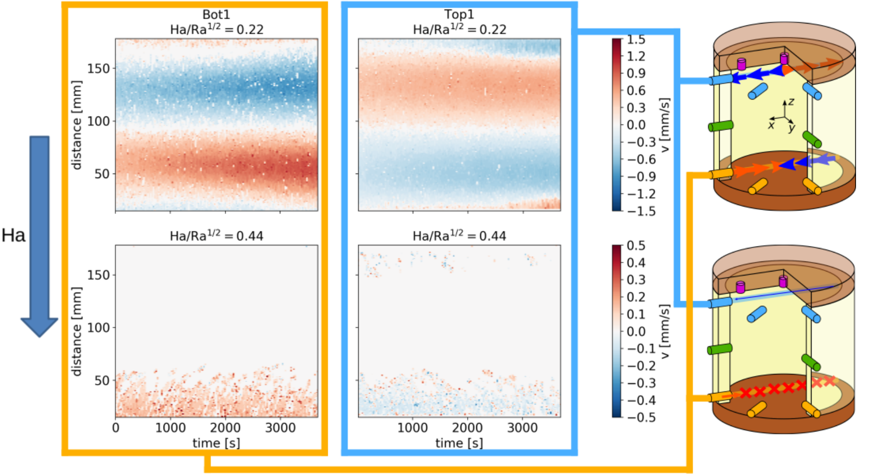
Results of Flow Measurements



linear profiles of the horizontal velocity

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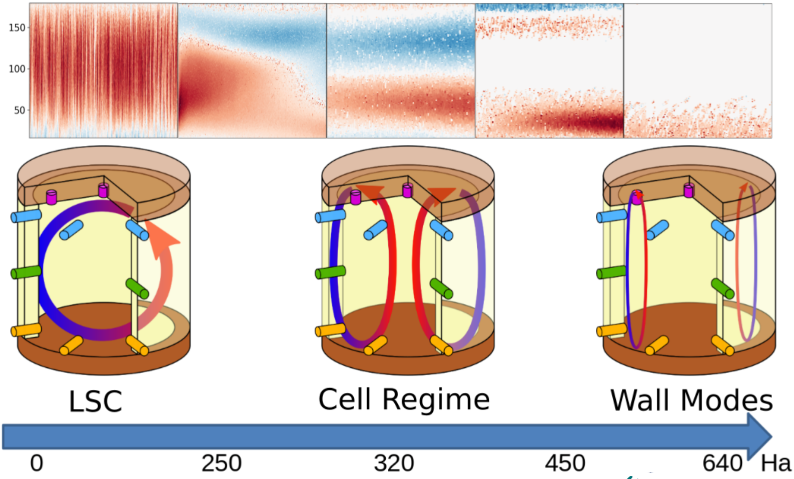
Flow Regimes



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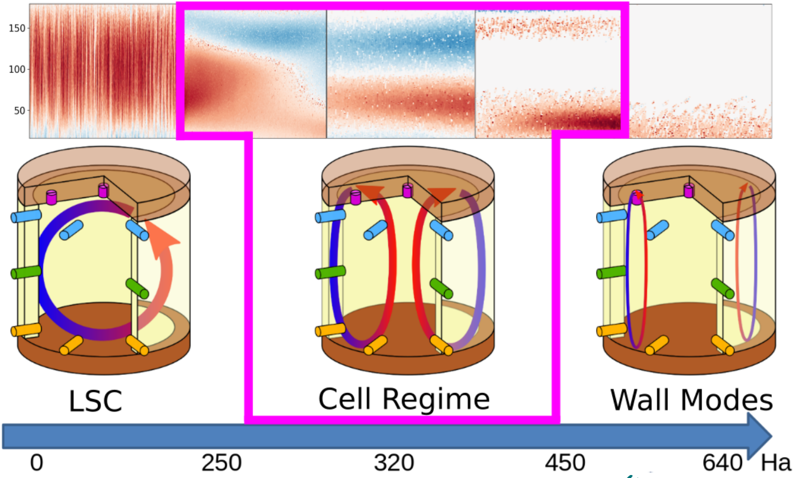
Flow Regimes



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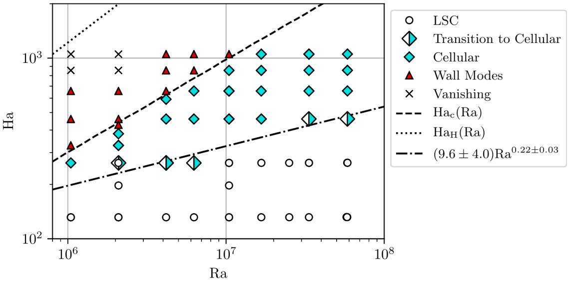
Flow Regimes: Cell Regime



- Large Scale Convection roll (LSC) below Ha=100
- 5 different cellular flow structures

Source figures: T. Zürner phd thesis submitted 2019 at TU Ilmenau

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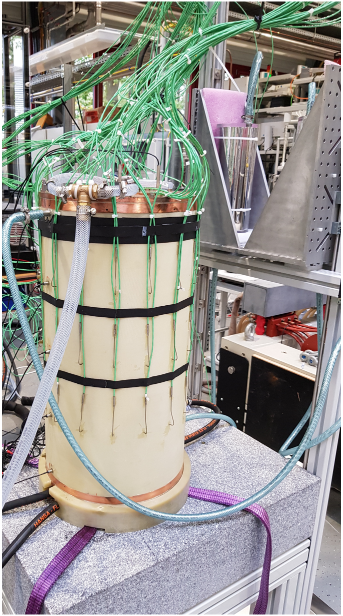
Outlook



- aspect ratio $\Gamma = \frac{1}{2}$
- filled with GaInSn alloy
- Ra$= 2 \times 10^7$ to 5×10^9
- combination of ultrasound probe, temperature and Contactless Inductive Flow Tomography (CIFT) measurements
- three-dimensional velocity measurement
- comparison to DNS

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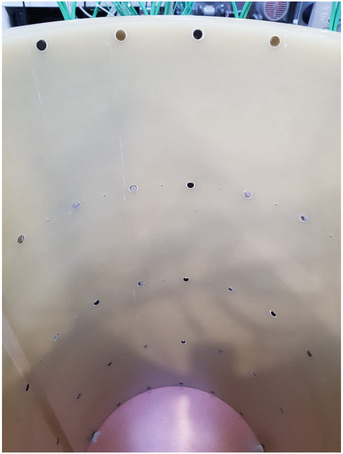
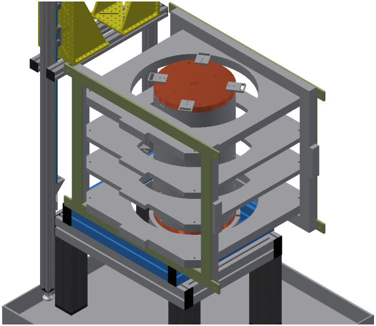
Outlook



inside view of cell with ultrasound probe positons



planned coil-configuration for inductive flow tomography

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References and Acknowledgements

- T. Zürner, F. Schindler, T. Vogt, S. Eckert, and J.Schumacher: *Combined Measurement of Velocity and Temperature in Liquid Metal Convection*, J. Fluid Mech. (2019), Volume 876, pp. 1108-1128
- T. Zürner, F. Schindler, T. Vogt, S. Eckert and J. Schumacher: *Flow regimes of Rayleigh-Bénard convection in a vertical magnetic field*, J. Fluid Mech. (2019), submitted

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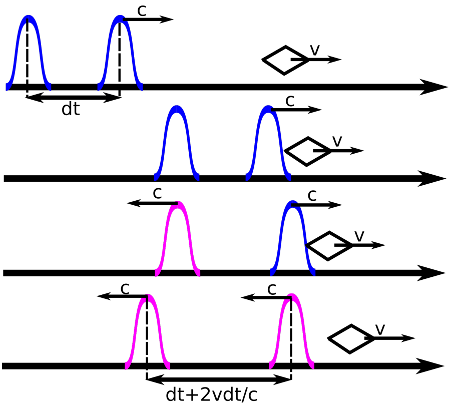
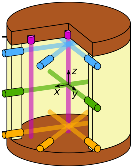
Ultrasound Velocimetry

Working Principle



- Multiple ultrasound impulses sent out
- Particles in flow reflect
- Position determined by traveling time
- Speed determined by delay



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Cellular Structures