LV 704161, SS 2025

Seminar mit Bachelorarbeit: Experimentalphysik

Themenauswahl der Forschungsgruppe

Ultracold Quantum Matter Theory

Betreuung:

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Themenliste, Stand 15.01.2025

- RB1: The Rayleigh-Taylor instability in a binary quantum fluid
- NM1: Bridging Supersolidity and the Josephson Effect

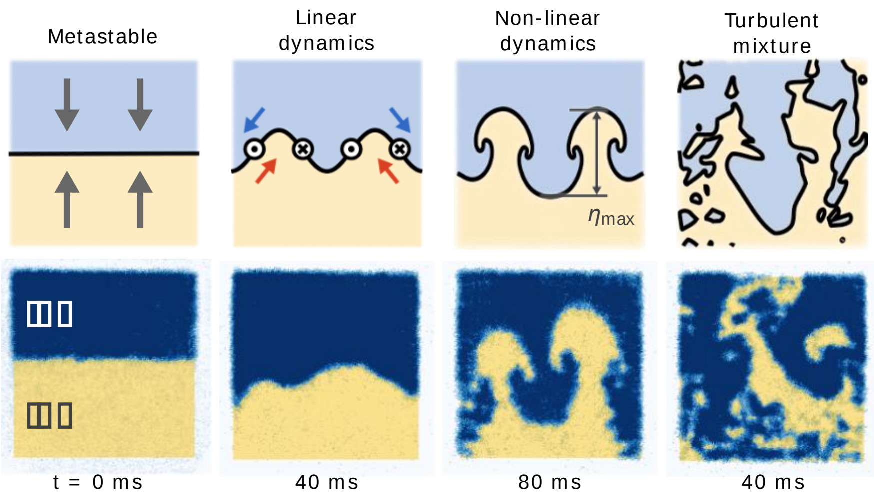
Bereits zugewiesene Projekte werden durchgestrichen, neue Projekte können laufend hinzugefügt werden.

RB1: The Rayleigh-Taylor instability in a binary quantum fluid

In nature, instabilities often give rise to large-scale structures, seeded by small fluctuations. The Rayleigh-Taylor instability (RTI), which occurs at the interface between two fluids of different densities, is a notable example. Its applications span a wide range, from the interface of oil and water to volcanic mushroom clouds and even supernova explosions.

Ultracold quantum gases might initially seem like an unlikely platform to realize the RTI, but a recent experiment-theory collaboration by Geng et al. has achieved exactly that. Beyond observing mushroom-like structures, they identified ripplon interface modes and vortex chains, highlighting both the similarities and the novel differences between the RTI in classical and quantum fluids.

This thesis will begin by introducing fundamental concepts of quantum gases and their excitations. It will then explore recent theoretical and experimental studies of the RTI from the perspective of quantum gases. Additionally, there will be an optional theoretical component to simulate the RTI.



Evolution of the Rayleigh-Taylor instability. The upper panels present schematics, while the lower panels display corresponding experimental results. Component 1 is shown in yellow, and component 2 depicted in blue. Figure adapted from Geng et al.

Literature:

- *The Rayleigh-Taylor instability in a binary quantum fluid*, Y. Geng et al., arXiv:2411.19807 (2025) (currently under peer review)
- *Interface dynamics of a two-component Bose-Einstein condensate driven by an external* force, Phys. Rev. A **83**, 043623 (2011)
- *Rayleigh-Taylor instability and mushroom-pattern formation in a two-component Bose-Einstein condensate*, Sasaki et al., Phys. Rev. A **80**, 063611 (2009)
- *Bose-Einstein Condensation and Superfluidity*, L. Pitaevskii and S. Stringari, Oxford University Press (2016) (available in university library)
- *A Primer on Quantum Fluids*, Carlo F. Barenghi and Nick G. Parker, Springer (2016) (open access version here)

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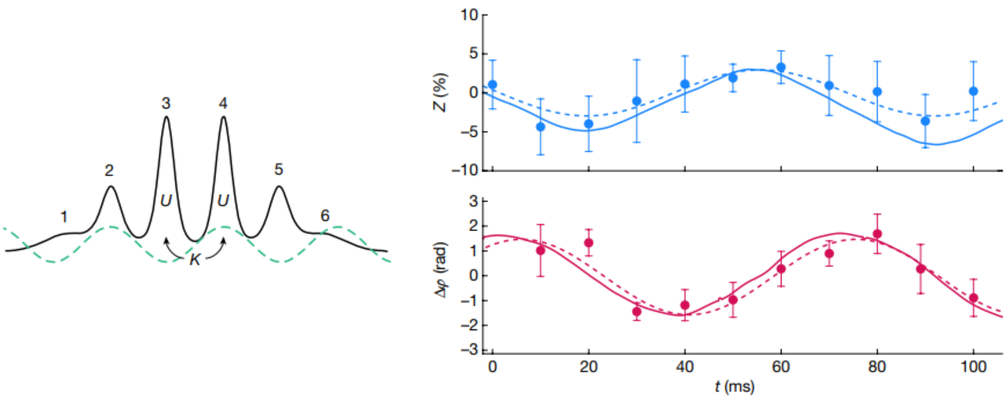
NM1: Bridging Supersolidity and the Josephson Effect

Supersolids are a fascinating state of matter that blend two seemingly contradictory properties: the frictionless flow of a superfluid and the rigid structure of a solid. This unique coexistence paves the way for exploring exotic quantum phenomena that push the boundaries of our understanding of matter.

In this thesis, we aim to investigate whether the flow of neutral particles in supersolids can serve as an analog to a supercurrent — the continuous flow of electrons in a Josephson junction, where two superconductors are separated by an insulating layer, requiring no applied voltage.

Starting with the fundamental concepts of ultracold gases, we will uncover the physics behind the exotic phase of matter – the supersolid. Building upon recent advancements in the field [see Biagioni et al.], this thesis also offers an optional theoretical possibility to numerically explore the self-induced Josephson effect in supersolids based on existing code.



Josephson oscillations in a supersolid. The left plot sketches the supersolid density profile with a black line. The right plots demonstrate the Josephson oscillations of the density imbalance (Z) and phase difference (Δϕ) in time. Figure adapted from Biagioni et al.

Literature:

- *Measurement of the superfluid fraction of a supersolid by Josephson effect,* Biagioni et al., Nature, 629, p. 773–777 (2024)
- *Bose-Einstein Condensation and Superfluidity*, L. Pitaevskii and S. Stringari, Oxford University Press (2016) (available in university library)
- *A Primer on Quantum Fluids*, Carlo F. Barenghi and Nick G. Parker, Springer (2016) (open access version here)

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