LV 704161, SS 2023

Seminar mit Bachelorarbeit: Experimentalphysik

Themenauswahl der Forschungsgruppe

Ultracold Quantum Matter Theory

Betreuung:

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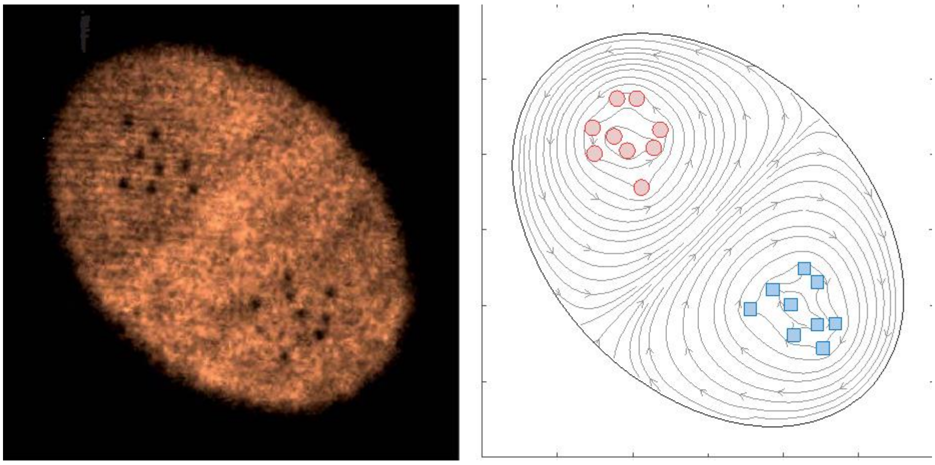
- Giant quantum vortex clusters
- ~~Supersonic expansion of a quantum gas~~

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

Giant quantum vortex clusters

In nature it is extremely common for large, isolated vortices to form, with examples arising in systems as diverse as turbulent liquids or plasmas, to the whirling storm that is Jupiter's Great Red Spot. In the middle of last century, Lars Onsager developed a theory to aid our understanding of the spontaneous formation of giant vortices that may, for example, arise when vortices of opposite circulation annihilate to leave the remaining vortices in *ultrahot* configurations. Despite Onsager's breakthrough, even now the topic of turbulence remains only partly understood.

Ultracold quantum gases may at first seem an unlikely platform for the study of ultrahot vortices but, in some sense, they present the perfect opportunity to explore Onsager's theory in its purest form, since the velocity profile of each vortex is inherently quantized, just like in Onsager's original description! This thesis will first introduce the fundamental concepts of quantum gases and their quantized vortices. Recent theoretical and experimental research of giant vortex clusters will be explored from the perspective of quantum gases, and along the way a deeper intuition will be developed for what temperature really is. There will be an optional theoretical component to simulate the generation and evolution of quantum vortices using existing computer code.



Left: Experiment showing two vortex clusters consisting of quantized vortices (black spots) in an ultracold quantum gas. Figure taken from Gauthier et al., Science **364**, 1264 (2019). Right: simulation showing vortices and flow contours.

Literature:

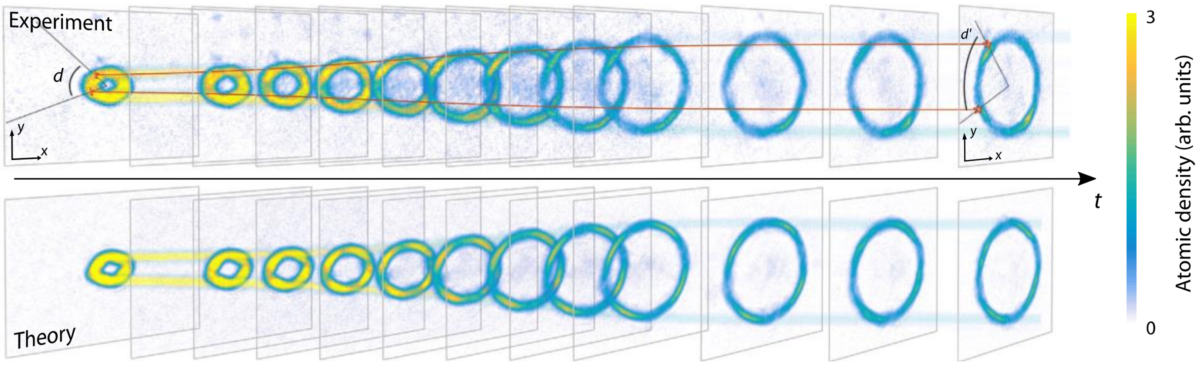
- *Rotating trapped Bose-Einstein condensates*, A. L. Fetter, Rev. Mod. Phys. 81, 647 (2009)
- *A Primer on Quantum Fluids*, Carlo F. Barenghi and Nick G. Parker, Springer (2016) (open access version here)
- *Emergence of Order from Turbulence in an Isolated Planar Superfluid*, Simula et al., Phys. Rev. Lett. **113**, 165302 (2014)
- *Giant vortex clusters in a two-dimensional quantum fluid*, Gauthier et al., Science **364**, 1264 (2019)
- *True Mechanism of Spontaneous Order from Turbulence in Two-Dimensional Superfluid Manifolds*, Kanai et al., Phys. Rev. Lett. 127, 095301 (2021)

For further information please contact Russell Bisset

Supersonic expansion of a quantum gas

Can concepts of an expanding universe be studied in the lab by analogy? A remarkable experiment by Eckel et al. forced an ultra-cold quantum gas to expand hypersonically, after which they observed redshifts of the long-wavelength excitations, as well as the production of topological defects.

This thesis will first introduce the fundamental concepts of quantum gases and their possible excitations, such as sound waves, solitons and quantized vortices. There will be an optional theoretical component to explore the interplay of such excitations by conducting dynamic computer simulations using existing code. Then the experiment by Eckel et al. will be presented and discussed.



Supersonic expansion of a Bose-Einstein condensate ring. Experiment (top) versus theory (bottom). Figure taken from Eckel et al..

Literature:

- *A Rapidly Expanding Bose-Einstein Condensate: An Expanding Universe in the Lab*, S. Eckel, A. Kumar, T. Jacobson, I. B. Spielman, and G. K. Campbell, Physical Review X **8**, 021021 (2018)
- *A Primer on Quantum Fluids*, Carlo F. Barenghi and Nick G. Parker, Springer (2016) (open access version here)
- *Bose-Einstein Condensation and Superfluidity*, L. Pitaevskii and S. Stringari, Oxford University Press (2016) (available in university library)

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