Strongly Correlated Quantum Matter Group

AG Nägerl

www.quantummatter.at

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universität innsbruck

FOR 2247

FWF Der Wissenschaftsfonds.

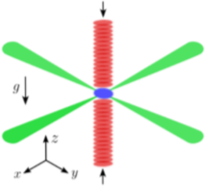
erc

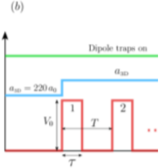
Atoms, Light, and Molecules Innsbruck Physics Research Center

Group structure

RbCs

Strongly interacting driven systems





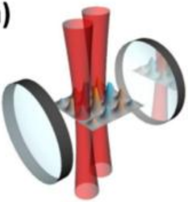
Cs III

Investigation of quantum dynamics in highly interacting quantum wires

CavYt (under construction)

Yb atoms in tweezer arrays, coupled via photon exchange

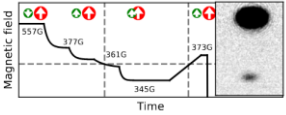
a)

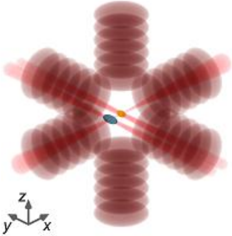


KCs

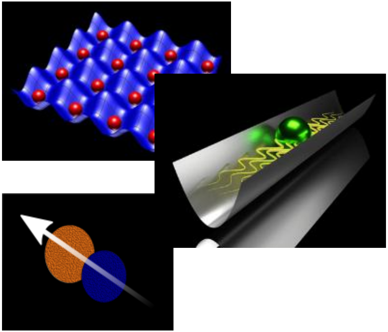
Creation of dipolar molecules under quantum microscope

a)





Research Highlights



- Quantum simulation
- Many-body quantum dynamics
- Novel quantum phases of matter

Formation of ultracold $^{39}K^{133}Cs$ Feshbach molecules, C. Beulenkamp et al., arxiv 2506.16520 (2025).

Spectroscopy and ground state transfer of ultracold bosonic $^{39}K^{133}Cs$ molecules, K.P. Zamarski et al., Phys.Rev.Lett. 135 (2025).

Observing Bethe strings in an attractive Bose gas far from equilibrium, M. Hovarth, et al. arxiv 2505.10550 (2025).

Anyonization of bosons in one dimension: an effective swap model, A.Wang et al. Phys.Rev.Lett. (2025).

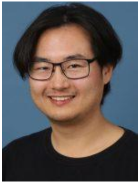
Origin and emergent features of many-body dynamical localization, A. Yang et al. arxiv 2503.04683 (2025).

Observing anyonization of bosons in a quantum gas, S. Dahr et al. Nature 642 (2025).

Observation of many-body dynamical localization, Y. Guo et al. Science 389 (2025).

Bachelor project: Unlocking Quantum Intuition

Numerical Simulation of Full Many-Body 1D Dynamics



Dr. Yi Zeng

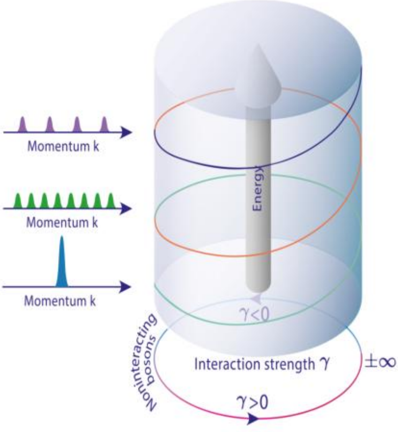
In this project, you will simulate the **time-evolution** of quantum systems. You will gain a deep, visual, and intuitive understanding of quantum dynamics that purely analytical or experimental projects rarely offer.

What you will do

- Learn from existing simulation code and implement it in the supercomputing cluster.
- Simulate and benchmark with known physics
- Simulate 1D topological pumping and compare with experimental results.

What you will learn

- Computational Physics: Master numerical techniques for simulating full-many body physics.
- Quantum Fundamentals: Form intuitive understanding of wavefunctions, coherence and correlations.
- Research Skills: Directly applicable to theoretical and experimental work in our group

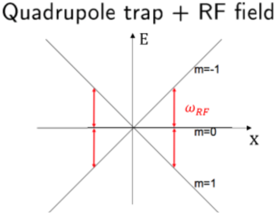


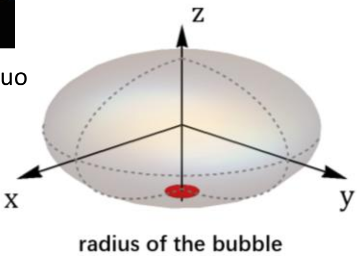
Designing an RF-Dressed Bubble Trap for Ultracold Cesium Atoms

Project Goal

To design and analyze an RF-dressed bubble trap for 133 Cs atoms, starting from atomic Zeeman structure and ending with experimentally relevant trap parameters.

Dr. Yianliang Guo





Project Milestones

1. **Atomic Structure and Zeeman Shifts**
   Understand the hyperfine and Zeeman structure of Cs. Identify states suitable for RF dressing.

3. **Magnetic Field Geometry and Bubble Shape**
   Model standard magnetic-field configurations.
   Calculate and visualize the spatial shape of the resonant bubble surface.

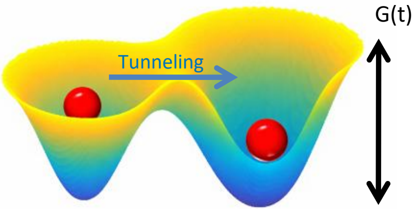
4. **RF-Dressed Potential and Trap Properties**
   Compute the effective RF-dressed potential.
   Estimate shell thickness, radial confinement, and typical
   trap frequencies.

Theoretical study of a BEC in driven double-well potential:

BEC in optical potentials are a key platform for quantum simulation. In specific, double-well potentials are a simple scenario to study how condensates behave, allowing to extrapolate to more complex phenomena. Moreover, the implementation of periodic drivings bring a poweful tool to exhibit quantum behaviour.

- The project aims for you to study the tunneling dynamics of BEC in the presence of a periodic driving. Consists on a theory revision of the Gross-Pitaeskii equation, Floquet theory accompanied with numerical simulations.

Emilio Aguilera

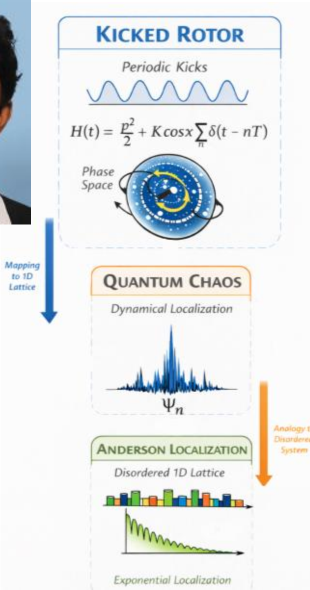


Quantum kicked rotor: Anderson localization in momentum space

Anderson localization is a phenomenon observed for electrons in a disordered potential. An analog can be replicated in momentum space for a quantum mechanical setup with cold atoms. This shows the power of quantum simulations using cold atoms, allowing to study rich physics observable in condensed matter systems.

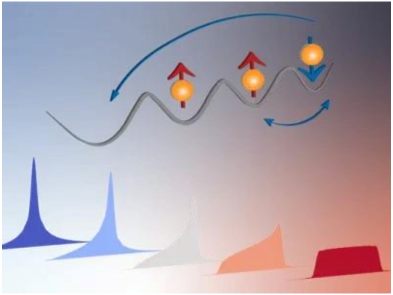
- The project aims to study BEC theory, Floquet theory, quantum chaos and classicallity. Consists of doing a theory review accompanied with numerical simulations.

Karthick Ramanthan



Bachelor projects

Exploring quantum fluids with fractional quantum statistics



- Anyons are quasiparticles that are neither bosons nor fermion. Instead they obey fractional quantum statistics.
- Recently 1D anyons were realized in cold atom experiments [1,2]
- We want to further explore these systems by measuring how excitations (e.g. sound waves, bound states) travel in such systems.
- What's cool about them?
  - They are chiral→ prefer to travel in one direction
  - Different propagation velocities in different directions
  - Can form bound states even without interaction

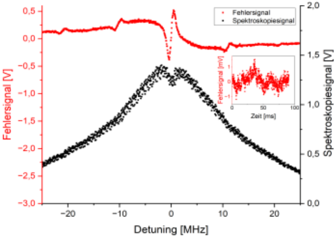
Sudipta Dahr

1. J. Kwan et al., Science 386, 1055 (2024)
2. S. Dhar et al., Nature 642, 53 (2025).

Master projects: on request

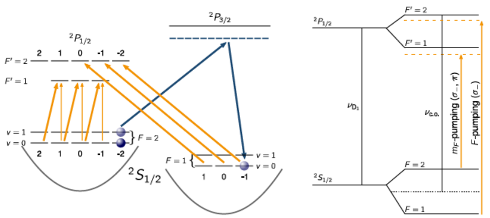
Recent examples:

- Erik Richter-Alten, Stabilizing a laser system for cooling and trapping of Ytterbium atoms (2025).



- Florian Reiter, Raman Sideband Spectroscopy and Optical Pumping for Imaging Purposes of 39K in an Optical Lattice (2023).

3. Raman Sideband Spectroscopy and Optical Pumping



(a) Scheme for RSC of ^{39}K

(b) Energy levels for F- and m_F-pumping