Q 50: Quantum Gases (joint session Q/A)

Time: Thursday 14:30–16:30 Location: Aula

Q 50.1 Thu 14:30 Aula

Braiding Laughlin quasi-holes in ultracold atoms using Ramsey interferometry — •Felix Palm[1,2], Nader Mostaan[1,2], Nathan Goldman[2], and Fabian Grusdt[1] — [1]LMU Munich & MCQST, Munich, Germany — [2]CENOLI, Université Libre de Bruxelles, Brussels, Belgium

Braiding non-Abelian anyons in topologically ordered systems has been proposed as a possible route towards topologically protected quantum computing. While recent experiments based on various platforms have made significant progress towards this goal, coherent control over individual anyonic excitations has still not been achieved today. At the same time, progress in cold-atom quantum simulators resulted in the realization of a two-boson $\nu = 1/2$-Laughlin state, a paradigmatic fractional quantum Hall state hosting Abelian anyonic quasi-holes.

Here we show that cold atoms in quantum gas microscopes are a suitable platform to create and manipulate these quasi-holes. First, we show that a Laughlin state of eight bosons can be realized by connecting small patches accessible in experiments. Next, we demonstrate that two cross-shaped pinning potentials are sufficient to create two quasi-holes in this Laughlin state. Starting with these two quasi-holes we numerically perform an adiabatic exchange procedure, and reveal their semionic braiding statistics for various exchange paths, thus clarifying the topological nature of these excitations. Finally, we propose an experimentally feasible interferometry protocol to probe the braiding phase in quantum gas microscopes, using a two-level impurity immersed in the fractional quantum Hall fluid.

Q 50.2 Thu 14:45 Aula

Adiabatic Preparation of a Chiral Spin Liquid — •Moritz Schlechtriem, Francesco Petiziol, and André Eckardt — Technische Universität Berlin, Institut für Theoretische Physik, Hardenbergstraße 36, 10623 Berlin, Germany

Efficient protocols to prepare spin-liquid states are essential for exploring these phases of matter and harnessing their potential for applications. The goal of this study is to investigate the adiabatic preparation of a chiral spin liquid ground state on the Kagome lattice. Considering different easily-realizable initial Hamiltonians and different system sizes, the minimal duration for a high-fidelity adiabatic transition into the spin-liquid phase is determined and optimal adiabatic paths are explored. In a second step, the analysis is extended to the case in which the spin-liquid Hamiltonian is realized via Floquet engineering.

Q 50.3 Thu 15:00 Aula

The anyon-Hubbard model: From few to many-body — •Martin Bonkhoff — I. Institut für Theoretische Physik, Universität Hamburg

Recent experimental progress in the engineering of density-dependent Peierls phases has rekindled the interest in one-dimensional anyonic lattice models of the Hubbard type. We review specific ground-state properties of such anyons on hand of the single-species anyon-Hubbard model. Thereby we focus primarily on the distinction between few-particle systems, or very small system sizes, and a real many-body setting [2,3]. For the former case we use integrable techniques to study the properties of the model, which is contrasted then with field-theoretical methods for long-wavelengths. The emphasis is thereby on the coherence properties of the model that are intrigiungly modified by the statistical interactions in contrast to ordinary, local inter-particle interactions. We find a quite different phenomenology for the two regimes and discuss related experimental challenges.

[1] Martin Bonkhoff, Simon B. Jäger, Imke Schneider, Axel Pelster, and Sebastian Eggert, Phys. Rev. B 108, 155134 (2023)

[2] Martin Bonkhoff, Kevin Jägering, Sebastian Eggert, Axel Pelster, Michael Thorwart, and Thore Posske, Phys. Rev. Lett. 126, 163201 (2021)

Q 50.4 Thu 15:15 Aula

Bogoliubov theory of 1D anyons in a lattice — •Binhan Tang[1], Axel Pelster[1], and Martin Bonkhoff[2] — [1]Physics Department and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany — [2]I. Institute for Theoretical Physics, Universität Hamburg, Germany

In a one-dimensional lattice anyons can be defined via generalized commutation relations containing a statistical parameter, which interpolates between the boson limit and the pseudo-fermion limit. The corresponding anyon-Hubbard model is mapped to a Bose-Hubbard model via a fractional Jordan-Wigner transformation, yielding a complex hopping term with a density-dependent Peierls phase. Here we work out a corresponding Bogoliubov theory. To this end we start with the underlying mean-field theory, where we allow for the condensate a finite momentum and determine it from extremizing the mean-field energy. With this we calculate various physical properties and discuss their dependence on the statistical parameter and the lattice size. Among them are both the condensate and the superfluid density as well as the equation of state and the compressibility. Based on the mean-field theory we then analyse the resulting dispersion of the Bogoliubov quasi-particles, which turns out to be in accordance with the Goldstone theorem. In particular, this leads to two different sound velocities for wave propagations to the left and the right, which originates from parity breaking.

Q 50.5 Thu 15:30 Aula

Hamiltonian learning for quantum field theories — Robert Ott[1,2], Torsten Zache[1,2], •Maximilian Prüfer[3], Sebastian Erne[3], Mohammadamin Tajik[3], Hannes Pichler[1,2], Jörg Schmiedmayer[3], and Peter Zoller[1,2] — [1]Institute for Theoretical Physics, University of Innsbruck — [2]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences — [3]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien

Synthetic quantum systems, such as those based on bosonic quantum gases, offer an excellent opportunity to study complex phenomena arising in quantum many-body physics. Recently, a set of efficient tools called Hamiltonian learning (HL) has been developed to uncover the underlying microscopic interactions in quantum systems from experiments. While HL is well developed for discrete lattice-based many-body systems, its application to continuous quantum systems faces a challenge due to the absence of a lattice scale. In this work, we propose a protocol that capitalizes on the locality of effective field theories to extract their Hamiltonians from experimental data. By varying the resolution scale of the measurements, our protocol gives access to the scale dependence of coupling parameters reminiscent of the running of couplings with the renormalization group flow. To demonstrate the effectiveness of our method, we apply it to theoretical studies of both classical and quantum fields. We furthermore showcase its application in an ultracold quantum gas experiment, learning the Hamiltonian underlying its classical statistical description.

Q 50.6 Thu 15:45 Aula

Towards simulation of lattice gauge theories with ultracold ytterbium atoms in hybrid optical potentials — •Rene Villela[1,2], Tim Höhn[1,2], Etienne Staub[1,2], Leonardo Bezzo[1,2], Ronen Kroeze[1,2], and Monika Aidelsburger[1,2,3] — [1]Ludwig-Maximilians-Universität, München, Germany — [2]Munich Center for Quantum Science and Technology, München, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

Gauge theories play a fundamental role in our understanding of nature, ranging from high-energy to condensed matter physics. Their formulation on a regularized periodic lattice geometry, so-called lattice gauge theories (LGTs), has proven invaluable for theoretical studies, as numerical studies on, e.g., their real-time dynamics are computationally challenging. We report progress on developing a quantum simulator for LGTs using neutral ytterbium atoms. Ytterbium's internal level structure provides a ground and metastable clock state pair, and fermionic isotopes further host nuclear spin degrees of freedom. We combine optical lattice and optical tweezers technology that can enable robust and scalable implementation of LGTs. To realize state-selective control, which is key for our approach to simulate LGTs, we exploit magic and tune-out wavelengths. We present the first measurements of such wavelengths near the narrow cooling transition at 556 nm and discuss prospects in implementing local gauge invariance.

Q 50.7 Thu 16:00 Aula

Fast preparation of cold Ytterbium gases for Rydberg quantum optics experiments — •Xin Wang, Thilina Muthuarachchige, Tangi Legrand, Ludwig Müller, Wolfgang Alt,

Eduardo Uruñuela, and Sebastian Hofferberth — Institute of Applied Physics, University of Bonn, Germany

Mapping the strong interaction between Rydberg excitations in ultracold atomic ensembles onto single photons paves the way to realize and control high optical nonlinearities at the level of single photons. Demonstrations of photon-photon gates or multi-photon bound states based on this concept have so far exclusively employed ultracold alkali atoms. Two-valence electron species, such as Ytterbium, offer unique novel features namely narrow-linewidth laser-cooling, optical detection and ionization or long-lived nuclear-spin memory states.

In this talk, we present our experimental progress towards the realization of strong photon-photon interactions, mediated by the Yb-174 Rydberg polaritons formed in a 1-D ultracold Ytterbium gas. Specifically, we discuss our compact two-chamber experimental design enabling fast production of ultracold Yb-174 gases at high density. Instead of an oven and Zeeman slower, we use a fast-loading two-stage hybrid MOT sequence to prepare and load the atoms in an elongated dipole trap, where we generate Rydberg polaritons under Rydberg electromagnetically induced transparency. Owing to the zero nuclei spin of Yb-174 and singlet spin state in bivalent structure, longer coherent times are expected compared to experiments with alkali atoms.

Q 50.8 Thu 16:15 Aula

Borromean states in a one-dimensional three-body system — •Tobias Schnurrenberger[1], Lucas Happ[2], and Maxim Efremov[1] — [1]German Aerospace Center (DLR), Institute of Quantum Technologies, 89081, Ulm, Germany — [2]Few-body Systems in Physics Laboratory, RIKEN Nishina Center for Accelerator-Based Science, Wako, Saitama 351-0198, Japan

We show the existence of Borromean states in a one-dimensional quantum three-body system composed of two identical, heavy bosons and a different, lighter particle. It is assumed that there is no interaction between the two bosons, while the heavy-light subsystems do not have a bound state. Within the framework of the Faddeev equations, the three-body spectrum and the corresponding wave-functions are computed numerically. In addition, we identify the parameter-space region of the heavy-light interaction, where the Borromean states occur, investigate their dependence on the mass ratio, and evaluate their geometric properties.