Q 58: Ultra-cold Atoms, Ions and BEC IV (joint session A/Q)

Time: Friday 11:00–13:00 Location: HS 1098

Q 58.1 Fri 11:00 HS 1098

Accurate and efficient Bloch-oscillation-enhanced atom interferometry — •Florian Fitzek[1,2], Jan-Niclas Kirsten-Siemss[2], Ernst M. Rasel[2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Bloch oscillations of atoms in optical lattices offer a powerful technique to significantly enhance the sensitivity of atom interferometers by orders of magnitude. To fully exploit the potential of this method, an accurate theoretical description of losses and phases beyond current treatments is essential. In this work, we introduce a comprehensive theoretical framework for Bloch-oscillation-enhanced atom interferometry [Fitzek *et al.*, arXiv:2306.09399]. We confirm its accuracy through comparison with an exact numerical solution of the Schrödinger equation [Fitzek *et al.*, Sci Rep 10, 22120 (2020)]. Using our approach, we define the fundamental efficiency and accuracy limits of Bloch-oscillation-enhanced atom interferometers and establish design criteria to achieve their saturation. We compare these limits to current state-of-the-art atom interferometers and formulate requirements for the improvement of future quantum sensors.

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Q 58.2 Fri 11:15 HS 1098

Quantum fluctuations in one-dimensional supersolids — •Chris Bühler, Tobias Ilg, and Hans Peter Büchler — Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, University of Stuttgart

In one dimension, quantum fluctuations prevent the appearance of long-range order in a supersolid, and only quasi-long-range order can survive. We derive this quantum critical behavior and study its influence on the superfluid response and properties of the solid. The analysis is based on an effective low-energy description accounting for the two coupled Goldstone modes. We find that the quantum phase transition from the superfluid to the supersolid is shifted by quantum fluctuations from the position where the local formation of a solid structure takes place. For current experimental parameters with dipolar atomic gases, this shift is extremely small and cannot be resolved yet, i.e., current observations in experiments are expected to be in agreement with predictions from mean-field theory based on the extended Gross-Pitaevskii formalism.

https://journals.aps.org/prresearch/abstract/10.1103/PhysRevResearch.5.033092

Q 58.3 Fri 11:30 HS 1098

Realizing freely programmable passively phase-stable 2D optical lattices — David Wei[1,2], •Daniel Adler[1,2], Kritsana Srakaew[1,2], Suchita Agrawal[1,2], Pascal Weckesser[1,2], Immanuel Bloch[1,2,3], and Johannes Zeiher[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 Munich, Germany

Ultracold atoms in optical lattices have become a vital platform for experimental quantum simulation, enabling the precise study of a variety of quantum many-body problems. For most experiments, the layout of the lattice beams restricts the accessible lattice configurations and thus the underlying physics. Here, we present a novel tunable lattice, which provides programmable unit cell connectivity and in principle allows for changing the geometry mid-sequence. Our approach builds on the phase-stable realization of a square or triangular lattice combined with microscopically projected repulsive local potential patterns. We benchmark the performance of this system through single-particle quantum walks in the square, triangular, kagome, and Lieb lattices. In the strongly correlated regime, we microscopically characterize the geometry dependence of the quantum fluctuations.

Q 58.4 Fri 11:45 HS 1098

Phase diagram of the extended anyon Hubbard model in one dimension — •Imke Schneider[1], Martin Bonkhoff[2], Kevin Jägering[1], Shijie Hu[3], Axel Pelster[1], and Sebastian Eggert[1] — [1]University of Kaiserslautern-Landau, Landesforschungszentrum OPTIMAS — [2]Universität Hamburg — [3]Beijing Computational Science Research Center

Anyons with arbitrary exchange angle can be realized using ultracold atoms in optical lattices. Here, we study the anyonic extended Hubbard model in one dimension. At unit filling a repulsive next-nearest neighbor interaction generally leads to gapped phases but it is far from trivial which correlations are the dominant ones as a function of topological exchange angle and on-site interaction U. We find that a careful derivation of all terms in the Luttinger liquid theory predicts an intermediate phase between a Mott insulator for large repulsive U and a charge density wave at negative U. As a function of exchange angle the intermediate phase changes from Haldane insulator for pseudo bosons to a dimerized phase for pseudo fermions at an interesting multicritical point. Our results are confirmed by extensive numerical simulations.

Q 58.5 Fri 12:00 HS 1098

Spontaneous ignition of an ion trap engine — •Peter Stabel, Diego Fieguth, and James Anglin — RPTU Kaiserslautern

Do the microscopic roots of thermodynamics extend even before the onset of chaotic ergodization, into the integrable Hamiltonian mechanics of small, isolated systems? Here we propose a set of experiments on the three-dimensional motion of a single ion in a linear Paul Trap, in which the focus is not on any form of thermalization, but on the engine-like secular transfer of energy between fast and slow degrees of freedom, analogous to the rapid motions of hot gas particles slowly lifting a weight. The ion's three motional degrees of freedom constitute the entire system, which is isolated and undriven; a high-frequency transverse vibrational mode of the ion plays the role of a battery or fuel tank, or hot reservoir to power steady axial motion against an opposing force. We show that this combustion engine-like system can generically run autonomously, but that only under a certain more stringent condition can the engine also start autonomously. This non-trivial condition for autonomous starting of the engine-like process can be derived from unitarity, via the classical Kruskal-Neishtadt-Henrard theorem and its recent quantum extension. Although these post-adiabatic theorems do not involve ergodization, they do involve a certain increase of phase space areas, or subspace dimensions, and may play a role similar to that played macroscopically by thermodynamics, in constraining the design of microscopic autonomous machines.

Q 58.6 Fri 12:15 HS 1098

Emergence of a Bose polaron in a small ring threaded by the Aharonov-Bohm flux — •Fabian Brauneis[1], Areg Ghazaryan[2], Hans-Werner Hammer[1,3], and Artem Volosniev[2] — [1]Technische Universität Darmstadt, Department of Physics, 64289 Darmstadt, Germany — [2]Institute of Science and Technology Austria (ISTA), 3400 Klosterneuburg, Austria — [3]ExtreMe Matter Institute EMMI and Helmholtz Forschungsakademie Hessen für FAIR (HFHF), 64291 Darmstadt, Germany

The model of a ring threaded by the Aharonov-Bohm flux underlies our understanding of a coupling between gauge potentials and matter. The typical formulation of the model is based upon a single particle picture, and should be extended when interactions with other particles become relevant. Here, we illustrate such an extension for a particle in an Aharonov-Bohm ring subject to interactions with a weakly interacting Bose gas. Our findings demonstrate that the system's ground state can be effectively characterized using the Bose polaron concept – a particle dressed by interactions with a bosonic environment. Our results suggest the Aharonov-Bohm ring as a platform for the few- to many-body crossover of quasi-particles that arise from an impurity immersed in a medium.

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Q 58.7 Fri 12:30 HS 1098

Effective Theory for the Gaudin-Yang model — •Timothy George Backert[1], Hans-Werner Hammer[1,3], Artem Volosniev[2], Fabian Brauneis[1], Joachim Brand[4], and Matija Čufar[4] — [1]Technische Universität Darmstadt, Department of Physics

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We investigate the crossover from a Bardeen-Cooper-Schrieffer superfluid with loosely bound Cooper pairs to a Bose-Einstein condensate of tightly bound dimers (molecules) for a one-dimensional spin-1/2 Fermi gas (Gaudin-Yang model [GY]) on a ring. We obtain exact Bethe-Ansatz solutions which describe the BCS-BEC crossover in the form of a transition from a (BCS-like) gas of loosely bound fermion pairs to a Tonks-Girardeau gas of tightly bound dimers. For the experimentally relevant case of an external potential only numerical solutions can be obtained. In order to obtain analytical insights into the case with an external potential, we set up an effective theory with fermions and dimers as degrees of freedom and determine the coupling constants by matching to the Bethe-Ansatz results. We find good agreement with the numerical results for small particle numbers. This paves the way for the exploration of many-body systems using this effective theory.
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Q 58.8 Fri 12:45 HS 1098

Three-charged-particle systems in the framework of coupled coordinate-space few-body equations — •Renat Sultanov — Odessa College, Department of Mathematics, 201 W. University Blvd. Odessa, TX USA

We study *three-charged-particle* low-energy elastic collision and particle-exchange reaction with special attention to the systems with Coulomb and an additional nuclear interaction employing a close-coupling expansion scheme to a set of coupled two-component few-body equations [1]. First we apply our formulation to compute low-energy elastic scattering phase shifts for the $d+(t\mu^-)_{1s}$ collision, which is of significant interest for the muon-catalyzed-fusion D-T cycle. Next, we study the particle-exchange reaction $d+(pX^-) \to p+(dX^-)$ with the long-lived elementary heavy lepton stau X^- which can play a critical role in the understanding of the Big-Bang nucleosynthesis and the nature of dark matter. We also study the total cross sections and rates for two particle-exchange reactions involving antiprotons ($\bar{p}$), deuteron (d) and triton (t), e.g., $\bar{p}+(d\mu^-)_{1s} \to (\bar{p}d)_{1s}+\mu^-$ and $\bar{p}+(t\mu^-)_{1s} \to (\bar{p}t)_{1s}+\mu^-$, where μ^- is a muon. The effect of the final state short-range strong ($\bar{p}d$) and ($\bar{p}t$) nuclear interactions is significant in these reactions, which increases the reaction rates by a factor of $\approx$3. Additionally (if time permits), a 3-body $\bar{p}+Mu$ collision will be discussed, where Mu is a muonium atom [2].

1. R. A. Sultanov and S. K. Adhikari, Phys. Rev. C 107, 064003 (2023).
2. R. A. Sultanov and D. Guster, J. Phys. B 46, 215204 (2013).