Q 49: Ultra-cold atoms, ions and BEC III (joint session A/Q)

Time: Thursday 10:30–12:15 Location: A-H2

Invited Talk Q 49.1 Thu 10:30 A-H2

Chemistry of an impurity in a Bose-Einstein condensate — •Arthur Christianen[1,2], Ignacio Cirac[1,2], and Richard Schmidt[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Munich Center for Quantum Science and Techonology, Munich, Germany

In ultracold atomic gases, a unique interplay arises between phenomena known from condensed matter, few-body physics and chemistry. Similar to an electron in a solid, a quantum impurity in an atomic Bose-Einstein condensate is dressed by excitations from the medium, forming a polaron quasiparticle with modified properties. At the same time, the atomic impurity can undergo the chemical reaction of three-body recombination with atoms from the BEC, which can be resonantly enhanced due to universal three-body Efimov bound states crossing the continuum. As an intriguing example of chemistry in a quantum medium, we show that such Efimov resonances are shifted to smaller interaction strenghts due to participation of the polaron cloud in the bound state formation. Simultaneously, the shifted Efimov resonance marks the onset of a polaronic instability towards the decay into larger Efimov clusters and fast recombination.

References: [1] A. Christianen, J.I. Cirac, R. Schmidt, "Chemistry of a light impurity in a Bose-Einstein condensate", arXiv:2108.03174 [2] A. Christianen, J.I. Cirac, R. Schmidt, "From Efimov Physics to the Bose Polaron using Gaussian States", arXiv:2108.03175

Q 49.2 Thu 11:00 A-H2

Formation of spontaneous density-wave patterns in DC driven lattices – an experimental study — •Henrik P. Zahn, Vijay P. Singh, Marcel N. Kosch, Luca Asteria, Lukas Freystatzky, Klaus Sengstock, Ludwig Mathey, and Christof Weitenberg — Universität Hamburg, Hamburg, Deutschland

Driving a many-body system out of equilibrium induces phenomena such as the emergence and decay of transient states, which can manifest itself as pattern and domain formation. The understanding of these phenomena expands the scope of established thermodynamics into the out-of-equilibrium domain. Here, we observe the out-of-equilibrium dynamics of a Bose-Einstein condensate in an optical lattice subjected to a strong DC field, realized by strongly tilting the lattice. We observe the emergence of pronounced density wave patterns – which spontaneously break the underlying lattice symmetry – using a novel single-shot imaging technique with two-dimensional single-site resolution in three-dimensional systems, which also resolves the domain structure. Further, we investigate formation and decay time scales of the pattern formation as well as the role of tunnelling transverse to the tilt for the type of emerging pattern.

Q 49.3 Thu 11:15 A-H2

Formation of spontaneous density-wave patterns in DC driven lattices - a theoretical study — •Lukas Freystatzky[1,2], Vijay Singh[1,3], Henrik Zahn[4], Marcel Kosch[4], Luca Asteria[4], Klaus Sengstock[1,2,4], Christof Weitenberg[2,4], and Ludwig Mathey[1,2,4] — [1]Zentrum für optische Quantentechnologien, Universität Hamburg, Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Hamburg, Germany — [3]Institut für Theoretische Physik, Leibniz Universität Hannover, Hanover, Germany — [4]Institut für Laserphysik, Universität Hamburg, Hamburg, Germany

We study the phenomenon of spontaneous density-wave patterns, which emerges in a Bose-Einstein condensate in an optical lattice subjected to a strong DC field, realized by strongly tilting the lattice. We use dynamical classical field simulations and analytical approaches to analyse the out-of-equilibrium dynamics of the system, which shows the emergence of pronounced density-wave patterns that spontaneously break the underlying lattice symmetry. This observation and the corresponding formation and decay time scales of the pattern formation are consistent with the measurements. We identify the dominant processes using Magnus expansion and describe the emergence of the density wave pattern in a perturbative approach.

Q 49.4 Thu 11:30 A-H2

Exploring orbital extensions of the Fermi-Hubbard model with ultracold ytterbium atoms — •Giulio Pasqualetti[1,2,3], Oscar Bettermann[1,2,3], Nelson Darkwah Oppong[1,2,3], Immanuel Bloch[1,2,3], and Simon Fölling[1,2,3] — [1]Ludwig-Maximilians-Universität, Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

The Fermi-Hubbard model (FHM) represents a paradigmatic milestone in condensed-matter physics. In the last decades, neutral atoms in optical lattices have become a powerful platform for investigating its properties in a clean and well-controlled environment. However, experiments have so far mostly explored the single-orbital limit of the FHM.

Here, we explore orbital extensions of the FHM with ultracold ytterbium atoms. The electronic ground state of neutral ytterbium possesses a SU(N) symmetry, which allows the study of the FHM with larger spin multiplicity. Moreover, a metastable electronic state known as the clock state can serve as a completely independent orbital degree of freedom, enabling the study of the mass-imbalanced FHM utilizing state-dependent potentials. In our experiment, we probe these orbital extensions of the FHM in different dimensionalities, investigating their spectroscopic properties, their thermodynamics, and dynamic response.

Q 49.5 Thu 11:45 A-H2

Quantum thermodynamics: Heat leaks and fluctuation dissipation — •Oleksiy Onishchenko[1], Daniël Pijn[1], Janine Hilder[1], Ulrich Poschinger[1], Raam Uzdin[2], and Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Mainz, Germany — [2]Fritz Haber Center for Molecular Dynamics, The Hebrew University, Jerusalem, Israel

Quantum thermodynamics focuses on extending the notions of heat and work to microscopic systems, where the concepts of non-commutativity and measurement back-action play a role [1]. In this work, we show a novel way to test the unitary functioning of a quantum processor by detecting heat leaks [2]. We also observe the first experimental signatures of operator non-commutativity on work fluctuations, as suggested theoretically [3]. Our experimental system consists of one or multiple Ca+ ion qubits held in a microstructured Paul trap. We initialize qubits in a statistical mixture of |0> and |1>, thus emulating thermal states. For the heat leak test, we reveal the amount of non-unitary evolution of the system qubits by measuring only in the computational basis and without accessing the environment. For the quantum work measurement, we set the operation and measurement bases to be non-commuting, and then evaluate the resulting work distribution.

[1] Sai Vinjanampathy and Janet Anders, Contemporary Physics 57, 545-579 (2016).

[2] D. Pijn et. al., arXiv:2110.03277v1 (2021).

[3] M. Scandi et. al., Physical Review Research 2, 023377 (2020)

Q 49.6 Thu 12:00 A-H2

Methods for atom interferometry with dual-species BEC in space — •Jonas Böhm[1], Maike D. Lachmann[1], Baptist Piest[1], Ernst M. Rasel[1], and the MAIUS team[1,2,3,4,5,6] — [1]Institut für Quantenoptik, LU Hannover — [2]ZARM, U Bremen — [3]DLR RY Bremen — [4]Institut für Physik, HU Berlin — [5]Institut für Quantenoptik, JGU Mainz — [6]FBH, Berlin

Atom interferometry is a promising tool for precise measurements, e.g. for quantum tests of the weak equivalence principle. As the sensitivity scales with the squared time atoms spend in the interferometer, this recommends low expansion velocities of the atomic ensembles. Hence, conducting these experiments in microgravity with Bose-Einstein-Condensates (BEC) is of great interest. The sounding rocket mission MAIUS-1 demonstrated the first creation of a BEC and matter wave interferences in space [1,2]. With the follow-up missions MAIUS-2 and -3, we extend the apparatus by another species to perform atom interferometry with ^{87}Rb and ^{41}K, paving the way for implementing and testing the methods of dual-species interferometers on board of space stations or satellites. In this contribution, the manipulation of BECs using Raman double-diffraction processes to form (asymmetric) Mach-Zehnder-type interferometers, e.g. for inertial sensing, are presented for a compact, robust, and autonomously operating setup that generates ^{87}Rb and ^{41}K BECs with a high repetition rate.

[1] D. Becker, et al., Nature 562, 391-395 (2018). [2] M.D. Lachmann, H. Ahlers, et al., Ultracold atom interferometry in space. Nat Commun 12, 1317 (2021).