# Q 19: Ultra-cold atoms, ions and BEC I (joint session A/Q)

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

Q 19.1 Tue 10:30 A-H2

**Imaging the interface of a qubit and its quantum many-body environment** — Sidharth Rammohan[1], •Aritra Mishra[2], Shiva Kant Tiwari[1], Abhijit Pendse[1], Anil. K. Chauhan[3], Rejish Nath[4], Alexander Eisfeld[2], and Sebastian Wüster[1] — [1]Indian Institute of Science Education and Research, Bhopal, India — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [3]Palacký University, Olomouc, Czechia — [4]Indian Institute of Science Education and Research, Pune, India

Decoherence affects all quantum systems and impedes quantum technologies. In this contribution, we theoretically demonstrate that for a Rydberg atom in a Bose-Einstein condensate, experiments can image the system environment interface that is central for decoherence [1]. High precision absorption images of the condensate can capture transient signals that show real time buildup of the mesoscopic entangled states in the environment. The tuning of the decoherence time scales is possible even from nano seconds to micro seconds using the principle quantum number. As a result, probing is possible even before other sources of decoherence kick in [2]. Finally, we discuss the case in which the system is under a constant microwave drive. This simple modification drastically changes the Hamiltonian as well as the system dynamics, making it non-Markovian, which we study using an advanced numerical technique called the Hierarchy of Pure States [3].

[1] S. Rammohan, et al., (2020), URL https://arxiv.org/abs/2011.11022
[2] S. Rammohan, et al., *Phys. Rev. A.* 103, 063307 (2021)
[3] D. Suess, et al., *Phys. Rev. Lett.* 113, 150403 (2014)

Q 19.2 Tue 10:45 A-H2

**Observation of Feshbach Resonances between $^{138}$Ba$^{+}$ and $^{6}$Li** — •Fabian Thielemann[1], Pascal Weckesser[1,2], Joachim Welz[1], Wei Wu[2], Thomas Walker[1], and Tobias Schaetz[1] — [1]Albert-Ludwigs Universität, Freiburg — [2]Max Planck Institut für Quantenoptik, Garching

The experimental control over Feshbach resonances in ensembles of ultracold atoms has lead to breakthrough results in the field. An ion, overlapped with a cloud of ultracold atoms, exhibits a longer range interaction potential and can offer a high degree of control at the single particle level. Reaching the ultracold regime, at which Feshbach resonances emerge, in hybrid traps has so far proven difficult due to micromotion heating. In this talk we present the first observation of Feshbach resonances between ions and atoms by immersing a single $^{138}$Ba$^{+}$ ion into a cloud of ultracold $^{6}$Li atoms and demonstrate tunability of the two-body and three-body scattering rate of the atom-ion system.

Q 19.3 Tue 11:00 A-H2

**Observation of Hole Pairing in Mixed-Dimensional Fermi-Hubbard Ladders** — •Sarah Hirthe[1,2], Thomas Chalopin[1,2], Dominik Bourgund[1,2], Petar Bojovic[1,2], Annabelle Bohrdt[3,4], Fabian Grusdt[5,2], Eugene Demler[3,6], Immanuel Bloch[1,2,5], and Timon Hilker[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Munich Center for Quantum Science and Technology, Munich, Germany — [3]Harvard University,Cambridge, USA — [4]ITAMP, Harvard-Smithsonian Center for Astrophysics, Cambridge, USA — [5]Ludwig-Maximilians-Universität, Munich, Germany — [6]ETH Zurich, Zurich, Switzerland

Doping an antiferromagnet lies at the heart of many strongly correlated systems and the pairing of dopants in particular is believed to play a key role in the emergence of high-Tc superconductivity. In the talk I will discuss our recent direct observation of hole-pairing due to magnetic order in a Fermi-Hubbard type system in our Lithium quantum-gas microscope. We engineer mixed-dimensional Fermi-Hubbard ladders in which the tunneling along the rungs is suppressed, while enhanced spin exchange supports singlet formation, thus drastically increasing the binding energy. We observe pairs of holes preferably occupying the same rung of the ladder. We furthermore find indications for repulsion between pairs when there is more than one pair in the system.

Q 19.4 Tue 11:15 A-H2

**Adiabatic charge pumping in bosonic Chern insulator analogs** — •Isaac Tesfaye, Botao Wang, and André Eckardt — TU Berlin, Institut für Theoretische Physik, Hardenbergstr. 36, 10623 Berlin, Deutschland

Mimicking fermionic Chern insulators with bosons has drawn a lot of interest in experiments by using, for example, cold atoms [1,2] or photons [3].
Here we present a scheme to prepare and probe a bosonic Chern insulator analog by using an ensemble of randomized bosonic states.
By applying a staggered superlattice, we identify the lowest band with individual lattice sites. The delocalization over this band in quasi-momentum space is then achieved by introducing on-site disorder or local random phases.
Adiabatically turning off the superlattice then gives rise to a bosonic Chen insulator, whose topologically non-trivial property is further confirmed from the Laughlin-type quantized charge pumping.
Our protocol may provide a useful tool to realize and probe topological states of matter in quantum gases or photonic waveguides.

[1] Aidelsburger, Monika, et al. "Measuring the Chern number of Hofstadter bands with ultracold bosonic atoms." Nature Physics 11.2 (2015): 162-166.
[2] Cooper, N. R., J. Dalibard, and I. B. Spielman. "Topological bands for ultracold atoms." Reviews of modern physics 91.1 (2019): 015005.
[3] Ozawa,Tomoki, et. al. "Topological photonics." Rev. of Mod. Phys. 91.1 (2019): 015006

Q 19.5 Tue 11:30 A-H2

**Machine learning universal bosonic functionals** — •Benavides-Riveros Carlos L.[1], Schmidt Jonathan[2], and Fadel Matteo[3] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187 Dresden, Germany — [2]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, 06120 Halle (Saale), Germany — [3]Department of Physics, University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland

The one-body reduced density matrix $\gamma$ plays a fundamental role in describing and predicting quantum features of bosonic systems, ultra-cold gases or Bose-Einstein condensates. The recently proposed reduced density matrix functional theory for bosonic ground states establishes the existence of a universal functional F[$\gamma$] that recovers quantum correlations exactly. Based on a novel decomposition of $\gamma$, we have developed a method to design reliable approximations for such universal functionals [1]. Our results demonstrate that for translational invariant systems the constrained search approach of functional theories can be transformed into an unconstrained problem through a parametrization of a Euclidian space. This simplification of the search approach allows us to use standard machine learning methods to perform a quite efficient computation of both F[$\gamma$] and its functional derivative. For the Bose-Hubbard model, we present a comparison between our approach and the quantum Monte Carlo method.

[1] Phys. Rev. Research 3, L032063 (2021).

Q 19.6 Tue 11:45 A-H2

**Fibre cavity based quantum network node with trapped Yb ion** — •Santhosh Surendra, Pascal Kobel, Ralf Berner, Moritz Breyer, and Michael Köhl — Physikalisches institute, University of Bonn, Bonn, Germany

Quantum networks are promising to revolutionise information exchange and cryptography. An important part of these networks are nodes where quantum states can be stored, and manipulated. In this work, we investigate such a quantum communication node formed by a trapped Yb ion coupled to an optical fibre cavity. Using a resonant fibre cavity for the electric dipole transition at 370nm, we are able to collect the emitted photons with high efficiency, which carry quantum information from node to node via their polarisation. We use pulsed excitation to realise a fibre coupled, deterministic single photon source, where the photons are entangled with the hyperfine states of the ion with a high fidelity of 90.1(17)%. The state of the trapped ion represents the quantum memory, which is used to realise a memory enhanced quantum key distribution protocol (BBM92), being the first step towards realising a quantum repeater node.

Q 19.7 Tue 12:00 A-H2

**Pattern formation in quantum ferrofluids: From supersolids to superglasses** — •Jens Hertkorn[1], Jan-Niklas Schmidt[1], Mingyang Guo[1], Fabian Böttcher[1], Kevin S. H. Ng[1], Sean D. Graham[1], Paul Uerlings[1], Tim Langen[1], Martin Zwierlein[2], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Germany — [2]MIT-Harvard Center for Ultracold Atoms, Research Laboratory of Electronics, and Department of Physics, Massachusetts Institute of Technology, USA

Pattern formation is a ubiquitous phenomenon observed in nonlinear and out-of-equilibrium systems. In equilibrium, ultracold dipolar quantum gases have been shown to host superfluid quantum droplet patterns, which realize a supersolid phase. Here we theoretically study the phase diagram of such quantum ferrofluids in oblate trap geometries and discover a wide range of exotic states of matter. Beyond the supersolid droplet regime, we find crystalline honeycomb and amorphous labyrinthine states with strong density connections. These patterns, combining superfluidity with a spontaneously broken spatial symmetry, are candidates for a new type of supersolid and superglass, respectively. The stabilization through quantum fluctuations allows one to find these patterns for a wide variety of trap geometries, interaction strengths, and atom numbers. Our study illuminates the origin of the various possible morphologies of quantum ferrofluids, highlights their emergent supersolid and superglass properties and shows that their occurrence is generic of strongly dipolar interacting systems.