# A 10: Ultra-cold Atoms, Ions and BEC I (joint session A/Q)

Time: Tuesday 11:00–13:00 Location: N 1

A 10.1 Tue 11:00 N 1

**Dark-state semi-localization and subradiance in dissipative systems** — •Raphaël Menu, Thomas Botzung, and Johannes Schachenmayer — CESQ/ISIS, Université de Strasbourg, Strasbourg, France

Since their discovery, hybrid states of light and matter have sparked bustling interest across diverse fields, ranging from condensed matter physics and atomic physics to chemistry. While "bright" states are largely unaffected by disorder, it has been demonstrated that strong light-matter coupling gives rise to unconventional localization behavior in "dark" light-matter states [1,2]. This phenomenon, coined as semi-localization, has been theoretically evidenced in ensembles of quantum emitters with randomly distributed transition frequencies coupled to a single-mode cavity. However, for meaningful comparison with experimental realizations, a proper description of semi-localization must account for cavity losses and spontaneous emission. In this work, we assess the feasibility of observing semi-localization as a transient phenomenon under experimental conditions [3]. We explore the robustness of this phenomenon in dissipative systems using experimentally accessible figures of merit, and investigate the relation between subradiance and localization phenomena.

[1] T. Botzung & al. Phys. Rev. B 102, 144202 (2020)
[2] J. Dubail & al. Phys. Rev. A 105, 023714 (2022)
[3] M. Baghdad & al, arXiv:2208.12088 (2022)

A 10.2 Tue 11:15 N 1

**Mass-Gap Description of Heavy Impurities in Fermi Gases** — Xin Chen, •Eugen Dizer, Emilio Ramos Rodríguez, and Richard Schmidt — Institut für Theoretische Physik, Universität Heidelberg, 69120 Heidelberg, Germany

Single impurities immersed in a degenerate Fermi gas exhibit fascinating many-body phenomena, such as the polaron-to-molecule transition and Anderson's orthogonality catastrophe (OC). It is known that mobile impurities of finite mass can be described as quasiparticles, so called Fermi polarons. In contrast, Anderson showed in 1967 that the ground state of a static, infinitely heavy impurity in a Fermi sea is orthogonal to the ground state of the system without impurity - a hallmark of the OC and a fundamentally non-perturbative effect. As a result, conventional variational approaches or path integral methods fail to capture this phenomenon accurately. Despite decades of research, a unified approach connecting the quasiparticle description of Fermi polarons with Anderson's OC has remained elusive. In this work, we present a theoretical framework for arbitrary-mass impurities in a Fermi sea that incorporates Anderson's OC, the polaron-to-molecule transition and the quasiparticle picture. Our theory provides a simple yet powerful description of interacting quantum systems, with broad implications for ultracold atom experiments, atomically thin semiconductors, and future studies of strongly correlated matter. Phys. Rev. Lett. 135, 193401 (2025).

A 10.3 Tue 11:30 N 1

**Quantum doubles in symmetric blockade structures** — •Simon Fell — Institute for Theoretical Physics III, University of Stuttgart

Exactly solvable models of topologically ordered phases with non-abelian anyons typically require complicated many-body interactions which do not naturally appear in nature. This motivates the "inverse problem" of quantum many-body physics: given microscopic systems with experimentally realistic two-body interactions, how to design a Hamiltonian that realizes a desired topological phase? We solve this problem on a platform motivated by Rydberg atoms, where elementary two-level systems couple via simple blockade interactions. Within this framework, we construct Hamiltonians that realize topological orders described by non-abelian quantum double models. We analytically prove the existence of topological order in the ground state, and present efficient schemes to prepare these states. We also introduce protocols for the controlled adiabatic braiding of anyonic excitations to probe their non-abelian statistics. Our construction is generic and applies to quantum doubles $\mathcal{D}(G)$ for arbitrary finite groups $G$. We illustrate braiding for the simplest non-abelian quantum double $\mathcal{D}(S_3)$.

A 10.4 Tue 11:45 N 1

**Paramagnetic Phases of Strongly Correlated Lattice Fermions with Cavity-Mediated Long-Range Interactions** — •Renan da Silva Souza, Youjiang Xu, and Walter Hofstetter — Goethe-Universität, Institut für Theoretische Physik, 60438 Frankfurt am Main, Germany

We investigated the steady-state paramagnetic phases of a Fermi-Hubbard model on a square lattice coupled to a transversely pumped optical cavity, using real-space dynamical mean-field theory (RDMFT) [1]. The cavity mediates long-range interactions [2] which compete with the onsite Hubbard interactions. This system exhibits a transition into a superradiant checkerboard density-wave (DW) phase with finite occupation imbalance. At quarter filling, we find that increasing temperature leads to the crystallization of a homogeneous Fermi-liquid (FL) phase into a DW phase. At half filling, we find regions of metastability between different RDMFT solutions where the occupation imbalance shows a hysteretic behavior characteristic of first order phase transitions. In those regions, the DW solution coexists with either the homogeneous FL or the Mott insulating solution. We obtain the thermodynamic phase transition by comparing the energies of the different solutions in the region of metastability.

[1] M. Snoek et al. NJP 10, 093008 (2008)
[2] V. Helson et al. Nature 618, 716-720 (2023)

A 10.5 Tue 12:00 N 1

**Topological Order in Symmetric Blockade Structures** — •Tobias Florian Maier, Hans Peter Büchler, and Nicolai Lang — Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, University of Stuttgart, 70550 Stuttgart, Germany

The bottom-up design of strongly interacting quantum materials with prescribed ground-state properties is a highly nontrivial task, especially if only simple constituents with realistic two-body interactions are available on the microscopic level. We study two- and three-dimensional structures of two-level systems that interact via a simple blockade potential in the presence of a coherent coupling between the two states. For such strongly interacting quantum many-body systems, we introduce the concept of blockade graph automorphisms to construct symmetric blockade structures with strong quantum fluctuations that lead to equal-weight superpositions of tailored states. Drawing from these results, we design a quasi two-dimensional periodic quantum system that – as we show rigorously – features a topological $\mathbb{Z}_2$ spin liquid as its ground state. Our construction is based on the implementation of a local symmetry on the microscopic level in a system with only two-body interactions [1].

[1] T. F. Maier, H. P. Büchler and N.Lang, *Topological Order in Symmetric Blockade Structures*, PRX Quantum **6**(3) (2025), doi:10.1103/dtlf-2q82.

A 10.6 Tue 12:15 N 1

**Spin and density order of ultracold two-component fermions coupled to an optical cavity** — •Daniel Samoylov, Renan da Silva Souza, Youjiang Xu, and Walter Hofstetter — Goethe Universität, Institut für Theoretische Physik, 60438 Frankfurt, Germany

Ultracold two-component fermions coupled to a transversely pumped optical cavity experience cavity-mediated long-range interactions [1]. In the dispersive regime, when confined to a two-dimensional static optical lattice the steady states of this system can be described by an extended Hubbard Hamiltonian with long-range interactions mediated by the cavity photons. We use real-space dynamical mean-field theory (RDMFT) [2] to study the phase diagram of this system. We investigate the competition of the (superradiant) checkerboard density-wave (DW) phase and the magnetically ordered spin-density-wave (SDW) phase at half filling. For small values of the Hubbard onsite interaction strength and the cavity-mediated long-range interaction strength we find a homogeneous paramagnetic phase. The full phase diagram of the system is obtained by varying the Hubbard onsite interaction strength and the cavity-mediated long-range interaction strength at a fixed low temperature. We identify a region of coexistence between the DW and SDW solutions obtained within RDMFT. The thermodynamic phase transition in this region is obtained by comparing the energies of the different RDMFT solutions.

[1] K. Roux et al., Nat. Commun., 11, 1, 2974 (2020)
[2] M. Snoek et al., New J. Phys. 10, 093008 (2008)

A 10.7 Tue 12:30 N 1

**Towards stable, strongly dipolar mixtures of ultracold dysprosium atoms** — •Marian Dürbeck, Lennard Reihs, Johannes Seifert, Bala Choudhari, Juan Pablo Marulanda Serna, Nelson Werum, Marco De Pas, Gerard Meijer, and Giacomo Valtolina — Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin

Quantum gases of magnetic atoms, such as dysprosium (Dy), have recently enabled the realization of the long-sought-after supersolid phase. More exotic regimes of supersolidity have been predicted for mixtures of these magnetic atoms. We report on our efforts to create stable mixtures of Dy. We show a broadly applicable frequency-modulation scheme for simultaneously slowing and trapping different isotopes of Dy and discuss progress in creating strongly dipolar Bose-Bose mixtures.

A 10.8 Tue 12:45 N 1

**Collective excitations in Quantum Bubbles** — •Timothé Estrampes[1,2], Brendan Rhyno[1], Charles Garcion[1], Ernst M. Rasel[1], Éric Charron[2], and Naceur Gaaloul[1] — [1]Leibniz University Hannover, Institut für Quantenoptik, Germany — [2]Université Paris-Saclay, CNRS, Institut des Sciences Moléculaires d'Orsay, France

The realization of the first quantum bubbles, both in microgravity using radiofrequency dressing (Nature 606, 281-286 (2022)) and on the ground with quantum mixtures (PRL 129, 243402 (2022)), has opened the way to studying the evolution of condensed atoms in non-trivial geometries. Among these, collective excitation modes are of particular interest, as they are readily accessible experimentally. It has been shown that, during the transition from a filled to a hollow geometry, the behavior of excitation modes is non-monotonic. In this work, we investigate the behavior of collective excitations in quantum bubbles and search for potential thermodynamic signatures of the hollowing transition.