ABSTRACTS

of the

oral presentations

Experimental observation of the 4D Anderson Transition with Ultracold Atoms

Farid Madani, Maxime Denis, Pascal Szriftgiser, Jean Claude Garreau, Adam Rançon, and Radu Chicireanu

Univ. Lille, CNRS, UMR 8523 – PhLAM – Laboratoire de Physique des Lasers Atomes et Molécules, F-59000 Lille, France

The Anderson model describes electron transport in a disordered crystal [1]. In one and two dimensions, it leads to Anderson localization, where the electron's wave function is exponentially localized in space. For $d > 2$, a quantum phase transition occurs between a localized (insulating) phase and a delocalized (metallic) phase, known as the Anderson transition (AT) [2]. In most phase transitions, the role of fluctuations decreases as a system's dimension increases, and mean-field theories capture the system's critical behavior above a given "upper critical dimension". In contrast, AT criticality has been predicted to remain highly non-trivial even in dimensions greater than three, posing significant theoretical challenges to existing frameworks.
The AT has been studied in 3D, both numerically and experimentally, and its critical exponent for the localization phase has been measured [3]. In this work, we go further by investigating this phase transition in 4D through an ultracold atoms experiment. To do so, we use the atomic kicked rotor system, which belongs to the universality class of the Anderson model. To emulate dimensions higher than 3, we engineer synthetic dimensions by modulating the amplitude of a pulsed optical potential, thereby increasing the system's effective dimensionality [4]. This allows us to observe the phase transition and measure the critical exponents in both the diffusive and localized phases. We thus experimentally obtain critical exponents that are in very good agreement with Wegner's relation (which links the critical exponents to the system's dimension). Moreover, the measured exponents infirm the predictions of the mean-field self-consistent theory [5], and are in excellent agreement with numerical simulations of the Anderson model in $d = 4$. Finally, we measure the two-parameter scaling function which characterizes the behavior near the critical point. These results open a new paradigm for experimentally exploring complex critical phenomena in higher dimensions.

[1] P.W. Anderson, Absence of Diffusion in Certain Random Lattices, Physical Review 109 (1958), p. 1492-1505..
[2] E. Abrahams, P. W. Anderson, D. C. Licciardello, and T. V. Ramakrishnan, Scaling theory of localization: Absence of quantum diffusion in two dimensions, Phys. Rev. Lett. 42, 673 (1979).
[3] Gabriel Lemarie, Julien Chabe, Pascal Szriftgiser, Jean Claude Garreau, Benoit Gremaud, and Dominique Delande, Observation of the anderson metal-insulator transition with atomic matter waves: Theory and experiment,Phys. Rev. A 80, 043626 (2009).
[4] Giulio Casati, Italo Guarneri, and D. L. Shepelyansky, Anderson transition in a one-dimensional system with three incommensurate frequencies, Phys. Rev. Lett. 62, 345-348 (1989).
[5] D. Vollhardt and P. Wolfle, Scaling equations from a self-consistent theory of anderson localization, Phys. Rev. Lett. 48, 699 (1982).

Partially quantized currents in supersolids

Niccolò Preti,[1,2,3] Charles Drevon,[2,3] Nicolò Antolini,[3] Giulio Biagioni,[4] Giovanni Ferioli,[1,2] Andrea Fioretti,[3] Carlo Gabbanini,[3] and Giovanni Modugno[1,2,3]

[1] *Dipartimento di Fisica e Astronomia, Università di Firenze, Firenze, Italy*
[2] *European Laboratory for Nonlinear Spectroscopy, Università di Firenze, Firenze, Italy*
[3] *Consiglio Nazionale delle Ricerche, Istituto Nazionale di Ottica, Sede Secondaria di Pisa, Pisa, Italy*
[4] *Universite Paris-Saclay, Institut d' Optique Graduate School, CNRS, Laboratoire Charles Fabry, Palaiseau, France*

It has been predicted [1] that a supersolid could host persistent currents whose nature strongly depend on the superfluid fraction f_s of the system. In particular, the angular momentum of these currents is not quantized as in the case of regular superfluids, but depends on f_s, thus making these currents partially quantized. I will showcase experimentally accessible protocols to both excite partially quantized currents for a supersolid on a ring and also to measure its angular momentum. These protocols were valided by making numerical simulations of the excitation and probing schemes using the Gross-Pitaevskii equation. I will also report on an ongoing experiment aimed at trapping a supersolid on a ring where we will apply our protocol to observe the partial quantization of the current states of a supersolid [2,3].

[1] Tengstrand, M. Nilsson, et al. "Persistent currents in toroidal dipolar supersolids." Physical Review A 103.1 (2021): 013313.
[2] Preti, Niccolò, et al. "Blue repulsive potential for dysprosium Bose-Einstein condensates." Physical Review A 110.2 (2024): 023307.
[3] Preti, N. "Towards dipolar supersolids in a ring." IL NUOVO CIMENTO 100.256 (2024): 47.

Anomalous transport in classical many-body dynamics

Rustem Sharipov,[1] Matija Koterle,[1] Sašo Grozdanov,[1,2] and Tomaž Prosen[1,3]

[1] *Department of Physics, Faculty of Mathematics and Physics, University of Ljubljana*
[2] *Higgs Centre for Theoretical Physics, University of Edinburgh*
[3] *Institute for Mathematics, Physics, and Mechanics, Jadranska 19, SI-1000 Ljubljana, Slovenia*

Classical cellular automata represent a class of explicit discrete spacetime lattice models in which complex large-scale phenomena emerge from simple deterministic rules. With the goal to uncover different physically distinct classes of ergodic behavior, we perform a systematic study of three-state cellular automata (with a stable 'vacuum' state and 'particles' with ± charges). The classification is aided by the automata's different transformation properties under discrete symmetries: charge conjugation, spatial parity and time reversal. In particular, we propose a simple classification that distinguishes between types and levels of ergodic behavior in such system as quantified by the following observables: the mean return time, the number of conserved quantities, and the scaling of correlation functions. In each of the physically distinct classes, we present examples and discuss some of their phenomenology. This includes chaotic or ergodic dynamics, phase-space fragmentation, Ruelle-Pollicott resonances, existence of quasilocal charges, and anomalous transport with a variety of dynamical exponents.

[1] https://arxiv.org/pdf/2503.16593.

Anyonization of bosons

Sudipta Dhar,[1] Botao Wang,[2,3] Milena Horvath,[1] Amit Vashisht,[2,3] Yi Zeng,[1] Mikhail B. Zvonarev,[4] Nathan Goldman,[2,3,5] Yanliang Guo,[1] Manuele Landini,[1] and Hanns-Christoph Nägerl[1]

[1] *Institut für Experimentalphysik und Zentrum für Quantenphysik, Universität Innsbruck, Technikerstraße 25, Innsbruck, 6020, Austria*
[2] *Center for Nonlinear Phenomena and Complex Systems, Université Libre de Bruxelles, CP 231, Campus Plaine, B-1050 Brussels, Belgium*
[3] *International Solvay Institutes, 1050 Brussels, Belgium*
[4] *Université Paris-Saclay, CNRS, LPTMS, 91405 Orsay, France*
[5] *Laboratoire Kastler Brossel, Collège de France, CNRS, ENS-Université PSL, Sorbonne Université, 11 Place Marcelin Berthelot, 75005 Paris, France*

Anyons are low-dimensional quasiparticles that obey fractional statistics, hence interpolating between bosons and fermions. In two dimensions, they exist as elementary excitations of fractional quantum Hall states and they are believed to enable topological quantum computing. One dimensional (1D) anyons have been theoretically proposed, but their experimental realization has proven to be difficult. Here, we discuss the experimental realization and theoretical investigation of anyonic correlations in a 1D strongly-interacting quantum gas, resulting from the phenomenon of spin-charge separation [1]. A mobile impurity provides the necessary spin degree of freedom to engineer anyonic correlations in the charge sector and simultaneously acts as a probe to reveal these correlations. Starting with bosons, the statistical phase is tuned to transmute bosons via anyons to fermions, leading to an asymmetric momentum distribution, which manifests as a hallmark of anyonic correlations. Going beyond equilibrium conditions, we also study the dynamical properties of the anyonized bosons, reminiscent of the dynamical fermionization of anyons. Our work opens up the door to the exploration of nonequilibrium anyonic phenomena in a highly controllable setting.

[1] S. Dhar, B. Wang, M. Horvath, A. Vashisht, Y. Zeng, M. B. Zvonarev, N. Goldman, Y. Guo, M. Landini, and H.-C. Nägerl, Anyonization of bosons, arXiv:2412.21131 (2024).

ABSTRACTS

of the

poster presentations

Erbium-Lithium: towards a new quantum mixture experiment

Alexandre De Martino, Florian Kiesel, Kirill Karpov, Jonas Auch, and Christian Groß

University of Tübingen

The goal of this Erbium-Lithium mixture experiment, is to lower the current temperature limit for fermions. One key for this shall be the strong mass imbalance, as we use heavy bosonic erbium atoms as a heat reservoir for the light fermionic lithium atoms. While trapping erbium in a shallow trap at 1064 nm, we want to utilize the tuneout wavelength of erbium at 841 nm. This enables an additional, narrow trap for lithium. In addition to this cooling aspect, the combination of erbium and lithium enables polaron physics, with heavy dopants of erbium in an lithium environment.

Microscopy of Density-Wave Ordering in Strongly Interacting Fermi Gases

Gaia Stella Bolognini,[1,2] Tabea Nelly Clara Buhler,[1,2] Aurélien Hadrien Fabre,[1,2] Zeyang Xue,[1,2] Timo Zwettler,[1,2] Giulia Del Pace,[1,2] and Jean-Philippe Brantut[1,2]

[1] *Laboratory for Quantum Gases, EPFL, Lausanne, Switzerland*
[2] *Quantum Science and Engineering Center, EPFL, Lausanne, Switzerland*

With this poster, I will present our investigation on the emergence of density wave order in a degenerate Fermi gas strongly coupled to the electromagnetic field of a high-finesse cavity [1,2]. This ordered state simultaneously exhibits superradiance in the cavity field and self-organisation of the atoms into a crystalline lattice [3]. Our experimental setup combines real-time monitoring of the cavity field with high-resolution microscopy over the atomic cloud. With this last capability, we achieve the first direct, in situ imaging of the periodic modulation of the charge-density waves. These observations enable the reconstruction of correlations between photonic and atomic signatures in the formation of the phase transition and provide new insights into the ordering process, opening new avenues for the investigation of light-induced phase transition in fermionic systems.

[1] Roux, H., Helson, V., K., Konishi and Brantut J.P. Cavity-assisted preparation and detection of a unitary Fermi gas, New J. Phys., 23, 043029.

[2] Roux K., Konishi H., Helson V. and Brantut J.P., Strongly correlated Fermions strongly coupled to light, Nat Commun 11, 2974 (2020).

[3] Helson, V., Zwettler, T., Mivehvar, F. et al. Density-wave ordering in a unitary Fermi gas with photon-mediated interactions, Nature 618, 716-720 (2023).

Collective response of an array of Dy atoms

Nathan Bonvalet

Institut d'Optique Graduate School, Université Paris-Saclay

I will present our work on an experimental platform producing arrays of single dysprosium atoms [1], [2] at Institut d Optique. The goal of the project is to study and control the collective response to light of an atomic array, benefiting from the specificity of the atomic structure of Dy. This response is modified by the resonant dipole interaction that exists between atoms driven by resonant light, which exhibits both a real (conservative) and imaginary (dissipative) part, leading to a description of the system in terms of a dissipative spin ensemble. I will focus on recent works carried out on the experiment including the single-atom resolved mapping of the distribution of the excitation through an ordered 1D array [3]. Moreover I will present improvements of the experimental setup. This includes novel techniques for ground-state cooling on dysprosium and the generation of sub-wavelength arrays of atoms in order to create subradiant states.

[1] D. Bloch *et al.*, *Phys. Rev. Lett.* **131** 203401 (2023).
[2] D. Bloch *et al.*, *Phys. Rev. A* **110** 033103 (2024).
[3] B. Hofer *et al.*, arXiv:2412.02541v1 (2024).

Bouncing Bose-Einstein Condensates: A Novel Path to Discrete Time Crystals

Mohammed Bouras,[1] Ali Zaheer,[1] Chamali Gunawardana,[1] Arpana Singh,[1] Krzysztof Giergiel,[2] Krzysztof Sacha,[3] Andrei Sidorov,[1] and Peter Hannaford[1]

[1] *Optical Sciences Centre, Swinburne University of Technology, Melbourne, Australia*
[2] *CSIRO Manufacturing, Melbourne, Australia*
[3] *Institute of Theoretical Physics, Jagiellonian University, Krakow, Poland*

In recent years, the idea of time crystals-states in which a periodically driven many-body system spontaneously breaks time-translation symmetry-has gained considerable attention. These systems exhibit ultra-stable, subharmonic oscillations that lock to the external drive and remain robust against external disturbances, promising new avenues for quantum technology. Our work is dedicated to the experimental realization of a discrete time crystal using a Bose-Einstein condensate of potassium-39 atoms. By employing a periodically modulated atomic mirror, we induce a resonant bouncing behaviour in the weakly interacting condensate. This bouncing motion stabilizes into long-lived orbits with periods that are integer multiples of the driving period, effectively creating a temporal lattice comprising many distinct sites [1]. We utilize potassium-39 atoms due to their advantageous interaction properties, which include several broad Feshbach resonances [2]. These resonances allow for precise tuning of the attractive interactions near the zero crossing. Initially, we cool approximately 8×10^8 atoms using a two-dimensional magneto-optical trap (MOT) that loads into a three-dimensional MOT at a temperature of 2.6 mK. Given the small hyperfine splitting in the excited state, conventional laser cooling does not reach the Doppler limit. Therefore, we implement a hybrid D2/D1 MOT scheme along with grey molasses on the D1 line, successfully cooling the atoms to 6 μK. The cold ensemble is then transferred into a 1064 nm crossed-beam dipole trap, where we have identified four broad Feshbach resonances at 32.6, 59, 163, and 403 G. The 32.6 G resonance is exploited for evaporative cooling, moving us closer to achieving quantum degeneracy. In the final phase, the Bose-condensed atoms are dropped from a height of about 150 μm onto an atomic mirror generated by a 532 nm fibre laser beam modulated at 2.8 kHz. When the mirror's modulation frequency is synchronized with the atoms' bouncing period, a sequence of 30 stable wavepackets emerges-each acting as a site in a temporal lattice. By tuning the scattering length to a slightly negative value (approximately -1.6a_0), tunnelling between adjacent sites is suppressed, stabilizing a large-scale discrete time crystal ($s = 30$). This experimental platform not only demonstrates the creation of time crystals over many temporal lattice sites but also paves the way for exploring condensed matter phenomena in the time domain, including the development of "time-tronics" [3] as a time-based analogue to conventional electronics or atomtronics.

[1] K. Sacha, Physical Review A 98, 013613 (2015).
[2] K. Giergiel et al., New Journal of Physics 22, 085004 (2020).
[3] K. Giergiel, P. Hannaford and K. Sacha, arXiv: 2406.06387 (2024).

Classical surrogates of quantum control landscapes

Martino Calzavara,[1,2] Tommaso Calarco,[1,2,3] and Felix Motzoi[1,2]

[1] *Peter Grünberg Institute - Quantum Control (PGI-8), Forschungszentrum Jülich GmbH, Wilhelm-Johnen-Straße, 52428 Jülich, Germany*
[2] *Institute for Theoretical Physics, University of Cologne, Zülpicher Straße 77, 50937 Cologne, Germany*
[3] *Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy*

Since the introduction of the GRAPE algorithm for efficiently computing fidelity gradients, piecewise-constant controls have become a widely adopted ansatz for studying Quantum Optimal Control problems. The time evolution for this class of time-dependent Hamiltonians can be represented as a Parametrized Quantum Circuit, allowing us to analyze the properties of the fidelity as a function of the control pulses - the so-called Quantum Control Landscape - by employing concepts and techniques borrowed from Quantum Machine Learning (QML) and Variational Quantum Algorithms (VQA). Among these techniques are classical surrogate models, which represent the output of a quantum circuit as a linear combination of non-linear feature maps, providing valuable insights into the representational power of QML models and the structure of VQA landscapes. In this work, we employ classical surrogate models as a theoretical tool to investigate the properties of Quantum Control Landscapes, and to learn approximate representations of such landscapes using supervised learning.

Measurement of the condensate order parameter statistics across the Mott transition

Géraud Dupuy,[1] Paul Paquiez,[1] Maxime Allemand,[1] Thomas Chalopin,[1] David Clément,[1] Adam Rançon,[2] Nicolas Dupuis,[3] and Tommaso Roscilde[4]

[1] *Université Paris-Saclay, Institut d Optique Graduate School, CNRS, Laboratoire Charles Fabry, 91127, Palaiseau, France*
[2] *Univ. Lille, CNRS, UMR 8523, PhLAM Laboratoire de Physique des Lasers Atomes et Molécules,F-59000 Lille, France*
[3] *Sorbonne Université, CNRS, Laboratoire de Physique Théorique de la Matière Condensée, LPTMC, F-75005 Paris, France*
[4] *Univ Lyon, Ens de Lyon, CNRS, Laboratoire de Physique, F-69342 Lyon, France*

Transversally to all domain of physics, phases transitions display sharp modification of macroscopic aspects of a system under variation of environmental parameters. Since the middle of the twentieth century, the Ginzburg-Landau theory bridges these macroscopic properties of the system, notably the spontaneous symmetry breaking, and its microscopic behaviour, through the introduction of an order-parameter, switching from a zero average value in the disordered phase to a non-zero one in the ordered phase.

Our experiment puts helium-4 metastable atoms in optical lattices, such that it implements a Bose-Hubbard hamiltonian featuring a Superfluid to Mott insulator transition [1]. In this work, we monitor the condensate order parameter across the Mott transition. More precisely, we measure the full statistics [2] of the square root of the atom number with zero momentum, thanks to a single-atom-resolved detection in momentum space [3].

We observe marked differences between the ordered phase, the disordered phase, and the transition regime, in line with the Ginzburg-Landau paradigm. The fluctuations of the order parameter significantly increase on approaching the transition and, we show that their statistics are non-gaussian in this regime, from measuring non-zero high order cumulants. Finally, we emphasize the fact that our experiment is performed in a non-homogeneous trap, of finite size. A system that is currently difficult to address both theoretically and numerically, and where critical physics are often considered to not play a role.

[1] C. Carcy, et al. (2021). Certifying the Adiabatic Preparation of Ultracold Lattice Bosons in the Vicinity of the Mott Transition. Physical Review Letters. 126.

[2] G. Hercé, et al. (2023). Full counting statistics of interacting lattice gases after an expansion: The role of condensate depletion in many-body coherence. Physical Review Research. 5.

[3] M. Allemand, et al. (2024). Tomography of a Spatially Resolved Single-Atom Detector in the Presence of Shot-to-Shot Number Fluctuations. PRX Quantum. 5.

Contribution submission to the conference Damop 2025

Silvia Ferrante

University of Hamburg

From the optimisation of supply chains to efficient vehicle routing - computationally hard problems are deeply embedded into modern society. Finding solutions to these problems via classical means still requires substantial computational effort. On the contrary, quantum processors promise a significant advantage in solving them. To explore the potential of quantum computing for real-world applications, we set up Rymax One, a quantum processor designed to solve hard optimisation problems. We trap ultra-cold neutral Ytterbium atoms in arbitrary arrays of optical tweezers, ideally suited to solve optimisation problems and perform quantum operations in a hardware-efficient manner. The level structure of Yb provides the possibility of attaining qubits with long coherence times as well as Rydberg-mediated interactions and high-fidelity gate operations. These features allow us to realise a scalable platform for quantum processing to test the performance of novel quantum algorithms tailored to tackle real-world problems.

Measuring angular momentum in a ring-shaped Fermi superfluid

Marcia Frometa Fernandez,[1,2] Diego Hernández Rajkov,[1,2] Nicola Grani,[1,2,3] Francesco Scazza,[1,4] Sandro Stringari,[5] Massimo Inguscio,[1,2] Giulia Del Pace,[1,2,3] and Giacomo Roati[1,2]

[1] *European Laboratory for Nonlinear Spectroscopy (LENS), University of Florence, 50019 Sesto Fiorentino, Italy*
[2] *Istituto Nazionale di Ottica del Consiglio Nazionale delle Ricerche (CNR-INO) c/o LENS, 50019 Sesto Fiorentino, Italy*
[3] *Department of Physics, University of Florence, 50019 Sesto Fiorentino, Italy*
[4] *Department of Physics, University of Trieste, 34127 Trieste, Italy*
[5] *Department of Physics, University of Trento, 38123 Trento, Italy*

We report on the in-situ measurement of the angular momentum per particle on fermionic superfluid rings, trying to answer the question "are Cooper pairs really made by two atoms?". We excite two counter-propagating phonons, which in presence of a rotating superfluid, change their dispersion relation due to a Doppler shift. We use the recent development of persistent currents in ring traps [1] to implement this experimental scenario. This Sagnac-like interferometric protocol allows a direct measurement of the angular momentum by measuring the precession rate of the phonon interferometric signal. Contrary to simple bosonic superfluids [2, 3], where $\ell_z = \hbar$, for fermi superfluids $\ell_z = \hbar/2$, due to the pairing of two opposite spin fermions, required for superfluidity. The tunability of our system allows us to explore the BEC-BCS crossover, probing the angular momentum from tightly bound bosonic molecules to loosely coupled fermionic Cooper pairs.

[1] G. Del Pace et al., Phys. Rev. X 12, 041037 (2022).
[2] A. Kumar et al., New J. Phys. 18 p. 025001 (2016).
[3] Ch. W. Woffinden et al., SciPost. Phys. 15 p. 128 (2023).

Spin-based magnetic imaging of superconducting microwave metamaterials

Benedek Gaál,[1,2] Vincent Jouanny,[1,2] Simone Frasca,[1,2] Christophe Galland,[1,2] Pasquale Scarlino,[1,2] and Valentin Goblot[1,2]

[1] *Institue of Physics, École Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland*
[2] *Center for Quantum Science and Engineering, École Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland*

Quantum simulation, the process of studying well-controlled model quantum systems can help us gain insight about complex quantum phenomena. Our goal is to develop an integrated hybrid quantum system for analog quantum simulation. Coupled cavity arrays (CCAs) can serve as a powerful architecture for engineering the photonic environment for quantum simulation applications, for example they can be used to implement topological lattices [1], Dirac cones [2], flat bands [2], or non-Euclidean geometries [3]. Arrays of compact lumped-element microwave (MW) resonators based on high kinetic inductance disordered superconducting thin films offer a versatile platform for implementing CCAs due to high design freedom and robust fabrication process [4].

We use weakly coupled nitrogen-vacancy (NV) centers in diamond as microwave detectors [5] to image the MW field amplitude and direction in compact NbTiN superconducting resonators. This will provide direct insights into the spatial profiles of photonic eigenmodes in a 1D / 2D arrays of subwavelength cavities. The freedom in designing the resonators and the couplings, combined with the small footprint allows us to study interesting MW photonic metamaterials exhibiting flat bands or topologically protected states that could have useful applications for quantum technologies. In the future, engineering strong coupling between the NV ensembles and the resonators will allow us to study collective emission effects and the interaction of spin ensembles with artificial photonic environments.

[1] Youssefi et al. Topological lattices realized in superconducting circuit optomechanics. Nature 612, 666 672 (2022). DOI:10.1038/s41586-022-05367-9.

[2] Jacqmin et al. Direct Observation of Dirac Cones and a Flatband in a Honeycomb Lattice for Polaritons. Physical Review Letters, 112(11):116402 (2014), DOI:10.1103/PhysRevLett.112.116402.

[3] Kollár et al. Hyperbolic lattices in circuit quantum electrodynamics. Nature 571, 45 50 (2019). DOI:10.1038/s41586-019-1348-3.

[4] Jouanny et al. Band engineering and study of disorder using topology in compact high kinetic inductance cavity arrays. arXiv:2403.18150, 2024.

[5] Appel et al. Nanoscale microwave imaging with a single electron spin in diamond. New Journal of Physics, 17(11):112001 (2015). DOI:10.1088/1367-2630/17/11/112001.

Qubit-mediated spin-spin gates for hybrid quantum computing

Emanuele Dalla Torre, Michael Stern, and Dotan Goldberg

Bar-Ilan university, department of physics, Israel, Ramat Gan, 5290002.

Electronic spins associated with defects in semiconductors have emerged as promising candidates for quantum information processing due to their long coherence times. Recent experimental advances have demonstrated the feasibility of coupling multiple such spins to a single superconducting qubit, opening new avenues for scalable quantum architectures. In this work, we numerically investigate a theoretical scheme that leverages the qubit as an intermediary to implement controllable spin-spin gates. Our preliminary results indicate that, with an appropriate choice of system parameters, it is possible to engineer an effective interaction between the spins that remains robust against the qubit decay. This approach provides a pathway for enhancing gate fidelity in hybrid quantum systems and contributes to the broader effort of integrating defect-based qubits into superconducting platforms.

Mutual friction in a strongly interacting Fermi superfluid

Nicola Grani,[1,2,3] Diego Hernández-Rajkov,[2,3] Cyprien Daix,[1,2] Pierbiagio Pieri,[4,5] Michele Pini,[6,7] Piotr Magierski,[8,9] Gabriel Wlazłowski,[8,9] Marcia Frómeta Fernández,[2,3] Francesco Scazza,[10,11,2] Giulia Del Pace,[1,2,3] and Giacomo Roati[2,3]

[1] *Department of Physics, University of Florence, 50019 Sesto Fiorentino, Italy*
[2] *European Laboratory for Nonlinear Spectroscopy (LENS), University of Florence, 50019 Sesto Fiorentino, Italy*
[3] *Istituto Nazionale di Ottica del Consiglio Nazionale delle Ricerche (CNR-INO) c/o LENS, 50019 Sesto Fiorentino, Italy*
[4] *Department of Physics and Astronomy, University of Bologna, 40126 Bologna, Italy*
[5] *NFN, Sezione di Bologna, 40127 Bologna, Italy*
[6] *Institute of Physics, University of Augsburg, 86159 Augsburg, Germany*
[7] *Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany*
[8] *Faculty of Physics, Warsaw University of Technology, 00-662 Warsaw, Poland*
[9] *Department of Physics, University of Washington, Seattle, Washington 98195-1560, USA*
[10] *Department of Physics, University of Trieste, 34127 Trieste, Italy*
[11] *Istituto Nazionale di Ottica del Consiglio Nazionale delle Ricerche (CNR-INO), 34149 Trieste, Italy*

The motion of a quantized vortex is intimately connected with its microscopic structure and the elementary excitations of the surrounding fluid. In this work, we investigate the two-dimensional motion of a single vortex orbiting a pinned anti-vortex in a unitary Fermi superfluid at varying temperature. By analyzing its trajectory, we measure the yet-unknown longitudinal and transverse mutual friction coefficients, which quantify the vortex-mediated coupling between the normal and superfluid components. Both coefficients increase while approaching the superfluid transition. They provide access to the vortex Hall angle, which is linked to the relaxation time of the localized quasiparticles occupying Andreev bound states within the vortex core, as well as the intrinsic superfluid parameter associated with the transition from laminar to quantum turbulent flows. We compare our results with numerical simulations and an analytic model originally formulated for superfluid ^{3}He in the low-temperature limit, finding good agreement. Our work highlights the interplay between vortex-bound quasiparticles and delocalized thermal excitations in shaping vortex dynamics in unitary Fermi superfluids. Further, it provides a novel testbed for studying out-of-equilibrium vortex matter at finite temperatures.

Observation of many-body dynamical localization

Yanliang Guo

Institut für Experimentalphysik und Zentrum für Quantenphysik, Universität Innsbruck, Technikerstraße 25, Innsbruck, 6020, Austria

The quantum kicked rotor is a paradigmatic model system in quantum physics. As a driven quantum system, it is used to study the transition from the classical to the quantum world and to elucidate the emergence of chaos and diffusion. In contrast to its classical counterpart, it features dynamical localization, specifically Anderson localization in momentum space. The interacting many-body kicked rotor is believed to break localization, as recent experiments suggest [1,2].

In this talk, I will report the experimental observations of 1D strongly interacting gas under periodic and random driving. Starting from 2-nK samples in a compensated flat-bottom optical trap, we observe many-body dynamical localization (MBDL) in a 1D quantum kicked rotor (QKR) setting [3] as the interactions are tuned from zero into the Tonks-Girardeau (TG) regime. After some initial evolution, the momentum distribution freezes and retains its characteristic structure as the sample is kicked periodically hundreds of times. In contrast, for random kicking, the distribution becomes uniform and loses all structure, which indicates thermalization of the system.

[1] Interaction-driven breakdown of dynamical localization in a kicked quantum gas, A. Cao et al., Nature Physics 18, 1302 (2022).

[2] Many-body dynamical delocalization in a kicked one-dimensional ultracold gas, J. See Toh et al., Nature Physics 18, 1297 (2022).

[3] Observation of many-body dynamical localization, Y. Guo et al., arXiv:2312.13880 (2023).

Localization-landscape generalized Mott-Berezinskiĭ formula

Gabriel Hayoun and Marcel Filoche

Institut Langevin, ESPCI Paris, PSL University, CNRS, Paris, France

In semiconductors presenting some form of structural disorder, either in the spatial alloy composition or in the distribution of impurities, electronic states contributing to the conduction at low temperature are localized. In this situation, transport occurs by hopping between these states, and the low-frequency AC electronic conductivity can be modelled through the Mott-Berezinskiĭ (MB) formula, first derived by Mott on physical arguments [1-3], and later proved mathematically by Berezinksiĭ in 1973 [4]. This formula relies on several assumptions that are critical for its proper derivation:

- The temperature is low enough so that the Fermi energy lies in the localized part of the spectrum, where electronic quantum states are assumed to be Anderson-localized.
- The electronic states contributing to the conductivity are spatially well separated.
- The electronic states contributing to the conductivity are localized with uniform localization length ξ.
- Finally, although the MB formula is expressed in any dimension, Berezinskiĭ's mathematical derivation was only one-dimensional.

We generalize the MB formula thanks to the localization landscape (LL) theory [5]. We do not require identical localization length ξ for all states. Instead, it is assumed that the effective potential [6] is statistically isotropic and homogeneous. Original behaviors of the conductivity are then investigated.

[1] N. F. Mott, Electrons in disordered structures, Adv. Phys. 16, 49 (1967).
[2] N. F. Mott, Conduction in Non-crystalline Systems I. Localized Electronic States in Disordered Systems, in Sir Nevill Mott - 65 Years in Physics (World Scientific Series in 20th Century Physics, 1995) pp. 429-439.
[3] N. F. Mott and E. A. Davis, Electronic Processes in Non- Crystalline Materials (Oxford University Press, 2012).
[4] V. L. Berezinskii, Kinetics of a quantum particle in a one-dimensional random potential, Zh. Eksp. Teor. Fiz. 65, 1251 (1973).
[5] M. Filoche and S. Mayboroda, Universal mechanism for Anderson and weak localization, Proc. Natl Acad. Sci. USA 109, 14761 (2012).
[6] D. N. Arnold, G. David, D. Jerison, S. Mayboroda, and M. Filoche, Effective confining potential of quantum states in disordered media, Phys. Rev. Lett. 116, 056602 (2016).

Kelvin-Helmholtz Instability in atomic Fermi superfluids: short and long term dynamics

Diego Hernandez Rajkov,[1,2] Nicola Grani,[1,2,3] Marcia Frómeta Fernández,[1,2] Giulia Del Pace,[1,2,3] Francesco Scazza,[4,5] Maximilian Schemmer,[1,2] and Giacomo Roati[1,2]

[1] *Istituto Nazionale di Ottica del Consiglio Nazionale delle Ricerche (CNR-INO) c/o LENS, 50019 Sesto Fiorentino, Italy*
[2] *European Laboratory for Nonlinear Spectroscopy (LENS), University of Florence, 50019 Sesto Fiorentino, Italy*
[3] *Department of Physics, University of Florence, 50019 Sesto Fiorentino, Italy*
[4] *Department of Physics, University of Trieste, 34127 Trieste, Italy*
[5] *Istituto Nazionale di Ottica del Consiglio Nazionale delle Ricerche (CNR-INO), 34149 Trieste, Italy*

At the interface between two fluid layers in relative motion, infinitesimal fluctuations can be exponentially amplified, inducing vorticity and the breakdown of laminar flow. Here, we observe how the contact interface between two counter-rotating atomic superflows develops into an ordered circular array of quantized vortices, which loses stability and rolls up into vortex clusters [1]. We extract the instability growth rates and find they obey the same scaling relations across different superfluid regimes across the BEC-BCS crossover [1]. We show the spontaneous emergence of clustered structures due to the out-of-equilibrium phenomena occurring in long evolutions, a form of decay of two-dimensional quantum turbulence [2,3].

[1] Hernández-Rajkov, D., et al. Connecting shear flow and vortex array instabilities in annular atomic superfluids. Nat. Phys. 20, 939-944 (2024).
[2] Reeves, Matthew T., et al. Turbulent Relaxation to Equilibrium in a Two-Dimensional Quantum Vortex Gas, Phys. Rev. X 12, 011031 (2022).
[3] S. Simjanovski, et al., Shear-induced decaying turbulence in Bose-Einstein condensates, Phys. Rev. A 111, 023314 (2025).

Bose-Einstein condensation in flat bands from a real-space perspective

Kukka-Emilia Huhtinen and Sebastian Huber

Institute for Theoretical Physics, ETH Zürich

Flat band systems can be promising for the observation of correlated phenomena, since even small interactions dominate over the vanishing kinetic energy. However, the degeneracy of states on a flat band can hinder condensation; in fact, a stable Bose-Einstein condensate (BEC) is unlikely in many simple flat-band models. Some information about the stability of BECs in flat bands can be obtained from the quantum geometric tensor: within Bogoliubov theory, the quantum metric relates to, for instance, the speed of sound [1] and part of the superfluid weight when the condensation occurs in a Bloch state. The mean-field energy is however typically not minimised only by single Bloch states, but by a very large number of states with or without translational invariance. For instance, in the kagome lattice, the number of states minimising the mean-field energy is the number of three-colorings of the kagome lattice [2]. It is therefore not immediately clear that condensation should occur only in Bloch states.

Here, we use a real-space approach to study condensates in flat band lattices within Bogoliubov theory. This approach takes into account that condensation does not need to occur in translationally invariant states. We show how the stability of the condensate relates to the properties of compact localized states on the non-interacting flat band. We use this result to construct flat band models where condensation is possible within Bogoliubov theory. This work proposes an alternative perspective to the understanding of Bose-Einstein condensation on flat bands, centering on the real-space structure of the flat band eigenstates instead of the momentum-space geometry described by the quantum geometric tensor.

[1] A. Julku, G. M. Bruun, P. Törmä, Phys. Rev. Lett. 127, 170404 (2021).
[2] Y.-Z. You, Z. Chen, X.-Q. Sun, H. Zhai, Phys. Rev. Lett. 109, 265302 (2012).

Stirring the false vacuum via interacting quantized bubbles on programmable quantum annealer

Jaka Vodeb,[1,2] Gregor Humar,[1,3] Jean-Yves Desaules,[4,5] Andrew Hallam,[5] Andrea Rava,[6,7] Dennis Willsch,[6,8] Fengping Jin,[6] Madita Willsch,[6,9] Kristel Michielsen,[6,7,9] Zlatko Papić,[5] Marko Ljubotina,[4,10,11] Luka Pavešić,[12,13] and Dragan Mihailović[1,2,3]

[1] *Department of Complex Matter, Jožef Stefan Institute, Ljubljana, Slovenia*
[2] *CENN Nanocenter, Ljubljana, Slovenia*
[3] *Department of Physics, Faculty for Mathematics and Physics, University of Ljubljana, Ljubljana, Slovenia*
[4] *Institute of Science and Technology Austria, Klosterneuburg, Austria*
[5] *School of Physics and Astronomy, University of Leeds, Leeds, UK*
[6] *Jülich Supercomputing Centre, Institute for Advanced Simulation, Forschungszentrum Jülich, Jülich, Germany*
[7] *RWTH Aachen University, Aachen, Germany*
[8] *Faculty of Medical Engineering and Technomathematics, University of Applied Sciences Aachen, Jülich, Germany*
[9] *AIDAS, Jülich, Germany*
[10] *Technical University of Munich, TUM School of Natural Sciences, Physics Department, Garching, Germany*
[11] *Munich Center for Quantum Science and Technology (MCQST), München, Germany*
[12] *Dipartimento di Fisica e Astronomia âĂIJG. GalileiâĂİ, Padova, Italy*
[13] *Istituto Nazionale di Fisica Nucleare (INFN), Padova, Italy*

False vacuum decay, the transition from a metastable quantum state to a true vacuum state, is a crucial phenomenon in quantum field theory and non-equilibrium processes such as phase transitions and dynamical metastability. However, its non-perturbative nature and the limited experimental accessibility of this process make it difficult to study, leaving open questions about the formation, movement, and interactions of true vacuum bubbles. Here [1], we directly observe the quantized formation of these bubbles in real time, a fundamental aspect of false vacuum decay dynamics, using a quantum annealer to simulate a tilted Ising model spin chain. We develop an effective model that accurately describes both the initial bubble formation and subsequent interactions, even in the presence of dissipation. The annealer uncovers coherent scaling laws in the driven many-body dynamics over more than 1,000 intrinsic qubit time units. This work establishes a framework for exploring false vacuum dynamics in large quantum systems using quantum annealers and provides a basis for further explorations of false vacuum decay phenomena in two-dimensional spin models.

[1] Vodeb, J., Desaules, JY., Hallam, A. et al. Stirring the false vacuum via interacting quantized bubbles on a 5,564-qubit quantum annealer. Nat. Phys. 21, 386-392 (2025).

Critical quantum dynamics of observables at eigenstate transitions

Simon Jiricek,[1] Miroslav Hopjan,[2] Patrycja Łydżba,[3] Fabian Heidrich-Meisner,[1] and Lev Vidmar[2,4]

[1] *Institut für Theoretische Physik, Georg-August-Universität Göttingen, D-37077 Göttingen, Germany*
[2] *Department of Theoretical Physics, J. Stefan Institute, SI-1000 Ljubljana, Slovenia*
[3] *Department of Theoretical Physics, Wroclaw University of Science and Technology, 50-370 Wrocław, Poland*
[4] *Department of Physics, Faculty of Mathematics and Physics, University of Ljubljana, SI-1000 Ljubljana, Slovenia*

Based on the dynamics of survival probability in a quantum quench protocol, the intriguing critical phenomena of scale invariance was recently pointed out for eigenstates transitions, providing a promising tool to detect the boundaries of thermalizing behavior in closed quantum systems. In this work we generalize single-particle survival probability to transition probabilities between singleparticle states in the eigenbasis of the Hamiltonian before a quantum quench. Studying two paradigmatic quadratic Hamiltonians, i.e. the three-dimensional Anderson model and the onedimensional Aubry-André model, we demonstrate that the transition probabilities exhibit scaleinvariant mid- and late-time dynamics in a similar fashion as the survival probability. Futher, we show that under the dynamics governed by quadratic Hamiltonians, one-body observables in a many-body sector are given as linear combinations of single-particle transition probabilities. As the main result of this work, we then demonstrate that scale invariance occurs also for generic observables like the particle imbalance in a quench from an initial Hamiltonian that shares the observables eigenbasis.

[1] doi = 10.1103/PhysRevB.109.205157.

Signature of preformed pairs in angle-resolved photoemission spectroscopy

Klemen Kovač,[1,2] Alberto Nocera,[3,4] Andrea Damascelli,[3,4] Janez Bonča,[1,2] and Mona Berciu[3,4]

[1] *Jozef Stefan Institute, Ljubljana, Slovenia*
[2] *Faculty of Mathematics and Physics, Ljubljana, Slovenia*
[3] *Department of Physics and Astronomy, University of British Columbia, Vancouver, British Columbia, Canada, V6T 1Z1*
[4] *Stewart Blusson Quantum Matter Institute, University of British Columbia, Vancouver, British Columbia, Canada, V6T 1Z4*

We use density matrix renormalization group (DMRG) and variational exact diagonalization (VED) to calculate the single-electron removal spectral weight for the Hubbard-Holstein model at low electron densities. Tuning the strength of the electron-phonon coupling and of the Hubbard repulsion allows us to contrast the results for a liquid of polarons versus a liquid of bipolarons. The former shows spectral weight up to the Fermi energy, as expected for a metal. The latter has a gap in its spectral weight, set by the bipolaron binding energy, although this is also a (strongly correlated) metal. This difference suggests that angle-resolved photoemission spectroscopy could be used to identify liquids of pre-formed pairs. Furthermore, we show that the one-dimensional liquid of incoherent bipolarons is well approximated by a 'Bose sea' of bosons that are hard-core in momentum space, occupying the momenta inside the Fermi sea but otherwise non-interacting. This new proposal for a strongly-correlated many-body wavefunction opens the way for studying various other properties of incoherent (non-superconducting) liquids of pre-formed pairs in any dimension.

Towards efficient numerical description of hybrid quantum systems: a study of extended Hubbard-Holstein model

Piotr Kulik, João Pedro Mendonça, and Krzysztof Jachymski

Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warsaw, Poland

Systems with intermediate and strong coupling still pose important questions in the field of condensed matter. In these regimes, conventional analytical methods become ineffective, and numerical computations become computationally expensive due to the exponential scaling of the problem. Regardless, lots of different numerical methods (DMRG, QMC, ED) were developed to minimize scaling and examine the systems and its variants in the best possible way. The natural progression was to introduce hybrid systems, where bosons and fermions interacted with themselves, as well as with phonons or photons. Unfortunately, due to the infinite nature of this additional Hilbert space, these new types of systems require a novel approach. The method of non-Gaussian variational ansatz [1] allows us to map the problem onto an effective model that encapsulates a higher-order correlation effect. We use this method to study a hybrid system of electrons interacting with phonons, i.e. Hubbard-Holstein model.

[1] Shi, Tao, Eugene Demler, and J. Ignacio Cirac. "Variational study of fermionic and bosonic systems with non-Gaussian states: Theory and applications." Annals of Physics 390 (2018): 245-302.

Effects of coupling geometries on the multi-mode open Dicke model

Miriam Leonhardt,[1] Oliver Lunt,[1] and Andrew Daley[1,2]

[1] *Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom*
[2] *Department of Physics and SUPA, University of Strathclyde, Glasgow G4 0NQ, United Kingdom*

In the open Dicke model, which describes the collective coupling of N two level atoms to a single cavity mode, there is a well known phase transition in the steady-state behaviour of the system, as the light-matter coupling strength is varied, from a normal phase to a superradiant phase [1,2]. Multi-mode versions of this model, where several distinct clusters of N atoms are coupled to the degenerate modes of a confocal cavity, have been studied in the context of spin glass [3] and associative memory regimes [4], for which the couplings between different clusters of atoms and different modes are chosen effectively randomly, without the choice of a particular geometry.

In this theoretical work, we are investigating the effects of specific coupling geometries on the multi-mode Dicke model and its solutions. Even in the simplest possible, effectively 1D nearest neighbour geometry, in which there are M clusters of atoms and $M-1$ cavity modes arranged so that each cavity mode couples to two neighbouring clusters of atoms, we observe effects not seen in the standard, single-mode Dicke model. We show the existence of additional stable steady-state solutions beyond the superradiant transition, the number of which increases with the number of atom clusters in the system, and make predictions about their structure. We also investigate the dynamics of the system in the simplest configuration where this new behaviour is observed; a system composed of four clusters of two-level atoms coupled to three cavity modes.

[1] F. Dimer et al., *Phys. Rev. A* **75**, 013804 (2007).
[2] P. Kirton et al., *Adv. Quantum Technol.* **2**, 1800043 (2019).
[3] B. P. Marsh, et al., *Phys. Rev. X* **14**, 1 (2024).
[4] B. P. Marsh, et al., *Phys. Rev. X* **11** 021048 (2021).

A new interconnection platform for neutral atom arrays

Yi Li, Sébastien Garcia, and Alexei Ourjoumtsev

JEIP, Collège de France, PSL University, France

Advances in the manipulation of arrays of individual Rydberg atoms have demonstrated the potential of the latter for quantum information [1]. However, actual applications in quantum computing will require millions of logical qubits, themselves encoded on tenths of single atoms. The number of atoms in a single array will reach a limit (on the order of 10^4), defined by the available laser power, the field of view offered by high-NA optics or the resolution of spatial light modulators defining the geometry of the array. This limit calls for the development of distributed quantum processing, which requires quantum interconnections. Our proposal for this necessary development is a platform that will allow the connection of atomic processors through an intracavity Rydberg superatom.

By coupling an atomic cloud to a medium-finesse cavity and driving it to a highly excited state, we can achieve a collective two-level system called a superatom [2]. The main advantage of such a platform is that the collective coupling of the atomic cloud to the cavity bypasses the challenges for a high-finesse cavity and the high sensitivity of Rydbergs atoms to nearby dielectric surfaces. In our group, the coherent mapping of the state of the superatom onto a free-propagating photonic qubit has been demonstrated [3].

Building on this scheme, we propose trapping an array of atoms, via optical tweezers, next to the atomic cloud within the cavity mode. The aim is to entangle the individual atom with the superatom, then map the superatom onto a free-propagating light mode. This will result in an entangled single-atom single-photon state, forming a building block to distribute entanglement between distant single-atom arrays.

[1] Bluvstein, D., Evered, S.J., Geim, A.A. et al. Logical quantum processor based on reconfigurable atom arrays. Nature 626, 58-65(2024). https://doi.org/10.1038/s41586-023-06927-3.

[2] J. Vaneecloo, S. Garcia, A. Ourjoumtsev, Intracavity Rydberg superatom for optical quantum engineering : Coherent control, single-shot detection, and optical π phase shift, Phys. Rev. X 12, 021034 (2022).

[3] V. Magro et al, Deterministic freely propagating photonic qubits with negative Wigner functions, Nat. Photon. 17, 688-693.

Developing Neutral Atom Array Quantum Processors in Singapore

Zhengjiang Li,[1] Abhishek Jamunkar,[2] Tong-Yan Xia,[2] Vasu Dev,[2] Kai Xiang Lee,[2] Jinyu Zhou,[2] Vincent Mancois,[1] Kelvin Lim,[1] Jintao Yang,[2] Thanh Nguyen,[2] Mujahid Aliyu,[2] Zilong Chen,[2] David Wilkowski,[1,2] and Boon Long Ng[2]

[1] *School of Physical and Mathematical Sciences, Nanyang Technological University*
[2] *Centre for Quantum Technologies, National University of Singapore*

The effort to build quantum processors with 200 qubits or more is divided into multiple parallel subtasks to address both technical and conceptual challenges. On the technical front, we are working on a compact 2D MOT, 3D MOT, a science chamber for a 3D MOT operating in an ultrahigh vacuum environment, and a 2D neutral atom tweezer array. The 2D MOT enhances atom flux and isolates the vacuum environment of the 3D MOT through a differential pumping tube. In the 3D MOT, atoms are cooled to the microkelvin regime before being transferred into the tweezer array. On the conceptual side, we are identifying suitable atomic transitions for implementing quantum computing operations, quantum simulation, and quantum error correction.

Entanglement entropy of many-body systems with particle number conservation

Gregor Medoš[1,2] and Lev Vidmar[1,2]

[1] *Department of Theoretical Physics, Jožef Stefan Institute, Jamova cesta 39, Ljubljana SI-1000, Slovenia*
[2] *Department of Physics, Faculty of Mathematics and Physics, Jadranska ulica 19, University of Ljubljana, Ljubljana SI-1000, Slovenia*

Quantum entanglement in quantum many-body phyiscs is crucial in understading non-equilibrium dynamics and thermalization of closed systems, i.e., systems that are completely isolated from the environment. We can examine the bipartite entanglement entropy of quantum lattice systems of interacting bosons. The average entanglement entropy of highly excited eigenstates of a quantum chaotic Hamiltonian follows a volume law, described by Page's curve [1]. It has been shown in the hard-core boson limit that the presence of particle number conservation, the volume law term will depend on the average number of particles per lattice site [2]. The volume law leading term can be retrieved using a "mean-field" approach [3]. Using this approach we can explore soft-core bosons by generalizing the Bianchi-Dona distribution [4]. We manage to determine the volume law term of the average entanglement entropy for soft-core bosons using a generating function of the grand canonical ensemble at infinite temperature and a "mean-field" approach.

[1] Page, D. N. Physical review letters 71, 1291 (1993).
[2] Bianchi, E. et al., PRX Quantum 3, 030201 (2022).
[3] Vidmar, L. et al., Physical review letters 119, 220603 (2017).
[4] Cheng, Y. et al., Physical Review B 110, 235154 (2024).

High-repetition-rate fermionic quantum gas microscope for quantum simulation

Luca Muscarella,[1,2] Robin Groth,[1,2] Andreas Von Haaren,[1,2] Janet Qesja,[1,2] Francesco Testi,[1,3] Liyang Qiu,[1,2] Titus Franz,[1,2] Timon Hilker,[1,2,4] Immanuel Bloch,[1,2] and Philipp Preiss[1,2]

[1] *Max-Planck Institute of Quantum Optics*
[2] *Munich Center for Quantum Science and Technology*
[3] *Ludwig Maximilian University Munich*
[4] *University of Strathclyde*

Fermionic quantum simulators provide a powerful platform for exploring high-temperature superconductivity, topological phases, and many-body dynamics-challenges that persist even with the advent of qubit-based quantum computing. Here, we present recent results from our high-repetition-rate fermionic quantum gas microscope optimized for rapid data acquisition. Fast cycle times are achieved through high-power optical traps, rapid evaporative cooling, and efficient spin-resolved fluorescence imaging. Our system will feature stable bichromatic optical lattices for implementing two-fermion gates and single-particle addressing for precise single-qubit control, enabling the exploration of quantum information processing schemes.

Quantum Gas Microscopy of Fermions in the Continuum

Jean Paul Nohra,[1] Cyprien Daix,[1] Maxime Dixmerias,[1] Joris Verstraten,[1] Bruneau Peaudecerf,[2] Tim De Jong,[1] and Tarik Yefsah[1]

[1] *Laboratoire Kastler Brossel, ENS-Université PSL, CNRS, Sorbonne Université, Collège de France, 24 rue Lhomond, 75005, Paris, France*

[2] *Laboratoire Collisions Agrégats Réactivité, UMR 5589, FERMI, UT3, Université de Toulouse, CNRS, 118 Route de Narbonne, 31062, Toulouse CEDEX 09, France*

Quantum gas microscopy has emerged in the last years as a powerful technique to probe and manipulate quantum many-body systems at the single-atom level. For over a decade, however, it has only been used to study lattice and spin chain physics, prominently to explore the Hubbard model and its generalizations. In this poster, we will present our recent work on quantum gas microscopy of ultracold fermions in continuous space and their characterization at previously inaccessible levels of resolution and precision. Firstly, we will report on the imaging of the in-situ density probability of deterministically prepared single-atom wave packets as they expand in a plane, and how we obtain a crucial benchmark for the reliability of our imaging protocol [1]. Secondly, we will report on quantum gas microscopy of 2D and quasi-2D ideal Fermi gases, where we measure spatially-resolved density correlation functions of the second and third order, and reveal their temperature dependence [2]. Finally, we will show how using single-atom resolved images, we extract the number fluctuations in the system and perform accurate fluctuation-thermometry over a large dynamical range, from nearly zero temperature to several times the Fermi temperature. By probing number fluctuations on small subsystems, we are able to find a regime where quantum fluctuations play an important role, leading to a significant deviation from the behavior predicted for fermions by the fluctuation-dissipation theorem in the thermodynamic limit [3]. These results represent the first application of quantum gas microscopy to continuous-space many-body systems. Our approach offers radically new possibilities for the exploration of strongly interacting Fermi gases at the single-atom level.

[1] J. Verstraten, K. Dai, M. Dixmerias, B. Peaudecerf, T. De Jongh, T. Yefsah, "In Situ Imaging of a Single-Atom Wave Packet in Continuous Space", Phys. Rev. Lett. 134, 083403, 2025.

[2] T. De Jongh, J. Verstraten, M. Dixmerias, C. Daix, B. Peaudecerf, T. Yefsah, arXiv:2411.08776, 2024.

[3] M. Dixmerias, J. Verstraten, C. Daix, B. Peaudecerf, T. De Jongh, T. Yefsah, arXiv:2502.05132, 2025.

Strongly dissipative one dimensional quantum gases

Sukla Pal,[1] Jeff Maki,[1,2] and Alberto Biella[1]

[1] *Pitaevskii BEC Center, CNR-INO and Dipartimento di Fisica, Universita di Trento, 38123 Trento, Italy*
[2] *Department of Physics, University of Konstanz, 78464 Konstanz, Germany*

We study the effects of strong two-body losses in bosonic gases trapped in one-dimensional optical lattices. We are particularly interested in the mott insulating state with broken translational invariance, and we investigate the dynamics of the system in quantum Zeno regime [1, 2]. We construct a set of rate equations using Gaussian approximation and exploiting the connection with generalised Gibbs ensemble. Obtained results from the rate equations are compared with those from the exact Monte Carlo simulations using trajectory method, and we observe good agreement. There is also a strong possibility of observing our predictions in current state-of-the-art experiments.

[1] J. J . Garc ia-Ripoll et. al., Dissipation-induced hard-core boson gas in an optical lattice, New Journal of Physics 11 013053 (2009).
[2] D. Rossini et. al., Strong correlations in lossy one-dimensional quantum gases: From the quantum Zeno effect to the generalized Gibbs ensemble, Phys. Rev. A 103, L060201 (2021).

Absence of gapless Majorana edge modes in few-leg bosonic flux ladders

Felix A. Palm,[1,2] Cécile Repellin,[3] Nathan Goldman,[2,4] and Fabian Grusdt[1]

[1] *Ludwig-Maximilians-Universität München (Germany)*
[2] *CENOLI, Université Libre de Bruxelles (Belgium)*
[3] *Université Grenoble-Alpes, LPMMC (France)*
[4] *Laboratoire Kastler Brossel, Collège de France (France)*

The search for Majorana excitations has seen tremendous efforts in recent years, ultimately aiming for their individual controllability in future topological quantum computers. A promising framework to realize such exotic Majorana fermions are topologically ordered non-Abelian phases of matter, such as certain fractional quantum Hall states. Quantum simulators provide unprecedented controllability and versatility to investigate such states, and developing experimentally feasible schemes to realize and identify them is of immediate relevance. Motivated by recent experiments, we consider bosons on coupled chains, subjected to a magnetic flux and experiencing Hubbard repulsion. At magnetic filling factor $\nu = 1$, similar systems on cylinders have been found to host the non-Abelian Moore-Read Pfaffian state in the bulk. Here, we address the question of whether more realistic few-leg ladders can host this exotic state and its chiral Majorana edge states. To this end, we perform extensive density-matrix renormalization-group simulations and determine the central charge of the ground state. While we do not find any evidence of gapless Majorana edge modes in systems of up to six legs, exact diagonalization of small systems reveals evidence for the Pfaffian state in the entanglement structure. By systematically varying the number of legs and monitoring the appearance and disappearance of this signal, our work highlights the importance of finite-size effects for the realization of exotic states in experimentally realistic systems.

Charged Polarons in atom-ion hybrid systems

Luis Aldemar Peña Ardila

Dipartimento di Fisica, Università di Trieste, Strada Costiera 11, I-34151 Trieste.

Charged quasiparticles dressed by the low excitations of an electron gas constitute one of the fundamental pillars for understanding quantum many-body effects in some materials. Quantum simulation of quasiparticles arising from atom-ion hybrid systems may shed light on solid-state uncharted regimes. Here, we will discuss ionic polarons created as a result of charged dopants interacting with a Bose-Einstein condensate [1] and a polarized Fermi gas [2]. Here, we show that even in a comparatively simple setup consisting of charged impurities in a weakly interacting bosonic medium and an ideal Fermi gas with tunable atom - ion scattering length, the competition of length scales gives rise to a highly correlated mesoscopic state in the bosonic case; in contrast, a molecular state appears in the Fermi case. We unravel their vastly different polaronic properties compared to neutral quantum impurities using quantum Monte Carlo simulations. Contrary to the case of neutral impurities, ionic polarons can bind many excitations, forming a nontrivial interplay between few and many-body physics, radically changing the ground-state properties of the polaron.

[1] Cavazos U., LAPA., and Jachymski, K. PRA, 110 (L011301) 2024.
[2] Pessoa R., Vitiello S., and LAPA PRL, 133 (233002) 2025.

Center of mass excitation in a shell-shaped trap

Maxime Pesche, Matthieu Cassus-coussère, Thomas Badr, Laurent Longchambon, and Hélène Perrin

LPL

Bose Einstein condensate is a large topic of interest in the domain of atomic physics for its peculiar properties. In LPL, we study the collective modes of a BEC trapped into an ellipsoid surface. We prepare experimentally a cloud of around 10^5 rubidium atoms in a quadrupole magnetic field dressed with a radio-frequency. This creates a trapping potential for the atoms in the shape of an ellipsoid. By tuning the magnetic gradient, it this possible to partially compensate gravity and study the dynamics of the cloud when we vary this parameter. The motion of the center of mass of the cloud on the surface of the ellipsoid can be well described with a harmonic plus quartic oscillator model. We present here the experimental observation of such a motion induced by a modulated magnetic field from an external coil, that sets the whole shell into motion. From these observations, we manage to have access to specific parameters of the system, such as the trapping frequency and the quartic parameter.

Towards a real-time impurity solver using tensor train decomposition

Liam Rampon,[1] Michel Ferrero,[1] and Olivier Parcollet[2]

[1] *CPHT, École Polytechnique, France*
[2] *CCQ, Flatiron Institute, New York*

Keldysh diagrammatic expansions allow unbiased access to real-time correlators through a perturbative series. Obtaining the coefficients of said series require computating high-dimensional integrals, usually with Monte-Carlo sampling [1]. We instead use Tensor Cross Interpolation [2], a tensor compression technique originating from the MPS community, to perform the calculations. We obtain coefficients for benchmark impurity problems (flat, semi-circular, and DMFT self-consistent bath) at zero and finite temperature, with an order of magnitude speedup. We perform conformal map resummation [3] automatically and obtain spectral functions up to high Coulomb coupling, with sufficient resolution to observe Kondo physics.

[1] doi.org/10.1103/PhysRevB.100.125129.
[2] doi.org/10.21468/SciPostPhys.18.3.104.
[3] doi.org/10.1103/PhysRevX.9.041008.

A New Dipolar Quantum Gas Machine

Parvathy Sekhar,[1,2] Giovanni Ferioli,[2] Pietro Lombardi,[3] Luca Tanzi,[1,4] and Giovanni Modugno[1,2,4]

[1] *European Laboratory for Non-linear Spectroscopy(LENS), Sesto Fiorentino, 50019 Firenze, Italy*
[2] *Dip. di Fisica e Astronomica, Universita degli studi di Firenze, Sesto Fiorentino, 50019 Firenze, Italy*
[3] *CNR-INO, Sesto Fiorentino, 50019 Firenze, Italy*
[4] *CNR-INO, Sede Secondaria Adriano Gozzini, 56124 Pisa, Italy*

We present the design and preliminary characterization of a new generation experimental setup aimed at realizing dipolar quantum gases of Dysprosium-162 (^{162}Dy) for studying novel quantum phases, including supersolids. The apparatus combines recent technical innovations with insights from existing literature [1] [2] to create a compact and versatile experimental platform, currently under construction. The setup features a 2D MOT to deliver a collimated flux of cold atoms into a narrow-line 3D MOT. We perform numerical simulations and spectroscopic measurements to validate the atomic velocity distributions at different cooling stages. These efforts lay the groundwork for achieving quantum degeneracy in our setup, with high atom numbers and shall enable future studies of long-range interacting many-body systems.

[1] S. Jin et al., Physics Review A 108, 023719 (2023).
[2] G. Lamporesi et al., Rev. Sci. Instrum. 84, 063102 (2013).

FORESTALLED PHASE SEPARATION AS A PRECURSOR TO STRIPE AND SUPERCONDUCTING ORDER

Aritra Sinha and Alexander Wietek

Max Planck Institute for the Physics of Complex Systems

Stripe order and superconductivity are key features in the phase diagram of high-temperature cuprate superconductors, extensively studied within the two-dimensional Fermi-Hubbard model (FHM). Numerically, stripe order has been confirmed as the ground state of the two-dimensional FHM without nearest-neighbor (NN) coupling, while superconductivity emerges upon introducing NN couplings in specific parameter regimes. As temperature increases, both stripe and superconducting states transition into the enigmatic strange metal and pseudogap regimes, whose precise nature remains a long-standing puzzle. Using modern tensor network techniques, we discover a crucial aspect of these regimes. Infinite projected entangled pair state (iPEPS) simulations in the fully two-dimensional limit reveal a maximum in the charge susceptibility at temperatures above the stripe phase. This maximum is located around hole-doping $p = 1/8$ and intensifies upon cooling. Using minimally entangled typical thermal states (METTS) simulations on finite cylinders, we attribute the enhanced charge susceptibility to the formation of charge clusters, reminiscent of phase separation where the system is partitioned into hole-rich and hole-depleted regions. In contrast to genuine phase separation, the charge cluster sizes fluctuate statistically without a divergent charge susceptibility. Hence, while this precursor state features clustering of charge carriers, true phase separation is ultimately forestalled at lower temperatures by the onset of stripe order [1]. This charge clustering maybe linked to the pseudogap phenomenon, where antiferromagnetic (AFM) domains create an electronic gap while adjacent metallic regions partially fill it, characteristic of the pseudogap phase. Intuitively, antiferromagnetic correlations can be maximized whenever exactly two electrons reside on nearest-neighbor sites, and hence, strong antiferromagnetic correlations favor half-filled regions. Thus, an attraction between electrons mediated by antiferromagnetic correlations depletes other regions of the system, which constitute the hole-rich clusters. Additionally, in the t-J model with nearest- neighbor coupling t', we show that phase separation gives way to superconducting d-wave order, highlighting the interplay between AFM correlations, charge susceptibility, and superconductivity.

[1] Forestalled Phase Separation as the Precursor to Stripe Order, arXiv:2411.15158.

Towards a Dual-Species Dipolar Quantum Gas Microscope

Gerard Sola Berga,[1] Clemens Ulm,[1,2] Eva Casotti,[1,2] Andrea Litvinov,[1] Manfred J. Mark,[1,2] and Francesca Ferlaino[1,2]

[1] *Institute for Quantum Optics and Quantum Information Austrian Academy of Sciences, Innsbruck, Austria*

[2] *Institute for Experimental Physics, University of Innsbruck, Innsbruck, Austria*

Ultracold atoms in optical lattices have been established as a powerful toolbox for quantum simulation, enabling the study of many-body physics and strongly correlated condensed matter. In the last decade, single-site imaging and addressing of these lattice-confined atoms has been achieved by the experimental realization of quantum gas microscopes. Until 2023, quantum gas microscopes utilized atomic species with a negligible magnetic moment, which interact exclusively via short-range contact interaction. The addition of long-range interactions in a lattice leads to new exotic phases of matter, such as the Haldane insulator, an interaction-induced topological phase. Here, we report on the progress towards a quantum gas microscope utilizing the highly dipolar species erbium and dysprosium, which will allow the study of both single- and dual-species physics on the single-atom level. With this new setup, we aim to probe extended Bose- and Fermi-Hubbard models, entering a new quantum simulation framework, beyond the capabilities of conventional short-range interaction setups.

Single-Atom Trapping in Optical Tweezers for Quantum Simulation

Shawn Storm,[1] Luca Guariento,[4] Veronica Giardini,[2] Andrea Fantini,[1] Vladislav Gavryusev,[2,3] Jacopo Catani,[2,3] Leonardo Fallani,[1,2,3] and

[1] *Department of Physics and Astronomy, University of Florence*
[2] *European Laboratory for Non-Linear Spectroscopy (LENS), University of Florence, Sesto Fiorentino, Italy*
[3] *National Institute of Optics (CNR-INO), National Research Council, Sesto Fiorentino, Italy*
[4] *Department of Physics Ettore Pancini, University of Napoli Federico II, Napoli, Italy*

We have successfully trapped individual strontium-88 atoms in optical tweezers, marking a significant step toward the realization of a scalable quantum simulator. Our approach leverages a combination of blue and red magneto-optical traps to cool the atoms to microkelvin temperatures before loading them into an array of tightly focused optical tweezers. Currently, we use acousto-optic deflectors to generate the tweezer array. However, we are implementing a spatial light modulator to improve trap depth uniformity, which will enhance the stability and homogeneity of atomic confinement. This transition will enable more precise control over atomic interactions, paving the way for scalable quantum simulations and entanglement generation via controlled Rydberg interactions. Future directions include atom rearrangement, high-fidelity state preparation, and spin transport physics.

Creation of a Box-Shaped Potential for Ultracold Lithium Atoms Using a Digital Micromirror Device

Alberto Terenzi,[1,2] Nicola Grani,[1,2,3] Diego Hernández-Rajkov,[2,3] Marcia Frómeta Fernández,[2,3] Giulia Del Pace,[1,2,3] and Giacomo Roati[2,3]

[1] *Department of Physics, University of Florence, 50019 Sesto Fiorentino, Italy*
[2] *European Laboratory for Nonlinear Spectroscopy (LENS), University of Florence, 50019 Sesto Fiorentino, Italy*
[3] *Istituto Nazionale di Ottica del Consiglio Nazionale delle Ricerche (CNR-INO) c/o LENS, 50019 Sesto Fiorentino, Italy*

We report on the implementation of a box-shaped optical potential with hard walls for ultracold lithium atoms using a Digital Micromirror Device (DMD). The DMD enables high-resolution spatial shaping of laser light, allowing us to design and dynamically control potential landscapes with unprecedented flexibility. In our setup, a set of telescopes are used to project a structured intensity pattern onto the atoms system, achieving a resolution of approximately $2\,\mu m$. With this system we can create a uniform potential region with sharp boundaries that closely mimics an idealized box potential, a key tool for studying homogeneous quantum gases. Unlike conventional harmonic traps, which introduce inhomogeneities due to their curvature, box potentials enable the study of bulk properties without density-dependent effects. A major advantage of the DMD-based technique is its versatility in real-time potential engineering. By dynamically reprogramming the micromirror configuration, we can modify the shape and depth of the potential on demand, allowing for the investigation of time-dependent quantum phenomena. Furthermore, this flexibility also improves the loading mechanism of the box. By varying the box dimensions from $50\,\mu m$ to $5\,\mu m$ we can maximize the number of trapped atoms. This mechanism is fundamental for achieving a good signal-to-noise ratio and enabling the observation of fine effects, that would be extremely valuable to develop atomtronic circuits.

Three-component mixtures of several fermions in one-dimensional harmonic trap

Marek Teske and Tomasz Sowinski

Institute of Physics, Polish Academy of Sciences

In this work, we study the many-body ground-state properties of three-component mixture of few fermions confined in one-dimensional harmonic trap and interacting with zero-range forces described with the Hamiltonian:

$$\hat{\mathscr{H}} = \sum_{\sigma} \int \mathrm{d}x\, \hat{\Psi}^{\dagger}_{\sigma}(x) \left[-\frac{1}{2}\frac{\mathrm{d}^2}{\mathrm{d}x^2} + \frac{1}{2}x^2 \right] \hat{\Psi}_{\sigma}(x) + \sum_{\sigma \neq \sigma'} g_{\sigma\sigma'} \int \mathrm{d}x\, \hat{n}_{\sigma}(x) \hat{n}_{\sigma'}(x).$$

Starting with a simple system of two-component mixture of four repulsively interacting particles, we explore impact of interactions with additional particle from the third component. We find that for any two-component repulsion g_{AB}, along with increasing interaction with third component $g = g_{AC} = g_{BC}$, the system undergoes structural transition in spatial ordering of the components. This transition is clearly visible in the single-particle density profiles $n_{\sigma} = \langle \mathtt{G} | \hat{n}_{\sigma} | \mathtt{G} \rangle$ as well as in the inter-component two-particle correlations $\mathscr{G}_{AB}(x, x') = \langle \mathtt{G} | \hat{n}_A(x) \hat{n}_B(x') | \mathtt{G} \rangle - \langle \mathtt{G} | \hat{n}_A(x) | \mathtt{G} \rangle \langle \mathtt{G} | \hat{n}_B(x') | \mathtt{G} \rangle$.

Multipolar Fermi Surface Deformations: Probing Electron Hydrodynamics in 2D Metals

Davis Thuillier and Thomas Scaffidi

University of California - Irvine

Recent developments in electron hydrodynamics have demonstrated the importance of considering the full structure of the electron-electron scattering operator. This physics has erstwhile been missed due to the use of the single relaxation time approximation. We introduce a first-principles calculation of the scattering operator for electron-electron interactions with multi-orbital effects which makes possible the calculation of both transport coefficients and quasi-conserved quantities given an arbitrary Fermi surface in 2D. As a first application, we calculate the resistivity and viscosity of Sr_2RuO_4 in a regime where electron-electron scattering is dominant and compare the values of these quantities to our simulation to obtain a ratio of the effective lifetimes for momentum and shear deformation relaxation respectively. This ratio is analogous to the ratio of the $l = 1$ and $l = 2$ modes in the free electron model which serves as an indicator of a hydrodynamic regime. We may likewise use this ratio to predict hydrodynamic behavior for bulk 2D metals and thereby broaden the limited number of hydrodynamic candidate materials. We provide the code for these calculations in the software package Ludwig.jl which supports a large class of 2D materials and materials with pseudo-2D band structure.

Chiral polaron formation on the edge of topological quantum matter

Amit Vashisht,[1] Ivan Amelio,[1] Laurens Vanderstraeten,[1] Georg Bruun,[2] Oriana Diessel,[3,4] and Nathan Goldman[1,5]

[1] *CENOLI, Université Libre de Bruxelles, CP 231, Campus Plaine, B-1050 Brussels, Belgium*
[2] *Department of Physics and Astronomy, Aarhus University, Ny Munkegade, DK-8000 Aarhus C, Denmark*
[3] *ITAMP, Center for Astrophysics, Harvard and Smithsonian, Cambridge, Massachusetts 02138, USA*
[4] *Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA*
[5] *Laboratoire Kastler Brossel, Collège de France, CNRS, ENS-PSL University, Sorbonne Université, 11 Place Marcelin Berthelot, 75005 Paris, France*

Immersing a mobile impurity in a quantum many-body environment can reveal fundamental properties of the background medium, hence providing a powerful probe of quantum matter. This approach is particularly intriguing when considering media with exotic properties, such as strongly-correlated phases and topological states of matter. In this work, we study the dressing of a mobile impurity interacting with a chiral mode, as provided by the edge of topological quantum matter. The resulting ”chiral polaron” is characterized by an asymmetric spectral function, which reflects the chirality and group velocity of the topological edge mode and the drag experienced by the mobile impurity. We first build our theoretical understanding from an effective one-dimensional chiral model, which captures the hallmark signatures of the chiral polaron. We then demonstrate how this simple picture extends to realistic models of integer and fractional Chern insulator states, by adapting tensor-network methods to polaron spectroscopy. Injecting mobile impurities on the edge of topological quantum matter is shown to be a powerful tool to probe exotic edge properties, particularly suitable for cold-atom experiments.

[1] https://doi.org/10.48550/arXiv.2407.19093.

Building a multi-ion mixed-qudit-boson simulator for quantum chemistry

Paul Venetz,[1,2] Philip Leindecker,[1,2] Edgar Brucke,[1,2] Luka Milanovic,[1,2] and Cornelius Hempel[1,2,3,4]

[1] *ETHZ-PSI Quantum Computing Hub*
[2] *Institute for Quantum Electronics, ETH Zürich, Otto-Stern-Weg 1, 8093 Zürich, Switzerland*
[3] *Quantum Center, ETH Zurich, CH-8093, Switzerland*
[4] *Laboratory for Nano and Quantum Technologies (LNQ), Paul Scherrer Institut (PSI)*

Mixed-qudit-boson (MQB) simulators [1] are versatile platforms for studying quantum systems that involve both discrete and continuous degrees of freedom. By combining qudits, bosonic modes, and efficient coupling between them, they can enable simulations outside regimes where classical methods excel. This is particularly relevant in chemistry, where MQB simulators allow the study of phenomena beyond the Born-Oppenheimer approximation. An iconic example is conical intersections, which play a fundamental role in various chemical processes, including the very first step in the process of human vision [2].

While individual conical intersections have been successfully simulated on trapped-ion MQB simulators [3,4] using only single qubits, modelling more realistic energy landscapes requires scaling up to accommodate a larger number of electronic states and vibrational modes. This can be realised using an ion-chain in a linear Paul trap, which we have built at PSI. In this poster, we present our latest advancements, focusing on individual addressing with crossed AODs and spatially resolved readout using a fast camera.

[1] MacDonell, R. J. et al. Analog quantum simulation of chemical dynamics. Chem. Sci. 12, 9794-9805 (2021).
[2] Sen, S. and Deupi, X. Study of Photoselectivity in Linear Conjugated Chromophores Using the XMS-CASPT2 Method. ACS Phys. Chem Au 4, 736-749 (2024).
[3] Valahu, C. H. et al. Direct observation of geometric-phase interference in dynamics around a conical intersection. Nat. Chem. 15, 1503-1508 (2023).
[4] Whitlow, J. et al. Quantum simulation of conical intersections using trapped ions. Nat. Chem. 15, 1509-1514 (2023).

A new quantum computing platform based on Yb atoms in optical tweezer arrays

Louise Wolswijk,[1,2] Thomas Beller,[2,3] Krishan Joshi,[1,2] Jacopo Catani,[1,2] Andreas Trenkwalder,[1,2] Francesco Cataliotti,[1,2,3] Massimo Inguscio,[1,2,3] Giacomo Roati,[1,2,3] Giacomo Cappellini,[2,3] Leonardo Fallani,[1,2,3] and Luca Tanzi[2,3]

[1] *National Institute of Optics (CNR-INO), National Research Council, Via N. Carrara 1, 50019, Sesto Fiorentino, Italy*
[2] *European Laboratory for Non-Linear Spectroscopy (LENS), University of Florence, Via N. Carrara 1, 50019, Sesto Fiorentino, Italy*
[3] *Department of Physics and Astronomy, University of Florence, Via G. Sansone 1, 50019, Sesto Fiorentino, Italy*

Alkaline earth-like atoms are promising candidates for the next-generation fault-tolerant quantum computing platforms. We are currently developing a new experiment based on fermionic 171Yb atoms in programmable arrays of optical tweezers. The optical tweezer array offers a platform in which the geometry of the atoms can be arbitrarily reconfigured by programming the phase mask imprinted on the tweezer laser beam using a spatial light modulator (SLM). Rapid rearrangement of atoms within the tweezer array sites can also be performed using a pair of acousto-optic deflectors (AODs). The two nuclear spin states of 171Yb will be used as robust and long-lived qubits, with the metastable clock state offering the possibility of implementing quantum error correction protocols, exploiting ground and metastable states as ancilla and data qubits. Multiqubit gates will be implemented exploiting state-selective coupling to Rydberg states.

Topological pump in N-leg spin ladder and its plateau transition by the Chern number

Cota Yamamoto,[1] Yoshihito Kuno,[2] Tomonari Mizoguchi,[1] Kazuki Sone,[1] and Yasuhiro Hatsugai[1]

[1] *Univ. of Tsukuba*
[2] *Akita Univ.*

A topological pump is a quantized charge transport as a time-periodic process in the adiabatic approximation proposed by Thouless and its pumped charge is given by the Chern number [1]. It is experimentally realized by using ultracold atoms and the quantization of the discontinuous shift of the center of mass (CoM) of an atomic cloud is observed [2,3]. The experimental realization triggers further studies. The bulk-edge correspondence guarantees that the shift of the CoM is equal to the Chern number and is quantized due to the edge states [4]. Ref. [5] proposes a general idea to construct a topological pump from the viewpoint of the SPT phases and phase transitions among them. Application to spin systems is also considered[6,7].

In this study [8], we consider a topological pump in an N-leg spin ladder by applying the framework of Ref. [5]. Spin ladders are known to have a rich symmetry protected topological (SPT) phase structure and several gapless transition points [9,10] and thus various pumps whose pumped spin is quantized as different integer values can emerge.

We introduce spatial clusterization to the N-leg spin ladder whose strong coupling limit is a set of $2N$-site staircase-shaped clusters. By changing the modulation amplitude, STP phases emerge. We find that the N-leg ladder experiences N-time SPT phase transitions. We use these gapless transition points as topological obstructions to construct a topological pump. A pump parameter path is set to connect two different SPT phases enclosing the gapless points . Specifically, we add the time-dependent staggered magnetic field, which breaks all the symmetries protecting the SPT phases. By the Chern numbers we characterize the pump and numerically find plateau transitions. We also discuss the pump in an open boundary and the bulk-edge correspondence.

[1] D. J. Thouless, Phys. Rev. B 27, 6083 (1983).
[2] M. Lohse, C. Schweizer, O. Zilberberg, M. Aidelsburger, and I. Bloch, Nature Physics 12, 350 (2016).
[3] S. Nakajima, T. Tomita, S. Taie, T. Ichinose, H. Ozawa, L. Wang, M. Troyer, and Y. Takahashi, Nature Physics 12, 296 (2016).
[4] Y. Hatsugai and T. Fukui, Phys. Rev. B 94, 041102 (2016).
[5] Y. Kuno and Y. Hatsugai, Phys. Rev. Res. 2, 042024 (2020).
[6] R. Shindou, Journal of the Physical Society of Japan 74, 1214 (2005).
[7] Y. Kuno and Y. Hatsugai, Phys. Rev. B 104, 045113 (2021).
[8] C. Yamamoto, Y. Kuno, T. Mizoguchi, K. Sone, Y. Hatsugai, in preparation.
[9] G. Sierra, Journal of Physics A: Mathematical and General 29, 3299 (1996).
[10] N. Chepiga, F. Michaud, and F. Mila, Phys. Rev. B 88, 184418 (2013).

Fermionization in optical quasicrystals and one-dimensional bosonic hard rods

Shengjie Yu, Zhaoxuan Zhu, Dean Johnstone, and Laurent Sanchez-Palencia

CPHT, CNRS, Ecole Polytechnique, Institut Polytechnique de Paris, 91120 Palaiseau, France

Quasicrystals, a fascinating class of materials with long-range but nonperiodic order, have revolutionized our understanding of solid-state physics due to their unique properties at the crossroads of long-range-ordered and disordered systems. The quantum simulation of quasicrystals in synthetic quantum matter systems offers a unique playground to investigate these systems with unprecedented control parameters. It is shown that there exists a Mott phase in the strongly interacting regime, accompanied with a fermionization phenomenon [1, 2, 3]. The strong repulsive interaction makes particles separated in space, resembling free fermions. However, due to the existence of some annular traps, the spatial separation does not apply to those subsystems, leading to an energy shift on the equation of state. It turns out that those annular traps can be modelized as one-dimensional systems consisting of some hard rods. We give the exact solution of one-dimensional quantum hard rods and thermodynamics. Correlation functions are compared with Luttinger liquid theory.

[1] R. Gautier, H. Yao, and L. Sanchez-Palencia, *Strongly interacting bosons in a two-dimensional quasicrystal lattice*, Phys. Rev. Lett. **126**, 110401 (2021).

[2] Z. Zhu, H. Yao, and L. Sanchez-Palencia, *Thermodynamic phase diagram of two-dimensional bosons in a quasicrystal potential*, Phys. Rev. Lett. **130**, 220402 (2023).

[3] Z. Zhu, S. Yu, D. Johnstone, and L. Sanchez-Palencia, *Localization and spectral structure in two-dimensional quasicrystal potentials*, Phys. Rev. A **109**, 013314.