Lattice-based Quantum Simulation

726. WE-Heraeus-Seminar

29 November – 01 December 2021

ONLINE

WILHELM UND ELSE HERAEUS-STIFTUNG

Introduction

The Wilhelm und Else Heraeus-Stiftung is a private foundation that supports research and education in science with an emphasis on physics. It is recognized as Germany's most important private institution funding physics. Some of the activities of the foundation are carried out in close cooperation with the German Physical Society (Deutsche Physikalische Gesellschaft). For detailed information see https://www.we-heraeus-stiftung.de

Aims and scope of the 726. WE-Heraeus-Seminar:

Quantum simulation, the use of a controllable quantum system to mimic the operation of other, more complex quantum systems, provides a pathway for solving quantum problems with a complexity level not accessible by classical computers. This quantum technology is presently classified as a leading approach to solve complex many-body problems with potential applications in the design of new materials and drugs. The WE-Heraeus Seminar aims at bringing together experts in this emerging field to train students (at the MSc and PhD Levels) and young researchers interested in the area and discuss recent developments in a stimulating and informal atmosphere. The seminar will cover topics such as (i) theoretical basis for quantum simulation, (ii) state-of-the-art of different platforms for quantum simulation (e.g., optical lattices of cold atoms, superconducting qubits, photonic simulators); (iii) novel concepts for scalable quantum processing and simulation exploring strongly coupled light-matter states, (iv) theoretical models for strongly correlated and dissipative systems, and (v) application of topological protection for robust quantum simulation. The scientific program will be complemented by poster sessions where the participants can present their results and discuss them with experts in the field. The exchange and cross-fertilization of ideas enabled by the seminar is expected to strengthen existing collaborations and foster new ones as well as enhance the visibility of the field.

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Introduction

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Program

Monday, 29 November 2021

08:45 – 09:00	Jaqueline Bloch	**Welcome words**
09:00 – 09:50	Ignacio Cirac	**Quantum simulation: Algorithms for finite energies and temperatures**
09 :50 – 10:40	Pascale Senellart-Mardon	**Quantum optics and quantum thermodynamics with semiconductor quantum dots**
10:40 – 11:10	*COFFEE BREAK*	
11:10 – 12:00	Vahid Sandoghdar	**Towards cooperative effects with organic molecules**
12:00 – 12:15	Stefan Jorda	**About the Wilhelm and Else Heraeus-Foundation**
12:15 – 13:00	**Postersession I**	
13:00	*LUNCH BREAK*	
14:50 – 15:40	Rick van Bijnen	**Entanglement Hamiltonian Tomography**
15:40 – 16:30	Iacopo Carusotto	**Topological quantum fluids of light**
16:30 – 17:00	*COFFEE BREAK*	
17:00 – 17:20	Alejandro Fainstein	**Polaromechanical crystals**
17:20 – 18:10	**Postersession II**	
18:10 – 19:00	Gil Refael	**Anomalous exciton transport in response to a uniform, in-plane electric field**

Program

Tuesday, 30 November 2021

09:00 – 09:50	Atac Imamoglu	**Strongly correlated electrons in atomically thin semiconductors**
09 :50 – 10:40	Tilmann Esslinger	**Geometric pumping: self-consistent and Floquet-driven**
10:40 – 11:10	*COFFEE BREAK*	
11:10 – 12:00	Moti Segev	**Photonic time-crystals**
12:00 – 12:50	Paul Walker	**Towards quantum optics with polariton cross-Kerr interaction**
13:00	*LUNCH BREAK*	
14:50 – 15:40	**Postersession III**	
15:40 – 16:30	Andrea Alberti	**Atoms at their quantum speed limit**
16:30 – 17:00	*COFFEE BREAK*	
17:00 – 17:20	Pasquale Scarlino	**Ultracompact cavity array for analog quantum simulation**
17:20 – 18:10	Peter Zoller	**Programmable quantum simulators as \`optimal' quantum sensors**
18:10 – 19:00	Alicia Kollár	**Band engineering for quantum simulation in circuit QED**

Program

Wednesday, 01 December 2021

09:00 – 09:50	Dieter Meschede	**From the Stern-Gerlach centenary to optical lattices**
09 :50 – 10:40	Eytan Grosfeld	**Dynamics and topology in interacting bosonic lattices**
10:40 – 11:10	*COFFEE BREAK*	
11:10 – 12:00	Sven Höfling	**Growth-defined lattices for polaritons**
12:00 – 12:50	Helgi Sigurdsson	**Networks of liquid light**
12:50 – 13:00	Marzena Szymanska	**Closing words**

End of the seminar

Posters

Poster session I

Albert Adiyatullin	**Observation of Floquet winding metals in a photonic lattice**
Daniel Alcalde Puente	**Convolutional restricted Boltzmann machine aided Monte Carlo: An application to Ising and Kitaev models**
Maya Amouzegar	**Circuit QED lattices**
Harriet Apel	**Characterisation of duality maps encompassing strong-weak dualities**
Christoph Bennenhei	**Ultrastrong light-matter interaction of J-aggregated squaraine in an open cavity for non-linear topological photonics**
Andrea Bergschneider	**Exciton-polaron dynamics in charge-tunable atomically thin semiconductors**
Aicha Bouhlala	**The role of transition metals (Mo, W) in magnetic properties of doped CeO_2 : First-principles characterization**
Giulio Campanaro	**Coupling qubits on separate chips in a tileable superconducting circuit**
Pierre Capiod	**Electronic quantum simulators based on atomic scale manipulations of molecules on metallic surfaces**
Dimitri Chafatinos Lisandro	**Phonon engineering in polariton traps and lattices of traps**
Paolo Comaron	**Non-hermitian topological insulators in one-dimensional light-matter systems**

Poster session I

Piotr Deuar	**Scalable full quantum dynamics of dissipative Bose-Hubbard systems and multi-time correlations**
Marco Di Liberto	**Topological phonons in arrays of ultracold dipolar particles**
Sanja Djurdjic Mijin	**Raman spectroscopy of quasi-two-dimensional materials**
Federico Domínguez	**Decoherence scaling transition in the dynamics of quantum information scrambling**
Yurii Dumin	**Lattice models of the strongly out-of-equilibrium phase transformations**
Jack Dunham	**Improved tensor-network algorithm for the simulation of two-dimensional open quantum spin lattices**
Rajveer Fandan	**Exciton–plasmon coupling in 2D semiconductors accessed by surface acoustic waves**
Alexander Ferrier	**Positive-P simulations of driven-dissipative Bose-Hubbard Lieb lattices**
Janek Fleper	**Ultracold fermions in optical superlattices**
Quentin Fontaine	**Observation of KPZ universal scaling in a one-dimensional polariton condensate**

Posters session II

Daniel Dahan	**Classical and quantum chaos in chirally-driven, dissipative Bose-Hubbard systems**
Joanna Gajewska	**Studying Bose-Hubbard models with machine learning algorithms**
Ioannis Georgakilas	**Tunable room temperature condensation of exciton-polaritons in 1D lattices**
Luca Giacomelli	**Understanding superradiant phenomena with synthetic vector potentials in atomic Bose-Einstein condensates**
Daniel González-Cuadra	**Rotor Jackiw-Rebbi model: A cold-atom approach to chiral symmetry restoration and charge confinement**
Tobias Grass	**Quantum simulation with carbon nanotubes: from Mott insulator to phonon-induced electron pairing**
Martin Guillot	**Direct measurement of the quantum geometric tensor in exciton-polariton systems**
Clément Hainaut	**Floquet engineering of XYZ Hamiltonians with Rydberg atoms**
Dawid Hryniuk	**BEC Statistics via fock state sampling**
Frederic Hummel	**Ultra-long-range Rydberg molecules**
Vincent Jouanny	**Ultracompact cavity array for analog quantum simulation**
Jalil Khatibi Moqadam	**Superconducting circuits for simulating staggered quantum walks**
Péter Kómár	**Quantum devices in the cloud**

Posters session II

Christian Kriso	**Frequency-modulated combs in VECSELs**
Viacheslav Kuzmin	**Probing infinite many-body quantum systems with finite-size quantum simulators**
Alexander Kuznetsov	**Polariton-phonon interactions in optomechanical lattices**
Lukas Lackner	**Tunable exciton-polaritons emerging from WS2 monolayer excitons in a photonic lattice at room temperature**
Snezana Lazic	**Dynamic acousto-mechanical tuning of quantum light emission from atomic defects in hexagonal boron nitride**
Tangi Legrand	**Point-spread-function engineering for 3D imaging of atoms in optical lattices**
Dylan Lewis	**Optimal quantum spatial search with one-dimensional long-range interactions**
Michelle Lienhart	**Quantum dot optomechanics in superconducting surface acoustic wave resonators**
Franco Lisandrini	**Majorana edge modes and numerical stability in a particle-conserving setting**
Cristóbal Lledo	**Polariton condensation in a synthetic Landau level**

Posters session III

Dominik Maile	**Exponential speedup of incoherent tunneling via dissipation**
Natalia Masalaeva	**Spin and density self-ordering in dynamic polarization gradients fields**
Conor McKeever	**An iPEPO algorithm for two-dimensional open quantum systems**
Tawfik Mouhrach	**Phase diagram and thermodynamic study of the mixed Spin-1/2 and Spin-3 Blume-Capel model: renormalization group theory**
Andrzej Opala	**Feed-forward exciton-polariton neural network**
Alice Pagano	**Optimal quantum gates for Rydberg atoms quantum computer**
Dawid Paszko	**Electronic localization in small-angle twisted bilayer graphene**
Van Dong Pham	**Electronic boundary states in dimerized quantum-dot chains engineered atom by atom**
Bastián Real	**Chiral emission induced by optical Zeeman effect in polariton micropillars**
Felix Rönchen	**A new apparatus for trapping single Strontium atoms in arrays of optical microtraps**
Mirko Rossini	**Epigenetic relevance of quantum phenomena in DANN**
Hasnae Saadi	**Magnetic properties and phase diagrams of a spin-3/2 Blume-Capel multilayer system**
Rafael Salas-Montiel	**Integrated nanophotonic waveguide lattices as photonic quantum simulators**

Posters session III

Markus Schmitt	**Simulating correlated matter far from equilibrium with neural quantum states**
Chithra H. Sharma	**Electron-spin-resonance in a proximity-coupled MoS2/graphene van-der-Waals heterostructure**
Anna Sidorenko	**Spectral imaging of the anomalous π mode in periodically driven plasmonic waveguide arrays**
Philipp Stammer	**High photon number entangled states and coherent state superposition from extreme-UV to far-IR**
Niklas Tausendpfund	**Majorana edge modes: A road to an U(1) symmetric realization in coupled wires**
Deepankur Thureja	**Tunable quantum confinement of neutral excitons using electric fields and exciton-charge interactions**
Darius Urbonas	**Tunable exciton-polariton condensation in a two-dimensional Lieb lattice at room temperature**
Konrad Viebahn	**Topological pumping via two-frequency driving**
Anne-Maria Visuri	**Transport through a dissipative superconducting contact**
Zhiyuan Wei	**Sequential generation of tensor network states**
Falk-Richard Winkelmann	**Measuring the Wigner function of atoms in optical lattices**
Mingyun Yuan	**Remote GHz acoustic control of exciton qubits**

Abstracts of Talks

(in alphabetical order)

Atoms at their quantum speed limit

Manolo R. Lam[1], Gal Ness[2], Gautam Ramola[1], Richard Winkelmann[1], Dieter Meschede[1], Yoav Sagi[2], Andrea Alberti[1]

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How fast can a quantum system evolve between two states? This question is not only important for its basic nature, but it also has far-reaching implications on future quantum technologies. In this talk, I will report on a recent study [1] testing experimentally two well-known limits on the maximum evolution rate, named after their discoverers—Mandelstam–Tamm and Margolus–Levitin. Despite their fundamental character, only the Mandelstam–Tamm limit has been so far investigated in experiments and exclusively in effective two-level systems. In our experiment, we follow the motion of an atom trapped in an optical lattice using fast matter wave interferometry. A geometric analysis of the matter wave evolution reveals striking difference between a two-level and a multi-level system—excitations of a multi-level system do not saturate the speed limit but, unexpectedly, produce a small, universal deviation from it.

In the second part of my talk, I will address the related question of what is the fastest route—the quantum brachistochrone—to transport an atom between distant states. We demonstrate [2] coherent transport of an atomic wave packet over a distance of 15 times its size in the shortest possible time. Because of the large separation between the two sites, ours is a paradigmatic example of a quantum process where the Mandelstam–Tamm and Margolus–Levitin speed limits fail to capture the relevant time scale. In contrast, we show that quantum optimal control provides us with solutions to the quantum brachistochrone problem.

Our results, establishing quantum speed limits beyond the simple two-level system, are important to understand the ultimate performance of quantum computing devices, quantum simulators, and related advanced quantum technologies such as atomtronics.

[1] G. Ness, M. R. Lam, W. Alt, D. Meschede, Y. Sagi, and A. Alberti, "Observing quantum-speed-limit crossover with matter wave interferometry," (2021), arXiv:2104.05638 [quant-ph]

[2] M. R. Lam, N. Peter, T. Groh, W. Alt, C. Robens, D. Meschede, A. Negretti, S. Montangero, T. Calarco, and A. Alberti, "Demonstration of Quantum Brachistochrones between Distant States of an Atom," Phys. Rev. X 11, 011035 (2021)

KPZ scaling in the coherence decay of a 1D extended polariton condensate

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The Kardar–Parisi–Zhang (KPZ) equation[1], originally derived to describe the kinetic roughening of growing interfaces is a stochastic non-linear differential equation that applies to a large class of non-equilibrium systems, ranging from the growth of nematic liquid crystal clusters, of bacterial colonies, or the propagation of a combustion front. Interestingly the spatial and temporal correlation functions of the height h(r,t) of the growing interface interface show power law decays, with universal critical exponents that depend only on the dimensionality of the system. Recently, it was realized that a mapping can be obtained between the KPZ equation and the equation describing the phase of a homogeneously distributed polariton condensate [2-4]. In 1D, the spatial and temporal decay of the firrst order coherence is thus expected to evidence universal KPZ scalings. In 2D, the presence of KPZ physics in the condensate phase is still debated, since vortex proliferation may destroy the KPZ order [5-6]. In the present talk, I will explain why KPZ scaling is so difficult to evidence in polariton condensates. Indeed a modulation instability tends to fragment them into mutually incoherent parts [7], thus preventing the exploration of large scale coherence. Triggering polariton condensation on the negative mass of polariton lattices, we manage to tame this instability, and generate very extended polariton condensates both in 1D and 2D lattices [8]. We explored recently the first order spatio-temporal coherence of 1D extended condensates. We evidence a time and space window, in which all measured data collapse onto a universal scaling function characteristic for KPZ universality class [9]. These results highlight the profound difference between driven-dissipative condensates and their equilibrium counterpart, and lay the ground for future investigations of KPZ physics in 2D polariton systems.

[1] M. Kardar, G. Parisi, and Y. C. Zhang, Dynamic Scaling of Growing Interfaces, Phys. Rev. Lett. 56, 889 (1986)
[2] E. Altman, et al., Two-Dimensional Superfluidity of Exciton Polaritons Requires Strong Anisotropy, Phys. Rev. X 5, 011017 (2015).
[3] K. Ji, et al., Temporal coherence of one-dimensional nonequilibrium quantum fluids, Phys. Rev. B 91, 045301 (2015).
[4] L. He, et al., Scaling properties of one-dimensional driven-dissipative condensates, Phys. Rev. B 92, 155307 (2015)
[5] P. Comaron, et al., Dynamical Critical Exponents in Driven-Dissipative Quantum Systems, Phys. Rev. Lett. 121, 095302 (2018)
[6] Q. Mei, K. Ji, and M. Wouters, Spatiotemporal scaling of two-dimensional nonequilibrium exciton-polariton systems with weak interactions, arXiv:2002.01806 (2020).
[7] M. Wouters and I. Carusotto, "Excitations in a nonequilibrium Bose-Einstein condensate of exciton polaritons," Phys. Rev. Lett. 99, 140402 (2007)
[8] F. Baboux, et al., Unstable and stable regimes of polariton condensation, Optica 5, 1163 (2018)
[9] Q. Fontaine et al, in preparation

Topological quantum fluids of light

I. Carusotto[1]

[1]*INO-CNR BEC Center, Trento, Italy*

In this talk I will present some among the most exciting recent developments of the field of Topological Quantum Fluids of Light at the crossroad of many-body physics, non-equilibrium statistical mechanics, topological physics, and quantum optics [1,2].

In the first part I will summarize the new remarkable features of topological lasing, aka non-equilibrium condensation into a topological edge mode. These systems are capturing the interest of a wide community spanning across fundamental and applied research: in particular, they exploit topological protection to stabilize long-distance phase-locking against fabrication disorder and they display Kardar-Parisi-Zhang universality in the emission coherence [3,4].

In the second part, I will move to strongly quantum correlated phases of photonic matter, in particular fractional quantum Hall fluids [5]. After presenting schemes to exploit pumping and losses to dynamically stabilize the desired many-body state, I will discuss observable consequences of the anyonic nature of the excitations with fractional charge and statistics and possible strategies to experimentally highlight them in realistic experiments [6,7].

References

[1] I. Carusotto, C. Ciuti, *Quantum fluids of light*, Rev. Mod. Phys. **85**, 299 (2013).

[2] T. Ozawa, et al., *Topological Photonics*, Rev. Mod. Phys. **91**, 015006 (2019).

[3] I. Amelio, I. Carusotto, *Theory of the coherence of topological lasers*, Phys. Rev. X **10**, 041060 (2020).

[4] A. Loirette-Pelous, I. Amelio, M. Seclì, I. Carusotto, *Linearized theory of the fluctuation dynamics in 2D topological lasers*, arXiv:2101.11737.

[5] I. Carusotto, et al., *Photonic Materials in Circuit Quantum Electrodynamics*, Nature Physics **16**, 268 (2020).

[6] E. Macaluso, et al., *Charge and statistics of lattice quasiholes from density measurements: a Tree Tensor Network study*, Phys. Rev. Research **2**, 013145 (2020).

[7] A. Muñoz de las Heras, E. Macaluso, I. Carusotto, *Anyonic molecules in atomic fractional quantum Hall liquids: a quantitative probe of fractional charge and anyonic statistics*, Phys. Rev. X **10**, 041058 (2020).

Quantum Simulation: Algorithms for finite energies and temperatures

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Quantum many-body systems are very hard to simulate, as computational resources (time and memory) typically grow exponentially with system size. However, quantum computers or analog quantum simulators may perform that task in a much more efficient way. In this talk, I will review some of the quantum algorithms that have been proposed for this task and then explain the advantages and disadvantages of analog quantum simulators. In particular, I will describe methods to simulate the dynamics, to find ground states, or compute physical properties at finite temperatures.

References

[1] S. Lu, M. C. Banuls, and J. I. Cirac, PRX Quantum 2, 020321 (2021)

Geometric pumping: self-consistent and Floquet-driven

Tilman Esslinger

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We report on a self-consistent geometric pumping mechanism, transporting atoms in a Bose-Einstein condensate coupled to a dissipative cavity field. The phenomenon relies on a self-oscillation between two superradiant crystals of different inversion symmetry and is set in motion by cavity dissipation. We monitor the evolution through the phase winding of the cavity field relative to the driving field and through direct observation of the atomic motion [1].

We use a Floquet drive to experimentally realize a topological pump in a generic sinusoidal lattice without a sliding potential. Two-frequency lattice shaking is used to adiabatically prepare a topological Floquet-Bloch band, starting from a trivial insulating state of ultracold fermions [1].

References

[1] https://www.quantumoptics.ethz.ch/articles.php

Polaromechanical Crystals

D. L. Chafatinos[1], A. S. Kuznetsov[2], P. Sesin[1], I. Papuccio[1], F. Mangussi[1], A. E. Bruchhausen[1], A. A. Reynoso[1], G. Usaj[1], K. Biermann[2], P. V. Santos[2], and
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We introduce polaromechanical crystals, two-dimensional arrays of zero-dimensional traps confining fluids of exciton-polariton condensates (simply polaritons) and 20 GHz phonons within a semiconductor microcavity [1]. The traps with dimensions down to 1x1 µm2 exhibit large coherence times for polariton fluids (ns-long) as for confined phonons (100's ns) with no observable reduction with decreasing trap size. These crystals combine strongly interacting hybrid phonon-polariton oscillators at the lattice sites with inter-site coupling mediated by strong optomechanical interactions. They are, thus, conceptually closer to metamaterials with resonant unit cells rather than to conventional optomechanical crystals based on Bragg co-localisation of light and vibrations in planar structures. The optomechanical character of the inter-site coupling has remarkable consequences. It is observed, for instance, that when a lattice site is locally perturbed through non-resonant continuous wave optical excitation, the crystal responds by locking the energy detuning with neighbor sites to integer multiples of the phonon quantum, thus evidencing synchronization blockade and collective behaviour of the polariton and phonon fields. The exciton-mediated strong polariton-phonon interactions make accessible the so-called ultra-strong optomechanical coupling regime. The coherent control of quantum light fluids with hyper-sound and, conversely, the coherent control of extremely-high frequency sound with light, are envisaged based on the proposed scalable semiconductor platform.

References

[1] D. L. Chafatinos, A. S. Kuznetsov, S. Anguiano, A. E. Bruchhausen, A. A. Reynoso, K. Biermann, P. V. Santos, and A. Fainstein, Polariton-driven phonon laser, Nature Communications **11**, 4552 (2020).

Dynamics and topology in interacting bosonic lattices

Eytan Grosfeld

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I will present models of interacting bosons on the honeycomb lattice in the presence of several types of anisotropies and interactions. The phase diagrams of the models will be extracted as function of the filling and the different anisotropies. Among these phases, we identify weak and strong topological phases, extract the presence of their edge states and their chirality and derive methods to characterize their topological properties. Finally, I will discuss the effect of the chirality of the driving field on the dynamics of bosons hopping on one-dimensional lattices forming rings.

References

[1] Amrita Ghosh and Eytan Grosfeld, Weak topological insulating phases of hard-core-bosons on the honeycomb lattice, SciPost Phys. **10**, 059 (2021)

[2] Amrita Ghosh and Eytan Grosfeld, Chiral Bosonic Topological Insulator on the Honeycomb Lattice with Anisotropic Interactions, Phys. Rev. B **103**, 205118 (2021)

[3] Daniel Dahan, Geva Arwas and Eytan Grosfeld, Classical and Quantum Chaos in Chirally-Driven, Dissipative Bose-Hubbard Systems, arXiv:2105.10953 (2021)

Strongly correlated electrons in atomically thin semiconductors

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In this talk, I will describe recent experiments in atomically-thin transition metal dichalcogenides (TMDs) where Coulomb interactions between electrons dominate over their kinetic energy. Our measurements provide a direct evidence that the electrons at densities $< 3 \cdot 10^{11}$ cm^{-2} in a pristine $MoSe_2$ monolayer form a Wigner crystal even at $B = 0$ [1]. This is revealed by our low-temperature ($T = 80$ mK) magneto-optical spectroscopy experiments that utilize a newly developed technique allowing to unequivocally detect charge order in an electronic Mott-insulator state [2]. This method relies on the modification of excitonic band structure arising due to the periodic potential experienced by the excitons interacting with a crystalline electronic lattice. Under such conditions, optically-inactive exciton states with finite momentum matching the reciprocal Wigner lattice vector $k = k_W$ get Bragg scattered back to the light cone, where they hybridize with the zero-momentum bright exciton states. This leads to emergence of a new, umklapp peak in the optical spectrum heralding the presence of periodically-ordered electronic lattice.

Twisted bilayers of TMDs in turn offer a wealth of new phenomena, ranging from dipolar excitons to correlated insulator states. Another striking example of qualitatively new phenomena in this system is our recent observation of an electrically tunable two-dimensional Feshbach resonance in exciton-hole scattering [3], which allows us to control the strength of interactions between excitons and holes located in different layers. Our findings enable hitherto unexplored possibilities for optical investigation of many-body physics, as well as realization of degenerate Bose-Fermi mixtures with tunable interactions.

Bibliography:

[1] T. Smoleński, P. E. Dolgirev, C. Kuhlenkamp, A. Popert,1 Y. Shimazaki, P. Back, X. Lu, M. Kroner, K. Watanabe, T. Taniguchi, I. Esterlis, E. Demler, and A. Imamoglu, arXiv:2010.03078 (2020).
[2] Y. Shimazaki, C. Kuhlenkamp, I. Schwartz, T. Smolenski, K. Watanabe, T. Taniguchi, M. Kroner, R. Schmidt, M. Knap, A. Imamoglu, arXiv:2008.04156 (2020).
[3] I. Schwartz, Y. Shimazaki, C. Kuhlenkamp. K. Watanabe, T. Taniguchi, M. Kroner, A. Imamoglu, arXiv:2105.03997 (2021).

Band Engineering for Quantum Simulation in Circuit QED

A. Kollár[1]

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The field of circuit QED has emerged as a rich platform for both quantum computation and quantum simulation. Lattices of coplanar waveguide (CPW) resonators realize artificial photonic materials in the tight-binding limit [1,2]. Combined with strong qubit-photon interactions, these systems can be used to study dynamical phase transitions, many-body phenomena, and spin models in driven-dissipative systems. I will show that waveguide resonators permit the creation of unique devices which host photons in curved spaces, gapped flat bands, and novel forms of qubit-qubit interaction. I will show that graph theory is the natural language for describing these microwave photonic systems and how it can be used to understand the types of devices that can be achieved [3].

References

[1] D. Underwood *et al.*, Phys. Rev. A **86**, 023837 (2012)
[2] A. J. Kollár et al., Nature **571**, 45 (2019)
[3] A. J. Kollár et al., Comm. Math. Phys. **376**,1909 (2019)

From the Stern-Gerlach centenary to optical lattices

Dieter Meschede

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We will soon celebrate the 100th anniversary of one of the most famous experiments in physics, the observation of the so-called quantization of space by Stern and Gerlach in 1922. In my introductory lecture I will draw lines and conclusions from this game changing result to the present state of optical lattices with special regard to quantum walks. I will also explore the question how quantum engineers are taking over the role of physicists from academic atomic physics and quantum optics.

Anomalous exciton transport in response to a uniform, in-plane electric field

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(in collaboration with Swati Chaudhary and Christina Knapp)

Excitons are neutral objects, that, naively, should have no response to a uniform, electric field. Could the Berry curvature of the underlying electronic bands alter this conclusion? In my talk I will show that Berry curvature can indeed lead to anomalous transport for excitons in 2D materials subject to a uniform, in-plane electric field. By considering the constituent electron and hole dynamics, we demonstrate that there exists a regime for which the corresponding anomalous velocities are in the same direction. I will show both semiclassical and numerical support of this effect, and discuss its relationship to Bloch oscillations, as well as potential realizations.

Towards cooperative effects with organic molecules

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Laboratory manipulation of single quantum emitters and single photons has matured to a routine procedure over the past two decades. In our laboratories, we have developed a series of techniques and platforms for the realization of efficient coupling between single molecules and single photons, showcasing single-molecule vacuum Rabi splitting and various nonlinear optical effects at the single-photon level. We have now embarked on a new challenge to extend this high level of coupling to a handful of molecules and photons. To do this, we develop a chip-based photonic circuit. In this presentation, I report on our recent progress and describe some of the experimental difficulties that need to be addressed in order to couple several molecules via a one-dimensional photonic channel.

Ultracompact cavity array for analog quantum simulation

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Photonic cavity arrays form the basis of one of the most promising paradigms for quantum simulation to study complex many-body physics [1]. We developed a non-trivial structured photonic environment that could enable a multimode strong and ultra-strong coupling with a qubit. This platform consists of a unidimensional metamaterial implemented by an array of coupled superconducting microwave cavities made from thin Niobium Nitride (NbN) films. Such disordered superconductor allows to reach a very high kinetic inductance [2], which presents a two-fold advantage: a) It allows to reach ultra-strong coupling with an artificial atom as the amplitude of the zero-point voltage fluctuation is proportional to the square root of the resonators' impedance [3], which can be highly increased thanks to the kinetic inductance; b) It allows to strongly reduce the resonator/metamaterial footprint.
Furthermore, working with a metamaterial allows engineering a non-trivial photonic dispersion relation, where it is possible to obtain states displaying topological properties (SSH-states [4]). We have been able to fabricate and characterize unidimensional metamaterials made of up to 88 ultra-compact resonators. We are currently expanding this technology to 2D metamaterials, where we expect to engineer further topological edge states.

References

[1] D. L. Underwood, W. E. Shanks, J. Koch, and A. A. Houck, Phys. Rev. A **86**, 023837 (2012).
[2] D. Niepce, J. Burnett, and J. Bylander, Phys. Rev. Applied **11**, 044014 (2019).
[3] N. Samkharadze, A. Bruno, P. Scarlino, G. Zheng, D. P. DiVincenzo, L. DiCarlo, and L. M. K. Vandersypen, Phys. Rev. Appl. **5**, 044004 (2016).
[4] E. Kim, X. Zhang, V. S. Ferreira, J. Banker, J. K. Iverson, A. Sipahigil, M. Bello, A. González-Tudela, M. Mirhosseini, and O. Painter, Phys. Rev. X **11**, 011015 (2021).

Photonic Time-Crystals

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Photonic Time Crystals (PTCs) are dielectric media whose refractive index is modulated periodically in time at time scales of an optical cycle. These systems conserve momentum but not energy, and are characterized by momentum bands and bandgaps, where the amplitudes of their eigenmodes can increase (or decrease) exponentially. I will introduce the fundamentals of PTCs, discuss the topological features of waves propagating in PTCs, localization in PTCs containing disorder, and spatiotemporal photonic crystals. But more interesting than all the rest - I will discuss the classical and quantum features of light emission in PTCs from various radiation sources, such as free electrons, classical dipoles, quantum fluctuations, and the emission by atoms. The latter opens new avenues for making widely tunable lasers that extract energy from the temporal modulation of the medium.

Quantum optics and quantum thermodynamics with semiconductor quantum dots

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Semiconductor quantum dots have emerged as very interesting artificial atoms. When inserted in optical microcavities, their interaction with their solid-state environment can be reduced, and they can emit highly indistinguishable single photons [1]. Taking advantage of all the tools of semiconductor nano-processing, our devices have come closer and closer to the text-book atom-photon interface and allow to explore fundamental aspects of light emission process.

In this talk, I will discuss how we recently revisited the process of spontaneous emission. We first demonstrate that the quantum coherence imprinted at the atomic level is transferred to the light field in the spontaneous emission process. We generate light in pure quantum superpositions of 0,1 or even 2 photons [2]. We more recently demonstrated that one can perform operation on a single atom that is undergoing spontaneous emission and generate photon-number entanglement [3]. Finally, we recently explored the energetic of spontaneous emission. We show that the work exerted by the atom onto the empty cavity mode corresponds to the coherent part of the spontaneously emitted field. At low temperatures, the observed work transfer is close to the theoretical upper bound, a value that is degraded at higher temperatures when coupling the atom to the phonon bath. We then study the discharge this optical quantum battery onto a classical field and discuss the conditions for maximal work transfer [4].

References

[1] P. Senellart, G. Solomon and A. White, Nature nanotechnology 12, 1026 (2017)
[2] C. Anton, et al, Nature Photonics 13, 803–808 (2019)
[3] S. Wein et al, arXiv:2106.02049
[4] I. Maillette de Buy Wenniger et al, in preparation

Networks of liquid light

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Recent years have seen a surge of advancements in optical manipulation over bosonic light-matter quasiparticles known as exciton-polaritons in semiconductor microcavities. These particles appear under strong-coupling conditions between cavity photons and embedded quantum-well excitons. Characterised by very high interaction strengths, nonlinearities, and picosecond timescales, these coherent light sources provide an exciting testbed to explore room-temperature nonequilibrium Bose-Einstein condensation in the optical regime.

In this talk, I will present results on all-optically engineered macroscopic networks of connected exciton-polariton condensates, which permit studies on fundamental emergent behaviours in complex nonequilibrium dynamical systems while subject to a drive and bosonic final-state stimulation. I will explain how a uniquely polaritonic feature gives rise to so-called "ballistic condensates" which, when spatially coupled, form a bosonic condensed matter analog of time-delay coupled oscillators that are ubiquitous in nature. I will present experimental and theoretical results on large-scale condensate networks displaying aforementioned emergent behaviors, including: spontaneous synchronization with unprecedented long-range spatial and temporal correlations [1,2], strong polarization buildup and control [2], geometric frustration and formation of persistent superfluid currents [3], non-invasive optical control of the network coupling weights [4], and synthesis of artificial lattices with non-Hermitian flatband and topological properties [5,6].

Lastly, I will discuss recent developments on the role of polariton condensate networks as nonlinear information processing elements in the optical computing paradigm. I will address three examples: room-temperature optical logic, analog simulators of spin-glass Hamiltonians, and as neuromorphic computing hardware.

References

[1] Töpfer et al., Communication Physics 3, 2 (2020).
[2] Töpfer et al., Optica 8, 106 (2021).
[3] Gnusov et al., Physical Review B 102, 125419 (2020).
[4] Cookson et al., Nature Communications 12, 2120 (2021).
[5] Alyatkin et al., Physical Review Letters 124, 207402 (2020).
[6] Pickup et al., Nature Communications 11, 4431 (2020).
[7] Alyatkin et al., Nature Communications 12, 5571 (2021).

Fully Quantum Scalable Approaches to Driven-Dissipative Lattice Models

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Being able to accurately describe the dynamics and steady states of driven and/or dissipative but quantum correlated lattice models is of fundamental importance in many areas of science: from quantum information to biology. An efficient numerical simulation of large open systems in two spatial dimensions is a challenge. In this talk we will discuss two successful and complementary approaches: one based on phase space and the second on tensor-network techniques.

In particular, we demonstrate the positive-*P* method to be ideal across a wide range of parameters, where interactions and dissipation are comparable, and especially for cases with low occupations for which common semiclassical approximations break down. The presence of dissipation alleviates instabilities in the method that are known to occur for closed systems, allowing the simulation of the full dynamics. Focusing on the driven-dissipative Bose-Hubbard model, we find the region of Positive-*P* applicability to be complementary to that of the truncated Wigner and demonstrate its use in a number of examples with nontrivial quantum correlations, including large and highly nonuniform systems with tens of thousands of sites.

For problems where dissipation is too small to stabilise the stochastic approaches (and otherwise), we develop a tensor network method, based on an infinite projected entangled pair operator ansatz, applicable directly in the thermodynamic limit. We incorporate techniques of finding optimal truncations of enlarged network bonds by optimizing an objective function appropriate for open systems. In particular, we consider dissipative transverse quantum Ising, driven-dissipative hard-core boson, and dissipative anisotropic XY models in non-mean-field limits, proving able to capture substantial entanglement in the presence of dissipation.

Between the two approaches we are able to study regimes that are accessible to current experiments but lie well beyond the applicability of existing techniques.

References

[1] “Fully quantum scalable description of driven dissipative lattice models”, P. Deuar, A. Ferrier, M. Matuszewski, G. Orso, and M. H. Szymańska [PRX Quantum, **2**, 010319 (2021)]

[2] “Stable iPEPO Tensor-Network Algorithm for Dynamics of Two-Dimensional Open Quantum Lattice Models”, C. Mc Keever and M. H. Szymańska [Phys. Rev. X 11, 021035 (2021)]

Entanglement Hamiltonian Tomography

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Entanglement is the crucial ingredient of quantum many-body physics, and characterizing and quantifying entanglement in closed system dynamics of quantum simulators is an outstanding challenge in today's era of intermediate scale quantum devices. Here we discuss an efficient tomographic protocol for reconstructing reduced density matrices and entanglement spectra for spin systems. The key step is a parametrization of the reduced density matrix in terms of an entanglement Hamiltonian involving only quasi local few-body terms. This ansatz is fitted to, and can be independently verified from, a small number of randomised measurements. The ansatz is suggested by Conformal Field Theory in quench dynamics, and via the Bisognano-Wichmann theorem for ground states. Not only does the protocol provide a testbed for these theories in quantum simulators, it is also applicable outside these regimes. We show the validity and efficiency of the protocol for a long-range Ising model in 1D using numerical simulations. Furthermore, by analyzing data from 10 and 20 ion quantum simulators, we demonstrate measurement of the evolution of the entanglement spectrum in quench dynamics.

References

[1] C. Kokail, R. van Bijnen, A. Elben, B. Vermersch and P. Zoller, Nature Physics **17**, 936 (2021)

[2] C. Kokail, B. Sundar, T.V. Zache, A. Elben, B. Vermersch, M. Dalmonte, R. van Bijnen, and P. Zoller, arXiv:2105.04317 (2021)

Towards quantum optics with polariton cross-Kerr interaction

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Achieving strong deterministic interactions between single photons is an important goal for future optical quantum technologies[1]. Attempts to achieve this using optical nonlinearities face a challenging tradeoff where bulk-like materials are easy to scale up to many identical devices but provide only weak nonlinearity[2]. Meanwhile sub-wavelength size emitters (quantum dots, atoms) provide strong interactions[3] but are challenging to scale up.

Quantum well (QW) exciton-polaritons are hybrid part-light part-matter quasi particles arising from strong coupling between excitons and cavity photons. Their excitonic content provides Kerr-like nonlinear interactions more than 1000x higher than in weakly coupled semiconductors. At the same time, since QWs are homogeneous in the plane, the polariton properties depend only on the optical cavity, allowing engineering of the tradeoff between interaction strength and scalability.

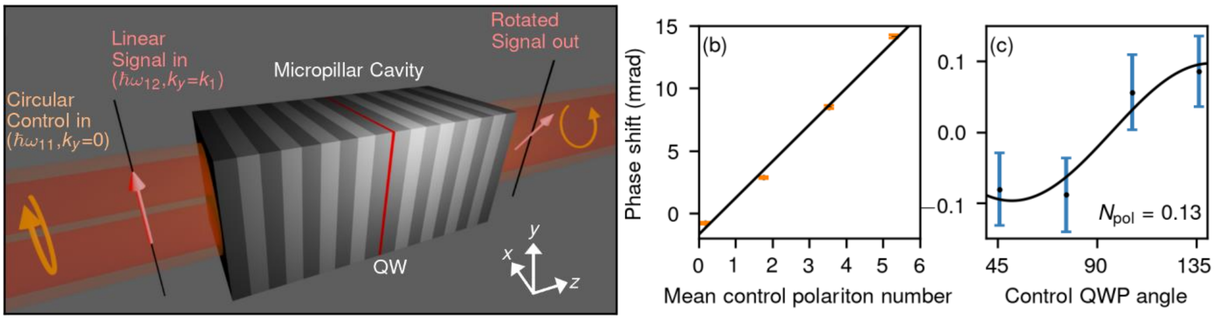

Fig 1. (a) Schematic of polariton cavity phase shifter excited by control and signal lasers at different frequencies. (b) Phase shift vs. number of particles. (c) Phase shift dependence on control polarisation.

In this paper I will present recent measurements[4] of nonlinear cross phase modulation between distinct optical modes of a QW polariton microcavity resonator driven by few-photon average intensity lasers. I will discuss perspectives for using scalable polariton single photon phase shifters as a resource for future quantum optics technologies.

References

[1] D. E. Chang et. al. *Nat. Photonics* **8**, 685-694 (2014)
[2] N. Matsuda et. al. *Nat. Photonics* **3** 95 (2009)
[3] Shuo Sun et. al. *Science* **361**, 57–60 (2018)
[4] T. Kuriakose, P. M. Walker, et. al, arXiv:2106.13650

Programmable Quantum Simulators as `Optimal' Quantum Sensors

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Abstract: Traditionally, quantum simulators are discussed as quantum devices solving `complex' quantum many-body problems, e.g. as preparation of highly entangled ground states or in quench dynamics. Here we exploit the capability of quantum simulators to generate and manipulate `complex' entangled many-body states to build an `optimal' Ramsey interferometer for phase estimation, where optimality is defined as reaching the ultimate limits allowed by quantum physics. We define and study variational quantum algorithms running on programmable quantum simulators acting as quantum sensors [1,2]. We show both theoretically and experimentally on a N=26 spin trapped-ion platform that low-depth quantum circuits can achieve close-to-optimal quantum interferometry [2,3].

References

[1] Raphael Kaubruegger, Pietro Silvi, Christian Kokail, Rick van Bijnen, Ana Maria Rey, Jun Ye, Adam M. Kaufman, Peter Zoller, Variational spin-squeezing algorithms on programmable quantum sensors, Phys. Rev. Lett. 123, 260505 (2019)

[2] Raphael Kaubruegger, Denis V. Vasilyev, Marius Schulte, Klemens Hammerer, Peter Zoller, Quantum Variational Optimization of Ramsey Interferometry and Atomic Clocks, arXiv:2102.05593; and PRX, in press

[3] Christian D. Marciniak, Thomas Feldker, Ivan Pogorelov, Raphael Kaubruegger, Denis V. Vasilyev, Rick van Bijnen, Philipp Schindler, Peter Zoller, Rainer Blatt, Thomas Monz, Optimal metrology with programmable quantum sensors, arXiv:2107.01860

Abstracts of Posters

(in alphabetical order)

Observation of Floquet winding metals in a photonic lattice

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Periodic driving is widely used to imprint exotic topological properties of various systems, which are promising for robust signal propagation and quantum simulations. Beyond that, periodic driving of a lattice can allow the spectrum to wind simultaneously in quasienergy and quasimomentum direction, giving rise to new topological features. In particular, such winding manifests itself in an exotic oscillations of a wavepacket injected in the system, directly reflecting the topological properties of the bands [1].

Here we report first observation of such *Floquet winding metals* in a photonic mesh lattice. In this system comprised by two coupled optical fiber rings, propagation of a wavepacket in a synthetic 1D lattice is simulated by dynamics of light pulses in the fibers [2]. Natural periodicity of the fiber rings allows us to apply Floquet driving by periodically changing the coupling between two fiber rings. We directly access the band structure of winding metals by measuring both quadratures of the light pulses forming the synthetic lattice [3]. To confirm the topological features of the bands, we inject a wavepacket into a single band and follow its evolution. Our results open the road for future investigation of these exotic phases in quantum regime.

References

[1] L. K. Upreti et al., Phys. Rev. Lett. **125**, 186804 (2020)
[2] A. Regensburger et al., Nature **488**, 167 (2012).
[3] C. Lechevalier et al., arXiv:2105.02621 (accepted)

Convolutional restricted Boltzmann machine aided Monte Carlo: An application to Ising and Kitaev models

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Machine learning is becoming widely used in analyzing the thermodynamics of many-body condensed matter systems. Restricted Boltzmann machine (RBM) aided Monte Carlo simulations have sparked interest, as they manage to speed up classical Monte Carlo simulations. In the poster/talk, based on my paper [1], I will explain how we used the convolutional restricted Boltzmann machine (CRBM) method to reduce the number of parameters to be learned drastically by taking advantage of translation invariance. Furthermore, I will show that it is possible to train the CRBM at smaller lattice sizes, and apply it to larger lattice sizes. To demonstrate the efficiency of CRBM, I show the application to the Ising and honeycomb Kitaev models.

References

[1] Puente, D. A., & Eremin, I. M. (2020). Convolutional restricted Boltzmann machine aided Monte Carlo: An application to Ising and Kitaev models. *Physical Review B*, *102*(19), 195148.

Circuit QED Lattices

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The field of circuit QED has emerged as a rich platform for both quantum computation and quantum simulation. Lattices of coplanar waveguide (CPW) resonators realize artificial photonic materials in the tight-binding limit [1]. Combined with strong qubit-photon interactions, these systems can be used to study dynamical phase transitions, many-body phenomena, and spin models in driven-dissipative systems. Here we show our experimental progress towards fabrication and characterization of this novel physics beyond the linear regime by incorporating qubit nonlinearities in a lattice of resonators.

References

[1] D. Underwood et al., Phys. Rev. A 86, 023837 (2012)

Characterisation of duality maps encompassing strong-weak dualities

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The ideas of analogue Hamiltonian simulation are synonymous to those of duality whereby two superficially different theories are mathematically equivalent in some sense. What it means for one quantum system to simulate the entire physics of another has recently been put on a theoretical footing [1], leading to a framework consisting of spectrum preserving maps on operators. Here we relax this theory of simulation to include a rescaling of the spectrum which could physically correspond to changing of units. This rescaling is essential to encompass strong-weak dualities and we explicitly show how this extension is required to include the Kramer-Wannier duality. We also present equivalent formulations of our definition of duality in terms of partition functions and entropy of states. We hope that our more general mathematical framework provides a useful tool to explore the full potential of quantum simulators.

References

[1] T. Cubitt, A. Montanaro, S. Piddock. Proceedings of the National Academy of Sciences of the United States of America. **115**, 9497-9502 (2018).

Ultrastrong light-matter interaction of J-aggregated squaraine in an open cavity for non-linear topological photonics

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Organic molecule exciton-polaritons in artificial lattices are an emerging platform to emulate complex electronic Hamiltonians at ambient conditions [1]. Their main advantage are the less demanding experimental conditions compared to cold atoms in optical lattices and monolithic III-V semiconductor platforms at few-Kelvin temperatures due to the much larger exciton binding energy. An open cavity configuration introduces the additional flexibility to tune the strong light-matter coupling in situ [2][3]. We present J-aggregated squaraine dye (SQ) thin films as a promising candidate as the active material for exciton-polaritons in optical cavities due to its high oscillator strength in a tunable spectral range [4]. Using white light reflection spectroscopy, we demonstrate ultrastrong coupling of light to the SQ thin film in an open cavity at room temperature. Our findings are supported by transfer matrix calculations. Ongoing experiments aim to show bosonic condensation of the polaritons. In the next step, the introduction of structured photonic lattices to the open cavity will allow to investigate the coupling to tailored potential landscapes and possibly explore phenomena of non-trivial topology in synthetic lattices.

References

[1] M. Dusel, et al., Nat Commun **11**, 2863 (2020)
[2] F. Scafirimuto, et al., Communications Physics **4**, 39 (2021)
[3] L. Lackner, et al., Nat Commun **12**, 4933 (2021)
[4] M. Schulz, et al., Nat Commun **9**, 2413 (2018)

Exciton-polaron dynamics in charge-tunable atomically thin semiconductors

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Fermi polarons are quasiparticles that consist of an impurity dressed by particle-hole excitations of the Fermi sea [1] where the impurity properties are getting renormalized. They represent an important concept to describe interacting many-body systems and have therefore been studied both theoretically and experimentally on various platforms.

We investigate strongly bound excitons in monolayer transition metal dichalcogenides (TMDs) immersed in a Fermi sea of electrons or holes in a device with tunable doping density [2]. By means of an ultrafast upconversion scheme we study the polaron properties in the time domain: After excitation with a short pulse, we upconvert the emitted photons with a short gate pulse of controllable delay. This allows us to resolve decay times down to 150 fs.

Using this technique we measure the decay of the repulsive (RP) and attractive polaron (AP) dependent on the doping density and compare it to theoretical expectations. In this way, we gain not only insight into the decay channels in the many-body system but also into the nature of the interactions between electrons and excitons.

References

[1] F. Chevy, PRA 74, 063628 (2006).
[2] M. Sidler et al., Nature Physics 13, 255-261(2017).

The role of transition metals (Mo, W) in magnetic properties of doped CeO_2 : First-principles characterization

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Abstract : A systematic investigation on structural, electronic, and magnetic properties of $Ce_{0.75}A_{0.25}O_2$ (A = W, Mo) is performed using first-principles calculations within the framework Full-Potential Linear Augmented Plane Wave (FP-LAPW)method based on DFT by solving Kohn-Sham equations [1] as implemented in the WIEN2k package [2–3].. The exchange-correlation potential has been treated using the generalized gradient approximation (WC-GGA) developed by **Wu-Cohen**. The host compound CeO2 was doped with transition metal atoms W and Mo in the doping concentration of 25% to replace the Ce atom. In structural properties, the equilibrium lattice constant is observed for the W-doped CeO2 compound which exists within the value of 5.314 A° and the value of 5.317 A° for Mo-doped CeO_2. The present results show that $Ce_{0.75}A_{0.25}O_2$ (A=W, Mo) systems exhibit semiconducting behavior in both spin channels. Although undoped CeO_2 is a non-magnetic semiconductor. The band structure of these doped compounds was plotted and they exhibit direct band gap at the Fermi level (E_F) in the majority and minority spin channels. In the magnetic properties, the doped atoms W and Mo play a vital role in increasing the magnetic moments of the supercell and the values of the total magnetic moment are found to be 1.998 μ_B for W-doped CeO_2 and to be 2.002 μ_B for Mo-doped CeO_2 compounds. Calculated results indicate that the magneto-electronic properties of the $Ce_{1-x}A_xO_2$ (A= W, Mo) oxides supply a new way to the experimentalist for the potential applications in spintronic devices.

Keywords : FP-LAPW, DFT, CeO_2, spintronic

[1] P. Hohenberg, W. Kohn, , Phys. Rev. 136 (1964) B864–B871.

[2] W. Kohn, L.J. Sham, Phys. Rev. 140 (1965) A1133–A1138.

[3] P. Blaha, K. Schwarz, G.K.H. Madsen, D. Kvasnicka, J. Luitz, R. Laskowski, F. Tran, L.D. Marks, Karlheinz Schwarz, Techn Universitat Wien, Austria), 2018, ISBN 3-9501031-1-2.

Coupling qubits on separate chips in a tileable superconducting circuit

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Superconducting quantum circuits are a promising hardware platform for the simulation of lattice Hamiltonians, but circuits are typically defined on a planar surface, limiting connectivity to 2D. Multi-layer and flip-chip architectures and bus resonators allow for increased connectivity of the qubit lattice at the expense of additional complexity. Here, we present an approach to go beyond 2D that makes use of out-of-plane capacitive coupling, readout and control of qubits with coaxial symmetry [1][2]. Two layers of qubits can be fabricated on different substrates and kept separated by the CNC machined sample holder by a macroscopic distance, meaning no fabrication steps are added to achieve multiple qubit layers. We present a single unit-cell demonstration comprising two out-of-plane coupled fixed-frequency transmon qubits. We show the architecture is compatible with high coherence and high fidelity single-qubit operations, and demonstrate a conditional phase gate between the two qubits on separate substrates. Our proof-of-principle experiment employs fixed-frequency transmon qubits, but can be modified to use flux-tuneable and multi-mode qubits to explore different kinds of lattice and interaction.

References

[1] J. Rahamim et al., Applied Physics Letters, **110**, 222602 (2017)
[2] P. A. Spring et al., arXiv:2107.11140 (2021)

Electronic quantum simulators based on atomic scale manipulations of molecules on metallic surfaces

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A new class of quantum simulator (QS) has emerge in the past years based on atomic-scale manipulations of Carbon Monoxide (CO) molecules on a Cu(111) surface[1]. The Cu(111) surface hosts an 2D electron gas and the CO molecules act as repulsive scatterers for the surface electrons confining them in certain regions of the surface. Multiple lattices were created using this technique showing Dirac cones and dispersionless bands (or flat bands)[2,3]. Compact localized states (CLS) associated to flat bands are particularly interesting as they are eigenstates of a Hamiltonian, are compactly localized in a sub-region of the lattice, and have strictly zero amplitude otherwise. Those states are robust against any kind of perturbations and have been proposed for the storage and transfer of information[4]. In this presention, I will first present the technique of atomic scale manipulations of molecules on the Cu(111) surface. Then, I will present a new kind of CLS, namely boundary CLS in a diamond-necklace chain where the CLS exist only at the boundary of the chain, similar to topological localized states in a Su-Schrieffer-Heeger chain.

References

[1] K. Gomes et al. Nature **306**, 483 (2012)
[2] M. Slot et al. Nature Physics **13**, 672-677 (2017)
[3] T. Gardenier et al. ACS Nano ***14***, 13638-13644 (2020)
[4] M. Röntgen, Physics Review Letters **123**, 080504 (2019)

Non-Hermitian Topological Insulators in One-Dimensional Light-Matter Systems

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The control of topological properties in optical systems is a contemporary attracting objective from both experimental and theoretical perspective. Recently, topological insulators were suggested to be realizable in the strong matter-light coupling regime [1] and lately experimentally probed in exciton-polaritons lattices of coupled microcavities [2]. Here, the edge mode populated by a polariton condensate presents novel topological effects which differ from those demonstrated so far. Motivated by this recent achievements, we investigate the properties of topological edge states and topological phase transition in a four-site unit-cell one-dimensional chain [Fig 1(a)] [3]. Here the topological band-gap is generated by the gain and loss mechanisms rather than the different hopping ratio between the individual cells [4]. We theoretically analyse the system in general terms, allowing to address relevant physical structures well beyond polaritonic setups and investigating the transition from Hermitian to non-Hermitian topological insulators. Our results clearly indicate the presence of different topological phases with diverse number of non-Hermitian topologically protected end states [Fig 1(b)]. We find that such transitions arise due to enforced exceptional points which can be predicted directly from the bulk Bloch wave functions [Fig 1(c)]. This allows us to establish a new type of bulk-boundary correspondence for non-Hermitian systems and to compute the phase diagram of an open chain analytically. We then numerically study the physically stable solutions of the system in the presence of nonlinear terms by solving the temporal evolution of the tight-binding model considered. Our results predict an establishment of single edge-mode lasing in microcavity arrays. Investigation of the proposed system is within the current experimental reachability. Finally, we discuss the possible controlled coherent transfer of interface states [5] driven by spatially localised, adiabatic pump modulation. It is demonstrated that for appropriate system parameters the coherence degree is preserved after multiple transitions, paving the way towards long-range transfer of a coherent quantum state.

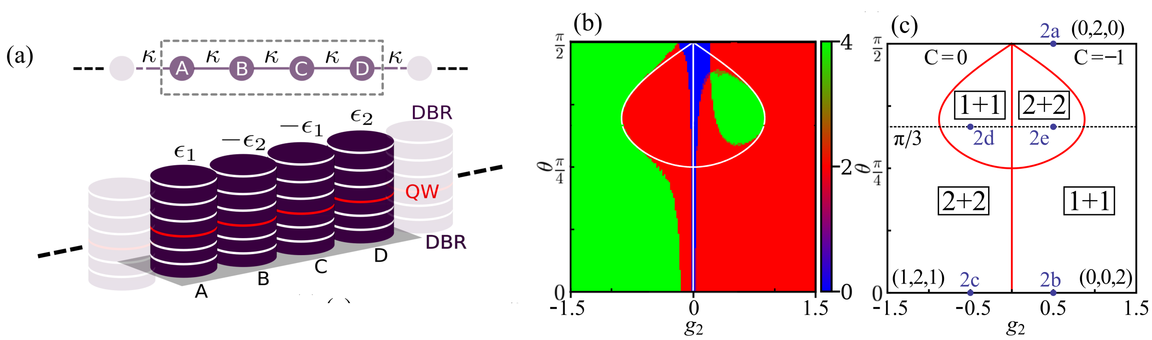

FIG. 1. (a) The non-Hermitian four-site unit cell chain of microcavity pillars with embedded quantum wells. The onsite complex potential $\epsilon_{1,2} = g_{1,2}e^{i\theta}$ is function of the pumping modulation amplitudes $g_{1,2}$, and non-Hermiticity parameter θ. (b),(c) Topological phase diagram for the symmetric system $g_1 = |g_2|$ obtained by (b) counting the end states and (c) combining the information from Chern number C, Wilson loop invariant and enforced exceptional points.

References:

[1] T. Karzig et al., Phys. Rev. X , **5**, 031001, 2015; A. V. Nalitov et al., Phys. Rev. Lett., **114**, 116401, 2015
[2] P. St-Jean et. al, Nature Photonics, **11**, 2017, 651–656, 2017; S. Klembt et. al, Nature, **562**, 552–556, 2018
[3] P. Comaron, V. Shahnazaryan, W. Brzezicki, T. Hyart, and M. Matuszewski, Phys. Rev. Res. **2**, 022051(R), 2020
[4] K. Takata and M. Notomi, Phys. Rev. Lett., **121**, 213902, 2018
[5] P. Comaron, V. Shahnazaryan and M. Matuszewski, Optics Express, **28**, 38698-38709, 2020

Classical and Quantum Chaos in Chirally-Driven, Dissipative Bose-Hubbard Systems

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We study the dissipative Bose-Hubbard model on a small ring of sites in the presence of a chiral drive and explore its long-time dynamical structure using the mean field equations and by simulating the quantum master equation. Remarkably, for large enough drivings, we find that the system admits, in a wide range of parameters, a chaotic attractor at the mean-field level, which manifests as a complex Wigner function on the quantum level. The latter is shown to have the largest weight around the approximate region of phase space occupied by the chaotic attractor. We demonstrate that this behavior could be revealed via measurement of various bosonic correlation functions. In particular, we employ open system methods to calculate the out-of-time-ordered correlator, whose exponential growth signifies a positive quantum Lyapunov exponent in our system. This can open a pathway to the study of chaotic dynamics in interacting systems of photons.

[1] D. Dahan, G. Arwas, and E. Grosfeld, Classical and quantum chaos in chirally-driven, dissipative bose-hubbard systems, arXiv preprint arXiv:2105.10953 (2021).

Scalable full quantum dynamics of dissipative Bose-Hubbard systems and multi-time correlations

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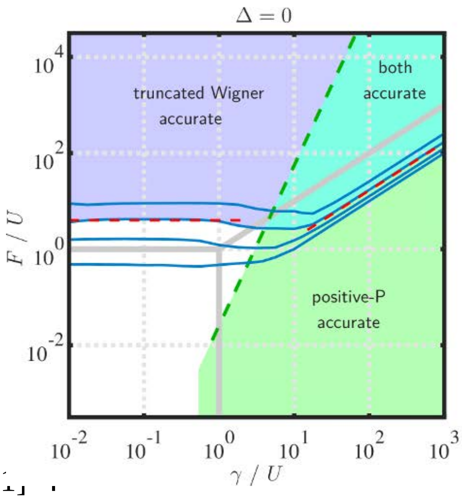
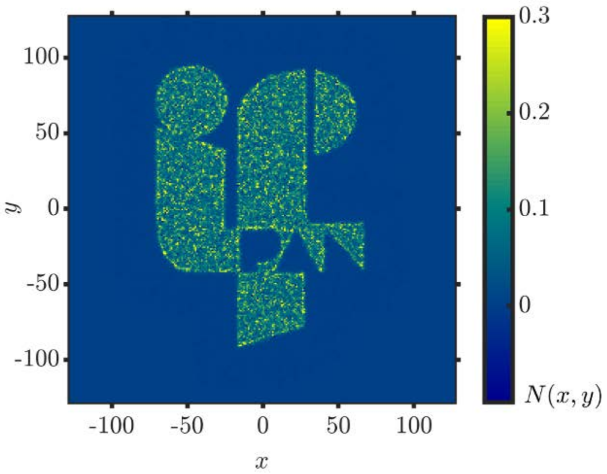
We find the positive-P method known from quantum optics to be effective at simulating large driven-dissipative Bose-Hubbard models across a wide range of parameters. For example, full quantum dynamics of a nonuniform 256x256 lattice of sites is demonstrated (right figure) [1]. Accessible parameters include those where interactions and dissipation are significant, occupations low and common semiclassical approximations can break down. Antibunching or strong two-particle interference such as in the anomalous photon blockade can be simulated. The presence of dissipation alleviates instabilities in the positive-P method that were known to occur for closed systems, allowing the simulation of full quantum dynamics up to and including the steady state. In the accessible regime numerical effort scales merely linearly with the number of sites, quadratically with the precision, and doesn't care about symmetry or its lack. We also find that the regions of applicability of the positive-P, and truncated Wigner approaches are mutually complementary (left figure). Together these approaches cover the majority of parameter space in the dissipative Bose-Hubbard model [1]. The phase space approach also provides a simple and physically intuitive way to calculate many unequal time correlations, allowing their investigation in a non-perturbative and scalable way [2].





References

[1] . . Deuar, A. Ferrier, M. Matuszewski, G. Orso, M. H. Szymanska, PRX Quantum **2**, 010319 (2021).

[2] P. Deuar, Quantum **5**, 455 (2021).

Topological phonons in arrays of ultracold dipolar particles

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The notion of topology in physical systems is associated with the existence of a nonlocal ordering that is insensitive to a large class of perturbations. This brings robustness to the behaviour of the system and can serve as a ground for developing new fault-tolerant applications. We discuss how to design and study a large variety of topology-related phenomena for phonon-like collective modes in arrays of ultracold polarized dipolar particles. These modes are coherently propagating vibrational excitations, corresponding to oscillations of particles around their equilibrium positions, which exist in the regime where long-range interactions dominate over single-particle motion. We demonstrate that such systems offer a distinct and versatile tool to investigate topological effects that can be accessed by choosing the underlying crystal structure and by controlling the anisotropy of the interactions. Our results show that arrays of dipolar particles provide a promising unifying platform to investigate topological phenomena with phononic modes.

References

[1] **M. Di Liberto**, A. Kruckenhauser, P. Zoller and M. A. Baranov, arXiv: 2108.11856

Raman Spectroscopy of quasi-two-dimensional materials

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Quasi-2D materials, an emerging field of experimental Solid State physics, host various low-dimensional quantum phenomena making them potential candidates for quantum technology[1,2,3]. The main focus being on transition metal dichalcogenides, quantum dots and single photon emitters were successfully demonstrated in various 2D materials such as hBN[4], MoS_2[5], $MoSe_2$[6], WS_2[7] and WSe_2[8]. Despite significant contributions to the field of 2D quantum information technologies, it remains insufficiently researched with many problems yet to be solved. To get a better insight into potential applications of 2D materials in quantum information technologies, we need to obtain a better understanding of 2D materials as such. Here we present Raman Spectroscopy studies of transition metal trihalides CrI_3 and VI_3, and transition metal dichalcogenide 1T-TaS_2, all promising candidates for next-generation devices and quantum technologies [9,10,11,12].

[1] Novoselov, K. S. et al. Two-dimensional gas of massless Dirac fermions in graphene. *Nature* **438**, 197 (2005).

[2] Nayak, C. et al. Non-Abelian anyons and topological quantum computation. *Rev. Mod. Phys.* **80**, 1083–1159 (2008).

[3] Qian, X. et al. Quantum spin Hall effect in two-dimensional transition metal dichalcogenides. *Science* **346**, 1344–1347 (2014).

[4] Tawfik, S. A. et al. First-principles investigation of quantum emission from hBN defects. *Nanoscale* **9**, 13575–13582 (2017).

[5] Lee, K. et al. Coulomb blockade in monolayer MoS_2 single electron transistor. *Nanoscale* **8**, 7755–7760 (2016).

[6] . Branny, A. et al. Discrete quantum dot like emitters in monolayer $MoSe_2$: Spatial mapping, magneto-optics, and charge tuning. *Appl. Phys. Lett*. **108**, 142101 (2016).

[7] Song, X.-X. et al. Temperature dependence of Coulomb oscillations in a few-layer two-dimensional WS_2 quantum dot. *Sci. Rep.* **5**, 16113 (2015).

[8] Song, X.-X. et al. A gate defined quantum dot on the two-dimensional transition metal dichalcogenide semiconductor WSe_2. Nanoscale 7, 16867–16873 (2015).

[9] I. Vaskivskyi, et al. Fast electronic resistance switching involving hidden charge density wave states *Nat. Commun.* **7**, 11442 (2016).

[10] Huang, C, et al. Quantum Anomalous Hall Effect in Ferromagnetic Transition Metal Halides. *Phys. Rev. B* **95** (4), 045113 (2014).

[11] Ezawa, Z. F. Spin-Pseudospin Coherence and CP 3 Skyrmions in Bilayer Quantum Hall Ferromagnets. *Phys. Rev. Lett*. **82** (17), 3512−3515 (1999).

[12] Mukherjee, A. *et al.* Observation of site-controlled localized charged excitons in CrI_3/WSe_2 heterostructures. *Nat Commun* **11,** 5502 (2020).

Decoherence scaling transition in the dynamics of quantum information scrambling

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Reliable processing of quantum information for developing quantum technologies requires precise control of out-of-equilibrium many-body systems [1]. This is a highly challenging task because the fragility of quantum states to external perturbations increases with the system size. Here, we report on a series of experimental quantum simulations that quantify the sensitivity of a controlled Hamiltonian evolution to perturbations that drive the system away from the targeted evolution [2, 3, 4]. Based on out of-time ordered correlations [1, 5], we demonstrate that the decay rate of the process fidelity increases with the effective number K of correlated qubits as K^{α}. As a function of the perturbation strength, we observe a decoherence scaling transition of the exponent α between two distinct dynamical regimes. In the limiting case below the critical perturbation strength, the exponent α drops sharply below 1, and there is no inherent limit to the number of qubits that can be controlled. This resilient quantum feature of the controlled dynamics of quantum information is promising for reliable control of large quantum systems.

References

[1] R. J. Lewis-Swan, A. Safavi-Naini, A.M. Kaufman and A.M. Rey, Nat. Rev. Phys., **1**, 627 (2019).
[2] G. A. Álvarez, D. Suter, & R. Kaiser, Science, **349(6250)**, 846-848, (2015).
[3] F.D. Domínguez, M.C. Rodríguez, R. Kaiser, D. Suter and G.A. Álvarez, Physical Review A, **104(1)**, 012402 (2021).
[4] F.D. Domínguez and G.A. Álvarez, arXiv preprint arXiv:2107.03870 (2021).
[5] B. Swingle, Nat. Phys., **14, 988** (2018).

Lattice Models of the Strongly Out-of-Equilibrium Phase Transformations

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The strongly out-of-equilibrium symmetry-breaking phase transformations are important both in the condensed-matter (superfluids, superconductors, liquid crystals) and elementary-particle physics (Higgs fields). A well-known but still unresolved puzzle of such phase transformations is an extremely low observable concentration of the topological defects (such as domain walls/kinks, strings/vortices, and monopoles) as compared to the theoretical predictions by the so-called Kibble-Zurek scenario [1, 2].

The aim of the present report is to show that the lattice models can be a powerful tool to elucidate this disagreement. Namely, we approximate a pattern of the symmetry-broken domains by the lattice-type structure and study how the residual correlations between the elementary cells (*e.g.*, caused by the entanglement of order parameter, as was found by Carmi *et al.* [3]) affect the probability of occurrence of the topological defects.

As a simplest example, we consider a mapping of the symmetry-broken states in the φ^4 real-field model onto the spin model of Ising type [4]. Thereby, it is found that the residual correlations between the domains can reduce the number of the resulting defects dramatically if the specific energy concentrated in the domain walls is sufficiently large. Moreover, a similar effect can be important also in the cosmological phase transitions [5].

References

[1] T.W.B. Kibble, J. Phys. A **9**, 1387 (1976)
[2] W.H. Zurek, Nature **317**, 505 (1985)
[3] R. Carmi, E. Polturak, and G. Koren, Phys. Rev. Lett. **84**, 4966 (2000)
[4] Yu.V. Dumin, New J. Phys. **11**, 103032 (2009)
[5] Yu.V. Dumin, Adv. High Energy Phys. **2014**, 241831 (2014)

Improved Tensor-Network Algorithm for the Simulation of Two-Dimensional Open Quantum Spin Lattices

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Quantum many-body systems in the presence of drive and dissipation are some of the more difficult problems to solve numerically. Algorithms based on tensor networks have found great success in the context of closed quantum systems, and open systems in one-dimension, however their extension to two-dimensional open quantum systems has only recently come to fruition. This poster presents an adaptation of the infinite projected entangled pair operator (iPEPO)-based tensor network algorithm detailed in Ref. [1] that instead leverages the variational uniform matrix product state (VUMPS) algorithm [2] to contract infinite two-dimensional tensor networks. Near critical points, the VUMPS algorithm has been shown to perform significantly faster compared to the corner transfer matrix renormalisation group (CTMRG) method utilised in the original proposal [3], therefore we expect the VUMPS adaptation to inherent this computational speed up, while remaining stable and providing accurate results when compared to a known numerically exact method. This tensor network algorithm can be used to obtain the steady states and transient dynamics of two-dimensional quantum lattice models evolving according to the Lindblad equation.

References

1. C. Mc Keever and M. H. Szymańska, Phys. Rev. X **11**, 021035 (2021)
2. V. Zauner-Stauber *et al.* Phys. Rev. B **97**, 045145 (2018)
3. M. T. Fishman *et al.* Phys. Rev. B **98**, 235148 (2018)

Exciton–Plasmon Coupling in 2D Semiconductors Accessed by Surface Acoustic Waves

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We theoretically demonstrate the coupling between excitons in 2D semiconductors and surface plasmons in a thin metal film by means of a surface acoustic wave (SAW), proving that the generated exciton-plasmon polaritons (or plexcitons) are in the strong coupling regime (figure 1). The strain field of the SAW creates a dynamic diffraction grating providing the momentum match for the surface plasmons, whereas the piezoelectric field, that could dissociate the excitons, is cancelled out by the metal. This is exemplified for monolayer MoS_2 and mono- and few-layer black phosphorus on top of a thin silver layer on a $LiNbO_3$ piezoelectric substrate, providing Rabi splittings of 100-150 meV. Thus, we demonstrate that SAWs are powerful tools to modulate the optical properties of supported 2D semiconductors by means of the high-frequency localized deformations tailored by the acoustic transducers, that can serve as electrically switchable launchers of propagating plexcitons suitable for active high-speed nanophotonic applications.

Reference

[1] R. Fandan, J. Pedrós and F. Calle, ACS Photonics, 8, 1698 (2021)

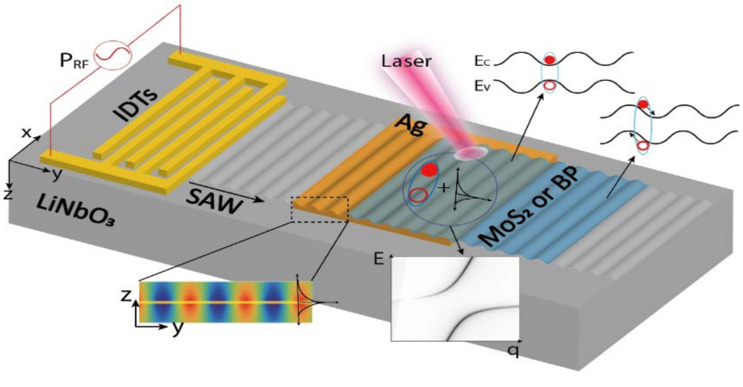

Figure 1: Schematic of the device proposed.

Positive-P simulations of driven-dissipative Bose-Hubbard Lieb lattices

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The positive-P method allows for scalable numerical simulations of many-body quantum systems without approximations, where quantum mechanical observables are calculated by appropriate averages over stochastic trajectories in phase space. Traditionally, for closed systems, the fundamental limitation on the positive-P method has been the occurrence of a noise amplification instability which eventually causes the trajectories to escape to infinity, limiting useful results to short times. However, in recent work we have demonstrated that, in open quantum systems such as the driven-dissipative Bose-Hubbard model, sufficient dissipation can stabilise the trajectories fully, allowing dynamics to be simulated up to the steady state and beyond [1]. Here, we continue to study the driven-dissipative Bose-Hubbard model, focusing on Lieb lattice geometries, which have been explored in many recent experiments using, for example, polariton micropillars. We investigate an effect whereby, under particular driving schemes, significant antibunching of second order correlations can be achieved on specific sites in the lattice, via a mechanism similar to the unconventional photon blockade. This effect should be observable in parameter regimes accessible to current polariton micropillar experiments.

References

[1] P. Deuar, A. Ferrier, M. Matuszewski, G. Orso, and M. H. Szymańska, PRX Quantum 2, 010319 (2021)

Ultracold fermions in optical superlattices

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The quantum simulation of Fermi-Hubbard models using ultracold atoms in optical lattices has been essential to deepen our understanding of condensed matter systems. With the precise tunability of the model parameters and the possibility to even change the dimensionality of the systems, it allows to investigate many-body quantum phases. In particular, probing spin correlations has been of interest in understanding high-temperature superconductivity.

Our experimental setup is based on a three-dimensional optical lattice where a vertical lattice confines the atoms in two-dimensional layers. Recently, the vertical lattice has been extended to a superlattice to implement pairs of layers coupled by interlayer tunneling [1]. By tuning the tunneling within the layers, the crossover between interlayer spin correlations and antiferromagnetic correlations in the layers was observed.

To introduce the superlattice capabilities to the two-dimensional layers, we are currently working on the implementation and stabilization of an in-plane superlattice. In the future, we are going to investigate topological systems and transport properties in time-dependent superlattices.

References

[1] M. Gall, N. Wurz et al. *Nature* **589**, 40-43 (2021)

Observation of KPZ universal scaling in a one-dimensional polariton condensate

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Revealing universal behaviors in different systems is a hallmark of statistical physics. At equilibrium, simple models (like the Ising one) have been pivotal in understanding the critical properties of a whole class of systems. Reversely, a clear description of the universal properties of several non-equilibrium systems is still missing. In this context, the Kardar-Parisi-Zhang (KPZ) equation [1] has emerged as a quintessential model to investigate non-equilibrium phenomena and phase transitions.

Current experimental observations of KPZ dynamics have mainly focused on probing the critical roughening of growing interface in classical systems [2]. However, recent theoretical works suggest that the phase of an extended polariton condensate behaves as an interface, whose spatio-temporal evolution falls into the KPZ universality class [3,4]. Those results are also relevant for out-of-equilibrium BECs and lasers. Determining if KPZ physics governs the phase correlations in all those systems is of critical importance. For instance, it would set an intrinsic limitation on the achievable coherence of large-area laser sources.

In the present poster, I first explain how to generate highly elongated polariton condensate in a 1-dimensional polariton lattice. I then describe how measuring the condensate coherence enables to retrieve the roughness of the phase front. Finally, I show that data points lying within a well-defined spatio-temporal window collapse onto a single scaling function, characteristic of the KPZ universality class. These results highlight the differences between driven-dissipative and equilibrium condensates and lay the groundwork for future investigations of KPZ physics in 2D polariton systems.

References

[1] M. Kardar, G. Parisi, and Y. C. Zhang, Phys. Rev. Lett. **56**, 889 (1986)
[2] T. Halpin-Healy and Y.-C. Zhang, Physics Reports **254**, 215 (1995)
[3] E. Altman, et al., Phys. Rev. X **5**, 011017 (2015).
[4] K. Ji, et al., Phys. Rev. B **91**, 045301 (2015)

Studying Bose-Hubbard models with machine learning algorithms

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Properties of the zero-temperature phase diagram of the one-dimensional Bose-Hubbard model are studied with Machine Learning techniques. The many-body ground state is found by a variational scheme based on the Restricted Boltzmann Machines. The Fock space is sampled via the Monte Carlo algorithm. As a result, ground-state energies for different systems' sizes are determined and then extrapolated to their thermodynamic limit counterparts. Finally, well-known boundaries of the first two insulating lobes are reconstructed.

Tunable room temperature condensation of exciton-polaritons in 1D lattices

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Exciton-polaritons are hybrid light-matter quasiparticles arising from the strong coupling between a cavity photon and an electronic material excitation that can undergo non-equilibrium Bose-Einstein Condensation (BEC). By trapping these condensates in engineered potential landscapes we can create tunable and easy to measure artificial systems for simulating different Hamiltonians. In our work we create exciton-polariton condensates by exciting a ladder-type conjugated polymer, inside a length-tunable Fabry-Perot microcavity. We use focused ion beam (FIB) milling to pattern the microcavity, thus introducing also lateral confinement of the light [1].

First, we fabricate and optically characterize 1D lattices with equal coupling strength between all sites. We study tunable condensation in different modes of these chains and examine how the variation of the coupling strength affects their properties, bandstructure and localization due to disorder. Next, we show our progress in the investigation of a chain with alternating coupling strengths, a so-called Su-Schrieffer–Heeger (SSH) chain. By using our tunable system as well as local excitation, we intend to demonstrate a topological phase transition and non-reciprocal transport, which was recently predicted by theorists [2].

To summarize, we use exciton-polariton condensates trapped in potential landscapes as a room-temperature platform for analogue simulations of interesting physical phenomena in 1D lattices that exploit the tunable and dissipative nature of the system.

References

[1] F. Scafirimuto, “Room-Temperature Exciton-Polariton Condensation in Tunable Zero-Dimensional Microcavity”, ACS Photonics **5**(1), pp 85-89 (2018)

[2] T. J. Sturges, “Modelling lattices of organic polaritons”, arXiv 2106.07004

Understanding superradiant phenomena with synthetic vector potentials in atomic Bose-Einstein condensates

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We theoretically investigate superradiant effects in quantum field theories in curved space-times by proposing an analogue model based on Bose-Einstein condensates subject to a synthetic vector potential. The breaking of the irrotationality constraint of superfluids allows to study superradiance in simple planar geometries and obtain intuitive insight in the amplified scattering processes at ergosurfaces. When boundary conditions are modified allowing for reflections, dynamical instabilities are found, similar to the ones of ergoregions in rotating space-times. Their stabilization by horizons in black hole geometries is discussed. At the quantum level this setup displays spontaneous superradiant emission, that was predicted for quantum fields around rotating black holes and can be here detected via correlation measurements. All these phenomena are reinterpreted through an exact mapping with the physics of one-dimensional relativistic charged scalar fields in electrostatic potentials. Our study provides a deeper understanding on the basic mechanisms of superradiance: by disentangling the different ingredients at play, it shines light on some misconceptions on the role of dissipation and horizons and on the competition between superradiant scattering and instabilities. Moreover, it shows how the tools of cold atoms physics can be used to build toy models displaying effects discovered in more complex systems in different areas of physics.

References

[1] L. Giacomelli, and I. Carusotto, *Physical Review A* ***103***, 043309 (2021)
[2] L. Giacomelli, and I. Carusotto, *Physical Review A* **104**, 013313 (2021)

Rotor Jackiw-Rebbi Model: A Cold-Atom Approach to Chiral Symmetry Restoration and Charge Confinement

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Understanding the nature of confinement, as well as its relation with the spontaneous breaking of chiral symmetry, remains one of the long-standing questions in high-energy physics. The difficulty of this task stems from the limitations of current analytical and numerical techniques to address nonperturbative phenomena in non-Abelian gauge theories. In this work [1], we show how similar phenomena emerge in simpler models, and how these can be further investigated using state-of-the-art cold-atom quantum simulators. More specifically, we introduce the rotor Jackiw-Rebbi model, a (1+1)-dimensional quantum field theory where interactions between Dirac fermions are mediated by quantum rotors. Starting from a mixture of ultracold atoms in an optical lattice, we show how this quantum field theory emerges in the longwavelength limit. For a wide and experimentally relevant parameter regime, the Dirac fermions acquire a dynamical mass via the spontaneous breakdown of chiral symmetry. We study the effect of both quantum and thermal fluctuations, and show how they lead to the phenomenon of chiral symmetry restoration. Moreover, we uncover a confinement-deconfinement quantum phase transition, where mesonlike fermions fractionalize into quarklike quasiparticles bound to topological solitons of the rotor field. The proliferation of these solitons at finite chemical potentials again serves to restore the chiral symmetry, yielding a clear analogy with the quark-gluon plasma in quantum chromodynamics, where the restored symmetry coexists with the deconfined fractional charges. Our results indicate how the interplay between these phenomena could be analyzed in more detail in realistic atomic experiments.

References

[1] D. González-Cuadra et al., PRX Quantum 1, 020321 (2020)

Quantum simulation with carbon nanotubes: from Mott insulator to phonon-induced electron pairing

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The quantum simulation of novel materials is one of the most promising near-term applications of quantum technologies. In this context, a key role is played by the Hubbard model which describes electrons in a tight-binding lattice, and which has successfully been implemented in different quantum simulation platforms, including cold atoms and semiconducting devices. Here we propose a novel arena for studying Hubbard-like physics which is based on quantum dots on a suspended carbon nanotube [1]. Such a setup is well suited for including one additional ingredient, electron-phonon coupling, which is highly relevant in various materials at finite temperature. In particular, electron-phonon coupling is the key to strongly correlated phases such as conventional or high-Tc superconductivity, and it can be the mechanism behind different types of charge and spin order (antiferromagnetism, charge density waves, etc.). In the proposed quantum simulation setup, we find that, by increasing the electron-phonon coupling within the experimentally feasible parameter range, the system undergoes a transition from a Mott insulating state to a polaronic state. The appearance of pairing correlations and the spontaneous breaking of the translational symmetry are fascinating consequences of the electron-phonon coupling.

References

[1] Utso Bhattacharya, Tobias Grass, Adrian Bachtold, Maciej Lewenstein, Fabio Pistolesi, arXiv 2106.09418, accepted for publication in Nano Lett., (2021)

Direct measurement of the quantum geometric tensor in exciton-polariton systems

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Often the study of topological properties of a given system has been focused on the measurement of a topological gap or edge-state, however, the topological properties of matter are not only encoded in the dispersion relation of a given Hamiltonian, but also in the eigenstates structure of said Hamiltonian. The quantum geometric tensor, an object composed of the Berry curvature and the metric tensor, encodes these topological properties in the bulk of a given system, from which it is possible to get a more complete understanding of the system, as well as being able to compute topological invariants among other things. We present experimental direct measurement of the quantum geometric tensor in a planar polaritonic cavity with spin-orbit coupling and time-reversal symmetry breaking. These effects arise respectively from a TE/TM splitting of the polariton photonic component and a Zeeman splitting of the excitonic part. In exciton-polariton systems, the spin internal degree of freedom can be accessed by polarization-resolved measurements, which in turn gives access to the eigenstates composition of a given energy band and then the possibility to compute the quantum geometric tensor.

This measurement of the quantum geometric tensor for a planar cavity paves the way for the study of the topological properties of more complex geometries; such has polaritonic graphene, Lieb or dislocated Lieb lattices, all of which, in the presence of time-reversal symmetry breaking and spin-orbit coupling, show non-trivial topological phases.

Floquet Engineering of XYZ Hamiltonians with Rydberg atoms

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Controlling interactions is the key element for the quantum engineering of many-body systems. Based on Floquet's theorem [1], the stroboscopic dynamics of periodically driven quantum systems is effectively described by a time-independent Hamiltonian which can be engineered by controlling the properties of the drive [2, 3]. We demonstrate such Floquet engineering with a system of spins represented by Rydberg states driven by a global microwave field in a cold atomic gas.
By using a sequence of spin manipulations, we show the ability to change the symmetry properties of the effective Heisenberg XYZ Hamiltonian which affects drastically the relaxation dynamics of the system [4]. By applying the Floquet engineering technique on ordered systems constituted of arrays of Rydberg atoms we illustrate the dynamically tunable coherent evolution for 2 atoms and we explore the dynamics of 1D domain wall for various engineered Heisenberg Hamiltonian [5].

References

[1] G. Floquet *et al.*, Annales de l'Ecole Normale Supérieur **12**, 47 (1883)
[2] J. H. Shirley *et al.*, Phys, Rev, **138** B979 (1965)
[3] N. Goldman and J. Dalibard, Phys. Rev. X **4**, 031027 (2014)
[4] S. Geier *et al.*, arXiv:2105.01597 (2021)
[5] P. Scholl *et al.*, arXiv:210714459 (2021)

Stabilizing Disorder-Free Localization

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Disorder-free localization is a paradigm of nonergodicity in translation-invariant quantum many-body systems hosting gauge symmetries. The quench dynamics starting from simple initial states, which correspond to extensive superpositions of gauge superselection sectors, exhibits many-body localization with the system dynamically inducing its own disorder. An open question concerns the stability of disorder-free localization in the presence of gauge-breaking errors, and whether processes due to the latter can be controllably suppressed. Here, we show that translation-invariant *single-body gauge terms* induce a quantum Zeno effect that reliably protects disorder-free localization against errors up to times at least polynomial in the protection strength. Our experimentally feasible scheme not only shows that disorder-free localization can be reliably stabilized, but also opens promising prospects for its observation in quantum simulators.

BEC Statistics via Fock State Sampling

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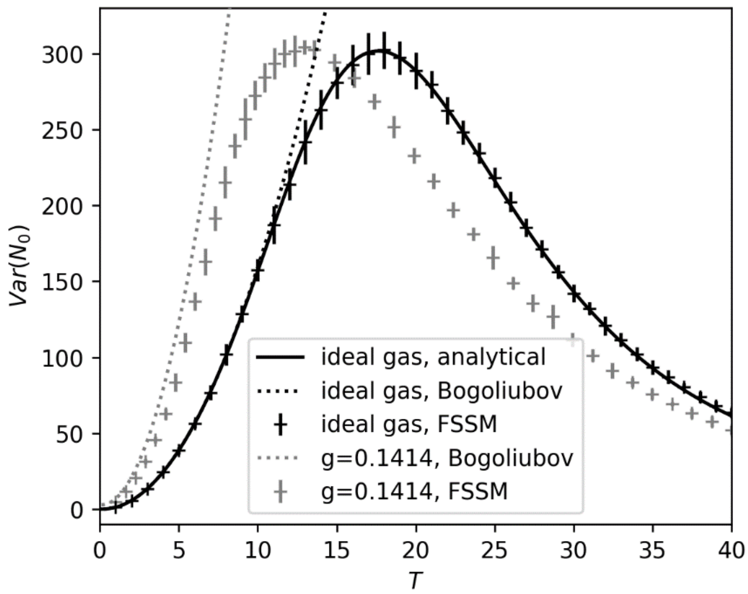
The problem of condensate atom number fluctuations has been studied since the 1940s but remains contentious. It has enjoyed renewed interest recently, when in 2019 the first experimental measurements of condensate fluctuations were realized.[1] It has been shown that the fluctuations depend strongly on the choice of statistical ensemble used in their description.[2]

We present a new method of studying the statistics of weekly-interacting BECs at finite temperature based on the sampling of the underlying distribution of Fock states, governed by the principle of Bose enhancement. We find significant dependence of the fluctuations of the number of condensed atoms on the choice of statistical ensemble and interaction strength in a periodic box and harmonic trap, in good agreement with analytical results. In turn, the discrepancies between the ensembles depend strongly on the geometry of the trap.



[1] M. A. Kristensen, M. B. Christensen, M. Gajdacz, M. Iglicki, K. Pawłowski, C. Klempt, J. F. Sherson, K. Rzążewski, A. J. Hilliard, and J. J. Arlt, Phys. Rev. Lett. **122**, 163601 (2019)

[2] M. B. Christensen, T. Vibel, A. J. Hilliard, M. B. Kruk, K. Pawłowski, D. Hryniuk, K. Rzążewski, M. A. Kristensen, and J. J. Arlt, Phys. Rev. Lett. **126**, 153601 (2020)

Ultra-long-range Rydberg Molecules

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When a Rydberg atom is excited in the presence of a ground-state atom, stable molecular configurations can be formed due the attractive scattering of the Rydberg electron off the ground-state atom. This process occurs frequently in ultracold Rydberg gas experiments with clear spectroscopic signatures. These ultra-long-range Rydberg molecules (ULRM) have exciting and exaggerated features inherited from the parent Rydberg atom, such as huge bond lengths and permanent electric dipole moments, oscillatory potential energy curves, and extreme susceptibility to external fields. Recently, they have been utilized to perform high precision experiments of electron scattering properties including higher partial wave scattering [1] as well as to probe the quantum statistics of the underlying gas. I will provide an overview of the theoretical model and main experimental achievements as well as providing an outlook on opportunities utilizing ULRM to excite ion-pair states of opposite charge [2] and studying dynamical molecular processes such as associative ionization and radiationless decays due to the presence of conical intersections in the underlying electronic potentials [3].

References

[1] F. Engel et al., Phys. Rev. Lett. **123**, 073003 (2019)
[2] F. Hummel et al., New J. Phy. **22**, 063060 (2020)
[3] F. Hummel et al, Phys. Rev. Lett. **127**, 023003 (2021)

Ultracompact cavity array for analog quantum simulation

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Photonic cavity arrays form the basis of one of the most promising paradigms for quantum simulation to study complex many-body physics [1]. We developed a non-trivial structured photonic environment that could enable a multimode strong and ultra-strong coupling with a qubit. This platform consists of a unidimensional metamaterial implemented by an array of coupled superconducting microwave cavities made from thin Niobium Nitride (NbN) films. Such disordered superconductor allows to reach a very high kinetic inductance [2], which presents a two-fold advantage: a) It allows to reach ultra-strong coupling with an artificial atom as the amplitude of the zero-point voltage fluctuation is proportional to the square root of the resonators' impedance [3], which can be highly increased thanks to the kinetic inductance; b) It allows to strongly reduce the resonator/metamaterial footprint.
Furthermore, working with a metamaterial allows engineering a non-trivial photonic dispersion relation, where it is possible to obtain states displaying topological properties (SSH-states [4]). We have been able to fabricate and characterize unidimensional metamaterials made of up to 88 ultra-compact resonators. We are currently expanding this technology to 2D metamaterials, where we expect to engineer further topological edge states.

References

[1] D. L. Underwood, W. E. Shanks, J. Koch, and A. A. Houck, Phys. Rev. A **86**, 023837 (2012).
[2] D. Niepce, J. Burnett, and J. Bylander, Phys. Rev. Applied **11**, 044014 (2019).
[3] N. Samkharadze, A. Bruno, P. Scarlino, G. Zheng, D. P. DiVincenzo, L. DiCarlo, and L. M. K. Vandersypen, Phys. Rev. Appl. **5**, 044004 (2016).
[4] E. Kim, X. Zhang, V. S. Ferreira, J. Banker, J. K. Iverson, A. Sipahigil, M. Bello, A. González-Tudela, M. Mirhosseini, and O. Painter, Phys. Rev. X **11**, 011015 (2021).

Superconducting circuits for simulating staggered quantum walks

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The staggered quantum walk is a type of discrete-time quantum-walk model without a coin which is generated on a graph using particular partitions of the graph nodes. The main idea is to embed the coin degrees of freedom in the underlying graph, hence, the dynamics is realized by accessing a dynamical graph in which the graph edges can be removed and restored on demand. The walker freely evolves, however, the active edges are periodically modified, according to some predefined rules. In this presentation, I explain an implementation of the staggered quantum walk model with superconducting microwave resonators, made from finite sections of superconducting transmission stripline, coupled through superconducting quantum interference devices (SQUIDs). Each SQUID is controlled by an individual wave generator that produces magnetic flux pulses, providing the system with tunable couplings. The tunability of the interactions makes this system an excellent toolbox for staggered quantum walks. I will focus on the one-dimensional case and discuss its generalization to the two-dimensional lattice. The system is restricted to the "single-photon" regime, and the methods for single-photon generation and detection are used. In order to prepare and measure photons in an arbitrary resonator, individual transmon qubits are coupled capacitively to the resonators. Each transmon qubit is also coupled capacitively to a separate superconducting resonator, a coplanar waveguide cavity, which is required for manipulating the qubit state.

References

[1] J. Khatibi Moqadam, M. C. de Oliveira, R. Portugal, Physical Review B **95**, 144506 (2017)

[2] J. Khatibi Moqadam, A. T. Rezakhani, Physical Review A **98**, 012123 (2018)

Quantum Devices in the Cloud

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AWS provides access to quantum devices to any member of the public through the Amazon Braket service. Quantum tasks, are submitted via secure internet connection, scheduled and run by connected quantum hardware, and results are transferred to the customer. Operations that rely on quantum resources can be combined with classical processing schedules to create reproducible research pipelines. The nature of quantum tasks is continually evolving and expanding: from running gate-based quantum circuits, through optimizing quadratic cost functions with quantum annealing, to lattice-based quantum simulations in the future; the cloud brings an increasing variety of quantum resources straight to the web browser of every researcher. We present an easy-to-install open-source Python package [1] that provides a unified way to define and execute quantum jobs on devices such as Rigetti, IonQ, and D-Wave, as well as on corresponding classical simulators powered by either local or cloud hardware.

References

[1] https://amazon-braket-sdk-python.readthedocs.io

Frequency-modulated combs in VECSELs

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Frequency comb generation in lasers has been an active field of research in the last two decades due to its tremendous potential for applications in frequency metrology and telecommunications [1]. While initially relying on mode-locked lasers that emit ultrashort pulses recent years have witnessed the generation of frequency combs in laser platforms where the modes are locked only by the intrinsic nonlinearity of the gain medium and not by the use of an additional saturable absorber [2]. In general, these lasers do not emit pulses but instead are characterized by a strong linear chirp in the time-domain and thus called frequency-modulated (FM) combs [3]. First discovered in quantum cascade lasers they also have been demonstrated in various other edge-emitting semiconductor lasers [4,5]. In order to comprehensively characterize these comb sources, the development of a coherent beatnote spectroscopy technique called shifted wave interference Fourier transform spectroscopy (SWIFTS) has turned out to be crucial [6]. Here, we use SWIFTS to measure the intermode phase of a vertical-external-cavity surface-emitting laser (VECSEL) with low group delay dispersion and discover that the laser operates as FM comb over a certain part of its optical spectrum [7]. This makes VECSELs the first surface-emitting laser platform where the physics of FM combs can be studied as well as potentially useful for high-power dual-comb spectroscopy.

References

[1] S.T. Cundiff et al., Rev. Mod. Phys. **75**, 325 (2003)
[2] A. Hugi, et al., Nature **492**, 229 (2012)
[3] M. Singleton, et al., Optica **5**, 948 (2018)
[4] J. Hillbrand, et al., PRL **124**, 023901 (2019)
[5] L. A. Sterczewski, et al., APL Photonics **5**, 076111 (2020)
[6] D. Burghoff, et al., Opt. Express **23**, 1190 (2015)
[7] C. Kriso et al., Optica **8**, 458 (2021)

Probing infinite many-body quantum systems with finite-size quantum simulators

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Experimental studies of synthetic quantum matter are necessarily restricted to approximate ground states prepared on finite-size quantum simulators. In general, this limits their reliability for strongly correlated systems, for instance, in the vicinity of a quantum phase transition (QPT). My poster presents a protocol [1] that makes optimal use of a given finite-size simulator by directly preparing, on its bulk region, a mixed state representing the reduced density operator of the translation-invariant infinite-sized system of interest. This protocol is based on coherent evolution with a local deformation of the system Hamiltonian. For systems of free fermions in one and two spatial dimensions, the poster illustrates the underlying physics, which consists of quasi-particle transport towards the system's boundaries while retaining the bulk ``vacuum''. For the example of a non-integrable extended Su-Schrieffer-Heeger model, it is demonstrated that the protocol enables a more accurate study of QPTs.

References

[1] Kuzmin Viacheslav, Torsten V. Zache, Lorenzo Pastori, Alessio Celi, Mikhail Baranov, and Peter Zoller. "Probing infinite many-body quantum systems with finite size quantum simulators." arXiv preprint arXiv:2108.12378(2021).

Polariton-phonon interactions in optomechanical lattices

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Lattices of microcavity exciton-polaritons (strongly coupled photons and quantum well excitons) are attractive for classical and emerging solid-state quantum simulators and other photonic applications that require scalability. Such lattices are a host for a plethora of technologically relevant phenomena, to mention a few, potential-landscape engineering, topologically protected transport and lasing. Here we present a dynamically reconfigurable polariton platform based on the µm-sized intra-cavity traps coupled to MHz and GHz acoustic strain [1]. The traps with sizes down to 1×1 μm^2 are arranged in molecules and lattices, giving rise to coupled states and polariton bands, respectively. Specifically, we realized square, Lieb and honeycomb potential landscapes for polaritons. To demonstrate tuneability, the traps were subjected to a standing surface acoustic wave (SAW) with frequency 380 MHz (λ_{SAW} = 8 µm). Strain of the SAW induces a sinusoidal energy modulation of polaritons in a trap up to a few meV [2]. The acoustic impact on the energy spectrum depends on the ratio between the trap size (w_{Trap}) and acoustic wavelength (λ_{SAW}). For small ratios ($w_{Trap} < \lambda_{SAW}$) the trap energy levels shift as a whole. In the case of $w_{Trap} > \lambda_{SAW}$ the modulation leads to the dynamic change of the trap potential shape. We showed the coherent modulation and symmetry control of a lattice of coupled traps by strain fields, which enables the creation of dynamic states within the band gap of the lattice. Using bulk acoustic transducers [3], we demonstrated modulation of confined polaritons at 20 GHz [4]. Interactions between GHz phonons and polariton condensates lead to phonon dressing of the confined levels (sidebands). This opens a way towards coherent control of polariton lattices. These functionalities represent important steps towards tunable polaritonic devices based on lattices of interacting polariton traps.

References

[1] A. S. Kuznetsov, P. L. J. Helgers, K. Biermann, and P. V. Santos, Phys. Rev. B **97**, 195309 (2018)
[2] A. S. Kuznetsov, K. Biermann, and P. V Santos, Phys. Rev. Res. **1**, 1 (2019)
[3] D. H. O. Machado, A. Crespo-Poveda, A. S. Kuznetsov, K. Biermann, L. V. A. Scalvi, and P. V. Santos, Phys. Rev. Appl. **12**, 1 (2019)
[4] A. S. Kuznetsov, D. H. O. O. Machado, K. Biermann, and P. V. Santos, Phys. Rev. X **11**, 1 (2021)

Tunable exciton-polaritons emerging from WS_2 monolayer excitons in a photonic lattice at room temperature

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The engineering of non-linear light-matter states in optical lattices has emerged as a key research strategy for the exploration of Hamiltonians in the spirit of ultrafast- and possibly quantum-simulation. It furthermore has revealed its potential to probe non-trivial topology phenomena. Excitons in atomically thin crystals have emerged as an ideal active medium for such purposes, since they couple strongly with light, and bear the potential to harness giant non-linearities and interactions.
In this work, we present a pioneering experiment conducted at room temperature in an open optical cavity of high quality, with an implemented one-dimensional photonic lattice (see Fig. 1a). In our present work we integrate an atomically thin layer of WS_2 in such a device. We discuss the emergence and tunability of a lattice-band-structure in the tight-binding configuration at room temperature, fuelled by the emission from monolayer excitons. (Fig. 1b) [1].

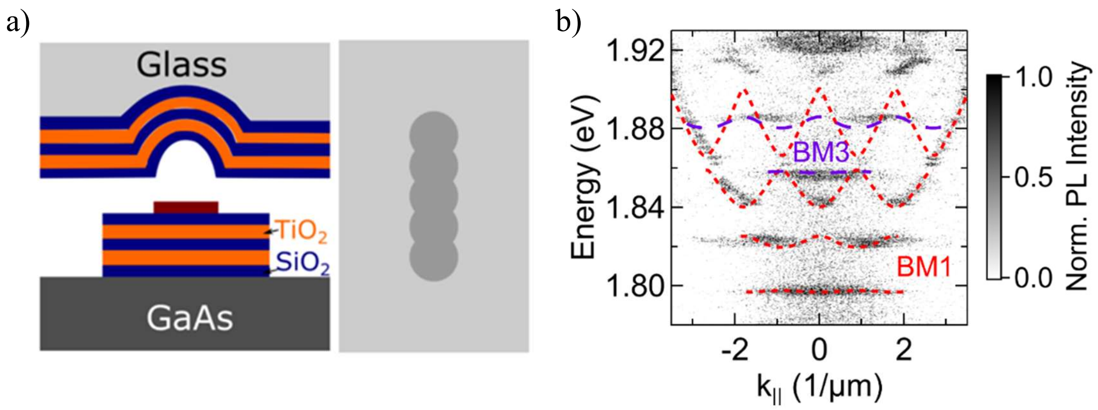

Figure 1: a) Schematic presentation of the open cavity system shown in a vertical cut. The bottom and top mirrors are composed by 10 Bragg pairs of SiO2/TiO2. The top mirror is deposited on a pre-structured glass substrate (see a sketch of the one-dimensional photonic lattice). b) Dispersion relation of WS_2 polaritons in the one-dimensional chain showing a typical Bloch-band structure.

References

[1] L. Lackner *et al.*, *Nat Commun* **12,** 4933 (2021).

Dynamic acousto-mechanical tuning of quantum light emission from atomic defects in hexagonal boron nitride

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Efficient production and manipulation of single-photons are crucial prerequisites for quantum light applications. Future on-chip quantum photonics requires controllable emitters that can be operated on-demand and with the possibility of in situ control of the photon emission wavelength and time. Among various available non-classical light sources, atomic defects based on monolayers, multilayers and crystals of hexagonal boron nitride (h-BN) have emerged as a promising physical system for quantum light emission. They have been shown to host robust, high-temperature and ultra-bright multicolor single photon emitters, which are most likely originating from midgap vacancy-related localized defects. To date, spectral tuning of the optical emission from non-classical light sources in h-BN has only been demonstrated experimentally over a few-meV-wide range by static strain. Here, we report on the dynamic real-time control of the photon emission wavelength from individual h-BN atomic defects subjected to the propagating surface acoustic waves (SAWs) [1]. Luminescent intrinsic defects are identified using spatially, polarization- and time-resolved micro-photoluminescence spectroscopy. They exhibit a pronounced antibunching signature of single photon emission in the photon correlation experiments. When perturbed by the SAW-induced elastic vibration of frequency ~330 MHz, the h-BN defect-related quantum emitters are periodically strained and their optical transitions are modulated by the acousto-mechanical coupling within a ~2 meV bandwidth. This SAW-governed spectral fine-tuning is further combined with spectral detection filtering for temporal control of the emitted photons. In this way, both spectral tunability and on-demand emission of single photons are achieved simultaneously. Altogether, this study opens the door to the use of sound for scalable integration of h-BN emitters in nanophotonic and related quantum information technologies. The advantage of such acoustically mediated control scheme is that it allows in-situ manipulation of the optical emission properties over a wide frequency range (up to GHz frequencies).

References

[1] S. Lazić et al., Commun. Phys. **2**, 113 (2019)

Point-spread-function engineering for 3D imaging of atoms in optical lattices

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Quantum gas microscopes can resolve atoms trapped in a three-dimensional optical lattice down to the single site in the horizontal plane. Along the line of sight, however, a much lower resolution is achieved when the position in this direction is inferred from the defocus alone. It is shown how phase-front engineering can be used to detect atoms' positions with submicrometer spatial resolution in the three dimensions using a single image acquisition. By means of a spatial light modulator, we imprint a phase modulation in the Fourier plane of the imaging system, resulting in a superposition of Laguerre-Gaussian modes at the camera location / in the camera plane. As a result, the so-called point spread function of the imaging system exhibits a spiraling intensity distribution along the line of sight. The angle of the spiraling distribution encodes the position in the third dimension. As a proof of concept, we set up an optical experiment reproducing the conditions of a quantum gas microscope. The choice and optimization of the mode superposition and an implementation scheme for Bonn's quantum simulator setup is discussed. This method can find applications in other optical lattices experiments to extend the domain of quantum simulations from two to three dimensions.

Optimal Quantum Spatial Search with One-Dimensional Long-Range Interactions

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Continuous-time quantum walks can be used to solve the spatial search problem [1], which is an essential component for many quantum algorithms that run quadratically faster than their classical counterpart, in $O(\sqrt{n})$ time for n entries. However, the capability of models found in nature is largely unexplored – e.g., in one dimension only nearest-neighbour Hamiltonians have been considered so far, for which the quadratic speedup does not exist. Here, we prove that optimal spatial search, namely with $O(\sqrt{n})$ run time and high fidelity, is possible in one-dimensional spin chains with long-range interactions that decay as $1/r^{\alpha}$ with distance r. In particular, near unit fidelity is achieved for $\alpha \approx 1$ and, in the limit $n \to \infty$, we find a continuous transition from a region where optimal spatial search does exist ($\alpha < 1.5$) to where it does not ($\alpha > 1.5$). Numerically, we show that spatial search is robust to dephasing noise and that, for reasonable chain lengths, $\alpha \lesssim 1.2$ should be sufficient to demonstrate optimal spatial search experimentally with near unit fidelity.

References

1. A. M. Childs and J. Goldstone, Physical Review A **70**, 022314 (2004)

Quantum Dot Optomechanics in Superconducting Surface Acoustic Wave Resonators

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Surface acoustic waves (SAW) are a proven tool to control the emission of quantum dots (QDs). In particular, SAWs enable the injection of charge carriers into the dots [1,2] or the modulation of their energy levels [3]. Previous work by our group has given us the possibility to enhance this sound-matter coupling between the SAW and the QDs by transferring them on a strong piezo-electric $LiNbO_3$ SAW-chip by epitaxial lift-off [4]. This enabled the realization of a hybrid (Al)GaAs-$LiNbO_3$ SAW resonator by QD integration inside the SAW resonator and observing frequency and position dependent optomechanical coupling of single quantum dots to the resonator modes [5]. Here, we now explore the possibility to enhance the interaction between the phononic modes and the QDs in a superconducting NbN SAW resonator. We demonstrate strong optomechanical coupling between single QDs and the phononic modes of the superconducting SAW resonator for frequencies around 400 MHz and different resonator designs. This coupling is determined by the applied acoustic field and the local amplitude of the acoustic field at the QD‘s position showing the splitting of energy-levels consistent with strain modulation via the GaAs deformation potential. By using time-correlated single-photon counting, we also resolve the temporal dynamics of the modulated QD exciton transition under coupling to various SAW cavity modes.

References

[1] J. R. Gell et al., Appl. Phys. Lett. 93, 081115 (2008);
[2] S. Völk et al., Nano Lett. **10**, 3399 (2010);
[3] F. J. R. Schülein et al., Phys. Rev. B **88**, 085307 (2013);
[4] J. Pustiowski et al., Appl. Phys. Lett. **106**, 013107 (2015);
[5] E. D. S. Nysten et al., Appl. Phys. Lett. **117**, 121106 (2020).

Majorana edge modes and numerical stability in a particle-conserving setting

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Previously, it has been shown that a system consisting of two fermionic chains interacting only by exchanging pairs can host Majorana zero energy modes on the edges [1,2]. Because of this pair-hopping term the particle number on each individual chain is not conserved but the parity is. In this work we have studied the robustness of the Majorana edge modes against different perturbations added to the system and the stability of the MPS simulations when we do not work with single-chain parity as a good quantum number.
We have found that the edge states survive until moderate values of the perturbations, but more importantly we show that because the lowest lying states on each parity sector are almost degenerate, one has to be particularly careful when working MPS simulations without conserving the single-chain parity as one can get easily stuck in a local minimum. To circumvent this situation it is necessary to apply strategies such as choosing different initial states or applying a strong noise term in the first few sweeps.

References

[1] A Yu Kitaev, Phys.-Usp. **44**, 131 (2001)
[2] C. V. Kraus, M. Dalmonte, M. A. Baranov, A. M. Läuchli and P. Zoller, Phys. Rev. Lett. **111**, 173004 (2013)

Polariton condensation in a synthetic Landau level

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One of the most interesting aspects of condensed matter is the interplay between interactions and the effect of an external magnetic field or rotation. In microcavity lattices, these effects can be engineered by using polaritons and a strained honeycomb geometry [1,2,3]. Here, we propose the use of this platform to create a non-equilibrium Bose-Einstein condensate of polaritons in a Landau level, without the actual need for external rotation nor reciprocity-breaking elements. We show that thanks to the competition between interactions, dissipation and a suitably designed incoherent drive, the condensate spontaneously becomes chiral by selecting a single Dirac valley of the honeycomb lattice, occupying the lowest Landau level, and forming a vortex array. Our results offer the perspective of using this platform to study the exciting physics of arrays of quantized vortices with light and, moreover, to explore the transition from a vortex-dominated phase to strongly correlated quantum phases as the interaction energy is increased.

References

[1] G. Salerno *et al*. 2D Mater. **2**(3), 034015 (2015);
[2] G. Salerno *et al*. PRB **95**, 245418 (2017).
[3] O. Jamadi *et al*. Light Sci. Appl. **9**, 194 (2020).

Exponential speedup of incoherent tunneling via dissipation

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We study the escape rate of a particle in a metastable potential at zero temperature in the presence of a dissipative bath coupled to the momentum of the particle and find that this rate is exponentially enhanced. In particular, the influence of momentum dissipation depends on the slope of the barrier that the particle is tunneling through. We investigate also the influence of dissipative baths coupled to the position, and to the momentum of the particle, respectively. In this case the rate exhibits a nonmonotonic behavior as a function of the dissipative coupling strengths [1].
The theoretical findings of [1] can be directly tested in superconducting quantum circuits in which dissipative position and momentum interactions translate to dissipative phase or charge couplings. In particular, momentum/charge dissipation can be readily implemented using capacitances and resistances [2]. We propose a circuit based on a current biased Josephson junction and two resistors coupled to the charge and phase, respectively. We insert realistic circuit parameters and find that the dissipative effects on the escape rate of the phase show qualitatively the same behavior as in [1].

References

1. D. Maile, S. Andergassen, W. Belzig, and G. Rastelli, Phys. Rev. Research **3**, 033019 (2021)
2. D. Maile, S. Andergassen, W. Belzig, and G. Rastelli Phys. Rev. B **97**, 155427 (2018)

Spin and density self-ordering in dynamic polarization gradients fields

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In our work [1] we study the zero-temperature quantum phase diagram for a two-component Bose-Einstein condensate in an optical cavity. The two atomic spin states are Raman coupled by two transverse orthogonally polarized, blue-detuned plane-wave lasers inducing a repulsive cavity potential. For a weak pump the lasers favor a state with homogeneous density and predefined uniform spin direction. When one pump laser is polarized parallel to the cavity mode polarization, the photons coherently scattered into the resonator induce a polarization gradient along the cavity axis, which mediates long-range density-density, spin-density, and spin-spin interactions. We show that the coupled atom-cavity system implements central aspects of the t-J-V-W model with a rich phase diagram. At the mean-field limit we identify at least four qualitatively distinct density- and spin-ordered phases including ferromagnetic and antiferromagnetic order along the cavity axis, which can be controlled via the pump strength and detuning. Real-time observation of amplitude and phase of the emitted fields bears strong signatures of the realized phase and allows for real-time determination of phase transition lines. Together with measurements of the population imbalance, most properties of the phase diagram can be reconstructed.

References

[1] N. Masalaeva, W. Niedenzu, F. Mivehvar and H. Ritsch, Phys. Rev. Research **3**, 013173 (2021)

An iPEPO algorithm for two-dimensional open quantum systems

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An algorithm for the efficient numerical simulation of many-body open quantum systems in two spatial dimensions based on an infinite Projected Entangled Pair Operator (iPEPO) tensor network ansatz [1] is presented. The central development is a technique for finding optimal truncations of enlarged network bonds by optimizing an objective function which is appropriate for mixed states and which accounts for the influence of spatial correlations on local dynamics. To demonstrate the accuracy of the method, comparisons are made with numerically exact calculations. Additionally, the newly developed method is used to calculate the steady state of a spin-1/2 anisotropic dissipative XY model on a square lattice in order to investigate the model's properties beyond the mean field approximation.

[1] Mc Keever, C. and Szymańska, M.H. *Stable ipepo tensor-network algorithm for dynamics of two-dimensional open quantum lattice models*. Phys. Rev. X, **11**, 021035 (2021). doi:10.1103/PhysRevX.11.021035.

Feed-forward exciton-polariton neural network.

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Technological solutions based on the CMOS technology reach the physical limits imposed by quantum effects. Progress in computing and communication enforces the necessity to process large data sets in an ever shorter time. Unfortunately, the performance of commonly used computers based on the von Neumann architecture reaches its limit. This limitation results in the von Neumann bottleneck. Physical limits of the miniaturisation of integrated circuits make it impossible to solve this problem traditionally. Arguably, the best solution to avoid the technological impasse is using an optoelectronic system with architecture inspired by the structure of a brain. The features which are crucial for a so-called neuromorphic computing system are: the nonlinearity of the active medium, the possibility of precise input state manipulation, scalability, energy efficiency and speed of operation. All of the above criteria are fulfilled by exciton-polariton quantum fluids of light [1,2,3]. This work demonstrates the first experimental realisation of a feed-forward exciton-polariton neural network optimised using a backpropagation algorithm, see Fig. 1 [4]. The backpropagation algorithm allows a significant improvement of the neural network performance. The presented method enables effective applications of polariton networks that contain only several neurons.

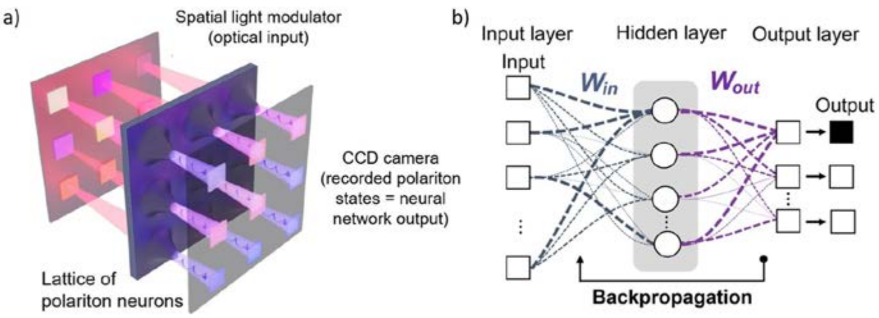

Fig.1 a) Scheme of the experimental configuration, b) schematic model of the considered exciton-polariton neural network.

References

[1] D. Ballarini, et all. **Nano Lett**, **20**, 5, 3506–3512 (2020)
[2] R. Mirek, et all. **Nano Lett.**, 21, 9, 3715–3720 (2021)
[3] A. Opala, et all, **Phys. Rev. Applied, 11**, 064029, (2019)
[4] A. Opala, R. Panico, et all, arXiv:2107.11156

Optimal quantum gates for Rydberg atoms quantum computer

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Arrays of identical neutral atoms trapped in optical tweezers are a promising candidate for use in quantum computing. These platforms are highly scalable to large numbers of qubits and neutral atoms boost several attractive features as long coherence times and the possibility to be entangled via strong dipole-dipole interactions by driving them to highly excited Rydberg states. This work is developed inside the framework of the QRydDemo project, whose aim in the next few years is to realize a neutral atom quantum processor with several hundred qubits. The smallest building blocks for the quantum computer are one and two-qubit gates: to entangle two atoms in the quantum register, a controlled-phase (CZ) gate will be implemented by shining fine-tuned laser pulses onto them. In this work, after giving a theoretical description of the Hamiltonian of two neutral atoms in the quantum register, a numerical simulation of this system is exploited to reproduce the behavior of the two-qubit CZ gate. Realistic effects are taken into account as finite temperature, imperfect Rydberg blockade, or decay out of the Rydberg state. A protocol with constant pulses is analyzed and its optimal parameters are found through classical optimizers. Then, time-dependent pulses are introduced and the optimal pulses are found through the optimal control algorithm dCRAB in an open-loop optimization. For the experimental realization of the gate, this analysis is of pivotal importance to know in which aspect more effort has to be put to maximize the experimental precision of the operation and thus improving the performance of the whole device.

Electronic localization in small-angle twisted bilayer graphene

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Twisted bilayer graphene (tBG) at and around specific magic angles exhibiting correlated insulating phases and superconductivity has boosted the new field of “twistronics” where strong electron-electron interactions play a dominant role in the electronic properties of the system. Below a threshold twist angle of around 1°, this superlattice undergoes self-organized lattice reconstruction, forming a periodic domain and thus strongly modifying its electronic structure compared to those observed above this threshold angle. Although low-angle tBG has been intensively investigated using effective electronic approaches, an in-depth investigation using more accurate calculations is still highly desirable. In this work, we developed and performed atomistic calculations using Green’s function techniques to solve tight-binding models, where the lattice reconstruction obtained by simulations is taken into account. Indeed, it was shown that the lattice reconstruction presents very significant effects on the electronic structure of low-angle (around and below 1°) tBG systems. Especially, the second magic angle around 0.5° predicted in other works is no longer observed, which is a direct consequence of the mentioned lattice reconstruction. In addition, the local electronic properties and the helical network in these tBG systems were systematically investigated. Our work thus presents valuable contributions that could be helpful for further development of the field of “twistronics”. For instance, it successfully helped to interpret experimental data.

References

[1] V. Hung Nguyen *et al*, *2D Mater.* **8**, 035046 (2021)
[2] A.C. Gadelha *et al*, *Nature* **590**, 405–409 (2021)

Electronic boundary states in dimerized quantum-dot chains engineered atom by atom

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A topological insulator has an insulating bulk but zero-energy gap states at its boundary – the latter corresponding to the surface in three dimensions, the surrounding edge in two dimensions, or the structural ends in a uniform one-dimensional (1D) system. The boundary states derive from the symmetry and the atomic structure of the bulk material and the Hamiltonian describing these states is invariant against perturbations that leave the bulk gapped. In this work, we create artificial dimerized chains assembled from quantum dots on a semiconductor surface using atom manipulation by low-temperature scanning tunneling microscopy (STM). Our scanning tunneling spectroscopy measurements reveal the emergence of molecule-like states due to the quantum coupling between the dots. In particular, we observe electronic states localized at the ends as well as at domain walls between the two dimerizations within the chain. The existence of these boundary states is consistent with the tight-binding description of the Su-Schrieffer-Heeger (SSH) model of 1D topological phases. However, we also find that our dimerized quantum-dot chains exhibit an asymmetry in the energy level spectrum, which is reflected in particular by an upward shift of the boundary states. This surprising observation arises because the constituent dots are charged and create a varying onsite potential along the chain, thus breaking the sublattice symmetry and thereby causing the observed deviation from the ideal SSH model. Our experimental results demonstrate a robust and versatile route towards constructing and exploring 1D topological systems using artificial lattices. This opens the perspective to construct more advanced topological lattices also in two dimensions. Our results reveal the crucial role of electrostatics in quantum structures built on semiconductor surfaces.

Chiral emission induced by optical Zeeman effect in polariton micropillars

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The low sensitivity of photons to external magnetic fields is one of the major challenges for the engineering of photonic lattices with broken time-reversal symmetry. We show experimentally that time-reversal symmetry can be broken for microcavity polaritons in the absence of any external magnetic field thanks to polarization dependent polariton interactions [1]. Circularly polarized excitation of carriers in a micropillar induces a Zeeman-like energy splitting between polaritons of opposite polarizations. In combination with optical spin-orbit coupling inherent to semiconductor microstructures [2], the interaction induced Zeeman splitting results in emission of vortical beams with a well-defined chirality. Our experimental findings can be extended to lattices of coupled micropillars opening the possibility of controlling by optical means the topological properties of polariton Chern insulators[3].

References

[1] M. Vladimirova *et al.*, Phys. Rev B **82**, 075311 (2010)
[2] N. Carlon Zambon, P. St-Jean *et al.*, Nat. Photonics **13**, 283-288 (2019)
[3] S. Klembt *et al.*, Nature **562**, 552-556 (2018).

A new apparatus for trapping single Strontium atoms in arrays of optical microtraps

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We present the design and implementation of the vacuum system featuring a custom designed Titanium vacuum chamber with optical access along six different axes.
The apparatus offers space to incorporate two high-NA objectives (NA > 0.65) to manipulate and read out atoms cooled to the motional ground state.
One of the two objectives is characterized and currently being installed. In addition we describe the sequence of cooling steps we implemented to rapidly cool thermal Strontium atoms to microkelvin temperatures.
To produce optical dipole traps we set up and characterized a liquid-crystal based spatial light modulator. We are able to produce highly uniform one-, two- and three-dimensional geometries of hundreds of optical foci. The system will be integrated into the main experiment in the upcoming months.
In the future the experiment will be used as a quantum simulator profiting from the powerful combination of high imaging efficiency and arbitrary arrangements of single atoms.

Epigenetic relevance of quantum phenomena in DNA

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The behaviour of excited particles along the DNA strand inside a cell has been a topic of foremost interest in the field of biophysics in the last 20 years. On one hand, understanding how the dynamics of such particles can affect the geometry and structural properties of the DNA, locally or globally, can lead to new insights in the field of epigenetics [1]. On the other hand, the DNA strand itself has been analysed to explore its potential as a molecular conducting nano-wire.

With this poster we provide a description of different tight-binding models with dissipative background, exploring their population dynamics and coherence properties. The choice of the parameters for the models is taken to mimic some specific DNA sequences which are relevant in the epigenetic field of research. We provide then some experimental results which justify our interest in this topic and in this methods. Apart from single charge dynamics, we also consider excitonic dynamics in various DNA sequences, in particular with respect to charge separation and localization.

References

[1] E. R. Bittner, J. Chem. Phys. **125**, 094909 (2006)

Magnetic Properties and Phase Diagrams of a Spin-3/2 Blume-Capel Multilayer System

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The magnetic properties, phase diagrams and hysteresis behavior of a spin-3/2 Blume-Capel multilayer system are studied using the Monte Carlo Simulation. First, we have established the ground-state phase diagrams for T=0. Then, we have plotted the thermal variations of the two sublattices and total magnetizations as well as the corresponding phase diagrams in order to investigate the effects of some Hamiltonian parameters, namely the exchange interactions, the crystal field and the number of layers. Finally, we have analyzed the hysteresis behavior where there is the formation of one or three loops. This study shows the appearance of certain numbers of characters, especially the existence of second- and first-order phase transition lines and critical isolated end-points **[1, 2].**

References

[1] N. Tahiri, H. Ez-Zahraouy, and A. Benyoussef, Physica A 388, 3426 (2009).
[2] W. Wang, F. Xue, and M. Wang, Physica B 515, 104 (2017).

Integrated nanophotonic waveguide lattices as photonic quantum simulators

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Today, many quantum mechanics phenomena could lead to revolutionary applications in quantum technologies such as in quantum computation, information, communication, metrology, and simulation. However, the implementation and control of such phenomena are still difficult to achieve and problematic to implement in a large scale. Integrated nanophotonics is a key enabling technology for the implementation of quantum simulators. Indeed, integrated quantum nanophotonics, implemented via coupled waveguides, can mimic different physical quantum mechanics systems due to their mutual equivalence [1,2].
In this work, we aim at developing scalable programable quantum simulators with the use of optical coupled waveguide lattices. The dynamics of quantum system can be mapped into space domain and thus, implemented with the help of coupled waveguide lattices [3-5]. Here, we present the numerical simulations that mimic the dynamics of a quantum system, namely the Heisenberg spin chain, where coherent transport of quantum states is observed for different input ports. A coherent transport was achieved with a fidelity higher than 99%. The fabrication of the quantum simulator in a silicon nitride platform is presented as well as preliminary characterization of the device.

References

[1] Aspuru-Guzik *et al.*, Nature physics **8**, 285–291 (2012).
[2] Boggio et al., JOSA B **31**(11), 2846-2857 (2014).
[3] Joglekar *et al.*, Eur. Phys. J. Appl. Phys **63**(3), 30001 (2013).
[4] Perez-Lejia *et al.*, Physical Review A **87**(1), 012309 (2013).
[5] S. Duran Gomez. Centro de Investigaciones en Óptica, A.C., México and Université de Technologie de Troyes, France. Master thesis, (2019).

Simulating correlated matter far from equilibrium with neural quantum states

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The efficient numerical simulation of non-equilibrium real-time evolution in quantum matter constitutes a key challenge for today's computational methods. However, the idea of utilizing deep learning models as ansatz for the wave function has recently given a new twist to established variational methods — holding potential to overcome current limitations. On this poster I outline the time-dependent variational principle for neural quantum states to simulate isolated and open quantum many-body systems. In settings of immediate relevance for quantum simulation with Rydberg atom arrays I present results showing that this approach can exceed or complement the capabilities of state-of-the-art tensor network methods.

References

1. M. Schmitt and M. Heyl, Phys. Rev. Lett. **125**, 100503 (2020)
2. M. Reh, M. Schmitt, and M. Gärttner, arXiv:2104.00013
3. M. Schmitt, M. M. Rams, J. Dziarmaga, M. Heyl, and W. H. Zurek, arXiv:2106.09046

Electron-Spin-Resonance in a proximity-coupled MoS_2/Graphene van-der-Waals heterostructure

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The extended family of van der Waals (vdW) materials offers a comprehensive resource to tailor hybrid systems of semiconducting, metallic, superconducting, and insulating layers that exhibit novel properties. [1,2] MoS_2 and Graphene are two among the most widely studied vdW-systems. MoS_2 is a semiconductor transition metal dichalcogenide (TMDC) with high spin-orbit coupling (SOC) where carrier density and thus conductivity can be tuned easily by application of gate voltages. The mobility and conductivity of MoS_2 is limited predominantly due to the Schottky contact that it forms with most metals. On the other hand, graphene is a semimetal with Dirac electrons (holes) and high conductivity and carrier mobilities. The lack of a sufficiently large band gap and the relatively small intrinsic SOC of the order of 20-40 μeV [3], however, prohibits certain device applications. Proximity induced SOC is predicted in graphene on MoS_2 and has been signaled in the observation of weak-anti-localization [4] and spin Hall effects [5]. Modification in SOC will also be reflected in the deviation of *g*-factor from the free electron value of 2.0023.

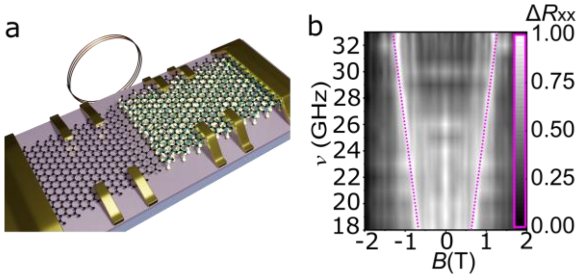

Fig.1 Schematic of the device (left). ESR measurement showing the resonance at different frequencies shown with red line as a guide to the eye (right). Measurements done at 1.5 K

Here, we report low-temperature measurements on a MoS_2/Graphene heterostructure shown in Fig. 1 (a). The device is laterally separated into a pure layer of graphene (left) and an MoS_2/Graphene stack (right) that allows us to study and compare the interaction-induced changes in the graphene layer using magneto-transport. Resistively-detected electron-spin-resonance measurements (Fig. 1 (b)) reveal that the *g*-factor in the hybrid system is ~1.91 further deviating from the previously measured *g*-factor of 1.952 ±0.002 for pure graphene. [3,6] Understanding the nature of the interlayer coupling will facilitate observation of topological phases and designing spin-transfer devices.

References

[1] K. S. Novoselov *et al.* , Science **353**, aac9439 (2016).
[2] C. H. Sharma *et al.* , Commun. Phys. **1**, 90 (2018).
[3] J. Sichau *et al.* and R. H. Blick, Phys. Rev. Lett. **112**, 046403 (2019).
[4] J. I. J. Wang *et al.* , Nano Lett. **15**, 1898 (2015).
[5] A. Avsar *et al.* , Nat. Commun. **5**, 4875 (2014).
[6] R. G. Mani *et al.* , Nat. Commun. **3**, 996 (2012).

Spectral imaging of the anomalous π mode in periodically driven plasmonic waveguide arrays

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Evanescently coupled waveguides provide a convenient platform for simulation of various quantum phenomena that experimental realization in analogous condensed matter systems is otherwise difficult. The basis for this is the mathematical identity between the coupled mode theory equations and the discrete Schrödinger equation in the tight-binding approximation. Here, we implement the periodically driven Su-Schrieffer-Heeger model (1D topological insulator) using dielectric loaded surface plasmon polariton waveguides. By precisely tailoring parameters of driving, we investigate its effect on the transport of surface plasmon polaritons and the resulting band structure. We present real and Fourier space observation of the anomalous π mode appearing in the periodically driven system.

References

[1] K. Okamoto, „Fundamentals of optical waveguides“, Academic press, (2006)
[2] A. Sidorenko, Z. Fedorova, J. Kroha, S. Linden, in preparation

High photon number entangled states and coherent state superposition from extreme-UV to far-IR

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We present a theoretical study on the generation of entangled coherent states and of coherent state superpositions, with photon numbers and energies, orders of magnitude higher than those provided by the current technology [1]. This is achieved by utilizing a quantum mechanical multimode description of the single- and two-color intense laser field driven process of high harmonic generation in atoms. It is found that all field modes involved in the high harmonic generation process are entangled, and upon performing a quantum operation, leads to the generation of high photon number non-classical coherent state superpositions spanning from the extreme-ultraviolet to the far infrared spectral region. These states can be considered as a new resource for fundamental tests of quantum theory and quantum information processing.

References

[1] P. Stammer *et. al,* arXiv:2107.12887

Majorana Edge Modes:
A Road to an U(1) Symmetric Realization in Coupled Wires

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In this work, we examine a model with global number conservation showing strong evidence of hosting Majorana Edge Modes. This phase was originally described by A. Kitaev introducing a p-wave superconducting potential into a one dimensional nanowire. However, due to environmental effects it was not possible up to now to observe these Majorana Edge Modes. With our approach we give an example which is experimentally realizable and has in the low energy regime an effective Hamiltonian supporting Majorana Edge Modes.

References

[1] C. Kraus et al., Phys. Rev. Lett. 111, 173004 (2013)
[2] M. Cheng et al., Phys Rev. B 84, 094503 (2011)
[3] F. Iemini et al., Phys Rev. Lett. 115 156402 (2015)

Tunable quantum confinement of neutral excitons using electric fields and exciton-charge interactions

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Achieving fully tunable quantum confinement of excitons has been a long-standing goal in optoelectronics and quantum photonics. We have recently demonstrated electrically controlled 1D quantum confinement of neutral excitons in a monolayer transition metal dichalcogenide semiconductor [1]. This confinement relies on a combination of dc Stark effect induced by inhomogeneous in-plane electric fields and a novel polaronic confinement mechanism arising from interactions between excitons and itinerant charge carriers.

Furthermore, we find that the combined application of out-of-plane magnetic fields in such settings leads to unexpected consequences for excitons confined in these unique potentials. Specifically, we observe that the quantum confined excitons exhibit unusually large diamagnetic coefficients, which can be electrically tuned and reach values up to 2.5 $\mu eV/T^2$. These values imply an exciton size ~6 nm, which is strikingly enhanced compared to the 1s exciton Bohr radius ~1 nm.

Here, we will outline future prospects of such electrically confined 1D excitons. First and foremost, electrical confinement of excitons with an enhanced in-plane dipole moment is expected to boost exciton-exciton interactions while allowing for hybridization with a microcavity mode. Strong interactions in a 1D wire could enable the realization of a Tonks-Girardeau gas with photon correlations providing signatures of fermionization [2]. Therefore, electrically quantum confined excitons could become building blocks for scalable arrays of identical, independently tuned quantum emitters and have implications for ongoing efforts towards realizing strongly correlated photonic systems.

References

[1] D. Thureja et. al, arXiv:2102.08989
[2] Carusotto, Iacopo, et al. Physical review letters 103.3, 033601 (2009)

Tunable exciton-polariton condensation in a two-dimensional Lieb lattice at room temperature

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Microcavities with embedded optically active materials allow to create exciton-polariton condensates [1] in the strong light–matter interaction regime. These condensates exhibit quantum fluid properties up to room temperature, and, when crystal-like lattices are imprinted in the cavity [2, 3], they can be used to emulate and study solid-state physics toy models.
Here, we use tunable nanoscale defect cavities supporting room–temperature zero-dimensional exciton-polariton condensation to form a nano-fabricated two-dimensional Lieb lattice with an organic polymer [4]. We exploit the tunability of our open cavity to selectively condense into the s-, p- and d-lattice bands. Furthermore, we interferometrically measure long-range first-order coherence across the lattice and assess the influence of the disorder in the system.
These are key first steps to investigate extended topological polariton systems at ambient conditions.

References

[1] J. Plumhof, Nature Materials **13**, 247 (2014)
[2] D. Urbonas, ACS Photonics **3**, 1542 (2016)
[3] F. Scafirimuto, ACS Photonics **5**, 85 (2018)
[4] F. Scafirimuto, Communications Physics **4**, 39 (2021)

Topological pumping via two-frequency driving

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Thouless pumps allow robust quantised transport of particles in one-dimensional periodic potentials, in which the Hamiltonian is varied in a slow, cyclic manner. The time-trace of the adiabatic change plays the role of a second dimension, in which the topological pump can be understood as a quantum Hall effect. Previously, Thouless pumps in atomic and optical systems have relied on 'sliding' the underlying potential landscape in order to induce transport. However, such strong deformations of the lattice potential are not feasible in solid crystals, preventing the implementation of Thouless pumps in real materials. Here, we employ a Floquet drive to experimentally realise a topological pump in a generic sinusoidal lattice without a sliding potential. Two-frequency lattice shaking [1] is used to adiabatically prepare a topological Floquet-Bloch band, starting from a trivial insulating state of ultracold fermions. Near-quantized charge transport is achieved by modulating the drive waveform slow enough to ensure adiabaticity. Our results pave the way for studying topological pumping in Floquet-driven real materials.

References

[1] Sandholzer et al., arXiv:2110.08251

Transport through a dissipative superconducting contact

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In superconducting contacts, the coherent tunneling of a single quasiparticle together with Cooper pairs leads to a sub-gap current structure [1]. This phenomenon, also called multiple Andreev reflections, is well known in condensed-matter superconducting junctions. Current-voltage characteristics consistent with multiple Andreev reflections have also been measured in a cold-atom setup where two superfluids are coupled by a quantum point contact [2]. Further cold-atom experiments have probed transport in the presence of local particle losses [3]. Motivated by these experiments, we investigate theoretically the effect of a local particle loss on the multiple Andreev reflection process. To quantify this effect, we use the Keldysh formalism [4] to calculate current-voltage characteristics of a superconducting contact. We compare the effect of dissipation by particle loss to that of a finite temperature, and find that they are qualitatively different.

References

[1] G. E. Blonder et al., Phys. Rev. B **25**, 4515 (1982); D. Averin, A. Bardas, Phys. Rev. Lett. **75**, 1831 (1995); J. C. Cuevas et al., Phys. Rev. B **54**, 7366 (1996)
[2] D. Husmann et al., Science **18**, 1498 (2015)
[3] L. Corman et al., Phys. Rev. A **100**, 053605 (2019)
[4] A. Kamenev, Cambridge University Press (2011); L. M. Sieberer et al., Rep. Prog. Phys. **89**, 096001 (2016)

Sequential generation of tensor network states

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The sequential generation of tensor network states provides a way to deterministically prepare entangled states on both matter-based and photon-based quantum devices. In this work, first, we discuss two implementations to sequentially generate photonic matrix product states, one based on a Rydberg atomic array [1], and another based on a microwave cavity dispersively coupled to a transmon [2]. We show both implementations can generate a large number of entangled photons. Then, we introduce plaquette projected entangled-pair states (p-PEPS)[3], a class of states in a lattice that can be generated by applying sequential unitaries acting on plaquettes of overlapping regions. They satisfy area-law entanglement, possess long-range correlations, and naturally generalize other relevant classes of tensor network states. We identify a subclass that can be more efficiently prepared in a radial fashion and that contains the family of isometric tensor network states. We also show how such subclass can be efficiently prepared using an array of photon sources, and devise a physical realization by extending the above cavity-transmon setup [2].

References:

[1] Zhi-Yuan Wei et al., Physical Review Research, 3(2), 023021.
[2] Zhi-Yuan Wei et al., arXiv:2109.06781
[3] Zhi-Yuan Wei et al., arXiv:2107.05873

Measuring the Wigner function of atoms in optical lattices

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We propose a direct method to reconstruct the Wigner function of neutral atoms trapped in optical potentials. The Wigner function W(x,p) can be obtained measuring the expectation value of the parity operator, which transforms x → -x and p → -p. We show how spin-dependent optical potentials can be used to physically implement the parity operator. We employ a Ramsey interrogation scheme to directly obtain the average value of the parity operator, and thus of the Wigner function. State-dependent transport of the lattice potential is used to probe different positions in phase space. The proposed method is compared to that proposed by Davidovich and Lutterbach [1], and then realized in cavity QED [2].

References

[1] Lutterbach, L. G., & Davidovich, L. (1997). Scheme for Direct Measurement of the Two-mode Wigner Function in Cavity QED and Ion Traps. PRL, 78(13), 2547 2550. https://doi.org/10.1071/ph00004

[2] Nogues, G. et al. (2000). Measurement of a negative value for the Wigner function of radiation. PRA, 62(5), 054101 --054101. https://doi.org/10.1103/PhysRevA.62.054101

Remote GHz acoustic control of exciton qubits

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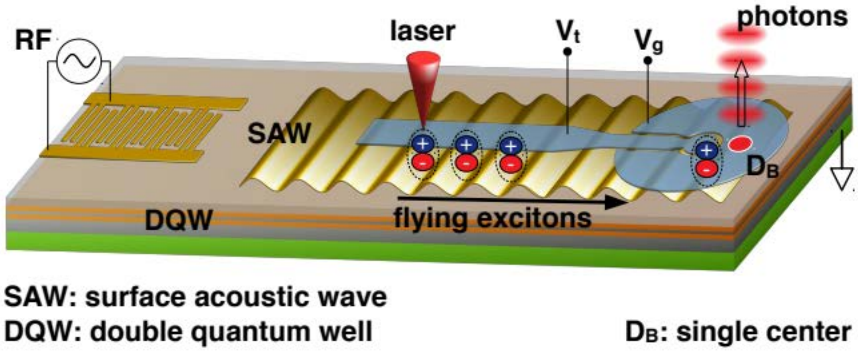

Quantum communication networks require on-chip transfer and manipulation of single qubits as well as their interconversion to single photons for long-range information exchange. Flying exciton qubits propelled by GHz surface acoustic waves are outstanding messengers to fulfill these requirements.

Here, we demonstrate the acoustic manipuation of single exciton qubits, consisting of individual excitons bound to impurity centers, as well as flying exciton qubits in a semiconductor quantum well. The single excitons emit at a rate as high as 3.5 GHz, determined by the acoustic frequency. Furthermore, the surface acoustic wave can transfer long-lived excitons over several microns along a quantum channel, a realization of flying exciton qubits, which can remotely pump a single exciton qubit. Our results pave the way for the hybrid acousto-optical platform of exciton-based, on-demand qubit control.

References

[1] M. Yuan, K. Biermann, S. Takada, C. Bäuerle and P. Santos, *ACS Photonics,* **8**, 758-764 (2021)