ICFO - IMPRS joint workshop 2023

19 - 21 April 2023

ICFO

IMPRS for Quantum Science and Technology
INTERNATIONAL MAX PLANCK RESEARCH SCHOOL

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QUSIDE

ICFO-IMPRS Joint Workshop
19-21 April 2023

We are very happy to present you the final program of the **ICFO-IMPRS Joint Workshop 2023.**

This workshop aims to bring together talented and motivated PhD students in the field of quantum science and technology and creating networking among the two institutions.

In this booklet you can find the description of the activities, which will be held during the workshop. There will be a total of **9 talks from international experts** to update the participants on the new possibilities, recent discoveries, and groundbreaking advancements in the field of quantum technologies. Each talk will be around 50 min long, followed by a 10 min Q&A session. In addition, there will be a space during the **coffee break** for the Ph.D. candidates to interact more directly with the invited speakers.

Moreover, Ph.D. candidates will share their most recent contributions in a **poster session** and three sessions of Ph.D. talks. In the poster session, the submitted works will be shortly introduced by their authors in an elevator-pitch-style presentation (~1 min per poster). After that, the attendants will be able to interact with the posters and their authors within a virtual environment. For the Ph.D. talks, there will be two separate rooms with simultaneous presentations. The talks have been grouped by topic. Each talk will be around 12 minutes long and followed by a short 3 minutes Q&A session.

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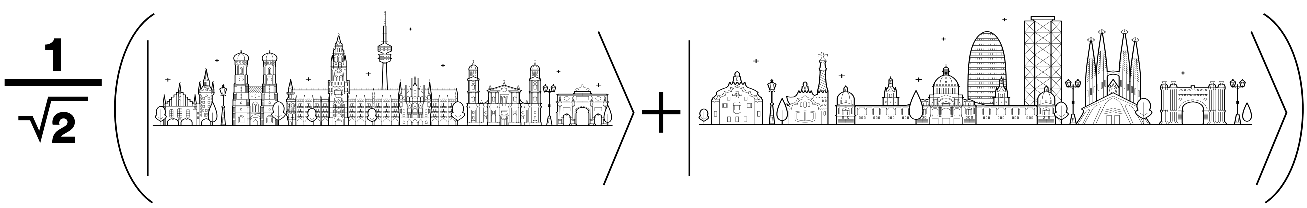
On the second day of the workshop, there will also be an **Industry session** in which we will give you the chance to interact with experts from two selected companies.

Alongside the scientific activities, there will also be several **social activities** that will give opportunities to meet your fellow students in a more relaxed environment.

We hope you enjoy it! Looking forward to seeing each other in person very soon!

Organising committee:
Benjamin Schiffer (IMPRS), Bennet Windt (IMPRS), Daniel Gonçalves-Romeu (ICFO), Fionnula Curran (ICFO), Johannes Josef Halbinger (IMPRS), Maria Balanzó-Juandó (ICFO), Teresa Karanikolaou (ICFO).



Program

Wednesday 19th

9:00 - 9:30	**Opening speech**
9:30 - 10:30	**Prof. Acín** - Certifying ground-state properties of many-body systems
10:30 - 11:30	**Prof. Sainz** - Quantum resources from non-classical phenomena
11:30 - 12:00	**Coffee break**
12:00 - 13:00	**Student talks**
13:00 - 15:00	**Group photo + Lunch**
15:00 - 16:00	**Prof. Tura -** Preparation and verification of tensor network states
16:00 - 18:00	**Poster Session**

Thursday 20th

09:30 - 10:30	**Prof. Zeiher** - Quantum simulation and computation with arrays of neutral atoms
10:30 - 11:30	**Prof. Tarruell -** TBC
11:30 - 12:00	**Coffee break**
12:00 - 13:15	**Student talks**
13:15 - 15:00	**Lunch**
15:00 - 16:00	**Prof. von Delft** - Tensor Networks for Quantum Physics and Beyond: an Overview
16:00 - 17:00	**Industry session**
17:00 - 20:00	**Free time / Discussions**
20:00	**Conference dinner**

Program

Friday 21st

09:30 - 10:30	**Prof. Weitz** - Complex quantum phases in flat-band van-der-Waals systems: making, controlling and measuring by quantum transport
10:30 - 11:30	**Prof. Koppens** - Nanocavities, nano-imaging, and quantum technologies with twisted and stacked 2D materials
11:30 - 12:00	**Coffee break**
12:00 - 13:15	**Student talks**
13:15 - 15:00	**Lunch**
15:00 - 16:00	**Prof. Mitchell** - Quantum sensing with atoms and light
16:00 - 16:30	**Closing Ceremony**

Student talks

Wed 19th April

Auditorium

12:00 - 12:15	**Alex Hesse (IMPRS)** - Observation of edge states in topological Floquet systems
12:15 - 12:30	**Guillem Müller-Rigat (ICFO)** - TBC
12:30 - 12:45	**Lukas Homeier (IMPRS)** - Realizing lattice gauge theories in tweezer arrays
12:45 - 13:00	**Sirui Lu (IMPRS)**- Algorithms for simulating thermal quantum many-body systems: quantum computation, tensor networks and neural networks

BLR

12:00 - 12:15	**Javier Rivera-Deán (ICFO)** - Device Independent Quantum Key Distribution with realistic single-photon source implementations
12:15 - 12:30	**Cristian Boghiu (ICFO)** - A Python library for classical and quantum causal compatibility
12:30 - 12:45	**Benjamin Schiffer (IMPRS)** - Quantum eigenstate broadcasting assisted by a coherent link
12:45 - 13:00	**Maria Balanzó-Juandó (ICFO)**- Device-independent self-testing of any pure entangled state with Extended Bell scenario and Mutually Unbiased Measurements

Student talk

Thu 20th April

Auditorium

12:00 - 12:15	**Mohit Lal Bera (ICFO)** - Characterisation of topological features in generalised Su-Schrieffer-Heeger chains using light-matter interaction
12:15 - 12:30	**Leo Feldmann (ICFO)** - Highly efficient cavity-enhanced solid-state quantum memory based on atomic frequency comb
12:30 - 12:45	**Tim Hoehn (IMPRS)** - State-dependent potentials for the ground and clock state in ultracold ytterbium
12:45 - 13:00	**Eduardo Beattie (ICFO)**- Detection of single ions in a nanoparticle coupled to a fiber cavity
13:00 - 13:15	**Jonatan Höschele (ICFO)**- Towards a strontium quantum-gas microscope

BLR

12:00 - 12:15	**Carlos Pascual García (ICFO)** - Security of Discrete Modulated Continuous Variable Quantum Key Distribution
12:15 - 12:30	**Arthur Christianen (IMPRS)** - The strong-coupling Bose polaron
12:30 - 12:45	**Melissa Will (IMPRS)** - Hilbert space fragmentation in a tilted, 2D Bose Hubbard model
12:45 - 13:00	**Josef Willsher (IMPRS)** - Spin-Peierls instability of the U(1) Dirac spin liquid
13:00 - 13:15	**Anubhav Kumar Srivastava (ICFO)** - Optimal quantum thermometry using Rice-Mele model

Student talks

Fri 21st April

Auditorium

12:00 - 12:15	**Clemens Kuhlenkamp (IMPRS)** - Robust spin liquids in 2D materials
12:15 - 12:30	**Rafael Luque Merino (ICFO)** - Ultrafast electronic cooling in MATBG
12:30 - 12:45	**Oriana Diessel (IMPRS)** - Bose polaron interactions in a cavity-coupled monolayer semiconductor
12:45 - 13:00	**Niccolò Baldelli (ICFO)** - Superconductivity and stripes of strongly-correlated electrons in a magnetic field
13:00 - 13:15	**Wilhelm Kadow (IMPRS)** - Hole doped quantum spin liquids

BLR

12:00 - 12:15	**Bennet Windt (IMPRS)** - Fermionic matter-wave quantum optics with cold-atom impurity models
12:15 - 12:30	**Teresa Karanikolaou (ICFO)** - Effect of an optical dipole trap on resonant atom-light interactions
12:30 - 12:45	**Florian Fertig (IMPRS)** - Tomography of distant single Atoms
12:45 - 13:00	**Daniel Goncalves Romeu (ICFO)** - Local dissipation effects in the driven-dissipative Dicke phase transition
13:00 - 13:15	**David Castells (IMPRS)** - Controlling light-matter interaction using collective effects of subwavelength atom arrays

Abstracts

Wednesday 19th

Prof. Antonio Acín (ICFO) - Certifying ground-state properties of many-body systems

A ubiquitous problem in physics is to understand the ground-state properties of classical and quantum many-body systems. It is also one of the main applications of first-generation of quantum computing devices, such as quantum optimisers or simulators. Classically, since an exact solution soon becomes too costly when increasing the system size, variational approaches are often employed as a scalable alternative: energy is minimised over a subset of all possible states and then different physical quantities are computed over the solution state. However, strictly speaking, all what these methods provide are provable upper bounds on ground-state energy. Relaxations to the ground-state problem based on semi-definite programming represent a complementary approach, providing lower bounds to the ground-state energy but, again, no provable bound on any other relevant quantity. We first discuss how these relaxations can be useful to benchmark the performance of quantum optimisers. After that, we show how relaxations, when assisted with an energy upper bound, can be used to derive certifiable bounds on the value of any physical parameter, such as correlation functions of arbitrary degree or structure factors, at the ground state. We illustrate the approach in paradigmatic examples of 1D and 2D spin-one-half systems.

Prof. Ana Belén Sainz (Gdansk) - Quantum resources from non-classical phenomena

In this talk we will discuss what it means for something to be a resource. We will focus on the case of non-classical phenomena serving as resources, and pay special attention to those aspects that may be relevant for boosting our performance at communication and information-processing tasks. We will also identify important details that are relevant for studying conversions of resources and the quantification of their resourcefulness. This presentation is meant to provide a broad picture on the type of foundational research connected to quantum resources, and give you a platform from which to further pursue your own interests.

Dr. Jordi Tura (ICFO) - Preparation and verification of tensor network states

We consider a family of tensor network states defined on regular lattices that come with a natural definition of an adiabatic path to prepare them. This family comprises relevant classes of states, such as injective Matrix Product and Projected Entangled-Pair States, and some corresponding to classical spin models. We show how uniform lower bounds to the gap of the parent Hamiltonian along the adiabatic trajectory can be efficiently computed using semi-definite programming. This allows one to check whether the adiabatic preparation can be performed efficiently with a scalable effort. We also derive a set of observables whose expectation values can be easily determined and that form a complete set, in the sense that they uniquely characterize the state. We identify a subset of those observables which can be efficiently computed if one has access to the quantum state and local measurements, and analyze how they can be used in verification procedures.

Abstracts

Thursday 20th

Prof. Johannes Zeiher (IMPRS) - Quantum simulation and computation with arrays of neutral atoms

Arrays of neutral atoms offer a rich toolbox for quantum simulation and quantum computation. In this lecture, I will give an overview over the recent developments in experimental quantum simulations with cold atoms, focusing in particular on optical lattices and tweezer arrays. I will introduce the basic features of both platforms, compare their properties and showcase exemplary quantum simulation experiments that have been performed recently. Furthermore, I will briefly explain how atom arrays can be used as a platform for quantum computation and quantum information applications, and report on the current state-of-the-art in the field.

Prof. Jan von Delft (IMPRS) - Tensor Networks for Quantum Physics and Beyond: an Overview

During the last two decades, tensor networks have emerged as a powerful new language for encoding the wave functions of quantum many-body states, and the operators acting on them, in terms of contractions of tensors. Insights from quantum information theory have led to highly efficient and accurate tensor network representations for a variety of situations, particularly for one- and two-dimensional (1d, 2d) lattice models. For these, tensor network-based approaches, such as the numerical renormalization group (NRG), the density matrix renormalization group (DMRG), and projected entangled pair stated (PEPS), rank among the most accurate and reliable numerical methods currently available.

In parallel, ideas from quantum information theory have also inspired mathematical progress on parsimonious representations of functions of several continuous variables. Numerical computations with such functions typically involve a compromise between two contrary desiderata:
accurate resolution of the functional dependence, versus parsimonious memory usage. Recently, two promising strategies have emerged for satisfying both requirements: the so-called quantics representation, which expresses functions as multi-index tensors, with each index representing one bit of a binary encoding of one of the variables; and tensor cross interpolation, which, if applicable, yields parsimonious interpolations for multi-index tensors. These strategies can be combined to benefit from the advantages of both schemes. This yields very efficient representations of seemingly complicated functions, and opens up new, "quantum-inspired" perspectives for manipulating (integrating, multiplying, convolving) them using tensor network tools.

My talk will offer a broad overview of current applications of tensor network methods to quantum many-body problems and beyond.

Abstracts

Friday 21st

Prof. Thomas Weitz (IMPRS) - Complex quantum phases in flat-band van-der-Waals systems: making, controlling and measuring by quantum transport

“The exchange interaction can lead to correlated states in low dimensional systems such as the graphene family. Regions of large density of states are especially prone to correlation effects. In this talk I will give an introduction into the making of flat-band-systems by Morié or electrostatic engineering. I will also discuss how to probe such states by low temperature charge transport. Finally I will discuss two of our recent experiments. First, the recently identified exchange driven quantum anomalous Hall (QAH) nu=2 state that exhibits quantized charge Hall conductance close to zero magnetic field as well as spin, valley and spin-valley anomalous quantum Hall effects and out-of-plane ferroelectricity in suspended bilayer graphene [1]. And second our recent measurements [2] in h-BN encapsulated Bernal bilayer graphene where we realized flat electronic bands at an electric-field tunable van-Hove-singularity and placed the Fermi level in them via electrostatic gating. In such device structures we have found indications of exotic states consistent with for example a Chern insulator finite density in the valence band.

[1] F. R. Geisenhof, F. Winterer, A. M. Seiler, J. Lenz, T. Xu, F. Zhang and R. T. Weitz, “”Quantum anomalous Hall octet driven by orbital magnetism in bilayer graphene””, Nature 598, 53 (2021)
[2] A. M. Seiler, F. R. Geisenhof, F. Winterer, K. Watanabe, T. Taniguchi, T. Xu, F. Zhang and R. T. Weitz, “”Quantum cascade of new correlated phases in trigonally warped bilayer graphene””, Nature 608, (2022) 298

Prof. Frank Koppens (ICFO) - Nanocavities, nano-imaging, and quantum technologies with twisted and stacked 2D materials

In this talk we will discuss what it means for something to be a resource. We will focus on the case of non-classical phenomena serving as resources, and pay special attention to those aspects that may be relevant for boosting our performance at communication and information-processing tasks. We will also identify important details that are relevant for studying conversions of resources and the quantification of their resourcefulness. This presentation is meant to provide a broad picture on the type of foundational research connected to quantum resources, and give you a platform from which to further pursue your own interests.

Abstracts

Friday 21st

Prof. Morgan Mitchell (ICFO) - Quantum sensing with atoms and light

Atomic sensors can have both extreme sensitivity - to electric and magnetic fields, rotation, gravity, light, candidate dark matter particles... - and also metrological accuracy, because atoms are the same everywhere on earth and elsewhere. Progress in the miniaturization of atomic sensors makes them appealing for applications that previously were only accessible to solid state sensors, such as brain imaging, aerial surveys of archaeological sites, and satellite orientation. With miniaturization comes an increasing role of quantum statistical effects that can be managed by the tools of quantum metrology. I will discuss the use of quantum techniques like squeezing, quantum non-demolition measurement, back-action evasion in the context of atomic sensors, illustrated with experimental demonstrations. Some of the results are perhaps surprising, such as the nearly complete elimination of quantum measurement back-action in a high-performance atomic magnetometer.

Abstracts student talks

Alex Hesse (IMPRS) - Observation of edge states in topological Floquet systems

Floquet engineering, i.e., periodic modulation of a system's parameters, has proven as a powerful tool for the realization of quantum systems with exotic properties that have no static analog. In particular, the so-called anomalous Floquet phase displays topological properties even if the Chern number of the bulk band vanishes. [1]

Our experimental system consists of bosonic atoms in a periodically driven honeycomb lattice. Depending on the driving parameters, several out-of-equilibrium topological phases can be realized, including an anomalous phase. [2]

As the bulk-boundary correspondence relates the properties of the bulk bands to the number of topologically protected edge modes, special interest lies in studying the behavior of them. We are investigating the real-space evolution of a wavepacket close to the edge after the release from a tightly-focused optical tweezer. This way, we observe the chiral nature of the edge state, even in the anomalous Floquet phase, thereby directly revealing the topological nature of this phase.

[1] Rudner et al., Phys. Rev. X 3, 031005 (2013)
[2] Wintersperger et al., Nat. Phys. 16, 1058-1063 (2020)

Lukas Homeier (IMPRS) - Realizing lattice gauge theories in tweezer arrays

Quantum simulation platforms have demonstrated their power to realize quantum matter and to measure novel probes ranging from snapshots to time dynamics. With the growing toolbox of experimental capabilities, new types of models become achievable; in particular models with local symmetry constraints such as lattice gauge theories, which are a central framework in almost all disciplines of physics from condensed matter to quantum information, to name a few. Despite its relevance, they remain elusive in the strong coupling regime or at finite matter density. While quantum simulators are a promising route to explore gauge theories, they are vulnerable to gauge-breaking errors. Hence, efficient and realistic gauge protection is essential to enable large-scale experimental implementations.

First, I introduce a protection scheme for Z2 lattice gauge theories with dynamical matter in (2+1) D that is based on only two-body interactions; thus we simplify previous protection schemes from four- to two-body interactions allowing a realistic and robust implementation in Rydberg tweezer arrays. Second, I propose a scheme in which spin-exchange interactions energetically enforce a local SU(2) gauge constraint, which is suitable to implement in ultracold molecules. Combined with tunneling along a synthetic dimension, the scheme enables the large-scale realization of non-Abelian quantum link models with dynamical matter on the honeycomb lattice. The effective models that can be implemented with our methods feature many exotic signatures ubiquitous to gauge theories from quantum spin liquids to charge confinement.

Abstracts student talks

Sirui Lu (IMPRS) - Algorithms for simulating thermal quantum many-body systems: quantum computation, tensor networks and neural networks

Tackling the quantum many-body problem at finite temperatures poses considerable challenges due to the exponential growth of computational resources required with system size. In this talk, we explore a set of interconnected algorithms designed for simulating thermal quantum many-body systems efficiently. Our first algorithm aims to minimize the free energy of a variational state using a neural network-inspired ansatz, leveraging the Markov chain Monte Carlo technique in a classical setting, while avoiding error accumulation inherent to imaginary time evolution methods. Complementing this, our second algorithm focuses on the microcanonical ensemble, employing quantum computation combined with Monte Carlo sampling to effectively mitigate the notorious sign problem in quantum Monte Carlo methods. As we examine the effectiveness of these algorithms, we connect them to advanced tensor network methodologies, showcasing the versatile computational landscape and synergy in techniques for simulating thermal quantum many-body systems.

Javier Rivera-Deán (ICFO) - Device Independent Quantum Key Distribution with realistic single-photon source implementations

Device Independent Quantum Key Distribution (DIKQD) aims at generating secret keys between distant parties without the parties trusting their devices. We investigate a proposal for performing fully photonic DIQKD, based on single-photon sources and heralding measurements at a central station placed between the two parties. We derive conditions to attain non-zero secret-key rates in terms of the the photon efficiency, indistinguishability and the second order autocorrelation function of the single-photon sources. Exploiting new results on the security bound of such protocols allows us to reduce the requirements on the physical parameters of the setup. Our analysis shows that in the considered schemes, key rates of several hundreds of secret bits per second are within reach at distances of several tens of kilometers.

Cristian Boghiu (ICFO) - A Python library for classical and quantum causal compatibility

We introduce Inflation, a Python library for assessing whether an observed probability distribution is compatible with a causal explanation. This is a central problem in both theoretical and applied sciences, which has recently witnessed important advances from the area of quantum nonlocality, namely, in the development of inflation techniques. Inflation is an extensible toolkit that is capable of solving pure causal compatibility problems and optimization over (relaxations of) sets of compatible correlations in both the classical and quantum paradigms. The library is designed to be modular and with the ability of being ready-to-use, while keeping an easy access to low-level objects for custom modifications.

Abstracts student talks

Benjamin Schiffer (IMPRS) - Quantum eigenstate broadcasting assisted by a coherent link

Preparing the ground state of a local Hamiltonian is a crucial problem in understanding quantum many-body systems, with applications in a variety of physics fields and connections to combinatorial optimization. While various quantum algorithms exist which can prepare the ground state with high precision and provable guarantees from an initial approximation, current devices are limited to shallow circuits. Here we consider the setting where Alice and Bob, in a distributed quantum computing architecture, want to prepare the same Hamiltonian eigenstate. We demonstrate that the circuit depth of the eigenstate preparation algorithm can be reduced when the devices can share limited entanglement. Especially so in the case where one of them has a near-perfect eigenstate, which is more efficiently broadcast to the other device. Our approach requires only a single auxiliary qubit per device to be entangled with the outside. We show that, in the near-convergent regime, the average relative suppression of unwanted amplitudes is improved to 1/(2e√)≈0.30 per run of the protocol, outperforming the average relative suppression of 1/e≈0.37 achieved with a single device alone for the same protocol.

Maria Balanzó-Juandó (ICFO) - Device-independent self-testing of any pure entangled state with Extended Bell scenario and Mutually Unbiased Measurementssystems.In this project, we find a way of self-testing any pure entangled state by using mutually unbiased measurements (MUMs). The idea is to generalise a result in which one has to trust one party's measurements in order to self-test the state. Our approach is to first self-test the "trusted" party and then self-test the state. To do this, we use MUMs and other techniques of self-testing.

Mohit Lal Bera (ICFO) - Characterisation of topological features in generalised Su-Schrieffer-Heeger chains using light-matter interaction.

Su-Schrieffer-Heeger (SSH) chains are paradigmatic examples of 1D topological insulators hosting zero en- ergy edge modes when the bulk of the system has a non-zero topological winding invariant. Recently, high- harmonic spectra of SSH chains that are coupled to an external laser field of a frequency much smaller than the band gap have shown huge differences between the harmonic yield depending on the system being or not being in a topological phase. This has suggested that high harmonic spectroscopy may act as a successful tool for topological phase detection. We investigate this claim in the paper by studying an extended version of the SSH chain with higher neighbor hoppings which results in a topological model with higher topological invariants. We explicitly address how good and sensitive a tool HHG spectra is for topological phase detection when there are more than one topological phases. We also propose a quantitative scheme based on tuning the filling of the system to precisely locate the number of edge modes in each topological phase of this chain.

Abstracts student talks

Leo Feldmann (ICFO) - Highly efficient cavity-enhanced solid-state quantum memory based on atomic frequency comb

We report a high-efficiency solid-state quantum memory. We prepared an atomic frequency comb quantum memory inside an impedance-matched cavity in order to enhance the efficiency. We achieve storage of a time-bin qubit with 52% efficiency and of weak coherent states with 62% at 2us storage time. Further, we stored weak coherent states in the spin-state with over 20% efficiency, enabling on-demand read-out.

Tim Hoehn (IMPRS) - State-dependent potentials for the ground and clock state in ultracold ytterbium

The ground and meta-stable clock state pair in ytterbium provides an excellent resource for quantum metrology, simulation and computation applications. Being capable of individually addressing the two optical clock qubit states in a state-selective manner enhances the controllability of such systems, allowing for novel methods for state preparation, read-out or simulation schemes. Utilizing high-resolution clock spectroscopy, we present the first measurements of the Yb ground-state tune-out wavelength and of two new magic wavelengths as well as a route towards the determination of the clock-state tune-out wavelength. We further showcase how this will be used in our hybrid tweezer-lattice experiment to probe and engineer lattice gauge theories, using state-dependent potentials to robustly implement local gauge invariance.

Eduardo Beattie (ICFO) - Detection of single ions in a nanoparticle coupled to a fiber cavity

Rare earth ion-doped crystals constitute a promising platform for quantum information processing and networking. They feature exceptional spin coherence times to store information, narrow optical transitions to act as an interface to optical photons, and possibilities to realize quantum gates between single ion qubits through electric dipole interactions. As with other quantum emitters, by coupling them to optical cavities we can channel their emission into the cavity mode while also decreasing their emission lifetime, which allows for efficient and high-rate spin-photon interfaces to be realized.

Jonatan Höschele (ICFO) - Towards a strontium quantum-gas microscope

Ultracold atoms in optical lattices represent an outstanding tool to create and study quantum many-body systems. Combining these lattice systems with the properties of alkaline-earth atoms like strontium gives rise to exciting phenomena such as cooperative effects in atom-photon scattering and exotic magnetic phases of the Fermi-Hubbard model.

Abstracts student talks

Carlos Pascual García (ICFO) - Security of Discrete Modulated Continuous Variable Quantum Key Distribution

Continuous Variable Quantum Key Distribution with discrete modulation has the potential to provide unconditional security using commercial technologies and well-known error correction protocols. However, proving finite-size security against coherent attacks remains a challenge. In this work, we design a discrete modulated, preparation and measurement QKD protocol based on using coherent states and heterodyne measurements, and prove that it is secure against coherent attacks according to a virtual protocol based on the Entropy Accumulation Theorem. We report non-trivial finite keys for n = 1e12 rounds.

Arthur Christianen (IMPRS) - The strong-coupling Bose polaron

Important properties of complex quantum many-body systems and their phase diagrams can already be inferred from the impurity limit. A paradigmatic example is the Bose polaron problem, describing an impurity-atom immersed in a Bose-Einstein condensate (BEC) of ultracold atoms. The most interesting feature of this model is the competition between the emergent impurity-mediated attraction between the bosons from the BEC and their intrinsic repulsion [1]. The arising higher-order correlations are challenging to describe theoretically, so far preventing a unified description of the ground state properties of this model. Using variational techniques, we show that if the mediated interactions overcome the background repulsion, the impurity can locally trigger a collapse of the BEC[2,3]. If instead the background repulsion is stronger, we find a smooth crossover of a polaron state into a small molecule. In both cases, there is a tight connection between the many-body physics of polaron formation and the underlying few-body scattering processes. We finally demonstrate that both the instability- and the crossover-regime can be realized in state-of-the-art experiments [1].

[1] Arthur Christianen, J.Ignacio Cirac, Richard Schmidt, in preparation
[2] Arthur Christianen, J.Ignacio Cirac, Richard Schmidt, Phys. Rev. Lett. 128, 183401 (2022)
[3] Arthur Christianen, J.Ignacio Cirac, Richard Schmidt, Physical Review A 105, 053302 (2022)

Melissa Will (IMPRS) - Hilbert space fragmentation in a tilted, 2D Bose Hubbard model

Quantum many-body systems out of equilibrium can exhibit very rich and exciting phenomena. A particularly important question is whether and how a quantum system thermalizes under unitary evolution. In this context, three classes of systems have been identified: ergodic, localized and an intermediate regime exhibiting so called quantum many-body scars. In this talk we will discuss how an electric field induces so called Hilbert space fragmentation in a two dimensional Bose Hubbard gas with maximum particle number of two per site. Tuning onsite interaction in resonance with the electric field, the effective Hamiltonian shows scattering of the Hilbert space into disconnected sub spaces. We identify the checkerboard state as completely frozen and compare it to dynamics of a dimer configuration, which is part of the largest sector. Furthermore, we find two types of excitations on top of the checkerboard state. An excitation with reduced energy can only travel along a quasi-one-dimensional axis. In contrast, an excitation with increased energy by moving it one site, is mobile in the entire system. Using a cellular automate we compare diffusion of those distinct excitations.

Abstracts student talks

Josef Willsher (IMPRS) - Spin-Peierls instability of the U(1) Dirac spin liquid

Quantum spin liquids are tantalising phases of quantum matter, but experimental evidence of their existence has remained elusive. Recent theoretical and numerical studies have provided evidence that triangular-lattice Heisenberg magnets may host a U(1) Dirac spin liquid (DSL): a state of matter whose low-energy description is given by compact quantum electrodynamics in 2+1 dimensions coupled to four Dirac fermions, which is believed to flow to a strongly interacting conformal fixed point. We study spin-lattice interactions within a conformal field theory framework and show that the DSL state is generically unstable to a static deformation, precipitating VBS ordering. This instability represents a first two-dimensional analog of the spin-Peierls instability of the one dimensional spin-Half Heisenberg chain. We discuss implications for experimental realisations of the DSL in real 2D materials by addressing finite-temperature and quantum phonon limits; although we predict a weak-coupling regime within which the spin-liquid phase remains stable, perturbation theory predicts it may not be experimentally accessible.

Anubhav Kumar Srivastava (ICFO) - Quantum thermometry with one-dimensional fermionic chains

With the advent of quantum technologies, there is a dire need to accurately measure the temperature of systems at regimes where quantum effects are dominant. This is challenging since there is no observable to measure the temperature of a given quantum system directly. Thus, we need quantum estimation theory to provide us with the lower bound for the temperature accuracy of a quantum system via the Cramér-Rao bound, which is inversely proportional to the square root of Quantum Fisher Information (QFI) for a general thermal state. In short, if we can maximize the QFI for a given system, we will have ideal bounds for the variance in temperature of the given quantum system. It was further showed in 2015 that an optimal quantum thermometer has a particular energy spectrum with a single ground state but a highly degenerate first excited state. This energy gap is proportional to the estimated temperature of the system.[1]

We propose a quantum thermometer with a topological SSH model realized with ultracold fermions in a one-dimensional optical lattice. The proposed thermometer has a very similar energy level structure to the OQT. Assuming that the thermometer is already thermalized to the thermal state of the given system, we study QFI for temperature estimation accuracy. We also analyze the thermalization dynamics when our thermometer in the pure state is coupled to a given many-body quantum system. We can characterize it using the Bures' distance between the reduced density matrices of the thermometer and the system.
[1] Correa, Luis A., et al. ""Individual quantum probes for optimal thermometry."" Physical review letters 114.22 (2015): 220405.

Clemens Kuhlenkamp (IMPRS) - Robust spin liquids in 2D materials

Spin liquids are exotic phases of matter with fractionalized excitations and intrinsic topological order. While spin liquids have been predicted to appear in frustrated magnets, they usually occupy small regions of the phase diagram, making it particularly challenging to find unequivocal evidence for their existence. In this talk, I will present how to circumvent the need to fine-tune experimental parameters by combining layer pseudo-spin with strong external magnetic fields in heterostructures of 2D materials. The external field breaks time-reversal symmetry and generates an exceptionally robust chiral spin liquid, which we understand in terms of simple analytical arguments. Crucially, by using the layer degree of freedom, one can access novel optical and transport probes, which can directly detect topological order. I will also discuss exotic quantum critical points between symmetry-protected states and phases with intrinsic topological order which emerge in these systems.

Rafael Luque Merino (ICFO) - Ultrafast electronic cooling in MATBG

we study the cooling of hot electrons in moiré graphene using time- and frequency-resolved photovoltage measurements as a direct probe of its complex energy pathways including electron-phonon coupling. We report on a dramatic speedup in hot carrier cooling of twisted bilayer graphene near the magic angle: the cooling time is a few picoseconds from room temperature down to 5 K, whereas in pristine graphene coupling to acoustic phonons takes nanoseconds.

Oriana Diessel (IMPRS) - Bose polaron interactions in a cavity-coupled monolayer semiconductor

The interaction between a mobile quantum impurity and a bosonic bath leads to the formation of quasiparticles, termed Bose polarons. The elementary properties of Bose polarons, such as their mutual interactions, can differ drastically from those of the bare impurities. Here, we explore Bose polaron physics in a two-dimensional nonequilibrium setting by injecting $\sigma-$ polarised exciton-polariton impurities into a bath of coherent $\sigma+$ polarised polaritons generated by resonant laser excitation of monolayer $MoSe_2$ embedded in an optical cavity. By exploiting a biexciton Feshbach resonance between the impurity and the bath polaritons, we tune the interacting system to the strong-coupling regime and demonstrate the coexistence of two new quasiparticle branches. Using time-resolved pump-probe measurements we observe how polaron dressing modifies the interaction between impurity polaritons.

We theoretically model the interactions using variational wave function Ansaetze for a single and a two-polaron state.

Remarkably, we find experimentally and theoretically that the interactions between high-energy polaron quasiparticles, that are repulsive for small bath occupancy, can become attractive in the strong impurity-bath coupling regime. We provide the first direct measurement of Bose polaron-polaron interaction strength in any physical system and pave the way for exploration and control of many-body correlations in driven-dissipative settings.

Abstracts student talks

Niccolò Baldelli (ICFO) - Superconductivity and stripes of strongly-correlated electrons in a magnetic field

Geometrically frustrated interacting quantum systems can be characterized by intriguing many-body states of matter. We demonstrate that a bosonic mixture of Cesium atoms trapped in a one dimensional optical lattice at the anti-magic wavelength represents a suitable platform for tackling this challenging topic. In particular, we derive a setup able to effectively model the physics of an interacting single-component Bose gas confined in a frustrated triangular ladder. Our numerical inspection reveals that the ground state of this system is characterized by the presence of chiral superfluids and bond-order-wave insulators, both peculiar of frustrated quantum magnets. Moreover, we present an alternative detection protocol where measurements of a string correlation function and momentum distribution allow us to probe these many-body states accurately.

Wilhelm Kadow (IMPRS) - Hole doped quantum spin liquids

Quantum spin liquids are fascinating phases of matter, hosting fractionalized spin excitations and unconventional long-range quantum entanglement. Usually spin liquids exist in Mott insulators at half-filling. Here, we investigate the influence of a single mobile hole in the ground state of paradigmatic spin liquid models using techniques based on matrix product states. We find that several phases compete that can destroy the quantum spin liquid ground state towards an ordered state. However, if the spin liquid survives the hole insertion, the hole spectral function, as measured by angle-resolved photoemission spectroscopy, provides a useful tool to characterize quantum spin liquids. In this case, the single hole separates into a spinon and chargon. These fractional excitations then determine the low energy properties of the system.

Bennet Windt (IMPRS) - Fermionic matter-wave quantum optics with cold-atom impurity models

The quintessential quantum optical system is composed of one or multiple quantum emitters coupled to a bath of (electromagnetic) modes. This coupling leads to individual and collective spontaneous emission, as well as bath-mediated emitter interactions. Engineering non-trivial bath dispersion relations can lead to exotic phenomena, such as population trapping in bound states, sub- and superradiant collective emission, purely coherent bath-mediated interactions, and more. It has been recently suggested and experimentally confirmed that such features can be observed using cold atoms in state-dependent optical lattices rather than traditional optical setups (e.g. photonic crystal waveguides). I propose an extension of the cold-atom setup to fermionic atoms, which unlocks a new paradigm of non-Markovian quantum optics with fermionic matter waves. I discuss how the theoretical formulation of single-excitation dynamics in atom-photon systems can be extended to multi-excitation dynamics in fermionic impurity models. Within this new framework, I present signatures of non-Markovian individual and collective fermionic matter-wave dynamics, as well as some exotic ground-state features.

Abstracts student talks

Teresa Karanikolaou (ICFO) - Effect of an optical dipole trap on resonant atom-light interactions

The optical properties of a fixed atom are exquisitely well-known and investigated. For example, one important phenomenon is that the atom can have an extraordinarily strong response to a resonant photon, as characterized by a resonant elastic scattering cross section given by the wavelength of the transition itself. The case of a tightly trapped ion, where the ground and excited states are equally trapped, is also well-known. Then, the elastic cross section is reduced by a fraction corresponding to the square of the "Lamb-Dicke parameter", while this same parameter also dictates the probability of inelastic scattering that gives rise to motional heating. In contrast, there are many emerging quantum optics setups involving neutral atoms in tight optical dipole traps, such as coupled to nanophotonic waveguides and cavities or in atomic arrays, where the goal is to utilize efficient atom-light interactions on resonance. Often, while the ground state is trapped, the excited state may in fact be untrapped or even anti-trapped. Here, we systematically analyze the consequences that this unequal trapping has on reducing the elastic scattering cross section, and increasing the motional heating rate. This analysis may be useful to optimize the performance of quantum optics platforms where equal trapping cannot be readily realized.

Florian Fertig (IMPRS) - Tomography of distant single Atoms

Entanglement of distant quantum memories forms the building block of quantum networks. Neutral atoms with long coherence times are possible candidates for such a quantum network link and can be entangled via the entanglement swapping protocol.

Our experiment consists of two nodes, currently 400 m apart, employing single optically trapped Rubidium-87 atoms as quantum memories. A new collection setup allows for an increased entanglement event rate of 1/20 Hz allowing a state analysis and reconstruction of the entangled state.

Here, we use quantum state tomography for the first time on atom-atom entanglement and evaluate the influence of different kind of experimental improvements on the fidelity of the entangled state. We introduce time-filtering, a method to increase the atom-atom entanglement fidelity. At the cost of events we reach a fidelity > 90% well suited for demanding tasks like device-independent QKD.

Daniel Goncalves Romeu (ICFO) - Local dissipation effects in the driven-dissipative Dicke phase transition

The driven Dicke model, wherein an ensemble of atoms is driven by an external field and undergoes collective spontaneous emission due to coupling to a leaky cavity mode, is a paradigmatic model that exhibits a driven dissipative phase transition as a function of driving power. Recently, a highly analogous phase transition was experimentally observed, not in a cavity setting, but rather in a free-space atomic ensemble. Motivated by this, we present our ongoing efforts to better characterize the free-space problem, and understand possible differences compared to the cavity version. We specifically discuss a cavity QED model with weak local dissipation as a minimal model for the free space. We find that the presence of

Abstracts student talks

local dissipation dramatically changes the properties of the phase transition. In particular, we present preliminary arguments that suggest that the free-space case might exhibit a smooth crossover rather than a true phase transition in the thermodynamic (large atom number) limit.

David Castells (IMPRS) - Controlling light-matter interaction using collective effects of subwavelength atom arrays

In this talk we will discuss what it means for something to be a resource. We will focus on the case of non-classical phenomena serving as resources, and pay special attention to those aspects that may be relevant for boosting our performance at communication and information-processing tasks. We will also identify important details that are relevant for studying conversions of resources and the quantification of their resourcefulness. This presentation is meant to provide a broad picture on the type of foundational research connected to quantum resources, and give you a platform from which to further pursue your own interests.

Industry session

Johannes Zeiher (PLANQC)

Planqc is building quantum computers that store information in individual atoms – nature's most pristine qubits. Quantum information is processed by arranging these qubits in highly scalable arrays and manipulating them with precisely controlled laser pulses. planqc's unique combination of quantum technologies is the fastest way to scale to thousands of qubits, a prerequisite for industry-relevant quantum advantage. Planqc was founded in 2022 by Alexander Glätzle, Sebastian Blatt, Johannes Zeiher, Lukas Reichsöllner, together with Ann-Kristin Achleitner and Markus Wagner. planqc is based in Garching near Munich, Germany.

Marta Alcaide (QUSIDE)

Bringing a scientific idea from the lab to the market is a long and challenging journey that requires a combination of innovative technical skills, an adaptable entrepreneurial mindset, and savvy business acumen. In this talk, we will share our experience at Quside of creating and growing a successful spin-off company: from our beginnings at ICFO labs, through productizing the technology, to getting ready for mass production. We will highlight the key milestones and challenges of the process, such as building a multidisciplinary team, securing funding, and finding a market fit. We will also discuss the state of the quantum industry sector, focusing on the opportunities and challenges ahead for the field. Finally, we will reflect on the skills and mindset that scientists can develop during their academic training that can be useful for deep-tech startup environments.

Join us for an inspiring talk that combines quantum science, trailblazing innovation, and daring entrepreneurship!

Abstracts posters

NEST Hall

1. Raja Yehia (ICFO) - Quantum City: simulation of a practical near-term metropolitan and european quantum network

We present the architecture and analyze the applications of a metropolitan-scale quantum network that requires only limited hardware resources for end users, the Quantum city. We then extend this architecture to connect quantum cities using satellite-based quantum communication. Using NetSquid, a quantum network simulation tool based on discrete events, we assess the performance of several quantum network protocols involving two or more users in various configurations in terms of topology, hardware and trust choices. Our analysis takes losses and errors into account and considers realistic parameters corresponding to present or near-term technology. Our results show that practical quantum-enhanced network functionalities are within reach today and can prepare the ground for further applications when more advanced technology becomes available.

2. Tomas Lamich (ICFO) - Quantum jump spectroscopy of a single neutral atom for precision intensity measurements

We present precise measurements of optical intensity with sub wavelength spatial resolution, by spectroscopy of Rb light shifts. We use a quantum jump technique to amplify the signal and to avoid systematic errors that can arise from tensor light shifts and saturation of the probed transition We demonstrate the technique by measuring the intensity at the focus of an optical tweezer. The technique also gives the temperature of the atom from the width of the observed spectral line.

3. Marta Cagetti (ICFO) - Real-time measurements of a carbon nanotube electromechanical system hosting a double-quantum dot

Mechanical resonators are systems that present high-quality factors and can easily couple to a wide range of forces rendering them excellent candidates for sensing and quantum information. In particular, carbon nanotubes (CNTs) have been exploited in many fields such as mechanical oscillators due to interesting proprieties [1]. Quantum dots (QDs) have been defined in nanotubes to read out and control the mechanical motion electrically [2]. One of the main difficulties in quantum dots defined in a carbon nanotube is measuring the system's dynamics when the electrons are bounded in the quantum dot, where common techniques based on conductance measurements are not applicable. This state is however interesting for the realization of electro-mechanical qubits, ultraprecise sensors, and quantum simulators [3]. The target is to employ CNT-based sensing dots to carry out real-time measurements of a carbon nanotube electromechanical system hosting a double quantum dot at a timescale faster than the mechanical period.

NEST Hall

4. Julia Bergmann (ICFO) - Engineering gauge theories with a Rydberg atom processor

In the last years, Rydberg atoms in reconfigurable optical tweezers proved to be an excellent platform to implement Spin-like Hamiltonians in ultracold atom experiments [1]. An important subject in this matter is the exploration of Ising models with S = 12 and higher in one, two and three dimensions, including the investigation of gauge theories emerging in condensed matter physics [2]. As an example, I consider the well-known Rokhsar-Kivelson Hamiltonian, a 2D U(1) lattice gauge theory describing quantum dimer and spin-ice dynamics, in different geometries and investigate the resulting phase diagrams [3]. I explain how to engineer tunable anisotropic attractive as well as repulsive interactions with so-called superatoms by organizing two or more individual atoms in small clusters sharing one Rydberg excitation. The control of the couplings translates in blockade and antiblockade conditions arising in the dual formulation of the Rokhsar-Kivelson Hamiltonian [4]. In collaboration with the experimental group of Leticia Tarruell, I develop protocols to investigate this and other gauge theories with Rydberg atoms in reconfigurable tweezer arrays.

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5. Dario Lago-Rivera (ICFO) - Multiplexed quantum teleportation from a telecom qubit to a matter qubit through 1 km of optical fibre

Distribution of quantum information over long distances is a basic need in the field of quantum communications. Quantum teleportation is an important capability that uses quantum entanglement as a resource to transmit arbitrary quantum bits (qubits) between distant parties. A scalable implementation of quantum teleportation should feature compatibility with the telecom infrastructure and a multimode capability that allows for the decoupling of the repetition rate of the set-up from the distance between parties. Moreover, the information should be transferred to a matter qubit with a storage time longer than the communication time such that the receiver can process the quantum states after they have been teleported. In order to address all of these needs, we use a cavity-enhanced spontaneous parametric down-conversion source to create entangled photon pairs. The idler photon is created in the telecom band and the signal photon is compatible with storage in a solid-state quantum memory based on a praseodymium-doped crystal. We used a source of time bin qubits to encode arbitrary states to be teleported. Thanks to the storage in the quantum memory, we could implement a unitary transformation on the teleported qubit conditioned on the result of the Bell-state measurement.

We demonstrated that the teleportation repetition rate did not affect the fidelity of the teleported state. Finally, we tested the system under a long distance scenario by separating sender and receiver with 1 km of optical fibre. We checked that the fidelity was the same as without the added distance. All the measured fidelities significantly violate all the classical bounds.

We believe that these results represent a functional and scalable realization of long distance quantum teleportation and will inspire future implementations of long distance quantum teleportation.

6. Roger Tormo Queralt (ICFO) - Towards a mechanical qubit in carbon nanotubes

Mechanical resonators are systems which present high quality factors and can easily couple to a wide range of forces. For this reason, they are excellent candidates for sensing and quantum information. While their qualities as sensors have been exploited for many years, it is only recently that their potential use as quantum bits (qubits) have been proposed. To enable a mechanical qubit, the resonator may be coupled to an external force which induces anharmonicity in the energy dispersion curve of the harmonic oscillator. The force exerted by a charge fluctuation in a double quantum dot on the mechanical vibration of a carbon nanotube has been shown. In practice this effect necessitates operation in the so-called strong coupling regime. In this regime, the energy difference between the ground and first excited states is significant enough to be used as a basis for a qubit. The qubit decoherence of the charge-mechanical hybrid system is expected to display a thousandfold improvement with respect to current state-of-the-art charge qubits. In our work we will show our effort towards implementing such a system experimentally.

7. Lukas Wangler (ICFO) - Quantum Optics with Atomic Arrays in Optical Cavities

We study arrays of atoms which are placed inside an optical cavity. In textbooks the spontaneous emission of a photon into free space is considered as a process that occurs independently for each atom. However, a more careful analysis reveals that this process can depend on correlations between the atoms. The correlated nature becomes apparent e.g. for arrays of two-level atoms with a spacing closer than the wavelength of their dipole-transition. We want to understand the phenomena related to the correlated emission process and exploit them for improved quantum optics protocols. In particular, we want to utilize an atomic array integrated in an optical cavity for improved schemes for creating spin-squeezed states. Spin-squeezed states are a particular class of entangled states. They have important applications in precision metrology (e.g. optical clocks and magnetometry), because they allow to reduce measurement uncertainties below the standard quantum limit. We envision to induce squeezing with the help of the cavity-mediated interaction and to exploit the correlated dissipation of the array in order to protect the system from decoherence due to spontaneous photon emission. We anticipate that our protocol will be able to produce states with stronger squeezing than in established schemes and hence achieve a larger metrological gain.

NEST Hall

8. Sandra Buob (ICFO) - Ultracold strontium in a magic-wavelength optical lattice

Ultracold atoms in optical lattices provide a fascinating platform to study quantum many-body systems. Strontium in a two-dimensional optical lattice, for example, enables investigating collective atom-photon scattering phenomena or exotic magnetic phases of the Fermi-Hubbard model. Adding site-resolved detection allows deeper insight into the complex physics models simulated in these systems, such as density and even spin correlation detection.

In our experiment, we aim at the realization of a strontium quantum-gas microscope. Our setup allows cooling of all stable isotopes of strontium. We load a blue magneto-optical trap (MOT) and enhance the atom number by shielding on the intercombination transition before further cooling in a red MOT. After evaporative cooling in an optical dipole trap, we reach a Bose-Einstein condensate of Sr-84. We are implementing a two-dimensional optical lattice at magic wavelength and a high-NA imaging system with single lattice site resolution. In the future steps, we are planning to introduce spin-dependent shelving in the clock state in order to detect the spin order in the lattice.

In the poster, I present the cooling processes required to reach the quantum degenerate regime, the current status of the optical lattice as well as the future steps of the experiment.

9. Félicien Appas (ICFO) - Towards long-lived on-demand Pr3+:YSO solid-state quantum memories using dynamical decoupling

The distribution of quantum entanglement across quantum networks is foreseen to enable key application for basic science and industry such as cloud quantum computing, secure communications or distributed quantum sensing. This requires the deployment of interconnected quantum systems over networks of optical fibers, where the maximum link distance is limited by optical losses. To overcome this restriction, quantum repeater architectures have been proposed, in analogy with classical telecommunication networks, to extend the reach of entanglement distribution. An enabling feature of these devices is the synchronization of chains of quantum nodes through quantum memories (QM) capable of storing photons for longer than the inter-node link communication time. In this work, we present a long-lived QM based on a Pr3+ doped YSO crystal that allows for on-demand storage and retrieval of light for times of up to several milliseconds, which is equivalent to the communication time of more than 1000 km optical fiber link. The storage relies on the intrinsically time-multiplexed atomic frequency comb (AFC) protocol, where dynamical decoupling (DD) is performed using radiofrequency pulse sequences to further increase the storage time. We present a characterization of the QM in terms of storage time and efficiency using classical pulses, as well as a protocol for on-demand retrieval within the DD sequence. These results pave the way towards demonstration of storage of single photons and light-matter entanglement in long-lived QM compatible with metropolitan-scale quantum networks.

NEST Hall

10. Nepomuk Ritz (IMPRS) - Real-frequency quantum field theory applied to the Anderson impurity model

A major challenge in the field of correlated electrons is the computation of dynamical correlation functions. For comparing with experiment, one is interested in their real-frequency dependence, which is difficult to get as imaginary-frequency data from the Matsubara formalism require analytic continuation, a numerically ill-defined problem. Here, we employ quantum field theory in the Keldysh instead of the Matsubara formalism, giving direct access to the self-energy and dynamical susceptibilities on the real-frequency axis. We present results from the functional renormalization group (fRG) and from solving the self-consistent parquet equations for the Anderson impurity model, and compare our results to benchmark data obtained with the numerical renormalization group as well as second-order perturbation theory. We find that capturing the full frequency-dependence of the four-point vertex significantly improves the fRG results compared to previous implementations, and that solving the parquet equations reproduces the NRG benchmark data best but is only feasible up to moderate couplings. Our methodical advances pave the way for treating more complicated models, e.g. adding a bias voltage or momentum degrees of freedom.

11. Marta Florido Llinàs (IMPRS) - Memory-enhanced quantum stochastic models for complex processes

Systems displaying complex stochastic behaviors are ubiquitous in nature and society, which means that building models that are capable of making faithful predictions about their future evolution is an essential task. However, this usually involves tracking prohibitively large amounts of information for complex systems, so it is necessary to develop effective tools to cut down on the amount of memory needed. In my poster, I present an overview of a classical approach to this, the so-called 'ϵ-machines' (which lie at the heart of a branch in complexity science known as computational mechanics), and their quantum counterparts. Then, I show how matrix product state-based methods can be used to further reduce the memory of these quantum stochastic models.

12. Anna Rupp (IMPRS) - Mesoscopic reconstruction in semiconductor van der Waals structures

Transition metal dichalcogenide semiconductors represent essential building blocks of van der Waals heterostructures. Vertical stacks of multiple monolayers give rise to physical properties that depend sensitively on the choice of materials, the rotation angle between the individual layers and the emergent band structure. With the poster we present reconstruction phenomena in MoSe2-WSe2 heterobilayers with small lattice mismatch and marginal-angle deviations away from parallel (rhombohedral R-type, or 0° twist) and antiparallel (hexagonal H-type, or 60° twist) alignment. Due to finite elasticity of lattice bonds, we find mesoscopic reconstruction of canonical moiré patterns into domains of different dimensionality. Secondary electron imaging in scanning electron microscopy was optimized to visualize the resulting morphology of domain landscapes, and optical spectroscopy was used to assign exciton characteristics to 2D, 1D and 0D domains.

13. Johannes Arceri (IMPRS) - Observation of edge states in topological Floquet systems

Floquet engineering, i.e., periodic modulation of a system's parameters, has proven as a powerful tool for the realization of quantum systems with exotic properties that have no static analog. In particular, the so-called anomalous Floquet phase displays topological properties even if the Chern number of the bulk band vanishes. [1]

Our experimental system consists of bosonic atoms in a periodically driven honeycomb lattice. Depending on the driving parameters, several out-of-equilibrium topological phases can be realized, including an anomalous phase. [2]

As the bulk-boundary correspondence relates the properties of the bulk bands to the number of topologically protected edge modes, special interest lies in studying the behavior of them. We are investigating the real-space evolution of a wavepacket close to the edge after the release from a tightly-focused optical tweezer. This way, we observe the chiral nature of the edge state, even in the anomalous Floquet phase, thereby directly revealing the topological nature of this phase.

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14. Reinis Irmejs (IMPRS) - Quantum Simulation of Z2 Lattice Gauge theory with minimal resources

The quantum simulation of fermionic gauge field theories is one of the anticipated uses of quantum computers in the NISQ era. In this work, we investigate various options for simulating the fermionic Z2 gauge field theory in (2+1) D. To simulate the theory on a NISQ device it is vital to minimize both the number of qubits used and the circuit depth. In this work we propose ways to optimize both criteria for simulating time dynamics. In particular, we develop a new way to simulate this theory on a quantum computer, with minimal qubit requirements. We provide a quantum circuit, simulating a single first order Trotter step, that minimizes the number of 2-qubit gates needed and gives comparable results to methods requiring more qubits.

15. Yiru Zhou (IMPRS) - Entanglement Distribution – Towards a Suburban Quantum Network Link

The crucial task for future quantum networks is to share entanglement over large distances. For that, quantum platforms with efficient light-matter interface, long coherence times, and the possibility to connect to low-loss quantum channels are required.

Here we present the distribution of entanglement between an atom and a photon. First, spontaneous emission of a photon at 780 nm from a single Rb-87 atom is employed to generate entanglement between the polarization of the photon and the respective Zeeman state of the atom. Then a state-selective Raman transfer is used to change the encoding of the atomic qubit in a combination of F=1 & F=2 hyperfine states [1]. The reduced sensitivity to magnetic fields in the new basis helps increase the atomic coherence time to 7 ms. Along with this, an efficient polarization-preserving quantum frequency conversion to telecom wavelengths minimizing the photon loss [2] enables the distribution of atom-photon entanglement over 101 km telecom fiber with a fidelity ≥70.8%.

This lays the groundwork for entangling two single atom based quantum memories physically located 14 km apart in a suburban environment [2, 3].

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16. Marianna Crupi (IMPRS) - Superposition of quantum channels to boost transmission of information

The ability to place channels in a superposition of alternative causal orders was shown to sometime boost the transmission of classical and quantum information. In particular it was proven to allow the transmission of information even through channels with zero capacity (e.g. completely depolarizing, information erasing channels). We studied this mechanism (known as the quantum-SWITCH) in various settings, varying the type and number of the input channels.

17. Amine Ben Mhenni (IMPRS) - Influence of the Dielectric Environment on Excitons in Atomically-thin Transition Metal Dichalcogenides

Control over the bandgap of materials is key to many applications in solid-state and quantum technologies. In atomically-thin transition metal dichalcogenides (TMDs), such control is additionally enabled in a unique and non-invasive way via the dielectric environment [1]. Due to their reduced dimensionality, these materials exhibit non-local screening. Both their electronic bandgap and their exciton binding energy are extremely sensitive to the effective dielectric constant. These effects, however, are comparable in amplitude and act against each other. The optical bandgap is only tunable over a small energy range [2]. In the vast majority of reports, a redshift of a few tens of meV was reported for the neutral exciton at higher dielectric constants [1]. Here, we use state-of-the-art fabrication techniques to produce TMD heterostructures with ultra-clean interfaces and with effective dielectric constants ranging over several orders of magnitude. We study the excitonic physics of these heterostructures using photoluminescence (PL) and differential reflectivity at cryogenic temperatures. Contrary to earlier reports, we show evidence for a blueshift of the neutral exciton at higher effective dielectric constants and demonstrate its tunability over an energy range of more than 30 meV. We vary the charge carrier density via electric gating and suppress the doping contribution. We reproduce the redshift from earlier reports and attributed it to interfacial contamination due to PDMS exfoliation and stacking. Our findings revive the promise of exciton quantum confinement and synthetic superlattices via nanoscale dielectric heterojunctions.

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18. Michelle Lienhart (IMPRS) - Quantum dot molecules as spin-photon interfaces for applications in quantum communication

Long coherence times, strong light-matter coupling, and tunability lie at the heart of all hardware for distributed quantum information technologies. This is particularly true for spin-photon interfaces based on III-V semiconductor quantum dots (QDs) since they combine properties such as light-matter-interactions, robust spin-photon selection rules, dominant emission into the zero-phonon line at low temperatures, and ease of integration into opto-electronic devices. Together, these properties make QDs promising as spin-photon interfaces. Tunnel-coupled pairs of QDs, so called QD-molecules (QDMs), additionally exhibit enhanced coherence times (T2*) using two-spin singlet-triplet (S-T0) qubits [1] which are inherently protected against electric and magnetic field noise. To unlock the increased coherence times of QDMs, we developed and investigated a device, where a single QDM is embedded in a low capacitance p-i-n diode structure (diode area: 10 μm x 25 μm) that allows for fast electrical switching (>500 MHz) and thus fast control of the tunnel coupling. A circular Bragg grating is deterministically positioned via in-situ electron beam lithography on top of a single QDM. In combination with a distributed Bragg reflector below the QDM, we achieve photon extraction efficiencies of up to 24.4% [2]. Our device enabled the demonstration of sequential and all-optical charging of the QDM via tunneling ionization. We showed one- and two-hole charging efficiencies of (93.5 ± 0.8)% and (80.5 ± 1.3)% are achieved, respectively [3]. Combining the control of the charge status, precise setting and fast switching of the inter-dot coupling, and high photon extraction efficiencies provides a perspective to use our devices for the deterministic generation of one- and two-dimensional photonic cluster states [4].

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19. Anxiang Ge (IMPRS) - Multiloop flow equations for single-boson exchange fRG

A severe bottleneck in the study of strongly correlated many-body systems is the numerical treatment of the four-point interaction vertex. The newly introduced single-boson exchange (SBE) decomposition is a conceptually and computationally appealing parametrization of the vertex. It decomposes the vertex in a part with the full dimensionality of the four-point function and lower-dimensional components that can be interpreted as effective exchange bosons or the coupling of (quasi-)particles to the latter. In a recent work we re-derive the SBE decomposition in a generalized framework (suitable for extensions to, e.g., inhomogeneous systems or real-frequency treatments). We then derive multiloop functional renormalization group (mfRG) flow equations for the ingredients of this SBE decomposition. With a suitable choice of the flow parameter these flow equations connect a system of interest with a well-controlled starting point, e.g. a free theory. The SBE decomposition also is beneficial for combined methods such as DMF2RG which makes use of a DMFT vertex as the starting point for the fRG flow. Hence, we also provide equations in the SBE approximation which focuses on the treatment of the lower dimensional SBE components, thereby strongly mitigating the numerical effort.

20. Kritsana Srakaew (IMPRS) - A subwavelength atomic array switched by a single Rydberg atom

Understanding and controlling light-matter interactions is essential for numerous applications in quantum science. Cooperative response between light-coupled atoms formed by a subwavelength atomic array has recently led to the realization strong light-matter coupling down to the level of single photons. Here, we control the optical response of such an cooperative array using a single ancilla atom excited to a Rydberg state. The switching behavior is controlled by admixing Rydberg character to the cooperative array and exploiting strong dipolar Rydberg interactions with the ancilla. Driving Rabi oscillations on the ancilla atom, we demonstrate coherent control the degree of transmission and reflection. Finally, increasing the array size directly reveals the spatial area around the ancilla atom where the switching is effective. Our results pave the way towards novel quantum metasurfaces and the creation of controlled atom-photon entanglement.

Abstracts posters

NEST Hall

21. Balázs Dura-Kovács (IMPRS) - Towards realising fast readout for Rydberg arrays

Ordered arrays of neutral atoms provide an appealing platform for quantum simulation and quantum computation. Laser-cooled atomic gases allow for simulating quantum many-body systems with unprecedented control over microscopic degrees of freedom. Quantum gas microscopes enable microscopic detection and manipulation of such systems down to the level of single atoms. We present the plans of an experimental platform aimed at achieving cavity-assisted, non-destructive, local readout of atoms in a tweezer array. Long-range and tunable interactions between highly-excited Rydberg states makes the platform suited to simulate spin models and features hardware requirements to realise a scalable quantum computer.

22. Daniel Adler (IMPRS) - Realizing and probing programmable 2D optical lattices with flexible geometries

Over the past decade, ultracold atoms in optical lattices have become a vital platform for experimental quantum simulation, enabling precise studies of a variety of quantum many-body problems. For most experiments, the layout of the confining lattice beams restricts the accessible lattice configurations and thus the underlying physics. Here, we present a novel tunable lattice, which provides programmable unit cell connectivity and in principle allows for changing the geometry mid-sequence. Our approach builds on the phase-stable realisation of a square or triangular base lattice combined with microscopically projected repulsive local potential patterns. With this technique, we realise Lieb and Kagome lattices, and benchmark the various configurations by exploring single particle quantum walks. We explore many-body physics in these lattices by observing parity fluctuations associated with the superfluid-to-Mott insulator transition.

23. Johannes Halbinger (IMPRS) - NRG computation of asymptotic vertex classes

Correlation functions play a central role in the theory of quantum many-body physics. One-particle correlation functions describe the propagation of single particles, whereas two-particle correlation functions describe the effective interaction (vertex) between those particles, thus giving insight into collective modes and signalling instabilities. Their numerical calculation, however, is very hard due to their dependence on three frequency arguments for local theories and additionally three momentum arguments in non-local settings. Therefore parametrizations of the vertex are needed, allowing for a reduction of the numerical cost and for physically meaningful approximations in cases where it is not feasible to keep the full vertex. We investigate two such parametrizations, the asymptotic and the single-boson-exchange decomposition, and compare their capability to qualitatively capture features of the full vertex of the single-impurity Anderson model down to lowest temperatures and frequencies using the numerical renormalization group.

NEST Hall

24. Joachim Leibold (IMPRS) - Probing metal thin films with NV-centers in diamond

Atomic-sized color centers in diamond (NV centers) have demonstrated nanoscale sensing of various properties such as electric and magnetic fields, strain, and temperature. Shallowly implanted NV center ensembles are inherently sensitive to magnetic resonance signals from molecules at the diamond surface. Recently they have been successfully applied to investigate the formation of self-assembled monolayers on an aluminum oxide layer deposited on the diamond surface. A novel research direction is the investigation of thin metal films on top of the diamond surface and surface processes on these. Metal surfaces play a key role in catalysis and electrochemistry, and a better understanding can foster new development with far-reaching implications. Metallic surfaces, however, pose severe challenges to NV-based surface measurements due to interactions between the metal and the NV centers, leading to a drastic decrease in the luminescence (quenching) of the NV centers – the primary source to read out the NV signal. We have investigated these effects on several diamond chips with NV centers of a variety of different depths to find optimal parameters regarding the sensitivity of these quantum sensors with respect to metal surfaces.

25. Daniel Goncalves Romeu (ICFO) - Local dissipation effects in the driven-dissipative Dicke phase transition

The driven Dicke model, wherein an ensemble of atoms is driven by an external field and undergoes collective spontaneous emission due to coupling to a leaky cavity mode, is a paradigmatic model that exhibits a driven dissipative phase transition as a function of driving power. Recently, a highly analogous phase transition was experimentally observed, not in a cavity setting, but rather in a free-space atomic ensemble. Motivated by this, we present our ongoing efforts to better characterize the free-space problem, and understand possible differences compared to the cavity version. We specifically discuss a cavity QED model with weak local dissipation as a minimal model for the free space. We find that the presence of local dissipation dramatically changes the properties of the phase transition. In particular, we present preliminary arguments that suggest that the free-space case might exhibit a smooth crossover rather than a true phase transition in the thermodynamic (large atom number) limit.

Accomodation

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http://www.hotelcanalolimpic.com/es/barcelona/

The hotel is located just a few minutes' walk from the workshop venue.

We hope you enjoy your stay at the Canal Olímpic Hotel and have a productive and enjoyable workshop experience.