Overview Talks

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Monday			
A	9:00	Von Zanthier	Quantum cooperativity induced by measurement processes
	10:00	Meier	The spatial coherence of pulsed electron beams from tungsten needle tips
	10:00	Chelluri	Quantum Cooperativity in Quantum Repeaters
B	11:00	Viola-Kusminiskiy	Quantum cooperativity of collective degrees of freedom
	11:30	Wachter	Optical signatures of the coupled spin-mechanics of a levitated magnetic microparticle
	12:00	Shaju	Observation of lasing using cold trapped Yb atoms
Tuesday			
C	9:00	Sandoghdar	Quantum cooperativity induced by interactions
	9:30	Sultanov	Polarization-entangled photons from ultrathin nonlinear layers
	9:50	Andrejic	Super-radiance in inhomogeneous X-ray waveguides
	10:10	Baßler	Light scattering off correlated quantum emitter systems and quantum degenerate systems
D	11:15	Morigi	Pushing the limits of quantum cooperativity
	11:45	Reitz	Cooperative quantum phenomena in light-matter platforms
	12:15	Lenk	Extended dynamical mean-field theory for photon-mediated interactions

Quantum cooperativity induced by measurement processes

by Joachim von Zanthier

The common denominator of all projects in area A is to understand and characterize the role of the quantum measurement in determining quantum cooperative dynamics. At its core is the investigation of how measurement and measurement back action establish quantum correlations, and how the emerging correlated states are robust against perturbations by the environment. The range of quantum platforms employed for the experiments in area A display a rich diversity, i.e., trapped ions, color centers in diamond, organic molecules, coherent electrons, spin ensembles and x-ray photons.

The spatial coherence of pulsed electron beams from tungsten needle tips

by Stefan Meier

Highly coherent electron emitters are essential for various applications such as electron microscopy, electron diffraction or electron holography. Among choices of different electron emitters, metallic needle tips have shown to be the most coherent standard electron sources up to date when operated in DC-field emission mode. We show our results on investigations of the spatial coherence of pulsed electrons (below one electron per pulse on average) emitted in a multiphoton-photoemission process induced by few-cycle laser pulses with a duration of 6 femtoseconds focused on a tungsten needle tip. We investigate the effective source size of these photoemitted electrons, which is a measure for the spatial coherence, and compare it with that of the DC-field emitted electrons, which have been already well investigated [1,2]. Despite of the different emission mechanisms, we can show that electrons emitted by multiphoton photoemission are as coherent as DC-field emitted ones [3]. In a next step, we investigate the dependence of the spatial coherence on the number of emitted electrons per pulse. We show that Coulomb repulsions between simultaneously emitted electrons can reduce the spatial coherence of the resulting beam. These effects are of great importance to combine high resolution electron microscopy with femtosecond time resolution.

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Quantum Cooperativity in Quantum Repeaters

by Siddardha Chelluri

As the transmission loss in the channel/optical fibers is exponentially scaled with the distance,"quantum repeaters" are required for long distance quantum communication. In this talk, an atomic ensemble based (quantum) repeater protocol (DLCZ) based on"quantum cooperative" phenomena like superradiance is discussed. Furthermore, to theoretically quantify the efficiency of a repeater protocol, a rate analysis procedure based on Markov chain model is introduced. Lastly, our current work on repeater rate analysis for a more realistic DLCZ protocol which includes memory loss error is discussed. The aim of this talk is to bridge abstract theoretical analysis and physical implementations of quantum repeater protocols.

Quantum cooperativity of collective degrees of freedom

by Silvia Viola-Kusminskiy

Area B aims at characterizing quantum cooperative dynamics of the collective degrees of freedom in mesoscopic systems. The aim is to push the limits of quantum cooperativity to the mesoscopic scale. The five projects conforming this area utilize different collective excitations across a wide range of different parameters. They include the dynamics of optomechanical collective modes of cold atomic ensembles, the properties of transport in crystals of trapped ions and in the presence of quantum defects, the controlled interaction of light with mechanical or magnetic degrees of freedom in nanostructured and levitated solid state systems.

Optical signatures of the coupled spin-mechanics of a levitated magnetic microparticle

by Vanessa Wachter

We propose a platform that combines the fields of cavity optomagnonics and levitated optomechanics in order to control and probe the coupled spin-mechanics of magnetic dielectric particles. We theoretically study the dynamics of a levitated Faraday-active dielectric microsphere serving as an optomagnonic cavity, placed in an external magnetic field and driven by an external laser. We find that the optically driven magnetization dynamics induces angular oscillations of the particle with low associated damping. Further, we show that the magnetization and angular motion dynamics can be probed via the power spectrum of the outgoing light. Namely, the characteristic frequencies attributed to the angular oscillations and the spin dynamics are imprinted in the light spectrum by two main resonance peaks. Additionally, we demonstrate that a ferromagnetic resonance setup with an oscillatory perpendicular magnetic field can enhance the resonance peak corresponding to the spin oscillations and induce fast rotations of the particle around its anisotropy axis.

Observation of lasing using cold trapped Yb atoms

by Saran Shaju

A gain medium is an integral part of any lasing mechanism. We observe optical gain in a medium of a few thousands Ytterbium-174 atoms which are magneto-optically trapped, using their $^1S_0$ - $^1P_1$ transition at 399 nm, inside a 5-cm long high-finesse cavity. The atoms are laser-pumped on the $^1S_0$ - $^3P_1$ transition at 556 nm and emit frequency-shifted light into the cavity. Single- and multi-mode emission is observed above a threshold pump intensity [1]. These facts indicate a lasing process, partially resembling the one found in cold Sr clouds [2], but in continuous-wave operation. We study steady-state and transient properties and show evidence for a multi-photon lasing mechanism including the MOT laser [1]. We also study the scattering of the 556 nm light into the cavity by the atoms magneto-optically trapped on the same transition when no 399 nm MOT light is present, in order to calibrate the cavity interaction from the observed frequency shifts. In the future, the analysis and understanding of our cold-atom lasing will be applied to study a possible similar process at the clock transition $^1S_0$ - $^3P_0$. The green transition $^1S_0$ - $^3P_1$ will be used for MOT-trapping and for creating a virtual level, which provides population inversion.

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Talks area C

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Quantum cooperativity induced by interactions

by Vahid Sandoghdar

Research Area C embraces projects where the interactions between the individual constituents are engineered. This includes the exchange of photons and a direct matter-matter coupling by quasi static electric and/or magnetic interactions. The cooperative response is then observed in the spatiotemporal structure of the emitted electromagnetic radiation. The corresponding signatures of cooperative behavior are the observation of super- and subradiant emission, the onset of spatio-temporal photon correlations including the emission of non-classical light. Research Area C investigates furthermore the impact of different dimensionalities, geometries, in the presence of disorder, and of the boundary conditions on the cooperative behavior of its platforms. In particular, structuring of media, control of thermal fluctuations and control of the coupling to the environment allows for a detailed analysis of the impact of noise, fluctuations, and dissipation on the cooperative response of the systems.

Polarization-entangled photons from ultrathin nonlinear layers

by Vitaliy Sultanov

We demonstrate the polarization entanglement of photon pairs generated in ultrathin nonlinear layers. The polarization state of the generated photon pairs is not restricted by the phase matching but only by the structure of the nonlinear tensor. We demonstrate a handy way of tuning this state by changing the pump polarization.

Light scattering off correlated quantum emitter systems and quantum degenerate systems

by Nico Baßler

My PhD thesis contains several smaller projects all related to the interaction of light with particles in a gaseous phase. Interaction of light with frozen two-level scatterers has already been explored in many theoretical works, for example using the coupled dipole model for which collective and cooperative properties were investigated in dense atomic clouds and I seek to extend this model in various ways. Extensions we are interested in are the inclusion of magnetic dipole-dipole interactions (with experiment, Patrick Windpassinger JGU), bosonic and fermionic particle statistics and the role of atomic motion in particular for bosons and fermions.

Talks area D

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Pushing the limits of quantum cooperativity

by Giovanna Morigi

The projects of Area D target to identify the foundational principles of quantum cooperative behavior. The purpose is to set the ground for a comprehensive theory that will permit to define what is quantum cooperativity in its generality, when a physical system can exhibit quantum cooperativity, how cooperativity can be designed, and which experimental setups are most promising for observing quantum cooperative behavior at the mesoscopic scale. The quantum cooperative dynamics, which are the platforms of these theoretical studies include superradiance, quantum synchronization, and quantum critical behavior in driven-dissipative systems. Projects in area D serve as pathfinder beyond the first funding period, both for exploring future experimental situations and setups, where novel cooperative effects may be prepared and studied, but also for guiding the eye for future theory projects and a more complete embedding of cooperativity in the framework of complex open manybody systems.

Cooperative quantum phenomena in light-matter platforms

by Michael Reitz

Quantum cooperativity is evident in light-matter platforms where quantum emitter ensembles are interfaced with confined optical modes and are coupled via the ubiquitous quantum electromagnetic vacuum. Cooperative effects can find applications, among other areas, in topological quantum optics, in quantum metrology or in quantum information. In this talk I will introduce a set of theoretical tools to tackle the behavior responsible for the onset of cooperativity by extending open quantum system dynamics methods, such as the master equation and quantum Langevin equations, to electron-photon interactions in strongly coupled and correlated quantum emitter ensembles. I will illustrate the methods on a wide range of current research topics such as the design of nanoscale coherent light sources, highly-reflective quantum metasurfaces or low intracavity power superradiant lasers. I will also discuss extensions to more complicated quantum emitter systems where e.g. vibronic couplings have to be taken into account.

Extended dynamical mean-field theory for photon-mediated interactions

by Katharina Lenk

The interplay of light and matter may give rise to intriguing cooperative effects in quantum many-body systems. This is even true in thermal equilibrium, where virtual photons induce interactions in the solid. The goal of this project is to treat these light-mediated interactions using an extended dynamical mean- field formalism. For that purpose, I consider a simplistic model of a chain of emitters inside a waveguide or a cavity that interact via an electrostatic dipole-dipole interaction. In mean-field approximation, the system exhibits a ferroelectric phase transition that is not modified by the light- matter coupling. Extended dynamical mean-field theory (EDMFT) allows to go beyond this simplified description and reveals that the photon-mediated interactions might enhance the ferroelectric order. Based on these considerations, I outline possible future steps to continue this project.

Posters Session I & II

Title	Presenter	Area
Spatial-temporal correlations of the light of an ion crystal	Stefan Richter	A01
Remote Imaging in a Three Atom System	Manuel Bojer	A01
Incoherent diffractive imaging with hard x-rays	Sebastian Karl	A03
Towards Measurement-Based Variational Quantum Simulation of the Multi-Flavor Lattice Schwinger Model with a Flavor-Dependent Chemical Potential	Stephan Schuster	A03
Measuring the temperature of a trapped ion with light	Marvin Gajewski	B01
Theory of Color Centers in SiC Coupled to Light and Mechanics	Maximilian Schober	B03
Dopant-selective etching of 4H-SiC for the fabrication of 3D structures & brief outlook of strain-induced line splitting in TS defects	André Hochreiter	B03
	Yanis Abdedou	B03
The dynamics of $^1S_0$-$^3P_1$ trapped Yb atoms in a high-finesse cavity	Dmitriy Sholokhov	B04
Optical to microwave conversion using mechanical and magnetic degrees of freedom inside a crystal	Fabian Engelhardt	B05
Coupling an Adsorbed Transition-Metal Complex to Light: Two-Channel YSR-States	Helene Müller	B05
Nonlinear optics at the single photon level with a single molecule strongly coupled to a Fabry-Pérot cavity	André Pscherer	C01
Transfer of topological properties of light onto dense ultra-cold dipolar media	Ishan Varma	C02
Periodic Ensembles of Germanium Nanohelices and Associated Müller Matrix	Günter Ellrott	C05
Dynamics of entanglement creation between two spins coupled to a chain	Sayan Roy	D02
Quantum Criticality of the long-range antiferromagnetic Heisenberg ladder	Patrick Adelhardt	D03
Ground-state properties of the Boson-Hubbard model on triangular lattice bilayer systems	Jan Koziol	D03
From non-Hermitian quantum spin models to frustrated open assemblies	Lea Lenke	D03
Cavity induced long-range interactions in the Fermi Hubbard model	Paul Fadler	D06
Optimal control of 4-level qubits Simultaneous readout and reset of superconducting qubits	Alexander Simm	Z02
Irreversibility investigated using quantum computing	Riccardo Roma	

Posters Session II

Title	Presenter	Area
Polarization-entangled photons from ultrathin nonlinear layers	Vitaliy Sultanov	C05
Non-local losses in cavity QED	Oksana Chelpanova	D04

Spatial-temporal correlations of the light of an ion crystal

by Stefan Richter

We measured first [1] and second order correlation functions of the light spontaneously emitted from a trapped, cold two-ion crystal for various detector positions in the temporal regime. Strikingly, the $g^{(2)}(x^{\rightarrow}, \tau)$ signal shows bunching or antibunching for different observer positions [2]. Position sensitive Micro Channel Plate detectors developed for applications in fluorescence lifetime microscopy combining a high spatial resolution with temporal resolution. By using two detectors in correlation mode, it is possible to implement intensity interferometry with the light of a two-ion crystals. The spatial modulation of $g^{(2)}(x_1^{\rightarrow}, x_2^{\rightarrow}, \tau)$ was predicted in [3] and can now be measured by recording the corresponding two photon events for any time difference ΔT and corresponding positions $x_1^{\rightarrow}$ and $x_2^{\rightarrow}$. After the event stream is recorded, the correlations for arbitrary geometries can be reconstructed.

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Remote Imaging in a Three Atom System

by Manuel Bojer

The time evolution of a system consisting of three two-level atoms spontaneously emitting photons gives rise to a time-dependent electric field amplitude in the far field. We study a system for which two atoms are very close to each other such that they are influenced by their dipole-dipole interaction. Although the residual atom is meant to be far away and thus does not interact with the collective subsystem, it can be used to alter the system's emission properties via measurement induced entanglement. We find a detection setup for which Glauber's third-order intensity correlation function shows an oscillatory behavior with respect to the position of the residual third atom that shifts in time with frequency given by the coherent coupling parameter between the first two atoms. This parameter crucially depends on the separation, particularly for small separations, enabling us to resolve the distance between the two close-by atoms with sub-Abbe resolution by analysing the time course of the correlation function for a fixed position of the third atom.

Incoherent diffractive Imaging with hard X-rays

by Sebastian Karl

Contrary to conventional coherent diffractive imaging (CDI), incoherent diffractive imaging (IDI) aims to utilize intensity correlations of incoherent hard x-ray fluorescence for diffractometric imaging. Utilizing incoherently scattered x-rays boosts IDI resolution beyond the values attainable with CDI, and correlation imaging enables the extraction of 3d information from a single sample information. We present the theoretical basis of IDI and simulation results for an upcoming initial phantom target beamtime at the European XFEL.

Towards Measurement-Based Variational Quantum Simulation of the Multi-Flavor Lattice Schwinger Model with a Flavor-Dependent Chemical Potential

by Stephan Schuster

Variational quantum simulations use classical optimization routines and trial state generation on a quantum computer in a closed feedback loop to investigate physical systems. Such simulations have already been successfully applied to different quantum theoretical models as well as to classical combinatorial problems using the quantum circuit model [1-3]. More recently, a variational quantum simulation of the lattice Schwinger model has been proposed which uses a one-way quantum computation instead of a quantum circuit [4]. This shifts the experimental challenges from complex gate realizations to the generation of an certain entangled state, which is then locally measured. In our work, we want to further explore variational quantum simulations in the one-way model and aim towards actual experimental realizations of one-way quantum computations as a long term goal. In a first step, we developed a one-way simulation protocol for the multi-flavor lattice Schwinger model in a flavor-dependent chemical potential, by considering model-specific symmteries in our quantum algorithm. The flavor-dependent potential makes this model more complex than the normal lattice Schwinger model, which makes the simulations more challenging. Our Investigations aim towards the regime where the conventional Monte Carlo approach would suffer from the so-called sign problem [5] and especially towards the massive regime, where no analytical predictions exist so far [6]. First classical simulation results of our quantum simulation protocol in the massless regime are very promising. We are currently trying to extend our simulations of this model to a larger system size and the massive regime.

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Measuring the temperature of a trapped ion with light

by Marvin Gajewski

We develop a theoretical formalism which allows us to identify and quantify the contribution of thermal excitation in the resonance fluorescence of a trapped ion during laser cooling dynamics.

Theory of Color Centers in SiC Coupled to Light and Mechanics

by Maximilian Schober

Silicon carbide (SiC) is a wide-bandgap semiconductor with mature technological and electronic applications. Color centers in SiC, such as the silicon vacancy, the di-vacancy or the recently discovered TS-center [1] are promising candidates for single photon emitters and solid-state quantum bits. The vision of project B03 is to investigate the coupling of color centers via mechanical or optical resonator modes. In a theoretical approach complementing experiments in B03, we will address the coupling of color centers to optical resonator modes via the centers' optical excitation and relaxation cycle as well as the coupling of their defect electrons and spins to mechanical modes. Our theoretical approach combines ab initio methods in the framework of density functional and many body theories for the construction and analysis of effective models. In the first step, we investigated the atomistic origin of the TS-center. The TS-center possesses three strong PL lines with characteristic Stark shifts and splitting via strain [2]. Using the known annealing behaviour and spectral properties, the search for the atomistic models can be constrained to a limited class of vacancy-related centers. However, in SiC the same defect occurs in distinct inequivalent configurations, which poses an additional challenge for the identification. By the analysis of calculated optical and electronic signatures (Stark shifts), and comparison with experimental findings, we have tracked down a tentative model, that will be further analysed in subsequent studies. In our poster, we report current results concerning the TS center in SiC and, based on them, our plans to proceed further.

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Dopant-selective etching of 4H-SiC for the fabrication of 3D structures & brief outlook of strain-induced line splitting in TS defects)

by André Hochreiter

Silicon carbide (SiC) is well known for its outstanding material properties where its physical and chemical stability make it attractive for broad applications in harsh environments [1, 2]. Its outstanding quality factor and frequency product (Q-f), which is 28 times larger than for Si, is crucial for Microelectromechanical Systems (MEMS) [3]. The fabrication of cantilevers relies on selective etching. Dopant-selective etching of SiC was firstly demonstrated by Shor et al. in 1992 and focused on hydrofluoric acid as an electrolyte [4]. Anodic or electrochemical etching (ECE) relies on the oxidation of the SiC surface. The p-type material is etched in the dark. The localization of holes in surface bonds leads to the formation of silicon dioxide, which is dissolved in an electrolyte of potassium hydroxide (1M KOH). Despite its inertness, the semiconductor is selectively dissolved. We continue van Dorp's extensive research on anodic dissolution of n- and p-type SiC in potassium hydroxide [5, 6, 7, 8] and present 3D-etched cantilever structures. This allows on-chip fabrication from bulk SiC material. We plan to couple the mechanical properties of such a cantilever with the TS defect in 4H-SiC. This point defect shows strain-induced line splitting patterns, which were only measured qualitatively [9]. We investigate such strain-induced line splitting quantitatively either with an electrically bend cantilever of defined forces or with a squeezable nanojunction (SNJ).

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The dynamics of $^1S_0$-$^3P_1$ trapped Yb atoms in a high-finesse cavity

by Dmitriy Sholokhov

We have observed and described continuous-wave lasing from cold Yb atoms, which are magneto-optically trapped, using their $^1S_0$-$^3P_1$ transition (399 nm), inside a 5-cm-long high-finesse cavity, and pumped on the $^1S_0$-$^3P_1$ transition (556 nm) [1]. Now, we are investigating the possibility of MOT trapping using the narrower $^1S_0$-$^3P_1$ transition and generating lasing on the $^1S_0$ - $^3P_1$ clock transition (578 nm). While trapping with 556 nm light, we observe strong interaction between cavity and atoms, which are continuously pumped by the trapping MOT light, and which scatter this light into the cavity. These processes, including the time-dependent atom number inside cavity mode, lead to complex dynamics of the quantum system. We present the characterization of these dynamics in our poster.

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Optical to microwave conversion using mechanical and magnetic degrees of freedom inside a crystal

by Fabian Engelhardt

Efficient microwave to optics conversion is important for quantum information processing, since it allows linking transmission lines to processing and storage nodes in quantum networks. In this project, we study a system that can perform this frequency conversion via a magnetic dielectric in which magnetic excitations (magnons) couple to optical and microwave photons, and to mechanical vibrations. In this hybrid systems, microwave-to-optics transduction is performed via a strong linear magnon-phonon coupling. This takes into advantage the also strong and experimentally well established magnon-microwave coupling and the optomechanical coupling. We explore different parameter regimes and conclude that the efficiency can be optimised for the case when the mechanical linewidth is very small compared to the mechanical mode frequency. Furthermore, the optical linewidth has to be large enough such that moderate pump powers are still sufficient. Otherwise, critically high photon numbers would occur that damage the optical cavity. We specialise our results by estimating the coupling and decay rate for the magnetic insulator Yttrium Iron Garnet (YIG), which is the material used in state-of-the-art magnonic systems. The coupling rates are limited by the spatial mode overlap of the constituent modes, but for perfect overlap, achievable by properly designing the device, conversion efficiencies close to unity can be expected.

Coupling an Adsorbed Transition-Metal Complex to Light: Two-Channel YSR-States

by Helene Müller

Floquet Engineering by driving a system with light has proven to give rise to novel and sometimes also competing interactions, which can allow for engi- neering of material properties. Switching over to quantum light holds promise for the same controllability but without excessive heating. Here we investigate theoretically a magnetic impurity adsorbed on a s-wave superconductor using an Anderson impurity model. Coupling the system to a light mode opens up an additional channel to which the impurity couples to through an odd number of photons. We focus on intra-gap states emerging from virtual charge fluctu- ations mediated by a photon mode and investigate the system in the quantum as well as classical limit of the light field. Approximating the impurity's spin as being classical we find analytical expressions for renormalized parameters of the system. Each channel can be tuned to undergo a quantum phase transition going along with fermion parity changes of the electronic system, giving rise to a rich ground state phase diagram.

Nonlinear optics at the single photon level with a single molecule strongly coupled to a Fabry-Pérot cavity

by André Pscherer

We recently demonstrated that the zero-phonon-line (ZPL) transition of a dibenzoterrylene (DBT) molecule in an anthracene crystal can be coupled to a single mode of a Fabry-Perot cavity with an efficiency of $\beta = 93\%$, effectively turning it into a coherent two-level system [1]. We now report on entering the strong coupling regime, and present results on single-photon switching and four-wave mixing using a single molecule as a medium [2]. A single quantum emitter intrinsically responds to optical fields in a nonlinear manner because of its irregular energy level spacing. It turns out that nonlinear effects can be observed even at the single- photon level when coupled to a microcavity. To demonstrate this, we have performed an experiment in which a weak laser beam with an intensity corresponding to one photon per excited state lifetime of the molecule controls the transmission of a second laser beam through the molecule-cavity system. Furthermore, we present data on efficient four-wave mixing experiments at the single-photon level [2].

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Transfer of topological properties of light onto dense ultra-cold dipolar media

by Ishan Varma

Dysprosium is a fascinating candidate for studying correlations in dense ultra- cold media. With the largest ground state magnetic moment of all elements in the periodic table (10 μB), it offers a platform to study the effect on scattering of light due to competition/cooperation between magnetic dipole-dipole interactions (DDI) and light induced correlations. When the inter-particle distance is close to the wavelength of the interacting light, the strong magnetic DDI significantly influence the propagation of light within the atomic sample. In particular, we want to look at signatures of cooperativity in light-scattering experiments. For this, we will investigate alterations in the transversal scattering behaviour and angular emission profile of the propagated light light and also alterations in the temporal dynamics of light, like the cooperative effects of super- and subradiance. Furthermore, we also intend to study the impact of Spin and Orbital Angular Momentum of selected light states on the propagation of light in dense dipolar media. This poster presents the first steps taken in order to study the transfer of topological properties of light onto atomic media. We discuss the implementation of an algorithm that enables simultaneous shaping of amplitude and phase of laser light, using a spatial light modulator (SLM). In addition, the initial characterization of our optical dipole trap for laser cooled Dysprosium atoms, which we will use to create dense atomic samples, is also presented.

Periodic Ensembles of Germanium Nanohelices and Associated Müller Matrix

by Günter Ellrott

Glancing angle deposition allows for the growth of complex nanostructures by positioning the sample at an angle to the incoming material flux [1]. To obtain high-quality free-standing structures, temperature during growth needs to be kept low. By applying a heat shield technique using polymer resists this can be done without external cooling, greatly reducing complexity within an evaporation vacuum chamber [2]. 4H-Silicon carbide substrates were prepared with germanium seeds of 50 nm diameter and 30 nm height in a rectangular pattern with a seed spacing of 150 nm. Using glancing angle deposition combined with the heat shield technique retrofitted to an existing evaporation chamber, forests of germanium nanohelices were successfully grown by rotating substrates around their surface normal during evaporation for 2 turns. The rotation speed was coupled to the evaporation rate by a feedback loop to ensure high quality structures even under varying evaporation rates. The resulting helices have a helical pitch of 240 nm, a helical diameter of 130 nm and a total height of 480 nm. Full Müller matrix spectroscopy was done on forests of both left and right chirality. Results show optical activity at visible light wavelengths related to the superimposed chirality which would not be expected in bulk material.

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Dynamics of entanglement creation between two spins coupled to a chain

by Sayan Roy

Abstract: We study the dynamics of entanglement between two spins which is created by the coupling to a common thermal reservoir. The reservoir is a spin 1/2 Ising transverse field chain thermally excited, the two defect spins couple to two spins of the chain which can be at a macroscopic distance. In the weak-coupling and low-temperature limit the spin chain is mapped onto a bath of linearly interacting oscillators using the Holstein -Primakoff transformation. We analyze the time evolution of the density matrix of the two defect spins for transient times and deduce the entanglement which is generated by the common reservoir. We discuss several scenarios for different initial states of the two spins and for varying distances.

Quantum Criticality of the long-range antiferromagnetic Heisenberg ladder

by Patrick Adelhardt

High-order series expansions using the method of perturbative continuous unitary transformations (pCUT) on white graphs in combination with classical Monte Carlo simulations for the graph embedding in the thermodynamic limit are used to study the quantum-critical breakdown including critical exponents of the one-dimensional long-range antiferromagnetic Heisenberg two-leg ladder. In particular, I study the closing of the elementary excitation gap and the divergence of the control-parameter susceptibility and the one-quasi-particle spectral weight in the rung-singlet phase to extract the critical point and all canonical critical exponents using (hyper-)scaling relations as a function of the decay exponent. Linear spin-wave calculations and exact diagonalization are used to supplement the pCUT results.

Ground-state properties of the Boson-Hubbard model on triangular lattice bilayer systems

by Jan Koziol

The ground-state properties of the Boson-Hubbard model on triangular lattice bilayer systems are investigated by means of mean-field calculations and stochastic series expansion quantum Monte Carlo calculations. We compute phase diagrams for repulsive and attractive density-density interlayer interactions using the mean-field approach. Besides behaviour that is directly related to phases already observed in the single-layer Boson-Hubbard model on the triangular lattice like solids with a fractional filling, supersolid and superfluid phases, we also observe $\mathbb{Z}_3 \times \mathbb{Z}_2$ three sublattice ordered phases emerging on the bilayer system.

From non-Hermitian quantum spin models to frustrated open assemblies

by Lea Lenke

In contrast to conventional quantum mechanics, open systems usually require different techniques. In some cases - such as gain-loss Hamiltonians - there exists an effective description in terms of a non-Hermitian Hamiltonians. Albeit non-Hermitian, these Hamiltonians can have real spectra, e.g. if they have unbroken PT-symmetry. Despite having been developed for Hermitian problems, we successfully apply the method of perturbative continuous unitary transformations (pCUTs) to two non-Hermitian PT-symmetric quantum spin models in order to determine their low-energy physics [1]. First, we use the exactly solvable Ising chain in a non-Hermitian staggered transverse magnetic field to benchmark our high-order series expansions. Its ground-state phase diagram consists of second-order quantum phase transitions, characterized by gap closing in the symmetry-broken phase, and exceptional lines in the high-field phase. We further study the robustness of the topologically ordered phase of the two-dimensional toric code in the same non-Hermitian field by closing of the low-field gap. We find that the well-known second-order quantum phase transition of the toric code in a Hermitian uniform field extends into a large portion of the non-Hermitian parameter space. Finally, we aim at extending the method of continuous unitary transformations (CUTs) to open frustrated systems like transverse-field Ising models in terms of a Lindbladian formulation and we describe the current status of the project.

References

[1] L. Lenke, M. Mühlhauser, K.P. Schmidt, High-order series expansion of non-Hermitian quantum spin models, arXiv:2108.05760.

Cavity induced long-range interactions in the Fermi Hubbard model

by Paul Fadler

Floquet theory provides an well known frame for engineering quantum materials under time periodic driving. In recent years the usage of optical cavity modes as driving field for solid states has increasingly been investigated. In this thesis we want to focus on cavity induced long-range interactions, which are a new feature of the coupling to the cavities field compared to regular time periodic driving. We limit our investigation to the one band Fermi-Hubbard model at half filling, in which the spins of the correlated electrons form a Heisenberg anti-ferromagnet for the undriven case. We perturbatively derive the induced long-range spin-spin interactions of the system on the basis of a spin-photon Hamiltonian, that describes the magnetical and optical properties of the cavity coupled Hubbard Hamiltonian. This spin-photon Hamiltonian can be obtained by perturbatively eliminating the double occupancies of the Hubbard model. Restraining the lattice size and topology to two dimers in the cavity, which is the minimal system allowing for induced interactions, we can perform an exact diagonalization. Its result shows, that the derivation of the induced interactions from the spin-photon Hamiltonian fails, if cavity modes frequency is not much larger than the Hubbard models onsite Coulomb interaction. We explore the causes of the deviation and show, that a proper fourth-order perturbative scheme is able to calculate the systems ground state energy accurately. We conclude with an outlook on how to make this description more applicable to physical systems. Finally, we also discuss other systems, which are likely to yield interesting novel physics, if they are coupled to a cavity and the induced long-range interactions are considered.

Optimal control of 4-level qubits

by Alexander Simm

We are trying to find optimal pulses that allow the active control of higher energy states of superconducting qubits. In contrast to limiting the devices to the lowest two levels, this would double the number of accessible qubits when using four energy levels per transmon. For the numerical simulation we use the C3 software package that simulates the device chain which generates microwave signals as well as optimisation algorithms for finding the optimal time-dependent Hamiltonian.

Simultaneous readout and reset of superconducting qubits

by Alexander Simm

Simultaneous readout and reset of superconducting qubits A recent idea for non-destructive readout of superconducting qubits from cavity QED is based on the observation that the dispersive regime of the Jaynes-Cummings model shows a Lamb shift of the photon field based on the qubit's state. However, non-linear corrections to the dispersive regime make the qubit susceptible to dephasing and mixing. We try to find a way to perform a deliberately destructive readout of a qubit which will at the same time reliably reset it to the ground state. This would eliminate successive measurements and X-gate operations which are usually needed for resetting qubits.

Irreversibility investigated using quantum computing

by Riccardo Roma

The purpose of this work is to verify through implementation on a quantum processor the emergence of irreversibility in the framework of constructor theory. Irreversibility is associated with the use of a quantum homogenizer for different initial states of substrate and reservoir. When the initial state is pure and the final state is mixed, there exist a constructor. This isn't true for the reverse process. First the quantum homogenizer is studied analitically under additional hypotheses. Then more general results are obtained through numerical simulations. Afterwards the homogenizer has been implemented as a series of circuits, simulated on classical computers and executed on a quantum processor. In the circuit implementation step, a review of initialization, optimization and error correction techniques applicable to the system taken into consideration has been realized.

Polarization-entangled photons from ultrathin nonlinear layers

by Vitaliy Sultanov

In this work, we demonstrate the polarization entanglement of photon pairs generated in ultrathin nonlinear layers for the first time. The polarization state of the generated photon pairs is determined only by the nonlinearity of a source. We demonstrate a handy way of two-photon polarization state tuning by utilizing different types of spontaneous parametric down-conversion occurring simultaneously.