TUE 11: Quantum Optics and Quantum Computation

Time: Tuesday 14:15–16:15 Location: ZHG104

TUE 11.1 Tue 14:15 ZHG104

Collective photon emission of correlated atoms in free space — •Joachim von Zanthier[1], Stefan Richter[1], Sebastian Wolf[2], and Ferdinand Schmidt-Kaler[2] — [1]Universität Erlangen-Nürnberg, 91058 Erlangen — [2]Universität Mainz, 55128 Mainz

Superradiance is one of the enigmatic problems in quantum optics since Dicke introduced the concept of coherent spontaneous emission by an ensemble of identical atoms in highly entangled Dicke states [1]. While single excited Dicke states have been investigated, the production of Dicke states with higher number of excitations remains a challenge. We generate these states via successive measurement of photons at particular positions in the far field starting from the fully excited system [2]. In this case, the collective system cascades down the ladder of symmetric Dicke states each time a photon is recorded. We apply this scheme to demonstrate directional super- and subradiance with two trapped Ca+ ions [3]. The arrangement for preparing the Dicke states and subsequently recording directional super- and subradiance corresponds to a generalized HBT setup. This shows that the two fundamental phenomena of quantum optics, Dicke superradiance and HBT interference, are two sides of the same coin. We also outline how to map the symmetric Dicke states onto the long-lived ground state Zeemann-levels of the Ca+ ions [4].

[1] R. H. Dicke, Phys. Rev. 93, 99 (1954).
[2] S. Oppel et al., PRL 113, 263606 (2014).
[3] S. Richter et al., PRR 5, 013163 (2023).
[4] M. Verde et al., ArXiv 2404.12513.

TUE 11.2 Tue 14:30 ZHG104

Training non-linear optical neural networks with Scattering Backpropagation — •Nicola Dal Cin[1,2], Florian Marquardt[1,2], and Clara Wanjura[1] — [1]Max Planck Institute for the Science of Light, Staudtstraße 2, 91058 Erlangen, Germany — [2]Department of Physics, University of Erlangen-Nuremberg, 91058 Erlangen, Germany

As deep learning applications continue to deploy increasingly large artificial neural networks, the associated high energy demands are creating a need for alternative neuromorphic approaches. Optics and photonics are particularly compelling as they offer high speeds and energy efficiency. Neuromorphic systems based on non-linear optics promise high expressivity with a minimal number of parameters. However, so far, there is no efficient and generic physics-based training method with gradients for non-linear optical systems with dissipation. In this work, we present "Scattering Backpropagation", the first efficient physics-inspired method for experimentally measuring approximated gradients for nonlinear optical neural networks. Remarkably, our approach does not require a mathematical model of the physical nonlinearity, and only involves two measurements of the system to compute all gradient approximations. In addition, the estimation precision depends on the deviation from reciprocity. We successfully apply our method to well-known benchmarks such as XOR and MNIST. Our method is widely applicable to existing state-of-the-art, scalable platforms, such as optics, microwave, and also extends to other physical platforms such as electrical circuits.

TUE 11.3 Tue 14:45 ZHG104

Hybrid Qubit Encoding: Splitting Fock Space into Fermionic and Bosonic Subspaces — •Francisco Javier del Arco Santos — Institute for Computer Science, University of Augsburg, Augsburg, Germany

The main issue of computational chemistry is solving the Schrodinger Equation. In consequence, many methods have been developed in order to approximate the ground and first excited molecular states. It has already been predicted that the application of quantum computers would be useful for this research area. However, nowadays quantum computers still being reduced in number of qubits (order of a few hundred) and with relatively high noise. Efficient encoding of electronic operators into qubits is essential for quantum chemistry simulations. Most of the methods treat Fermionic degrees of freedom and qubits one a one-to-one fashion, handling their interactions. Alternatively, pairs of electrons can be represented as quasi-particles and encoded into qubits, significantly simplifying calculations. This work presents a Hybrid Encoding that allows splitting the Fock space into Fermionic and Bosonic subspaces. By leveraging the strengths of both approaches, we provide a flexible framework for optimizing quantum simulations based on molecular characteristics and hardware constraints. Afterwards, it has been applied in order to simulate molecular systems, which would be prohibitive without this hybrid schema.

TUE 11.4 Tue 15:00 ZHG104

Thermodynamics of the micromaser — •Anja Seegebrecht and Tanja Schilling — University of Freiburg, Freiburg, Germany

The micromaser is a very simple model to study light-matter interactions and a prototypical example in quantum optics. It can also be used in various ways to discuss quantum thermodynamics. The interaction of thermal atoms with the cavity can be interpreted as a the action of a heat bath since field ends up in a Gibbs state. But the relaxation towards steady state can be non-monotonic. This is a peculiar feature for a thermalization process. Additionally we observe that heating and cooling happen at different rates. The trapping state feature can be used to construct a quantum battery model. With coherent atoms actually useful work (ergortropy) can be stored in the cavity by preparing a pure state. We explore the charging power, extraction protocols and stability of this setup.

TUE 11.5 Tue 15:15 ZHG104

Measuring nuclear resonant phase shifts with a nanoscale double-slit experiment — •Leon Merten Lohse[1,3], Ralf Röhlsberger[4,5,6,3], and Tim Salditt[2] — [1]Universität Hamburg — [2]Georg-August-Universität Göttingen — [3]Deutsches Elektronen-Synchrotron DESY, Hamburg — [4]Friedrich-Schiller-Universität Jena — [5]Helmholtz-Institut Jena — [6]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt

An electromagnetic wave scattering with atoms experiences a phase shift that encodes information about the atoms' quantum states and photon-matter interaction. While interferometers are readily available in the optical regime, measuring phase shifts in the x-ray regime is notoriously challenging, especially at the nanometer scale. To that end, we have devised and implemented a double-waveguide interferometer on the nanometer scale, reminiscent of Thomas Young's celebrated experiment from 1801. The interferometer has enabled us to measure the phase shift that an ultrathin layer of ^{57}Fe Mössbauer nuclei coherently imprints onto x-ray photons propagating through a single-mode x-ray waveguide. Using the extracted phase shift, we were able to accurately quantify the coupling strength between photons and nuclei. Based on this, one can envision to actively control the phase in x-ray nanophotonic devices.

TUE 11.6 Tue 15:30 ZHG104

Observation of Shapiro steps in an ultracold atomic Josephson junction — •Erik Bernhart[1], Marvin Röhrle[1], Florian Binoth[1], Vijay Pal Singh[2], Ludwig Mathey[3], Luigi Amico[2,4], and Herwig Ott[1] — [1]Department of Physics and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany — [2]Quantum Research Centre, Technology Innovation Institute, Abu Dhabi, UAE — [3]Zentrum für Optische Quantentechnologien and Institut für Quantenphysik, Universität Hamburg — [4]INFN-Sezione di Catania, Via S. Sofia 64, 95127 Catania, Italy

An ultracold atomic Josephson junction is an elementary example of quantum transport and offers a unique platform for quantum simulation of superconducting circuits. The related Josephson effect, where a dissipation-less supercurrent through a tunneling barrier is caused by a phase difference, is well known in superconductors. Is such a junction externally driven, the current-voltage characteristic displays discrete steps, named Shapiro steps, the basis of today's voltage standard. We report on the experimental observation of Shapiro steps in a driven Josephson junction in a gas of ultracold atoms. We demonstrate the universal features of the steps, most noticeable the quantization of the step height. Our experiment provides insights in the microscopic dissipative dynamics, where we observe that the dynamics are caused by phonon emission and collective excitations. The experimental results are underpinned by extensive numerical simulations. Our work expands the understanding of the microscopic dynamics of Shapiro steps and it transfers the voltage standard to ultracold quantum gases.

TUE 11.7 Tue 15:45 ZHG104

Shaping Slow Electron Beam with Plasmonic Near-field — •Fatemeh Chahshouri[1] and Nahid Talebi[1,2] — [1]Institute of Experimental and Applied Physics, Kiel University, 24098 Kiel, Germany — [2]Kiel, Nano, Surface, and Interface Science KiNSIS, Kiel University, 24098 Kiel, Germany

Recent progress in laser-induced near-field electron-photon interactions has opened new possibilities for quantum-coherent manipulation of free-electron wavepackets. In this work, we investigate how polarization, phase control, and field symmetry control inelastic and elastic interactions between slow electrons and plasmonic near-fields near gold nanorods beyond the nonrecoil approximation. First, we explore how the direction of the linear laser pulse controls energy transfer and transverse recoil of the electron beam. Extending this approach, we employ a sequential phase-locked interaction scheme and show that the initial optical phase and the phase offset between localized dipolar zones influence both amplitude and phase modulation of the electron wavepacket. Finally, we study electron shaping under the influence of a rotating plasmonic field, considering plasmonic rotors generated by two orthogonally polarized laser pulses with a controlled phase delay and circularly polarized light with defined handedness. We demonstrate angular momentum transfer and directional dependence of the electron modulation on the handedness of the plasmonic field in both real and reciprocal space. These results highlight the versatility of tailored near-fields for shaping free-electron beams and offer new tools for ultrafast interferometry and quantum-coherent electron microscopy.

TUE 11.8 Tue 16:00 ZHG104

Probing MHz Charge Dynamics in Diamond Using a Tin-Vacancy Color Center — Charlotta Gurr[1], •Cem Güney Torun[1], Gregor Pieplow[1], and Tim Schröder[1,2] — [1]Humboldt-Universität zu Berlin, Germany — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany

Color centers in diamond are affected by electric noise originating from the diamond host material itself [1]. This noise arises from free charge carriers being intermittently trapped and released by defects (charge traps) in the diamond lattice, generating a fluctuating electric field that shifts the energy levels of the color centers. As a result, the optical transitions become unstable, posing challenges for applications that rely on consistent sources of indistinguishable photons. Despite their significance, the characteristics of these charge traps remain poorly understood. In this work, we present a method to probe the dynamics of individual charge processes in diamond with MHz temporal resolution, utilizing a tin-vacancy color center. Our measurements reveal that charge capture and release rates vary across two orders of magnitude, from Hz to kHz, suggesting the presence of two distinct mechanisms governing these processes. Additionally, we observe that illumination with 520 nm light more strongly affects the charge release rates than higher-energy 445 nm light. These results provide new insights into the nature of charge traps in diamond and the underlying dynamics of single-charge trapping and release.

[1] Pieplow, Torun et al., *Quantum Electrometer for Time-resolved Material Science at the Atomic Lattice Scale*, arXiv:2401.14290, 2024