SYQC 1: Quantum Cooperativity of Light and Matter - Session 1

Time: Thursday 10:30–12:30 Location: Audimax

Invited Talk SYQC 1.1 Thu 10:30 Audimax
Super- and subradiant states of an ensemble of cold atoms coupled to a nanophotonic waveguide — •Arno Rauschenbeutel — Department of Physics, Humboldt-Universität zu Berlin, Germany

We experimentally and theoretically investigate collective radiative effects in an ensemble of cold atoms coupled to a single-mode optical nanofiber. Our analysis unveils the microscopic (i.e., atom per atom) dynamics of the system, showing that collective interactions gradually build up along the atomic ensemble in the direction of propagation of the nanofiber-guided excitation light pulses. Our theoretical results are supported by time-resolved measurements of the light transmitted and reflected by the atomic ensemble. In particular, when the excitation pulse is switched off on a time scale much shorter than the atomic lifetime, a superradiant decay up to 17 times faster than the single-atom decay rate is observed in the forward direction, while no speed-up occurs in the backward direction. For longer time scales, our measurements reveal the evolution of the ensemble from the superradiant state to a set of states that are fully subradiant with respect to the nanofiber-guided mode. Notably, our theoretical model identifies this complex dynamics as a key feature of the time evolution of one-dimensional systems prepared in a timed Dicke state. Our results highlight the unique opportunities offered by nanophotonic cold-atom systems for the experimental investigation of collective light-matter interaction.

SYQC 1.2 Thu 11:00 Audimax
Cooperative effects in dense cold atomic gases including magnetic dipole interactions — •Nico Bassler[1,2], Marvin Proske[3], Ishan Varma[3], Niels Petersen[3,4], Patrick Windpassinger[3,4], Kai Phillip Schmidt[1], and Claudiu Genes[2] — [1]Department of Physics, Friedrich-Alexander-Universität (FAU) Erlangen Nürnberg — [2]Max-Planck-Institut für die Physik des Lichts, Erlangen — [3]QUANTUM, Institut für Physik, JGU Mainz — [4]Graduate School Materials Science in Mainz

We theoretically investigate cooperative effects in cold atomic gases exhibiting both electric and magnetic dipole-dipole interactions, such as occurring in Dysprosium gases. In the quantum non-degenerate case, a quantum optics path is taken to show the emergence of tailorable XXZ quantum spin models in the high excitation limit. In the opposite case of the low excitation limit, we aim to provide analytical and numerical results detailing the effect of magnetic interactions on the directionality of scattered light and characterize sub- and superradiant effects. In the quantum degenerate case, we consider a many body physics approach in order to show the interplay between sub- and superradiance and the fermionic or bosonic quantum statistics of the gas.

SYQC 1.3 Thu 11:15 Audimax
Collective photon emission patterns from two atoms in free space — •Stefan Richter[1], Sebastian Wolf[2], Joachim von Zanthier[1], and Ferdinand Schmidt-Kaler[2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Staudtstraße 1, 91058 Erlangen — [2]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany

Modification of spontaneous decay in space and time is a central topic of quantum physics. It has been predominantly investigated in cavity quantum electrodynamic systems. However, altered spontaneous decay may equally result from correlations among the emitters in free space, as observed in super- and subradiance. Yet, such projective preparation of an entangled quantum state and the resulting modified emission pattern has not been observed due to the lack of ultra-fast multi-pixelated cameras. Using two trapped ions in free space, we projectively prepare atoms and observe the corresponding collective photon emission. Depending on the direction of detection of the first photon, we record fundamentally different emission patterns, including super- and subradiance. Our results demonstrate that the detection of a single photon may fundamentally determine the subsequent collective emission pattern of an atomic array, here represented by its most elementary building block of two atoms.

SYQC 1.4 Thu 11:30 Audimax
Modified spontaneous emission rates in free space via conditional measurements — •Manuel Bojer[1], Lukas Götzendörfer[1], Romain Bachelard[2], and Joachim von Zanthier[1] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Departamento de Física, Universidade Federal de São Carlos, Rodovia Washington Luís, km 235 - SP-310, 13565-905 São Carlos, SP, Brazil

We study the emission properties of three identical two-level atoms initially prepared in the excited state by measuring Glauber's third-order intensity correlation function. Assuming two of the three atoms located close to each other, such that they are subject to the dipole-dipole interaction, while the third one is placed several wavelengths away, we observe super- or subradiant emission behavior for the last recorded photon. Differently from the case where no conditional measurements are performed and/or no remote atom is present, the emission pattern presents both spatial and temporal modifications. In fact, the first two conditional photon measurements associated with the three-photon correlation function entangle the remote atom with the two other atoms while the dipole-dipole interaction between the two close atoms allows manipulating the decay rates, leading to a rich interference pattern for the last recorded photon with effective symmetric and antisymmetric decay rates depending on the direction of observation.

SYQC 1.5 Thu 11:45 Audimax
Coulomb interactions in pulsed laser-triggered electron beams from tungsten needle tips — •Stefan Meier, Jonas Heimerl, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Tungsten needle tips represent well-suited electron sources for various applications, including electron diffraction, electron microscopy or electron holography. In cold field emission, these tips provide a highly coherent electron beam, with coherence being the key parameter for most electron-optical applications. When femtosecond laser pulses are focused on the tip, electrons can be emitted promptly, leading to an ultrafast pulsed electron source. Previously, we could show that femtosecond pulsed electron emission is spatially as coherent as cold field emission from the same tip when operated with currents well below one electron per pulse on average [1]. In this talk, we show that the spatial coherence decreases when more than one electron per pulse is emitted on average, starting already at below one electron per pulse. These results are quantitatively well supported by numerical point-particle simulation results. Last, we show that the coherence decrease can be interpreted as an effective source size growth [2]. We will conclude with an outlook on the current status of correlation measurements, which might allow us to enter the quantum correlation regime and might, ultimately, yield quantum limited electron beams.

[1] S. Meier *et al.*, Appl. Phys. Lett. **113**, 143101 (2018).
[2] S. Meier and P. Hommelhoff, manuscript submitted.

Invited Talk SYQC 1.6 Thu 12:00 Audimax
Cooperative Effects in Pigment-Protein Complexes: Vibronic Renormalisation of System Parameters in Complex Vibrational Environments — •Susana F. Huelga — Institute of Theoretical Physics and IQST, Ulm University, Germany

The primary steps of photosynthesis rely on the generation, transport and trapping of excitons in pigment-protein complexes (PPCs). Generically, PPCs possess highly structured vibrational spectra, combining many discrete intra-pigment modes and a quasi-continuous of protein modes, with vibrational and electronic couplings of comparable strength. The intricacy of the resulting vibronic dynamics poses significant challenges in establishing a quantitative connection between spectroscopic data and underlying microscopic models. By considering two model systems, namely the water-soluble chlorophyll-binding protein of cauliflower and the special pair of bacterial reaction centers, we show how to address this challenge using numerically exact simulation methods. We demonstrate that the inclusion of the full multi-mode vibronic dynamics in numerical calculations of linear optical spectra lead to systematic and quantitatively significant corrections to electronic parameter estimation. These multi-mode vibronic effects are shown to be relevant in the longstanding discussion regarding the origin of long-lived oscillations in multidimensional nonlinear spectra.