SYQC 2: Quantum Cooperativity of Light and Matter - Session 2

Time: Thursday 14:00–16:00 Location: Audimax

Invited Talk SYQC 2.1 Thu 14:00 Audimax

Quantum simulation with coherent engineering of synthetic dimensions — •Paola Cappellaro — Nuclear Science and Engineering Department, Massachusetts Institute of Technology (MIT), Cambridge, USA

The high controllability of engineered qubit systems can be leveraged to explore exotic condensed matter systems by simulating synthetic topological phases of matters. Observation of novel effects can be achieved even in small quantum systems by exploiting their periodic driving, which can mimic the properties of spatially periodic materials and elucidate their symmetry and topological features. Two challenges have so-far prevented such exploration, the lack of an experimentally accessible characterization protocol and of strong-enough driving fields. Here I'll show how to overcome both challenges to achieve the first experimental study of dynamical symmetries and the observation of symmetry-protected selection rules * and their breaking. I will further show how these methods can be used to synthesize and characterize a tensor monopole in the 4D parameter space described by the spin degrees of freedom of a single solid-state defect in diamond. These results demonstrate the power of coherent control and Floquet engineering for quantum simulation.

SYQC 2.2 Thu 14:30 Audimax

Excitonic tonks-girardeau and charge-density wave phases in monolayer semiconductors — •Rafał Ołdziejewski[1,2], Alessio Chiocchetta[3], Johannes Knörzer[1,2], and Richard Schmidt[1,2] — [1]Max-Planck-Institute of Quantum Optics, Hans-Kopfermann-Straße 1, D-85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, D-80799 München, Germany — [3]Institute for Theoretical Physics, University of Cologne, Zülpicher Strasse 77, 50937 Cologne, Germany

Excitons in two-dimensional semiconductors provide a novel platform for fundamental studies of many-body interactions. In particular, dipolar interactions between spatially indirect excitons may give rise to strongly correlated phases of matter that so far have been out of reach of experiments. Here, we show that excitonic few-body systems in atomically thin transition-metal dichalcogenides confined to a one-dimensional geometry undergo a crossover from a Tonks-Girardeau to a charge-density-wave regime. To this end, we take into account realistic system parameters and predict the effective exciton-exciton interaction potential. We find that the pair correlation function contains key signatures of the many-body crossover already at small exciton numbers and show that photoluminescence spectra provide readily accessible experimental fingerprints of these strongly correlated quantum many-body states.

SYQC 2.3 Thu 14:45 Audimax

Propagation of ultrashort pulses in resonant X-ray waveguides — •Petar Andrejić[1], Leon Merten Lohse[2,3], and Adriana Pálffy[1] — [1]Friedrich-Alexander Universität Erlangen-Nürnberg — [2]Deutsches Elektronen-Synchrotron — [3]Georg-August-Universität Göttingen

Thin film structures are a well established and powerful platform for coupling and control of X-rays with resonant Mössbauer nuclei. Existing formalisms describe well the collective nuclear response in grazing incidence experiments, including for inhomogeneous hyperfine splittings [1], however, these formalisms assume long duration, well collimated synchrotron pulses, such that the problem can be considered quasi-monochromatic, with uniform amplitude.

Here, we show that ultrashort X-ray pulses coupled into to a thin film waveguide can propagate as guided modes over millimetre scale distances. The guided wave spectrum and spatial profiles are obtainable using the existing Green's function formalism. The coupling of the guided modes to the resonant nuclei embedded within the waveguide leads to a set of first order, few-mode Maxwell-Bloch equations, from which we obtain the transmission spectra of the waveguide. We discuss the properties of these spectra, including the role of the resonant nuclei in coupling otherwise orthogonal guided modes to each other, as well as the connection with the super-radiance decay and the collective Lamb shift previously observed in grazing incidence.

[1] P. Andrejić and A. Pálffy, Phys. Rev. A 104, 033702 (2021)

SYQC 2.4 Thu 15:00 Audimax

A systematic study of entanglement mediated by a thermal reservoir. — •Sayan Roy, Christian Otto, Raphaël Menu, and Giovanna Morigi — Theoretical Physics, Department of Physics, Saarland University, 66123 Saarbrücken, Germany

Entanglement is the main reason that allows quantum protocols to surpass the classical ones [1]. However, because of its quantum nature, it gets destroyed due to decoherence processes that occur as a result of interaction of the system with its surrounding environment [2]. Here, we investigate a model where environment-induced entanglement is observed. We consider two non-interacting defect spins coupled to a common thermal reservoir, modeled by a spin-$\frac{1}{2}$ Ising chain in a transverse field. Hereby, each of the defect spins is coupled to only one spin of the chain. We analyze the time evolution of the density matrix of the two defect spins which are initially prepared in a separable state. We identify three different regimes characterizing the dynamics of quantum correlations, which depend on the strength of the coupling between defect spins and spin chain. We discuss several scenarios by varying the distance and coupling strength between the two spins and provide physical insights into the dynamics.

[1] R. Horodecki, M. Horodecki and K. Horodecki Rev. Mod. Phys. **81(2)**, 865-942 (2009).
[2] W.H. Zurek Rev. Mod. Phys. **75(3)**, 715-775, (2003).

SYQC 2.5 Thu 15:15 Audimax

Applying continuous unitary transformations to open quantum systems — •Lea Lenke, Matthias Mühlhauser, and Kai Phillip Schmidt — Lehrstuhl für Theoretische Physik I, Staudtstraße 7, Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

We generalize the method of continuous unitary transformations (CUTs) to certain types of open systems. In some cases – such as gain-loss Hamiltonians – there exists an effective description in terms of non-Hermitian Hamiltonians. For the latter we successfully apply a perturbative CUT (pCUT) to two non-Hermitian PT-symmetric quantum spin models in order to determine their low-energy physics [1]. In a next step, we aim at generalizing this method further to dissipative frustrated systems described by a Lindblad master equation.

[1] L. Lenke, M. Mühlhauser, and K. P. Schmidt, "High-order series expansion of non-Hermitian quantum spin models", Phys. Rev. B 104, 195137 (2021).

Invited Talk SYQC 2.6 Thu 15:30 Audimax

Quantum Fractals — •Cristiane Morais-Smith — Institute for Theoretical Physics, University of Utrecht, The Netherlands

The human fascination for fractals dates back to the time of Christ, when structures known nowadays as a Sierpinski gasket were used in decorative art in churches. Nonetheless, it was only in the last century that mathematicians faced the difficult task of classifying these structures. In the 80's and 90's, the foundational work of Mandelbrot triggered enormous activity in the field. The focus was on understanding how a particle diffuses in a fractal structure. However, those were **classical fractals**. This century, the task is to understand **quantum fractals**. In 2019, in collaboration with experimental colleagues from the Debye Institute, we realized a Sierpinski gasket using a scanning tunneling microscope to pattern adsorbates on top of Cu(111) and showed that the wavefunction describing electrons in a Sierpinski gasket fractal has the Hausdorff dimension d = 1.58 [1,2]. However, STM techniques can only describe **equilibrium** properties. Now, we went a step beyond and using state-of-the-art photonics experiments in collaboration with colleagues at Jiao-Tong University in Shanghai, we unveiled the **quantum dynamics** in fractals. By injecting photons in waveguide arrays arranged in a fractal shape, we were able to follow their motion and understand their quantum dynamics with unprecedented detail. We built and investigated 3 types of fractal structures to reveal not only the influence of different Hausdorff dimension, but also of geometry [3].

[1] S.N. Kempkes, M.R. Slot, S.E. Freeney, S.J.M. Zevenhuizen, D. Vanmaekelbergh, I. Swart, and C. Morais Smith, *Design and characterization of electronic fractals*, Nature Physics **15**, 127 (2019).
[2] Physics Today **72**, 1, 14 (2019) https://physicstoday.scitation.org/doi/full/10.1063/PT.3.4105

[3] X.-Y. Xu, X.-W. Wang, D.-Y. Chen, C. Morais Smith, and X.-M. Jin, *Shining light on quantum transport in fractal networks*, Nature Photonics **15**, 703 (2021).