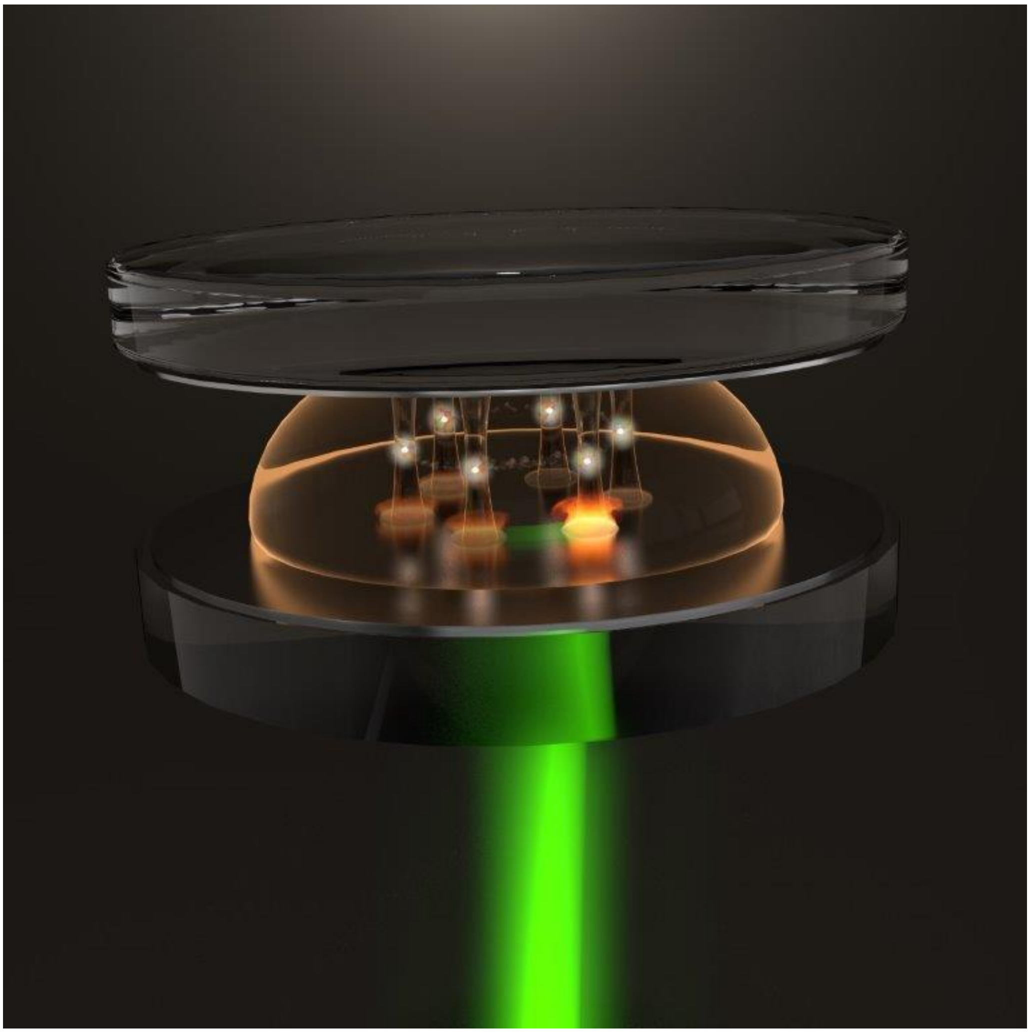
OSCAR[1] Reports–

an SFB/TR 185 quarterly magazine



[1] stands for **O**pen **S**ystem **C**ontrol of **A**tomic and Photonic Matte**R;** funded by the Deutsche Forschungsgemeinschaft since July 01, 2016

Controlling transport through an impurity by periodic drive (area A)

Transport through an AC driven impurity: Fano interference and bound states in the continuum

S. Reyes, D. Thuberg, D. Perez, Ch. Dauer, S. Eggert
New J. Phys. **19**, 043029 (2017)

Controlling charge- and spin-transport in solid-state materials is a very challenging task. For example in order to change the key parameters of excitation transport in tight-binding models - the hopping matrix elements be-tween lattice sites - one has to exert pressure or change the chemical composition of the material. An important goal of research area A is to develop and explore new mechanisms to modify fundamental transport parameters of quantum systems. In recent years a very versatile approach has been developed thereto, utilizing fast periodic driving. This Floquet engineering allows an in-situ control of amplitudes and also phases of the hopping. The latter corresponds to the action of effective gauge fields and has led to the development of a whole new class of materials, so-called Floquet topological insulators.

Periodic driving can also result in resonance phenomena. An important example are AC-driven localized bound states embedded in the continuum of scattering states. In a recent theoretical study the group of Sebastian Eggert has now shown that these *bound states in the continuum*, first proposed by von Neumann and Wigner in 1929, can be created by driving an impurity in a one-dimensional quantum chain, as shown in Fig. 1, and can be utilized to locally control the transport.

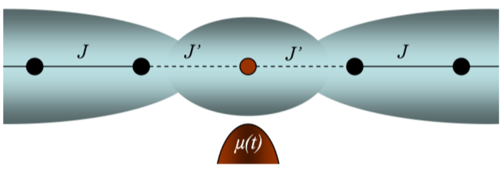


Fig. 1 Schematic setup of a one-dimensional chain with a periodically driven impurity, modelled by an oscillating chemical potential. The blue shaded areas indicate the regions of the leads and the impurity.

The model describes e.g. driven quantum dots attached to electric leads or atomic quantum gases in optical lattices with a central site for different lattice depths. It could, however, also be experimentally realized in coupled waveguide systems investigated within the CRC. Based on Floquet formalism the exact transmission probability through the impurity was calculated and a number of remarkable properties were found. As known also from other previous work it was shown that the system can be tuned to perfect transmission despite the presence of an impurity (i.e. for $\mu \neq 0$), see Fig. 2.

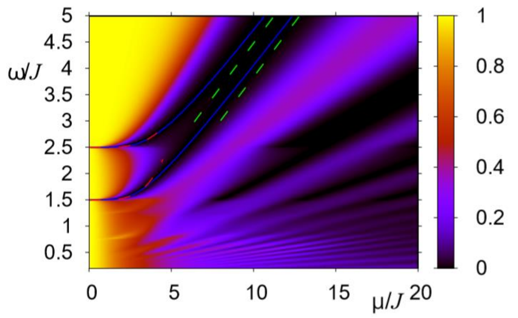


Fig. 2 Transmission probability as function of frequency ω and strength μ of the periodically driven chemical potential. The dashed green line corresponds to analytical high-frequency approximation.

On the other hand the transmission can also be completely blocked at specific high frequencies even at very small driving amplitudes, signalling a quantum resonance catastrophe caused by Fano-type resonances. As verified by the numerics the model can be mapped to a static effective model with modified hopping strength J' from and to the leads at very high driving frequencies.

The work by Reyes et al. adds an interesting element to the toolbox of coherent control of small quantum systems and provides understanding beyond a perturbative high-frequency approach.

How long-range order emerges in a photon condensate (area B)

First-order spatial coherence measurements in a thermalized two-dimensional photonic quantum gas
T. Damm, D. Dung, F. Vewinger, M. Weitz, J. Schmidt, Nature Comm. **8** 158 (2017)

The emergence of long-range order is the hallmark of Bose-Einstein condensation of a thermal gas of massive bosons forming a macroscopically occupied state. Close to the critical point of the phase transition the correlation length is expected to behave in a universal way and should display a characteristic scaling. While the build-up of long-range coherence and the associated critical scaling have been verified for massive particles in many experiments, similar observations for optical quantum gases such as exciton polaritons or photons have been difficult due to cavity losses and finite-size effects. In a recent experiment by Tobias Damm and coworkers, the group of Martin Weitz reported the first quantitative study of first-order coherence of a photon gas when crossing the BEC transition.

In a two-dimensional trapped quantum gas the phase transition can be either of the Bose-Einstein or the Berezinskii-Kosterlitz-Thouless type depending on the role of interactions. A quantitative measurements of the correlation length can shed light thereon and allows to extract critical exponents.

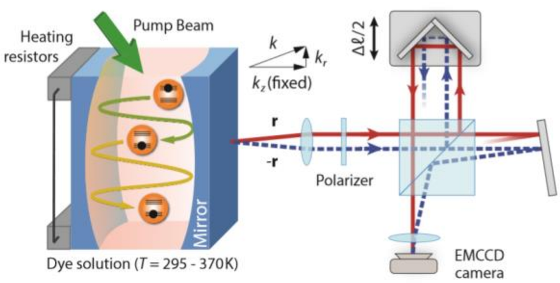


Fig. 3 Dye filled microcavity confining a two-dimensional gas of photons with effective mass. To investigate the transversal and longitudinal coherence a Michelson interferometer is used.

In the experiment, the trapped photon gas is prepared in the microcavity setup shown in Fig. 3. Absorption and reemission of photons from a liquid dye solution guarantees thermalization on a time-scale short compared to the cavity lifetime. Since the number of photons is not conserved due to possible effective particle exchange with the photo-excitable dye-molecules, the system is actually in a grand-canonical setting.

First-order correlations are detected by a Michelson interferometer. Using a retroreflector instead of a mirror in the reference arm inverts the two-dimensional image and thus leads to an interference of photons emitted from points ***r*** and -***r*** in the transverse plane. Observing the visibility of the interference pattern thus allows to extract the transverse coherence length. Temporal correlations and the corresponding longitudinal coherence length are measured by scanning the longitudinal position of the retroreflector. First the temperature dependence of the transverse coherence length above the critical temperature of condensation was investigated and found to agree well with the expected $T^{-1/2}$ behaviour of a non-interacting Bose gas. Then, by increasing the driving strength, the photon number was changed from below to above the critical value of condensation. Below condensation the coherence length corresponds to the thermal de-Broglie wavelength of the photon gas. At the phase transition the correlation length shows a sharp increase way above the value set by the full-width-half-maximum of the TEM_{00} mode (see Fig. 4).

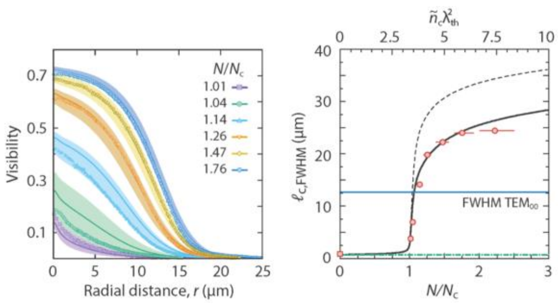


Fig. 4 Emerging of long-range correlations in a photon condensate when crossing the BEC transition. *Left*: Variation of fringe visibility with distance from trap center for different photon numbers N just above the critical value N_c. Symbols are experimental data, solid curves are theoretical predictions with uncertainty range. *Right:* transverse coherence length along with theoretical predictions without (dashed) and with (solid) technical limitations taken into account.

The results agree very well with theoretical predictions for a non-interacting Bose gas.

Dissipation speeds up correlation spread in many-body systems (area B)

Remnants of light-cone propagation of correlations in dissipative systems
J.S. Bernier, R.Tan, L. Bonnes, Chu Guo, D. Poletti, C. Kollath
Phys. Rev. Lett. **120**, 020401 (2018)

Understanding the physical principles of the non-equilibrium dynamics of complex quantum systems is one of the outstanding questions of many-body physics. An important aspect thereof is the spread of quantum correlations in a system which, among other things, determines the dynamics of phase transitions from a disordered to an ordered phase and could help to understand how these transitions can be induced dynamically. For unitary quantum systems with finite dimensional local Hilbert space, which are described by a local Hamiltonian, the seminal work of Lieb and Robinson[2] showed that the spread of correlations after a sudden change of parameters is characterized by an effective light cone. An interesting and unsolved question is how this picture changes in an open system, i.e. when there is a coupling to reservoirs. While the coupling to reservoirs is generically expected to lead to a reduction of the amplitude of correlations, the effect on their spread is not clear. In a very recent work by Jean-Sebastien Bernier and co-workers, the group of Corinna Kollath found a very surprising result: Decoherence can speed up the propagation of correlations and may thus affect the dynamics of phase transitions in an unexpected way.

The work considers the one-dimensional Bose-Hubbard model deep in the Mott-insulating regime subject to local dephasing noise. The model is non-trivial but simple enough to be able to perform numerical simulations of the many-body density matrix using a time-dependent matrix product state (t-MPS) method. The numerical investigations were complemented by approximate analytical studies in terms of holon and doublon excitations.

The presence of noise typically destroys the light-cone character of the build-up of correlations after a sudden change of parameters when the system is initially prepared in an equilibrium state. E.g. it changes the transport of particles in the Bose-Hubbard model from ballistic to diffusive. In the present system it was found, however, that the light-cone spreading of correlations persists at least for the intermediate time that could be simulated numerically, even though the size of correlations decreased exponentially, see Fig 5.

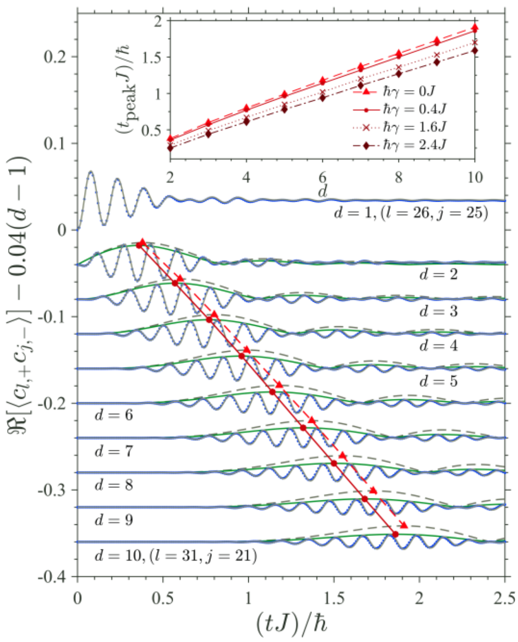


Fig. 5 Time evolution of the real part of the single-particle correlator over distance *d* after a sudden quench in the Mott insulating regime with (red circles) and without dissipation (red triangles). Blue dots correspond to t-MPS simulation, the full green and dashed lines show corresponding envelopes. The insert shows times at which the first maximum reaches a given distance for different dissipation strength.

It was also shown that the dephasing does not affect all correlations in the same way. While under unitary and dissipative dynamics, first-order correlations spread ballistically, density-density correlations are strongly modified by the coupling to the environment. This is because dephasing leads to heating and thus to creation of holons and doublons. As a consequence the spread of density correlations quickly turns from ballistic to diffusive destroying the light-cone structure.

[2] E.H. Lieb and D.W. Robinson, Commun. Math. Phys. **28**, 251 (1972)