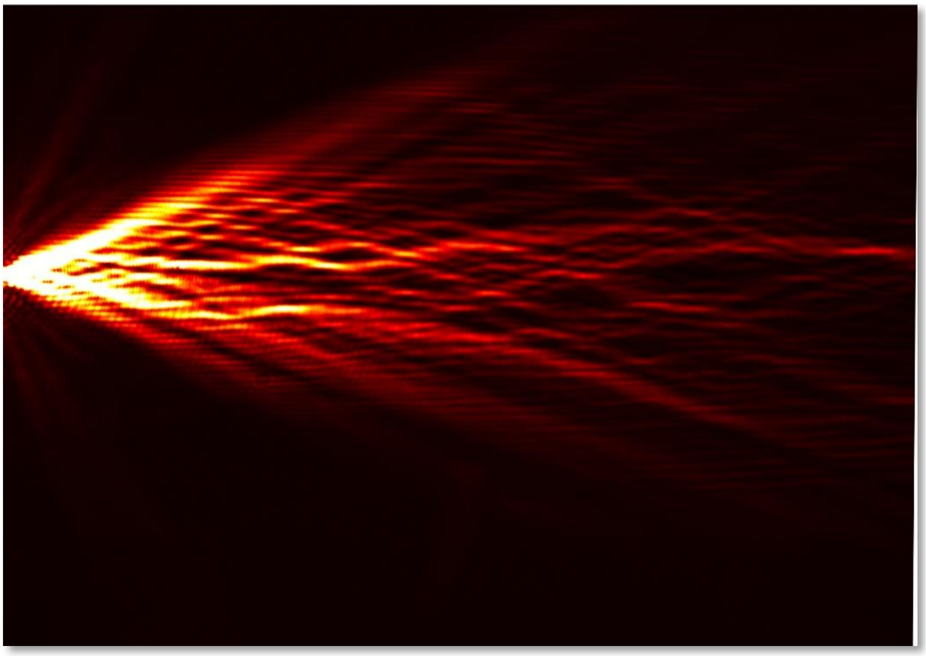
OSCAR[1] Reports–

an SFB/TR 185 quarterly magazine (3/2019)

Author: Prof. Dr. Johann Kroha



[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

Periodically Driven Many-Body Systems: A Floquet Density Matrix Renormalization Group Study (Area A)

Developing the density matrix renormalization group method for steady-state nonequilibrium systems with time-periodic drive

S. Sahoo, I. Schneider, S. Eggert

ArXiv:1906.00004 (2019)

Time-periodic driving is an important way of controlling and steering quantum condensed matter and ultracold gas systems. In the low-frequency or adiabatic limit, changing the Hamiltonian parameters along a closed loop in parameter space can induce quantized transport, that is, Thouless pumping, if the loop encloses a nonzero Berry flux. In the high-frequency regime, where the driving frequency is large compared to the intrinsic energy scales, effective time-averaging of the system parameters occurs which can be used to tune a system, e.g., through a phase transition like the Mott-Hubbard transition in an optical lattice. Driving at intermediate frequencies, however, can induce completely new states of matter as well as resonant impurity states. For example, a two-dimensional Dirac semimetal can be driven to a Floquet topological insulator with chiral edge states carrying quantized transport analogous to the integer quantum Hall effect.

The foundation for the emergence of such new phases of matter which are not present in the underlying, nondriven system, is the discrete structure in Fourier frequency space: The Hamiltonian can be represented in the basis of time-periodic functions of integer multiples of the driving frequency ω, the Floquet frequencies. This leads to a discrete, time-independent Hamiltonian matrix in Floquet frequency space (analogous to the reciprocal lattice for spatially periodic Hamiltonians), the Floquet Hamiltonian. Thus, this frequency lattice increases the effective dimension of a periodically driven system by one and can have profound implications for the band structure and topological properties.

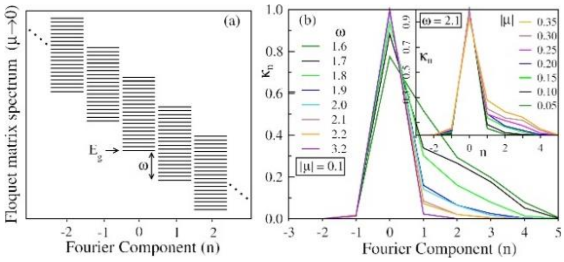


Fig. 1 (a) Infinite replication of the eigenstate spectrum due to periodic driving. (b) Contributions of different Floquet subbands n to a periodically driven state.

Another consequence is that the quasienergies ε_α, i.e., the energy eigenvalues of the quasistationary Floquet states $|\Psi_\alpha(t)\rangle$, are determined only modulo an integer multiple n of the driving frequency ω, as can be seen directly from the form of the Floquet states. Hence, the eigenstate spectrum is neither bounded from below nor from above, see Fig. 1 (a). Indeed, the lower ω, the more Floquet bands contribute significantly to the dynamics, see Fig. 1 (b). Periodically driven systems with interactions, where a numerical treatment is unavoidable, have, therefore, mostly been analyzed by direct time evolution using the time-dependent density-matrix renormalization group (tDMRG). However, this makes it difficult to understand the band structure, resonance conditions, and topological properties in the Floquet-Bloch Brillouin zone.

The group lead by I. Schneider and S. Eggert has made here an important step forward by developing the DMRG for the Floquet Hamiltonian in frequency representation. They solved the problem of the unbounded spectrum by a "shift and square" method. In a first step, for a small system the Floquet subband is determined whose ground state is adiabatically connected to (i.e., has the largest overlap with) the nondriven system. The quasienergies are defined with respect to that Floquet band. In a second step, the Hamiltonian is squared to obtain a spectrum bounded from below and to construct a normalizable density matrix. In a third step, a usual DMRG iteration is then applied to that bounded, time-independent Floquet Hamiltonian system. The steps (1) to (3) are repeated until convergence of the DMRG procedure. In their first work, the authors have applied this procedure to compute correlations functions for Heisenberg spin chains, with promising results for further applications.

Fluctuation Dynamics of an Open Photon Bose-Einstein Condensate (Area B)

Hidden oscillatory nonequilibrium fluctuations in a steady-state Bose-Einstein condensate

F. E. Öztürk, T. Lappe, G. Hellmann, J. Schmitt, J. Klaers, F. Vewinger, J. Kroha, M. Weitz

Phys. Rev. A **100**, 043803 (2019)

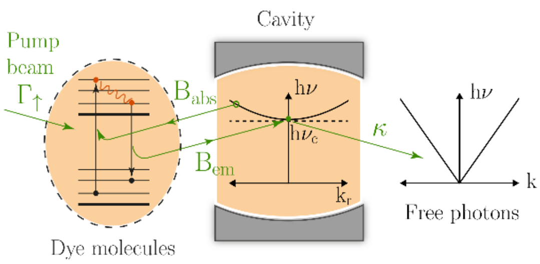


Fig. 2 Schematic view of the coupled cavity photon-dye system. Left: dye spectrum with electronic (thick lines) and rovibrational (thin lines) excitations. Center: cavity with massive photon dispersion. Right: electromagnetic environment with linear photon dispersion.

It is well known that, when a system is driven out of thermodynamic equilibrium, the fluctuations increase. This remains true even if the external drive and dissipative losses compensate each other such that a stationary equilibrium particle distribution is obtained. In electronic nanowires carrying a stationary average current these enhanced fluctuations are known as shot noise. Bose-Einstein condensates of photons in a microcavity filled with a dye solution, created by the Weitz group for the first time in 2010, constitute a peculiar driven-dissipative system. The cavity photons have a massive transverse dispersion because a discrete longitudinal mode is selected, see Fig 2. The dye molecules are pumped by an external laser to their electronic excited state, where the rovibrational excitations equilibrate fast into a thermal distribution. The dye molecules emit photons into the cavity. The photon gas equilibrates, in turn, with the rovibrational dye excitations via multiple absorption/re-emission processes and undergoes Bose-Einstein condensation above a critical photon density.

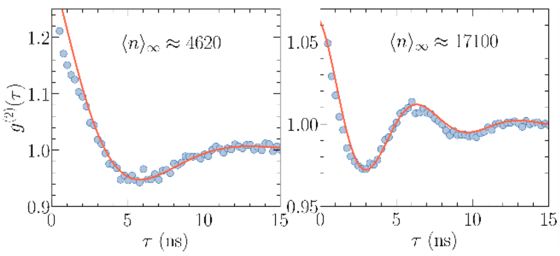


Fig. 3 Damped oscillatory behavior of the photon number correlation function $g^{(2)}(\tau)$ for two different photon numbers in the cavity. The red curves are fits of the Lindblad theory.

Despite this stationary state with (nearly) thermal spectral photon distribution above the transverse cavity ground state there is a constant flow of energy from the dye to the photon system and out to the electromagnetic environment (see Fig. 2), characterizing the photon gas as a nonequilibrium system. F. Öztürk and collaborators found that the nonequilibrium photon number fluctuations $g^{(2)}(\tau)$ are damped-oscillatory in time, see Fig. 3, in contrast to white noise. The oscillation frequency depends characteristically on the average cavity photon number. Using a Lindblad theory for the reservoir of dye excitations, they could trace back this behavior to the nonlinear, dissipative coupling of photon and dye subsystems. Thus, the oscillatory number correlations are a characteristics of the two-component, grand canonical dye-photon system with non-linear, incoherent coupling to the dye excitations.

Interferometric Near-Field Characterization of Plasmonic Slot Waveguides in Single- and Polycrystalline Gold Films (Area A&C)

Understanding loss mechanisms in nanoscale plasmonic waveguides

M. Prämassing, m. Liebtrau, H. J. Schill, S. Irsen, S. Linden

ArXiv:1907.06695 (2019)

Surface plasmon polariton waveguides are important devices to confine and guide light on scales far below the light wavelength, to couple light to nanoantennas and more. A surface plasmon polariton (SPP) is a hybrid excitation comprised of a light wave and a plasmon confined to the surface of a metal. The strong confining and guiding effect occurs because the plasmon propagation is governed by electronic length scales, in particular, by the screening length which is much shorter than the light wavelength. The light wave is then “dragged along” by the plasmon. A disadvantage of this guiding mechanism is the generally short propagation length in the micrometer range. The possible polariton decay channels are Ohmic losses due to the dissipative electron motion in the metal and radiative losses of the light field.

S. Linden and his group performed a systematical, quantitative investigation of the relative importance of these loss channels depending on various system parameters. They studied a waveguide comprised of a slot cut into a thin gold film on the surface of a glass or indium tin oxide (ITO) substrate, depending on the film quality and the slot width. To obtain accurate values for the propagation length L from a fit of the measured data to a theoretical model, it was necessary to simultaneously measure the effective index of refraction n of the waveguide. Phase-sensitive measurements of the electromagnetic field distribution were done with far-subwavelength resolution by a lock-in scanning near-field optical microscope (SNOM) with subsequent interference with a reference beam.

Their analysis, supported by theoretical finite-element simulations, showed that for large slot width the radiative loss channel dominates, because most of the excitation energy resides in the electromagnetic field inside the slot, while for small slot width the plasmonic constituent of the excitation contains most of the energy, so that Ohmic losses dominate. This trade-off means that an optimal propagation length is reached for an intermediate slot width, see Fig. 4 (b). In the Ohmic-loss dominated regime, the gold film quality is of crucial importance. Polycrystalline films have reduced propagation length compared to homogeneous film due to enhanced electronic scattering. This analysis is an important step towards optimization of SPP-wave guides.

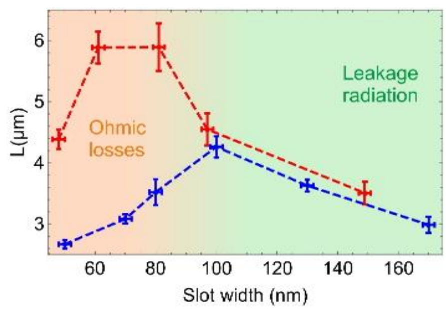


Fig. 4 Propagation length in dependence on the waveguide slot width. Red data: homogeneous film, blue data: polycrystalline film.