TT 22: Nonequilibrium Quantum Many-Body Systems I (joint session TT/DY)

Time: Tuesday 9:30–13:15 Location: HSZ 204

TT 22.1 Tue 9:30 HSZ 204

Ultrafast dynamics of quantum many-body systems including dynamical screening and strong coupling — •Michael Bonitz[1], Jan-Philip Joost[1], Hannes Ohldag[1], Erik Schroedter[1], and Iva Brezinova[2] — [1]CAU Kiel, Institute for Theoretical Physics and Astrophysics — [2]TU Wien, Institute of Applied Physics, Vienna, Austria

Dynamical screening is a key property of charged many-particle systems. Its theoretical description is based on the GW approximation that is extensively applied for ground-state and equilibrium situations. The main limitation of the GW approximation is the neglect of strong electronic correlation effects. Here we derive the nonequilibrium dynamically screened ladder (DSL) approximation that self-consistently includes, in addition to the GW diagrams, also particle-particle and particle-hole T-matrix diagrams. Our DSL approach is formulated within the G1-G2 scheme [1,2] that is linear in time, in contrast to the cubic scaling of standard Nonequilibrium Green functions simulations. The price to pay for this speedup is the need to store the two-particle Green function. This can be avoided with a recently developed quantum fluctuations approach [3].

[1] N. Schluenzen et al., Phys. Rev. Lett. 124, 076601 (2020)
[2] J.-P. Joost al., Phys. Rev. B 105, 165155 (2022)
[3] E. Schroedter et al., Cond. Mat. Phys. 25 , 23401 (2022)

TT 22.2 Tue 9:45 HSZ 204

Spectral response of a charge density wave insulator to periodic driving — •Alexander Osterkorn, Constantin Meyer, and Salvatore Manmana — Institut für Theoretische Physik, Georg-August-Universität Göttingen, Germany

Periodically driven quantum many-body systems host unconventional behavior not realized at equilibrium. Here we address in detail the emergence of a cosine-like band in the gap region of the nonequilibrium single-particle spectral function of strongly interacting spinless fermions on a chain in the charge density wave phase [1]. We compare the dynamics of the periodically driven system to the quench dynamics with an effective Floquet Hamiltonian and discuss the role of doublon excitations in both cases. This is investigated using both matrix product state based time evolution techniques as well as time-dependent Hartree-Fock. [1] arXiv:2205.09557

TT 22.3 Tue 10:00 HSZ 204

Floquet engineering in tilted lattices — •Melissa Will[1], Pablo Sala[2,3], and Frank Pollmann[1] — [1]Department of Physics, T42, Technische Universität München, James-Franck-Straße 1, D-85748 Garching, Germany — [2]Department of Physics and Institute for Quantum Information and Matter, California Institute of Technology, Pasadena, California 91125, USA — [3]Walter Burke Institute for Theoretical Physics, California Institute of Technology, Pasadena, California 91125, USA

Quantum many-body systems out of equilibrium can exhibit very rich and exciting phenomena. A particularly important question is whether and how a quantum system thermalizes under unitary evolution. In this context three classes of systems have been identified: ergodic, localized and an intermediate regime exhibiting so called quantum many-body scars. In this talk we discuss whether a time-periodic, local drive can induce thermalization of a localized system. We consider interacting hard-core bosons in an one dimensional, tilted system with periodic driving. We find that the system becomes ergodic for resonant driving frequencies. In contrast, if the tilt is not close to a multiple of driving frequency, the system stays localized. This observation can theoretically be understood by deriving an effective Hamiltonian using a Magnus expansion. Using large scale numerical methods, we explore entanglement entropy and imbalance over time. Our theoretical predictions are in good agreement with numerics.

TT 22.4 Tue 10:15 HSZ 204

Photoinduced spinful excitons in Hubbard systems with magnetic superstructures — Constantin Meyer and •Salvatore R. Manmana — Institute for Theoretical Physics, Göttingen University, Friedrich-Hund-Platz 1, 37077 Göttingen

The possibility to form excitons in photo-illuminated correlated materials is central from fundamental and application oriented perspectives. We show how the interplay of electron-electron interactions and a magnetic superstructure leads to the formation of a peculiar spinful exciton, which can be detected in the nonequilibrium spectral function and the time-dependent optical conductivity. We study these quantities by using matrix product states (MPS) following an electron-hole excitation in a class of one-dimensional Hubbard models with on-site interactions and alternating local magnetic fields, which realize correlated band insulators. An excitation in only one specific spin direction leads to an additional band in the gap region of the spectral function only in the opposite spin direction, and to an additional peak in the optical conductivity. We discuss implications for experimental studies in correlated insulator systems.

TT 22.5 Tue 10:30 HSZ 204

Photoinduced pairing states of excitonic insulators — •Satoshi Ejima — DLR Quantencomputing-Initiative, Hamburg, Germany

Applying the time-dependent density-matrix renormalization group technique, we explore photoinduced pairing states in the half-filled extended Falicov-Kimball model (EFKM) in one dimension, both with and without internal SU(2) symmetry. In the time-dependent photoemission spectra simulated with the optimal pump pulse parameters, an extra band appears above the Fermi energy after pulse irradiation, implying a photoinduced metallization. Even in the absence of the SU(2) structure, the electron-electron pair correlations can also be enhanced during the pump, while they decrease over time after pulse irradiation. This suggests a possible photoexcited metallization of Ta_2NiSe_5, a strong candidate for an excitonic insulator material, for which the EFKM is considered to be the minimal theoretical model. Computing the time-dependent photoemission spectra with the parameter set for this material, i.e., in the EFKM without SU(2) symmetry, we demonstrate the photoinduced insulator-to-metal transition, in accord with recent findings in time- and angle-resolved photoemission spectroscopy experiments on Ta_2NiSe_5.

[1] S. Ejima, F. Lange, H. Fehske, Phys. Rev. B **105**, 245126 (2022)

15 min. break

Invited Talk TT 22.6 Tue 11:00 HSZ 204

Higgs spectroscopy of superconductors in nonequilibrium — •Dirk Manske — Max-Planck-Institut für Festkörperforschung

Higgs spectroscopy is a new and emergent field [1-3] that allows to classify and determine the superconducting order parameter by means of ultra-fast optical spectroscopy. There are two important ways to activate the Higgs mode in superconductors, namely a single-cycle *quench* or an adiabatic, multicycle *drive* pulse, which I will discuss in detail. Furthermore, I will review and report on the latest progress on Higgs spectroscopy, in particular on the role of the third-harmonic-generation (THG) [4-6] and the possible IR-activation of the Higgs mode by impurities or external dc current [7,8]. I also provide new predictions for time-resolved ARPES experiments in which, after a quench, a continuum of Higgs mode is observable and a phase information of the superconducting gap function would be possible to extract [9]. Finally, I show that the Higgs mode may shed some light on the 25-years-old A1g-puzzle in equilibrium Raman scattering on high-T_c cuprates [10].

[1] Nat. Commun. 11, 287 (2020)
[2] Phys. Rev. B 101, 184519 (2020)
[3] Nat. Commun. 11, 1793 (2020)
[4] Phys. Rev. B 104, 174508 (2021)
[5] Nature Commun., accepted (2022)
[6] Nature Commun., submitted (2022)
[7] Phys. Rev. B 101, 220507 (2020)
[8] Phys. Rev. B 104, 134504 (2021)
[9] Phys. Rev. B 101, 224510 (2020)
[10] Phys. Rev. Lett. 127, 197001 (2021)

TT 22.7 Tue 11:30 HSZ 204

Periodically driven spin-1/2 XXZ antiferromagnetic chains — •Aslam Parvej, Imke Schneider, and Sebastian Eggert — Technische Universität Kaiserslautern, Kaiserslautern, Germany

Time-periodically driven quantum systems are of great interest due to the possibility of unconventional states of matter and Floquet engineering. The interplay of many-body interactions and time-periodic manipulations facilitate new phenomena in the steady state. We analyze the Floquet steady states of finite spin-1/2 XXZ antiferromagnetic chains with periodically driven anisotropy parameter at frequencies below the band width, so that resonances are in principle possible. We use a numerical real-time approach with an adiabatic time evolution protocol by ramping up the driving amplitude of the external periodic drive to prepare a non-equilibrium Floquet steady state. Parametric resonances are expected when the driving frequencies are equal to twice the energy gaps in a finite system. However, the observed resonance absorption of energy and heating is surprisingly weak in our system even for large driving amplitude. This changes if a square wave is used for driving.

TT 22.8 Tue 11:45 HSZ 204

Controllable effects of the mass term in time-periodic driven sine-Gordon models. — •Dimo Claude[1], Simon Jäger[1], Christoph Dauer[1], Piotr Chudzinski[2], Imke Schneider[1], and Sebastian Eggert[1] — [1]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany. — [2]Institute of Fundamental Technological Research, Polish Academy of Science, 02-106 Warszawa, Poland.

Recently, the full Floquet solution of a Luttinger Liquid with periodically modulated interactions has been derived and resonant wavevectors have been identified. There, the quantum state can only be stabilized when damping mechanisms of the one-dimensional systems are included. In our work, we investigate the time-periodic Luttinger Liquid under a non-linear perturbation which originates from the Sine-Gordon potential. This term provides interactions among the different modes of the Luttinger Liquid and can potentially confine the parametrically amplified modes. We investigate this model up to fourth order of the phase field using a mean-field approach. The resulting effective model is quadratic in the field operators while the non-linearity remains, due to the explicit dependence of the frequencies on the time-dependent quantum state. Using a self-consistency relation between the number of density wave excitations and the systems' energy, we discuss the formation of a non-equilibrium steady state and study its stability.

TT 22.9 Tue 12:00 HSZ 204

Influence of phononic dissipation on impact ionization processes in a photodriven Mott insulator — •Paolo Gazzaneo, Tommaso Maria Mazzocchi, Jan Lotze, and Enrico Arrigoni — Institute of Theoretical and Computational Physics, Graz University of Technology, 8010 Graz, Austria

It has been suggested that in strongly correlated materials, highly photoexcited charge carriers could use their extra energy to excite additional carriers across the Mott gap via impact ionization [1,2]. However, the influence of electron-phonon scattering on photocurrent and impact ionization in Mott photovoltaic setups is still an open question.

We address this issue in a nonequilibrium steady state study on the occurrence of impact ionization in a simplified model of a Mott photovoltaic device in presence of acoustic phonons [3], consisting of a Mott-insulating layer coupled to two wide-band fermion leads.

For a small hybridization to the leads, we obtain a peak in the photocurrent as a function of the driving frequency which can be associated with impact ionization processes, while for larger hybridizations we find a suppression of impact ionization with respect to direct photovoltaic excitations. The effect of acoustic phonons produces a slight enhancement of the photocurrent for small driving frequencies and a suppression at frequencies around the main peak at all considered hybridization strengths.

[1] E. Manousakis, Phys. Rev. B 82, 125109 (2010)
[2] J. E. Coulter et al., Phys. Rev. B 90, 165142 (2014)
[3] Gazzaneo et al., Phys. Rev. B 106, 195140 (2022)

TT 22.10 Tue 12:15 HSZ 204

Correlated Mott insulators in strong electric fields: Role of phonons in heat dissipation — •Tommaso Maria Mazzocchi, Paolo Gazzaneo, Jan Lotze, and Enrico Arrigoni — Institute of Theoretical and Computational Physics, Graz University of Technology, 8010 Graz, Austria

Mott-insulating models can undergo an insulator-to-metal transition when subject to a constant bias voltage [1], which makes them suitable to describe the resistive switch observed in correlated insulators [2]. Nonequilibrium state-of-the-art techniques rely on the coupling to fermion baths to dissipate the field-induced excess energy [1,3]. However, a realistic description of heat-exchange requires the inclusion of phonons. In [4] we study a single-band Hubbard model in a static electric field coupled to electron and acoustic phonon baths. The nonequilibrium steady-state is addressed via the dynamical mean-field theory using the auxiliary master equation approach as impurity solver. Phonons are included via the Migdal approximation. Using both the electron and phonon baths the steady-state current is slightly enhanced by phonons for field strengths close to half of the gap and suppressed at the gap resonance. With phonons alone, dissipation can occur only at the resonances and the current at the metallic phase is suppressed by almost one order of magnitude.

[1] C. Aron, Phys. Rev. B 86, 085127 (2012)
[2] E. Janod et al., Adv. Funct. Mater. 25, 6277 (2015)
[3] Y. Murakami et al., Phys. Rev. B 98, 075102 (2018)
[4] T.M. Mazzocchi et al., Phys. Rev. B 106, 125123 (2022)

TT 22.11 Tue 12:30 HSZ 204

Correlated Mott insulators and photovoltaics out of equilibrium: phonons and heat dissipation — •Enrico Arrigoni, Tommaso Mazzocchi, Paolo Gazzaneo, Daniel Werner, and Jan Lotze — Institute of Theoretical and Computational Physics, Graz University of Technology, 8010 Graz Austria

I will present recent results for correlated Mott systems in a nonequilibrium driven steady state. Results are obtained via nonequilibrium Dynamical Mean Field Theory with an impurity solver based upon a combination of Keldysh Green's functions and Lindblad formalism for open quantum systems [1]. Recent improvements based upon a Configuration Interaction treatment of the many body Lindblad equation allow for an efficient solution of the impurity problem deep in the Kondo regime [2].

In particular, I will discuss the interplay of strong correlation and Joule dissipation by phonons near the Mott dielectric breakdown [3] and in photoexcitation induced transport across a Mott insulating gap [4].

[1] E. Arrigoni et al., Phys. Rev. Lett. 110, 086403 (2013)
A. Dorda et al., Phys. Rev. B 89 165105 (2014)
A. Dorda et al., Phys. Rev. B 92, 125145 (2015)
[2] D. Werner et al., arXiv:2210.09623 (2022)
[3] T. Mazzocchi at al., Phys. Rev. B 106, 125123 (2022)
[4] M. Sorantin et al., Phys. Rev. B 97, 115113 (2018)
P. Gazzaneo et al. Phys. Rev. B 106, 195140 (2022)

TT 22.12 Tue 12:45 HSZ 204

Photoinduced prethermal order parameter dynamics in the two-dimensional large-N Hubbard-Heisenberg model — •Alexander Osterkorn and Stefan Kehrein — Institut für Theoretische Physik, Georg-August-Universität Göttingen, Germany

We study the microscopic dynamics of competing ordered phases in a two-dimensional correlated electron model [1], which is driven with a pulsed electric field of finite duration. In order to go beyond a mean-field treatment of the electronic interactions we adopt a large-N generalization of the Hubbard model and combine it with the semiclassical fermionic truncated Wigner approximation as a time evolution method. This allows us to calculate dephasing corrections to the mean-field dynamics and to obtain stationary states, which we interpret as prethermal order. We use this framework to simulate the light-induced transition between two competing phases (bond density wave and staggered flux) and find that the post-pulse stationary state order parameter values are not determined alone by the amount of absorbed energy but depend explicitly on the driving frequency and field direction. While the transition between the two prethermal phases takes place at similar total energies in the low- and high-frequency regimes, we identify an intermediate frequency regime for which it occurs with minimal heating [2].

[1] Phys. Rev. B 39, 11538 (1989)
[2] arXiv:2205.06620

TT 22.13 Tue 13:00 HSZ 204

Observation of magnon bound states in the long-range, anisotropic Heisenberg model — Florian Kranzl[1], •Stefan Birnkammer[2], Manoj Joshi[1], Alvise Bastianello[2], Rainer Blatt[1], Michael Knap[2], and Christian Roos[1] — [1]Universität Innsbruck, Innsbruck, Austria — [2]Technische Universität München, Garching, Germany

Over the recent years coherent, time-periodic modulation has been established as a versatile tool for realizing novel Hamiltonians. Using this approach, known as Floquet engineering, we experimentally realize a long-ranged, anisotropic Heisenberg model with tunable interactions in a trapped ion quantum simulator. We demonstrate that the spectrum of the model contains not only single magnon excitations but also composite magnon bound states. For the experimentally realized long-range interactions, the group velocity of magnons is unbounded. Nonetheless, for sufficiently strong interactions we observe bound states of these unconventional magnons which possess a non-diverging group velocity. By measuring the configurational mutual information between two disjoint intervals, we demonstrate the implications of the bound state formation on the entanglement dynamics of the system. Our observations provide key insights into the peculiar role of composite excitations in the non-equilibrium dynamics of quantum many-body systems.