TT 66: Ultrafast Dynamics of Light-Driven Systems

Time: Friday 9:30–12:45 Location: H2

Invited Talk TT 66.1 Fri 9:30 H2

Non-equilibrium superconductivity: from post-quench dynamics to controlling competing orders — •Peter P. Orth — Department of Physics and Astronomy, Iowa State University, Ames, Iowa 50011, USA

Understanding and controlling the non-equilibrium behavior of correlated quantum systems is one of the major research goals in condensed matter physics. It holds promise to dynamically tune material properties on ultrafast timescales. One route to optical control of correlated matter is via excitation of optical phonons. Another avenue is to excite acoustic phonons, which, due to their low excitation energies, generally leads to less heating. We demonstrate that driving acoustic phonons to a non-equilibrium state results in the remarkable phenomenon of a momentum-dependent effective temperature, by which electronic states at different regions of the Fermi surface are subject to distinct local temperatures. This has a profound effect on the delicate balance between competing ordered states in unconventional superconductors, opening a new avenue to control correlated phases. We also report on a joint theory-experiment study of THz pump-probe spectroscopy of superconductors Nb_3Sn and NbN. To quantitatively describe the superconducting gap dynamics, we present a semi-phenomenological approach that captures not only the coherent BCS gap dynamics at sub-picosecond timescales but also dissipative processes beyond BCS. Finally, we explore gap dynamics in two-band systems, where we find that the presence of two gap scales leads to the appearance of a new exponent in the universal power-law decay of the oscillations.

TT 66.2 Fri 10:00 H2

Floquet behavior of correlated systems with light-matter coupling — •Mona Kalthoff[1], James Freericks[2], Götz Uhrig[3], Dante Kennes[4], Angel Rubio[1], and Michael Sentef[1] — [1]Max-Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany — [2]Georgetown University, Washington, D.C., United States of America — [3]Technische Universität Dortmund, Dortmund, Germany — [4]Freie Universität Berlin, Berlin, Germany

Periodically driven nonequilibrium many-body systems have a quasi-energy spectrum which can be tailored by external driving fields, known as Floquet engineering of desired system properties[1]. However, continuous periodic driving is not realizable in pump-probe experiments in solids. For instance it is not clear which criteria a pulse has to meet for a system exposed to a pulsed drive to approach the Floquet limit of a periodically driven system. However, there are analytical results for noninteracting band electrons in infinite dimensions[2]. Moreover we discuss t-DMRG results for interacting 1D chains in the charge density wave phase to study the emergence of Floquet behavior for realistic pulse shapes. This builds on the recently proposed Floquet engineering in quantum chains[3].

[1] Sentef et al., Nat. Comm. 6, 7047 (2015); Uhrig et al, arXiv:1808.10199 (2018)
[2] Kalthoff et al., Phys. Rev. B 98, 035138 (2018)
[3] Kennes et al., Phys. Rev. Lett. 120, 127601 (2018)

TT 66.3 Fri 10:15 H2

Transient Floquet engineering of superconductivity — •Nagamalleswara Rao Dasari and Martin Eckstein — Department of Physics, University of Erlangen-Nuremberg, 91058 Erlangen, Germany

Intense time-periodic laser fields can transform the electronic structure of a solid into strongly modified Floquet-Bloch bands. While this suggests multiple pathways to induce electronic orders such as superconductivity or charge density waves, the possibility of preparing low-energy phases of Floquet Hamiltonians remains unclear because of the energy absorption at typical experimentally accessible driving frequencies. Here we investigate a realistic pathway towards laser control of electronic orders, which is the transient enhancement of fluctuating orders. Using a conserving Keldysh Green's function formalism, we simulate the build-up of short range Cooper-pair correlations out of a normal metal in the driven attractive Hubbard model. Even for frequencies only slightly above or within the bandwidth, a substantial enhancement of correlations can be achieved before the system reaches a high electronic temperature. This behavior relies on the non-thermal nature of the driven state. The effective temperature of the electrons at the Fermi surface, which more closely determines the superconducting correlations, remains lower than an estimate from the global energy density. Even though short ranged, the fluctuations can have marked signatures in the electronic spectra.

TT 66.4 Fri 10:30 H2

Ultrafast dynamics of superconductors: Cooper-pair Dephasing or Thermalization? — •Christopher Stahl and Martin Eckstein — Lehrstuhl für Theoretische Festkörperphysik, FAU Erlangen-Nürnberg, Deutschland

We investigate the ultrafast dynamics of superconductivity in a BCS model. The reduction of the gap after different excitation protocols, which has been observed in various theoretical and experiential studies, may in principle be due to dephasing of the pair correlations at individual momenta, or due to thermalization to a hot electron state. While in time-dependent BCS theory it is clear that the gap would only dephase, we show, using non-equilibrium dynamical mean-field theory, that dephasing and thermalization can be clearly distinguished on short times even beyond mean-field theory. Furthermore we propose an experimental protocol to obtain the pair correlations at individual momenta and thus distinguish the two scenarios. This scheme, which is based on a measurement of the statistical variance of the number of photoelectrons in each momentum state in time-resolved pump-probe photoemission spectroscopy, can more generally provide a way to obtain two-particle quantities in a time-resolved fashion. The technique requires only a small bandwidth of the probe pulse in frequency space and can therefore yield a high time-resolution.

TT 66.5 Fri 10:45 H2

Light induced transient dynamics of the charge transfer insulator La_2CuO_4 — •Amrit Raj Pokharel[1], Markus Beyer[2], Steinn Ymir Agustsson[1], Manuel Obergfell[1,2], Tao Dong[1], Gennady Logvenov[3], Ivan Bozovic[3], Zala Lenarcic[4], Peter Prelovsek[4,5], and Jure Demsar[1,2] — [1]Institute of Physics, University of Mainz, Germany — [2]Department of Physics, University of Konstanz, Germany — [3]Brookhaven National Laboratory, USA — [4]Jozef Stefan Institute, Slovenia — [5]University of Ljubljana, Slovenia

We investigate the transient dynamics of La_2CuO_4, the parent compound of the Lanthanum based cuprate high temperature superconductors, upon photo excitation with UV photons across the charge transfer (CT) gap of 2.1 eV. The resulting transient state is studied for extracting the time-evolution of the broadband complex dielectric function in the spectral range of 0.5 - 2.6 eV. Experiments are performed as a function of the excitation density over several orders of magnitude, up to 0.1 absorbed photons/Cu-atom. Modeling the changes in the complex dielectric function with the (induced) Drude - Lorentz model reveals a pronounced renormalization of the CT gap, accompanied by the light-induced mid-gap absorption, resembling the evolution of optical properties by chemical doping. The data provide strong constraints on the possible photogenerated free carrier (Drude) response. We demonstrate, that even at the highest excitation densities, where in the case of comparable chemical doping a metallic state is realized, photodoping results in a negligible density of free carriers, underscoring the underlying Mott physics.

TT 66.6 Fri 11:00 H2

Excitation Dynamics in the Antiferromagnetic Mott Insulator Ca_2RuO_4 — •Parmida Shabestari[1,2], Anita Mahinpei[1,2], Min-Jae Kim[1,2], Hao Chu[1,2], Maximillian Krautloher[1], Joel Bertinshaw[1], Bernhard Keimer[1], and Stefan Kaiser[1,2] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]4th Physics Institute, Stuttgart University, Stuttgart, Germany

Among ruthenates, the antiferromagnetic Mott insulator Calcium Ruthenate, Ca_2RuO_4, has shown remarkable complexity in spin, orbital and phonon correlations. Strong spin-orbit coupling manifests in the form of a complex Phonon, Magnon and collective Higgs mode spectrum. Here we report on the transient dynamics after photoexcitation across the Mott gap, revealing saturation and depletion regimes. In addition we find a so far unknown coherent low frequency mode, which we characterize by Impulsive Stimulated Raman and Terahertz spectroscopy as a possible paramagnon.

15 min. break.

TT 66.7 Fri 11:30 H2

Enhancement of superconductivity in MgB_2 by narrow-band THz pumping — •Nilabha Bhattacharjee[1], Amrit Raj Pokharel[1], Tao Dong[1,2], Alexej Pashkin[3], Stephan Winnerl[3], Manfred Helm[3], Zi Zhao Gan[4], Yue Wang[4], Li Yu Shi[4], Nan Lin Wang[4], and Jure Demsar[1] — [1]Institute of Physics, Johannes Gutenberg-University Mainz, Mainz — [2]International Center For Quantum Materials (ICQM), Peking University — [3]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Dresden — [4]Institute of Condensed Matter Physics, School of Physics, Peking University

First observations of amplified superconductivity by electromagnetic radiation at sub-gap frequencies date back to late 1960's [1]. These works reported an increase of the gap and the superconducting transition temperature in type-I superconductors Al and Sn. Recently, enhancement effects have also been observed in NbN by using picosecond narrow-band THz pulses, tuned to the vicinity of the superconducting gap frequency [2]. Here we report on systematic studies of the superconducting gap dynamics in MgB_2. Tuning the pump frequency between the two superconducting gap energies in this two-band superconductor we observe strong superconducting enhancement effects competing with THz driven pair-breaking. For temperatures close to the transition temperature (T_c = 36 K) the enhancement effects seem to dominate, giving rise to a global amplification of superconductivity.

[1] A. F. G. Wyatt, et al., Phys. Rev. Lett. 16, 1166 (1966)
[2] M. Beck, et al, Phys. Rev. Lett. 110, 267003 (2013)

TT 66.8 Fri 11:45 H2

Collective modes in non-equilibrium in unconventional superconductors with competing ground states — •Marvin A. Müller[1], Pavel A. Volkov[1,2], and Ilya Eremin[1] — [1]Institut für Theoretische Physik III, Ruhr-Universität Bochum, D-44801 Bochum, Germany — [2]Department of Physics and Astronomy, Rutgers University, Piscataway, New Jersey, 08854, USA

Motivated by the recent development of terahertz pump-probe spectroscopy, we investigate the short-time dynamics and collective modes in superconductors with multiple attractive pairing symmetries. We consider a single-band square lattice model with nearest neighbor attraction. This interaction decouples into $s-$, $d-$ and $p-$wave channels and by variation of band filling this yields strong competition between these channels. Driving the system out of equilibrium, we find signatures of collective states of symmetries different from the groundstate symmetry, which are called Bardasis-Schrieffer modes in the context of $s-$wave groundstate. We show that, depending on the polarization direction, additional order parameter symmeries can be excited in pump-probe experiments and the collective 'Bardasis-Schrieffer' modes can be observed.

TT 66.9 Fri 12:00 H2

All-optical nonequilibrium pathway to stabilizing magnetic Weyl semimetals in pyrochlore iridates — •Gabriel E. Topp[1], Nicolas Tancogne-Dejean[1], Alexander F. Kemper[2], Angel Rubio[1,3], and Michael A. Sentef[1] — [1]Max Planck Institute for the Structure and Dynamics of Matter, Center for Free Electron Laser Science, 22761 Hamburg, Germany — [2]Department of Physics, North Carolina State University, Raleigh, NC, USA — [3]Center for Computational Quantum Physics (CCQ), Flatiron Institute, 162 Fifth Avenue, New York NY 10010

The 227 pyrochlore iridates were conjectured to exhibit an antiferromagnetically ordered Weyl semimetallic (AF-WSM) phase provided that one could tune the ordered magnetic moment. In our work [1] we propose an ultrafast nonequilibrium pathway to engineering a nonequilibrium AF-WSM phase with short laser pulses. Relying on ab initio TDDFT+U calculations, we investigate the open-system dynamics after an interaction quench in a mean-field dynamics simulation starting from the AFI phase. By computational time- and angle-resolved photoemission spectroscopy (tr-ARPES) measurements, we track the emergence of nonequilibrium Weyl fermions on a femtosecond timescale.

[1] G. E. Topp et al., Nature Communications 9, 4452 (2018)

TT 66.10 Fri 12:15 H2

Ultrafast spin dynamics and high-harmonic generation in multilayer systems based on graphene — •Dominik Schulze and Jamal Berakdar — Institute for physics, Martin-Luther-University Halle-Wittenberg, 06120 Halle (Saale), Germany

High harmonic generation in solids is attracting considerable research due to prospect application in solid-state based emitting devices and ultrafast optoelectronics.

Our research interest is devoted to the role of spin and its exploitation in ultrafast spintronics. In this talk, we present our research on high-harmonic generation in spin-orbital coupled systems such as multilayer systems based on graphene.

The goal is twofold: 1) to utilize these systems as a local radiation source, and 2) to analyze the emitted, time-dependent spectra that may carry footprints of internal spin-dependent mechanism that are important for the operation of spintronic devices.

We present results on multilayer systems composed of graphene on a substrate which induces a strong spin-orbit coupling into the graphene layer. This leads to various interesting effects resulting from the sublattice potential, the Rashba type spin-orbit coupling and a time-reversal symmetry breaking. Full-fledge calculations show how the gap opening at the K and K' points of the graphene affects the high harmonic generation of inter band excitations.

TT 66.11 Fri 12:30 H2

Spin-orbit induced dynamics in a driven single molecule junction — •Moritz Frankerl, Milena Grifoni, and Andrea Donarini — Institut für Theoretische Physik, Universität Regensburg, 93035 Regensburg, Germany

Recent experiments based on THz-STM have shown how to obtain both space and time resolution of molecular dynamics on its intrinsic length and time scales [1]. The average transmitted charge is recorded as a function of tip position and pump-probe pulse delay. We report here on the theoretical investigation of the combined spin and orbital dynamics of a single molecule copper-phthalocyanine junction. The dynamics is studied directly in the time domain, with the full pump-probe scheme simulated within a generalized master equation approach. The spin-orbit coupling on the metallic center is responsible for intertwined spin and orbital dynamics. Control and electrical read out can be achieved respectively via an external magnetic field and coupling to ferromagnetic leads.

[1] T. L. Cocker et al., Nature **539**, 263 (2016)