Can light induce superconductivity?

Quantum Monte Carlo approach to the dynamics of strongly correlated systems

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In Short

- Modeling of materials that exhibit unconventional superconductivity
- Search for new strongly correlated non-equilibrium states
- Effects of screened long-range interaction beyond Hubbard type interactions

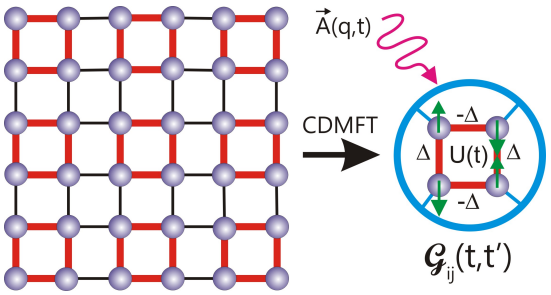

Figure 1: *Schematic mapping from the square lattice to a cluster-impurity with dynamic interaction $U(t)$, d-wave superconducting gap Δ and Weiss-field $\mathcal{G}$. The system is driven out of equilibrium by a laser pulse, that is represented by the vector potential $A(\mathbf{q}, t)$.*

Strongly correlated materials exhibit a vast variety of complex phases and dynamics. Understanding the mechanism behind the interplay of these phenomena are amongst the most challenging problems in the field of condensed matter physics.

In this project we will investigate the electronic dynamics of models for materials exhibiting unconventional superconductivity. The ultimate goal is the understanding of the superconducting mechanism and how its critical temperature T_c can be tuned up to room temperature.

In particular, a large body of experimental work in this field has been performed in Hamburg within a Cluster of Excellence (The Hamburg Centre for Ultrafast Imaging) [1]. The experiments have shown that certain materials can be driven by laser pulses system into new non-equilibrium transient states, which can exhibit superconductivity. We intend to support those experimental results with numerical calculations.

Furthermore we investigate long ranged correlations and collective excitations with perspective on multi-orbital real materials.

We model the cuprates using the single orbital Hubbard model which is capable of capturing many phenomena found by experiments, such as the Mott transition, antiferromagnetic order, superconductivity and other complex phases. Despite the simple appereance of the model, analytical methods can resolve only very limited regions in the phase diagram and numerical methods are inevitable for further progress. Iron pnictides have been classified as Hund's metals and can be modeled in a similiar fashion using multiorbital generalizations of the Hubbard model.

In order to extend the applicability of the Hubbard model we also consider the extended Hubbard model with non-local interactions. This is treated within the so called dual boson approach.

For the solution of Hubbard model we make use of the dynamical mean-field theory (DMFT). The dynamical mean-field treats the local quantum fluctuation exactly which makes it a very successful method for the uncovering of the physics of interacting systems. With extensions of DMFT even certain non-local correlations can be taken into account, which our group accomplished recently thanks to the computing resources provided by HLRN [2–4].
One of the great achievements of DMFT was to provide a comprehensive picture of Mott insulators and Hund's metals at finite temperatures. We have already successfully developed working implementations for the equilibrium DMFT and also cluster-DMFT, that can find superconducting solutions [5]. We also plan to apply an existing non-equilibrium [6] cluster-DMFT implementation (Fig. 1). The success of DMFT is based on the state-of-the-art numerical methods for the solution of the Anderson impurity model. The solution involves the computation of high-dimensional integrals that is a well-suited problem for quantum Monte-Carlo (QMC) methods using Metropolis sampling. For the latter we use a continuous-time formulation without time-discretization errors [7]. Our setup uses the hybridization expansion of the partition function, that is also known as the strong coupling approach. We develop new QMC-based methods for the non-equilibrium case, that e.g. reduce the dynamical sign problem. Furthermore, we implement strong coupling diagramatic methods, such as non-crossing approximation, to benchmark and complement QMC calculations.

WWW

https://theorie.physnet.uni-hamburg.de/group_magno/

More Information

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Project Partners

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