TT 56: Superconductivity: Theory I

Time: Wednesday 15:00–18:30 Location: CHE/0089

TT 56.1 Wed 15:00 CHE/0089

Non-thermal pairing glue of electrons in the steady state — •Michele Pini[1,2], Christian H. Johansen[3,2], and Francesco Piazza[1,2] — [1]University of Augsburg, Augsburg, Germany — [2]MPI-PKS, Dresden, Germany — [3]Pitaevskii BEC Center, CNR-INO and Department of Physics, Trento, Italy

The study of mechanisms for enhancing superconductivity has been a central topic in condensed matter physics due to the combination of fundamental and technological interests. One promising route is to exploit non-equilibrium effects in the steady state. Efforts in this direction have so far focused on enhancing the pairing mechanism known from thermal equilibrium through modified distributions for the electrons or the bosons mediating the electron-electron interaction. In this work, we identify an additional pairing mechanism that is active only outside thermal equilibrium. By generalizing Eliashberg theory to non-equilibrium steady states using the Keldysh formalism, we derive a set of Eliashberg equations that capture the effect of this genuinely non-thermal pairing glue even in the weak-coupling regime. We discuss two examples where this mechanism has a major impact. First, in a temperature-bias setup, we find that superconductivity is enhanced when the boson mediator is colder than the electrons. Second, we find that an incoherent drive of the boson mediator at energies much greater than the temperature pushes the system far from thermal equilibrium but leaves the critical coupling essentially unchanged, owing to a competition between electron heating and the enhancement of pairing by the non-thermal glue.

TT 56.2 Wed 15:15 CHE/0089

Critical behavior of the Superconducting Phase Transition in a Lattice Gauge Theory Approach — •Greta S. Reese[1,2] and Ludwig Mathey[1,2] — [1]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany — [2]Center for Optical Quantum Technologies, University of Hamburg, 22761 Hamburg, Germany

We present a U(1) lattice gauge model to describe the superconducting phase transition of a type-II superconductor. Using the Landau Ginzburg free energy, we perform Monte Carlo simulations to investigate how the presence of a gauge field influences the nature of the phase transition. In particular, we study the effects of the gauge field on the Cooper pair density and the heat capacity.

TT 56.3 Wed 15:30 CHE/0089

Enhancing superconductivity using thermal bosons — •Ekaterina Vlasiuk[1], Eugene Demler[2], and Richard Schmidt[1] — [1]Institute for Theoretical Physics, Heidelberg University, Philosophenweg 16, 69120 Heidelberg, Germany — [2]Institute for Theoretical Physics, ETH Zurich, 8093 Zurich, Switzerland

We investigate how the strong coupling of a superconductor to thermal bosons can enhance its superconducting critical temperature. To tackle this problem, we use a functional Renormalization Group (FRG) approach that allows us to describe the competition between the build-up of boson-induced attraction between fermions and diametral density fluctuations in the scattering channel between bosons and fermions. Thus self-consistently treating the mutual influence of bosonic and fermionic sectors allows us to uncover an increase of the critical temperature which is pronounced in the BCS limit but self-regulated as unitary fermion interactions are approached. Also, we find that the mutual influence leads to a nontrivial dependence of the critical temperature on the mass ratio between particles. We identify the regimes where our theory is applicable by investigating the phase diagram of enhanced/induced superconductivity for bosons being in either a condensed or thermal state. Moreover, we outline possible experimental realizations in cold atomic systems as well as discuss the implementation in an alternative solid-state platform - bilayer TMD materials - where excitons play the role of bosons.

TT 56.4 Wed 15:45 CHE/0089

Generalized condition for odd-frequency pairing in multiband materials — •Florian Kayatz[1,2], Annica M. Black-Schaffer[1], and Jorge Cayao[1] — [1]Department of Physics and Astronomy, Uppsala University, Box 516, SE-752 37 Uppsala, Sweden — [2]WISE - allenberg Initiative Materials Science for Sustainability, Department of Physics and Astronomy, Uppsala University, Sweden

Odd-frequency superconductivity has been predicted to arise in various physical systems, including multiband materials, and is known to lead to phenomena such as the unusual Meissner response and long-range proximity effect [1]. The emergence of odd-frequency superconductivity is often explained in terms of a condition derived up to first order in the superconducting order parameter [2], leaving higher order corrections unaccounted. Here, we extend this analysis and derive the odd-frequency condition involving higher-order contributions of the order parameter, as well as a generalized expression valid to all orders. In addition, we explore the conditions for the emergence of odd-frequency correlations between individual bands. This allows us to identify cases where the structure of the Hamiltonian inherently forbids odd-frequency pairing. As an example, we apply our condition to a weakly coupled system consisting of a transition metal dichalcogenide monolayer proximitzed by a conventional spin-singlet s-wave superconductor.

[1] J. Linder and A. V. Balatsky, *Rev. Mod. Phys.* **91**, 045005 (2019)
[2] C.Triola,J.Cayao,A.M.Black-Schaffer*Ann.Phys.***532**,1900298(2020)

TT 56.5 Wed 16:00 CHE/0089

Enhanced Superconductivity in Proximity to Peaks in Densities of States — •Joshua Althüser[1], Ilya Eremin[2], and Götz S. Uhrig[1] — [1]TU Dortmund, Otto-Hahn-Straße 4, 44227 Dortmund, Germany — [2]Institut für Theoretische Physik III, Ruhr-Universität Bochum, 44801 Bochum, Germany

For the BCS theory of superconductivity, the electron-phonon interaction is transformed to an attractive electron-electron interaction in the vicinity of the Fermi energy only. An optimized transformation, however, reveals that the electrons attract one another whenever their energies do not differ more than the phonon energy ω_D. Consequently, the order parameter becomes finite even away from the Fermi energy. Intriguingly, an accumulation of density-of-states at an energy $\varepsilon_\mathrm{Peak}$ in proximity to the Fermi energy induces a significant order parameter around $\varepsilon_\mathrm{Peak}$, which easily exceeds the one at E_F for moderate coupling strengths. We predict measurable signatures in the thermodynamic and spectroscopic response of this unexpected phenomenon, guiding future experimental searches for it.

TT 56.6 Wed 16:15 CHE/0089

Fluctuation conductivity in multicomponent superconductors — •Sondre Duna Lundemo and Asle Sudbø — Center for Quantum Spintronics, Department of Physics, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway

Multicomponent superconductors exhibit many properties that have no counterpart in single-component superconductors, ranging from Leggett modes to novel topological phase transitions. These features derive from the multiorbital character of the parent metallic state, and sometimes leave universal signatures in physical observables. In this talk, we scrutinize the electrodynamic response of such a metal as it approaches the superconducting critical point. In particular, we will elucidate whether the multicomponent character of the incipient superconducting order affects the electrical conductivity and highlight the importance of using a gauge-invariant approximation scheme for calculating it.

TT 56.7 Wed 16:30 CHE/0089

Constraints on the theoretical modeling of hole-doped La_2CuO_4 — •qiwei li[1], hanif hadipour[2], xue-jing zhang[1], and eva pavarini[1] — [1]Peter Grünberg Institute, Forschungszentrum Jülich, 52428 Jülich, Germany — [2]Department of Physics, University of Guilan, Rasht 41335-1914, Iran

The low-energy electronic properties of hole-doped La_2CuO_4 are believed to be well captured by the single-band Hubbard model describing x^2-y^2 electrons. This finds support, e.g., on Fermi surface and angle resolved photoemission experiments. Here we show [1] that this imposes constraints on the microscopic description of the system. Results are obtained via the LDA+DMFT method using a continuous time hybridization expansion Quantum Monte Carlo impurity solver, as implemented in [2].

[1] Q. Li, H. Hadipour, X-J Zhang, E. Pavarini, in preparation
[2] A.Flesch, G.Zhang, E.Koch, E.Pavarini, PRB **85**, 035124 (2012)

15 min. break

TT 56.8 Wed 17:00 CHE/0089

Superlinear Hall angle, magnetotransport, and superconductivity in solvable models for strange metals — •Davide Valentinis[1,2], Aavishkar A. Patel[3,4], Subir Sachdev[5], and Joerg Schmalian[2,1] — [1]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, Karlsruhe (DE) — [2]Institute for Theoretical Condensed Matter physics, Karlsruhe (DE), Karlsruhe Institute of Technology — [3]Center for Computational Quantum Physics, Flatiron Institute, New York (USA) — [4]International Centre for Theoretical Sciences, Tata Institute of Fundamental Research, Bengaluru (IN) — [5]Harvard University, Cambridge, MA (USA)

We provide exact numerical solutions from the Kubo formula for the DC magnetoconductivity tensor of the two-dimensional (2D) spatially disordered Yukawa-Sachdev-Ye-Kitaev (2D-YSYK) model on a square lattice, at first order in applied perpendicular magnetic field. This system describes fermions endowed with a Fermi surface and coupled to a bosonic scalar field through spatially random Yukawa interactions, which admit mean-field exact numerical solutions. From the interplay between YSYK interactions and square-lattice embedding, and the non-Boltzmann frequency dependent self energies, we find a superlinear evolution of the Hall-angle cotangent and the inverse carrier mobility with temperature, concomitant with linear-in-temperature resistivity, in an extended crossover regime above the low-temperature Marginal Fermi Liquid (MFL) ground state. In addition, a superconducting state with finite phase stiffness, mediated by the same YSYK interactions, emerges out of the MFL.

TT 56.9 Wed 17:15 CHE/0089

Achieving analogue states of high-T_c superconductivity with current quantum simulators — •Thomas Köhler and Adrian Kantian — SUPA, Institute of Photonics and Quantum Sciences, Heriot-Watt University, EH14 4AS Edinburgh, Scotland, United Kingdom

Employing the recently introduced matrix-product states plus mean-field method (MPS+MF) [Bollmark et al. 2020; 2023; 2025, Marten et al. 2023], we show how to realize the analogue of a high-T_c superconducting state in a t-J bi-plane lattice model with strongly enhanced inter-plane spin-spin coupling. Implementation of such systems using ultra cold atomic lattice gases has been demonstrated using metastable tilted Fermi-Hubbard systems [Hirthe et al. 2023]. We show that t-J bi-planes constructed in this way can achieve a critical temperature T_c for the onset of a correlated state analogous to high-T_c superconductivity that would be accessible within currently reachable entropy-per-particle. We further identify the optimal parameter regimes for such states to be realized, rule out the existence of any competing charge density wave-instabilities, and show how to unambiguously detect the onset of superconducting order.

TT 56.10 Wed 17:30 CHE/0089

Understanding and enhancing superconductivity in cuprates with low-energy Hamiltonians and explicit machine learning — •Jean-Baptiste Morée[1] and Ryotaro Arita[1,2] — [1]RIKEN Center for Emergent Matter Science, Wako, Saitama 351-0198, Japan — [2]Department of Physics, University of Tokyo, Bunkyo-ku, Tokyo 113-0033, Japan

Cuprate superconductors exhibit a wide range of transition temperatures $T_c \approx 6$–$166\,\mathrm{K}$ despite sharing a common electronic structure dominated by a Cu $3d_{x^2-y^2}$–O $2p_\sigma$ antibonding orbital. Ab initio low-energy Hamiltonians combined with many-variable variational Monte Carlo have shown that T_c is primarily controlled by the nearest-neighbor hopping $|t_1|$ and the ratio $u = U/|t_1|$ (with U the onsite effective Coulomb repulsion), with only minor influence from longer-range terms. Applied pressure enhances T_c mainly by increasing $|t_1|$.

In this talk, I present recent progress [1] on the material dependence of these parameters using a new explicit, interpretable machine-learning approach. By analyzing structural and chemical descriptors across 36 cuprates, the algorithm reveals that $|t_1|$ increases when ionic radii in the block layer are reduced, while u can be tuned through the ionic charges. These results provide simple, physically transparent guidelines for designing cuprates with enhanced superconducting properties.

[1] J.-B. Morée and R. Arita, Phys. Rev. B **110**, 014502 (2024).

TT 56.11 Wed 17:45 CHE/0089

Strong-coupling superconductivity near Gross-Neveu quantum criticality in Dirac systems — •Veronika Stangier[1], Daniel Sheehy[2], and Jörg Schmalian[1] — [1]Karlsruhe Institute for Technology, Karlsruhe, Germany — [2]Louisiana State University, Baton Rouge, USA

We investigate superconductivity in two-dimensional massless Dirac fermions at charge neutrality, coupled to bosonic collective modes via a Yukawa interaction. Despite the absence of carriers at zero temperature, we uncover the surprising possibility that such systems can become superconducting near a Gross-Neveu quantum critical point. Remarkably, superconductivity emerges precisely when the fermionic excitations lose coherence - once their anomalous dimension in the normal state becomes sufficiently large. In other words, well-defined quasiparticles fail to superconduct, whereas strongly incoherent ones can. To capture this behavior, we develop a general framework for four-component Dirac systems and derive explicit algebraic criteria for the onset of pairing. Within this description, different bosonic modes - classified by their transformation under time-reversal and internal symmetries - select distinct superconducting channels. We then apply this approach to Dirac models of spin-orbit-coupled systems with orbitals of opposite parity and extend it to analyze superconductivity in moiré Dirac materials such as double-bilayer WSe_2 and twisted bilayer graphene.

TT 56.12 Wed 18:00 CHE/0089

Chiral superconductivity in time-reversal symmetry broken honeycomb systems — •Lucca Marchetti[1], Matthew Bunney[1,2], and Stephan Rachel[1] — [1]School of Physics, University of Melbourne, Melbourne, Australia — [2]Institute for Theoretical Solid State Physics, RWTH Aachen University, Aachen, Germany

Rhombohedral graphene — stacked graphene layers in the ABC configuration — has emerged as an exciting playground for strongly correlated physics and superconductivity. Recent experiments on N-layer rhombohedral graphene reveal signatures of spin-valley polarised Fermi surfaces. Probes at low temperature exhibit several regions of superconductivity, with signs of chiral triplet pairing states.

To better discern how broken symmetries in the normal state affect underlying many-body states we focus on 2D single-layer honeycomb systems in the presence of various symmetry breaking terms. We employ the truncated-unity functional renormalization group technique to analyse the leading instabilities of the associated Hubbard model. We discuss how the different broken symmetries affect the resulting superconductivity, and the implications this has for chiral and/or triplet pairing states. We further characterise the superconducting states in a topological context through calculation of Chern number landscapes, where we find regions of topological superconductivity.

TT 56.13 Wed 18:15 CHE/0089

A universal route to chiral Ising superconductivity in monolayer TaS_2 and $NbSe_2$ — •Lucia Gibelli[1], Simon Höcherl[1], Julian Siegl[1], Viliam Vano[2], Somesh C.Ganguli[2], Magdalena Marganska[3], and Milena Grifoni[1] — [1]University of Regensburg, Germany — [2]University of Aalto, Finland — [3]University of Science and Technology, Wroclaw

Ising superconductivity in two archetypal intrinsic superconductors, monolayer 1H-TaS_2 and 1H-$NbSe_2$, is investigated in a bottom-up approach [1]. Using ab initio-based tight-binding parameterizations for the relevant low-energy d-bands, the screened interaction is evaluated microscopically, in a scheme including Bloch overlaps. In direct space, the screened potential displays for both systems long-range Friedel oscillations alternating in sign. Upon scaling, the oscillation pattern becomes universal, with the location of minima and maxima locked to the lattice. Solving the momentum-resolved gap equations, a chiral ground state with p-like symmetry is generically found. Due to the larger Ising spin-orbit coupling, the chiral gap is more anisotropic in TaS_2 than in $NbSe_2$. This is reflected in tunneling spectra displaying V-shaped features for the former, in quantitative agreement with low-temperature scanning tunneling experiments on TaS_2. At the same time, our results reconcile the apparent discordance with hard gap tunneling spectra reported for the sibling $NbSe_2$ [2]. They also agree with recent top-down calculations on the same material.

[1] L. Gibelli et al., arXiv:2509.05784 (2025)
[2] J. Siegl et al., Nature Communications, 16(1):8228 (2025)