TT 56: Correlated Electrons: Quantum-Critical Phenomena – Theory

Time: Wednesday 9:30–13:15 Location: A 053

TT 56.1 Wed 9:30 A 053

Superconductivity and charge order near the onset of antiferromagnetism in metals — •Max Henner Gerlach[1], Yonathan Schattner[2], Simon Trebst[1], and Erez Berg[2] — [1]University of Cologne, Germany — [2]Weizmann Insitute of Science, Rehovot, Israel

The quantum-critical transition of a system of itinerant electrons into an antiferromagnetically ordered phase has long been believed to play an important role in the physics of superconductors such as the electron-doped cuprates and the iron pnictides. The complete understanding of this quantum-critical point has remained a key challenge for both analytical and numerical approaches. On the computational side, a numerically exact simulation of such fermionic systems via quantum Monte Carlo studies has long been precluded by the infamous negative sign problem. Only recently a way has been found to set up sign-problem-free simulations of lattice models that realize the universal physics close to this phase transition [1].

Building upon this conceptual work, we introduce further improvements to the Monte Carlo sampling techniques adapted to such a model, allowing us to better understand the properties of the quantum-critical point and the instability towards d-wave-like superconductivity in its vicinity. In addition, we study a competing instability towards a charge-density-wave-like order, which we support by a supplementary interaction. Taken together, our results further improve our understanding of the rich physics of a relatively simple single-band electron model appropriate for the cuprates.

[1] E. Berg, M. A. Metlitski, and S. Sachdev,
Science **338**, 1606 (2012)

TT 56.2 Wed 9:45 A 053

Quantum Critical Transitions in Spin and Charge Ordered Systems — •Corentin Morice[1], Premala Chandra[2], Stephen E. Rowley[1], and Siddharth S. Saxena[1] — [1]University of Cambridge, Cambridge, United Kingdom — [2]Rutgers University, Piscataway, New Jersey, USA

This talk will focus on search and discovery of novel forms of quantum order in ferroelectric and multiferroic systems. Materials tuned to the neighbourhood of a zero temperature phase transition often show the emergence of novel quantum phenomena. Much of the effort to study these new emergent effects, like the breakdown of the conventional Fermi-liquid theory in metals has been focused in narrow band electronic systems. But Spin or Charge ordered phases in insulating systems can also be tuned to absolute zero. Close to such a zero temperature phase transition, physical quantities like susceptibility change into unconventional forms due to the fluctuations experienced in this region giving rise to new kinds ordered states.

TT 56.3 Wed 10:00 A 053

Interference of quantum critical excitations and soft diffusive modes in a disordered antiferromagnetic metal — •Philipp Weiss[1], Boris Narozhny[1], and Jörg Schmalian[1,2] — [1]Institut für Theorie der Kondensierten Materie, Karlsruher Institut für Technologie, Karlsruhe, Germany — [2]Institut für Festkörperphysik, Karlsruher Institut für Technologie, Karlsruhe, Germany

We study a two-dimensional metallic system close to an antiferromagnetic critical point within the framework of the spin-fermion model. The model describes fermionic quasiparticles interacting with bosonic collective spin modes close to the antiferromagnetic wave vector $\vec{Q}$. Since $\vec{Q}$ is a large momentum scale, in first order of the spin-fermion coupling, low-energy fermions are only coupled to spin fluctuations at "hot spots" of the Fermi surface which are connected by $\vec{Q}$. However, at second order a fermion at an arbitrary point of a generic Fermi surface can be scattered successively by two spin fluctuations via an intermediate high-energy state and, in total, suffer only a small momentum transfer. This gives rise to an interference of critical spin fluctuations and diffusive excitations of the disordered metal. Integrating out the fermionic high-energy modes above a certain low-energy cutoff, we derive an effective low-energy action which exhibits a local interaction vertex for low-energy fermions on the entire Fermi surface. This interaction is mediated by a composite propagator. Using a diagrammatic approach, we calculate the temperature-dependent interaction correction to dc-conductivity induced by the composite propagator in the presence of disorder and find a correction to residual resistivity.

TT 56.4 Wed 10:15 A 053

Disorder-driven Coulomb gas transitions in classical three-dimensional dimer models — •Stefan Wolff[1,2] and Simon Trebst[2] — [1]Helmholtz-Institut für Strahlen- und Kernphysik, Bonn, Germany — [2]Institut für Theoretische Physik, Universität zu Köln, Germany

Frustrated magnets can harbor emergent Coulomb phases at low temperatures that exhibit a characteristic power-law decay of correlations and an extensive ground-state manifold. Here we discuss this physics in the context of classical dimer models – prototypical systems that allow to directly study such Coulomb phases. Our focus is on the effect of disorder, which we model by successive percolation of the bonds in a family of three-dimensional lattices with varying coordination number. Notably, our large-scale numerical simulations clearly demonstrate that the break-down of the Coulomb phase is well separated from the percolation transition. We discuss the order of the various phase transitions and the nature of the intermediate phase.

TT 56.5 Wed 10:30 A 053

Dimensionless ratios at the honeycomb Hubbard model critical point — •Thomas C. Lang[1] and Ribhu K. Kaul[2] — [1]Boston University, Boston, USA — [2]University of Kentucky, Lexington, USA

We study the nature and location of the phase transition between the semi-metal and Mott insulating antiferromagnetic state in the half-filled Hubbard model on the honeycomb. Using unbiased quantum Monte Carlo simulations, we measure dimensionless fermionic correlation and magnetic ratios, which provide precise and independent estimates for the couplings at which a mass gap opens in the single particle spectrum and at which the magnetic order sets in. An analysis of our data provides evidence for a direct continuous critical point between the semi-metal and the antiferromagnet, and an accurate window for the critical coupling, which does not include any of the previous estimates for the onset of magnetic order.

TT 56.6 Wed 10:45 A 053

Deconfined quantum criticality beyond designer Hamiltonians — •Ribhu K. Kaul[1] and Thomas C. Lang[2] — [1]University of Kentucky, Lexington, USA — [2]Boston University, Boston, USA

The SU(6) symmetric generalization of the Hubbard model on the square lattice constitutes a candidate for a direct, continuous quantum phase transition from Néel to valence bond solid (VBS) order. By constructing dimensionless quantities such as ratios of the magnetic structure factor and valence bond correlations we are able to unambiguously determine the existence of weak, but robust antiferromagnetic order in the weak coupling regime and a plaquette VBS in the strong coupling limit. Furthermore these ratios provide a tool to accurately determine the (critical) point from both sides of the phase transition separating the two limits. Preliminary results suggest a direct continuous transition for which we extract basic estimates for the critical exponents and compare the scaling function with results from designer SU(6) spin models to investigate whether this quantum phase transition is compatible with the scenario of deconfined quantum criticality.

TT 56.7 Wed 11:00 A 053

Universal phase diagram of quantum dissipative many-body systems — •Gianluca Rastelli — Fachbereich Physik & Zukunftskolleg, Universität Konstanz, D-78457 Konstanz, Germany

The interplay between quantum dissipation and interactions in quantum many-body systems can give rise to a wealth of novel phenomena. The one-dimensional coplanar rotor model (also known as quantum phase model) is a paradigmatic model for studying quantum phase transitions with dissipative coupling to an external bath. It can describe, for instance, one-dimensional chains of superconducting islands connected by Josephson junctions and shunt resistances [1]. At zero temperature, a quantum phase transition occurs by tuning the interaction strength between the phases. When the system is coupled to the environment, the common accepted scenario is that the dissipation suppresses the quantum fluctuations and, therefore, enhances the classical ground state characterised by long-range order [2,3]. Contrary to previous studies, I focus on a system which is coupled to the environment with a dissipative interaction designed in way to reduce the quantum fluctuations of the conjugate variables of the local phases. I will show that this anomalous dissipation leads to a reversed behaviour of the phase diagram: Increasing the dissipation causes a stabilisation of the disordered quantum ground state.

[1] R. Fazio and H. van der Zant, Phys. Rep. 355, 235 (2001).
[2] S. Chakravarty, G.L. Ingold, S. Kivelson, and A. Luther, Phys. Rev. Lett. 56, 2303 (1986).
[3] P. A. Bobbert, R. Fazio, G. Schön, and G. T. Zimanyi, Phys. Rev. B 41, 4009 (1990).

15 min. break.

TT 56.8 Wed 11:30 A 053

Phase diagram of the Kane-Mele-Coulomb model — •Martin Hohenadler[1], Francesco Parisen Toldin[1], Fakher F. Assaad[1], and Igor F. Herbut[2] — [1]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Germany — [2]Department of Physics, Simon Fraser University, Burnaby, Canada

We determine the phase diagram of the Kane-Mele model with a long-range Coulomb interaction using an exact quantum Monte Carlo method. Long-range interactions are expected to play a role in honeycomb materials because the vanishing density of states in the semimetallic weak-coupling phase suppresses screening. According to our results, the Kane-Mele-Coulomb model supports the same phases as the Kane-Mele-Hubbard model. The nonlocal part of the interaction promotes short-range sublattice charge fluctuations, which compete with antiferromagnetic order driven by the onsite repulsion. Consequently, the critical interaction for the magnetic transition is significantly larger than for the purely local Hubbard repulsion. Our numerical data are consistent with $SU(2)$ Gross-Neveu universality for the semimetal to antiferromagnet transition, and with 3D XY universality for the quantum spin Hall to antiferromagnet transition.

[1] M. Hohenadler, F. Parisen Toldin, I. F. Herbut, and F. F. Assaad, Phys. Rev. B 90, 085146 (2014)

TT 56.9 Wed 11:45 A 053

Fermionic quantum criticality in honeycomb and π-flux Hubbard models — •Francesco Parisen Toldin[1], Martin Hohenadler[1], Fakher F. Assaad[1], and Igor F. Herbut[2] — [1]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Germany — [2]Department of Physics, Simon Fraser University, Burnaby, Canada

We numerically investigate the critical behavior of the Hubbard model on the honeycomb and the π-flux lattice, which exhibits a direct transition from a Dirac semimetal to an antiferromagnetically ordered Mott insulator. We use projective auxiliary-field quantum Monte Carlo simulations and a careful finite-size scaling analysis that exploits improved renormalization-group invariant observables. This approach, which is successfully verified for the 3D XY transition of the Kane-Mele-Hubbard model, allows us to extract estimates for the critical couplings and the critical exponents. The results confirm that the critical behavior for the semimetal to Mott insulator transition in the Hubbard model belongs to the Gross-Neveu-Heisenberg universality class on both lattices.

[1] F. P. Toldin, M. Hohenadler, F. F. Assaad, I. F. Herbut, arXiv:1411.2502

TT 56.10 Wed 12:00 A 053

Spin Dynamics of the Heisenberg Bilayer from Quantum Monte Carlo — •Maximilian Lohöfer[1], Stefan Wessel[1], Frederic Mila[2], Tommaso Coletta[2], and Fakher Assaad[3] — [1]Institute for Theoretical Solid State Physics, RWTH Aachen — [2]Institut de théorie des phénomènes physiques, Ecole polytechnique fédérale de Lausanne — [3]Institut für Theoretische Physik und Astrophysik, Universität Würzburg

The spin-1/2 Heisenberg model on the square lattice blayer provides a basic example to study quantum critical behavior in interacting quantum spin systems. While its static equilibrium properties have been intensively investigated in the past, thus far only few studies have discussed the details of the reconstruction of the excitation spectrum across the quantum phase transition between the antiferromagnetically ordered phase and the quantum disordered regime. Here, based on stochastic series expansion quantum Monte Carlo (SSE) simulations and stochastic analytic continuation (SAC) methods, we calculate the dynamical spin structure factors in this model in different symmetry sectors. We analyse the evolution of the low-energy modes, related to Goldstone modes as well as the longitudinal amplitude mode in the ordered phase upon crossing through the quantum critical point and consider the corresponding restoration of the SU(2) symmetry in the disordered regime. The obtained spectra are also discussed in view of results from series expansions, improved spin wave theory and strong-dimer perturbation theory.

TT 56.11 Wed 12:15 A 053

Anomalous dynamical exponent at the Ising-nematic quantum critical point — •Tobias Holder and Walter Metzner — Max-Planck-Institute for Solid State Research, D-70569 Stuttgart, Germany

We present a systematic study of higher order fluctuation corrections for a two-dimensional critical metal at the onset of Ising-nematic order. This type of instability is of interest in the study of competing orders in high-temperature superconductivity and with spin liquids. In the critical regime, strong forward scattering gives rise to non-Fermi liquid behavior with overdamped quasiparticles and a dynamical critical exponent $z = 3$.

Using a renormalization group approach to the spin-fermion model in a two-patch approximation, we analyze the structure of density-density vertices of any order. This allows for a general classification of finite and singular contributions, which reveals a renormalization of $z = 3$ at four loop order. The results are applicable to a wide range of non-Fermi liquids.

TT 56.12 Wed 12:30 A 053

Selfconsistent Renormalization Group for Kondo Breakdown in Kondo lattice or Multi-Impurity Systems — •Ammar Nejati, Katinka Ballmann, and Johann Kroha — Universität Bonn

The conditions for breakdown of Kondo quasiparticles near a heavy-fermion quantum phase transition are still a controversial issue. We present a renormalization group (RG) theory for the breakdown of Kondo screening in multi-impurity Kondo systems without direct interimpurity dipole coupling, without pre-assumptions about magnetic ordering or Fermi surface criticality. Kondo singlet formation is signalled by the RG divergence of the conduction electron – local Kondo spin vertex Γ at the Kondo scale T_K. In a multi-impurity system, Γ acquires a non-local, RKKY-mediated contribution from conduction electrons scattering at surrounding Kondo sites, which depends on the dynamical, local spin response χ on those sites. Because of its inverse dependence on T_K at low energies, $\chi = (g\mu_B)^2/T_K$, the $\beta-$function depends parametrically on the Kondo scale in a selfconsistent way. As a result, we find a universal suppression of the Kondo scale $T_K(y)$ in Kondo lattice and multi-impurity systems, depending on a dimensionless RKKY coupling parameter y. Local Kondo screening is predicted to break down at a maximum RKKY coupling y_{max}, where y_{max} is a universal function of the bare $T_K(0)$. At the breakdown point, the T_K-suppression assumes the universal value $T_K(y_{max})/T_K(0) = 1/e \approx 0.368$, in remarkable quantitative agreement with STM spectroscopy on two-impurity systems [1].

[1] J. Bork *et al.*, Nature Physics **7**, 901 (2011).

TT 56.13 Wed 12:45 A 053

Steady state dynamics and effective temperatures of quantum criticality in open systems — •Farzaneh Zamani[1], Pedro Ribeiro[2], and Stefan Kirchner[3] — [1]Max Planck Institute for Physics of Complex Systems, 01187 Dresden, Germany — [2]Russian Quantum Center, Business-center "Ural", Novaya street 100A, Skolkovo village, Odintsovo district, Moscow area, 143025 Russia — [3]Center for Correlated Matter, Zhejiang University, China

We present our results for the steady-state –both thermal and non-thermal– scaling functions and steady-state dynamics in a quantum impurity model of local quantum criticality. Our model, the pseudogap Kondo model, allows us to obtain full scaling functions in and out of equilibrium. We discuss the (equilibrium) zero-temperature residual entropy at various fixed points. We also consider the non-equilibrium steady-state, obtained by applying a finite bias voltage and study the concept of effective temperatures near fully interacting as well as weak-coupling fixed points. In the vicinity of each fixed point we establish the existence of an effective temperature –different at each fixed point– such that the equilibrium fluctuation-dissipation theorem is recovered. Interestingly, steady-state scaling functions in terms of the effective temperatures coincide with the equilibrium scaling functions in terms of the temperature. This result extends to higher correlation functions as is explicitly demonstrated for the Kondo singlet strength. We also study the non-linear charge transport in terms of the effective temperatures.

TT 56.14 Wed 13:00 A 053

Spin-orbit coupling in interacting quantum wires — •Nikolaos Kainaris[1,2] and Sam T. Carr[3] — [1]Institut für Theorie der Kondensierten Materie, KIT Karlsruhe, Germany — [2]Institut für Nanotechnologie, KIT Karlsruhe, Germany — [3]School of Physical Sciences, University of Kent, Canterbury, United Kingdom

We present analysis of the interacting quantum wire problem in the presence of spin-orbital interaction. We find that the most generic model describing spin-orbit-coupling effects is a two band model with a difference in Fermi velocities δv. This velocity difference destroys the spin-charge-separation and breaks the SU(2) symmetry in the low-energy Luttinger liquid theory. We show that electron-electron interactions then can open a gap in the spin sector of the theory when the interaction strength U is smaller than δv in appropriate units. The resulting spin-density-wave (SDW) state has a number of interesting properties reminiscent of topological insulators. We show that the the SDW state is robust against non-magnetic disorder and has zero-energy edge modes localized at its boundary.