TT 41: Quantum-Critical Phenomena (joint session TT/DY)

Time: Thursday 9:30–12:45 Location: H31

TT 41.1 Thu 9:30 H31

Missing Spectral Weight in a Paramagnetic Heavy-Fermion System — •Debankit Priyadarshi[1], Jingwen Li[1], Chia-Jung Yang[1], Ulli Pohl[2], Oliver Stockert[3], Hilbert von Löhneyesen[4], Shovon Pal[5], Manfred Fiebig[1], and Johann Kroha[2,6] — [1]ETH Zurich, Switzerland. — [2]University of Bonn, Germany — [3]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [4]Karlsruhe Institute of Technology, Germany — [5]NISER, HBNI, Jatni, India. — [6]University of St. Andrews, UK

Time-resolved terahertz spectroscopy (THz-TDS) has proven to be a powerful method to study the correlation dynamics in many-body systems, particularly heavy-fermions [1]. The competition between the Kondo screening effect and the Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction in these materials drives a quantum phase transition (QPT) between a magnetically ordered and a liquid-like ground state of heavy Kondo quasiparticles. These quasiparticles disintegrate near a quantum critical point (QCP). Using THz-TDS, we report a suppression in the quasiparticle spectral weight in $CeCu_{6-x}Au_x$ on the antiferromagnetic side of the QPT at temperatures much higher than the Neel temperature, which has a different origin from the suppression at QCP [2]. We study the paramagnetic phase of $CeCu_{6-x}Au_x$ with x = 0.2, 0.3, and 0.5 samples, and show that the suppression results from a quantum frustration effect induced by the temperature-independent RKKY interaction, which may influence material properties at QCP.

[1] C. Wetli *et al.*, Nat. Phys. 14, 1103 (2018);
[2] J.Li *et al.*, arXiv:2408.07345 (2024).

TT 41.2 Thu 9:45 H31

Terahertz Crystal Electric Field Transitions in a Kondo-Lattice Antiferromagnet — •Payel Shee[1], Chia-Jung Yang[2], Shishir Kumar Pandey[3], Ashis Kumar Nandy[1], Ruta Kulkarni[4], Arumugam Thamizhavel[4], Manfred Fiebig[2], and Shovon Pal[1] — [1]NISER, HBNI, Jatni, India. — [2]ETH Zurich, Switzerland. — [3]Artificial Intelligence for Science Institute, Beijing, China. — [4]Tata Institute of Fundamental Research, Mumbai, India.

The interplay between the Kondo effect and Ruderman-Kittel-Kasuya-Yosida (RKKY) leads to the emergence of many intriguing phenomena in strongly correlated systems. Metallic materials doped with magnetic impurities are ideal for such studies. These impurities interact with the crystal electric field (CEF) produced by neighboring ions, lifting the degeneracy of their energy levels and creating CEF states. Given that CEF excitations occur in the millielectronvolt (meV) range, the terahertz (THz) frequency range is particularly suited for these investigations. Using time-domain THz reflection spectroscopy, we show the first direct evidence of two low-energy CEF transitions at 0.6 THz (2.5 meV) and 2.1 THz (8.7 meV) in $CeAg_2Ge_2$, a prototype Kondo-lattice antiferromagnet. In addition, we also observe that the lower CEF transition peak undergoes a blue-shift once the sample enters into the antiferromagnetic phase. The temporal spectral weights obtained directly from the THz time traces corroborate the corresponding CEF energy scales of the compound [2].

[1] S. Pal *et al.*, Phys. Rev. Lett. 122, 096401 (2019);
[2] P. Shee *et al.*, Phys. Rev. B 109, 075133 (2024).

TT 41.3 Thu 10:00 H31

Tuning a ferromagnetic quantum phase transition by interface engineering in artificial heterostructures — Robin Heumann[1], Robert Gruhl[1], Ludwig Scheuchenpflug[1], Leonard Schüler[2], Vasily Moshnyaga[2], and •Philipp Gegenwart[1] — [1]Lehrstuhl für Experimentalphysik VI, Universität Augsburg — [2]Erstes Physikalisches Institut, Georg-August-Universität-Göttingen

The substitution series $Sr_{1-x}Ca_xRuO_3$ between the itinerant ferromagnet $SrRuO_3$ (SRO) and the non-Fermi liquid paramagnetic metal $CaRuO_3$ (CRO) constitutes a broadly smeared quantum phase transition (QPT) between $x = 0.7$ and 1. To avoid the impact of structural disorder we explore the possibility of tuning ferromagnetism by confining SRO to thin layers placed in between those of CRO. Ordered epitaxial $[SRO_n/CRO_m]_K$ superlattices, with n ranging from 8 down to the monolayer limit, keeping $m/n = 2$ and 3 with $K = 32/n$, were grown on $SrTiO_3$ (100) substrates, characterized and investigated by electrical transport and Hall effect measurements. We observe stable ferromagnetism from SRO layers for $n \geq 3$ and fragile low-temperature ferromagnetism due to the SRO/CRO interfaces. The latter survives down to the monolayer limit $n = 1$, explaining the difficulty to cross a ferromagnetic QPT in $Sr_{1-x}Ca_xRuO_3$. We also find that the effective interface density $K/(n + m)$ is a new suitable control parameter and construct the T_C vs $K/(n + m)$ phase diagram.

TT 41.4 Thu 10:15 H31

Interplay of nematic fluctuations and transverse phonons near a nematic quantum critical point — •Morten H. Christensen[1], Michael Schütt[2], Avraham Klein[3], and Rafael M. Fernandes[4] — [1]Niels Bohr Institute, University of Copenhagen — [2]University of Minnesota — [3]Ariel University — [4]University of Illinois Urbana-Champaign

In an electronic fluid absent an atomic lattice, an electronic nematic transition can be described as a consequence of a Pomeranchuk instability of the Fermi surface with an associated critical nematic mode. As a coupling to an atomic lattice is introduced, the nematic transition is accompanied by a structural distortion of the lattice. Here, we study the fluctuation spectra near such a coupled nematic-structural transition driven primarily by the electronic nematic fluctuations. This requires coupling the nematic fluctuations to transverse phonons which implies that the transition is no longer accompanied by a critical nematic mode, but rather by the vanishing of the transverse phonon velocity along a certain direction. To understand how, e.g., superconductivity is affected by this, knowledge of the dynamic behaviour of the hybrid nematic/phonon soft excitation is crucial. The purpose of this presentation is to elucidate the properties of this mode. We find that the low-energy fluctuations are generally overdamped except near the soft lattice directions where they become underdamped. How the transition from overdamped to underdamped takes place depends on the proximity to the nematic quantum critical point.

TT 41.5 Thu 10:30 H31

Chiral Heisenberg Gross-Neveu-Yukawa criticality: Honeycomb vs. SLAC fermions — •Thomas C. Lang[1] and Andreas M. Läuchli[2,3] — [1]Institute for Theoretical Physics, University of Innsbruck, Austria — [2]Laboratory for Theoretical and Computational Physics, Paul Scherrer Institute, Switzerland — [3]Institute of Physics, École Polytechnique Féedérale de Lausanne, Switzerland

We perform large scale quantum Monte Carlo simulations of the Hubbard model at half filling with a single Dirac cone close to the critical point, which separates a Dirac semi-metal from an antiferromagnetically ordered phase where SU(2) spin rotational symmetry is spontaneously broken. We discuss the implementation of a single Dirac cone in the SLAC formulation for eight Dirac components and the influence of dynamically induced long-range super-exchange interactions. The finite size behavior of dimensionless ratios and the finite size scaling properties of the Hubbard model with a single Dirac cone are shown to be superior compared to the honeycomb lattice. We extract the critical exponents believed to belong to the chiral Heisenberg Gross-Neveu-Yukawa universality class which coincide for the two lattice types once honeycomb lattices of sufficient linear dimension are considered.

TT 41.6 Thu 10:45 H31

Fractionalized multicriticality in Kitaev spin-orbital liquids — •Max Fornoville[1,2] and Lukas Janssen[3] — [1]Max Planck Institute for Solid State Research, 70569 Stuttgart, Germany — [2]School of Natural Sciences, Technische Universität München, 85748 Garching, Germany — [3]Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01062 Dresden, Germany

Two-dimensional spin-orbital magnets with Kitaev-like exchange frustration realize spin-orbital liquid ground states that are characterized by the appearance of gapless Majorana fermions and a static $\mathbb{Z}_2$ gauge field. It has been shown that the introduction of an antiferromagnetic Heisenberg interaction between nearest-neighbor spin degrees of freedom facilitates a transition towards a partially ordered spin-orbital liquid state with a spontaneously broken spin-rotation symmetry. The associated quantum critical point belongs to the fractionalized fermionic Gross-Neveu-SO(3)* universality class and only partially gaps out the fermionic spectrum. Here, we consider an enlarged theory space, introducing an anisotropic XXZ interaction in the spin sector. The explicit breakdown of spin-rotation symmetry allows for two types of antiferromagnetic order, depending on the nature of the anisotropy. By means of Majorana mean-field theory and ε-expansion to leading order, we uncover the phase diagram of the model and characterize its multicritical behavior. Additionally, we present evidence for the appearance of a symmetry-enhanced first-order transition between the two ordered phases.

15 min. break

TT 41.7 Thu 11:15 H31

One-loop perturbative structure of a (2+1)D bosonized non-Fermi liquid — •Parasar R. Thulasiram[1,2], Chris Hooley[3], and Roderich Moessner[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [3]Centre for Fluid and Complex Systems, Coventry University, Coventry, United Kingdom

Non-Fermi liquids are a class of metals with no quasiparticle excitations often arising from the interaction of slow collective modes, such as an emergent critical boson, with a Fermi surface. Minimal models of this type are called Hertz-Millis-Moriya models and historically suffer from uncontrolled approximations in perturbation theory and patchy treatments of the Fermi surface, preventing the study of global-Fermi surface physics. Delacrétaz et al. (2022) recast Fermi liquid theory in any dimension via a bosonic field that parametrizes macroscopic particle-hole excitations about the whole Fermi surface. This bosonized field theory is suggested to reduce the order in perturbation theory necessary to calculate important quantities and is considerate of whole Fermi surface fluctuations, potentially providing the first robust results of a Hertz-Millis-Moriya theory when coupled to a critical boson. We present initial results of the one-loop critical boson self-energy in 2+1D for calculating the dynamical critical exponent and discuss the benefits and challenges of this theory.

TT 41.8 Thu 11:30 H31

Exotic quantum criticality in Luttinger semimetals — •David Moser and Lukas Janssen — TU Dresden, Deutschland

Luttinger semimetals are three-dimensional strongly-spin-orbit-coupled systems, in which valence and conduction bands touch quadratically at the Fermi level. They provide a rich playground for highly unconventional physics and serve as a parent state to a number of exotic states of matter, such as Weyl semimetals, topological insulators, or spin ice. Here, we discuss various quantum critical phenomena beyond standard quantum criticality, including quasiuniversality, fixed-point annihilation scenarios, and large-N aspects. Our results are relevant for the low-temperature behavior of rare-earth pyrochlore iridates, such as $Pr_2Ir_2O_7$ or $Nd_2Ir_2O_7$.

TT 41.9 Thu 11:45 H31

Examination of the antiferromagnetic superradiant intermediate phase and the effects of geometrical frustration in the Dicke-Ising model — •Jonas Leibig, Anja Langheld, Andreas Schellenberger, and Kai Phillip Schmidt — Chair for Theoretical Physics V, FAU Erlangen-Nürnberg, Germany

We map the Dicke-Ising model to a self-consistent matter Hamiltonian in the thermodynamic limit [1, 2] and solve it using a variety of methods, including exact diagonalization, perturbative and numerical linked-cluster expansions, and density matrix renormalization group. In one dimension, we explore the intermediate phase in the antiferromagnetic model and the multi-critical point in the ferromagnetic model, comparing our results with complementary quantum Monte Carlo simulations [2]. Additionally, we investigate the antiferromagnetic model on the frustrated geometry of the sawtooth chain. We employ high-order series expansions in the strong coupling limit, where the mapping to the self-consistent matter Hamiltonian is definitively valid. Independently, we analyze in greater detail whether the mapping also holds in the specific regime emerging from the frustrated Ising limit induced by an infinitesimal light-matter perturbation.

[1] K. Lenk, J. Li, P. Werner, M. Eckstein, arXiv:2205.05559;
[2] A. Langheld, M. Hörmann, K. P. Schmidt, arXiv:2409.15082.

TT 41.10 Thu 12:00 H31

Critical behavior of the 1d superconductor in the FLEX approximation — •Šimon Kos[1], Sunil D'Souza[1], Jan Gebel[1], Ján Minár[1], and Václav Janiš[2] — [1]University of West Bohemia, Univerzitní 8, CZ-301 00 Plzeň, Czech Republic — [2]Institute of Physics, The Czech Academy of Sciences, Na Slovance 2, CZ-18200 Praha 8, Czech Republic

The dynamical quantum fluctuations below the lower critical dimension push the superconducting critical point to zero temperature. We study the quantum critical behavior of the 1d superconductor with one-particle self-consistency provided by the FLEX approximation within the canonical Baym-Kadanoff scheme. We use the non-interacting singlet electron-electron bubble in the two-particle vertex of the Schwinger-Dyson equation, allowing for a qualitatively correct and tractable treatment of the low-energy critical behavior compatible with the Mermin-Wagner theorem. We use a polar approximation to transform the convolutive Schwinger-Dyson equation into an algebraic one that can be solved semi-analytically. We confirm the position of the critical point and assess the low-temperature behavior of the Hubbard model with attractive interaction.

TT 41.11 Thu 12:15 H31

Tunable criticality and pseudo-criticality in a quantum dissipative spin system — •Manuel Weber — Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, Germany

The study of competing orders in two-dimensional quantum magnets was strongly motivated by the prediction of non-Landau quantum phase transitions, but often we found symmetry-enhanced first-order transitions or pseudocriticality with a logarithmic drift of critical exponents. Here we present results for a (0+1) dimensional spin-boson model where all of these phenomena occur due to a fixed-point annihilation within the critical manifold. Our recently-developed wormhole quantum Monte Carlo method for retarded interactions allows us to study the critical properties of this model with unprecedented precision. We find a tunable transition between two ordered phases that can be continuous or first-order, and even becomes weakly first-order in an extended regime close to the fixed-point collision. We provide direct numerical evidence for pseudo-critical scaling on both sides of the collision manifesting in an extremely slow drift of critical exponents. We also find scaling behavior at the symmetry-enhanced first-order transition as described by a discontinuity fixed point. Our study motivates future work in higher-dimensional quantum dissipative spin systems.

TT 41.12 Thu 12:30 H31

Universality of the quantum Heisenberg model with sub-volume long-range couplings — •Daniel Resch and Thomas C. Lang — Institute for Theoretical Physics, University of Innsbruck, Austria

We investigate the critical properties of effective spin models which emerge from low energy band structures, or momentum space patches of strongly interacting fermions. As representative worst case scenario we present quantum Monte Carlo simulations of phase transitions in the major-axis coupled, long-range quantum Heisenberg model in two spatial dimensions at finite and zero temperature. We quantify the effects of sub-volume anisotropic long range spin-coupling with power-law form $1/r^\alpha$ on the critical exponents of the transitions where SU(2) spin symmetry is spontaneously broken for at low, finite temperatures in accordance with the Mermin Wagner Hohenberg theorem. Performing finite-size scaling analyses for different α we determine the extent of the regimes where the (quantum) phase transitions are represented by Gaussian fixed point, short-range Wilson-Fisher, or continuously varying long-range non-Gaussian critical exponents.