TT 24: Quantum-Critical Phenomena

Time: Wednesday 15:00–19:00 Location: H23

TT 24.1 Wed 15:00 H23

Quantum criticality on a compressible lattice — •Saheli Sarkar, Lars Franke, Nikolas Grivas, and Markus Garst — Karlsruhe Institute of Technology, Karlsruhe, Germany

As an example of quantum criticality on a compressible lattice we study the Lorentz invariant Φ^4 theory with an N-component field Φ, where strain couples to the square of the order parameter. In three spatial dimensions this coupling as well as the self-interaction of the Φ field are both marginal on the tree-level. We compute the one-loop renormalization group equations treating the Φ field as well as the phonons on the same footing. We find that the velocities of the Φ field as well as of the phonons are renormalized yielding an effective dynamical exponent $z > 1$. The renormalization group flow is found to depend on the number of components N. Whereas we find run-away flow for $N < 4$ a new fixed-point emerges for $N >= 4$. We discuss the relation to known results for classical criticality. Our findings are directly relevant to insulating quantum critical antiferromagnets.

TT 24.2 Wed 15:15 H23

Metallic and deconfined quantum criticality in Dirac systems — •Zihong Liu[1], Matthias Vojta[2], Fakher Assaad[1], and Lukas Janssen[2] — [1]Institut für Theoretische Physik und Astrophysik and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, 97074 Würzburg, Germany — [2]Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01062 Dresden, Germany

Motivated by the physics of spin-orbital liquids, we study a model of interacting Dirac fermions on a bilayer honeycomb lattice at half filling, featuring an explicit global SO(3)×U(1) symmetry. Using large-scale auxiliary-field quantum Monte Carlo (QMC) simulations, we locate two zero-temperature phase transitions as function of increasing interaction strength. First, we observe a continuous transition from the weakly-interacting semimetal to a different semimetallic phase in which the SO(3) symmetry is spontaneously broken and where two out of three Dirac cones acquire a mass gap. The associated quantum critical point can be understood in terms of a Gross-Neveu-SO(3) theory. Second, we subsequently observe a transition towards an insulating phase in which the SO(3) symmetry is restored and the U(1) symmetry is spontaneously broken. While strongly first order at the mean-field level, the QMC data is consistent with a direct and continuous transition. It is thus a candidate for a new type of deconfined quantum critical point that features gapless fermionic degrees of freedom.

TT 24.3 Wed 15:30 H23

Deconfined multi-critical point — •Zhenjiu Wang[1] and Adam Nahum[2] — [1]Max-Planck Institute for the Physics of Complex Systems, D-01187, Dresden, Germany — [2]Laboratoire de Physique, Ecole Normale Superieure, CNRS, Universit*e PSL, * Sorbonne Universite, Universite de Paris, 75005 Paris, France

We numerically investigate a deconfined quantum critical point (DQCP) that happens between Neel and valence bond solid phase in a 3-dimensional loop model. Amazingly, this DQCP is an Liftshitz tricritical point due to an explicit lattice symmetry breaking term. This perturbation breaks lattice translational symmetry as well as a mirror-reflection symmetry whereas production of these two operations leave system invariant, hence only an additional vector potential term is coupled to the non-linear sigma model in IR theory. A helical valence bond solid state with spatially modulated valence bond order parameter separates VBS and Neel state due to this explicit vector potential, and a continuous phase transition between Neel and HVB state is simply described by the criticality of DQCP with an emergent Lorenz invariance in IR limit.

TT 24.4 Wed 15:45 H23

Specific heat and magnetocaloric effect at transverse-field quantum criticality in $LiHoF_4$ — •Andreas Wendl[1], Heike Eisenlohr[2], Jan Spallek[1], Christopher Duvinage[1], Matthias Vojta[2], and Christian Pfleiderer[1,3,4] — [1]Physik Department, TU München, Garching, Germany — [2]Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, Dresden, Germany — [3]Centre for QuantumEngineering (ZQE), TU München, Garching, Germany — [4]Munich Centre for Quantum Science and Technology (MCQST), TU München, Garching, Germany

The perhaps best understood example of a quantum critical point is the response of the dipolar Ising ferromagnet $LiHoF_4$ under a transverse field [1-3]. We report an experimental and theoretical study of the specific heat and magneto-caloric effect of $LiHoF_4$ as a function magnetic field down to mK temperatures using a bespoke experimental set-up permitting studies under arbitrary magnetic field orientations. We derive the low temperature entropy landscape and discuss our findings in terms of a theoretical model taking quantitatively into account the non-Kramers nature of the Ho ions, the effects of hyperfine coupling and the presence of magnetic domains.

[1] D. Bitko et al., Phys. Rev. Lett. **77**, 940 (1996)
[2] H. M. Ronnow et al., Science **308**, 389 (2005)
[3] P. B. Chakraborty et al., Phys. Rev. B **70**, 144411 (2004).

TT 24.5 Wed 16:00 H23

Muon spin rotation and relaxation study on $Nb_{1-y}Fe_{2+y}$ — •Jannis Willwater[1], Daniela Eppers[1,2], Thomas Kimmel[1], Elaheh Sadrollahi[1,3], Jochen Litterst[1], Malte Grosche[4], Christopher Baines[5], and Stefan Süllow[1] — [1]IPKM, TU Braunschweig, Germany — [2]PTB, Braunschweig, Germany — [3]IFMP, TU Dresden, Germany — [4]Cavendish Laboratory, University of Cambridge, United Kingdom — [5]PSI, Villigen, Switzerland

The study of metallic materials with a ferromagnetic quantum critical transition revealed a plethora of novel and exotic behavior. In $Nb_{1-y}Fe_{2+y}$, a well-known example, the magnetic ground state reacts extremely sensitively to the chemical composition. Previous experiments show that by varying y, two ferromagnetic ultralow-moment and a SDW phase can be reached in the phase diagram. In particular, the magnetism disappears in a narrow range which is associated with the occurrence of a quantum critical point.

Here, we present a comprehensive study of the magnetic behaviour of $Nb_{1-y}Fe_{2+y}$ by means of muon spin rotation and relaxation. After establishing the muon stopping site, we studied and validated the magnetic phase diagram on different single and polycrystals. The focus of our study was the first investigation of a quantum critical sample, which shows no signs of long-range order, using a microscopic measurement technique. We demonstrate that magnetism at the lowest temperatures is dominated by magnetic fluctuations and that $Nb_{1-y}Fe_{2+y}$ emerges to be uniquely suited to study quantum criticality close to weak itinerant ferromagnetic order.

TT 24.6 Wed 16:15 H23

Quantum criticality of the long-transverse-field Ising model extracted by Quantum Monte Carlo simulations — •Jan Alexander Koziol, Anja Langheld, Sebastian C. Kapfer, and Kai Phillip Schmidt — Lehrstuhl für Theoretische Physik I, Staudtstraße 7, Friedrich-Alexander Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

The quantum criticality of the ferromagnetic transverse-field Ising model with algebraically decaying interactions is investigated by means of stochastic series expansion quantum Monte Carlo, on both the one-dimensional linear chain and the two-dimensional square lattice. Utilizing finite-size scaling (FSS), we extract the full set of critical exponents as a function of the decay exponents of the long-range interactions. We resolve the three different regimes predicted by field theory, ranging from the nearest-neighbor Ising to the long-range Gaussian universality classes with an intermediate regime giving rise to a continuum of critical exponents. Focusing on the non-trivial intermediate regime, we verify our study by the well-known limiting regimes. In the long-range Gaussian regime, we treat the effect of dangerous irrelevant variables on the homogeneity laws by means of a modern FSS formalism.

TT 24.7 Wed 16:30 H23

Quantum criticality of the long-range antiferromagnetic Heisenberg ladder — •Patrick Adelhardt and Kai Phillip Schmidt — Friedrich-Alexander-Universität Erlangen-Nürnberg

The Mermin-Wagner theorem excludes the breaking of a continuous symmetry in one-dimensional spin systems at zero temperature for sufficiently short-ranged interactions. Introducing algebraically decaying long-range couplings on the antiferromagnetic Heisenberg two-leg ladder, we show that a direct second-order quantum phase transition between the topologically ordered rung-singlet phase in the short-range limit and a conventionally Néel-ordered antiferromagnet can be realized in a one-dimensional system. We study the quantum-critical breakdown in the rung-singlet phase using the method of perturbative continuous unitary transformations (pCUT) on white graphs in combination with classical Monte Carlo simulations for the graph embedding in the thermodynamic limit supplemented with linear spin-wave calculations to extract the critical point. Exploiting (hyper-)scaling relations, the pCUT method is used to determine the entire set of canonical critical exponents as a function of the decay exponent. We find that the critical behavior can be divided into a long-range mean-field regime and a regime of continuously-varying exponents similar to the long-range transverse-field Ising model despite the presence of distinct orders on different sides of the critical point and the absence of criticality in the short-range limit.

TT 24.8 Wed 16:45 H23

Electronuclear quantum criticality — Jacintha Banda[1], Daniel Hafner[1], Javier F. Landaeta[1], Elena Hassinger[1,2], Keisuke Mitsumoto[3], Mauro Giovannini[4], Julian Sereni[5], Christoph Geibel[1], and •Manuel Brando[1] — [1]Max Planck Institute for Chemical Physics of Solids, D-01187 Dresden, Germany — [2]Technical University Munich, Physics department, 85748 Garching, Germany — [3]Liberal Arts and Sciences, Toyama Prefectural University, Imizu, Toyama 939-0398, Japan — [4]Department of Chemistry and Industrial Chemistry (DCCI), University of Genova, 16100 Genova, Italy — [5]Department of Physics, CAB-CNEA, CONICET, 8400 San Carlos de Bariloche, Argentina

We present here a rare example of electronuclear quantum criticality in a metal. The compound $YCu_{4.6}Au_{0.4}$ is located at an unconventional quantum critical point (QCP). The relevant Kondo and RKKY exchange interactions are very weak, of the order of 1 K with a strong competition between antiferromagnetic and ferromagnetic correlations, possibly due to geometrical frustration within the fcc Yb sublattice. This causes strong spin fluctuations which prevent the system to order magnetically. Because of the very low Kondo temperature the Yb^{3+} $4f$-electrons couple weakly with the conduction electrons allowing the coupling to the nuclear moments of the ^{171}Yb and ^{173}Yb isotopes to become important. Thus, the quantum critical fluctuations observed at the QCP derive not from purely electronic states but from entangled 'electronuclear' states. This is evidenced in the anomalous temperature and field dependence of the specific heat at very low temperatures.

15 min. break

TT 24.9 Wed 17:15 H23

Bosonization duality in 2+1 dimensions and critical current correlation functions in Chern-Simons U(1)*U(1) Abelian Higgs model — •Vira Shyta[1], Flavio Nogueira[1], and Jeroen van den Brink[1,2] — [1]Institute for Theoretical Solid State Physics, IFW Dresden, Helmholtzstr. 20, 01069 Dresden, Germany — [2]Institute for Theoretical Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, 01069 Dresden, Germany

While the phase structure of the U(1)*U(1)-symmetric Higgs theory is still under debate, we have shown that a version of this theory with an additional Chern-Simons term undergoes a second-order phase transition. We established that such a theory is a bosonized dual of a topological field theory of massless fermions featuring two gauge fields. Here we elaborate on several aspects of this duality, focusing on the critical current correlators and on the nature of the critical point as reflected by the bosonization duality. The current correlators associated to the U(1)*U(1) symmetry and the topological current are shown to coincide up to a universal prefactor, which we find to be the same for both U(1) and U(1)*U(1) topological Higgs theories. The established duality offers in addition another way to substantiate the claim about the existence of a critical point in the bosonic Chern-Simons U(1)*U(1) Higgs model: a Schwinger-Dyson analysis of the fermionic dual model shows that no dynamical mass generation occurs. The same cannot be said for the theory without the Chern-Simons term in the action.

TT 24.10 Wed 17:30 H23

Fixed-point structure and critical behavior of generalized Gross-Neveu models in 2+1 dimensions — •Konstantinos Ladovrechis, Shouryya Ray, Tobias Meng, and Lukas Janssen — Institute for Theoretical Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, Germany

The universal behavior of matter near points of continuous phase transitions is an intriguing phenomenon in condensed matter and statistical physics. At quantum critical points, the presence of gapless fermion degrees of freedom leads to new quantum universality classes without any classical analogues. Here, we discuss zero-temperature phase transitions between two-dimensional Dirac semimetals and long-range-ordered phases, in which spin and/or charge symmetries are spontaneously broken. These transitions are described by generalized Gross-Neveu models in 2+1 dimensions. We identify and classify fixed points of the renormalization group in the theory space spanned by a basis of short-range interactions compatible with the given symmetries, and we compute the corresponding quantum critical behaviors. Implications for the physics of interacting Dirac systems will be discussed as well.

TT 24.11 Wed 17:45 H23

Torus spectroscopy of the chiral Heisenberg quantum phase transition — •Thomas C. Lang[1], Davide Breoni[1,2], Seth Whitsitt[3], Michael Schuler[1], Stefan Wessel[4], and Andreas M. Läuchli[1,5] — [1]Institute for Theoretical Physics, University of Innsbruck, Austria — [2]Institute for Theoretical Physics II: Soft Matter, Heinrich Heine-Universität Düsseldorf, Germany — [3]Joint Quantum Institute, NIST and the University of Maryland, College Park, Maryland, USA — [4]Institut für Theoretische Festkörperphysik, JARA-FIT and JARA-HPC, RWTH Aachen University, 52056 Aachen, Germany — [5]Institute of Physics, École Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland

We establish the universal torus low-energy spectra at the strongly coupled chiral Heisenberg fixed point in $D = (2 + 1)$ dimensions by means of quantum Monte Carlo simulations and exact diagonalization. The fixed point and the associated Gross-Neuveu-Yukawa field theory are directly relevant for the long-wavelength physics of certain interacting Dirac systems, such as repulsive spinfull fermions on the honeycomb lattice, or π-flux square lattice and are compared against results from SLAC fermions. The torus energy spectrum has been shown previously to serve as a characteristic fingerprint of relativistic fixed points and is a powerful tool to discriminate quantum critical behavior in numerical simulations. We are able to address the subtle crossover physics of the low-energy spectrum flowing from the Dirac fixed point to the chiral Heisenberg fixed point, and compare against earlier attempts to extract the Fermi velocity renormalization.

TT 24.12 Wed 18:00 H23

Finite size spectrum of the staggered six-vertex model with $U_q(\mathfrak{sl}(2))$-invariant boundary conditions — •Sascha Gehrmann[1] and Holger Frahm[2] — [1]Institute of Theoretical Physics, Leibniz University Hannover, Germany — [2]Institute of Theoretical Physics, Leibniz University Hannover, Germany

The finite-size spectrum of the critical $\mathbb{Z}_2$-staggered spin-1/2 XXZ model with quantum group invariant boundary conditions is presented. The conformal weights, which are found to have a continuous component, can be described in terms of the non-compact $SU(2,\mathbb{R})/U(1)$ Euclidean black hole conformal field theory (CFT) for a range of the staggering parameter. Besides the continuous part of the spectrum of this CFT, we find also levels from the discrete part emerging as the anisotropy is lowered. The finite size amplitudes of both the continuous and the discrete levels can be parameterized by the corresponding eigenvalues of a quasi-momentum operator which commutes with the Hamiltonian and the transfer matrix of the model.

TT 24.13 Wed 18:15 H23

Fixed-point annihilation and duality in the SU(2)-symmetric spin-boson model — •Manuel Weber[1] and Matthias Vojta[2] — [1]Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany — [2]Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, Germany

The annihilation of two intermediate-coupling renormalization-group (RG) fixed points is of interest in diverse fields from statistical mechanics to high-energy physics and has so far been studied using perturbative techniques. Here we present high-accuracy quantum Monte Carlo results for the SU(2)-symmetric $S = 1/2$ spin-boson (or Bose-Kondo) model. We study the model with a power-law bath spectrum $\propto \omega^s$ where, in addition to a critical phase predicted by perturbative RG, a stable strong-coupling phase is present. Using a detailed scaling analysis, we provide direct numerical evidence for the collision and annihilation of two RG fixed points at $s^* = 0.6540(2)$, causing the critical phase to disappear for $s < s^*$. Moreover, we uncover a surprising duality between the two fixed points, corresponding to a reflection symmetry of the RG beta function, which we utilize to make analytical predictions at strong coupling which are in excellent agreement with numerics. We comment on the consequences for impurity moments in critical magnets.

TT 24.14 Wed 18:30 H23

Applying continuous unitary transformations to open quantum systems — •Lea Lenke, Matthias Mühlhauser, and Kai Phillip Schmidt — Lehrstuhl für Theoretische Physik I, Staudtstraße 7, Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

We generalize the method of continuous unitary transformations (CUTs) to certain types of open systems. In some cases – such as gain-loss Hamiltonians – there exists an effective description in terms of non-Hermitian Hamiltonians. For the latter we successfully apply a perturbative CUT (pCUT) to two non-Hermitian PT-symmetric quantum spin models in order to determine their low-energy physics [1]. In a next step, we aim at generalizing this method further to dissipative frustrated systems described by a Lindblad master equation.

[1] L. Lenke, M. Mühlhauser, K. P. Schmidt, Phys. Rev. B 104, 195137 (2021)

TT 24.15 Wed 18:45 H23

Finite-size scaling at quantum phase transitions above the upper critical dimension — •Anja Langheld, Jan Alexander Koziol, Patrick Adelhardt, Sebastian C. Kapfer, and Kai Phillip Schmidt — Lehrstuhl für Theoretische Physik I, Staudtstraße 7, Friedrich-Alexander Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

The hyperscaling relation and standard finite-size scaling (FSS) are known to break down above the upper critical dimension due to dangerous irrelevant variables. The upper critical dimension becomes experimentally accessible, for instance, in systems with long-range interactions such as the long-range transverse-field Ising model, which can be realized in systems of trapped ions.

We present a coherent formalism for FSS at quantum phase transitions above the upper critical dimension following the recently introduced Q-FSS formalism for thermal phase transitions. Contrary to long-standing belief, the correlation sector is affected by dangerous irrelevant variables. The presented formalism recovers a generalized hyperscaling relation and FSS form.

Using this new FSS formalism, we determine the full set of critical exponents for the long-range transverse-field Ising chain in all criticality regimes ranging from the nearest-neighbor to the long-range mean field regime. For the same model, we also explicitly confirm the effect of dangerous irrelevant variables on the characteristic length scale.