TT 47: Quantum-Critical Phenomena

Time: Thursday 9:30–13:00 Location: HSZ 204

TT 47.1 Thu 9:30 HSZ 204

The mystery of the missing heavy-fermion weight — •Chia-Jung Yang[1], Oliver Stockert[2], Hilbert v. Löhneysen[3], Shovon Pal[1,4], Johann Kroha[5], and Manfred Fiebig[1] — [1]Department of Materials, ETH Zurich, Switzerland — [2]MPI for Chemical Physics of Solids, Dresden, Germany — [3]KIT Karlsruhe, Germany — [4]School of Physical Science, NISER Bhubaneshwar, India — [5]University of Bonn, Germany

The fermionic quasiparticle weight is one of the keys to understanding the quantum critical scenarios across a quantum phase transition (QPT). In heavy-fermion compounds, $CeCu_{6-x}Au_x$ (CCA), Cu substitution by Au expands the lattice, thereby inducing a QPT at x = 0.1 from a paramagnetic Fermi-liquid state to an antiferromagnetically-ordered ground state. Recently, the evolution of spectral weight has been revealed in CCA at x = 0, 0.1, and 1.0 via terahertz (THz) time-domain spectroscopy [1,2]. Here, we further investigate the spectral weight within the RKKY-dominated region where x = 0.2 and 0.3. In both samples, we find that the spectral weight increases slightly with decreasing temperature (T), but settles at a strongly suppressed, T-independent value already at and below 100 K, about two orders of magnitude above the Néel temperature [3]. This indicates that across QPT in CCA, the Kondo singlet formation is suppressed by the T-independent RKKY interaction, not by the critical magnetic fluctuations, in agreement with theoretical predictions [4].

[1] Nat. Phys. **14**, 1103 (2018)
[2] PRR **2**, 033296 (2020)
[3] Eur. Phys. J. B **5**, 447 (1998)
[4] PRL **118**, 117204 (2017)

TT 47.2 Thu 9:45 HSZ 204

Phonon softening close to a structural instability at zero temperature — T. Gruner[1,2], S. Lucas[1], C. Geibel[1], K. Kaneko[3], S. Tsutsui[4,5], K. Schmalzl[6], and •O. Stockert[1] — [1]Max-Planck-Institut für Chemische Physik fester Stoffe, 01187 Dresden, Germany — [2]Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, United Kingdom — [3]Materials Sciences Research Center, Japan Atomic Energy Agency, Tokai, Naka, Ibaraki 319-1195, Japan — [4]Japan Synchrotron Radiation Research Institute, SPring-8, Sayo, Hyogo 679-5198, Japan — [5]Institute of Quantum Beam Science, Graduate School of Science and Engineering, Ibaraki University, Hitachi, Ibaraki 316-8511, Japan — [6]Jülich Centre for Neutron Science JCNS, Forschungszentrum Jülich GmbH, Outstation at ILL, 38042 Grenoble, France

The structural transition in $LuPt_2In$ is interesting since it can be tuned to zero temperature upon substituting Pd for Pt in $Lu(Pt_{1-x}Pd_x)_2In$. Of particular interest is the appearance of a superconducting dome around the structural quantum criticality. We combined inelastic neutron and x-ray scattering measurements and studied in detail this structural transition in $Lu(Pt_{1-x}Pd_x)_2In$. As a result we determined the low-energy phonon dispersions and clearly identified the relevant phonon branch becoming soft at the transition. In general, the theoretical calculations broadly agree with the measured dispersion. However, large tails of the superstructure intensity above the structural transition clearly point to a non-mean-field behavior, which might be related to quantum criticality and/or the superconducting dome.

TT 47.3 Thu 10:00 HSZ 204

Search for ferromagnetic quantum phase transitions in CePt — Marc Seifert[1], •Florian Kübelbäck[1], Pau Jorba[1], Michael Schulz[2], Georg Benka[1], Andreas Bauer[1], and Christian Pfleiderer[1] — [1]Physik-Department, Technical University of Munich, D-85748 Garching, Germany — [2]MLZ, Technical University of Munich, D-85748 Garching, Germany

We report an investigation of the ferromagnetic properties and the putative existence of quantum phase transitions in CePt. Tracking the neutron depolarization of polycrystalline samples under pressure by means of bespoke diamond anvil cell and focussing neutron guides [1], we confirm the presence of a ferromagnetic to paramagnetic quantum phase transition at 13 GPa as inferred previously from the resistivity [2]. An additional drop in the depolarization deep in the ferromagnetic state for pressures up to 5 GPa suggests an additional small moment to large moment transition. We explore the nature and possible existence of a second quantum phase transition in the ferromagnetic state of single-crystal CePt grown under ultra-high vacuum compatible conditions. The pressure versus temperature phase diagram of CePt and its magnetic properties will be compared with the emergence of a Kondo cluster glass in the isostructural sibling CePd of CePt when suppressing ferromagnetic order by substitutional Rh doping [3].

[1] P. Jorba et al., Phys. Stat. Solidi b, 2100623 (2022)
[2] J. Larrea et al., Phys. Rev. B, **72**, 035129 (2005)
[3] M. Seifert et al., Phys. Rev. Res. **4**, 043029 (2022)

TT 47.4 Thu 10:15 HSZ 204

Quantum criticality on a compressible lattice — Saheli Sarkar, •Lars Franke, Nikolas Grivas, and Markus Garst — Institut für Theoretische Festkörperphysik, Karlsruhe, Germany

It is a long standing result in the theory of classical criticality that a second order phase transition when coupled to a compressible lattice will become first order if the Larkin-Pikin criterion[1] is satisfied. More recently the extension of these results to quantum criticality has sparked the interest of the community[2,3]. However, until now a detailed analysis of a microscopic theory describing a quantum phase transition on a compressible lattice and its implications for the nature of the phase transition as well as the consequences for the lattice has been missing. Here we provide this calculation for a Lorentz-invariant ϕ^4-theory with quadratic coupling to strain and analyse it using renormalization group (RG) methods to one-loop order. We find that both critical and phonon velocity flow with RG leading to an additional fixed point where the phonons have a renormalized dynamical exponent. Furthermore, our results show that the quantum version of the Larkin-Pikin criterion[2] holds, but even when the criterion is not satisfied a structural instability can still occur, if the coupling is large enough.

[1] A. Larkin and S. Pikin, Sov. Phys. JETP 29, 891 (1969)
[2] P. Chandra, P. Coleman, M. A. Continentino, and G. G. Lonzarich, Phys. Rev. Res. 2, 043440 (2020)
[3] A. Samanta, E. Shimshoni, and D. Podolsky, Phys. Rev. B 106, 035154 (2022)

TT 47.5 Thu 10:30 HSZ 204

Marginal Fermi liquid at a magnetic quantum critical point from dimensional confinement — •Bernhard Frank[1], Zi Hong Liu[2], Fakher F. Assaad[2], Matthias Vojta[1], and Lukas Janssen[1] — [1]Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01062 Dresden, Germany — [2]Institut für Theoretische Physik und Astrophysik and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, 97074 Würzburg, Germany

Metallic quantum criticality is frequently discussed as a source for non-Fermi liquid behavior, but controlled theoretical treatments are scarce. Here, we identify and study a novel magnetic quantum critical point in a two-dimensional antiferromagnet coupled to a three-dimensional environment of conduction electrons. By combining an effective field theory analysis and sign-problem-free quantum Monte Carlo simulations, we demonstrate that the quantum critical point exhibits marginal Fermi liquid behavior. In particular, we compute the electrical resistivity for transport across the magnetic layer, which is shown to display a linear temperature dependence at criticality. Experimental realizations in Kondo heterostructures are discussed.

TT 47.6 Thu 10:45 HSZ 204

Transverse-field quantum phase transitions in $CoNb_2O_6$ — •Alexander Engelhardt[1], Andreas Wendl[1], Andreas Bauer[1], Andreas Erb[2], Matthias Vojta[3], and Christian Pfleiderer[1] — [1]Physik-Department, Technical University of Munich, D-85748 Garching, Germany — [2]Walther-Meißner-Institut, D-85748 Garching, Germany — [3]Institut for Theoretical Physics, Technical University of Dresden, D-85748 Garching, Germany

The ferromagnetic Ising chain in a transverse magnetic field displays the perhaps best understood theoretical example of a quantum phase transition. One of the closest realizations has been reported in the columbite compound $CoNb_2O_6$ [1,2,3], in which, however, weak interchain couplings result in incommensurate antiferromagnetism as a function of decreasing temperature, followed by a transition to commensurate antiferromagnetic order. We have grown high-quality single-crystal $CoNb_2O_6$ by means of optical float-zoning. Measuring the transverse magnetic ac susceptibility of a spherical sample down to 90 mK under arbitrary field orientations, we have mapped out the emergence of the quantum phase transitions associated with the incommensurate and commensurate antiferromagnetic order under transverse field, as well as the evolution of the magnetic phase diagram when systematically tilting the magnetic field away from the hard magnetic axis.

[1] R. Coldea et al., Science **327**, 177 (2010)
[2] M. Fava et al., PNAS **117**, 25219 (2020)
[3] C. M. Morris et al., Nat. Phys. **17**, 852 (2021)

TT 47.7 Thu 11:00 HSZ 204

Non-Fermi liquid behavior at flat hot spots at the onset of density wave order in two-dimensional metals — •Lukas Debbeler and Walter Metzner — Max Planck Institute for Solid State Research, Stuttgart, Germany

We analyze the quantum critical point (QCP) at the transition towards incommensurate charge or spin density wave order with a $2k_F$ wave vector that connects a single pair of hot spots on the Fermi surface. From a theoretical point of view the fate of this QCP is debated. Strong fluctuations might lead to a discontinuously opening gap and therefore a first order transition [1]. On the other hand a fluctuation driven flattening at the hot spots of the Fermi surface has been found [2,3], which could protect the QCP. Hence, we investigate the effect of quantum critical fluctuations for a flat Fermi surface at the nesting points. We report non-Fermi liquid properties and provide numerical values for anomalous exponents.

[1] B. L. Altshuler et al., Phys. Rev. B 52, 5563 (1995)
[2] J. Sýkora et al., Phys. Rev. B 97, 155159 (2018)
[3] J. Halbinger et al., Phys. Rev. B 99, 195102 (2019)

15 min. break

TT 47.8 Thu 11:30 HSZ 204

Frozen deconfined quantum criticality — •Vira Shyta[1,2], Jeroen van den Brink[1,3], and Flavio Nogueira[1] — [1]Institute for Theoretical Solid State Physics, IFW Dresden, Helmholtzstr. 20, 01069 Dresden, Germany — [2]Kyiv Academic University, 36 Vernadsky blvd., Kyiv 03142, Ukraine — [3]Institute for Theoretical Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, 01069 Dresden, Germany

There is a number of contradictory findings with regard to whether the theory describing easy-plane quantum antiferromagnets undergoes a second-order phase transition. The traditional Landau-Ginzburg-Wilson approach suggests a first-order phase transition, as there are two different competing order parameters. On the other hand, it is known that the theory has the property of self-duality which has been connected to the existence of a deconfined quantum critical point (DQCP). The latter regime suggests that order parameters are not the elementary building blocks of the theory, but rather consist of fractionalized particles that are confined in both phases of the transition and only appear at the critical point. Here we establish from exact lattice duality transformations and renormalization group analysis that the easy-plane CP1 antiferromagnet does feature a DQCP. We uncover the criticality starting from a regime analogous to the zero temperature limit of a certain classical statistical mechanics system which we therefore dub frozen. At criticality our bosonic theory is dual to a fermionic one with two massless Dirac fermions, which thus undergoes a second-order phase transition as well.

TT 47.9 Thu 11:45 HSZ 204

Finite temperature entanglement negativity of fermionic topological phases and quantum critical points — •Wonjune Choi[1,2], Frank Pollmann[1,2], and Michael Knap[1,2] — [1]Department of Physics, Technical University of Munich, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany

In condensed matter physics, topology is vital in describing quantum phases of matter beyond the Ginzburg-Landau paradigm. Two symmetry-preserving quantum states may not be adiabatically connected if the topological structure encoded in the many-body entanglements is distinct. Hence, this talk presents how quantum entanglements can be quantified to unveil the underlying topological nature of the gapped topological phases and the quantum critical points. We demonstrate that the logarithmic negativity between spatially separated disjoint intervals can sharply count the topologically protected edge modes. Notably, the quantized values of the negativity could reveal the topological indices of the gapless quantum states described by the conformal field theories having the same central charge. At finite temperatures, the entanglement negativity for the disjoint intervals is no longer quantized. However, the negativity for the two adjacent intervals leaves the structure similar to the quantum critical fan, which signals the highly entangled ground state even at a finite temperature window.

TT 47.10 Thu 12:00 HSZ 204

Symmetry enriched topological quantum phase transition in projected entangled pair states — •Lukas Haller, Yu-Jie Liu, Wen-Tao Xu, and Frank Pollmann — Department of Physics, Technical University of Munich, 85748 Garching, Germany

Phase transitions between topologically ordered phases can exhibit a rich structure and are generically challenging to study. In this context, we consider the 2D toric code decorated with 1D symmetry protected topological states and construct a family of parametrized projected entangled pair states (PEPS), which describes the ground states of time-reversal (TR) symmetric Hamiltonians. The system can exhibit three distinct phases of matter: (i) A trivial phase; (ii) the toric code phase, where TR symmetry is not fractionalized; (iii) a symmetry enriched topological (SET) phase, where TR symmetry can be fractionalized on anyons. We characterize different phases using topological entanglement entropy and membrane order parameters. By mapping the PEPS to the partition functions of 2D classical models, we show that the trivial phase is separated from the toric code and the SET phases by critical points described by an Ising conformal field theory (CFT) with central charge $c = 1/2$, while the phase transition between the toric code and the SET phase is described by a compactified free-boson CFT with $c = 1$. The model realizes a direct phase transition between the toric code and the SET phases at a microscopic level.

TT 47.11 Thu 12:15 HSZ 204

Antiferromagnetic Weyl quantum criticality in three-dimensional Luttinger semimetals — •David Jonas Moser and Lukas Janssen — Technische Universität Dresden, 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 a quantum critical point between Luttinger and antiferromagnetic Weyl semimetals using a renormalization group approach. 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 47.12 Thu 12:30 HSZ 204

Renormalization group flow of the Yukawa-SYK model — •Niklas Cichutek and Peter Kopietz — Goethe University Frankfurt

We use the functional renormalization group to calculate the global renormalization group flow of the Yukawa-SYK model describing N fermions on a quantum dot which are coupled to M phonons by a disorder-induced Yukawa coupling in the large N and M limit for an arbitrary ratio $\frac{N}{M}$. By determining the fixed-point structure we identify the different phases as well as the quantum critical point and their corresponding anomalous dimensions. The stability analysis of the fixed points sheds light on the self-tuning to criticality of the Yukawa-SYK model.

TT 47.13 Thu 12:45 HSZ 204

Quantum criticality of Heisenberg systems with long-range interactions — •Patrick Adelhardt and Kai Phillip Schmidt — Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU)

The majority of numerical approaches investigating long-range quantum systems is restricted to one-dimensional systems and systems in two dimensions with quickly decaying long-range interactions. While models with discrete symmetries like the long-range transverse-field Ising model have been studied thoroughly, much less is known about long-range models with continuous symmetries where long-range interactions can cricumvent the Hohenberg-Mermin-Wagner theorem in one dimension allowing the spontaneous breaking of continuous symmetries or can give rise to massive excitations violating Goldstone's theorem. We study the breakdown of the rung-singlet phase in the quasi one-dimensional Heisenberg ladders as well as two-dimensional Heisenberg bilayer systems with algebraically decaying long-range interactions. To this end we use the method of perturbative continuous unitary transformations (pCUT) as a white graph expansion with classical Monte Carlo simulations yielding high-order series in the thermodynamic limit about the limit of isolated dimers. This allows us to determine the critical point as well as critical exponents as a function of the decay exponent.