TT 56: Correlated Electrons: Quantum-Critical Phenomena

Time: Thursday 9:30–13:00 Location: HSZ 304

TT 56.1 Thu 9:30 HSZ 304

Quasiparticle critical slowing down in a heavy-fermion system — •S. Pal[1], C.-J. Yang[1], F. Zamani[2], K. Kliemt[3], C. Krellner[3], H. v. Löhneysen[4], J. Kroha[2], and M. Fiebig[1] — [1]ETH Zürich, Switzerland. — [2]Universität Bonn, Germany. — [3]Goethe-Universität Frankfurt, Germany. — [4]KIT Karlsruhe, Germany.

Rare-earth heavy-fermion systems such as $YbRh_2Si_2$ show a quantum phase transition between a fully Kondo-screened paramagnetic Fermi-liquid phase and an antiferromagnetically ordered phase. When excited by THz pulses, the Kondo state disintegrates and coherently recovers on timescales in the order of 2 ps, corresponding to the Kondo lattice temperature of $T_K^* = 25$ K. We use THz time-domain spectroscopy[1,2] to probe the coherent Kondo spectral weight of $YbRh_2Si_2$ in presence of an in-plane magnetic field. By tuning the magnetic field, we are able to map the logarithmic build-up of quasiparticle spectral weight around 25 K across the quantum phase transition. We find that near the critical magnetic field of $B_c = 67$ mT, first the Kondo weight rises logarithmically with decreasing temperature, reaching a maximum near the Kondo lattice temperature. It is then followed by a reduction until 10 K indicating Kondo breakdown. Upon decreasing the temperature further, we find that the THz response signal starts building up logarithmically until the lowest temperatures measured. A critical, two-band Fermi-liquid theory indicates that this signals quasiparticle critical slowing down for a fermionic field - an observation of which in our experiments is indeed intriguing.

[1] Nat. Phys. **14**, 1103 (2018)
[2] Phys. Rev. Lett. **122**, 096401 (2019).

TT 56.2 Thu 9:45 HSZ 304

Fermi surface topological transition in $Sr_3Ru_2O_7$ — •Dmitri Efremov[1], Alex Shtyk[2], Andreas Rost[3], Claudio Chamon[4], Andrew Mackenzie[6], and Joseph Betouras[5] — [1]IFW, Dresden — [2]Harvard University, Cambridge — [3]University of St Andrews,St Andrews — [4]Boston University, Boston — [5]Loughborough University, Loughborough — [6]Max Planck Institute for Chemical Physics of Solids, Dresden

A wide variety of complex phases in quantum materials are driven by electron-electron interactions, which are enhanced through density of states peaks. A well-known example occurs at van Hove singularities where the Fermi surface undergoes a topological transition. Here we discuss that higher order singularities, where multiple disconnected leaves of Fermi surface touch all at once, naturally can occur at points of high symmetry in the Brillouin zone. Such multicritical singularities can lead to stronger divergences in the density of states than canonical van Hove singularities. As a concrete example of the power of these Fermi surface topological transitions, we demonstrate how they can be used in the analysis of experimental data on $Sr_3Ru_2O_7$. Understanding the related mechanisms opens up new avenues in material design of complex quantum phases

TT 56.3 Thu 10:00 HSZ 304

Low temperature transverse susceptibility of $LiHoF_4$ — •Andreas Wendl, Felix Rucker, Christopher Duvinage, and Christian Pfleiderer — Physik Department TU München, James-Franck Straße 1, 85748 Garching

$LiHoF_4$ exhibits the experimental realisation of the simplest quantum spin model of a ferromagnetic quantum phase transition: the transverse field Ising model [1]. Application of a magnetic field perpendicular to the easy magnetic axis, suppresses long-range ferromagnetic order above a critical field, $B_c \approx 5.1$ T. We report measurements of the transverse ac susceptibility of a spherical single-crystal of $LiHoF_4$. For our study we used a bespoke miniature ac susceptometer optimised for measurements at milli-Kelvin temperatures under arbitrary directions of the applied magnetic field using a vector magnet. This allowed us to determine the phase diagram under tilted magnetic fields as well as the precise magnetic field dependence of the Curie temperature at low fields under strictly transverse field geometry. In addition, we tracked the thermal and quantum freezing of ferromagnetic domains.

[1] D. Bitko et al., Phys. Rev. Lett. **77**, 940 (1996)
[2] F. Rucker and C. Pfleiderer, Rev. Sci. Instrum. **90**, 073903 (2019).

TT 56.4 Thu 10:15 HSZ 304

Ferromagnetic magnons in $YbNi_4P_2$ — •Oliver Stockert[1], Kristin Kliemt[2], Zita Huesges[3], Stefan Lucas[1], Cornelius Krellner[2], Astrid Schneidewind[4], and Karin Schmalzl[5] — [1]Max-Planck-Institut für Chemische Physik fester Stoffe, Dresden — [2]Physikalisches Institut, Goethe-Universität, Frankfurt am Main — [3]Helmholtz-Zentrum für Materialien und Energie, Berlin — [4]Forschungszentrum Jülich, Outstation MLZ, Garching — [5]Forschungszentrum Jülich, Outstation ILL, Grenoble

The heavy-fermion compound $YbNi_4P_2$ exhibits ferromagnetic order below the very low Curie temperature $T_C = 150$ mK. Upon substituting As for P the ordering temperature T_C in $YbNi_4(P_{1-x}As_x)_2$ can be continuously suppressed with the occurrence of a quantum critical point [1]. So far bulk measurements have been used to characterize the ferromagnetic order in $YbNi_4P_2$ [2]. In contrast, neutron diffraction failed in detecting any ferromagnetic signal. In order to better characterize the magnetism in $YbNi_4P_2$, we performed inelastic neutron scattering on a large $YbNi_4P_2$ single crystal [3] at the triple-axis spectrometers IN12 (ILL, Grenoble), PANDA (MLZ, Garching) and FLEXX (HZB, Berlin). We observe clear magnetic excitations in $YbNi_4P_2$ at low temperatures with a dispersion as expected for a ferromagnet. Our findings are a direct evidence of the ferromagnetic order in $YbNi_4P_2$.

[1] A. Steppke et al., Science 339 (2013) 933
[2] C. Krellner, C. Geibel, J. Phys. Conf. Ser. 391 (2012) 012032
[3] K. Kliemt, C.Krellner, J. Crystal Growth 449 (2016) 129.

TT 56.5 Thu 10:30 HSZ 304

Non-Fermi liquid behaviors in $Y_{1-x}Pr_xIr_2Zn_{20}$ studied by thermal expansion — •Andreas Wörl[1], Yu Yamane[2], Yoshifumi Tokiwa[1], Takahiro Onimaru[2], and Philipp Gegenwart[1] — [1]Experimental Physics 6, Center for Electronic Correlations and Magnetism, University of Augsburg, Germany — [2]Graduate School of Advanced Sciences of Matter, Department of Quantum Matter, Hiroshima University, Japan

The overscreening of quadrupole moments by two-channels of conduction electrons, generally known as two-channel Kondo effect, causes non-Fermi liquid behavior. A prototype material to study this effect is the quadrupole Kondo lattice $PrIr_2Zn_{20}$ [1]. Y substituted $PrIr_2Zn_{20}$ single crystals exhibit non-Fermi liquid behaviors in specific heat [2], electrical resistivity [2] and elastic constants [3], which are compatible with the theoretical single-site two channel Kondo model. In this talk, we present results on the thermal expansion and magnetostriction of $Y_{1-x}Pr_xIr_2Zn_{20}$ single crystals which allow for a further characterization of this novel hybridization effect.

[1] T. Onimaru et al., Phys. Rev. B 94, 075134 (2016)
[2] Y. Yamane et al., Phys. Rev. Lett. 121, 077206 (2018)
[3] T. Yanagisawa et al., Phys. Rev. Lett. 123, 067201 (2019)

TT 56.6 Thu 10:45 HSZ 304

Deconfined critical point in a doped random quantum Heisenberg magnet — •Darshan Joshi, Chenyuan Li, and Subir Sachdev — Department of Physics, Harvard University, Cambridge MA 02138, USA

We study a t-J model with both t and J random and all-to-all. This model has been studied earlier [1], and can be mapped to an Anderson impurity coupled to self-consistent fermionic and bosonic baths. We employ renormalization group and large M (for models with SU(M) spin symmetry) analyses, and find evidence for a deconfined critical point at zero temperature and small doping. The critical spin correlations are similar to those in a random magnet [2]. A disordered Fermi liquid phase is expected at large doping, while a spin glass phase is expected at small doping. We note connections to the physics of the underdoped cuprates.

[1] O. Parcollet and A. Georges, Physical Review B 59, 5341 (1999).
[2] S. Sachdev and J. Ye, Physical Review Letters 70, 3339 (1993).

TT 56.7 Thu 11:00 HSZ 304

Nonordinary Edge Criticality of Two-Dimensional Quantum Critical Magnets — Lukas Weber[1], Francesco Parisen Toldin[2], and •Stefan Wessel[1] — [1]RWTH Aachen University, Germany — [2]Würzburg University, Germany

Based on large-scale quantum Monte Carlo simulations, we examine

the correlations along the edges of two-dimensional semi-infinite quantum critical Heisenberg spin-1/2 and spin-1 systems. In particular, we consider coupled quantum spin-dimer systems at their bulk quantum critical points, including the columnar-dimer model and the plaquette-square lattice. The alignment of the edge spins strongly affects these correlations and the corresponding scaling exponents, with remarkably similar values obtained for various quantum spin-dimer systems. We furthermore observe subtle effects on the scaling behavior from perturbing the edge spins that exhibit the genuine quantum nature of these edge states.

15 min. break.

TT 56.8 Thu 11:30 HSZ 304

Emergent spin 1/2 chains at domain walls of Kekulé valence-bond solids — •Toshihiro Sato[1], Martin Hohenadler[1], Tarun Grover[2], John McGreevy[2], and Fakher F. Assaad[1] — [1]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Germany — [2]Department of Physics, University of California at San Diego, USA

Dirac fermions with dynamically generated anticommuting Z_2 Kekulé valence-bond solid (KVBS) and SO(3) antiferromagnetic (AFM) mass terms allow for the generation of a topological θ-term in the low energy effective field theory. Such a topological term is at the origin of phase transitions beyond the Ginzburg-Landau paradigm: topological defects of one phase carry the charge of the other and proliferate at the transition. In the vicinity of criticality and in the KVBS phase, the θ-term implies that a domain wall of the Z_2 order parameter harbours a spin 1/2 Heisenberg chain. Using pinning fields to stabilize the domain wall, we show that our auxiliary field quantum Monte Carlo simulations indeed support the emergence of spin-1/2 chain at the Z_2 defect.

TT 56.9 Thu 11:45 HSZ 304

Quantum critical behavior of the Hubbard model on the honeycomb lattice — •Francesco Parisen Toldin and Fakher F. Assaad — Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Germany

We study the quantum critical behavior of the Hubbard model on the honeycomb lattice by means of large-scale projective Auxiliary-field quantum Monte Carlo simulations, which target the ground state of the model. At T=0 the model hosts a continuous phase transition between a Dirac semimetal and an antiferromagnetic Mott insulating phase, whose critical behavior belongs to the Gross-Neveu-Heisenberg universality class, also known as chiral Heisenberg. We investigate the universal properties of the phase transition by a finite-size scaling analysis of time-displaced critical correlation functions.

TT 56.10 Thu 12:00 HSZ 304

Nematic phase transitions of Dirac fermions — •Jonas Schwab[1], Lukas Janssen[2], Kai Sun[3], Zi Yang Meng[4], Igor Herbut[5], and Fakher F. Assaad[1] — [1]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Germany — [2]Institut für Theoretische Physik, Technische Universität Dresden, Germany — [3]Physics Department, University of Michigan, Ann Arbor, MI 48109, USA — [4]Institute of Physics, Chinese Academy of Sciences, Beijing 100190,China — [5]Department of Physics, Simon Fraser University, Burnaby, British Columbia V5A 1S6, Canada

We consider Dirac fermions, as realized by a pi-flux tight binding model on a square lattice, coupled to an Ising model in a transverse field. The coupling is chosen such that the ordering of the Ising spins triggers a meandering of the Dirac fermions and thereby a nematic deformation of the "Fermi" surface. We consider two models where the nematic transition reduces the initial C_{4V} (C_{2V}) symmetry to C_{2V} ($2V$). Auxiliary field quantum Monte Carlo simulations reveal that the C_{4V} (C_{2V}) symmetric model show a continuous (first order) transition. An analytical understanding of the transition is derived.

TT 56.11 Thu 12:15 HSZ 304

Doping a dynamically generated quantum spin Hall insulator — •Zhenjiu Wang[1], Toshihiro Sato[1], Yuhai Liu[2], Martin Hohenadler[1], Wenan Guo[2,3], and Fakher F. Assaad[1] — [1]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Germany — [2]Beijing Computational ScienceResearch Center, Beijing 100193, China — [3]Department of Physics, Beijing Normal University, Beijing 100875, China

We consider a quantum spin Hall (QSH) insulator in which the spin-orbit coupling is dynamically generated by spontaneous symmetry breaking of the SU(2) spin symmetry. At the particle-hole symmetric point tuning the *band-width* leads to a direct and continuous quantum phase transition to an s-wave superconductor. This transition has an emergent Lorentz symmetry and is described by the theory of de-confined quantum criticality with emergent charged U(1) gauged spinons [1]. Here we will doped the QSH insulator by tuning the chemical potential. We observe a continuous quantum phase transition again to an s-wave superconductor. Such a phase transition has no emergent Lorentz invariance and fractionalized particles. In particular the dynamical exponent takes the value $z = 2$ and one observes pronounced long-wavelength Goldstone modes. The above stems from auxiliary field quantum Monte Carlo simulations of a designer model, that, by definition, is free of the negative sign problem.

[1] Yuhai Liu, Zhenjiu Wang, Toshihiro Sato, Martin Hohenadler, Chong Wang, Wenan Guo, and Fakher F. Assaad, Nature Communications 10 (2019), no. 1, 2658.

TT 56.12 Thu 12:30 HSZ 304

Soluble fermionic quantum critical point in two dimensions — •Shouryya Ray[1,2], Matthias Vojta[1,2], and Lukas Janssen[1,2] — [1]Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden, Germany — [2]Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01062 Dresden, Germany

We study a quantum critical point in two spatial dimensions between a semimetallic phase characterized by a stable quadratic Fermi node, and an ordered phase in which the spectrum develops a dynamical band gap. The quantum critical behaviour can be computed exactly and we explicitly derive the scaling laws of various observables. While the correlation functions at criticality satisfy usual power laws with anomalous exponents $\eta_\phi = 2$ and $\eta_\psi = 0$, the correlation length and the order parameter exhibit essential singularities upon approaching the quantum critical point from the insulating side; phenomenological similarities to the classical Berezinskii-Kosterlitz-Thouless transition are elucidated. On the semimetallic side, the correlation length remains infinite, and leads to emergent scale invariance.

TT 56.13 Thu 12:45 HSZ 304

Gapless Coulomb State Emerging from a Self-Dual Topological Tensor-Network State — •Guo-Yi Zhu — Max-Planck-Institute for the Physics of Complex Systems

In the tensor network representation, a deformed Z2 topological ground state wave function is proposed and its norm can be exactly mapped to the two-dimensional solvable Ashkin-Teller model. Then the topological (toric code) phase with anyonic excitations corresponds to the partial order phase of the Ashkin- Teller model, and possible topological phase transitions are precisely determined. With the electric- magnetic self-duality, a novel gapless Coulomb state with quasi-long-range order is obtained via a quantum Kosterlitz-Thouless phase transition. The corresponding ground state is a condensate of pairs of logarithmically confined electric charges and magnetic fluxes, and the scaling behavior of various anyon correlations can be exactly derived, revealing the effective interaction between anyons and their condensation. Deformations away from the self-duality drive the Coulomb state into either the gapped Higgs phase or the confining phase.