# TT 24: Quantum-Critical Phenomena

Time: Tuesday 9:30–13:15 Location: H 2053

TT 24.1 Tue 9:30 H 2053

**Quantum criticality on a compressible lattice** — Saheli Sarkar[1], •Lars Franke[2], Nikolas Grivas[2], and Markus Garst[1,2] — [1]Institute for Quantum Materials and Technology, Karlsruhe Institute of Technology, D-76131 Karlsruhe, Germany — [2]Institute of Theoretical Solid State Physics, Karlsruhe Institute of Technology, D-76131 Germany

The stability of a quantum critical point in the $O(N)$ universality class with respect to an elastic coupling, that preserves $O(N)$ symmetry, is investigated for isotropic elasticity in the framework of the renormalization group (RG) close to the upper critical dimension $d = 3 - \epsilon$. With respect to the Wilson-Fisher fixed point, we find that the elastic coupling is relevant in the RG sense for $1 \leq N \leq 4$, and the crystal becomes microscopically unstable, i.e., a sound velocity vanishes at a finite value of the correlation length $\xi$. For $N > 4$, an additional fixed point emerges that is located at a finite value of the dimensionless elastic coupling. This fixed point is repulsive and separates the flow to weak and strong elastic coupling. As the fixed point is approached the sound velocity is found to vanish only asymptotically as $\xi \to \infty$ such that the crystal remains microscopically stable for any finite value of $\xi$. The fixed point structure we find for the quantum problem is distinct from the classical counterpart in $d = 4 - \epsilon$, where the crystal always remains microscopically stable for finite $\xi$.

TT 24.2 Tue 9:45 H 2053

**Quantum critical Dirac semimetals and finite-temperature effects** — •Mireia Tolosa-Simeón[1], Laura Classen[2,3], and Michael M. Scherer[1] — [1]Institut für Theoretische Physik III, Ruhr-Universität Bochum, Bochum, Germany — [2]Max Planck Institute for Solid State Research, Stuttgart, Germany — [3]Department of Physics, Technical University of Munich, Garching, Germany

The chiral Ising-, XY-, and Heisenberg models serve as effective descriptions of Dirac semimetals undergoing a quantum phase transition into a symmetry-broken ordered state. Interestingly, their quantum critical points govern the physical behavior of the system in the vicinity of the transition even at finite temperatures. In this contribution, we explore the chiral models at zero and finite temperature, both in the Dirac phase as well as in the symmetry-broken phases. To that end, we set up a functional renormalization group approach, which allows us to systematically track (1) the phenomenon of pre-condensation, (2) the manifestation of the Mermin-Wagner-Hohenberg theorem due to pseudo-Goldstone fluctuations at finite temperatures, and (3) the quantitative behavior of the system in the quantum critical fan, e.g., by calculating the quasiparticle weight. Our work aims at a more holistic understanding of chiral models near their quantum critical point, including, e.g., the description of non-Dirac-liquid behavior, in analogy to the non-Fermi-liquid behavior in metallic quantum critical points.

TT 24.3 Tue 10:00 H 2053

**Exotic quantum criticality in pyrochlore iridates** — •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 various quantum critical phenomena beyond standard quantum criticality, including quasiuniversality and fixed point annihilation scenarios. 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 24.4 Tue 10:15 H 2053

**Quantum criticality of the antiferromagnetic XXZ square lattice bilayer with long-range interactions** — •Patrick Adelhardt and Kai Phillip Schmidt — Department of Physics, Staudtstraße 7, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Germany

The majority of numerical approaches investigating quantum systems with algebraically decaying long-range interactions is restricted to one dimensions or to two-dimensional systems 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. We study the breakdown of the rung-singlet phase in the two-dimensional XXZ bilayer model with unfrustrated staggered long-range interactions. To this end we use the method of perturbative continuous unitary transformations (pCUT) 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, the dispersion in the rung-singlet phase close to it, as well as critical exponents as a function of the decay exponent. While for quickly-decaying interactions we identify three critical regimes with 3D XY, Heisenberg, and Ising criticality depending on the anisotropy in the XXZ Hamiltonian, for strong interactions we observe a single long-range mean-field regime and continuously varying critical exponents between these regimes.

TT 24.5 Tue 10:30 H 2053

**(Almost) Everything is a Dicke model** — •Andreas Schellenberger and Kai Phillip Schmidt — FAU Erlangen-Nürnberg, Erlangen, Deutschland

We investigate classes of interacting quantum spin systems in a single-mode cavity with a Dicke coupling, as a paradigmatic example of correlated light-matter systems. Coming from the limit of weak light-matter couplings and large system sizes, we map the relevant low-energy sector of these models onto the exactly solvable Dicke model.

We apply the outcomes to the Dicke-Ising model as a paradigmatic example [1,2], in agreement with results obtained by mean-field theory [2]. We further accompany and verify our findings with finite-size calculations, using exact diagonalization and the series expansion method pcst++ [3].

[1] J. Rohn et al., Phys. Rev. Research 2 (2020) 023131
[2] Y. Zhang et al., Sci Rep 4 (2014) 4083
[3] L. Lenke et al., Phys. Rev. A 108 (2023)

TT 24.6 Tue 10:45 H 2053

**Quantum Monte Carlo simulation of the Dicke-Ising model on hypercubic lattices** — •Anja Langheld, Max Hörmann, and Kai Phillip Schmidt — Department Physik, Staudtstraße 7, Friedrich-Alexander Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

We study the Ising model in a light-induced quantized transverse field [1, 2] using quantum Monte Carlo to investigate the influence of light-matter interactions on correlated quantum matter. To avoid a direct sampling of the photons, we develop a quantum Monte Carlo algorithm based on the recently introduced wormhole algorithm for spin-boson systems [3], in which the bosonic degrees of freedom are integrated out analytically.

We provide quantitative phase diagrams and critical properties for ferromagnetic as well as antiferromagnetic interactions on hypercubic lattices. For antiferromagnetic interactions, we confirm the existence of a non-trivial intermediate phase, displaying magnetic order and finite photon density at the same time, predicted by a semi-classical mean-field study [1]. However, this intermediate phase turns out to be much smaller and certain phase transitions turn out to be of first order rather than of second order. In the case of ferromagnetic interactions, a change in the order of the quantum phase transition for finite Ising coupling and longitudinal field is observered.

[1] J. Rohn et al., Phys. Rev. Research 2 (2020) 023131
[2] Y. Zhang et al., Sci Rep 4 (2014) 4083
[3] M. Weber et al., Phys. Rev. Lett. 119 (2017) 097401

TT 24.7 Tue 11:00 H 2053

**From Nordic Walking in Wess-Zumino-Witten Theory to Deconfined Pseudocriticality** — •Bilal Hawashin[1], Astrid Eichhorn[2], Lukas Janssen[3], Michael Scherer[1], and Shouryya Ray[2] — [1]Institut für Theoretische Physik III, Ruhr-Universität Bochum, 44801 Bochum, Germany — [2]CP3-Origins, University of Southern Denmark, Campusvej 55, 5230 Odense M, Denmark — [3]Institut für Theoretische Physik and Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, 01062 Dresden, Germany

An exciting class of non-Landau transitions are deconfined quantum

critical points (DQCP) which exhibit emergent fractional excitations and gauge fields at criticality. The primary example in the study of DQCPs has been a system of half-integer spins on a square lattice with competing interactions. Whether or not this system shows true criticality is a major open question in the field. In fact, numerical simulations for this model provide evidence for weak-first order behavior. The effective field theory describing the behaviour between those orders is a 3D Wess-Zumino-Witten theory with target manifold $S^4$. I will discuss a first study of this model using the non-perturbative functional renormalization group. We show that the Wess-Zumino-Witten term gives rise to two possible mechanisms explaining pseudocriticality and drifting exponents: (1) the well-known Walking mechanism and (2) a new mechanism, dubbed Nordic Walking. We provide an estimate for effective thermodynamic critical exponents and their drifts as a function of system size.

**15 min. break**

TT 24.8 Tue 11:30 H 2053

**Manipulating topology of quantum phase transitions by flavor enhancement** — •Gabriel Rein[1,2], Marcin Raczkowski[1], Toshihiro Sato[2,3], Zhenjiu Wang[4], and Fakher F. Assaad[1,2] — [1]Institut für Theoretische Physik und Astrophysik Universität Würzburg, 97074 Würzburg, Germany — [2]Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, 97074 Würzburg, Germany — [3]Theoretical Solid State Physics, IFW Dresden, 01069 Dresden, Germany — [4]Ludwig-Maximilians-Universität München, Theresienstr. 37, 80333 München, Germany

We consider a dynamically generated quantum spin Hall (QSH) state, characterized by skyrmion excitations of the SO(3) order parameter carrying charge $2e$. A model described in [1] uses parameter $\lambda$ to drive a continuous transition, akin to deconfined quantum criticality, from a QSH insulator to an s-wave superconductor (SSC) via the condensation of charge $2e$ skyrmions. Here we enhance the symmetry of the model by introducing an additional flavor index $N_f = 2$. Remarkably, we observe a new Kékulé (VBS) phase and transitions between QSH/SSC as well as VBS/SSC. All phase transitions turn out to be of Ginzburg-Landau type. For the VBS/SSC transition we argue that this is due to a $\theta$-term at $\theta = N_f\pi$. For the QSH/SSC transition, we conjecture that in 2+1 d the non-linear sigma model with level $N_f$ Wess-Zumino-Witten term has relevant operators that induce ordered phases, thus requiring fine-tuning for observing a continuous transition. Similarities to the 1+1 d case [2] are highlighted.
[1] Y. Liu *et al.*, Nat. Comm. **10** (2019) 2658
[2] I. Affleck *et al.*, Phys. Rev. B **36** (1987) 5291

TT 24.9 Tue 11:45 H 2053

**Deconfined Quantum Criticality in the long-range, anisotropic Heisenberg Chain** — •Anton Romen[1,2], Stefan Birnkammer[1,2], and Michael Knap[1,2] — [1]Technical University Munich (TUM), TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany

Deconfined quantum criticality describes continuous phase transitions that are not captured by the Landau-Ginzburg paradigm. In our work, we investigate deconfined quantum critical points in the long-range, anisotropic Heisenberg chain. With matrix product state simulations, we show that the model undergoes a continuous phase transition from a valence bond solid to an antiferromagnet. We extract the critical exponents of the transition and connect them to an effective field theory obtained from bosonization techniques. We show that beyond stabilizing the valance bond order, the long-range interactions are irrelevant and the transition is well described by a double frequency sine-Gordon model. We propose how to realize and probe deconfined quantum criticality in our model with trapped-ion quantum simulators.

TT 24.10 Tue 12:00 H 2053

**Magnetic Structure of the spin-1/2 antiferromagnetic XXZ chain $PbCo_2V_2O_8$** — •Cintli Aguilar Maldonado[1], Konrad Puzniak[1,2], Ralf Feyerherm[1], Karel Prokes[1], Nazmul Islam[1], Lukas Keller[3], Yurii Skourski[4], and Bella Lake[1,2] — [1]Helmholtz-Zentrum Berlin, Germany — [2]Technische Universität Berlin, Germany — [3]Paul Scherrer Institut, Switzerland — [4]Helmholz-Zentrum Dresden-Rossendorf, Germany

The quasi-1D antiferromagnetic materials $AM_2V_2O_8$, have been found to harbour a wealth of exotic phases including Quantum phase transitions as a function of applied magnetic field. Here the M-sites are filled by a magnetic transition metal ion such as $Cu^{2+}$, $Ni^{2+}$, $Co^{2+}$ or $Mn^{2+}$, while the divalent A-site ion and $V^{5+}$ are non-magnetic. Depending on the nature of the magnetic ion, different spin moments and anisotropies can be explored. Of particular interest are the members $ACo_2V_2O_8$ where A = Sr, Ba, which give rise to effective 1D spin-1/2 antiferromagnets with Heisenberg-Ising (or XXZ) exchange anisotropy due to the $Co^{2+}$ ions which form 4-fold screw chains along the tetragonal **c**-axis. The intrachain coupling is strong and antiferromagnetic, while the interchain coupling is weak and eventually gives rise to long-range antiferromagnetic Néel order at sufficiently low temperatures. In this work $PbCo_2V_2O_8$, a new and unexplored member of the $ACo_2V_2O_8$ family, is studied by means of neutron powder and single crystal diffraction to determine the magnetic structure in zero magnetic field. The development of the magnetic structure under applied magnetic fields is also explored.

TT 24.11 Tue 12:15 H 2053

**Quantum phase transition in the quasi-1D Ising antiferromagnet $SrCo_2V_2O_8$ in a transverse magnetic field** — •Konrad Puzniak[1,2], Cintli Aguilar-Maldonado[1], Anup Bera[3], Ralf Feyerherm[1], Nazmul Islam[1], Manfred Reehuis[1], Wolfgang Schmidt[4], Martin Boehm[4], Paul Steffens[4], Astrid Schneidewind[5], Igor Radelytskyi[5], Christian Balz[6], Ross Stewart[6], and Bella Lake[1,2] — [1]Helmholtz-Zentrum Berlin, Berlin, Germany — [2]TU Berlin, Berlin, Germany — [3]Solid State Physics Division, Bhabha Atomic Research Centre, Mumbai, India — [4]Institut Laue Langevin, Grenoble, France — [5]Jülich Centre at MLZ, Garching, Germany — [6]Neutron and Muon Source, Didcot, UK

The one-dimensional spin-1/2 antiferromagnet with Heisenberg-Ising (XXZ) anisotropy is an ideal model system to explore fundamental physics concepts. We focus on the properties of its member, which is $SrCo_2V_2O_8$. This compound crystallizes in the tetragonal space group $I4_1cd$. The $Co^{2+}$ ions have effective $S = 1/2$ moments that are arranged in screw chains along the **c** axis. Weak interchain coupling gives rise to long-range magnetic order below $T_N = 5$ K. We report on inelastic neutron scattering, low-temperature heat capacity, and neutron diffraction conducted on single crystal $SrCo_2V_2O_8$ under transverse fields along the tetragonal **a**/**b** direction. In a transverse magnetic field applied along the **a** axis, $SrCo_2V_2O_8$ undergoes a transition at the field of $\mu_0 H^a_{c2} \approx 6.84$ T and the Néel-type magnetic ordering moment is completely suppressed in a magnetic field along the **a** axis, marking the emergence of a 3D quantum critical point.

TT 24.12 Tue 12:30 H 2053

**Search for ferromagnetic quantum phase transitions in CePt** — •Florian Kübelbäck[1], Marc Seifert[1], Pau Jorba[1], Michael Schulz[2], Georg Benka[1], Andreas Bauer[1,3], and Christian Pfleiderer[1,2,3,4] — [1]Physik-Department, Technical University of Munich, D-85748 Garching, Germany — [2]MLZ, Technical University of Munich, D-85748 Garching, Germany — [3]Zentrum für Quantum Engineering (ZQE), Technical University of Munich, D-85748 Garching, Germany — [4]Munich Center for Quantum Science and Technology (MCQST), Technical University of Munich, D-85748 Garching, Germany

We report the growth of single crystal of CePt by means of the optical floating-zone method and the investigation of the low-temperature properties of this ferromagnetic compound. We combine x-ray diffraction, magnetization, and ac susceptibility measurements at ambient pressure with neutron depolarization studies on polycrystalline samples in diamond anvil cells at high pressure [1] to study the evolution of the magnetic properties. For lab-based measurements of the magnetization under high pressure, a bespoke coil set was converted for use in a Quantum Design Physical Property Measurement System.
[1] P. Jorba et al., Phys. Status Solidi B 2100623 (2022).

TT 24.13 Tue 12:45 H 2053

**Failure of the Baym-Kadanoff construction to match consistently quantum dynamics with thermodynamic critical behavior** — Václav Janiš[1], Vladislav Pokorný[1], and •Šimon Kos[2] — [1]Institute of Physics, The Czech Academy of Sciences, Na Slovance 2, CZ-18200 Praha 8, Czech Republic — [2]University of West Bohemia, Univerzitní 8, CZ-301 00 Plzeň, Czech Republic

We disclose a serious deficiency of the Baym-Kadanoff construction of thermodynamically consistent conserving approximations. There are two vertices in this scheme: dynamical and conserving. The diver-

gence of each indicates a phase instability. We show that each leads to incomplete and qualitatively different behavior at different critical points. The diagrammatically controlled dynamical vertex from the Schwinger-Dyson equation does not obey the Ward identity and cannot be continued beyond its singularity. The divergence in the conserving vertex, obeying the conservation laws, does not invoke critical behavior of the spectral function and the specific heat. Any description of critical behavior, hence, remains unreliable unless the fluctuations of the order parameter in the conserving vertex lead to a divergence coinciding with that of the dynamical vertex.

TT 24.14 Tue 13:00 H 2053

**Quantum Monte Carlo simulations with nonlocal relativistic fermions** — •Thomas C. Lang[1] and Andreas M. Läuchli[2,3] — [1]University of Innsbruck, Innsbruck, Austria — [2]Paus Scherer Institut, Villigen, Switzerland — [3]École polytechnique fédérale de Lausanne, Lausanne, Switzerland

We compare large scale quantum Monte Carlo simulations of the Hubbard model at half filling with a single Dirac cone and on the honeycomb lattice close to the critical point, which separates a Dirac semimetal from an antiferromagnetically ordered phase where SU(2) spin rotational symmetry is spontaneously broken. The nonlocal nature of the finite size Dirac operator in real space results in a discontinuity at the boundary of the Brillouin zone. By comparing local and nonlocal Hamiltonians we discuss the efficiency of low energy effective Hamiltonians with respect to finite size corrections, momentum resolution and their applicability depending on the dimensionality of the problem. We address artefacts of the dynamically induced long range interaction in the ordered phase, the recovery of isotropy and linearity of the fermions and bosons close to criticality and extract the critical exponents, which are believed to belong to the chiral Heisenberg Gross-Neveu-Yukawa universality class.