
Boundary and Bulk Criticality 2019
1-4 October 2019, Würzburg

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Overview

Boundary and Bulk Criticality 2019 is a workshop held at the Institute for Theoretical Physics and Astrophysics of the University of Würzburg

Main topics of the workshop are:

- Classical boundary criticality
- Quantum boundary criticality
- Criticality in correlated fermions

The conference will start in the morning of Tuesday 1 October 2019 and end in the afternoon of Friday 4 October 2019.

Invited Speakers

- Wenan Guo (Beijing Normal University, China)
- Martin Hasenbusch (University of Heidelberg, Germany)
- Igor Herbut (Simon Fraser University, Canada)
- Lukas Janssen (University of Dresden, Germany)
- Ribhu Kaul (University of Kentucky, USA)
- Zi Yang Meng (China Academy of Sciences, China)
- Michael Scherer (University of Cologne, Germany)
- Stefan Wessel (University of Aachen, Germany)

Organizers

- Francesco Parisen Toldin (University of Würzburg)
- Fakher F. Assaad (University of Würzburg)

2019/10/02, 09:03:53

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Program

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10:05-10:30	**Coffee break**
10:30-11:30	**Janssen** *Soluble fermionic quantum critical point in two dimensions*
12:30-13:30	**Lunch**
14:00-14:25	**Ray** *Quantum criticality from dynamically generated Dirac cones in 2D Fermi systems with quadratic band touching*
14:25-14:50	**D'Emidio** *Entanglement entropy in quantum Monte Carlo: improved methods and applications*
14:50-15:35	**Coffee break**
15:35-16:00	**Yuhai Liu** *Superconductivity from the condensation of topological defects in a quantum spin-Hall insulator*
16:00-16:25	**Zhenjiu Wang** *Studies of Deconfined Quantum Criticality in a Half-filled Laudau Level*

2 October 2019

TIME	
09:00-10:00	**Scherer** *Lost and found: conformality in the abelian Higgs model, Dirac criticality and deconfined phase transitions*
10:00-10:30	**Group Photo & Coffee break**
10:30-11:30	**Meng** *What we talk about when we talk about fermion QCP*
12:30-13:30	**Lunch**
14:00-14:25	**Ma** *Magnetic and superconducting correlation in monolayer and twisted bilayer graphene*
14:25-14:50	**Lang** *New non-perturbative approaches to tackle the physics of critical relativistic fermions*
14:50-17:00	**Coffe break & Poster session**

3 October 2019

TIME	
09:30-10:30	**Kaul** *Designer spin-S models and their phase diagrams*
10:30-11:00	**Coffee break**
11:00-12:00	**Hasenbusch** *A finite size scaling study of boundary critical phenomena in the three-dimensional Ising universality class*
12:30-13:30	**Lunch**

4 October 2019

TIME	
09:00-10:00	**Wessel** *Nonordinary Edge Criticality of Two-Dimensional Quantum Critical Magnets*
10:00-10:30	**Coffee break**
10:30-11:30	**Guo** *Surface critical behavior of critical spin models*
12:30-13:30	**Lunch**
14:00-14:25	**Torres** *Emergent symmetry and order-to-order transitions of Dirac fermions with two compatible order parameters*
14:25-14:50	**Ihrig** *Abelian Higgs model at four loops, fixed-point collision and deconfined criticality*

Invited talks

Fixed point collisions and tensorial order parameters in Luttinger semimetals and some popular field theories

Igor Herbut * [1]

[1] Simon Fraser University – Canada

I will discuss the role of Coulomb interaction in Luttinger three-dimensional semimetals with the chemical potential at the point of quadratic band touching. The renormalization group treatment of the problem that includes both the long-range and the short-range parts of the Coulomb interaction exhibits a collision between the Abrikosov's non-Fermi liquid fixed point and the quantum critical point as the (spatial) dimensionality of the system is reduced from four towards two. In physical three dimensions we typically find only the slow runaway flow, which should be understood as signifying a low-energy instability towards an insulating phase with (tensorial) nematic ordering. General characteristics of the fixed-point collision scenario and its likely relevance to some other field theories, such as the QED3 for example, will also be discussed, time permitting.

*Speaker

Soluble fermionic quantum critical point in two dimensions

Lukas Janssen * [1]

[1] Institut für Theoretische Physik, Technische Universität Dresden – Germany

I will discuss a nontrivial 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 behavior can be computed exactly and I will derive the scaling laws of the free energy as well as the fermion and order-parameter correlation functions. While the correlation functions at criticality satisfy power laws with anomalous exponents, the correlation length and the free energy exhibit an essential singularity, akin to the classical Berezinskii-Kosterlitz-Thouless critical point. In the ordered phase, the correlation length is finite, but it remains infinite in the semimetallic phase, which consequently is characterized by emergent scale invariance. The quantum critical point can be realized using interacting electrons on kagome or checkerboard lattices.

*Speaker

Lost and found: conformality in the abelian Higgs model, Dirac criticality and deconfined phase transitions

Michael Scherer * [1]

[1] University of Cologne – Germany

Gapless interacting Dirac fermions appear in various condensed-matter scenarios as for example in graphene and related materials, but also in the dual description of the deconfined quantum critical point between Neel and valence bond solid orders in frustrated quantum magnets. The precise determination of the critical behavior of Dirac fermions defines a prime benchmark for complementary theoretical approaches and moreover will allow us to test conjectures based on duality arguments.
CRITICALITY FOUND: In my talk, I present a comprehensive analysis of the Gross-Neveu universality classes based on the recently achieved four-loop renormalization group calculations and compare to Monte Carlo and the conformal bootstrap. Further, I will also discuss the physical implications of the presence of dangerously irrelevant parameters for two-dimensional Dirac systems. This includes the emergence of two length scales and the generation of mass hierarchies.
CONFORMALITY LOST: Then, I show four-loop results for the abelian Higgs model, which is the textbook example for the superconducting transition and the Anderson-Higgs mechanism, and has become pivotal in the description of deconfined quantum criticality. This allows us to improve estimates for the critical number nc of scalars below which conformality is lost. Eventually, I discuss Miransky scaling occurring below nc and comment on implications for weakly first-order behavior of deconfined quantum transitions. An emergent hierarchy of length scales between deconfined quantum transitions corresponding to different n is predicted, which could be detected in numerical simulations.

*Speaker

What we talk about when we talk about fermion QCP

Zi Yang Meng * [1]

[1] China Academy of Sciences – China

*Speaker

Designer spin-S models and their phase diagrams

Ribhu Kaul * [1]

[1] University of Kentucky – United States

I will discuss our recent work where we have deviced a simple method to write down a large family of bipartite spin-S models that do not suffer from the sign problem. I will show a few examples illustrating how they allow us to study the effect of the size of the quantum spin on the phase diagrams of two-dimensional anti-ferromagnets.

*Speaker

A finite size scaling study of boundary critical phenomena in the three-dimensional Ising universality class

Martin Hasenbusch * [1]

[1] Institut für theoretische Physik, Universität Heidelberg – Germany

We discuss boundary critical phenomena for the bulk universality class of the three-dimensional Ising model. The phase diagram is explained and surface universality classes are introduced. Surface critical exponents are defined.
We present the results of our Monte Carlo simulations for the ordinary and the special boundary universality classes. The improved Blume-Capel model is simulated. Avoiding the leading correction of the bulk universality class allows to reduce systematic errors. We simulate at the bulk critical point and a finite size scaling analysis is performed.
Our results are compared with mean field, field theory, other Monte Carlo simulations and recent results obtained by using the conformal bootstrap method.

*Speaker

Nonordinary Edge Criticality of Two-Dimensional Quantum Critical Magnets

Stefan Wessel * [1], Francesco Parisen Toldin [2], Lukas Weber [1]

[1] RWTH Aachen University – Germany
[2] University of Würzburg – 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.

*Speaker

Surface critical behavior of critical spin models

Wenan Guo * [1]

[1] Beijing Normal University – China

Surface critical behavior (SCB) refers to the singularities of physical quantities on the surface at the bulk phase transition. It is closely related to and even richer than the bulk critical behavior, both in classical and quantum phase transitions. In this talk, I will talk our recent works on surface critical behavior of (2+1)-Dimensional quantum critical points and 3-Dimensional classical critical points. In particular, I will show that three types of SCB universality can be realized in the 2D dimerized quantum models at their critical points by engineering the surface configurations.

*Speaker

Contributed talks

Quantum criticality from dynamically generated Dirac cones in 2D Fermi systems with quadratic band touching

Shouryya Ray * [1], Matthias Vojta [1], Lukas Janssen [1]

[1] Institut für Theoretische Physik, Technische Universität Dresden – Germany

I shall present our study on the fate of 2D quadratic band touching semimetals with C3 symmetry in the presence of local 4-Fermi interactions (realizeable, e.g., in AB-stacked bilayer graphene). On one hand, there is a propensity to spontaneous symmetry breaking at infinitesimal interaction, known from 1-loop renormalization group for isotropic quadratic band touching systems. On the other hand, dangerously irrelevant operators (present in the free Hamiltonian due to the reduced symmetry) lead to a splitting of the quadratic band touching points into Dirac cones. This we establish explicitly by performing the relevant 2-loop calculation (the 1-loop contribution vanishes). Using our thus improved flow equations, we find that the dynamically generated Dirac cones stave off spontaneous symmetry breaking at weak coupling; the eventual transition is governed by a quantum critical point in the (2+1)D Gross-Neveu universality class, with emergent Lorentz symmetry.

*Speaker

Entanglement entropy in quantum Monte Carlo: improved methods and applications

Jonathan D'Emidio * [1]

[1] Ecole Polytechnique Fédérale de Lausanne – Switzerland

The Renyi entanglement entropy in quantum many-body systems can be viewed as the difference in free energy between partition functions with different trace topologies. We introduce an external field that controls the partition function topology, allowing us to define a notion of nonequilibrium work as the external field is varied. Nonequilibrium fluctuation theorems of the work provide us with statistically exact estimates of the Renyi entanglement entropy. This approach allows us to perform calculations for large subsystem sizes in a single nonequilibrium simulation. We make use of these ideas to extract central charges for 1D critical spin chains, goldstone modes in 2D magnetically ordered phases, and the topological entanglement entropy of a quantum spin liquid.

*Speaker

Studies of Deconfined Quantum Criticality in a Half-filled Laudau Level

Zhenjiu Wang * , Matteo Ippoliti , Roger Mong , Michael Zaletel , Fakher Assaad [1]

[1] University of Würzburg – Am Hubland, D-97074 Würzburg, Germany

We perform Quantum Monte Carlo studies of deconfined quantum criticality (DQC) based on models of interacting fermions. As opposed to previous studies by Nahum et al. [Phys. Rev. Lett. 115, 267203 (2015)] and Liu et al. [arXiv:1811.02583 (2018)], that suggests an emergent SO(5) symmetry at criticality, our model has an exact SO(5) symmetry at the Hamiltonian level. This relies on the fact that our model is defined in the continuum. As opposed to lattice regularization, that would break the SO(5) symmetry, we follow a suggestion by Ippoliti et al. [arXiv:1810.00009 (2018)], where the ultra-violet cutoff is realized by a magnetic field. Our model corresponds to 4 flavors of fermions with Hilbert space restricted to the zeroth Landau level (ZLL) of 8 component Dirac fermions as realized in Graphene. By tuning the ratio between an SU(4) symmetric interaction, and another one consisting of perfect squares of 5 anti-commuting mass term (fermion bilinears of e.g. 3 antiferromagnetic and 2 valence bond solid masses), a nonlinear sigma model containing only bosonic degrees of freedom is studied, with the competition between the stiffness and an SO(5) Wess-Zumino-Witten topological term. Auxiliary field quantum Monte Carlo studies are free of the negative sign problem due to the existence of two anti-unitary particle-hole transformations that leaves the propagator invariant for each Hubbard-Stratonovitch field configuration. In this talk we will summarize our results aimed at elucidating the existence of a critical phase in our model.

*Speaker

Superconductivity from the condensation of topological defects in a quantum spin-Hall insulator

Yuhai Liu * [1]

[1] Beijing Computational Science Research Center- (CSRC) – China

The discovery of quantum spin-Hall (QSH) insulators has brought topology to the forefront of condensed matter physics. While a QSH state from spin-orbit coupling can be fully understood in terms of band theory, fascinating many-body effects are expected if it instead results from spontaneous symmetry breaking. Here, we introduce a model of interacting Dirac fermions where a QSH state is dynamically generated. Our tuning parameter further allows us to destabilize the QSH state in favour of a superconducting state through proliferation of charge-2e topological defects. This route to superconductivity put forward by Grover and Senthil is an instance of a deconfined quantum critical point (DQCP). Our model offers the possibility to study DQCPs without a second length scale associated with the reduced symmetry between field theory and lattice realization and, by construction, is amenable to large-scale fermion quantum Monte Carlo simulations.

*Speaker

Magnetic and superconducting correlation in monolayer and twisted bilayer graphene

Tianxing Ma * [1]

[1] Beijing Normal University – China

Using exact quantum Monte Carlo method, we identify the phase diagram of the half filled, the lightly doped and heavily doped graphene, which shows a rather rich physical properties. At half filling, the system is driven to a Mott insulator with antiferromagnetic long range order by increasing interaction, and a transition from a d+id pairing to a p+ip pairing is revealed, depends on the next-nearest hoping and the electronic fillings. We also examine the recent novel electronic states seen in magic-angle graphene superlattices. From the Hubbard model on a double-layer honeycomb lattice with a rotation angle $\theta = 1.08$, we reveal that an antiferromagnetically ordered Mott insulator emerges beyond a critical U c at half filling, and with a small doping, the pairing with d+id symmetry dominates over other pairings at low temperature. The effective d+id pairing interaction strongly increase as the on-site Coulomb interaction increases, indicating that the superconductivity is driven by electron-electron correlation. Our non-biased numerical results demonstrate that the twisted bilayer graphene share the similar superconducting mechanism of high temperature superconductors, which is a new and idea platform for further investigating the strongly correlated phenomena.

*Speaker

New non-perturbative approaches to tackle the physics of critical relativistic fermions

Thomas Lang * [1]

[1] University of Innsbruck – Austria

Right at the interface between relativistic spin and fermionic physics lies the Gross Neveu Yukawa (GNY) field theory which is believed to capture the complex interplay of bosonic and fermionic quantum critical fluctuation in a class of universal critical exponents. Non-perturbative methods are essential to no only sort out quantitative differences in the literature, but to tackle basic open questions of the underlying physics. We present two novel approaches: First, quantum Monte Carlo simulations for the particularly challenging chiral Heisenberg GNY quantum phase transition of relativistic fermions with N=4,8,... Dirac spinor components subject to a repulsive local four fermion interaction in 2+1d, where we employ a two dimensional lattice Hamiltonian with a single, spin-degenerate Dirac cone, which exactly reproduces a linear energy-momentum relation for all finite size lattice momenta in the absence of interactions. This allows us to significantly reduce finite size corrections compared to the widely studied honeycomb and π-flux lattices. We extract a self-consistent set of critical exponents at criticality, determine the fermionic and bosonic velocities and provide evidence for the continuous degradation of the quasi-particle weight as the critical point is approached. Secondly, we perform level spectroscopy guided by exact diagonalization and perturbation theory for the chiral Ising GNY quantum phase transition with N=4 Dirac spinor components in order to identify a universal fingerprint of the critical field theory. Our investigation shows that precise knowledge of the spectrum even on small clusters already provides valuable insight into the properties of critical systems and that the strong interaction between the spinor field and the scalar order-parameter field strongly influences the critical energy levels on the torus.

*Speaker

Emergent symmetry and order-to-order transitions of Dirac fermions with two compatible order parameters

Emilio Torres * [1]

[1] Institute for theoretical physics, Universität zu Köln – Germany

The quantum phase diagram and critical behavior of a system of Dirac fermions coupled to two symmetry-compatible orders parameters is investigated in the vicinity of the multicritical point where the two ordered phases meet with the semimetallic phase. Recent numerical studies of such systems have found evidence for non-Landau transitions and emergent symmetry between the two ordered states, which has been interpreted within a scenario of deconfined quantum criticality in (2+1)-dimensional Dirac materials. We provide a thorough field-theoretical analysis of this transition based on non-perturbative functional renormalization group equations. Our findings support a robust emergence of enhanced symmetry at the multicritical point. We discuss our findings in the light of numerical Quantum Monte Carlo simulations for the case in which the order parameters correspond to phases with broken O(3) and Z2 symmetry.

*Speaker

Abelian Higgs model at four loops, fixed-point collision and deconfined criticality

Bernhard Ihrig * [1]

[1] Institute for theoretical physics University of Cologne – Germany

The abelian Higgs model serves as a prime textbook example for the superconduction transition and the Anderson-Higgs mechanism. In fact, the n-component extension of the AH model was suggested as a relavant model to describe certain quantum phase transitions beyond the Landau-Ginzburg paradigm. Explicitly, in d=2+1 dimensions the case of n=2 was discussed lately due to its relation to the $NCCP^1$ model. In this context, recent numerical analyses argue in favor of a weakly first-order phase transition while there is also evidence for a continous transition. We study the AH model with n complex scalar fields at unprecedented four-loop order in the $4 - \epsilon$ expansion and find that the annihilation of two fixed points occurs at a critical number of $n_c \approx 12.2 \pm 3.9$ in three dimensions. The nature of the emergent walking behavior just below the fixed point annihilation allows for so-called Miransky scaling and we comment on its possible implications for the deconfined quantum phase transition.

*Speaker

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