Third Reisensburg Meeting of FOR 723
December 7 and 8, 2011

Wednesday, December 7

9:00-9:05

Introduction

9:05-9:40

Wave packet analysis of renormalization group flows for interacting fermions

MATTHIAS OSSADNIK (ossadnik@itp.phys.ethz.ch)

One of the drawbacks of the renormalization group approach to interacting fermions is that often the flow leads to a strongly coupled problem at low energies, which is difficult to analyze in general.

In this talk, we present a new approach to this problem that is based on the Wilson-Wannier basis, an orthogonal wave packet basis with good localization properties in both real and momentum space. The localization in momentum space allows to resolve the geometry of the Fermi surface and to isolate low-energy degrees of freedom, while the real space localization leads to an effective Hamiltonian with short ranged interactions.

We illustrate the method by considering a few one-dimensional examples. We proceed by deriving an effective model for the so-called saddle point regime of the two-dimensional Hubbard model, where the Fermi surface is close to the saddle points in the Brillouin zone.

9:40-10:15

Effective interactions in multi-band systems from constrained summations

CARSTEN HONERKAMP (honerkamp@physik.rwth-aachen.de)

The application of many-body techniques for the study of correlation effects and unconventional superconductivity requires the formulation of an effective low-energy model that contains only the relevant bands near the Fermi level. However the bands away from the Fermi level are known to renormalize the low-energy interactions substantially. Here we compare different schemes to derive low-energy effective theories for interacting electrons in solids. The frequently used constrained random phase approximation (cRPA) is identified as a particular resummation of higher-order interaction terms that includes important parts o the leading virtual corrections. We then propose an adapted renormalization group scheme that includes the cPRA, but also allows one to go beyond the cRPA approximation. We study a simple two-band model in order to demonstrate the differences between the different approximations.

10:45-11:10

Frequency Dependent Vertex Functions of the 2D Hubbard Model at Weak Coupling

CHRISTOPH HUSEMANN

(c.husemann@fkf.mpg.de)

We present a functional renormalization group calculation for the two-dimensional (t, t')-Hubbard model at Van Hove filling. Using a channel decomposition we describe the momentum and frequency dependence of the vertex function in the normal phase. Compared to previous studies that neglect frequency dependencies we find higher pseudo-critical scales and a smaller region of d-wave superconductivity. A large contribution to the effective interaction is given by a forward scattering process with finite frequency exchange. We test different frequency parameterizations and in a second calculation include the frequency dependence of the imaginary self-energy. We also generalize the channel decomposition to frequency-dependent fermion-boson vertex functions.

11:10-11:30

Suppression of the Hubbard vertex from the quasiparticle weight

KAY-UWE GIERING (giering@thphys.uni-heidelberg.de)

We consider the two-dimensional fermionic repulsive Hubbard model at small coupling. Making use of the recently proposed efficient parameterisation for the Hubbard interaction vertex, not only its momentum but also its frequency dependence can be traced during the RG flow in the symmetric regime. This permits to study the full frequency dependence of the two-point function. Although a linear frequency parameterisation of the imaginary thermal self-energy turns out to be insufficient and needs to be refined, only the small frequency behaviour of this function significantly contributes to the flow. Reduced quasiparticle weights, in particular near the Van Hove points, result in a suppression of the flow of the four-point function. This effect can become rather strong. From a consistency point of view, the frequency dependence of interaction vertex and self-energy should be studied simultaneously. At Van Hove filling, the same landscape of Fermi liquid instabilities as in previous studies neglecting frequency dependences and self-energy insertions is found.

11:30-12:00

The polaron to molecule transition: functional RG with full feedback

TILMAN ENSS (tilman.enss@ph.tum.de)

A light impurity in a Fermi sea undergoes a transition from a polaron to a molecule for increasing interaction. We develop a new method to compute the spectral functions of the polaron and molecule in a unified framework based on the functional renormalization group with full self-energy feedback. We discuss the energy spectra and decay widths of the attractive and repulsive polaron branches as well as the molecular bound state, and confirm the scaling of the excited state decay rate near the transition. The quasi-particle weight of the polaron shifts from the attractive to the repulsive branch across the transition, while the molecular bound state has a very small residue characteristic for a composite particle.

[1] Richard Schmidt and Tilman Enss, Phys. Rev. A **83**, 063620 (2011).

12:00-12:30

Fermionic RG study of superconductivity in the attractive Hubbard model

ANDREAS EBERLEIN (a.eberlein@fkf.mpg.de)

We use the fermionic one-loop RG to study the superconducting ground state of the attractive Hubbard model. Using a channel-decomposition scheme for the vertex and the RG equations, we compute the frequency dependence of the self-energies as well as the momentum and frequency dependence of the two-particle vertex. In this talk, we discuss different approximations for the momentum dependence of the vertex as well as their impact on the gap reduction and the Ward identity. Furthermore, we propose an extension of the channel-decomposition scheme to the two-loop level that might allow for an efficient treatment of collective mode fluctuations within the fermionic RG.

14:00-14:30

Ferromagnetic instability and self-energy effects in 2D electronic systems

A. KATANIN (katanin@mail.ru)

I discuss conditions for ferromagnetism in the two-dimensional Hubbard model, as well as possible types of corresponding quantum phase transitions within functional renormalization-group approach. Below van Hove filling the fRG approach shows indications of the first-order quantum phase transition from ferromagnetic to paramagnetic phase, while above van Hove filling the intermediate incommensurate phase is obtained. The role of the self-effects for correct description of the phase diagram is discussed. I also consider treatment of the self-energy effects in the Wick-ordered fRG approach and possible perspectives of this method. In particular, introducing counterterms in the local fRG Wick-ordered schemes appear to be useful for studing correlated many-body systems.

14:30-15:00

A renormalization group approach to time dependent transport through correlated quantum dots

DANTE MARVIN KENNES (Dante.Kennes@rwth-aachen.de)

We develop a functional renormalization group approach which allows to study time dependent nonequilibrium transport through quantum dots featuring a few correlated fermionic degrees of freedom. With this two type of problems of current interest can be tackled. (i) The relaxation dynamics out of a nonequilibrium initial state into the voltage bias driven steady state of a time-independent Hamiltonian and (ii) the dynamics under an explicitely time-dependent Hamiltonian. As an application we study the relaxation dynamics of the interacting resonant level model, a basic model for understanding the physics of correlated charge fluctuations. We furthermore exploit a mapping of this model to the ohmic spin-boson model to gain insights into the relaxation properties of the latter.

15:00-15:30

Non-equilibrium time-evolution of bosons from the functional renormalization group

PETER KOPIETZ (pk@itp.uni-frankfurt.de)

We develop a functional renormalization group approach to obtain the time evolution of the momentum distribution function of interacting bosons out of equilibrium. Using an external out-scattering rate as flow parameter, we derive formally exact renormalization group flow equations for the non-equilibrium self-energies in the Keldysh basis.

A simple perturbative truncation of these flow equations leads to an approximate solution of the quantum Boltzmann equation which does not suffer from secular terms and gives accurate results even for long times. We demonstrate this explicitly within a simple exactly solvable toy model describing a quartic oscillator with off-diagonal pairing terms.

15:30-16:00

Nonequilibrium Kondo model: the RG flow from weak to strong coupling

MIKHAIL PLETYUKHOV (pletmikh@physik.rwth-aachen.de)

In this talk I'll discuss the renormalization group flow of the nonequilibrium Kondo model from high energies (weak coupling) to low energies (strong coupling). A new flowing scheme ("E-flow") within the Real Time Renormalization Group (RTRG) approach which uses the Laplace variable (E) as a flow parameter will be introduced. The accuracy of this scheme in equilibrium is checked via the comparison against the benchmark NRG calculation of the linear conductance at finite temperatures. In nonequilibrium, the new results for the voltage dependence of the differential conductance are presented.

Another remarkable feature of the E-flow scheme is that it provides an access to the full time dynamics of a system, once the corresponding flow equations have been integrated. In the second part of my talk I'll discuss an application of the E-flow scheme to the study of time evolution of the Kondo model in the strong coupling regime.

17:30-17:50

Interplay of Coulomb interaction and spin-orbit effects in multi-level quantum dots

STEPHAN GRAP (stephan.grap@rwth-aachen.de)

We study the effects of Coulomb repulsion on the electron transport through double quantum dots with Rashba spin-orbit interaction. Motivated by recent experiments, we compute the angular dependence of the renormalized g-factor due to the relative orientation of an applied Zeeman field B to the spin-orbit direction. In addition, we investigate the angular dependence of the spin-orbit induced level splitting which suppresses the Kondo ridges at finite B that are found in multi-level structures. We finally provide an intuitive physical picture for the interpretation of finite-bias spectroscopy data in terms of effective single-particle energy levels.

17:50-18:10

Adiabatic response in the interacting resonant level model

OLEKSIY KASHUBA (kashuba@physik.rwth-aachen.de)

We develop a generic method in Liouville space to describe the dissipative dynamics of coherent interacting quantum dots with adiabatic time dependence. We apply the method to the interacting resonant level model and calculate the adiabatic response to time-dependent gate voltages, tunnelling barriers and Coulomb interaction. We found that the generalised delay time related to RC time is robust against the time variations and discuss the observability of this effect in molecular systems and cold atom setups.

18:10-18:30

Renormalization-group analysis of a spin-1 Kondo dot: Non-equilibrium transport and relaxation dynamics

CHRISTOPH B. M. HÖRIG (hoerig@physik.rwth-aachen.de)

We study non-equilibrium transport through a spin-1 Kondo dot in a local magnetic field. To this end we perform a two-loop renormalization group analysis in the weak-coupling regime yielding analytic results for (i) the renormalized magnetic field and the g-factor, (ii) the time evolution of observables and the relevant decay rates, (iii) the magnetization and anisotropy as well as (iv) the current and differential conductance in the stationary state. In particular, we find that compared to a spin-1/2 Kondo dot there exist three additional decay rates resulting in an enhanced broadening of the logarithmic features observed in stationary quantities. Additionally, we study the effect of anisotropic couplings between reservoir and impurity spin.

Thursday, December 8

9:30-9:50

An FRG approach to the Heisenberg-Kitaev model

JOHANNES REUTHER (reuther@kit.edu)

We apply the Functional Renormalization Group method to frustrated spin-1/2 systems on two dimensional lattices such as the Heisenberg-Kitaev model. In order to be able to perform diagrammatic approximations, we use the pseudo fermion representation of spin operators. It turns out that the inclusion of three-particle correlations in the form proposed by Katanin is essential to describe the systems beyond the classical large-spin limit. Calculating the magnetic susceptibility we identify different magnetically ordered and paramagnetic phases. In particular, the Heisenberg-Kitaev model exhibits magnetically ordered states well beyond the isotropic Heisenberg limit as well as an extended gapless spin-liquid phase around the highly anisotropic Kitaev limit. From the RG flow of the magnetic susceptibility we extract both, the Curie-Weiss scale and the critical ordering scale (for the magnetically ordered states). The Curie-Weiss scale changes sign, indicating a transition of the dominant exchange from antiferromagnetic to ferromagnetic, deep in the magnetically ordered regime. We discuss our results in light of recent experimental susceptibility measurements for Na_2IrO_3 and Li_2IrO_3.

9:50-10:10

Benchmarking the functional renormalization group for spin systems

STEFAN GÖTTEL (goettel@physik.rwth-aachen.de)

We apply a recently developed functional renormalization group scheme [Phys. Rev. B **81**, 144410 (2010)] for quantum spin systems to the spin-1/2 antiferromagnetic XXZ model on a two-dimensional square lattice. Based on an auxiliary fermion representation we derive flow equations which allow a resummation of the perturbation series in the spin-spin interactions. We calculate the xx- and zz-susceptibility depending on the anisotropy parameter, which confirms the phase transition between planar and axial ordering at the isotropic point. Further more, as recently proposed in [Phys. Rev. B **84**, 100406(R) (2011)], we extract a critical temperature from the flow. However, the extracted critical temperature violates the Mermin-Wagner theorem. A correct description of the behavior in the vicinity of the phase transition is not possible and we are not able to perform a quantitative validation of the functional renormalization group for spin systems.

10:10-10:30

Quantum criticality of dipolar spin chains

ALDO ISIDORI (isidori@itp.uni-frankfurt.de)

We show that a one-dimensional chain of Heisenberg spins, interacting with long-range dipolar forces in a magnetic field perpendicular to the chain, exhibits a quantum critical point belonging to the two-dimensional Ising universality class. Within linear spin-wave theory (corresponding to the so-called Gaussian approximation) the long-wavelength magnon dispersion is characterized by a logarithmic singularity in the magnon velocity for vanishing momenta, due to the long range nature of dipolar interactions in one-dimension. However, in the vicinity of the critical point this logarithmic correction is renormalized to zero by the effects of quantum fluctuations, signaling the reemergence of scale invariance, in accordance with the Ising critical scenario. The quantum critical regime where linear spin-wave theory breaks down is studied using two independent non-perturbative methods, namely the density-matrix renormalization group (DMRG) and the functional renormalization group (FRG). The Ginzburg regime where non-Gaussian fluctuations are important is found to be rather narrow on the ordered side of the transition, and very broad on the disordered side.

11:00-11:20

Low-Dimensional Chiral Physics: Magnetic Catalysis

DANIEL D. SCHERER (daniel.scherer@uni-jena.de)

Magnetic catalysis describes the enhancement of symmetry-breaking quantum fluctuations in chirally symmetric quantum field theories by the coupling of fermionic degrees of freedom to a magnetic background configuration. We use the functional renormalization group to investigate this phenomenon for interacting Dirac fermions moving in 2+1 dimensional spacetime and provide for a clear renormalization-group picture.

11:20-11:40

Anomalous criticality near semimetal-to-superfluid quantum phase transition in a two-dimensional Dirac Cone model

BENJAMIN OBERT (b.obert@fkf.mpg.de)

We analyse a two-dimensional Dirac Cone model which undergoes a quantum phase transition between semimetal and a superfluid. We are interested in the the scaling behaviour at and near a quantum critical point separating both phases. To this end we compute the renormalization group flow for a Dirac Cone model consisting of attractively interacting electrons with a linear dispersion around a single Dirac point. We study both ground state and finite temperature properties. In two dimensions the electrons and the order parameter fluctuations exhibit power-law scaling with anomalous scaling dimensions. The quasiparticle weight and the Fermi velocity vanish at the quantum critical point. The order parameter correlation length turns out to be infinite everywhere in the semimetallic ground state.

[1] P. Strack, S. Takei, and W. Metzner, Phys. Rev. B **81**, 125103 (2010).

[2] B. Obert, S. Takei, and W. Metzner, Ann. Phys. (Berlin) **523**, No.8-9, 621-628 (2011)

11:40-12:00

Nonlocal effective average action approach to crystalline phantom membranes

NILS HASSELMANN (n.hasselmann@fkf.mpg.de)

We investigate the properties of crystalline phantom membranes, using a nonperturbative renormalization group approach. We avoid a derivative expansion of the effective average action and instead analyse the full momentum dependence of the elastic coupling functions. This leads to a more accurate determination of the critical exponents and further yields the full momentum dependence of the correlation functions of the in-plane and out-of-plane fluctuation. The flow equations are solved numerically for $D = 2$ dimensional membranes embedded in a $d = 3$ dimensional space. Within our approach we find a crumpling transition of second order which is characterized by an anomalous exponent $\eta_c \approx 0.63(8)$ and the thermal exponent $\nu \approx 0.69$. Near the crumpling transition the order parameter of the flat phase vanishes with a critical exponent $\beta \approx 0.22$. The flat phase anomalous dimension is $\eta_f \approx 0.85$ and the Poisson's ratio inside the flat phase is found to be $\sigma_f \approx -1/3$. At the crumpling transition we find a much larger negative value of the Poisson's ratio $\sigma_c \approx -0.71(5)$. We discuss further in detail the different regimes of the momentum dependent fluctuations, both in the flat phase and in the vicinity of the crumpling transition, and extract the crossover momentum scales which separate them. The results for the flat phase are compared with Monte Carlo simulations of thermal fluctuations of graphene and excellent agreement is found.

Finally, we also discuss how the technique can be combined with a local potential approximation to infinite order and present results for the momentum dependent two-point function of the O(n) model.

13:30-13:50

The zero-dimensional $O(N)$ vector model as a benchmark for perturbation theory, the large-N expansion and the functional renormalization group

LORENZ BARTOSCH (lb@itp.uni-frankfurt.de)

We consider the zero-dimensional $O(N)$ vector model as a simple example to calculate n-point correlation functions using perturbation theory, the large-N expansion, and the functional renormalization group (FRG). Comparing our findings with exact results, we show that perturbation theory breaks down for moderate interactions for all N, as one should expect. While the interaction-induced shift of the free energy and the self-energy are well described by the large-N expansion even for small N, this is not the case for higher-order correlation functions. However, using the FRG in its one-particle irreducible formalism, we see that very few running couplings suffice to get accurate results for arbitrary N in the strong coupling regime, outperforming the large-N expansion for small N. We further remark on how the derivative expansion, a well-known approximation strategy for the FRG, reduces to an exact method for the zero-dimensional $O(N)$ vector model.

13:50-14:10

Groundstate(s) of Bilayer Graphene

MICHAEL M. SCHERER (scherer@physik.rwth-aachen.de)

We employ the N-Patching fermionic RG scheme to investigate the phase space of a bilayer honeycomb lattice revealing the existence of a number of different many-body states, e.g. spin- and charge-density waves and a quantum spin hall state. For variations of long-ranged Coulomb potentials we find evidence for an antiferromagnetic (AFM) ground state. The fRG computations are complemented by establishing a connection to a mean-field approach and a lattice quantum Monte-Carlo study for an exclusive short-ranged onsite interaction.

14:10-14:30

Ultracold Atoms in a Box

JENS BRAUN (j.braun@uni-jena.de)

Ultracold gases of fermionic atoms have drawn a lot of attention in recent years. In this talk we discuss an ultracold Fermi gas at unitarity confined in a (periodic) box. Using renormalization group techniques, we explore the volume and particle-number dependence of universal quantities, such as the Bertsch parameter and the fermion gap. In addition, we analyze the role of a so-called pairing source in a finite volume. Our results indicate that the Bertsch parameter saturates rather quickly to its value in the thermodynamic limit as a function of increasing box size. On the other hand, the order parameter, namely the fermion gap, shows a stronger dependence on the box size than the Bertsch parameter, in particular for small values of the pairing source. Our results may contribute to a better understanding of finite-size and particle-number effects present in Monte-Carlo simulations of ultracold Fermi gases.

14:30-15:05

Functional renormalization for spontaneous symmetry breaking in the Hubbard model

C. WETTERICH (c.wetterich@thphys.uni-heidelberg.de)

The phases with spontaneously broken symmetries corresponding to antiferromagnetic and d-wave superconducting order in the two-dimensional t-t'-Hubbard model are investigated by means of the functional renormalization group. The introduction of composite boson fields in the magnetic, charge density and superconducting channels allows an efficient parameterization of the four-fermion vertex and the study of regimes where either the antiferromagnetic or superconducting order parameter, or both, are nonzero. We compute the phase diagram and the temperature dependence of the order parameter below the critical temperature, where antiferromagnetic and superconductiving order show a tendency of mutual exclusion.
