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Abstracts

Functional Renormalization Group Approach for Inhomogeneous Interacting Fermi-Systems

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The functional renormalization group (fRG) approach has the property that, in general, the flow equation for the two-particle vertex generates $\mathcal{O}(N^4)$ independent variables, where N is the number of interacting states (e.g. sites of a real-space discretization). In order to include the flow equation for the two-particle vertex one needs to make further approximations if N becomes too large. We present such an approximation scheme, called the coupled-ladder approximation, for the special case of an onsite interaction. Like the generic third-order-truncated fRG, the coupled-ladder approximation is exact to second order and is closely related to a simultaneous treatment of the random phase approximation in all channels, i.e. summing up parquet-type diagrams. The scheme is applied to a one-dimensional model describing a quantum point contact.

Dimensional BCS-BEC Crossover with Ultracold Atoms

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We investigate how the reduction of spatial dimension influences superfluidity of two-component fermions in the BCS-BEC crossover by means of the Functional Renormalization Group. Our approach allows to study the system over the whole parameter space of interaction strength, density, temperature, spin-imbalance, and dimension. The high precision and tunability of recent experiments allows for a solid benchmarking of our description. We present results on the equation of state and the phase diagram as a function of dimension.

Universality in 3d relativistic fermionic models

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We explore the fixed-point structure and RG flow of a 3d relativistic fermionic model with $\mathrm{U}(N_\mathrm{f})\times\mathrm{U}(N_\mathrm{f})$ symmetry, where N_f is the number of reducible four-component Dirac spinors. We discover a number of fixed points, exhibiting generically more than one relevant direction. Phase transitions to low-energy symmetry-broken regimes are expected to be of first order. As is known from their purely bosonic counterpart, such first order transitions can still have universal properties, if the corresponding flows pass by a fixed point in a subspace of higher symmetry. We find indications that such universal properties also occur near physically relevant fixed points beyond subspaces of higher symmetry. For detailed quantitative studies, we report on current developments for solving full potential flows with pseudo-spectral methods.

Instabilities on graphene's honeycomb lattice with electron-phonon interactions

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We study the impact of electron-phonon interactions on the many-body instabilities of electrons on the honeycomb lattice and their interplay with repulsive local and non-local Coulomb interactions at charge neutrality. To that end, we consider in-plane optical phonon modes with wavevectors close to the Γ point as well as to the $K, -K$ points and calculate the effective phonon-mediated electron-electron interaction by integrating out the phonon modes. Ordering tendencies are studied by means of a momentum-resolved functional renormalization group approach allowing for an unbiased investigation of the appearing instabilities. In the case of an exclusive and supercritical phonon-mediated interaction, we find a Kekulé and a nematic bond ordering tendency being favored over the s-wave superconducting state. The competition between the different phonon-induced orderings clearly shows a repulsive interaction between phonons at small and large wavevector transfers. We further discuss the influence of phonon-mediated interactions on electronically-driven instabilities induced by onsite, nearest neighbor and next-to-nearest neighbor density-density interactions. We find an extension of the parameter regime of the spin density wave order going along with an increase of the critical scales where ordering occurs, and a suppression of competing orders.

Competing order in correlated electron systems made simple: Consistent fusion of functional renormalization and mean-field theory

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We derive an efficient and unbiased method for computing order parameters in correlated electron systems with competing instabilities. Charge, magnetic, and pairing fluctuations above the energy scale of spontaneous symmetry breaking are taken into account by a functional renormalization group flow, while the formation of order below that scale is treated in mean-field theory. The method captures fluctuation-driven instabilities such as d-wave superconductivity. As a first application we study the competition between antiferromagnetism and superconductivity in the ground state of the two-dimensional Hubbard model.

Functional renormalization group in Floquet space and its application to periodically driven quantum dots

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The functional renormalization group (RG) was recently extended to study interacting, low-dimensional systems out of equilibrium. This includes correlated quantum dot setups with

explicitly time-dependent Hamiltonians as e.g. realized in quantum quenches or in the presence of time-dependent bias voltages [Phys. Rev. B 85, 085113 (2012), Phys. Rev. B 85, 245101 (2012)]. However, following this route periodic pumping processes, which are of particular interest in e.g. nanoelectronics and quantum information science, can only be described in an inefficient way. Taking advantage of the periodicity, we combine the Floquet theorem with the functional RG. This allows us to transform the double-time self-energy and Green functions in the Floquet basis [J.Phys.: Condens. Matter 20 085224] and the functional RG treatment resembles the stationary formalism. This makes it feasible to study transport in periodically driven systems. In my talk, I will introduce this Floquet theorem based functional RG and present first results on transport through a quantum dot described by the interacting resonant level model.

Superfluidity of imbalanced Fermi mixtures in d=2

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We study the nature of superfluid pairing in imbalanced Fermi mixtures in two spatial dimensions. We present evidence that the combined effect of Fermi surface mismatch and order parameter fluctuations of the superfluid condensate can lead to continuous quantum phase transitions from a normal Fermi mixture to an intermediate Sarma-Liu-Wilczek superfluid with two gapless Fermi surfaces – even when mean-field theory (incorrectly) predicts a first order transition to a phase-separated "Bardeen-Cooper-Schrieffer plus excess fermions" ground state. We propose a mechanism for non-Fermi liquid behavior from repeated scattering processes between the two Fermi surfaces and fluctuating Cooper pairs.

Dynamical regimes of dissipative quantum systems

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We reveal several distinct regimes of the relaxation dynamics of a small quantum system coupled to an environment within the plane of the dissipation strength and the reservoir temperature. This is achieved by discriminating between coherent dynamics with damped oscillatory behavior on all time scales, partially coherent behavior being nonmonotonic at intermediate times but monotonic at large ones, and purely monotonic incoherent decay. Surprisingly, elevated temperature can render the system 'more coherent' by inducing a transition from the partially coherent to the coherent regime. This provides a refined view on the relaxation dynamics of open quantum systems.

Fermions in gravity with local spin-base invariance

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We study a formulation of Dirac fermions in curved spacetime that respects general coordinate invariance as well as invariance under local spin-base transformations. The natural variables for this formulation are spacetime-dependent Dirac matrices subject to the Clifford-algebra constraint. In particular, a coframe, i.e. vierbein field is not required. This is of particular relevance for field theory approaches to quantum gravity, as it can serve for a purely metric-based quantization scheme for gravity even in the presence of fermions.

Fermionic N-Patch RG in Bilayer Square Lattice Hubbard Model

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The single-band two-dimensional Hubbard model has been subject to extensive studies in the context of high-T_c superconductivity. An interesting variation of this simple model is its bilayer version that is of relevance to high-T_c cuprates with coexisting electron and hole doped sheets. Furthermore, the bilayer Hubbard Hamiltonian has been investigated as a model for a Mott insulator to band insulator transition by numerous groups and various methods finding contradicting results about the paramagnetic or antiferromagnetic nature of the ground state at weak coupling. Here, we study the instabilities of interacting electrons on the square lattice bilayer by means of a momentum-resolved functional renormalization group approach (N-Patch RG) for a range of model parameters including the interlayer hopping, the onsite Coulomb repulsion and interlayer density-density interactions at and away from half filling. This allows for an unbiased investigation of the app earing ordering tendencies. Depending on the parameter regime the dominant instabilities turn out to be toward an antiferromagnetic spin-density wave (SDW), a charge density wave (CDW) and two types of superconducting order, namely with a d-wave and an extended s-wave symmetry. In this way the bilayer Hubbard model also allows to smoothly interpolate between the physics of cuprates and pnictides as a function of the interlayer hopping parameter. Finally, we combine our results at half-filling with quantum Monte Carlo simulations and mean-field theory to obtain a comprehensive picture of the phase diagram of this model.

Nonequilibrium transport through a Josephson quantum dot

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We study the electronic current through a quantum dot coupled to two superconducting leads which is driven by either a voltage V or temperature ΔT bias. The local two-particle interaction

U on the dot is treated using the functional renormalization group approach set up in Keldysh-Nambu space with U being the small parameter.

For $V > 0$, we re-encounter problems known from earlier weak coupling approaches (Hartree-Fock, second-order perturbation theory). In parameter regimes in which finite-bias-driven multiple Andreev reflections are not dominant, convergence with respect to numerical parameters is an issue. This problem was overcome. In the complementary regime, the methods at hand become unreliable. This problem remains and we argue that it will occur within any small-$|U|$ approach.

For $V = 0$, we use numerical renormalization group data at equilibrium ($\Delta T = 0$) to benchmark our method. We then turn to nonequilibrium ($\Delta T \neq 0$) and calculate some first results in this regime. We find a surprising increase of the current as a function of the superconducting phase difference in the regime which at $T = 0$ becomes the π (doublet) phase.

Why and how fRG methods can profit from High Performance Computing

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The principles of current High Performance Computing (HPC) architectures and Parallel Programming are presented, and we motivate the leverage they may provide with respect to numerical fRG calculations. We will comment on the recently founded JARA-HPC Simulation Lab "ab initio" which provides HPC expertise in various ways to the many-body community.

What is the fate of the Mott metal-insulator transition in the two-dimensional Hubbard Model?

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One of the most fundamental hallmarks of the physics of strong electronic correlations is, undoubtedly, the Mott-Hubbard metal-insulator transition (MIT). However, astonishingly little is known exactly even for its simplest modeling, i.e., the single-band Hubbard Hamiltonian. Our analysis of the two-dimensional Hubbard model on a square lattice exhibits divergent precursors of the MIT well in the metallic phase by considering purely local fluctuations [1], whose physical interpretation is still open.

Furthermore our calculations demonstrate that at low temperatures the critical interaction for the onset of an insulator is progressively reduced towards zero by the inclusion of spatial correlations on longer and longer length scales. Eventually an insulating spectral gap is always opened at low-enough temperatures by non-local antiferromagnetic fluctuations, irrespectively of the (pre-)formation of localized magnetic moments, so that the MIT completely disappears in this case [2].

[1] T. Schäfer, G. Rohringer, O. Gunnarsson, S. Ciuchi, G. Sangiovanni and A. Toschi, Phys. Rev. Lett. **110** 246405 (2013)
[2] T. Schäfer, F. Geles, D. Rost, G. Rohringer, E. Arrigoni, K. Held, N. Blümer, M. Aichhorn, A. Toschi, arXiv:1405.7250

Higgs mass bounds from the functional renormalization group

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We study the functional renormalization group flow of Higgs-Yukawa toy models to mimic the Higgs sector of the standard model. For the class of standard bare potentials of ϕ^4-type at a given ultraviolet cut-off, we show that a finite infrared Higgs mass range emerges naturally from the renormalization group flow itself. Higgs masses outside the resulting bounds cannot be connected to any conceivable set of bare parameters in this standard-model ϕ^4 class. By contrast, more general bare potentials allow to diminish the lower bound considerably. We identify a simple renormalization group mechanism for this depletion of the lower bound. If active also in the full standard model, Higgs masses smaller than the conventional infrared window do not necessarily require new physics at low scales or give rise to instability problems.

DMFT-enhanced fRG: New ideas and perspectives

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The dynamical mean-field theory (DMFT) represents one of the most powerful tools to take into account nonperturbatively the local physics at the basis of the Mott metal-insulator transition. After presenting a functional integral derivation of DMFT, we review DMF^{2}RG, the recently proposed approach [Phys. Rev. Lett. **112**, 196402] obtained by combining DMFT and fRG. Subsequently, we will shift our focus on several points that we will address in the future. In particular we discuss some of the possible methodological improvements to the present formulation and the potential practical applications of the improved scheme.

Momentum Shell RG from Simulation: Application to Crystalline Membranes

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The framework of Wilson's momentum shell renormalization group (MSRG) has proven to be a valuable conceptual tool, but is often prohibitively difficult to apply in perturbative calculations

beyond one loop order. Fortunately, my recently developed Fourier Monte Carlo algorithm allows to follow Wilsons MSRG scheme by simulation, thus eliminating perturbation theory. For the particularly convenient example of an Ising model with algebraically decaying interactions I have demonstrated [PRB **81**, 125135 (2010)] that by optimizing with respect to the shell thickness parameter this algorithm could in fact be turned from a merely qualitatively into a quantitatively useful tool. Here I present the first application of this prescription to a nontrivial real world system, namely a numerical calculation of the RG flow of crystalline membranes in the flat phase using Fourier Monte Carlo methods.

The Dual-Fermion fRG

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We propose a novel flow scheme for the fRG based on Dual Fermions (DF). Originally introduced to include non-local correlations beyond DMFT, the DF approach allows for a diagrammatic expansion around the DMFT solution which accounts for all local correlations in a non-perturbative way. The general idea of the DF formalism is to introduce auxiliary fermionic fields by means of a Hubbard-Stratonovich transformation that allow for a an expansion around an exactly solvable action. This expansion is usually performed by means of standard perturbative approaches. Our goal is to improve the DF expansion by setting up an fRG flow for the auxiliary fields. We will present a combined DF-fRG scheme in a general frame and discuss the potential for future applications.

Competing Orders and Multi-critical Phenomena

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We study competing orders and multi-critical phenomena in systems with two order parameters. They occur in many condensed matter systems, most prominently in graphene or high-Tc cuprate superconductors. For this purpose we investigate a model with $O(M) \oplus O(N)$ symmetry in three dimensions by means of the Functional Renormalization Group. We explain the bi- or tetra-critical phase structure near the multi-critical point, which is dominated by the stable fixed point. Depending on the parameters M and N the stable fixed point is either a decoupled, isotropic, or biconical fixed point.

Griffiths wings of electronic nematic phase transition

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A spatial xy anisotropy generated by a uniaxial pressure or strain can control a phase transition. In particular, the xy anisotropy couples directly to electronic nematic order and thus is expected to play a crucial role in a system exhibiting nematicity. Here we study the phase diagram of an electronic nematic phase transition in the presence of xy anisotropy. While a second order transition cannot occur in this case, mean-field theory predicts that a first order transition occurs near van Hove filling and its phase boundary forms a wing structure, which we term a Griffiths wing, referring to his original work of He^3-He^4 mixtures. The anisotropy of the electronic system exhibits a discontinuous change by crossing the wing, leading to a meta-nematic transition, i.e., the analog to a meta-magnetic transition observed clearly in ferromagnetic systems such as UGe_2 and UCoAl. The upper edge of the wing corresponds to a critical end line, which shows a non-monotonic temperature dependence, in sharp contrast to He^3-He^4 mixtures and ferromagnetic systems. We also study the effect of nematic order-parameter fluctuations by applying a functional renormalization-group scheme. We have found that the wing is very sensitive to fluctuations and is easily broken into two pieces, leading to a phase diagram topologically different from the mean-field result. A tiny wing is realized close to zero anisotropy, which makes the system close to a quantum critical end point (QCEP) even though the transition is of first order for zero anisotropy. The other wing is realized for a very strong anisotropy, yielding two QCEPs there. The present results can be relevant to various materials including a cold atom system.