

Titles and Abstracts:

Tommaso Calarco:

Quantum many-body dynamics, quantum control and the quantum speed limit

The control of quantum states is essential both for fundamental investigations and for technological applications of quantum physics. In quantum few-body systems, decoherence arising from interaction with the environment hinders the realization of desired processes. In quantum many-body systems, complexity of their dynamics further makes state preparation via external manipulation highly non-trivial. An effective strategy to counter these effects is offered by quantum optimal control theory, exploiting quantum coherence to dynamically reach a desired goal with high accuracy even under limitations on resources such as time, bandwidth, and precision. In this talk I will:

- introduce the quantum optimal control method we developed to this aim, the CRAB (Chopped Random Basis) algorithm, which is to date the only method that allows to perform optimal control of quantum many-body systems;
- present experimental results obtained via its application to various physical systems, from quantum logical operations in solid-state quantum optics to quantum criticality in ultra-cold atoms, both in open-loop and in closed-loop feedback scenarios, with applications ranging from quantum interferometry with Bose-Einstein condensates on atom chips to magnetic field sensing in diamond NV centers and to the preparation of optical-lattice quantum registers for quantum simulation;
- use these examples to illustrate the quantum speed limit, i.e. the maximum speed achievable for a given quantum transformation, and describe related effects of nonlinearity due to inter-particle interactions and more in general to dynamical complexity;
- propose a way to characterise the latter in an information-theoretical fashion by the bandwidth of the optimized control pulses, as well as a conjecture about using this method for discrimination between different levels of complexity in quantum many-body systems.

Jim Freericks:

Introduction to nonequilibrium dynamical mean-field theory

Starting from an assumption of introductory knowledge of fermionic many-body Green's functions in equilibrium, I will build up how one treats systems in nonequilibrium. This will include the following topics: (1) How to describe an electric field; (2) How to define the contour-ordered Green's functions and how to extract the more familiar Green's functions from them; (3) How to determine the self-energy and solve Dyson's equation; (4) How to implement the dynamical mean-field theory self-consistency loop; (5) How to measure experimental quantities of interest from the calculated Green's functions; and (6) A guide for how to perform calculations numerically and benchmark their accuracy.

Stephan Heßelmann:

Functional renormalization group analysis of spinless fermions on the honeycomb lattice beyond half filling

We study spinless fermions on a honeycomb lattice with repulsive interactions (spinless t - V model), which for the case of half filling is known to feature a Gross-Neveu chiral Ising quantum critical point at finite interaction strength. The phase diagram of this model for a finite chemical potential however remains elusive. We therefore perform an instability analysis using the functional renormalization group method with a basic Fermi surface patching scheme, which allows us to treat instabilities in different channels on an equal footing. The chemical potential is fixed at the beginning of the flow and defines the filling in terms of the free system. Below half filling but above the van-Hove filling the free Fermi surface is hole-like and we find a commensurate charge-density-wave to be dominant. Its characteristics are those of the half-filled case, which indicates phase separation at large interaction strength. Directly at the van-Hove filling the nesting property of the free Fermi surface stabilizes a dimerized charge-bond order phase. At lower fillings the free Fermi surface becomes electron-like and a superconducting instability with d -wave symmetry emerges. Finally we estimate the extend of the various phases and give expressions for their order parameters.

Martin Hohenadler:

Quantum Monte Carlo for retarded interactions

Coupled systems of fermions and bosons appear in numerous contexts in condensed matter physics. The bosons may represent, for example, quantum lattice fluctuations (phonons). In general, Monte Carlo simulations of such problems remain challenging because of the absence of efficient sampling methods for the bosons. In this talk, I discuss some recent progress based on the idea of integrating out the bosons and simulating the resulting fermionic problem with a retarded, boson-mediated interaction. This approach permits to simulate complex interactions and, in combination with global updates, lattice sizes that are significantly larger than in the past. Applications to electron-phonon models in one and two dimensions will be discussed.

Lukas Janssen:

Unconventional criticality in fermionic systems

The QED3-Gross-Neveu model is a (2+1)-dimensional U(1) gauge theory involving Dirac fermions and a critical real scalar field. This theory has recently been argued to represent a dual description of the deconfined quantum critical point between Neel and valence bond solid orders in frustrated quantum magnets. I will present a three-loop study of the critical behavior of the QED3-Gross-Neveu model. I will show that our estimates for the critical exponents satisfy a nontrivial scaling relation which follows from the emergent SO(5) symmetry implied by the duality conjecture. I also review explicit evidence for the equivalence between the QED3-Gross-Neveu model and a corresponding critical four-fermion gauge theory that was previously studied within the $1/N$ expansion.

Fengpin Jin:

Quantum typicality approach -- Application to transport in the one-dimensional XXZ model

In quantum theory, a typical state is a pure random state representing the majority of all possible states, drawn at random from a high-dimensional Hilbert space. The concept of typicality says that such a random state has the same properties as the full statistical ensemble. This concept, together with numerically solving the time-dependent Schrödinger equation (TDSE), is the basis of the so-called quantum typicality approach. It can be used to calculate various properties of quantum systems, such as the density of states (DOS) or certain static and dynamic functions. In this talk, I will start by reviewing the leading methods to solve the TDSE. Following this, I will present the basic concepts contained in the quantum typicality approach. Finally, I will present results of applying the method to transport in the 1D XXZ model.

Jelena Klinovaja:

Topological phases: from Majorana fermions to parafermions

In my talk, I will discuss low-dimensional condensed matter systems, in which topological properties could be engineered per demand. Majorana fermions can emerge in hybrid systems with proximity-induced superconducting pairing in which the usually weak Rashba spin-orbit interaction is replaced by magnetic textures. I will discuss candidate materials such as semiconducting nanowires [1] and atomic magnetic chains [2]. One further goal is to go beyond Majorana fermions and to identify systems that can host quasiparticles with more powerful non-Abelian statistics such as parafermions in double wires coupled by crossed Andreev proximity-induced pairing [3,4].

In all these proposals, a central ingredient is the proximity effect induced by a superconductor in some attached material. In particular, semiconducting quantum wires defined within 2DEGs and strongly coupled to thin superconducting layers have been extensively explored in many experiments as promising platforms to host Majorana bound states. I will present our numerical and analytical studies of such geometries with proximity effects [5-8].

If time allow, I will also switch to two- and three-dimensional topological system. I will discuss several setups in which topological phases can be engineered both in static [9,10] and driven (Floquet) [11,12] regimes.

- [1] J. Klinovaja and D. Loss, Phys. Rev. B 86, 085408 (2012).
- [2] J. Klinovaja, P. Stano, A. Yazdani, and D. Loss, Phys. Rev. Lett. 111, 186805 (2013).
- [3] J. Klinovaja and D. Loss, Phys. Rev. B 90, 045118 (2014).
- [4] J. Klinovaja, A. Yacoby, and D. Loss, Phys. Rev. B 90, 155447 (2014).
- [5] C. Reeg, D. Loss, and J. Klinovaja, Phys. Rev. B 97, 165425 (2018).
- [6] C. Reeg, D. Loss, and J. Klinovaja, Phys. Rev. B 96, 125426 (2017).
- [7] C. Reeg, J. Klinovaja, and D. Loss, Phys. Rev. B 96, 081301 (2017).
- [8] C. Reeg, C.Schrade, J. Klinovaja, and D. Loss, Phys. Rev. B 96, 081301 (2017).
- [9] J. Klinovaja and Y. Tserkovnyak, Phys. Rev. B 90, 115426 (2014).
- [10] J. Klinovaja, Y. Tserkovnyak, and D. Loss, Phys. Rev. B 91, 085426 (2015).
- [11] J. Klinovaja, P. Stano, and D. Loss, Phys. Rev. Lett. 116, 176401 (2016).
- [12] M. Thakurathi, D. Loss, and J. Klinovaja, Phys. Rev. B 95, 155407 (2017).

Carsten Lindner:

Dissipative quantum mechanics beyond Bloch-Redfield

The spin boson model is a prominent model to describe dissipation in a quantum mechanical two-state system induced by an energy exchange with the environment. At weak coupling, it has been also used to study dissipative effects in qubits. However, previous results for the case of weak coupling and arbitrary bias are incomplete or contain a wrong analytic form of certain terms in the solution. In this talk, we present the first fully consistent solution for this model one order beyond the Bloch-Redfield approximation at weak coupling and finite bias. We point out the importance of a systematic resummation of secular and logarithmic terms of the perturbation series representation for the computation of the correct solution, being valid on all time scales. To this end, we apply the real-time renormalization group (RTRG) method to resum all these terms.

Sabrina Maniscalco:

Open quantum systems, non-Markovian dynamics and the quantum speed limit

I will introduce the basic formalism of open quantum system theory, review the different interpretations of non-Markovian dynamics and memory effects and give some examples of reservoir engineering and non-Markovianity in the context of ultra cold gases. I will then focus on the speed of quantum evolution and discuss its behaviour for different paradigmatic non-Markovian systems, reviewing also the state-of-the-art on the connection between quantum speed limit and non-Markovianity.

Lisa Markhof:

Applications of second-order fRG in one dimension

The functional renormalization group (fRG) has been widely used to study many-body systems with competing energy scales [1]. Although it is in principle an exact method, in practice approximations are necessary to obtain a finite set of flow equations. The recently developed "extended coupled-ladder approximation" (eCLA) allows to take into account all terms up to second order in the interaction for specific models [2,3]. The self-energy feedback as well as a (partial) vertex feedback are incorporated in the flow. We use this scheme to investigate phase transitions in the one-dimensional tight-binding chain of spinless fermions at half filling. In a clean system with nearest and next-nearest neighbor interactions, the eCLA is able to capture phase transitions to charge-ordered phases, which is not possible in a lowest order fRG scheme. We also use the eCLA to study (pseudo-) disordered systems in order to investigate the phase transition from an ergodic to a many-body localized phase.

- [1] W. Metzner et al., Rev. Mod. Phys. 84, 299 (2012)
- [2] F. Bauer, J. Heyder, and J. von Delft, Phys. Rev. B 89, 045128 (2014)
- [3] L. Weidinger, F. Bauer, J. von Delft, Phys. Rev. B 95, 035122 (2017)

Tobias Meng:

Beyond Majorana: parafermions and interactions

This talk will discuss topological bound states with anyonic character in the presence of electron-electron interactions. Starting with the paradigmatic example of Majorana bound states arising at the edge of non-interacting topological systems, I will show that they are in fact but the most simple representative of a much larger class of anyonic bound states called parafermions. I will review the properties of these more general bound states and connect them to realizations in interacting quantum wires, and fractional quantum Hall states.

Anna Minguzzi :

Correlated quantum gases in low dimensions

In this talk I will present various theoretical approach to describe one-dimensional bosonic and fermionic gases at strong interactions, in particular the Luttinger liquid effective field theory and the exact solutions for integrable cases (Bethe Ansatz solution for the homogeneous Bose gas and Tonks-Girardeau solution for the limit of infinitely strong repulsive interactions). I will present then some applications of these approaches to understand equilibrium and dynamical properties of quantum gases in one dimension.

Julian Mußhoff:

Static and dynamical response functions from LDA+DMFT

Linear-response functions are essential for comparing theory to experiments, and yet for strongly correlated systems their calculation is very challenging. The state-of-the-art technique for real materials is based on the dynamical mean-field (DMFT) approach and the local-vertex approximation. The bottleneck of this method is the calculation of 3-frequencies local susceptibilities. Here we present an efficient scheme based on the massively-parallel general implementation of the continuous-time quantum Monte Carlo impurity solver of Ref. [1]. We use both the Legendre polynomial representation and a recently proposed numerical basis [2], and compare efficiency. To calculate lattice susceptibilities we solve the multi-orbital and multi-site Bethe-Salpeter equation. We present results for the static and dynamical response functions of representative systems.

- [1] A. Flesch, E. Gorelov, E. Koch, E. Pavarini, Phys. Rev. B 87, 195141 (2013)
- [2] H. Shinaoka, J. Otsuki, M. Ohzeki, K. Yoshimi, Phys. Rev. B 96, 035147 (2017)

Hoa Nghiem:

Recent development in the time-dependent numerical renormalization group

We report the recent development of the time-dependent numerical renormalization group: the derivation of the two-time Green's function $G(t+t',t)$ and the new formalism for multiple quenches. From the two-time Green's function, the time-dependent spectral function can be extracted for times both before and after the quench. The applications to systems being quenched from both mixed valence and Kondo correlated initial states to the Kondo correlated final states result in the development of the Kondo resonance as the time evolves. The new formalism for multiple quenches is applied to the Anderson impurity systems driven by periodic or adiabatic switching. Both results are compared to those calculated using previous formalism and exhibit higher accuracy. The details will be presented in the workshop.

Mikhail Pletyukhov:

Geometry of driven dissipative phase transitions

The recent progress in the study of driven dissipative phase transitions (DPT) in open quantum systems puts forward the following question: How can a hysteresis inherent to a nonlinear semiclassical or mean-field dynamics be interpreted in the quantum Liouvillian approach to open systems? It is relevant, e.g., for understanding the optical bistability taking place in the Kerr nonlinearity model, e.g. realizable in the waveguide QED.

In this talk I explain that for a Liouvillian description of hysteresis it is necessary to incorporate into the theory a measurement protocol which pre-defines a typical measurement time. A metastable state occurring after this time at every next experimental run appears to be dependent on the whole experimental procedure (that is, on a sequence of all preceding runs). This fact allows us to account within the Liouvillian approach (i.e. in terms of Liouvillian eigenstates) why different branches in parametric dependence of observables can at all occur in a system described by a linear set of equations (e.g., by the Lindblad master equation). Most surprisingly, metastable states in question allow for a description in terms of a path-dependent (in the parameter space) scaling factor, which is an open system analog of the geometric Berry phase in closed systems.

Frank Pollmann:

Tensor-Product State based Methods for 2D Lattice Systems

Tensor-product states (TPS) provide a new paradigm for describing quantum many body systems. In this lecture, I will introduce basic techniques that allow to efficiently simulate 2D classical and quantum systems. First, I will show how boundary matrix-product states can be used to calculate expectation values from a given TPS. Second, I will introduce a so called simplified update that allow to obtain ground states of local Hamiltonians.

Viktor Reimer:

Open-system dynamics – Kraus meets Keldysh

Going beyond the well-known Lindblad master equation in microscopic models of open quantum systems with continuous energy spectra is an ubiquitous problem in understanding the non-Markovian dynamics of mesoscopic and nanoscale quantum transport devices.

In my talk, I present a reorganization of the system-environment coupling expansion which reveals the completely positive and trace-preserving structure of microscopic Keldysh real-time diagrams by providing a direct link to Kraus operators of measurement processes in the environment.

Importantly, approximations that explicitly respect complete positivity can be formulated concisely using cutting rules for groups of Keldysh diagrams. This paves the way towards an approximate evaluation of entropic quantities to quantify non-Markovianity and information backflow such as the exchange entropy which strictly requires completely positive dynamics.

I illustrate the approach for an exactly solvable model which despite its simplicity features non-Markovian behavior expressed in a nontrivial time-dependence of the entropy exchanged with the environment.

Johannes Reuther:

Functional renormalization for magnetic systems

This talk gives an introduction into the pseudofermion functional renormalization group (PFFRG) technique which represents a novel approach to determine large size ground state correlations of a wide class of magnetic quantum systems. Using a diagrammatic pseudofermion representation for quantum spin models, the PFFRG performs systematic summations in all two-particle fermionic interaction channels, capturing the correct balance between classical magnetic ordering and quantum fluctuations. We first present applications of the PFFRG to paradigmatic quantum spin-1/2 Heisenberg systems in two dimensions such as kagome lattice models and benchmark our results against other numerical methods. We also discuss various extensions of the method treating three-dimensional systems or arbitrary spin magnitudes S . Finally, we briefly review recent developments such as the application to novel quantum magnetic materials and the investigation of fractional spin excitations.

Matteo Rizzi:

Symmetries in Tensor Networks: how to preserve quantum numbers

We will review the conceptual and numerical advantages of exploiting symmetries in tackling a quantum many-body problem. In particular, we will focus on global, point-wise, symmetries (like particle number, total spin, etc.) and see how they reflect into a reduced Hilbert-space dimension and into a block-structure of matrices and tensors. The framework is not restricted to any specific Tensor Network method, though we will focus on loop-free structures and Abelian groups for the sake of simplicity. We will see some examples where working in the canonical ensemble disclose a simpler theoretical analysis of the results. Finally, we give a glance at extending the formalism to non-Abelian symmetries, starting from $SU(2)$.

Tommaso Roscilde:

Quantum correlations and entanglement: classical nonsenses for quantum gases

The central goal of quantum many-body physics is to explore how quantum mechanics can affect the behaviour of macroscopic systems, dictating new phases of matter, or new ways in which phases transform into each other via phase transitions. Phases of matter and phase transitions are traditionally characterised using observables that are borrowed from classical mechanics, such as correlation functions, response functions, etc.; and macroscopic quantum phenomena are often characterised by exceptional behaviours of such observables at macroscopic length scales. But, at a more fundamental level, quantum many-body states require the development of new observables that do not have any classical analog (or “classical nonsenses”, as in my title). Indeed these observables should capture the most intimate feature of quantum many-body states, at the core of all the quantum weirdness: many-body quantum superposition (namely “the characteristic trait” of quantum mechanics, as Schrödinger would put it).

In this talk I shall discuss an approach which we recently developed to probe the quantum superposition nature of many-body systems, based on fundamental concept of quantum statistical physics. The observables detecting quantum superpositions - and more specifically the quantum fluctuations of observables that descend from them, and the correlations among such fluctuations, or quantum correlations in short - are simple differences between correlation functions and response functions, that would be otherwise identical in classical systems. I will describe how these estimators of quantum correlations can be practically calculated in quantum many-body systems at thermal equilibrium and beyond; how they can probe the existence of entanglement in the system, and more specifically its geometric structure (“who is entangled with whom”); and how they may be accessible to current experiments on quantum gases as paradigmatic realisations of quantum simulators of many-body systems.

Slava Rychkov:

The conformal bootstrap approach to the critical state

We will review the main ingredients which go into the conformal bootstrap approach to constraining critical theories, focusing on the 3D case. Reference: arXiv:1805.04405

Michael Scherer:

Critical behavior of Dirac fermions from perturbative renormalization

Gapless Dirac fermions appear as quasiparticle excitations in various condensed-matter systems. They feature quantum critical points with critical behavior in the 2+1 dimensional Gross-Neveu universality classes. The precise determination of their critical exponents defines a prime benchmark for complementary theoretical approaches, such as lattice simulations, the renormalization group and the conformal bootstrap. Despite promising recent developments in each of these methods, however, no satisfactory consensus on the fermionic critical exponents has been achieved, so far. In my talk, I show a comprehensive analysis of the Ising Gross-Neveu universality classes based on the recently achieved four-loop perturbative calculations. To that end, the perturbative series in 4 - epsilon spacetime dimensions is combined with the one for the purely fermionic Gross-Neveu model in 2 + epsilon dimensions by employing polynomial interpolation as well as two-sided Pade approximants. I also give an exhaustive appraisal of the current situation of Gross-Neveu universality by comparison to other methods. For large enough number of spinor components $N \geq 8$ as well as for the case of emergent supersymmetry $N = 1$, we find the renormalization group estimates to be in excellent agreement with the conformal bootstrap, building a strong case for the validity of these values. For intermediate N as well as in comparison with recent Monte Carlo results, deviations are found.

Robin Steinigeweg:

Dynamical quantum typicality

The concept of typicality states that a single pure state can have the same properties as the full statistical ensemble. This concept is not restricted to specific states and applies to the overwhelming majority of all possible states, drawn at random from a high-dimensional Hilbert space. In the cleanest realization, even a single eigenstate of the Hamiltonian may feature the properties of the full equilibrium density matrix, assumed in the well-known eigenstate thermalization hypothesis (ETH). The notion of property is manifold in this context and also refers to the expectation values of observables. Remarkably, typicality is not only a static concept and includes the dynamics of expectation values. Furthermore, it has become clear that typicality even provides the basis for powerful numerical approaches to the dynamics and thermalization of many-particle systems at nonzero temperatures. These approaches are in the center of my talk.

I demonstrate that typicality allows for significant progress in the study of real-time relaxation. To this end, I review numerical work [1-3] on current-current correlation functions of spin-1/2 systems. A comprehensive comparison with state-of-the-art methods unveils that typicality is satisfied in finite systems over a wide range of temperature and is fulfilled in both, integrable and non-integrable systems. Moreover, without the restriction to small systems or short times, typicality sheds light on several long-standing questions. As important examples, I discuss the relaxation process in integrable chains [1], non-integrable ladders [2], and many-body localized phases [3], as well as the relation to the ETH [4]. If time allows, I also summarize work on the real-time broadening of density profiles [5,6] and connect to the subsequent talk by F. Jin.

- [1] R. Steinigeweg, J. Gemmer, and W. Brenig, PRL **112**, 120601 (2014).
- [2] R. Steinigeweg, J. Herbrych, X. Zotos, and W. Brenig, PRL **116**, 017202 (2016).
- [3] R. Steinigeweg, J. Herbrych, F. Pollmann, and W. Brenig, PRB **94**, 180401(R) (2016).
- [4] R. Steinigeweg, A. Khodja, H. Niemeyer, C. Gogolin, and J. Gemmer, PRL **112**, 130403 (2014).
- [5] R. Steinigeweg, F. Jin, D. Schmidtke, H. De Raedt, K. Michielsen, J. Gemmer, PRB **95**, 035155 (2017).
- [6] R. Steinigeweg, F. Jin, H. De Raedt, K. Michielsen, and J. Gemmer, PRE **96**, 020105(R) (2017).

Henk Stoof:

Many-Body Physics of Cold Atoms

The interactions between two ultra-cold atoms can be engineered by a Feshbach resonance. In particular, this allows for inter-atomic interactions with the maximal strength allowed for by quantum mechanics, i.e., the so-called unitarity limit. In this lecture we try to give an overview of the many-body physics of cold atomic gases in this unitarity limit, considering both Bose and (two-component) Fermi gases. If time allows for it, we also discuss our latest progress in obtaining a theoretical description for the unitary Fermi gas by means of the gauge-gravity duality discovered in string theory.

Agnese Tagliavini:

Multiloop functional RG for correlated systems: An alternative route for solving parquet equations

In the last two decades the functional renormalization group (fRG) has been widely applied to study correlated electrons in lower dimensions, from quantum dots [1] to 2D systems [2,3]. Compared to several forefront many-electron solvers, its main strengths are (i) the ability to treat different ordering tendencies in an unbiased fashion and (ii) the possibility to approach infrared divergences in a controlled way.

In the current algorithmic implementations of the fRG, relevant approximations are typically applied, the most significant one being the truncation of the fRG flow equations to the one-loop level [4]. In this talk, I will present one of the first applications of the newly introduced multiloop extension of the fRG method (mfRG) [5]. In particular, I will show the progress obtained within the mfRG scheme in considerably suppressing the pseudocritical temperature in 2D, in line with the Mermin-Wagner theorem [6]. The convergence of the mfRG with the loop order and the stability of the results w.r.t. the choice of different cutoff schemes will be also discussed. Finally, we could explicitly demonstrate, numerically, the expected convergence of the mfRG solution to the parquet approximation (PA) for the case of the single impurity Anderson model. This finding makes the mfRG scheme a promising alternative for the solution of the parquet equations, both in the perturbative (PA) [7] and in the non-perturbative (Dynamical Vertex Approximation [8], QUADRILEX [9]) regime. The mfRG route to solve the parquet equations, in fact, avoids per construction the almost ubiquitous appearance of spurious divergences of reducible and irreducible vertex functions in many-electron diagrammatic expansions.

[1] Andergassen, S., T. Enss, and V. Meden, Phys. Rev. B **73** (2006)

[2] C.J. Halboth and W. Metzner, Phys. Rev. B **61** (2000)

[3] D. Zanchi and H.J. Schulz, Phys. Rev. B **61** (2000)

[4] W. Metzner, M. Salmhofer, C. Honerkamp, V. Meden, and K. Schönhammer, Rev. Mod. Phys. **84** (2012)

[5] F. B. Kugler and J. von Delft, Phys. Rev. B **97** (2018): [arXiv:1807.02898](https://arxiv.org/abs/1807.02898) (2018)

[6] A. Tagliavini, C. Hille *et al.*, [arXiv:1807.02697](https://arxiv.org/abs/1807.02697) (2018)

[7] N. E. Bickers, Int. J. Mod. Phys. B (1991)

[8] A. Toschi, A. A. Katanin and K. Held, Phys. Rev. B **75** (2007)

[9] T. Ayrál and O. Parcollet, Phys. Rev. B, **94** (2016)

Alessandro Toschi:

Breakdown of traditional many-body theories for correlated electrons: From vertex divergences to multiple solutions

One of the main differences arising when applying the Feynman diagrammatics to problems of QED or of condensed matter is the lack, in the latter case, of an evident small parameter to perform perturbative expansions. The main difficulties arise in the study of strongly correlated materials, for which the electronic screening is not efficient enough to significantly suppress the effects of the Coulomb interaction. While Feynman diagrammatic-based techniques are successfully exploited in the forefront method developments [1,2] for correlated materials, only very recently theoretical manifestations of the breakdown of perturbative resummations have been unveiled and analyzed. Among these, we recall the divergence of irreducible vertex functions [3] discovered to be a general feature of correlated and disordered models [4], as well as the surprising, intrinsic multivaluedness of the Luttinger-Ward functional [5].

In this talk, I will start by illustrating the general properties of these non-perturbative manifestations, and then demonstrate how they are, in fact, directly related to one another [6]. I will also elaborate on the physics responsible [4,6,7] for their appearance and, finally, discuss their implications for the applicability of many-electron algorithms in the intermediate-to-strong coupling regime.

[1] W. Metzner, M. Salmhofer, C. Honerkamp, V. Meden, and K. Schönhammer, RMP. **84**, 299 (2012).

[2] G. Rohringer, H. Hafermann, A. Toschi, A.A. Katanin, A.E. Antipov, M.I. Katsnelson, A.I. Lichtenstein, A.N. Rubtsov, and K. Held, RMP **90** 025003 (2017).

[3] T. Schäfer, G. Rohringer, O. Gunnarsson, S. Ciuchi, G. Sangiovanni, and A. Toschi, PRL **24** 246405 (2013).

[4] T. Schäfer, *et al.* PRB **94**, 235108 (2016); P. Chalupa, *et al.*, PRB **97** 245136 (2018); D. Springer, *et al.*, in preparation.

[5] E. Kozik, M. Ferrero, and A. Georges, PRL **114** 156402 (2015).

[6] O. Gunnarsson, G. Rohringer, T. Schäfer, G. Sangiovanni, and A. Toschi, PRL **119** 056402 (2017).

[7] O. Gunnarsson, *et al.*, PRB **93** 245102 (2016).