
Exact Eigenstates in Non-Integrable Systems: A violation of ETH

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Abstract

We find that several non-integrable systems exhibit some exact eigenstates that span the energy spectrum from lowest to the highest state. In the AKLT Hamiltonian and in several others “special” non-integrable models, we are able to obtain the analytic expression of states exactly and to compute their entanglement spectrum and entropy to show that they violate the eigenstate thermalization hypothesis

^{*}Speaker

Universality of the Hall Response(s) in strongly correlated quantum systems

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Abstract

Understanding the transport properties of quantum matter systems in the presence of electromagnetic fields is at the core of condensed matter physics. In this context, the Hall response is of particular interest. It is generally referred as the voltage drop generated at the edge of a conductor after injection of a current in the presence of a transverse magnetic field. In normal metals, the Hall response provides valuable information on the charge carrier density of the material. More generally, the Hall response probes important geometric and topological properties of quantum systems: the Fermi-surface curvature of metals under weak magnetic fields, the Berry curvature of anomalous Hall systems, and related topological invariants of band insulators (e.g., the band-integrated Berry curvature). As a consequence, studies of the Hall response are ubiquitous in fields focused on topological quantum matter and synthetic realizations thereof.

Nevertheless, the description of the (even qualitative) behavior of the Hall response of strongly correlated systems remains a longstanding theoretical puzzle, of broad experimental relevance – both in strongly correlated condensed matter systems, but also in novel quantum matter platforms such as neutral cold atoms and optical lattices, in which synthetic magnetic fluxes can be simulated. In two recent works [1-2], relying on analytical arguments, supported by out-of-equilibrium DMRG numerical simulations, we derived exact results for the Hall response of strongly correlated quantum systems. We show the universal dependence of the Hall constant R_H on the carrier density n , $R_H = -1/n$, despite the absence of well-defined quasi-particles because of interactions [1]. We also discuss an extended regime in coherent quantum lattices, in which the Hall response is totally absent [2]. This last effect does not rely on particle-hole symmetry and is robust to interactions, variations of magnetic field, chemical potential, and temperature. We show that this remarkable robustness traces back to a topological property of the Fermi surface, namely its central charge.

[1] "Universal Hall Response in Interacting Quantum Systems", Sebastian Greschner, Michele Filippone, and Thierry Giamarchi, *Phys. Rev. Lett.* 122, 083402 (Editor's Suggestion)

[2] "Vanishing Hall Response of Charged Fermions in a Transverse Magnetic Field", Michele Filippone, Charles-Edouard Bardyn, Sebastian Greschner, and Thierry Giamarchi, *arXiv:1903.02000*

^{*}Speaker

Spontaneous Exciton Formation and Condensation in InAs/GaSb Quantum Wells

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Abstract

Electron–hole pairing can occur in a dilute semimetal, transforming the system into an excitonic insulator state in which a gap spontaneously opens at the Fermi surface, analogous to a Bardeen–Cooper–Schrieffer (BCS) superconductor. In this talk I will report optical spectroscopic and electronic transport evidence for the formation of an excitonic insulator gap in an inverted InAs/GaSb double Quantum Wells (DQWs) system at low temperatures and dilute electron (n) – hole (p) densities [1]. Terahertz transmission spectra exhibit two absorption lines that are quantitatively consistent with predictions from the pair-breaking excitation dispersion calculated based on the BCS gap equation. Low-temperature electronic transport measurements reveal a gap of $\sim 25\text{K}$ with a critical temperature of $\sim 10\text{K}$ in the bulk, together with quantized edge conductance, suggesting the occurrence of a topological excitonic insulator phase. We will also mention the transport properties of the edge states, which suggest the formation of a helical Luttinger liquid [2]. In recent experiments using InAs/InGaSb DQWs with a thin tunneling barrier, a charge-unbalanced state ($p \gg n$) was observed in addition to the charge neutral state ($p \sim n$). We found that these bulk insulating states are lacking edge conductance, consistent with the notion that by tuning the inter-layer tunneling, a topological phase transition could take place in the exciton binding energy verses tunneling phase diagram, as proposed by [3, 4].

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- [3] D.I. Pikulin and T. Hyart, Interplay of exciton condensation and quantum spin Hall effect in InAs/GaSb bilayers, *Phys. Rev. Lett.* **112**, 176403 (2014)
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*Speaker

Beyond Kohn-Sham DFT: Explicitly correlated wave functions

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Abstract

In a recent study Medvedev et al. [4] showed that newly developed functionals in density functional theory (DFT), designed to improve in the energy estimate, do not necessarily reduce the error in the density, rather the opposite is seen. This, and the increasing number of specialized functionals, indicate the need of a paradigm change in DFT.

We aim to improve the accuracy of ab initio methods by starting from a Jastrow correlated wave function, i.e. a product of the correlation factor F and a Slater-determinant. The optimization problem splits in two coupled parts.

First the optimization of the correlation factor employs cluster expansion techniques. The Fermi-Hypernetted Chain (FHNC) summation technique is implemented to optimize the correlation function by energy minimization. Here even simple approximations [3] result, for the HEG, in more than 95% of the exact correlation energy and yields a pair distribution function very close to Monte Carlo (MC) results for a wide density range. Within a manageable computational effort the method can be generalized to realistic periodic materials as demonstrated for a 1D model system [2].

The second part is the optimization of the orbitals of the Slater-determinant. This can be done in two different ways, i) a DFT like approach, where the exchange correlation potential V_{xc} is obtained from coupling constant integration of the exchange correlation hole and ii) from a generalized Hartree-Fock (gHF) equation, with different effective potentials in the exchange and direct part.

The later is of particular interest, as it allows a microscopic interpretation of hybrid functionals. Present hybrid functionals appear to approximate the optimization of the Slater-determinant in the presence of a correlation factor.

Preliminary results show a striking similarity of the exchange potential in e.g. HSE06 and the effective potential in the exchange part in gHF for the HEG.

The final goal is to implement the coupled optimization of the correlation factor and the Slater-determinant for 3D materials as extension of present DFT implementations. We present the status of the development, in particular results for a periodic 1D model system [2] are shown. For a slowly varying density the local density approximation(LDA) is reproduced, but decreasing the period of the density variation, the results deviates from LDA, as expected. Finally an outlook on the performance for excited states is given.

M. G. Medvedev et al., Science 355, 49–52 (2017).

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M. Panholzer et al., arxiv:1807.04549 (accepted PRB)

*Speaker

Low-dimensional quantum systems

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Abstract

I present diffusion Monte Carlo (DMC) simulations on two-dimensional (2D) and one-dimensional (1D) arrangements in which the presence of correlations is important to fully understand the properties of the systems under consideration. In the first case, the equation of state of ^3He on clean and preplated graphite was calculated including the corrugation of the different substrates in the description afforded by the different Hamiltonians. The inclusion of that kind of correlations was a key ingredient to reconcile the theoretical model to the experimental data, with the appearance of a very dilute 2D-liquid phase. The 1D case presented is that of a set of $\text{SU}(6)$ fermions harmonically confined or loaded in an optical lattice. Again, to reproduce the experimental time-of-flight imaging experiments, one has to include correlations between pairs of spins of different type. Those correlations increase with the number of spin species in the cluster.

*Speaker

Anderson localization of few interacting bosons in a continuum with speckle disorder

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Abstract

The disorder-induced localization of few bosons interacting via a contact potential is investigated through the analysis of the level-spacing statistics familiar from random matrix theory. The model we consider is defined in a continuum and describes one-dimensional bosonic atoms exposed to the spatially correlated disorder due to an optical speckle field. First, we identify the speckle-field intensity required to observe, in the single-particle case, the statistics of Anderson localized systems in a computationally and experimentally feasible system size. Then, we analyze the two-body and the three-body systems, exploring a broad interaction range, from the noninteracting limit up to the vicinity of the strongly-interacting Tonks-Girardeau limit. Our main result is that the contact potential does not induce delocalization, indicating that Anderson localization can occur also in interacting few-body systems in a continuum. We also analyze how the ground-state energy evolves as a function of the interaction strength

*Speaker

Electronic two-body dissipation in molecules and clusters

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Abstract

The description of dynamical processes by time-dependent density functional theory (TDDFT) is known to be surprisingly successful. But for high excitations and/or long time evolution this mean-field approach is grossly underestimating dissipation, i.e. conversion of excitation energy into intrinsic thermalization. Such dissipative processes are driven by dynamical two-body correlations which go beyond DFT. A manageable description of dynamical correlations is developed in terms of a statistical ensemble of mean-field states where two-body collisions are realized by stochastic jumps between different mean-field configurations. This approach, called Stochastic TDDFT (STDDFT), is very versatile and covers even processes with large fluctuations of the mean field as, e.g., fragmentation. However, it becomes unnecessarily expensive in moderate situations staying at small fluctuations. Thus a series of approximations to STDDFT is developed down to an implementation of the relaxation-time approximation for finite systems. Typical examples of application will be presented with particular emphasis on the impact of dissipation in electronic dynamics driven by intense laser pulses.

*Speaker

Entropy production in non-linear Luttinger liquid

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Abstract

We study the non-equilibrium thermodynamic properties of non-linear Luttinger liquid using quantum kinetic equation. We present the continuity equation for entropy density and derive the entropy production. It is demonstrated that the two-particle scattering events give a zero entropy production and thus we study the effect of three-particle collisions. It is shown that at low temperatures the entropy production has a non-decaying power-law behavior. As an example, we use the entropy production to calculate the rate of Joule heat generation.

*Speaker

Macroscopic bosonic zero-mode generation in dissipative one-dimensional fermion model under uniform electric field

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Abstract

Recent investigations of high-field and ultra-fast-probe experiments have begun to unlock the mechanism of symmetry breaking in nonequilibrium-driven phase transitions in solids. Despite the intense effort with computational theories to understand the correlated behaviors near switching induced by an electric field, the fundamental role of an electric field on the electronic structure has not been well understood. We develop an analytic method of one-dimensional fermion model to propose a new framework of how to approach nonequilibrium effects in interacting quantum systems. Through a bosonized theory of one-dimensional fermion system, we show that the effect of a uniform electric field on a metallic fermion system is absorbed by the bosonic zero-mode (BZM) which has largely been ignored in condensed matter applications. The generation of the BZM becomes macroscopic with its statistical spectrum giving the field-induced effective temperature and the electric current. The residual effect of the electric field is then imparted to the non-zero boson modes, i.e., electron-hole excitations, through a dissipative kernel of the bosonized action which retains the effect of the hot-electron physics in excitations. We establish the equivalence of the fermionic and bosonic solutions and extend the theory to an interacting limit. We further discuss how this new finding impacts the understanding of a gapped fermion system as a model for the electronic resistive switching. In the context of the sine-Gordon theory, we show how the BZM results in the charge-density-wave pattern formation.

^{*}Speaker

Emergent quantum criticality in driven-dissipative cavity arrays

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Abstract

The possibility of realizing strongly correlated states in photonic cavity arrays has stimulated an intense research on open quantum many-body systems, establishing a fascinating interface between condensed matter physics and quantum optics. Among the phenomena emerging in these systems, dissipative phase transitions are nowadays deserving more and more attention. Due to the competition between the coherent and incoherent dynamics, a continuous tuning of the external parameters can lead to a criticality in the non-equilibrium steady state of the open system. In this regard, the question about the role played by quantum fluctuations in these critical phenomena is still a matter of debate.

Here, I will present a theoretical study of the driven-dissipative Bose-Hubbard model in the presence of two-photon driving and losses, a model that is within reach of current experimental techniques based on circuit-QED resonators [1]. The mean-field analysis of the steady state of this system reveals the occurrence of a second-order phase transition, characterized by the spontaneous breaking of the Z_2 symmetry of the model [2]. The critical exponents associated to the transition are computed using a fully many-body approach, based on the corner-space renormalization method. These show that the phase transition belongs to the universality class of the quantum transverse Ising model, revealing thus the important role of quantum fluctuations and long-range entanglement at the critical point [3].

Quadratically driven-dissipative photonic arrays are feasible both on a circuit-QED platform and using microcavity polaritons, as in both cases the coherent two-photon driving process has been experimentally demonstrated. Such systems would then be suitable for the simulation of a wide range of collective phenomena, among which the emergence of the spin liquid phase in frustrated magnets [4].

References

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- R. Rota and V. Savona, arXiv:1902.07631

*Speaker

Entanglement Negativity in Many-Body Systems: Its Measurement & Applications

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Abstract

We will describe how a genuine measure of mixed state entanglement between two non-complementary parts of a many-body system, namely the negativity, can be measured using a very few replicas of a system (say, in a quantum simulator) and machine learning techniques. We will also illustrate how this can give us insight into the entanglement structure of many-body states, particularly about the entanglement across a many-body localization transition.

^{*}Speaker

Restricted Boltzmann Machines for Quantum States with Nonabelian or Anyonic Symmetries

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Abstract

Although artificial neural networks have recently been proven to provide a promising new framework for constructing quantum many-body wave functions, the parameterization of a quantum wavefunction with nonabelian symmetries in terms of a Boltzmann machine inherently leads to biased results due to the basis dependence. We demonstrate that this problem can be overcome by sampling in the basis of irreducible representations instead of spins, for which the corresponding ansatz respects the nonabelian symmetries of the system.

I will present how to construct this local basis-independent approach and show that this construction goes beyond Restricted Boltzmann machines and neural network quantum states in general, and can be used with any variational ansatz depending on local degrees of freedom. Furthermore, I will lay the connection with tensor networks, as the basis we construct can be seen as a tensor network carrying the irreducible representations of the subsystems on the bonds. This connection can open the possibility of generalizing our approach to using other tensor network structures as basis states for general variational functions, more specifically by using the bond indices as input for another non-linear variational function. This has the advantage of using the transformative properties of tensor networks, while retaining the freedom of other variational families.

We apply our methodology to find the ground states of the one-dimensional antiferromagnetic Heisenberg (AFH) model with spin-half and spin-1 degrees of freedom, and obtain a substantially higher accuracy than when using the $s.z$ -basis as input to the neural network. Because our method transforms by construction as an irreducible representation of the symmetry group it can also target excited states without the need of constructing the ground state and other low-lying excited states first. We illustrate this by calculating the energy gap of the AFH model.

To show the versatility of the approach, we show that the ground state of anyonic spin chains can be naturally represented in our framework.

*Speaker

Moiré is Different: Wigner Insulating States in TBLG

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Abstract

While it is well known that for a single layer of graphene, the ratio of the Coulomb interaction to the kinetic energy displays no indication of strongly coupled physics as this ratio is independent of density, such is not the case for the twisted bi-layer system. I will focus on computing this ratio accurately for the twisted bi-layer system and show that it is highly sensitive to the filling, twist angle, and pressure. Our analysis explains the conundrum that under hydrostatic pressure, an insulating state at quarter-filling of the moiré superlattice (i.e., one charge per supercell) emerges, in sharp contrast with the previous ambient pressure measurements of Cao et al. where the quarter-filling state (QFS) is a metal $\nu = 1$.

*Speaker