2nd Adriatic Conference on Strongly Correlated Systems (and beyond)

16-18 February 2022
An ICTP virtual meeting
Trieste, Italy

The Abdus Salam
International Centre
for Theoretical Physics

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Unraveling the catalytic and photocatalytic decomposition of N_2O on Titanium dioxide based material: a DFT+U study

Elham Moharramzadeh Goliaei

The Abdus Salam International Centre for Theoretical Physics, Trieste, Italy

The catalytic and photocatalytic N_2O dissociation on Titanium oxide clusters is an important reaction for environmental protection. We studied the dissociation process of N_2O into N_2 with and without photo-excited electrons on Titanium oxide clusters supported on anatase (101). In the lack of photo-excited electron, N_2O decomposition is difficult due to the low exothermic reaction energy. However, the reaction energy declines in the presence of photo-excited electron on the Titanium oxide clusters. This is the first theoretical study of N_2O elimination on Titanium oxide clusters, which will direct the supplementary experimental work.

Kane-Mele and emergent topology in novel materials: from computational discovery to materials design

Antimo Marrazzo

University of Trieste, Italy

Recently, we predicted [1] monolayer jacutingaite (Pt2HgSe3, a naturally-occurring mineral) to be the very first large-gap Kane-Mele (KM) quantum spin Hall insulator (QSHI). Soon after [2,3], we discovered that 3D jacutingaite is a dual topological insulator where a weak Z2 topological phase of type (0;001) coexists with a non-trivial mirror Chern number (MCN). In this talk, I will start by discussing the rich physics of monolayer jacutingaite, including its close relationship with graphene and the interplay between spin-orbit coupling, crystal-symmetry breaking, and dielectric response. Then I will focus on 3D jacutingaite crystals, where ARPES experiments [3] report the presence of 001-surface states that we show [3] to be topologically protected and to emerge from a non-trivial interlayer coupling, where KM-QSHI monolayers interact through a strong second nearest-layer hopping: that breaks the standard paradigm of weak topological insulators. We have extended the KM model to 3D and explained the origin of the 001-surface states through the viewpoint of a k-dependent Su-Schrieffer-Heeger (SSH) model and its Zak phase [2].
Finally, I will show how an emergent ferroelectric quantum spin Hall insulating phase can spontaneously occur—or be engineered—in van-der-Waals heterostructures, in a way that is robust and can survive up to room temperature. I will outline the general idea by considering an heterostructure made of a well-known ferroelectric material and a suitably chosen, easily exfoliable trivial insulator. In one polarization state the system is trivial, while it becomes a QSHI with a 50 meV band gap upon polarization reversal. Remarkably, the topological band gap is mediated by the interlayer hybridization and allows to maximise the effect of intralayer spin-orbit coupling, promoting a robust ferroelectric topological phase that could not exist in monolayer materials and is resilient against relative orientation and lattice matching between the layers.

[1] A. Marrazzo et al., Phys. Rev. Lett. 120, 117701(2018)
[2] A. Marrazzo et al., Phys. Rev. Research 2, 012063(R) (2020)
[3] I. Cucchi, A. Marrazzo et al., Phys. Rev. Lett. 124, 106402 (2020)
[4] A. Marrazzo and M. Gibertini, submitted (2021)

The phase diagram of iron from quasi-*ab initio* calculations

Zhi Li

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In this study, we employ classical molecular dynamics simulations to explore iron over a broad pressure and temperature range. The classical potential is generated from *ab initio* reference data, which can accurately describe the interatomic force. We determine the phase diagram of iron by multiple techniques like thermodynamic integration. The most stable phase is used to compute the elastic constants and the seismic velocities. We also systematically examine the finite size effect, which has been proposed as an essential factor in stabilizing the body-centered cubic phase. Our results provide new insights into the interpretation of the seismic observations.

A flexible neural-network interatomic potential for mixed ionic materials: from bulks to clusters and nanoparticles

Samare Rostami

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Many interesting systems, such as interfaces, surfaces, grain boundaries, and nanoparticles, contain so many atoms that quantum-mechanical atomistic simulations become inconvenient or outright impossible. It is therefore desirable to develop accurate and flexible general-purpose interatomic potentials to make it possible to explore the potential energy surface of such structures. we generate a neural-network potential through charge equilibration technique (CENT) for different materials such as $Ti_xZr_{1-x}O_2$ with $0<x<1$ and alkali-halide materials MX with 6 chemical species (M = {Li, Na, K} and X = {F, Cl, Br}). The combination of the CENT potential with the symmetry functions generates a flexible and reliable method to reproduce the complexity of the energy landscape of these mixed materials with different boundary conditions. The reliability and transferability of the potential are verified by calculating some properties of bulk and slab configurations. Moreover, in order to investigate the performance of potential for different crystal phases and cluster configurations which are not included in our training data set, we performed a crystal structure search by minima hopping method. Beside reproducing known results in agreement with DFT calculations, we discovered novel polymorph and polytype structures , as well as for small clusters and nanoparticles for LiCl and mixed TiO2/ZrO2.

An unsupervised approach for studying free energy landscapes characterized by order-disorder transitions

Giulia Sormani

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The analysis of free energy landscapes provides a way to rationalize Molecular Dynamics simulations at a given temperature, therefore leading to a quantitative understanding of the relevant properties of biomolecules. In this context, data-science algorithms have shown their utility: the idea is to consider data of numerical simulations of biological events as an ensemble of realizations drawn from an underlying probability distribution in a high dimensional space. The characterization of this probability distribution allows obtaining the relevant properties of the system under study. However, the characterization of probability densities in high dimensional spaces is troublesome. To circumvent some of these problems, we use an algorithm that allows estimating the probability density (and thus the free energy) in the so-called embedding manifold, a relatively low dimensional manifold containing the data, without explicitly defining its functional form. This algorithm is then combined with a clustering technique able to find the maxima and the saddle points of the probability density.
In my talk, I'll focus on a specific application of this protocol I carried out during my Ph.D.: the study of the folding free energy landscape of the Villin Headpiece protein, always analyzing an MD trajectory.
A major outcome of this project is a new clustering technique that is capable to locate within the same framework the enthalpic traps (corresponding to free energy minima) and entropic traps (corresponding to large flat regions of the free energy). This algorithm can be really useful to analyze disorder-order transitions, and in general to study systems whose free energy landscape includes metastable states stabilized by the conformational disorder.

Emergent parametric resonances and time-crystal phases in driven BCS systems

Hector Pablo Ojeda Collado

ISC-CNR and Department of Physics, Sapienza University of Rome, Italy

We study the out-of-equilibrium dynamics of a Bardeen-Cooper-Schrieffer condensate subject to a periodic drive. We demonstrate that the combined effect of drive and interactions results in emerging parametric resonances, analogous to a vertically driving pendulum. In particular, Arnold tongues appear when the driving frequency matches $2\Delta 0/n$, with n a natural number, and $\Delta 0$ the equilibrium gap parameter. Inside the Arnold tongues we find a commensurate time-crystal condensate which retains the U(1) symmetry breaking of the parent superfluid/superconducting phase and shows an additional time-translational symmetry breaking. Outside these tongues, the synchronized collective Higgs mode found in quench protocols is stabilized without the need of a strong perturbation. Our results are directly relevant to cold-atom and condensed-matter systems and do not require very long energy relaxation times to be observed.

Nonlinear phenomena in thermally biased superconducting circuits

Giampiero Marchegiani

Technology Innovation Institute (TII), Abu Dhabi, UAE

Superconducting technology offers a suitable platform for the investigation of thermal transport phenomena due to the exponentially suppressed quasiparticle-photon interaction at cryogenic temperatures [1,2]. In this presentation, I will discuss some recent theoretical predictions for thermally biased superconducting circuits. Focusing on exotic effects beyond linear-response regime, I will explore two different physical mechanisms. First, I will present an interesting example where thermoelectricity is induced in standard superconducting tunnel junctions despite the intrinsic electron-hole (EH) symmetry when Josephson coupling is suppressed. This result represents a novel mechanism, which is valid in the presence of EH symmetry even beyond the superconducting paradigm [3]. The thermoelectricity can be related to a spontaneous breaking of EH symmetry and is amenable to current experimental investigation. Later, I will address photon-mediated heat transport in hybrid circuits, where both superconductors and normal metal elements are present. The sharp temperature dependence of the superconducting impedance can be exploited to achieve purely nonlinear thermal phenomena. In particular, the heat transport in hybrid superconducting-normal systems displays an almost ideal thermal diode effect [4]. Similarly, these elements can be used to implement negative differential thermal conductance, hence pointing toward the realization of photonic thermal transistors [5].

[1] F. Giazotto, T. T. Heikkilä, A. Luukanen, A. M. Savin, and J. P. Pekola, Rev. Mod. Phys. 78, 217 (2006)
[2] J. T. Muhonen, M. Meschke, and J. P. Pekola, Rep. Prog. Phys. 75, 046501 (2012)
[3] G. Marchegiani, A. Braggio, F. Giazotto, Phys. Rev. Lett. 124, 106801 (2020)
[4] G. Marchegiani, A. Braggio, F. Giazotto, Appl. Phys. Lett. 118, 022602 (2021)
[5] S. Saheb-Dey, G. Marchegiani, L. Amico, in preparation

Multi-stage Kondo effect in a multi-terminal geometry: a quantum lego interferometer

Andrei Pavlov

The Abdus Salam International Centre for Theoretical Physics, Trieste, Italy

Quantum systems characterized by an interplay between several resonance scattering channels demonstrate very rich physics. To illustrate it we consider a multi-stage Kondo effect in nano-devices as a paradigmatic model for a multi-mode resonance scattering. We show that the channel cross-talk results in a destructive interference between the modes. This interplay can be controlled by manipulating the tunneling junctions in the multi-level and multi-terminal geometry. We present a full-fledged theory of the multi-stage Kondo effect at the strong coupling Fermi liquid fixed point and discuss the influence of quantum interference effects to the quantum transport observables.

Working principles and design of noise-protected superconducting quantum circuits

Agustín Di Paolo

Massachusetts Institute of Technology (MIT), Boston, USA

Artificial atoms realized by superconducting circuits offer unique opportunities for storing and processing quantum information with high fidelity. Circuits that harness intrinsic noise protection implement computational states that are largely decoupled from local noise channels. The main challenge in engineering such systems is to simultaneously guard against errors while ensuring universal high-fidelity qubit control. Although partial noise protection is possible in superconducting circuits that rely on a single quantum degree of freedom, the promise of complete noise insensitivity can only be fulfilled by circuits of larger complexity. In this talk, we discuss basic principles for designing noise-protected devices and describe some of the recent experimental efforts in this direction.

Microwave activated two-qubit gate for fluxonium qubits via a tunable-transmon coupler

Leon Ding

Massachusetts Institute of Technology (MIT), Boston, USA

Two-qubit gate fidelities are currently a limiting factor for developing a large-scale useful quantum computer. The fluxonium qubit is a promising alternative to transmons, with coherence times reaching the order of milliseconds and GHz-order anharmonicity. In this work, we present a device containing two fluxonium qubits wired by a tunable-transmon coupler. The two-qubit gate is performed by driving a microwave activated CPHASE (MAP) gate with the higher levels of the fluxonium and the transmon excited state. We demonstrate that this architecture largely reduces the always-on ZZ interaction between the qubits, enabling faster and higher fidelity two-qubit gates.

Thursday, 17 February, 2022

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Growth of entanglement entropy under local projective measurements

Emanuele Tirrito

Scuola Internazionale di Studi Avanzati Superiori (SISSA), Trieste, Italy

Non-equilibrium dynamics of many-body quantum systems under the effect of measurement protocols is attracting an increasing amount of attention. It has been recently revealed that measurements may induce an abrupt change in the scaling-law of the bipartite entanglement entropy, thus suggesting the existence of different non-equilibrium regimes. However, our understanding of how these regimes appear and whether they survive in the thermodynamic limit is much less established. Here we investigate these questions on a one-dimensional quadratic fermionic model: this allows us to reach system sizes relevant in the thermodynamic sense. We show that local projective measurements induce a qualitative modification of the time-growth of the entanglement entropy which changes from linear to logarithmic. However, in the stationary regime, the logarithmic behavior of the entanglement entropy do not survive in the thermodynamic limit and, for any finite value of the measurement rate, we numerically show the existence of a single area-law phase for the entanglement entropy. Finally, exploiting the quasi-particle picture, we further support our results analysing the fluctuations of the stationary entanglement entropy and its scaling behavior.

Persistent oscillations after quantum quenches in d dimensions

Marianna Sorba

Scuola Internazionale di Studi Avanzati Superiori (SISSA), Trieste, Italy

We obtain analytical results for the time evolution of local observables in systems undergoing quantum quenches in d spatial dimensions. For homogeneous systems we show that oscillations undamped in time occur when the state produced by the quench includes single-quasiparticle modes and the observable couples to those modes. In particular, a quench of the transverse field within the ferromagnetic phase of the Ising model produces undamped oscillations of the order parameter when $d > 1$. For the more general case in which the quench is performed only in a subregion of the whole d-dimensional space occupied by the system, the time evolution occurs inside a light cone spreading away from the boundary of the quenched region as time increases. The additional condition for undamped oscillations is that the volume of the quenched region is extensive in all dimensions.

Exact calculation of entanglement dynamics in bi-partite states

Stefano Scopa

Scuola Internazionale di Studi Avanzati Superiori (SISSA), Trieste, Italy

In this talk I will revisit some recently developed tools stemming from quantum hydrodynamics for the calculation of the entanglement entropy in one-dimensional spin chains at zero temperature. In particular, I will consider some bi-partite initial states, as for instance a domain wall configuration. The focus of the talk will be mainly on free Fermi gases, where the hydrodynamic approach can be reduced to a study of the Wigner function with quantum fluctuations encoded as a Luttinger liquid. In the last part of the seminar, I will rapidly discuss the possible extension of this method to interacting integrable models.

Inhomogeneous quenches in the sine-Gordon theory

David Horvath

Scuola Internazionale di Studi Avanzati Superiori (SISSA), Trieste, Italy

In this talk inhomogeneous quantum quenches in the attractive regime of the sine–Gordon model are discussed. In the quench protocol, the system is prepared in an inhomogeneous initial state in finite volume by coupling the topological charge density operator to a Gaussian external field. After switching off the external field, the subsequent time evolution is governed by the homogeneous sine–Gordon Hamiltonian. Varying either the interaction strength of the sine–Gordon model or the amplitude of the external source field, an interesting transition is observed in the expectation value of the soliton density. This affects both the initial profile of the density and its time evolution and can be summarized as a steep transition between behaviors reminiscent of the Klein–Gordon, and the free massive Dirac fermion theory with initial external fields of high enough magnitude. The transition in the initial state is also displayed by the classical sine–Gordon theory and hence can be understood by semi-classical considerations in terms of the presence of small amplitude field configurations and the appearance of soliton excitations, which are naturally associated with bosonic and fermionic excitations on the quantum level, respectively. Features of the quantum dynamics are also consistent with this correspondence and comparing them to the classical evolution of the density profile reveals that quantum effects become markedly pronounced during the time evolution. These results suggest a crossover between the dominance of bosonic and fermionic degrees of freedom whose precise identification in terms of the fundamental particle excitations can be rather non-trivial. Nevertheless, their interplay is expected to influence the sine–Gordon dynamics in arbitrary inhomogeneous settings.

Phase transitions as resources for quantum metrology: excited-phase transitions

Ugo Marzolino

INFN, Trieste, Italy

Critical behaviour in phase transitions is a resource for enhanced precision metrology. A direct connection between phase transitions and metrology is the Fisher information, whose superextensivity identifies both systems at critical points and probes for enhanced precision metrology. After providing a general introduction, I specify the above connection in the excited state quantum phase transitions of the Lipkin-Meshkov-Glick model, characterised by Fisher information peaks and their widths. This model was first introduced for superconductivity and for nuclear systems, and recently realised in several condensed matter platforms. Applying the above results to metrology, I propose efficient and experimentally feasible schemes for precision magnetometry. These metrological schemes can be also exploited to measure microscopic properties of systems able to simulare the Lipkin-Meshkov-Glick model.

Enhanced sensitivity with attractive boson in atomtronic circuit

Juan Polo

Technology Innovation Institute (TII), Abu Dhabi, UAE

I will present our latest results involving an Atomtronic quantum device based on quantum solitonic particles trapped in a ring shaped optical lattice. I will first focus discuss the fractionalization of the elementary flux quanta and show that by including a weak link, in analogy to the famous superconducting quantum interference device (SQUID), one can prepare a qubit state that displays Rabi-like oscillations between different angular momentum states. I will also briefly discuss some of the other physical platforms that are currently being investigated and present similar features, Bosonic, fermionic or SU(N) fermions.

SU(N) Atomtronics

Wayne Jordan Chetcuti

Technology Innovation Institute (TII), Abu Dhabi, UAE

I will present our recent work on an atomtronic circuit consisting of strongly interacting fermions with N components that fulfill SU(N) symmetry - SU(N) fermions. By applying a combination of Bethe ansatz and numerical techniques, we analyze the persistent current of SU(N) fermions confined in a ring-shaped potential pierced with an effective magnetic flux for both repulsive and attractive interactions. For repulsive interactions, we observe that the combined effect of spin correlations, effective magnetic flux and interaction, leads to a re-definition of the elementary flux quantum for the ground-state of the system. Moreover, despite its mesoscopic nature, the persistent current is able to detect the superfluid to Mott phase quantum phase transition. For attractive interactions, we focus on the SU(3) case due to its relation with quantum chromodynamics (QCD). By taking trions and color superfluid states to be the analogues of hadrons and quark-quark pairs in QCD respectively, we explore this transition utilizing SU(3) fermions. We show that the persistent current is able to probe and clearly discriminate between the two phases.

Quantum liquids and droplets in one-dimensional optical lattices

Ivan Morera Navarro

University of Barcelona, Spain

In this talk I will present a new type of quantum liquids and droplets which appear in one-dimensional optical lattices. These appear in the strongly interacting regime and I will show how a few-body perspective can capture most of the relevant properties of these. I will discuss how such lattice quantum liquids can be produced in bosonic mixtures and dipolar bosonic systems which could already be realized in current ultracold atomic laboratories by adding a one-dimensional optical lattice. Finally, I will present the universal properties of liquids in one-dimension that would be relevant for future experimental and theoretical studies.

Cluster phases for cold dressed Rydberg atoms in ladders

Pierre Fromholz

University of Basel, Switzerland

Strong correlations in low-dimensional system are notorious to generate exotic phases of matter, often close to a Mott insulator regime. These regimes of parameter often involve half-filling for spin-1/2 fermions or ladder of hard-core bosons. Away from half-filling, for Hubbard-like model, only well-known Tomonaga Luttinger liquid with density wave instabilities are expected. When the interaction range extends to next-to nearest neighbours and beyond and for specific commensurate fillings, the particles may group up into heterogeneous clusters, themselves self-organising into Luttinger liquid or crystal. During the presentation, I will discuss about a system of cold Rydberg atom (hard-core bosons) in an optical ladder susceptible to host such cluster phases. This example would illustrate the effect of commensurability besides half-filling.

Collective excitations of a strongly-correlated photon fluid stabilized via incoherent drive and dissipation

Fabio Caleffi

Scuola Internazionale di Studi Avanzati Superiori (SISSA), Trieste, Italy

Utilizing a simple approach to Gaussian quantum fluctuations around the Lindblad dynamics, we explore theoretically the spectral properties of the non-equilibrium photonic phases hosted by a lattice of coupled cavities in presence of non-Markovian driving and dissipation, as well as strong photon interactions. In particular, we analyse how the energy spectrum of the system evolves across the Mott/superfluid-like transition exhibited by the model, pointing out the emergence of a diffusive Goldstone mode in the symmetry-broken phase and the close intertwining between dissipation and coherence. Our study goes in the direction of investigating the potential of driven-dissipative photonic fluids to quantum simulate a wider range of many-body scenarios.

Dynamics of an impurity coupled to two one-dimensional fermionic baths

Martino Stefanini

Scuola Internazionale di Studi Avanzati Superiori (SISSA), Trieste, Italy

We analyzed the low-energy dynamics of a mobile impurity interacting with two parallel, one-dimensional fermionic baths, a model that can be realized with cold atoms. The impurity is allowed to move along them, or to jump from one to the other. We first used a Lee-Low-Pines transformation to recast the Hamiltonian in a convenient form, and then we performed an improved version of time-dependent perturbation theory in the impurity-bath coupling, with a smart choice of the unperturbed Hamiltonian. The advantage of this procedure is that we are able to capture the orthogonality catastrophe, while providing analytic expressions for the whole impurity-bath state evolution, and keeping the computational effort low. We studied the dynamics of the system when the impurity is injected in the baths (prepared in their ground state) with a given wave packet, calculating the evolution of both impurity and baths observables.

Quantum simulation of lattice gauge theories with ultracold atoms

Federica Surace

California Institute of technology (Caltech), Pasadena, USA

Gauge theories are the cornerstone of our understanding of fundamental interactions among particles. Their properties are often probed in dynamical experiments, such as those performed at ion colliders and high-intensity laser facilities. Describing the evolution of these strongly coupled systems is a formidable challenge for classical computers, and represents one of the key open quests for quantum simulation approaches to particle physics phenomena. In this talk, I will first show how recent experiments done on Rydberg atom chains naturally realize the real-time dynamics of a U(1) lattice gauge theory, at system sizes that are difficult to achieve with classical computational methods. I will then illustrate how this Rydberg-atom quantum simulator can be used to probe various phenomena, including particle collisions and confinement.

Friday, February 18, 2022

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Steady-State Quantum Zeno Effect of Driven-Dissipative Bosons with Dynamical Mean-Field Theory

Matteo Seclì

UC Berkeley, Berkeley, USA

The study of the driven-dissipative quantum many-body problem has gained, in the last decade, considerable traction. Photonic systems, in particular, have emerged as particularly suited platforms thanks to the ease of introduction of driving and dissipation, and the latter has been harnessed as a convenient tool for the preparation of strongly-correlated many-body states. Despite these recent efforts, the picture on driven-dissipative many-body quantum systems is still incomplete and calls, among others, for the development of new, powerful numerical methods which are able to cope with the sheer size of the Hilbert space and, at the same time, to carefully handle the presence of correlations. In this work, we overcome these problems by employing the DMFT technique in the context of driven-dissipative bosonic lattices. As a case study for the effectiveness of our specific implementation of this technique, we demonstrate the ability to reproduce the so-called quantum Zeno effect in a Bose-Hubbard lattice of cavities with strong two-particle dissipation.

[1] Seclì et al, New J. Phys. 23, 063056.
[2] Seclì et al, arXiv:2201.03191.

Suppression of the superconducting state in a Josephson coupled pair of BCS superconductors

Matteo Ferraretto

Scuola Internazionale di Studi Avanzati Superiori (SISSA), Trieste, Italy

The physics of layered structures has recently attracted great attention due to its obiquitous application in several active research areas.For instance, most of the high-temperature superconductors (such as the cuprates and the iron based compounds) are solids composed by a pattern of periodically repeated layers with different atomic structure. Furthermore, modern experimental techniques allow for the artificial creation of thin films of materials, composed by very few layers, the most famous example being the bilayer graphene, which shows many non-trivial physical properties.

Layered systems are theoretically very challenging to investigate, since their properties are affected by both the intralayer and the interlayer particle interactions. Moreover, there are in principle several interlayer interaction processes that one has to account for: density-density repulsion, Hund's coupling, pair-hopping and spin-exchange, which makes it very difficult to gain a deep understanding of the underlying physics. A possible strategy to address this complicated problem is to disentangle the role of each single contribution, considering them one by one.

In this talk we are considering a bilayer system of s-wave superconductors and we are focusing our attention on the role of the pair-hopping interlayer interaction (Josephson coupling) in the resulting ground state. We will argue that the ground state is characterized by a quantum phase transition from a weakly coupled pair of s-wave superconductors to a strongly coupled pair of insulators, where electronic transport is still possible between the two layers by means of exchange of pairs. Moreover, we will see how this system eludes the simple picture of non-interacting quasiparticles, and one has to take into account the collective electronic behavior to understand the physics. In order to go beyond the naif quasiparticle picture, one has to consider the full dynamical structure of the self-energy, and a perfectly suitable tool for this is the Dynamical Mean Field Theory (DMFT).

Interplay between local electron-electron interaction and a Jahn-Teller phonon mode in multi-orbital systems

Alberto Scazzola

Scuola Internazionale di Studi Avanzati Superiori (SISSA), Trieste, Italy

The electron-electron repulsion and electron-phonon coupling are extremely important interaction terms in solids, that are responsible for many interesting phenomena like the Mott transition and the superconductivity. The question about the interplay between these two interactions was addressed by a wide majority of previous studies focusing on a single-band Hubbard-Holstein model. This led to the general expectation that the electron-phonon coupling, which causes an effective frequency-dependent local attraction, competes directly with the local electron-electron repulsion. We consider instead a two-band model with Jahn-Teller electron-phonon coupling, showing that the framework of multi-orbital systems, important for many interesting materials like Fe-based superconductors and Fullerides, offers the possibility to find a completely different picture where the phonons cooperate with the Mott physics. The new protagonists of this model are the electron-phonon coupling and the Hund's one. Their interplay leads to a rich phase diagram featuring the competition between two different realizations of a Mott insulator.

Discontinuous topological transitions in strongly correlated quantum spin Hall systems

Francesca Paoletti

Scuola Internazionale di Studi Avanzati Superiori (SISSA), Trieste, Italy

The topological properties of the electronic band structure are often assumed to be at odds with the presence of interaction. Using a combination of static and dynamical mean-field theory, we study the interplay of these two aspects in a generic model of interacting quantum spin Hall insulator.
In the strongly correlated regime, the enhanced local quantum fluctuations of the orbital polarization driven by the interaction determines a change of character of the topological quantum phase transition (TQPT). We show that, contrary to expectations, the TQPT takes place through a discontinuity which does not involve any gap closure or the breakdown of protecting symmetries, independently from the details of the interaction. We aim to verify that the emerging first order thermodynamic character associated to the interacting TQPT can be described in terms of an effective Landau-Ginzburg description other than a change in global topological invariant.

Influence functional approach to quantum many-body dynamics

Alessio Lerose

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Feynman-Vernon influence functional (IF) was originally introduced to describe the effect of a quantum environment on the dynamics of an open quantum system. We apply the IF approach to describe quantum dynamics of extended, strongly interacting many-body systems, viewing the system as an environment for its local subsystems. While the IF can be computed exactly only in certain many-body models, in one spatial dimension it generally satisfies an exact self-consistency equation. We view the IF as a fictitious wavefunction in the temporal domain, and approximate it using matrix-product states (MPS). This approach completely avoids the description of the massively entangled time-evolved wavefunction, trading the complexity of non-local equal-time correlations for that of local temporal correlations. This is efficient provided the temporal entanglement of the IF is sufficiently low. We illustrate the versatility of the IF approach by analyzing several models that exhibit a range of dynamical behaviors, from thermalizing to many-body localized, in both Floquet and Hamiltonian settings. The IF approach offers a new lens on many-body non-equilibrium phenomena, both in ergodic and non-ergodic regimes, connecting the theory of open quantum systems theory to quantum statistical physics.

Strongly correlated systems via Monte Carlo techniques: old workhorses and new challengers

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The study of strongly correlated systems is a central topic in condensed matter and statistical physics, which must in many cases be performed via numerical approaches, due to the lack of reliable analytical approaches. In this context, path integral Monte Carlo (PIMC) techniques have emerged as unbiased, state-of-the-art approaches for the study of the equilibrium and ground-state properties of a wide class of many-body systems. More recently, methods based on ideas stemming from machine learning and data mining have also shown great promise for the investigation of these fundamental problems.

The first part of my talk will offer a general introduction to the results I obtained via PIMC on a variety of quantum many-body systems of interest for realizations with cold atom experiments. Specifically, I will establish the theoretical framework for these approaches and discuss the accessible observables, giving direct examples of applications from my work, which will range from the discovery of exotic equilibrium and out-of-equilibrium states of matter to the characterization of long-range critical properties. The second part of my talk will discuss my work on the conjunction of PIMC techniques with data-mining-inspired observables for the characterization of quantum phase transitions, an approach which offers a new perspective on this type of critical phenomena and a competitive alternative to conventional methods for their study.

Dynamics of order parameter statistics in long range Ising model

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Advances in the field of synthetic quantum matter has allowed us to gain deeper insights into the static and dynamic properties of many body quantum systems. A primary objective of these experiments is to calculate the probability distribution function (PDF) of the order parameter in interest as it holds full information about the quantum fluctuation of the system. In this work we study the dynamics of the PDF of subsystem magnetization of a long-range quantum Ising model following a quantum quench. Our main objective is to observe if and how the initial long range order present in the system melts after a quantum quench. We have used a combination of Matrix Product State (MPS) based Density Matrix Renormalization Group (DMRG) and Time Dependent Variational Principle (TDVP) methods to simulate the long-range quantum Ising chain out of equilibrium.

Neural-Tensor mixed strategy for high-dimensional quantum many-body optimisation

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Since the introduction of the Density-Matrix Renormalization Group (DMRG) algorithm, Tensor-Networks (TNs) techniques have deeply revolutionized numerical approaches to the Quantum-Many Body (QMB) problem. Thanks to their versatility, TNs can provide winning strategies for all the main physical problems in one-dimensional QMB systems, but they have some fundamental limitations in higher dimensionality systems.
On the other hand, Neural-Networks (NNs) have been investigated in a plethora of different scientific contexts, and recently they have been used as powerful variational wave-functions for QMB systems.
In this work, we exploit a novel TN structure which extend the well-established Matrix Product State (MPS) representation of a QMB wave function. It can be efficiently manipulated by exploiting a new optimisation scheme which mix DMRG and NN algorithms, throwing a bridge between two paradigmatic techniques. We benchmark the new ansatz against challenging spin models both in one and two dimensions, demonstrating high accuracy and precision.

Learning Quantum Phase Transitions through Topological Data Analysis

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We implement a computational pipeline based on a recent machine learning technique, Topological Data Analysis, that has the capability of extracting powerful information-carrying topological features. We apply such a method to the study quantum phase transitions and, to showcase its validity and potential, we apply it for the study of two paramount important quantum systems: the 2D periodic Anderson model and the Hubbard model on the half-filled honeycomb lattice. Our results are perfectly consistent with the existing literature and suggest that this technique could be used to investigate quantum systems where transitions have not yet been detected with high accuracy. Joint work with Natanael C. Costa.

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