Quantum 2021 : Dynamics and local control of impurities in complex quantum environments

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Université Paris-Saclay

Institut Pascal

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Dynamics of spin impurities in a system with a temperature gradient (ONLINE presentation)

Auteur correspondant artem.volosnev@mail.ru

We study a spin impurity in a one-dimensional strongly interacting system. Our focus is on a system with a temperature gradient, which has not been studied before. First of all, we introduce a mathematical framework suitable for our study. To this end, we connect the finite-temperature dynamics of a strongly interacting one-dimensional system to a Heisenberg spin chain whose couplings are defined by the local temperature. This spin-chain mapping gives insight into the dynamics of a spin impurity. In particular, it shows that the impurity moves towards the hot side of the system: A temperature gradient accelerates the impurity in one direction more than in the other, leading to an overall spin current [somewhat similar to the spin Seebeck effect]

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Coexistence and phase separation of pairs and fermions in a one-dimensional model with pair-hopping (ONSITE presentation)

Auteur correspondant guillaume.roux@universite-paris-saclay.fr

We consider a simple model of spinless fermions in which the kinetic energy competes with a pair-hopping term. We show by means of numerical calculations that there exists a phase in which part of the fermions are paired while the others remain unpaired. These elementary components makes two mixed Luttinger liquids, one for pairs and one for fermions. A simple two-fluid model accounts remarkably well for the observed numerical data [1]. Adding nearest-neighbour interaction leads to a rich phase diagram [2] in which we observe a regime in which the two previous Luttinger liquids get phase separated. In the context of impurity physics, this model on a finite size chain allows for the creation of a single pair interacting with a fermionic bath or a single fermion interacting with a paired fermions bath.

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Quasiholes in the lowest Landau level pinned by impurities: detecting anyonic statistics from density profiles (ONSITE presentation)

Auteur correspondant leonardo.mazza@universite-paris-saclay.fr

When a quantum gas is confined to the lowest Landau level, quasiholes can be localised and pinned by static impurity potentials; as it is well known, they can have anyonic statistics, Abelian and non-Abelian. We present a method to characterize the anyonic statistics of quasiholes that is based only on static measurements of their density profile and that does not rely on any form of interference. We test our method on the paradigmatic examples of the Laughlin state and of the Moore-Read state, that is known to support excitations with non-Abelian statistics of Ising type.

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Strongly correlated electrons and excitons in moire superlattices (ONLINE presentation)

Auteur correspondant iatac@ethz.ch

Twisted bilayers of transition metal dichalcogenides offer a wealth of new phenomena, ranging from dipolar excitons to correlated insulator states. An example of qualitatively new phenomena in this system is our recent observation of an electrically tunable two-dimensional Feshbach resonance in exciton-hole scattering [1], which allows us to control the strength of interactions between excitons and holes located in different layers. Our findings enable hitherto unexplored possibilities for optical investigation of many-body physics, as well as realization of degenerate Bose-Fermi mixtures with tunable interactions.

[1] I. Schwartz, Y. Shimazaki, C. Kuhlenkamp. K. Watanabe, T. Taniguchi, M. Kroner, A. Imamoglu, arXiv:2105.03997 (2021).

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How the physics of quantum impurities became a central question in the relic neutrino detection (ONSITE presentation)

Auteur correspondant gene.cheypesh@gmail.com

I will explain that the systems where a beta-decaying atom is attached to a solid-state substrate are capable of making a break-through discovery for cosmology —detecting the so-called Relic Neutrino Background (CνB).

To collect enough statistics and achieve the superb energy measurement resolution required for this ambitious goal, a large-scale experiment involving a macroscopic number of beta-decayers must be eventually built.

The physics of the interaction between the beta-decayer and
the substrate is quite non-trivial and it imposes fundamental limitations on the experiment. I will review several effects that appear in such a system and describe some of the non-trivial theoretical and experimental problems that have to be solved
before a full-scale CnuB detector can be built.

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The 2N+1 many-body body problem; an impurity immersed in a spin 1/2 ferminonic superfluid (ONSITE presentation)

Auteur correspondant frederic.chevy@ens.psl.eu

The polaron is one of the paradigmatic concepts of many-body physics that describes the properties of the quasi-particle arising from the interaction between an impurity and a many-body environment. First introduced by Landau and Pekard to describe the behaviour of an electron shrouded by a cloud of phonons in a crystal, it has recently been applied to ultracold atoms where the properties of atomic impurities immersed in weakly interacting Fermi and Bose gases have been studied both theoretically and experimentally. In my talk I will describe how recent experiments on mixtures of ultracold Bose and Fermi gases have further extended the scope of polaronic physics by addressing the properties of impurities immersed in a strongly interacting medium. In particular I will discuss the crucial role played by three body-physics in this problem.

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The Out-of-Equilibrium Anderson impurity model: a numerically exact approach whith Diagrammatic Quantum Quasi Monte-Carlo (ONLINE presentation)

Auteur correspondant xavier.waintal@gmail.com

Calculating Feynman diagrams analytically is impractical beyond the first few orders. In this talk, I will discuss recent numerical algorithms that allow one to calculate all diagrams up to order 20 or more. I will show how this technique can be used to study the Anderson model, including for parameters deep into the Kondo regime both at equilibrium (in precise agreemeent with other techniques) and in out-of-equilibrium situations that were not accessible so far.

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Static and dynamic properties of a one-dimensional mobile impurity (ONSITE presentation)

Auteur correspondant o.gamayun@uva.nl

A single impurity particle in an ultracold atomic gas is a prospective model for probing relaxation dynamics of an interacting out-of-equilibrium quantum system. I will focus on McGuire's model that describes an impurity that propagates in a one-dimensional gas of free fermions. It is the simplest and yet fundamental model capturing the peculiar physics and mathematics of the non-equilibrium processes. The integrability of the model allows one to obtain a complete nonperturbative solution and express physical quantities in terms of the Fredholm determinants. After a detailed analysis of these determinants, I will discuss several striking physical phenomena such as incomplete relaxation and momentum-dependent impurity statistics. The universal properties of such one-dimensional systems can be described by the nonlinear Luttinger liquid (nLL). I will explain the microscopic derivation of nLL from the form-factors and discuss the generalization to finite temperatures.

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Dissipative dynamics of an impurity in the presence of the spin-orbit coupling (ONLINE presentation)

Auteur correspondant areg.ghazaryan@ist.ac.at

What happens when the impurity is immersed into a dissipative bath in the presence of spin-orbit coupling? This question is addressed in this talk.

To illustrate the main ideas, we first introduce a one dimensional toy model. Then, we employ a more elaborate Caldeira-Legett type coupled system. We show that the spin-orbit coupling and the presence of the dissipative medium might lead to a spin polarization in the system. We argue that our results are probably not directly applicable to classic solid state systems due to small spin-relaxation times. However, the obtained results can have important implications for electron dynamics in chiral molecules. In particular, the model can help to resolve certain features of the observed spin selectivity in chiral molecules (CISS effect) and of the mechanism of molecule-substrate interactions. As a specific example, we show how a chiral molecule can induce an in-gap Shiba state when placed on top of a s-wave superconductor, in agreement with recent experimental data.

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Quantum Impurities coupled to Markovian and Non-Markovian Environments (ONSITE presentation)

Auteur correspondant marco.schiro@college-de-france.fr

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Anderson localization of composite particles (ONLINE presentation)

Auteur correspondant fumika.suzuki@ist.ac.at

We investigate the effect of coupling between translational and internal degrees of freedom of composite quantum particles on their localization in a random potential. We show that entanglement between the two degrees of freedom weakens localization due to the upper bound imposed on the inverse participation ratio by purity of a quantum state. We perform numerical calculations for a two-particle system bound by a harmonic force in a 1D disordered lattice and a rigid rotor in a 2D disordered lattice. We illustrate that the coupling has a dramatic effect on localization properties, even with a small number of internal states participating in quantum dynamics.

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Local dynamic control of spin impurities using chiral molecules (ONSITE presentation)

Auteur: Yossi Paltiel[1]

[1] *The Hebrew University of Jerusalem*

Auteur correspondant paltiel@mail.huji.ac.il

Using the chiral induced spin selectivity (CISS) effect we were able to induce local spin impurities on magnetic and superconducting material. Dynamic control of spin impurities was also achieved. The CISS is an electronic phenomenon in which electron transmission through chiral molecules depends on the direction of the electron spin. Thus charge displacement and transmission in chiral molecules generates a spin-polarized electron distribution. This effect is metastable and may generate local magnetic defect that can be enhanced or removed by electric dipole. Also selective process may organize the molecules adsorption.In my talk I will present the CISS effect and its importance, both for applications and basic science. I will show that when chiral molecules are adsorbed on the surface of thin ferromagnetic film,they induce magnetization perpendicular to the surface, without the application of current or external magnetic field. On superconductors chiral molecules generate Shiba like states, as well as change the order parameter of the superconductor. Lastly, I will also point to open questions regarding dynamic control of skyrmions, and the CISS effect.

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Electric and heat transport in a charge two-channel Kondo device (ONLINE presentation)

Auteur correspondant l.fritz@uu.nl

Motivated by the experimental realization of a multi-channel charge Kondo device [Iftikhar et al., Nature 526, 233 (2015)], we study generic charge and heat transport properties of the charge two-channel Kondo model. We present a comprehensive discussion of the out-of-equilibrium and time-dependent charge transport, as well as thermal transport within linear response theory. The transport properties are calculated at, and also in the vicinity of, the exactly solvable Emery-Kivelson point, which has the form of a Majorana fermion resonant level model. We focus on regimes where our solution gives exact results for the physical quantum dot device, and highlight new predictions relevant to future experiments.

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The spatial structure of magnetic polarons in strongly interacting antiferromagnets (ONSITE presentation)

Auteur correspondant bruungmb@phys.au.dk

The properties of mobile impurities in quantum magnets are fundamental for our understanding of strongly correlated materials and may play a key role in the physics of high-temperature superconductivity. Hereby, the motion of hole-like defects through an antiferromagnet has been of particular importance. It creates magnetic frustrations that lead to the formation of a quasiparticle, whose complex structure continues to pose substantial challenges to theory and numerical simulations. In this article, we develop a non-perturbative theoretical approach to describe the microscopic properties of such magnetic polarons. Based on the self-consistent Born approximation, which is provenly accurate in the strong-coupling regime, we obtain a complete description of the polaron wave function by solving a set of Dyson-like equations that permit to compute relevant spin-hole correlation functions. We apply this new method to analyze the spatial structure of magnetic polarons in the strongly interacting regime and find qualitative differences from predictions of previously applied truncation schemes. Our calculations reveal a remarkably high spatial symmetry of the polaronic magnetization cloud and a surprising misalignment between its orientation and the polaron crystal momentum. The developed framework opens up a new approach to the microscopic properties of doped quantum magnets and will enable detailed analyses of ongoing experiments based on cold-atom quantum simulations of the Fermi-Hubbard model.

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Thermal instability, evaporation, and thermodynamics of one-dimensional liquids in weakly interacting Bose-Bose mixtures. Important perspectives for impurities. (ONLINE presentation)

Auteur correspondant giulia.de.rosi@upc.edu

We study the low-temperature thermodynamics of weakly interacting uniform liquids in one-dimensional attractive Bose-Bose mixtures. The Bogoliubov approach is used to simultaneously describe quantum and thermal fluctuations. First, we investigate in detail two different thermal mechanisms driving the liquid-to-gas transition, the dynamical instability, and the evaporation, and we draw the phase diagram. Then, we compute the main thermodynamic quantities of the liquid, such as the chemical potential, the Tan's contact, the adiabatic sound velocity, and the specific heat at constant volume. The strong dependence of the thermodynamic quantities on the temperature may be used as a precise temperature probe for experiments on quantum liquids.

The liquid-to-gas transition should also occur by reducing the concentration of one component in the mixture. By reaching the highly unbalanced mixture limit of our theory, one can explore the Bose polaron problem with attractive impurity-bath interaction, at finite temperature and in one spatial dimension where quantum and thermal fluctuations, which are both consistently taken into account in our theory, are strongly enhanced.

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Bond polarons (ONLINE presentation)

Auteur correspondant prokofev@physics.umass.edu

Polarons with different types of electron-phonon coupling have fundamentally different properties. When the dominant interaction is between the electron density and lattice displacement, the momentum of the ground state does not change and the polaron gets exponentially heavy at strong coupling. In contrast, one-dimensional and two-dimensional Peierls/Su-Schrieffer-Heeger (PSSH) polarons with interaction originating from displacement-modulated hopping may feature a shift of the ground-state momentum to finite values and appear to have moderate values of effective mass as coupling is increased. I will discuss recent Diagrammatic Monte Carlo data for two different models of bond polarons, as well as new results for bi-polarons with arbitrary on-site Hubbard repulsion U. This study is motivated by the possibility of having light bi-polarons in the strong coupling regime with high superconducting transition temperature.

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Quantum behavior of a heavy impurity in a Bose gas (ONLINE presentation)

Auteur correspondant meera.parish@monash.edu

The scenario of an infinitely heavy impurity in a quantum medium is a fundamental problem in physics, with relevance ranging from electron gases to open quantum systems. Here I will consider the case of a heavy impurity interacting with a dilute Bose gas at zero temperature –the so-called Bose polaron. When the impurity-boson interactions are short ranged, I will show that boson-boson interactions induce a quantum blockade effect, where a single boson can effectively block or screen the impurity potential. This behaviour depends on the quantum granular nature of the Bose gas and thus cannot be captured within a standard classical-field description. Using a combination of exact quantum Monte Carlo methods and a truncated basis approach, I will expose how the polaron

ground-state energy is linked to the spatial structure of the quantum correlations, spanning the infrared to ultraviolet physics.

Phys. Rev. Lett. 127, 033401 (2021)

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Dynamical formation of a magnetic polaron in a two-dimensional quantum antiferromagnet (ONLINE presentation)

Auteur correspondant michael.knap@ph.tum.de

The phase diagram of the two-dimensional Fermi-Hubbard model and its connection to high-temperature superconductivity have been the subject of a vast amount of theoretical and experimental studies in the past decades. Here, we present recent results motivated by the new perspective quantum gas microscopes provide. By developing matrix product state based algorithms, we study the dynamics of a single hole in the anti-ferromagnetic background and identify the relevant scales both at low and high temperatures [1]. The effective dynamics can be well captured by a doped hole moving in an anti-ferromagnetic environment as a bound state of spinons and chargons. We furthermore compare this simple effective picture in the finite temperature and finite doping regime of a cold atom experiment and find remarkable agreement [2]. For an unbiased comparison of theories and experiment, we develop a machine learning approach to classify experimental data at finite doping into different theoretical categories in order to determine which among a set of theories captures the physics best [3]. Furthermore, we will discuss how these concepts can be extended to more exotic quantum magnets.

[1] A. Bohrdt, F. Grusdt, MK, New J Phys 22 (2020)
[2] C. Chiu, et al. Science 365, 6450 (2019)
[3] A. Bohrdt, et al. Nature Phys. (2019)

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When Charge Quantization Leads to the Halon Effect -Part I(ONLINE presentation)

Auteur correspondant svistunov@physics.umass.edu

Under certain circumstances, a quasiparticle (or a static impurity) with a sharply defined integer particle charge becomes the so-called halon: It features a bimodal spatial charge distribution, with a small core and a halo of an arbitrarily large—critically divergent—size. I will discuss two distinctively different types of halons. The first type takes place at the point of a fluctuational quantum phase transition (for example, superfluid—Mott-insulator transition in two dimensions). The second type is a mobile Fermi polaron of large mass.

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Polaron interactions and bipolarons in one-dimensional Bose gases in the strong coupling regime (ONLINE presentation)

Auteur correspondant grigori.astrakharchik@upc.edu

Bose polarons, quasi-particles composed of mobile impurities surrounded by cold Bose gas, can experience strong interactions mediated by the many-body environment and form bipolaron bound

states. Here we present a detailed study of heavy polarons in a one-dimensional Bose gas by formulating a non-perturbative theory and complementing it with exact numerical simulations. We develop an analytic approach for weak boson-boson interactions and arbitrarily strong impurity-boson couplings. Our approach is based on a mean-field theory that accounts for deformations of the superfluid by the impurities and in this way minimizes quantum fluctuations. The mean-field equations are solved exactly in Born-Oppenheimer (BO) approximation leading to an analytic expression for the interaction potential of heavy polarons which is found to be in excellent agreement with quantum Monte-Carlo (QMC) results. In the strong-coupling limit the potential substantially deviates from the exponential form valid for weak coupling and has a linear shape at short distances. Taking into account lowest-order BO corrections we calculate bipolaron binding energies and find excellent agreement with QMC results for impurity-boson mass ratios as low as 3.

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High-order diagrammatic expansion around BCS: polarized superfluid phase of the attractive Hubbard model (ONSITE presentation)

Auteur correspondant werner@lkb.ens.fr

In contrast to conventional QMC methods, expansions of intensive quantities in series of connected Feynman diagrams can be formulated directly in the thermodynamic limit. Over the last decade, diagrammatic Monte Carlo algorithms made it possible to reach large expansion orders and to obtain state-of-the-art results for various models of interacting fermions in 2 and 3 dimensions, mostly in the normal phase.

We obtained first results inside a superconducting phase, for the 3D attractive Hubbard model [1]. Spontaneous symmetry breaking is implemented by expanding around a BCS Hamiltonian. All diagrams up to 12 loops are summed thanks to the connected determinant algorithm [2] with anomalous propagators. Working on the BCS side of the strongly correlated regime, we observe convergence of the expansion, and benchmark the results against determinant diagrammatic Monte Carlo [3]. In presence of a polarizing Zeeman field (where unbiased benchmarks are unavailable due to the fermion sign problem) we observe a first-order superconducting-to-normal phase transition, and a thermally activated polarization of the superconducting phase well described by a dilute gas of quasi-particles. We also discuss the large-order behavior of the expansion and its relation to Goldstone and instanton singularities.

[1] G. Spada, R. Rossi, F. Simkovic, R. Garioud, M. Ferrero, K. Van Houcke, F. Werner, arXiv:2103.12038
[2] R. Rossi, PRL 119, 045701 (2017)
[3] E. Burovski, N. Prokof'ev, B. Svistunov, M. Troyer, PRL 96, 160402 (2006)

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Quantum impurities in 1D chains and ladders (ONSITE presentation)

Auteur correspondant thierry.giamarchi@unige.ch

How an environment can modify the physical properties of a quantum particle is a long standing question. I will discuss this physics both for quantum bosonic chains for which the presence of the bath can lead to subdiffusion, but also for bosonic ladders for which the transverse degrees of freedom play a crucial role. I will discuss these theories in connection with experiments in cold atomic gases.

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Dynamical quantum Cherenkov transition of fast impurities in quantum liquids (ONLINE presentation)

Auteur correspondant kis@mit.edu

The challenge of understanding the dynamics of a mobile impurity in an interacting quantum many-body medium comes from the necessity of including entanglement between the impurity and excited states of the environment in a wide range of energy scales. In this talk, I will discuss the motion of a finite mass impurity injected into a three-dimensional quantum Bose fluid as it starts shedding Bogoliubov excitations. We uncover a transition in the dynamics as the impurity's velocity crosses a critical value which depends on the strength of the interaction between the impurity and bosons as well as the impurity's recoil energy. We find that in injection experiments, the two regimes differ not only in the character of the impurity velocity abatement, but also exhibit qualitative differences in the Loschmidt echo, density ripples excited in the BEC, and momentum distribution of scattered bosonic particles. The transition is a manifestation of a dynamical quantum Cherenkov effect, and should be experimentally observable with ultracold atoms using Ramsey interferometry, RF spectroscopy, absorption imaging, and time-of-flight imaging.

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Impurity particle driven through a quantum fluid by a constant force (ONLINE presentation)

Auteur correspondant o.lychkovskiy@skoltech.ru

Consider a mobile impurity particle in a one-dimensional fluid. Assume a constant force is applied to the impurity. How will it move? What kind of steady state will be established after initial transient dynamics? How will the steady state velocity of the impurity depend on the applied force, fluid temperature and impurity-fluid coupling? These questions have been extensively studied in the past couple of decades. Nevertheless, complete and definite answers are still lacking even in the simplest setups. The most striking thing that can happen to the impurity is Bloch oscillations in the absence of a lattice predicted theoretically in 2009 and observed experimentally in 2017. Alarmingly, the conditions for the emergence of such oscillations are a matter of an unsettled debate. I will overview this debate and outline several specific questions that should be addressed, theoretically or experimentally, to gain an unambiguous understanding of the effect. The dependence of the steady state velocity on the applied force is another matter of controversy: I will argue that reconciling different approaches to this problem inevitably implies a bizarre non-monotonic functional dependence far from naive linear response expectations.

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An emergent atom pump driven by global dissipation in a quantum gas (ONSITE presentation)

Auteur correspondant donner@phys.ethz.ch

Exposing a many-body system to external drives and losses can fundamentally transform the nature of its phases, and opens perspectives for engineering new properties of matter. How such characteristics are related to the underlying microscopic processes is a central question for our understanding of materials.

A versatile platform to address it are quantum gases coupled to the dynamic light field inside an optical resonator. This setting allows to create synthetic many-body systems with cavity-mediated long-range atom-atom interactions. If these are sufficiently strong, the system undergoes a structural phase transition to a crystal of matter and light. By engineering the involved light field modes, we

study in real-time the dynamics of a first-order phase transition between two such superradiant crystals.

The polaritonic nature of our system further allows us to bring coherent and dissipative couplings into competition. When the dissipation via cavity losses and the coherent timescales are comparable, we find a regime of persistent oscillations where the cavity field does not reach a steady state. In this regime the atoms experience a potential that periodically deforms itself, even without providing an external time dependent drive. Eventually, the dynamic lattice triggers a pumping mechanism. We show complementary measurements of the light field and of the atomic transport, proving the connection between the emergent non-stationarity and the pump.

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A weakly coupled impurity in a resonant Fermi gas: Connecting few-body inelastic decay to quantum correlations in a many-body system (ONSITE presentation)

Auteur correspondant salomon@lkb.ens.fr

We study the lifetime of a mixture of quantum degenerate fermions and bosons [1]. We show that when the interspecies coupling is weak, the loss rate is proportional to Tan's Contact parameter. When the fermion-fermion interactions are varied from weakly to strongly attractive, our prediction interpolates between three-body (2 free fermions+ 1 boson) to two-body (bound fermion molecule + boson) losses. At the unitary limit when the fermion-fermion scattering length is infinite, we predict a fractional loss-rate proportional to n 4/3 where n is the density of fermions. We confirm our analysis by measuring the lifetime of a 6 Li/ 7 Li dual superfluid mixture in the BEC-BCS crossover.

[1] S. Laurent, M. Pierce, M. Delehaye, T. Yefsah, F. Chevy, C. Salomon, Phys. Rev. Lett., 118, 103403 (2017)

35

Josephson effect(s) for strongly-correlated quantum gases in one dimension (ONLINE presentation)

Auteur correspondant anna.minguzzi@lpmmc.cnrs.fr

We study Josephson oscillations of two strongly correlated one-dimensional bosonic clouds separated by a localized barrier. Using a quantum-Langevin approach and the exact Tonks-Girardeau solution in the impenetrable-boson limit, we determine the dynamical evolution of the particle-number imbalance, displaying an effective damping of the Josephson oscillations which depends on barrier height, interaction strength and temperature. We show that the damping originates from the quantum and thermal fluctuations intrinsically present in the strongly correlated gas. Thanks to the density-phase duality of the model, the same results apply to particle-current oscillations in a one-dimensional ring where a weak barrier couples different angular momentum states. In the latter case, depending on interaction strength and temperature, we identify various dynamical regimes where the current oscillates, is self-trapped or decays with time and involve phase slips of thermal or quantum nature. We finally link the current oscillations in the large barrier limit to quantum shock waves.

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High-precision numerical solution of the Fermi polaron problem

and large-order behavior of its diagrammatic series (ONSITE presentation)

Auteur correspondant kris.van.houcke@phys.ens.fr

The Fermi polaron is a quasiparticle that emerges when a mobile impurity is coupled through a short-range interaction to a single-component ideal Fermi gas. Its energy, mass, and quasiparticle residue are renormalized since the bare particle is dressed by particle-hole excitations of the Fermi sea. Experimental studies with cold atomic gases raise a considerable theoretical interest in this system. While exact analytical results can be obtained in one dimension, most works in higher dimensions rely on approximate treatments of the strongly correlated many-body problem.

We present a simple determinant diagrammatic Monte Carlo algorithm to compute the ground-state properties of this system [1]. The fermionic sign does not cause any fundamental problem when going to high diagram orders, and we reach order N=30. The data reveal that the diagrammatic series diverges exponentially as (−1/R)ˆN with a radius of convergence R<1. Furthermore, on the polaron side of the polaron-dimeron transition, the value of R is determined by a special class of three-body diagrams, corresponding to repeated scattering of the impurity between two particles of the Fermi sea. A power-counting argument explains why finite R is possible for zero-range interactions in three dimensions. Resumming the divergent series through a conformal mapping yields the polaron energy with record accuracy.

[1] K. Van Houcke, F. Werner and R. Rossi, Phys. Rev. B 101, 045134 (2020).

36

Smooth Polaron-Molecule Transition in a Degenerate Fermi Gas with Multiple Impurities (ONLINE presentation)

Auteur correspondant yoav.sagi@physics.technion.ac.il

Understanding the behavior of a spin impurity strongly-interacting with a Fermi sea is a long-standing challenge in many-body physics. For short-range interactions and zero temperature, most theories predict a first-order phase transition between a polaronic ground state and a molecular one. We study this question with an ultracold Fermi gas [1]. Experimentally, the impurity problem poses a challenge: the signals from the minority atoms are inherently very weak. To overcome this difficulty, we have developed novel sensitive rf and Raman spectroscopic techniques, which are based on fluorescence detection. Raman spectroscopy allows us to isolate the quasiparticle contribution and extract the polaron energy [2-3]. As the interaction strength is increased, we observe a continuous variation of all observables, in particular a smooth reduction of the quasiparticle weight as it goes to zero beyond the transition point. Our observations are explained by a theoretical model where polaron and molecule quasiparticle states are thermally occupied according to their quantum statistics. At the experimental conditions, polaron states are hence populated even at interactions where the molecule is the ground state and vice versa. The emerging physical picture is thus that of a smooth transition between polarons and molecules and a coexistence of both in the region around the expected transition. A smooth transition happens even at zero temperature, while a true first-order transition occurs only in the single impurity limit.

[1] G. Ness et. al., Phys. Rev. X 10, 041019 (2020)
[2] C. Shkedrov, Y. Florshaim, G. Ness, A. Gandman, and Y. Sagi, PRL 121, 093402 (2018).
[3] C. Shkedrov, G. Ness, Y. Florshaim, and Y. Sagi, PRA 101, 013609 (2020).

40

Resolving the nonequilibrium Kondo singlet in energy-and position-space using quantum measurements (ONLINE presentation)

Auteur correspondant gcohen@tau.ac.il

The Kondo effect, a hallmark of strong correlation physics, is characterized by the formation of an extended cloud of singlet states around magnetic impurities at low temperatures. While many implications of the Kondo cloud's existence have been verified, the existence of the singlet cloud itself has not been directly demonstrated. We suggest a route for such a demonstration by considering an observable that has no classical analog, but is still experimentally measurable:"singlet weights" , or projections onto particular entangled two-particle states. Using approximate theoretical arguments, we show that it is possible to construct highly specific energy-and position-resolved probes of Kondo correlations. Furthermore, we consider a quantum transport setup that can be driven away from equilibrium by a bias voltage. There, we show that singlet weights are enhanced by voltage even as the Kondo effect is weakened by it. This exposes a patently nonequilibrium mechanism for the generation of Kondo-like entanglement that is inherently different from its equilibrium counterpart.

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Ipa Director's Welcome

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Driven-dissipative dynamics of coupled atomic clocks (ONSITE presentation)

Auteur correspondant eyuzbash@physics.rutgers.edu

I will present the nonequilibrium phase diagram for the driven-dissipative dynamics of two ensembles of ultra-cold atoms coupled to a resonant cavity. We will see that this relatively simple system displays a range of remarkable phenomena beyond usual superradiance. These include periodically and quasiperiodically modulated superradiance, chaos via quasiperiodicity, and synchronized chaos.

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Radio-frequency response and contact of impurities in a quantum gas (ONLINE presentation)

Auteur correspondant jesper.levinsen@monash.edu

We investigate the radio-frequency spectroscopy of impurities interacting with a quantum gas at finite temperature. In the limit of a single impurity, we show using Fermi's golden rule that introducing (or injecting) an impurity into the medium is equivalent to ejecting an impurity that is initially interacting with the medium, since the "injection"and "ejection"spectral responses are simply related to each other by an exponential function offrequency. Thus, the full spectral information for the quantum impurity is contained in the injection spectral response, which can be determined using a range of theoretical methods, including variational approaches. We use this property to compute the finite-temperature equation of state and Tan contact of the Fermi polaron. Our results for the contact of a mobile impurity are in excellent agreement with recent experiments and we find that the finite-temperature behavior is qualitatively different compared to the case of infinite impurity mass.

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Topological limit shape phase transitions: melting of Arctic Circles (ONSITE presentation)

Auteur correspondant d.m.gangardt@bham.ac.uk

A limit shape phenomenon in statistical mechanics is the appearance of a most probable macroscopic state. An iconic example of this phenomenon is given by Arctic Circle Theorem [2] of random tilings which in certain scaling limit can be mapped to imaginary time evolution of free fermions. A limit shape is usually characterized by a well-defined boundary separating frozen and liquid spatial regions. The earliest studies related to this phenomenon in the context of crystal
shapes are in works by Pokrovsky and Talapov [1].

In this talk I will present a phase transition of limit shape, which can be visualized as merging two melted regions (Arctic circles). By mapping onto a free fermionic problem and calculating corrspondent correlation functions we identify the transition as the third order transition known in lattice QCD [3]. We make connection to algebraic geometry, stressing the topological nature of the transition and identify universal features of the limiting shape. Relations with impurity problem in one-dimensional quantum liquids will be discussed.

[1] W. Jockusch, J. Propp and P. Shor, arXiv preprint math/9801068 (1998). "Random domino tilings and the arctic circle theorem."

[2] V. L. Pokrovsky and A. L. Talapov, Phys. Rev. Lett. 42, 65 (1979). "Ground State, Spectrum, and Phase Diagram of Two-Dimensional Incommensurate Crystals."

[3] D. J. Gross and E. Witten, Phys. Rev. D, 21 (2): 446, 1980. "Possible third-order phase transition in the large-n lattice gauge theory."; S. R. Wadia, , Phys. Lett. 93, 403 (1980) "N = ∞ phase transition in a class of exactly soluble model lattice gauge theories"

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Dynamics and energetics of fermionic impurities in a Bose Einstein condensate from moderate to near resonant interactions as they approach quantum criticality (ONLINE presentation)

Auteur correspondant crobens@mit.edu

Mixtures of quantum fluids lie at the forefront of research into strongly-correlated quantum matter. In this talk I will explore the rich many-body phase diagram of the Bose-Fermi mixture in the impurity limit by immersing fermionic impurities in a Bose-Einstein condensate (BEC) with near-resonant interactions.

I will describe an experiment, where we create Bose polarons near quantum criticality and probe their energy, spectral width, and short-range correlations as a function of temperature. We observe their inverse lifetime, determined via spectral width, to increase linearly with temperature at the Planckian scale, a hallmark of quantum critical behavior.

I will further present a study of dynamics of spin-polarized fermionic impurities immersed in a superfluid BEC through their collective excitations. We observe a dissipationless flow of the fermionic impurities, even as the mixture enters the strong-coupling regime where the impurities inherit the hydrodynamic modes of the BEC. We further probe the systems response as a function of temperature observing the fermions' transition from the collisionless to the hydrodynamic regime right at the superfluid transition temperature. Our experiments demonstrate the ability to pristinely control the fluid dynamics of a Bose-Fermi mixture in a dual-species ultracold atomic gas experiment.

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When Charge Quantization Leads to the Halon Effect -Part II (ONLINE presentation)

Auteur: Boris Svistunov[None]

Auteur correspondant svistunov@physics.umass.edu

Under certain circumstances, a quasiparticle (or a static impurity) with a sharply defined integer particle charge becomes the so-called halon: It features a bimodal spatial charge distribution, with a small core and a halo of an arbitrarily large—critically divergent—size. I will discuss two distinctively different types of halons. The first type takes place at the point of a fluctuational quantum phase transition (for example, superfluid—Mott-insulator transition in two dimensions). The second type is a mobile Fermi polaron of large mass.

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Rydberg atoms in ultracold gases - from electron to ion impurities (ONLINE presentation) NB!!! slides are truncated and youtube link temporarily removed to block access to unpublished data

Auteur correspondant f.meinert@physik.uni-stuttgart.de

I will report on our endeavor to control single Rydberg atoms immersed in degenerate atomic gases. Such Rydberg impurities allow us to study a rich plethora of effects resulting from the interaction of the Rydberg electron with the surrounding gas such as the formation and structure of ultralong-range Rydberg molecules. More recently, we have demonstrated that a Rydberg impurity can also serve as a precursor to generate a single low-energy ion via tailored photo- or field-ionization schemes. I will discuss how we control the produced ion with small electric fields in the absence of any trapping potentials. This allowed us to observe Rydberg blockade effects induced by a single charge and recently also to study diffusive transport of a single ion through a Bose Einstein condensate [1]. While the dynamics we study here is well captured by semi-classical Langevin collisions, our approach offers intriguing means to enter the elusive quantum regime for ion-atom scattering. In that context, I will finally discuss first results obtained with a new apparatus equipped with a high-resolution ion microscope to study ionic quantum impurities [2].

[1] T. Dieterle, M. Berngruber, C. Hölzl, R. Löw, K. Jachymski, T. Pfau, and F. Meinert, Phys. Rev. Lett. 126, 033401 (2021).
[2] C. Veit, N. Zuber, O. A. Herrera-Sancho, V. S. V. Anasuri, T. Schmid, F. Meinert, R. Löw, and T. Pfau, Phys. Rev. X 11, 011036 (2021).