Complex Quantum Systems Out of Equilibrium 2019

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Saturation of Strong Electron-Electron Umklapp Scattering at High Temperature

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We consider clean metals, at finite temperature, in which the inelastic rate, $\hbar/\tau_{ee}$, can become of the order of, or larger, than the band splitting energy. We show that in such systems, contrary to the common knowledge, the umklapp scattering rate becomes independent of both τ_{ee} and the temperature T, in three dimensional systems. We discuss the relation of this phenomenon to the saturation of resistivity at high temperature.

Screening effects on the Electron-glass system

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The conductivity measured for 2D Anderson insulator in proximity to a 2D metal plate[1, 2] has shown two unexpected characteristics: (1) It is smaller than the predicted value given by variable-range-hopping (VRH), which is opposed to the notion that interactions generically increase the frustration and therefore decrease the conductivity and relaxation. (2) It has an activation temperature dependence, rather than the expected Mott's or Efros-Shklivskii form. An explanation to the activation dependence was given by a model presented in an earlier work[3] that depicts a formation of static dipoles, in a 2D Metal-Insulator-Semiconductor junction, which are responsible for the modification of the single particle density of states (DOS) of the disordered semiconductor. Yet, the range of parameters in which this applies is not compatible with the experiment. Therefore, based on preliminary results we believe that these features of the conductivity can originate from a polaronic effect rather than the modification of the DOS. The polaronic effect naturally captures the decrease in the conductivity, and seems to give a robust crossover to an activation form for hopping lengths larger than the plates separation distance. By using a field theoretic approach we obtain an effective action that describes the interactions of the disordered electrons with two uncorrelated baths: A phonon bath present in the disordered sample and a 2D Fermi-Liquid in the metal. Our model incorporates both the dynamical polaronic effect and the static modification of the Coulomb interactions caused by the metal plate.

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Acknowledgments: We thank Zvi Ovadyahu for useful discussions.

Minimal models for chaotic quantum dynamics in spatially extended many-body systems

John Chalker

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I will give an overview of recent work on minimal models for quantum chaos in spatially extended many-body quantum systems, describing simple, solvable models.

The detailed study of generic quantum systems – ones without exact or approximate conservation laws – goes back at least as far as investigations of highly-excited states in nuclei in the 1950s. It saw revivals in the 1980s with work on systems such as quantum billiards, that have only a few degrees of freedom, and also in the context of mesoscopic conductors. It is attracting renewed current interest with a focus on many-body systems that are spatially extended. Part of the motivation for this comes from experiments on cold atom systems, and part comes from development on the theoretical understanding of eigenstates of many-body systems.

The study of dynamics in spatially many-body systems introduces new questions that do not arise in finite systems such as quantum billiards, or in extended single- particle systems, such as mesoscopic conductors. The questions concern the dynamics of quantum information and the approach to equilibrium. I will discuss how these can be answered in the context of minimal models.

[1] A. Chan, A. De Luca, and J. T. Chalker, Phys. Rev. Lett. 121, 060601 (2018) and Phys. Rev. X 8, 041019 (2018).

Universality of the electrical glassy features in disordered insulating systems

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Since the anomalous field-effect reported almost 30 years ago in indium oxide films by Zvi Ovadyahu and co-workers, electrical glassy features have been observed in disordered insulating systems as different as amorphous, microcrystalline and granular thin films. The explanations based on the existence of an electron glass, i.e. a glassy state of the electrons induced by the coexistence of disorder and ill-screened interactions, have strengthened over time. But some important discrepancies have also emerged among the experimental features which represent today so many obstacles to a comprehensive description of the observed phenomena.

During this presentation, we will compare field-effect measurements obtained on four different systems: amorphous indium oxide, amorphous niobium silicon, discontinuous gold and granular aluminium films. We will base our analysis on the results already published and on new data gathered in large temperature and resistance ranges. We will try to explain from where the observed differences might come from and why they do not undermine the universality of the glassy features.

Variable Range Hopping simulations in 3D systems

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Electron glasses have been studied for many years, both experimentally and theoretically, but a proper understanding of many crucial issues is still missing [1]. In this contribution, we focus our attention in the variable-range conductivity problem, and more specifically on numerical simulations of this problem. Up to now, simulations have been restricted to one- and two-dimensional systems. In three dimensions the problem becomes computationally harder and a proper percolation analysis still remains to be done. In the variable-range hopping regime and in the presence of Coulomb interactions, the conductivity is expected to follow Efros-Shklovskii's law [2]:

$$\sigma(T) \sim \frac{1}{T^{1+\alpha}} \exp\left\{ -\left(\frac{T_0}{T}\right)^{1/2} \right\} \tag{1}$$

The value of the preexponential exponent α is not known and influences the fitted value of the characteristic temperature T_0. The factor of one in the preexponential exponent comes from linearity of the current with respect to the electric field divided by the temperature. In our simulations, α will depend on the behaviour of the percolation network and its numerical determination is one of our main aims. We calculate the conductivity for many system sizes and temperatures. Through an analysis of the conductivity fluctuations versus system size we obtain the characteristic length of the percolation network as a function of temperature, that will be able to fit better with experiments that behave as 3 dimensional systems. We are going to discuss some preliminary results that suggest further work around this field.

[1] M. Pollak, M. Ortuno and A. Frydman *The Electron Glass*, Cambridge (2003).

[2] D.N. Tsigankov and A.L Efros, Phys. Rev. Lett. **88**, 176602 (2002).

Specific Heat Measurements through the Superconductor-Insulator Quantum Phase Transition

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The superconductor-insulator transition (SIT) is a prototype of a quantum phase transition which is very versatile experimentally: varying a non-thermal tuning parameter such as disorder, thickness, composition, magnetic field or gate-voltage causes the system to switch from a superconductor to an insulator. Though there has been increasing interest in this topic, the SIT has never been addressed from a thermodynamic point of view. So far, the experimental study of the SIT has mainly concentrated on resistivity based measurements such as transport and magnetoresistance and on global and local tunneling spectroscopy.

In my talk I will describe an experiment designed to go beyond conventional transport measurement. We use a unique highly sensitive setup to measure the specific heat of ultrathin Pb films through the SIT. The evolution of the specific heat through the quantum critical point in discontinuous films shows signatures for quantum criticality at the SIT and provides important information on electronic phenomena in the vicinity of the quantum phase transition. Continuous films exhibit thermodynamic signatures of the Berezinskii-Kosterlitz-Thouless Transition

Inelastic mean free path of low energy electrons in transition metals

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Free low energy electrons are produced in big amounts in condensed phase materials when irradiated by charged particles, i.e., by swift ion or electron beams, or are present naturally in metals. The knowledge of their inelastic mean free path is of paramount relevance for many applications, such as electron transport in nanostructured devices (where the mobility of electrons determines their performance of the devices) or in biological environments (where the effects produced by electrons are crucial for radiobiological applications). Both topics merge in modern radiotherapy treatments, where metallic nanoparticles are used as radiosensitisers to increase the damaging effect of radiation in tumour cells. This happens by the generation and transport of low energy electron cascades and their subsequent effects [1]. In this context, it is important to count on with models which allow predicting with good accuracy the electron inelastic mean free path in different metals for a wide energy range (from the keV-MeV energies used in electron beams down to energies of a few eV, characteristic of secondary electrons). This information is an important input for Monte Carlo radiation transport codes, which are very useful for assessing the energy deposition and for understanding radiation biodamage mechanisms [2].

The dielectric formalism is a theory widely used for evaluating electronic interactions for high energy (keV-MeV) charged particles in condensed phase materials (which has been successfully applied for biomaterials) [3]. Based on this formalism, we have introduced a new model which allows making accurate calculations also for electrons of energies down to a few electronvolts in metals. The model includes a detailed consideration of the energy transferred by the projectile in individual and collective (e.g. plasmons) electronic excitations, as well as ionizations, together with the inclusion of higher order corrections to the first Born approximation and an appropriate treatment of the electron indistinguishability and the Pauli exclusion principle [4].

Calculated inelastic mean free paths for gold, copper, molybdenum and platinum (materials of interest for radiosensitising nanoparticles) are in excellent agreement with the available experimental data, even at the elusive very low energy region. These results help to elucidate a reported disagreement between different sets of experimental data for very low energy electrons in some metals. The origin of such disagreement might be related to the possible interaction of low energy electrons with surface excitations, which need to be taken into account for certain experimental setups.

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Analog quantum simulation of chemistry problems with ultra-cold atoms

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Solving quantum chemistry problems with a quantum computer is one of the most exciting applications of future quantum technologies. Current efforts are focused on finding on efficient algorithm that allow the efficient simulation of chemistry problems in a digital way. In this talk, I will present a complementary approach to the problem which consists in simulating quantum chemistry problems using ultra-cold atoms. I will first show how to simulate the different parts of the Hamiltonian, and then benchmark it with simple molecules.

Evidence for thermal activation of the electron glass dynamics in a-InO_x and its universal features

T. Grenet and J. Delahaye

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Since the pioneering works on indium oxide in Jerusalem, the anomalous field effect and the associated glassy dynamics have been observed in an increasingly large span of systems including granular aluminum, various discontinuous metals, thallium oxide, and Nb_xSi as well as (Sb, Bi)GeTe alloys. However a clear general experimental picture is still lacking. We will concentrate on the important question of the influence of temperature on the dynamics, which has led to differing conclusions in the past.

We will provide a clear evidence of thermal activation in a-InO_x. We will further show that the behaviour is highly non arrhenius, and that the temperature dependence is strikingly similar to the one found in granular Al. It thus appears that the chemical and microstructural details of the materials are not important. Moreover together with results obtained in discontinuous metals and a-Nb_xSi, activation appears to be present in all the systems where this effect has been investigated. These results suggest that the glassy physics of all the electron glass systems may be universal, and show how new insights about the energy landscapes at work may be obtained.

Witten effect in superconducting topological insulators

Vincent Humbert

Material Research Laboratory, University of Illinois at Urbana-Champaign

Arrays of superconducting islands are widely used to study superconductivity and the conductor-to-insulator transition as they offer a tunable realization of two-dimensional (2D) superconductivity. Proximity to a three-dimensional time-reversal-invariant topological insulator (TI), which provides strong spin-orbit interaction and gapless surface states, should induce unconventional superconducting properties, building strong interest for the study of superconducting systems coupled with TIs.

In addition to Majorana bound states, vortices at the surface of TIs with proximity-induced superconductivity are predicted to have very peculiar properties arising from the axion term in the electromagnetic action of the bulk, which couples the electric and magnetic field.

In this presentation, I will present measurements performed on arrays of superconducting islands deposited on the TI Bi_2Se_3 that confirm the presence of the Witten effect. To support our claim, we perform analytical and numerical calculations of the Witten-effect-charged vortex motion and find it to be in good agreement with the performed experiments.

Stability of a topological insulator: interactions, disorder and parity of Kramers doublets

Victor Kagalovsky

Shamoon College of Engineering, Beer-Sheva, Israel

We study stability of multiple conducting edge states in a topological insulator against all multi-particle perturbations allowed by the time-reversal symmetry. We model a system as a multi-channel Luttinger liquid, where the number of channels equals the number of Kramers doublets at the edge. We show that in the clean system with *N* Kramers doublets there *always* exist relevant perturbations (either of superconducting or charge density wave character) which *always* open *N-1* gaps. In the charge density wave regime, *N-1* edge states get localised. The single remaining gapless mode describes sliding of 'Wigner crystal' like structure. Disorder introduces multi-particle backscattering processes. While the single-particle backscattering turns out to be irrelevant, the two-particle process may localise this gapless, in translation invariant system, mode. Our main result [1] is that an interacting system with *N* Kramers doublets at the edge may be either a trivial insulator or a topological insulator for *N=1* or *2*, depending on density-density repulsion parameters whereas any higher number *N>2* of doublets gets fully localised by the disorder pinning irrespective of the parity issue.

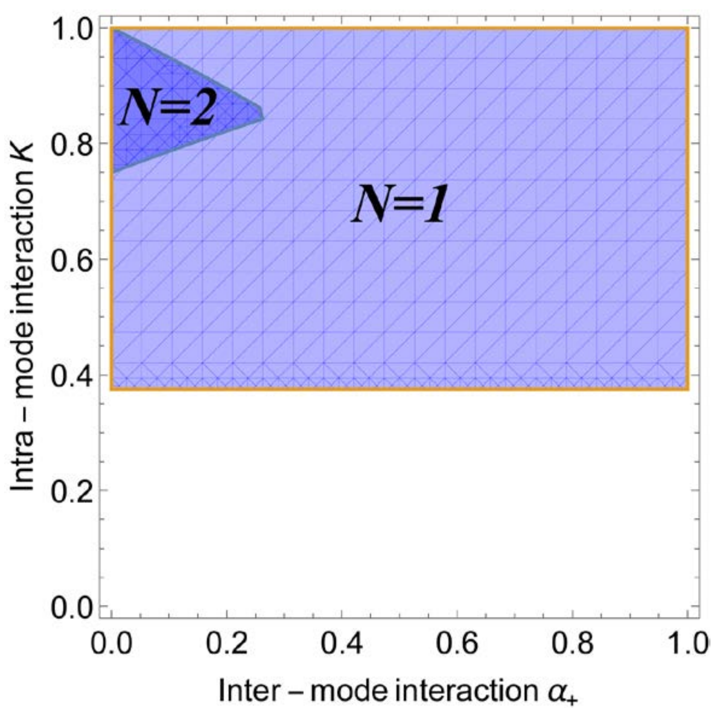

Fig 1: The phase diagram for a set of *N* Kramers doublets under a repulsive density-density interaction. The only two stable states, *N* = 1 and *N* = 2, are shown by light and dark blue regions, correspondingly.

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Enhancement of cooling rate of electrons by phonons in weak Anderson insulators

Vladimir Kravtsov

International Centre for Theoretical Physics (ICTP), Trieste, Italy

Though hopping transport of charge (hopping conductivity) in Anderson insulators was a subject of intensive research for a decades with lots of solid results, the transport of energy from hot electrons to cold phonons is barely not studied at all. In the paper [1] we show that the energy transport from electron to phonon sub-systems is enhanced near the Anderson localization transition by effects of multifractality and localization. The enhancement relative to dirty metals without localization and multifractality may be as large as 500. Our results give an explanation to a long-standing puzzle observed in [2] that the coefficient in front of T^{β} (T is electron temperature, $\beta \approx 5.5$) in the out-cooling rate is 10^3 times larger than the estimation [3] made from the standard theory of dirty metals with the elastic mean free path $1/k_F$. We also explain the apparent deviation of β from 6 by the presence of the Mott's pairs of resonant weakly localized states.

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Long-range adiabatic response in Anderson-insulators

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Transport studies of Anderson insulators taken far from equilibrium may yield unique information on fundamental issues related to the interplay of disorder and interactions. Such studies give, for example, a tool to estimate the inelastic scattering-rate. This in turn, revealed that deep in the insulating phase electron-electron inelastic scatterings are essentially suppressed [Phys. Rev. Lett., 108, 156602 (2012)], and therefore conductance hinges on the presence of phonons. The reduced inelastic scattering of the localized phase has further consequences. In this talk I shall describe another type of a nonequilibrium feature of Anderson insulators presumably suggestive of a long-range effect caused by local disturbance. The phase-coherence required for observability of the effect will be discussed.

Energy per particle for a many-body system of fermions by resumming the ladder diagrams

José Antonio Oller

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In the past I derived from Quantum Field Theory a new scheme for many-body theory. Based on this I give an algebraic derivation from first principles of the purely diagrammatical method introduced by N.Kaiser [NPA860,411(2011)] to resum ladder diagrams for the calculation of the energy density in a fermionic environment including only a contact interacting term, like in the Hubbard Hamiltonian. A generalization of this resummation for any of given fermion-fermion scattering matrix in vacuum results from the new derivation presented. Some other outcomes, like the Bertsch parameter, are discussed from this resummation.

Non-Magnetic Fractionally Quantized Conductance in Quasi-One Dimensional Semiconductor Structures

M.Pepper

University College London

We have investigated quasi-one dimensional carrier transport using holes, (electrons), in Ge – SiGe, (GaAs – AlGaAs), heterostructures in the ballistic regime. At values of carrier concentration below about 5.1010 cm^{-2} the integer ground state disappears to be replaced by fractional values of conductance. This occurs when the confinement of the carriers is relaxed to be on the verge of two-dimensionality. For holes in Ge we find that, in units of e^2/h, the fractional values of conductance are 1/2, spin degenerate, dropping to 1/4 in the presence of a parallel magnetic field and 1/16 which is spin polarized at zero field, [1]. The accuracy of the quantization was 0.5%, possibly corresponding to fractional charges of $e/2$ and $e/4$.

For electrons in GaAs we find a rich structure, the dominant fractional values of conductance, consistently observed, are in the presence of a weak, asymmetric confinement. The values found are 2/5, 1/2 and 1/6. In the presence of a parallel magnetic field a number of other fractions started to appear, [2]. These results will be discussed in relation to the formation of a zig-zag electron configuration with strong interactions between the two rows.

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[2] S. Kumar et al, to be published, arXiv:1810.09863

Hilbert Space Fragmentation and Many-Body Localization

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The investigation of the many-body localized (MBL) phase using exact numerical methods is limited to small systems due to the exponential increase of the size of the Hilbert space. At the same time, localized states display multifractality in the Hilbert space, a property which is numerically underutilized. In this talk I will show how a controlled decimation scheme can be developed in order to discard the irrelevant parts of the Hilbert space for the standard 1D random field Heisenberg model. This procedure fragments the Hilbert space in small clusters, on which the MBL problem can be studied by exact diagonalization. Quantitatively correct results, including the location of the MBL transition, are obtained on this very small fraction of the original Hilbert space, allowing to access large systems at high disorder.

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Error suppression for quantum annealing in the ultra-strong coupling regime

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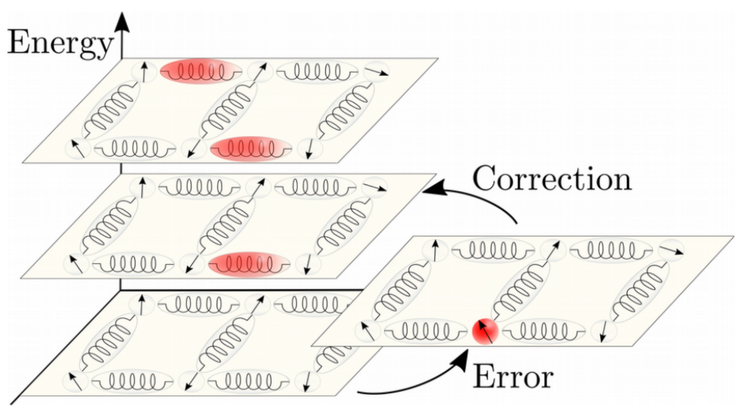
A quantum annealer is designed to evolve a set of qubits so that the initial ground-state is easy to prepare and the final one contains the solution to a given problem. We study the effect of noise for a hardware in which bosonic modes mediate the interactions between qubits in the ultra-strong coupling regime. Additionally to the ground- state, the solution of the annealing problem can be obtained from the spin sector of many other states in these devices. Due to this redundancy, the excess of energy caused by a local error can be transferred to the bosonic modes so that the error is corrected. We will show numerical simulations for annealing in an Ising model in which the effects of noise is significantly suppressed thanks to this mechanism.



Magnetic-field-tuned superconducting quantum phase transition in underdoped cuprates

Dragana Popovic

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The effectively two-dimensional (2D) behavior of underdoped cuprates, together with the possibility to vary the degree of charge correlations and disorder, present an unequaled opportunity to explore the suppression of 2D superconductivity by the magnetic field, a fundamental problem even in conventional superconductors. This talk will describe the results of a comprehensive series of experiments using several complementary electrical transport techniques on underdoped La-214 and Bi-2201 cuprates. The nature of the field-tuned superconducting transition and the normal state will be discussed, including the roles of quantum phase fluctuations, disorder, as well as charge and spin orders. The results will be also compared to those in conventional 2D superconductors.

Acknowledgements: This work has been done in collaboration with Zhenzhong Shi, Paul G. Baity, and T. Sasagawa. It was supported by NSF Grants Nos. DMR-1307075 and DMR-1707785, and the National High Magnetic Field Laboratory (NHMFL) through the NSF Cooperative Agreements Nos. DMR-1157490, DMR-1644779, and the State of Florida.

Unconventional Many-Body Localization in Long-Range Quantum Spin Glasses

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Spin glasses are a well-studied class of classical systems where random interactions lead to spin freezing at low temperatures. On the other hand, many-body localization is a quantum phenomenon where randomness and interactions lead to localization characterized by, amongst others, area law entanglement entropy and local integrals of motion. We show that a third, intermediate, state can emerge in a long-range one-dimensional spin glass under the application of a transverse field. At small applied fields and low temperatures the spin glass order remains, as characterized by the Edwards-Anderson order parameter. However, interacting low-energy spin resonances at large distances create unconventional long-range entanglement in eigenstates. The quench dynamics therefore display a wide variety in possible results: while some spins remain frozen, others 'thaw'. The "quantum spin glass" is therefore neither ergodic, nor many-body localized.

Controlled Surface Terahertz Plasmonics in Layered Superconductors

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Layered superconductors are periodic materials, in which thin superconducting layers are separated by the thicker insulator ones and are electrodynamically related to each other by means of intrinsic Josephson effect. Experimental confirmation of such model can be found in [1]. High-temperature superconductors based on Bi, La or Y with CuO_2 superconducting layers belong to this family of materials. The essential property of layered superconductors is the considerable anisotropy of their current-carrying capability. The current along the layers is of the same nature as in bulk superconductors, while the current across the layers is due to the Josephson effect. This anisotropic Josephson solid state plasma supports propagation of the specific excitations in layered superconductors, the Josephson plasma waves. These waves belong to terahertz frequency range, which makes such structures interesting for terahertz electronics (see, e.g., [2]). Also, the studying of interaction of strong terahertz pulses with layered superconductors (see, e.g., [3, 4]) may reveal new possibilities for high-temperature superconductive state control.

In this work, we study theoretically the effect of the external DC magnetic field on the Josephson plasma modes localized on a slab of layered superconductor sandwiched between two dielectric half-spaces (see Fig. 1). We derive and analyze the dispersion relations for the localized modes and demonstrate that the dispersion is anomalous in a wide range of the parameters. Moreover, it can be flexibly controlled by the DC magnetic field. We discuss some possible related phenomena, in particular, internal reflection of the localized plasma mode forced by inhomogeneity of the external DC magnetic field.

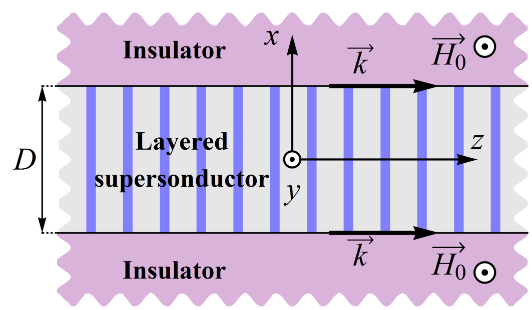

Figure 1: Sketch of the setup, where D is the thickness of the sample, $\vec{H}_0$ is the external DC magnetic field, $\vec{k}$ is the wave vector.

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Quantum fluctuations near a superconductor-insulator transition probed by Nernst effect

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Despite being intensively studied for the last three decades, the superconductor-insulator transition still has many unresolved questions. In particular, there is no common understanding as to which universality class best describes this transition and how it depends on its specific realizations (eg. in different materials or with different tuning parameters). Historically, the Bose-Hubbard model has been the cornerstone in the theoretical understanding of the SIT, which predicts $\nu \geq 1$ for a generic 2D SIT or $\nu = 2/3$ in the clean granular limit. But experiment reveals a much wider range of values as low as 0.4, clearly providing scope for further study.

At any quantum phase transition, the critical behaviour is generated by quantum fluctuations between the competing ground states. In the case of superconductors, the transverse Peltier effect (Nernst effect) provides a unique tool for probing quantum fluctuations of this emergent superconducting phase. This is because the electric signal generated by superconducting fluctuations (such as vortices) is by nature transverse to the direction of motion. This makes it advantageous over other probes like resistivity which has contributions from the quasiparticle channel.

Here, we use the Nernst effect to study the disorder-tuned SIT in amorphous Indium oxide. Earlier experiments had found a superconducting gap in the insulating phase of this SIT, as well as a pseudogap-like region on the superconducting side. In an experiment which is the first of its kind, we find pronounced Nernst effect on the insulating side of the SIT which originates from superconducting fluctuations. The dependence of the Nernst coefficient on disorder is in good qualitative agreement with a theoretical model developed for Josephson-coupled superconducting chains. By a scaling analysis of the underlying thermodynamic variable, the off diagonal Peltier coefficient α_{xy}, we find, surprisingly, $\nu \approx 0.7$ and $z \approx 1$, very close to the values $\nu = 2/3$, $z = 1$ of the (2+1)D-XY model (the clean limit). This is one more observation that proves that the SIT is still far from fully understood.

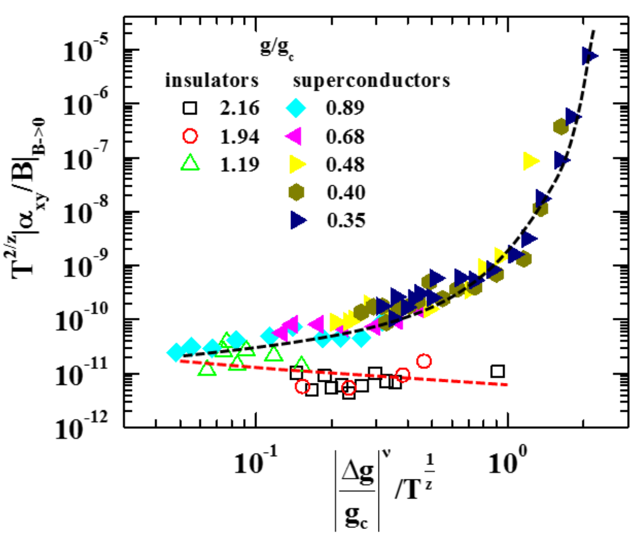

Fig 1: Scaling plot of the off-diagonal Peltier coefficient α_{xy}

[1] A. Roy, E. Shimshoni and A. Frydman, Phys. Rev. Lett. **121**, 047003 (2018).
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Low-temperature anomaly in disordered superconductors near B_{c2}

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Strongly disordered superconductors in a magnetic field display many characteristic properties of type-II superconductivity – except at low temperatures where an anomalous linear T-dependence of the resistive critical field B_{c2} is routinely observed. This behavior violates the conventional theory of superconductivity, and its origin remains a long-standing puzzle. In this talk I will present systematic measurements of the critical magnetic field and current on disordered superconducting films of various levels of disorder. Surprisingly, our measurements show that the B_{c2} anomaly near zero-temperature is accompanied by a clear mean-field like scaling behavior of the critical current. Our experimental findings together with theoretical considerations on the inherent vortex-glass state and its thermal fluctuations enable to explain the linear-T anomaly to occur in films as well as bulk superconductors with a slope that depends on the normal-state sheet resistance, in full agreement with the data.

Study of TTLSs and mitigation of their deleterious effects in superconducting circuits

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The generic existence of structural tunneling two-level systems (TTLS) in amorphous solids was postulated by the "Standard Tunneling Model" to explain the remarkable low temperature universality known by now to exist across the different classes of disordered solids. Being ubiquitous at low energies, TTLS dominate low energy noise, and as such restrict performance of quantum nanodvices including superconducting qubits, nanomechanical oscillators and photon detectors. Recently, the coupling of TTLS to superconducting qubits has facilitated experimental studies which provide novel insights regarding the nature of TTLS and their formation of a quantum glass [1,2]. These studies provide support to a recently suggested "Two-TTLS" model classifying TTLS by their spatial inversion symmetry properties into TTLS which interact weakly and strongly with the phonon field and consequently among themselves [3]. In this talk we will discuss the Two-TTLS model, its relation to quantitative universality, and the manifestation of its glassy dynamics in recent nonequilibrium experiments. In addition we will discuss a novel suggestion for the enhancement of qubits' relaxation and coherence times via the application of periodic bias to the TTLSs [4].

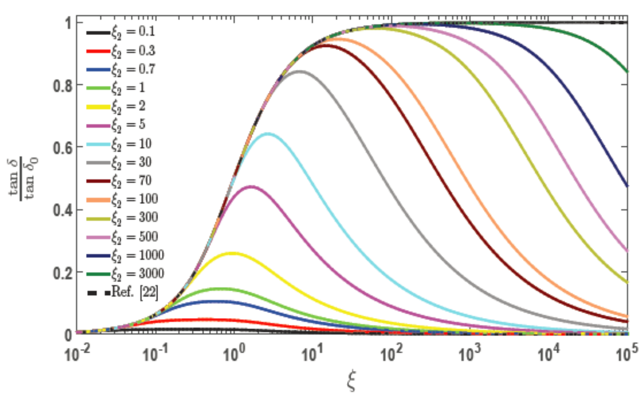

Fig 1: Theoretical results for the loss tangent of a superconducting microresonator as function of a dimensionless bias sweep rate. At low sweep rates the TTLSs are saturated by the resonator's field. Intermediate sweep rates desaturate the TTLSs and enhance loss. At high sweep rates the TTLSs decouple from the resonator, a result of multiple coherent Landau-Zener-Stueckelberg transitions [4].

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Spin-correlation mechanism of magnetoresistance in organic semiconductors

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Strong magnetic field dependence of resistivity and luminescence of various organic semiconductors with hopping transport was first observed experimentally in 2003 [1]. The magnetoresistance up to 10% was measures in magnetic field $\sim 10mT$ at room temperature. The phenomenon was named the organic magnetoresistance or OMAR. The qualitative description of OMAR [2] suggests that it appears due to the suppression of spin relaxation by the magnetic field. It should be stressed however that at room temperature and magnetic field $\sim 10mT$ there is practically no spin polarization of charge carriers. Therefore it is not obvious a priori why the rate of spin relaxation affects conductivity. It was shown in the recent paper [3] that OMAR is related to the non-equilibrium correlations. The spin correlations appear in the system with current and are important for transport. The magnetic field affects the rate of relaxation of these spin correlations.

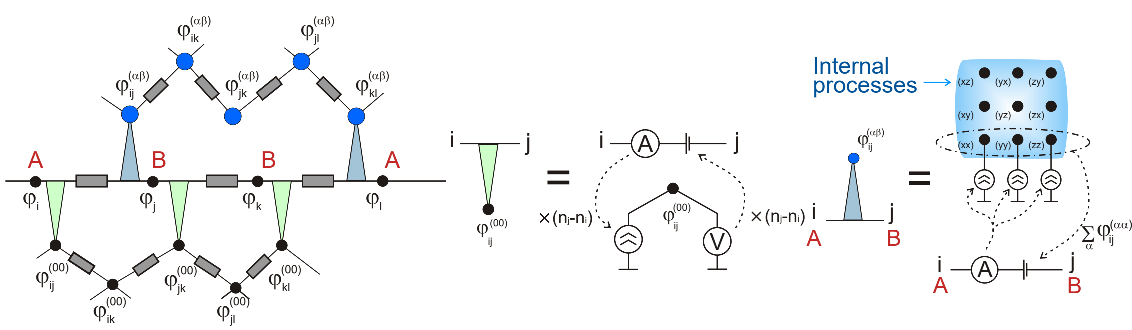

Figure 1: Equivalent circuit that includes four hopping sites and pair charge and spin correlations.

It is shown in the present talk that both charge and spin correlations can be included into the theory of hopping transport as the generalization of Mean-Field equations and Miller-Abrahams resistance network. The correlations are treated as additional nodes of the equivalent electric circuite that generalizes the Miller-Abrahams network. This approach can be used to describe non-equilibrium correlation effects in hopping transport including the organic magnetoresistance.

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Hopping in 2D array of tunnel-coupled quantum dots

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Self-organizing growth techniques that includes a carefully controlled strained layer epitaxy at low (300°C) temperature allows the formation of high density array of Ge/Si quantum dots (QDs) with nanometer dimensions and homogeneous size distribution. The areal density of nanoclusters is large enough for the charge transport through such a system at low temperatures being dominated by hole hopping between dots. This system is characterized by large localization radius of carriers and wide range of possible conductance magnitudes. Thus, changing of QDs doping and structural parameters of QDs, we observed the transition from strong localization regime to diffusive transport. The behavior of magnetoresistance (MR) is similar for samples in both regimes, it is negative in weak fields and becomes positive with increasing of magnetic field. Negative MR can be described in a frame of weak-localization approach with suggestion that quantum interference contribution to the conductance is restricted not only by the phase breaking length but also by the localization length. Hall effect was registered against a MR background both in high- and low- conductance cases. Hall coefficient in hopping regime shows non-monotonic dependence on QD filling factor and correlates with the similar behavior of localization radius. It was shown that the optimal triad model fails to describe the numerical results and experimental observed Hall effect data. It is related to the extremely small probability to find the optimal triad of sites in the percolation cluster in the variable-range-hopping (VRH) regime. We described the Hall mobility in the VRH regime with the empirical law obtained from the numerical results.
The QD system is characterized by anomalous slow relaxation of photoconductance (PC) that is accompanied by the persistent photoconduction, whereby the PC value was not restored on the initial level even after relaxation for several hours. The sign of the PC can either be positive or negative, depending on the initial filling of QDs with holes. The magnetic field effect on the PC relaxation depends on the filling factors ν of dots with holes and value of localization radius. For $\nu<2$ and localization radius smaller than magnetic length we observe the change of relaxation rate from slowing down to acceleration. The results were explained by different influence of the magnetic field on double-occupied and triple-occupied states, which contribution can be changed in the process of conductance relaxation.

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Transport and magnetic properties of granulated SiC_xN_y:Fe films

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The development of a new field of modern electronics, namely spintronics, requires the creation of new materials possessing combined properties of a ferromagnetic material and semiconductor. The problem is connected with a central obstacle for spin injection into semiconductors, a conductance mismatch between ferromagnetic metals (used for the spin injection) and semiconductor channels. The new material, iron-doped silicon carbonitride ($SiC_xN_y:Fe$), proposed in this work, provides an opportunity to tune the magnetic and transport properties in a wide range. The $SiC_xN_y:Fe$ films were synthesized using a CVD technique on high resistance Si(001) substrates by the thermal decomposition of two different gaseous mixtures (I and II types of structure). A series of $SiC_xN_y:Fe$ structures prepared at different temperatures with a variation of Fe concentration and the initial gaseous mixture composition was studied to solve the problem of the film synthesis with a possibility to change the conductivity in a wide range. It was shown that the variation of the Fe amount results in strong changing of the conductivity, up to 8 orders of magnitude at helium temperature. Analysis of the temperature dependence of conductivity have shown that increase of the iron content leads to the transition from hopping conductance to the diffusive transport. Variation of the deposition temperature and the gaseous mixture composition does not affect the conductivity. According to HRTEM study in the I type structures Fe is concentrated in large granules (~30 nm) homogeneously distributed in the matrix and in small nanoclusters (5-10 nm) between them. Large granules consist of several α-Fe clusters with different crystallographic orientations. In the II type of samples Fe is also present as α-Fe clusters, but with a much smaller size (~10 nm). The crystallographic axis [100], which corresponds to the easy magnetization axis for Fe nanocrystals, is oriented perpendicular to the substrate plane for the main part of Fe nanoparticles in these samples. Zero-field cooling curve obtained for II type samples shows a monotonic decrease of magnetization with temperature increase (without any peak) in the range 5-300 K. It means that Fe nanoparticles form the single-magnetic-domain with blocking temperature T_B larger than 300 K. Such type of structure is characterized by the large saturation magnetization, an existence of the hysteresis loop up to 300 K and collective FMR signal. In the I type of structure, a wide size dispersion and different crystallographic orientations of α-Fe clusters composing the large Fe granules causes a worsening of magnetic properties. Such type of samples is characterized by T_B=20 K and demonstrates a few times smaller saturation magnetization. Their ESR spectra contain many ESR lines with sharp asymmetrical shapes and different line widths, that we attributed to Fe nanoparticles of different sizes distributed randomly in the amorphous matrix.

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Integrable time-dependent Hamiltonians

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In the emerging field of coherent many-body dynamics, we seek to understand the behavior of an isolated quantum many-body system driven far from equilibrium by changing its Hamiltonian in time. In this talk, I will identify a general class of many-body and matrix Hamiltonians for which this problem is exactly solvable. In particular, I will outline a way to make the parameters (e.g., the interaction strength) of certain quantum integrable models time-dependent without breaking their integrability.

Interesting many-body models that emerge from this approach include a superconductor with the interaction strength inversely proportional to time, a Floquet BCS superconductor, and the problem of molecular production in an atomic Fermi gas swept through a Feshbach resonance as well as various models of multi-level Landau-Zener tunneling. I will solve the non-stationary Schrodinger equation exactly for all these models and discuss some interesting physics that emerges at large times.