TIDS 15

15th International Conference on

Transport in Interacting Disordered Systems

September 1-5, 2013

Eden Roc Hotel

Sant Feliu de Guíxols (Girona)

Book of abstracts

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1. General information

Conference scope

The conference is a continuation of the biennial meeting traditionally called HRP (Hopping and Related Phenomena) and now named TIDS. Previous conferences took place in Trieste (1985), Bratislava (1987), Chapel Hill (1989), Marburg (1991), Glasgow (1993), Jerusalem (1995), Rackeve (1997), Murcia (1999), Shefayim (2001), Trieste (2003), Egmond aan Zee (2005), Marburg (2007), Rackeve (2009), and Acre (2011). Central to these conferences are systems lacking translational symmetry. In such systems interactions are often important. Dramatic differences in the behavior of crystalline solids and the "disordered" systems are possible. Some examples of the latter are amorphous materials, polymer aggregates, materials whose properties are governed by impurities, and biological systems.

Specific topics of TIDS15 include: Hopping transport; Electron glasses and relation to other glassy systems; Anderson localization and many-body localization; Quantum glasses; Metal-insulator and superconductor-insulator transitions; Transport in nanoparticle assemblies; Disorder and interaction in cold atoms; Topological insulators; Transport in biological systems. The proceedings of TIDS15 will be published online in *AIP: Conference Proceedings*.

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2. Abstracts

The index reports only the presenters' names. For the list of coauthors of each presentation, see the corresponding abstract

Emergent percolation length and localization in random elastic networks

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We study, theoretically and numerically, a minimal model for phonons in a disordered system. For sufficient disorder, the vibrational modes of this classical system can become Anderson localized, yet this problem has received significantly less attention than its electronic counterpart. We find rich behavior in the localization properties of the phonons as a function of the density, frequency and the spatial dimension. We use a percolation analysis to argue for a Debye spectrum at low frequencies for dimensions higher than one, and for a localization/delocalization transition above two dimensions. We show that in contrast to the behavior in electronic systems, the transition exists for arbitrarily large disorder, albeit with an exponentially small critical frequency. The structure of the modes reflects a divergent percolation length that arises from the disorder in the springs without being explicitly present in the definition of our model. Within the percolation approach we calculate the speed-of-sound of the delocalized modes (phonons), which we corroborate with numerics. We find the critical frequency of the localization transition at a given density, and find good agreement of these predictions with numerics results using a recursive Green function method adapted for this problem. The connection of our results to recent experiments on amorphous solids are discussed.

Chaos and transport in disordered classical nonlinear chains

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The subject of this study is the long-time equilibration dynamics of a strongly disordered one-dimensional chain of coupled weakly anharmonic classical oscillators – a classical system whose quantum bosonic counterpart would exhibit many-body localization [1]. This is one of the simplest systems where the interplay between the Anderson localization and a classical nonlinearity can be studied. It is shown that in the regime of strong disorder and weak nonlinearity (the worst conditions for transport) the system has chaotic behavior. Chaos turns out to be concentrated on rare local segments of the chain [2, 3, 4]. Chaos allows the system to thermalize and provides a mechanism for the transport of conserved quantities [3].

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Signatures of glassy physics near the superconductor-insulator transition

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In the last few years there has been a resurgence of interest in the superconductor-insulator transition (SIT) induced by strong disorder in conventional superconductors[1]. Indeed, the improvement of the experimental techniques, as e.g. scanning tunneling microscopy, offered a new perspective on the characteristics of the superconducting state near the SIT. A typical example is provided by the spontaneous emergence of spatial inhomogeneity of the local density-of-state on nanometer scales, with a persistence of gap-like features even above the critical temperature (the so-called pseudogap)[2]. These findings stimulated a new theoretical investigation on some long-standing issues, as e.g. the validity of the "bosonic" vs "fermionic" picture of the SIT, and on new ones, as the emergence of a "glassy"-like behavior of the system, suggested by recent results obtained with the cavity approach for the Ising model in transverse random field,[3] a prototypical bosonic model for the SIT. In this talk I will try to make a short overview of the experimental and theoretical state-of-the art in this field, and I will discuss some recent results we obtained within a typical fermionic description of the SIT,[4,5] i.e. the attractive Hubbard model with on-site disorder. More specifically, I will show that by disorder triggers an unusual phase-fluctuations contribution to the transport response function, with a resulting glassy-like behavior. These effects, that require to use an approximation beyond the standard dirty-BCS approach, have direct consequences on measurable quantities like the superfluid density and the optical conductivity. These outcomes offer a new perspective on recent experimental results on disordered superconductors,[6–8] that are only partly theoretically understood.

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Quantum phases of interacting bosons in a 1D quasiperiodic lattice

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The interplay of disorder and interactions can have a large impact on the properties of quantum systems. It is well known that, whereas non-interacting particles can be localized by the destructive interference in a disordered potential, a weak repulsive interaction tends to establish coherence between single-particle localized states, thus weakening or destroying such localization. The interplay of disorder and strong interactions is instead still a challenging problem. One paradigmatic problem is that of low-temperature bosonic particles confined to a one-dimensional disordered environment, which, in addition to the standard superfluid and Mott phases, has been predicted to show a peculiar gapless insulating phase, the Bose glass [3, 4], that is still proving to be elusive in experiments.

We investigate the behavior of an ultracold bosonic quantum gas confined in a one-dimensional quasi-periodic lattice, where interactions and disorder can be independently tuned. By studying its momentum distribution, mobility and excitation spectrum features, we trace out a phase diagram showing a coherent phase surrounded by a gapless insulator. The latter has a bosonic character at low interactions, and a fermionic one at large interactions, consistent with the expectations for the presence of a Bose glass phase. Our results confirm long-standing theoretical predictions and indicate the way to study still open questions in 1D bosons and analogous disordered problems in higher dimensions and/or with fermions.

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Photoconductivity of ordered nanocrystals array

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We have proposed a theory of the photoconductivity of an ordered super crystal consisting of charged nanocrystals (NCs) instead of atoms. Such systems are extensively created and studied because of their unique photovoltaic and light emitted properties. Proposed mechanism explains a large differences in the mobilities of "quasi-localized" in NCs and "quasi-free" carriers, whose energy is above the localization energy of the NCs. This difference is due to the sharp decrease of the overlap of of wave functions of the neighboring NCs with increasing their energy. The combination of an interband photons and the Auger recombination transfers very efficiently a "quasi-localized" electrons into the "quasi-free" state resulting in a significant increase of the transport mobility. Important is that due to the narrow band of the quasi-localized electrons the Auger recombination is almost as strong as it is in a single NC. Thus it becomes an effective mechanism of production quasi-free carriers. We have developed a theory of both dark conductivity and photoconductivity for an almost periodic 3-dimensional array of NCs. In our model, the transport scattering time is controlled by a small random difference in the positions of the neighboring NCs. This difference might be of the order of 10%. For a typical set of parameters, our calculations show that the mobility of quasi-free carriers can be a few orders of magnitude larger than the mobility of equilibrium carriers. The properties of the Auger recombination explain also experimentally observed nonlinear light intensity dependence of the photoconductivity.

Temperature dependent memory in electron glasses

Aviad Frydman

Bar Ilan University

Discontinuous metal films exhibit slow conductance relaxation to equilibrium and memory effects similar to other electron glasses. However the temperature dependence of the dynamics is very different than that of systems studied in the past. I will present results on various discontinuous films (Au, Ni, Ag and Al) prepared at different temperatures in the range 10-300K. Among other features these systems demonstrate a crossover from classic to quantum glassy behavior and selective memory with regards to temperature. The significance of the results will be discussed.

Dirty bosons and cold atomic gases

Thierry Giamarchi
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The interplay between disorder and interactions is one of the most fascinating phenomena in quantum many body physics. This competition is particularly strong when dealing with one dimensional bosons. Indeed bosons tends to be superfluid, which is a phase which naturally resists disorder while disorder tends to lead to localization. Such a competition leads to a transition between a superfluid phase and a Bose glass phase. This transition has been investigated in the context of cold atomic gases. One particularly interesting realization uses not a truly disordered potential but a quasi-periodic one. I will discuss the physics of both these systems, their phase diagram and similarities and differences, as well as the consequences for their transport and expansion properties. I will compare the theoretical predictions with experiments done in the context of cold atomic gases.

Transport in nanocrystal solids and applications to infrared detection

Philippe Guyot-Sionnest

University of Chicago

Granular conducting systems were extensively studied from the 1960s to the 1980s, as physical realizations of disordered semiconductor, superconducting or metallic systems. Nowadays monodispersed colloidal nanoparticles can be synthesized with tunable optical and electronic properties. Many applications of these colloids involve films and their electrical transport, and understanding the physics of transport is of current and practical interest. With monodispersed Pb nanoparticles, we measured the insulating to superconducting transitions as the coupling between the particles increased. With CdSe semiconductor quantum dots, the systems studied displayed the variable range hopping models developed decades earlier by Efros, Shklovskii and Mott. We also found large 1/f electrical noise in monodispersed nanoparticle solids, Pb, Au, CdSe, therefore raising another difficult but practical question which is particularly relevant for infrared detection applications with HgTe quantum dots.

Efros-Shklovskii Variable Range Hopping in Reduced Graphene Oxide Sheets

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A solution processed route for producing reduced graphene oxide (RGO) sheets, which have a wide range of oxygen functionalities such as hydroxyl and epoxy groups, received great attention due to its (i) high throughput manufacturing, (ii) tunable electrical and optical properties via controlling the ratio of sp^2 C-C and sp^3 hybridized carbon (i.e., oxygen functional groups), and (iii) ability to anchor different types of nanoparticles and organic molecules, which pave the way for potential applications in flexible electronics, photovoltaics, supercapacitors, and batteries. [1] Functionalization of graphene creates disorders and the low-temperature electronic transport properties of these structures are akin to that of disordered semiconductors where electron localization and hopping conduction play a significant role. However, a clear understanding of the electronic transport properties of the RGO sheets is lacking as different studies report different conduction mechanisms such as Mott variable-range hopping (VRH) and Efros-Shklovskii (ES-) VRH. In this talk, we will present the detailed electronic transport properties of RGO sheets. At very low temperature (down to 4.2 K) we observe Coulomb blockade (CB) and ES-VRH, $R\sim exp[(T_{ES}/T)^{1/2}]$, implying that RGO can be considered as a graphene quantum dots array (GQD), where graphene domains act like QDs while oxidized domains behave like tunnel barriers between QDs (Fig. 1). [2]

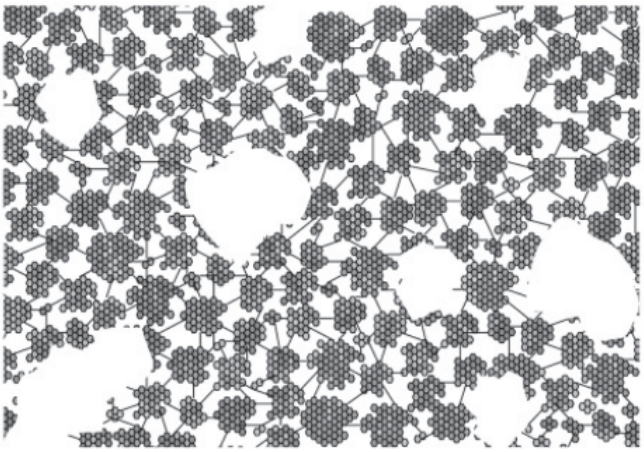

FIG.1: Schematic of RGO as GQD array. The light gray areas represent GQDs, the white regions represent oxidized carbon groups and topological defects. The lines between GQDs represent tunnel barriers. [2]

This was further confirmed by studying RGO sheets of varying carbon sp^2 fraction from 55-80%. T_{ES} was decreased from 3.1×10^4 to 0.42×10^4 K and electron localization length increasing from 0.46 to 3.21 nm with increasing sp^2 fraction (Fig.2). [3] From the localization length and using confinement effect, we estimate tunable band gap of RGO sheets with varying carbon sp^2 fraction. With the localization length, we calculate a bandgap variation of our RGO from 1.43 to 0.21 eV with increasing sp^2 fraction from 55 to 80 % which agrees remarkably well with theoretical prediction.

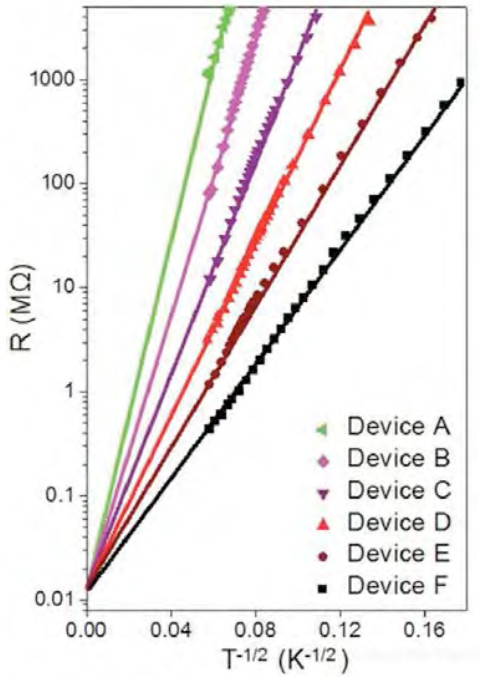

FIG.2: Semi-logarithmic-scale plot of R versus $T^{-1/2}$ for all RGO devices. The symbols are the experimental points and the solid lines are a fit to $T^{-1/2}$ behavior. Devices A, B, C, D, E and F denoted for carbon sp^2 fractions of 55, 61, 63, 66, 70 and 80 %. [3]

We also show that, in the high bias non-Ohmic regime at low temperature, the hopping is field driven and the data follow $R \sim exp[(E_0/E)^{1/2}]$ providing further evidence of ES-VRH. From our data, we predict that for the temperature range used in our study, Mott-VRH may not be observed even at 100 % sp^2 fraction samples due to residual topological defects and structural disorders.

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Competing tunnelling and capacitive channels in granular insulating thin films: universal response

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Granular magnetic solids, in which a distribution of nanometer single domain ferromagnetic (FM) metallic particles is randomly embedded in an insulating nonmagnetic matrix, comprise a very active research topic because their properties have promising technological applications and involve fundamental issues that could be relevant to get a full understanding of electric transport in disordered dielectric materials (DDM). In addition, film preparation techniques currently available provide granular systems with a well-controlled nanostructure, where the interparticle transport processes and magnetic behavior can be studied with good reproducibility. In particular, dc conduction for FM contents below the percolation threshold (dielectric regime) has been widely investigated in these systems at low electrical fields and a general understanding in terms of thermally-assisted tunneling has been gained. In this respect, we have shown that thin films composed of Co nanoparticles dispersed in a ZrO_2 insulating matrix (chosen as a model system because of the low degree of metal-oxide interdiffusion) exhibit tunneling magnetoresistance (TMR) that correlates well with the magnetization measurements [1]. TMR shows an abrupt enhancement at low temperatures because of co-tunneling processes involving several small particles present in the system due to a bi-modal size distribution [2]. Consequently, those thin films are of interest since they offer the opportunity to study the ac electric transport in a disordered granular medium where interparticle tunneling is non-negligible, in contrast with the majority of the previous works in DDM. We have shown that in the dielectric regime those granular films display a complex low frequency absorption phenomenon mimicking the so-called universal response of DDM, which is featured by the development of a peak in the dielectric loss that can be thought as an imaginary contribution to the capacitance [2, 3]. This dispersive behavior takes place at a frequency range where the interparticle tunneling and capacitive admittances become comparable in magnitude, giving rise to an intricate network of both intertwined conduction channels throughout the system. The temperature and frequency determine the complexity and nature of the actual ac electrical channels, which have been successfully modeled by a random R-C network enabling to get insights in the microscopic electric parameters of the problem [2, 3]. Interestingly, the ac conductance shows fractional power-law dependences on the frequency originating from two dispersive regions at low temperatures [3]. The first one is associated with the competition between interparticle tunneling and capacitive channels among large particles further apart so as not contributing to the tunneling processes. The second dispersive region is related to the additional contribution of the capacitance between smaller particles shortcutting tunneling channels.

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The ideal quantum glass transition: many-body localization without quenched disorder

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We explore the possibility and the conditions under which translationally invariant quantum many body systems undergo a genuine glass transition, at which ergodicity and translational invariance break down spontaneously. In contrast to analogous classical systems, where the existence of such an ideal glass transition remains a controversial question, a genuine phase transition is predicted in the quantum regime. This ideal quantum glass transition can be regarded as a many body localization transition due to self-generated disorder. The latter will be presented in the light of recent progress in the understanding of many body localization.

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Numerical simulations of electron glasses with logarithmic interactions

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We study hopping transport in two-dimensional arrays of random capacitors. The charge at each node is a sum of the charges located at the capacitor plates connected to this node. The interaction between charges depends logarithmically on the distance between them. The density of the energy states is roughly exponential, and can be explained in terms of a self-consistent theory. We investigate the temperature dependence of hopping conductivity and reveal the cusp characteristic to the Berezinskii-Kosterlitz-Thouless (BKT) transition. As the temperature decreases, the BKT behavior transforms into the Arrhenius dependence with the characteristic energy being proportional to the logarithm of the system size. We analyze the spatial distribution of the current as a function of temperature.

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IMPLICATIONS OF ELECTRON-GLASS EXPERIMENTS TO VRH TRANSPORT

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Abstract: In this talk some of the unique properties of Electron-Glasses are used to gain information on the fundamental nature of the (Coulomb interacting) Anderson-localized phase. Applying ac fields on hopping systems at low temperatures enhances the conductance via a non-ohmic effect, which does not necessarily involves heating. The experiments suggest that the electronic energy spectrum of the system remains discrete even for realistic electron-electron interaction. Therefore, electron thermalization at low temperatures hinges on the existence of a continuous bath (presumably, phonons). Implications of these results to the issue of many-body-localization and the long-standing mystery of the pre-exponential term of hopping conductivity will be discussed.
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Hopping transport and the "Coulomb gap triptych" in arrays of metallic and superconducting grains

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(Dated: April 10, 2013)

Granular metals and granular superconductors are interesting composite systems, in which the unique properties of quantum dots are combined with collective, correlation-driven effects between grains to produce novel material properties. This interplay is particularly evident in the conductivity, which in the heavily insulating limit proceeds by hopping of electrons between isolated grains. In this talk I discuss a model of hopping conductivity in insulating arrays of metal or superconductor grains. Using a simple computer simulation, we identify novel features of the single-particle density of states in these systems, including the appearance of repeated Coulomb gaps, which together form a structure that we call the "Coulomb gap triptych." This structure represents a synthesis of Coulomb blockade and Coulomb gap physics. We also study the conductivity as a function of temperature and show how Efros-Shklovskii variable range hopping assumes a dominant role regardless of the disorder amplitude. For arrays of superconducting grains, we discuss the dependence of the conductivity on the strength of the superconducting gap, and identify an unusual $\sqrt{2}$ effective charge that characterizes the hopping transport at a particular value of the gap.

J.Tejada

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From quantum magnetic relaxation to ressonant spin tunneling and related phenomena.

In my talk I will review the work done in the field of quantum nanomagnetism in the last three decades. I will start explaining the magnetic relaxation when the metastability is associated to the existence of a broad distribution of energy barriers, both anisotropy barriers and those associated to pinning centers. Then I will discuss the case of molecular magnets as the best example when existing a single barrier height for all the magnetic units and the discovery of ressonant spin tunneling [1]. I will finish discussing some of the most important related phenomena in this field like the experimental detection of the so called magnetic deflagration [2-4] and its posible quasi universal presence when metastable states are present in solid state materials and the emission of coherent electromagnetic radiation, superradiance, in the demagnetization process of molecular magnets [5]. I will also comment on the very recent experiments on quantum depinning of the magnetic core in 2d magnetic vortices [6] and the interfases between normal and superconductor zones in type I superconductors [7].

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Slow dynamics in the bacterial chemosensory receptor arrays

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Sensory receptors are transmembrane proteins that span both sides of the cell membrane and serve as mechanical relays. These molecules physically communicate external chemical signals into the cell where they control the activity of associated enzymes. In several cases, both in bacteria and in humans, interactions between sensory receptors and clustering play an essential role in signal transduction.

The bacterial chemosensory cluster contains thousands of receptors organized in a two-dimensional array. While the basic hexagonal structure of these large arrays is now becoming clear, their dynamics and operation are not yet understood. By measuring the fluorescence-polarization of tagged receptor-clusters in live *E. coli* cells, we show that prolonged stimulus induce slow physical changes in the packing of the receptors in the arrays, which seems to alter the functional coupling between the receptors and thus leading to non-stationary signal transduction.

On a connection between Jamming and Coulomb Glasses

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In glassy materials equilibrium thermodynamics does not apply. To describe the physical properties of these systems, one must understand the ensemble of configurations in which they lie. To do so requires a priori some understanding of the dynamics, together with the knowledge of how the system under consideration was prepared. A simplifying principle bypassing this program assumes that the configurations visited by the dynamics are barely stable toward some specific excitations. In the context of Coulomb glasses this idea led to the prediction of a Coulomb gap, with important consequences for transport. Here we report that an analogous principle of marginal stability applies [1] to simple models of amorphous solids, in particular to random packings of hard particles. In this analogy elasticity plays the role of the long-range Coulomb interaction, and the relevant excitations correspond to local changes of the contact network between particles, instead of the displacement of one electron. Stability of these excitations leads to a bound between the pair and the force distributions, that plays the role of the bound on the density of states in Coulomb glasses.

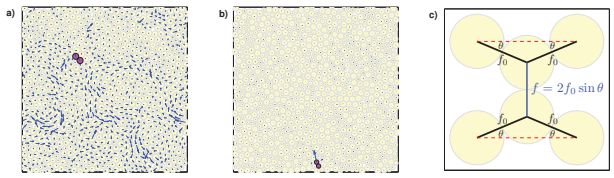

FIG. 1. Left: extended excitation leading to the opening of a contact between particles, and the formation of a new contact elsewhere. Center: Localized excitation. Both type of excitations -extended and localized- are found to be marginal in packings, leading thus to two bounds on the packing structures. Right: A simple sketch of a local rearrangement.

We predict in particular two bounds between three exponents characterizing the structure of packings, and show numerically that these bounds are saturated [2]. In these simple amorphous solids we argue that marginal stability is associated to the presence of avalanches of plasticity, with power-law distribution. We argue that the excitations we identified also play a key role in the rheology of the fluid phase, i.e. granular flows. In recent years, such flows have been studied in great detail empirically, supporting that they correspond to a new kind of dynamical critical phenomena, which is not understood theoretically. Our approach leads to a new handle to this problem, and raise the hope that the concepts developed in the field of dirty semi-conductors may apply to granular systems and structural glasses.

Note: such a talk would require to introduce the audience to the field of granular flows and jamming, which may not be very familiar to them, and then to develop the analogy of these systems with coulomb glasses. I don't think this is doable on 20 minutes. If the talk can be lengthen somewhat it is great, otherwise I would rather present this work to this community at another occasion.

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Disorder effects in 2D ferromagnetic semiconductor structures: GaAs/InGaAs/GaAs quantum well with remote Mn delta-layer

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We report the observation of anomalous, normal and quantum Hall effect in the same structure with rising external magnetic field. Anomalous Hall effect is the main contribution up to ≈ 2 T, then up to 8 T the Hall voltage is determined by the normal Hall effect and at higher magnetic fields the quantum Hall effect with the ν = 1 plateau at fields above 16 T takes place. Quantum Hall effect observation witnesses the 2D character of holes conductivity in the quantum well under ferromagnetic state of the structure. The ferromagnetic behavior is proved by anomalous contribution to the Hall effect as well as by direct magnetization [1] and polarization of electro- and photoluminescence [2] measurements. We discuss the anomalies in the temperature dependence of resistivity and noise in both metallic and insulating samples and interpret them as evidence for significant ferromagnetic correlations. The insulating samples are particularly interesting as they provide valuable clues to the nature of ferromagnetism in these structures [1].

We show how the interplay of disorder and nonlinear screening leads at low carrier densities to the formation of the nanoscale hole droplets in the transport layer. We find that in this droplet phase, ferromagnetic correlations result in anomalies in the resistivity at temperatures below the Curie temperature, and even in the absence of long-range ferromagnetic order. This is to be contrasted with bulk Mn-doped semiconductors where resistivity anomalies are expected above and near to the Curie temperature, and are associated with a ferromagnetic phase transition.

The ferromagnetic correlations also affect the resistivity noise directly through their effect on the fluctuations of relative orientations of the magnetization at the droplets and indirectly through their effect on the hole number fluctuations [3].

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How to Find Out the DOS in Disordered Organic Semiconductors

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We suggest a recipe on how to determine the density of states (DOS) in disordered organic semiconductors from the measured dependence of the charge carrier mobility on the concentration of carriers n. The recipe is based on a theory for the concentration-dependent mobility [1]. The essence of the theory is the observation that the exponential feature of the Fermi function makes physics qualitatively different for exponential and weaker energy-dependent DOS, on the one hand, and a steeper than exponential DOS, on the other hand.

As an example, we apply our theoretical results to experimental data obtained on two polymers [2] and show that from the class of trial DOS functions $g(\varepsilon) \propto \exp\left[-(\varepsilon/\sigma)^p\right]$ only those with $p > 1.8$ can explain the experimental results. In particular, we claim that the concentration-independent mobility at low n evidences that the DOS cannot be purely exponential, which is in contrast to numerous recent assumptions in the literature.

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Universal scaling form of AC response in variable range hopping

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There are many examples of disordered solids that display a universal scaling form of the AC conductance [1]. This is seen if one considers the conductivity $\sigma(\omega)$ as function of frequency ω at different temperatures. It is found that the curves for different temperatures collapse on a single universal curve if scaled according to the following equation:

$$\frac{\sigma(\omega)}{\sigma(0)} = F\left(\frac{\omega}{T\sigma(0)}\right) \tag{1}$$

Several models displaying this behavior have been studied [1], including hopping models. However, electron-electron interaction was neglected and only in the regime of nearest neighbor hopping was considered. It is therefore interesting to see if an interacting system displaying variable range hopping (VRH) will possess the same universality property.

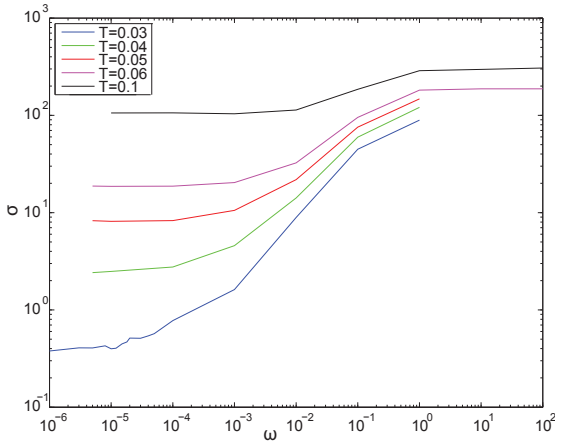

FIG. 1. The real part of the AC conductivity as a function of frequency for different temperatures.

We have studied the standard lattice model of hopping transport [2] using dynamical Monte Carlo simulations [3]. It is known that this model shows VRH DC conduction according to the Efros-Shklovskii law, $\sigma(0) \sim e^{-(T_0/T)^{1/2}}$, in a rather broad temperature range [3, 4]. We have simulated the response to an AC electric field as function of frequency for different temperatures in the VRH regime. The results are shown in Fig. 1. The general trend is the same at all temperatures: at low frequencies, the conductivity is frequency independent. At some frequency it will start to increase, and then saturate at high frequencies.

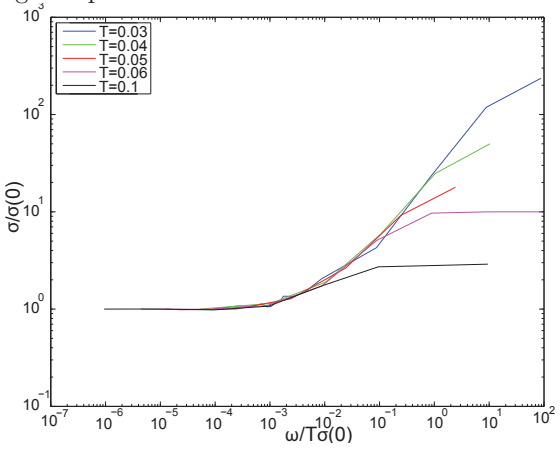

FIG. 2. The same data as in Fig. 1 rescaled according to Eq. (1).

To check the scaling form, Eq. (1), we replot the same data in Fig. 2, which shows $\sigma(\omega)/\sigma(0)$ as function of $\omega/T\sigma(0)$.

As can be seen, the curves fall on a common universal curve up to the point where they show a trend to saturation, $\omega \lesssim (10^{-2} - 10^{-1})T\sigma(0)$. Note that in this region the universal curve describes the values of $\sigma(\omega)$ differing by factor of ~ 300.

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Ergodicity breaking and wave function statistics in disordered interacting fermions

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We present the study of the breaking of ergodicity measured in terms of return probability in the evolution of 1d interacting fermions in a disordered potential. In the non ergodic phase a quantum state evolves in a much smaller fraction of the Hilbert space than would be allowed by the conservation of extensive observables. By the anomalous scaling of the participation ratios with system size we are led to consider the distribution of the wave function coefficients, a standard observable in modern studies of Anderson localization. The emergence of a power-law tail seems to be a fingerprint of the ergodicity breaking. The study of this exponent allows to introduce a criterion for the identification of the many-body localization transition which is quite robust and well suited for numerical investigations of a broad class of problems.

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Slow conductance relaxations and anomalous electrical field effect in a-NbSi thin films

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The number of disordered insulating systems in which out-of equilibrium electronic properties have been found is increasing as a function of time. It gathers now amorphous and crystalline indium oxide films, granular aluminium films, ultrathin and discontinuous films of metals. If some features are common to all these systems, like the existence of an anomalous electrical field effect, important differences are also observed. For example, a strong temperature dependence of the dynamics, not present in indium oxide or granular aluminium films, was recently highlighted in discontinuous films [1]. In order to understand the physical origin of the glassy features, it is of prime importance to determine what among the observed properties is universal and what is specific of a given system.

We will present for the first time the results obtained on insulating amorphous NbSi thin films. Such films can be either metallic or insulating, depending on their thickness and/or their Nb content. Interestingly enough, the insulating films display out-of equilibrium electronic features that are markedly different from what has been observed so far. Like in indium oxide and granular aluminium films, a slow relaxation of the conductance is observed after a quench to liquid helium. MOSFET devices reveal that this conductance relaxation comes with the growth of an anomalous electrical field effect. But unlike in indium oxide and granular aluminium films, the dynamics of the conductance relaxations depends strongly on the temperature and the anomalous electrical field effect is still visible up to room temperature. The possible physical meaning of these findings will also be discussed.

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Analytic model of hopping transport in organic semiconductors including both energetic disorder and polaronic contributions

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We developed an analytical model to describe hopping conductivity and mobility in organic semiconductors including both energetic disorder and polaronic contributions due to geometric relaxation. The model is based on a Marcus jump rate in terms of the small-polaron concept with a Gaussian energetic disorder, and it is premised upon a generalized Effective Medium approach (EMA) yet avoids shortcoming involved in the effective transport energy or percolation concepts. It is superior to our previous treatment [2, 3] since it is applicable at arbitrary polaron activation energy E_a with respect to the energy disorder parameter σ. It can be adapted to describe both charge-carrier mobility and triplet exciton diffusion. The model is compared with results from Monte-Carlo simulations. We show (i) that the activation energy of the thermally activated hopping transport can be decoupled into disorder and polaron contributions whose relative weight depend non-linearly on the σ/E_a ratio, and (ii) that the method of averaging over the transport path has a profound effect on the result of the EMA calculations of the Marcus hopping transport. The σ/E_a ratio governs also the carrier concentration dependence of the charge-carrier mobility in the large-carrier-concentration transport regime as realized in organic field-effect transistors. The carrier concentration dependence becomes considerably weaker when the polaron energy increases relative to the disorder energy, indicating the absence of universality that is at variance with earlier results [4]. The suggested model bridges a gap between disorder and polaron hopping concepts.

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Plasmon supported random lasing - Theory

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The enhancement of gain and consequently the decrease of the lasing threshold by the excitation of plasmons in metallic nano-structures has been observed experimentally in recent years [1]. Metal spheres or metal shell structures exhibit the formation of plasmons when the system is pumped.

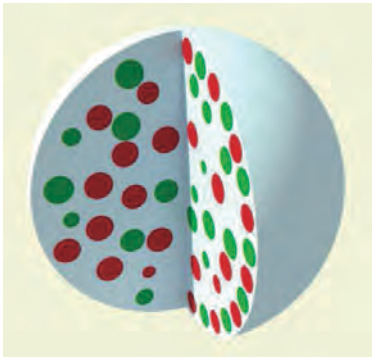

FIG. 1: Mix of dye molecules and plasmon enhancing metal nano-structures serve as low threshold random lasing setups. Mie resonances interact with pure enhancement effects of the dye material.

The plasmons yield field enhancement in the dye molecules close surrounding and inversion of the electronic level population within the dye. Previous theoretical considerations foot on evaluations of Mie theory of single spheres or single scattering simulations. Here we extend self-consistent localization theory [2, 4] using quantum-field diagrammatic methods which is self-consistently coupled to laser rate equations [3]. Metal coated spheres are included in different setups. We present transport and localization characteristics such as the diffusion coefficient, scattering and localization mean free paths as well as lasing thresholds [5] for different system parameters. Self-consistent enhancement as well as various losses are discussed in detail.

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Decoherence induced by magnetic impurities in a quantum Hall system

V. Kagalovsky

Scattering by magnetic impurities is known to destroy coherence of electron motion in metals and semiconductors. We investigate the decoherence introduced by a single act of electron scattering by a magnetic impurity in a quantum Hall system. We introduce a fictitious nonunitary scattering matrix $\boldsymbol{S}$ for electrons that reproduces the exactly calculated scattering probabilities. The strength of decoherence is identified by the deviation of eigenvalues of the product $\boldsymbol{SS}^{\dagger}$ from unity. The degree of nonunitary is related to the phase uncertainty acquired by an electron after one scattering event, and its square is inversely proportional to the electron's coherence length. We estimate the width of the metallic region at the quantum Hall effect inter-plateau transition and its dependence on the exchange coupling strength and the degree of polarization of magnetic impurities.

Emergent Novel Metallic State in a Disordered 2D Mott Insulator

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We explore the nature of the phases and an unexpected disorder-driven Mott insulator to metal transition in a single crystal of the layered dichalcogenide 1T-TaS_2 that is disordered without changing the carrier concentration by Cu intercalation. Angle resolved photoemission spectroscopy (ARPES) measurements reveal that increasing disorder introduces delocalized states within the Mott gap that lead to a finite conductivity, challenging conventional wisdom. Our results not only provide the first experimental realization of a disorder-induced metallic state but in addition also reveal that the metal is a non-Fermi liquid with a pseudogap in the ground state that persists at finite temperatures. Detailed theoretical analysis of the disordered Hubbard model shows that the novel metal is generated by the interplay of strong interaction and disorder.

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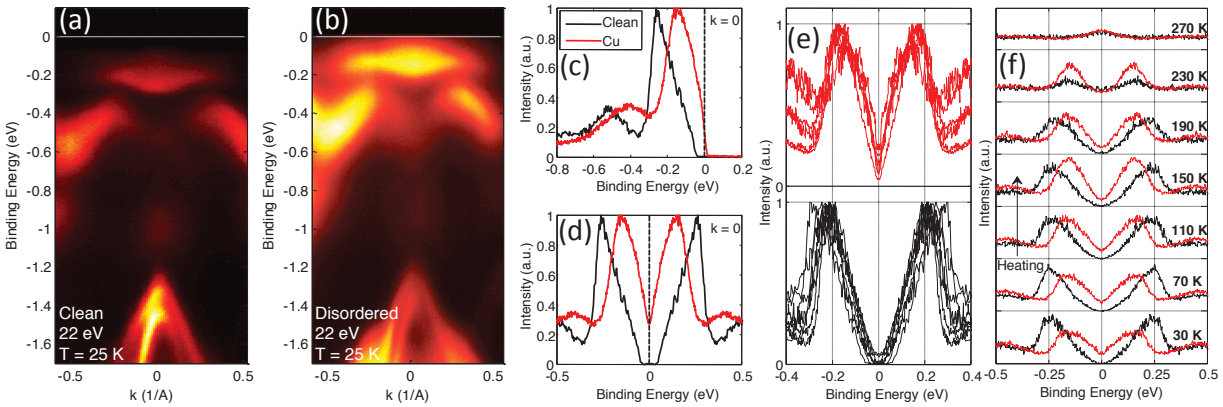

FIG. 1: ARPES spectra of a disordered Mott-insulator 1T-TaS_2: Spectra taken with 22eV photons along the $\Gamma - K$ direction at T= $25K$. Panel (a) for a clean system reveals a Mott gap as indicated by the lack of intensity within about 80 meV of the Fermi energy. Panel (b) for a disordered sample shows the presence of significant spectral weight close to the Fermi energy, inside the energy gap. In panels (c-f), the scans in black are for a clean system while those in red are for a Cu intercalated disordered system. (c) Comparison of the Energy Distribution Curve (EDC) at the Γ point taken from the scans in (a) and (b). The peak in the disordered 1T-TaS_2 is broadened and shifted towards lower binding energy and there is substantial intensity at zero energy. (d) The same EDCs shown in (c) after symmetrization clearly reveals the closing of the gap in the disordered sample, and the formation of a pseudogap with a suppressed intensity at the Fermi-level of about 20 % of the peak-intensity. (e) Reproducibility of the results: EDCs from 13 different samples (7 clean and 6 disordered) taken in different ARPES systems with different photon energies and polarizations, all reveal the same qualitative behavior. (f) Evolution of the pseudogap at the Γ point as function of increasing temperature. While at low temperatures the spectral weight at zero energy is much larger in the disordered samples, above the transition temperature the difference in the spectral functions of the clean and disordered samples disappears.

Superfluidity with disorder in a thin film of quantum gas

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We experimentally study the transport process of ultracold fermionic atoms through a mesoscopic, disordered quasi two-dimensional channel connected to two macroscopic reservoirs (see figure 1). By observing the current response to an applied chemical potential bias between the reservoirs, we directly access the resistance of the channel in a manner analogous to a solid state conduction measurement[1].

In a first experiment we investigate the properties of a strongly interacting bosonic superfluid gas of $^6Li_2$ Feshbach molecules forming a thin film confined in the quasi-two-dimensional channel with a tunable random potential, creating a microscopic disorder [2]. We measure the atomic current, extract the resistance of the film in a two-terminal configuration, and identify a superfluid state at low disorder strength, which evolves into a normal poorly conducting state for strong disorder. The transition takes place when the chemical potential reaches the percolation threshold of the disorder. The evolution of the conduction properties contrasts with the smooth behavior of the density and compressibility across the transition, measured in-situ at equilibrium. These features suggest the emergence of a glasslike phase at strong disorder.

In a second experiment we produce and investigate a strongly interacting Fermi gas subject to a random potential. We characterize it using in-situ imaging at the single impurity level, directly showing that the gas fragments into isolated pockets with increasing disorder. The in-situ imaging allows to extract the percolation threshold of the density distribution, providing a new class of observables for disordered cold atomic systems. Transport measurements in a two-terminal configuration show that a weak disorder preserves the superfluid character of the clean gas, while a stronger disorder drives the system out of the superfluid state. Our results suggest that percolation of paired atoms is responsible for the loss of superfuidity, and that disorder is able to drive the gas from the BCS regime to BEC.

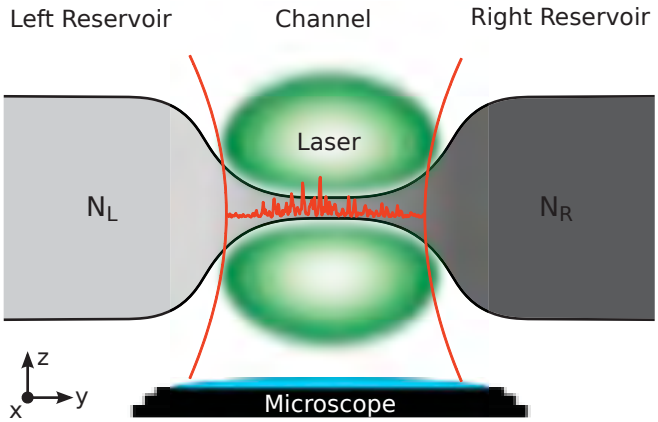

FIG. 1: Experimental Setup: Two atom reservoirs are connected by a narrow quasi-2D channel, created by a laser beam (green) at 532 nm with a $1/e^2$ waist of 30 μm along y, having a nodal line at the center. When a number imbalance between the reservoirs is present, an atomic current sets in through the channel. A speckle pattern (orange) of variable intensity is projected onto the channel along the z axis through a microscope objective

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Bose glass transition and spin-wave localization for disordered 2D bosons

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A spin-wave (SW) approach of the zero temperature superfluid — insulator transition for two dimensional hard-core bosons in a random potential $\mu = \pm W$ is developed. While at the classical level there is no intervening phase between the Bose-condensed superfluid (SF) and the gapped disordered insulator, the introduction of quantum fluctuations lead to a much richer physics. Upon increasing the disorder strength W, the Bose-condensed fraction disappears first, *before* the SF. Then a gapless Bose-glass (BG) phase emerges over a finite region, until the insulator appears. Furthermore, in the strongly disordered SF regime, a mobility edge in the SW excitation spectrum is found at a finite frequency Ω_c, decreasing with W, and presumably vanishing in the BG phase.

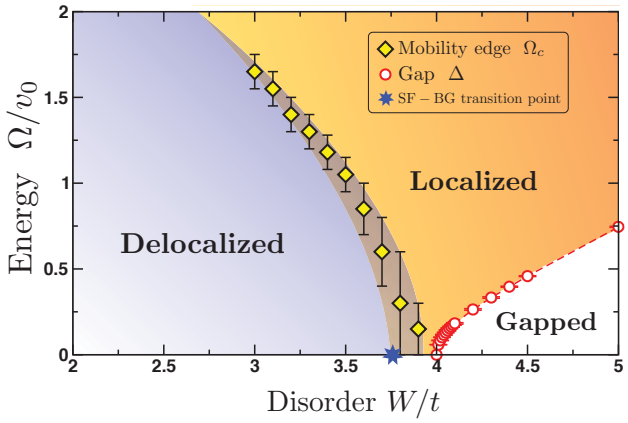

FIG. 1: Energy of the SW excitations Ω for 2D hard-core bosons in a random potential as a function of disorder strength W/t. All states are extended (delocalized) below a mobility edge Ω_c and localized above. The shaded area represents the localized-delocalized boundary with quite large error bars close to the SF-BG transition point where we expect $\Omega_c \to 0$. In the gapped insulating side, there is no state below the gap Δ, and all excitations above are localized, and connected to other localized excitations.

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Quantum phases and non-equilibrium dynamics with Rydberg atoms

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Motivated by recent experimental efforts to realize exotic phases and study non trivial quantum dynamics with ultracold atomic Rydberg gases, I will discuss two examples from our recent work in the field. Within the short (microsecond) coherence time of the system, optimized chirps allow the preparation of strongly interacting phases in a laser excited two-dimensional atomic Mott insulator, whose effective dynamics can be mapped to a long range spin model with external fields. In particular I will show the emergence of mesoscopic crystalline structures with a well-defined number of excitations via adiabatic sweeps of the laser parameters in finite two dimensional optical lattices. In the second part I will discuss the many body properties of free space ground state atoms weakly dressed to the Rydberg state. I will focus on the crossover between the so called density wave supersolid and the defect-induced supersolid introduced by Andreev-Lifschitz and Chester by a complete analysis of the phase diagram at low densities. Finally I will show how these interesting exotic phases can be probed by looking at the spectrum of the elementary excitations.

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Annealing-induced Superconductor-to-Insulator Transition

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We report on the study of the Superconductor-to-Insulator Transition (SIT) in Nb_xSi_{1-x} thin films through annealing.

Structurally, we have shown that annealing does not modify the microscopic structure of Nb_xSi_{1-x} but induces a change in the effective microscopic disorder. It therefore slightly changes the quantum interference patterns which, in turn, affects the superconducting properties of the films.

Transport measurements close to the SIT have shown that disorder affects superconductivity in a quantitatively different manner when the disorder is tuned by annealing or composition, and by the film thickness. These results question the pertinence of the sheet resistance as the relevant parameter to fully take into account the effect of disorder on superconductivity [1].

Annealing provides a mean to very finely tune the disorder in the vicinity of the SIT. The very low temperature behavior of the films has therefore been investigated in this regime and the possibility of a intermediate metallic ground state explored.

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On the metal-insulator transition of disordered materials: May its character be determined by how one looks at it?

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In a recent experimental study, Siegrist *et al.* investigated the metal-insulator transition (MIT) of $GeSb_2Te_4$ and related phase-change materials on increasing annealing temperature [1]. The authors claim these solids to form an "unparalleled quantum state of matter": They conclude that these phase-change materials exhibit a finite minimum metallic conductivity, in contrast to many other disordered substances. Here, these measurements are reanalyzed. It is shown that, according to a widely-used approach, the temperature dependences of the conductivity may also be interpreted in terms of a continuous MIT, see Fig. 1.

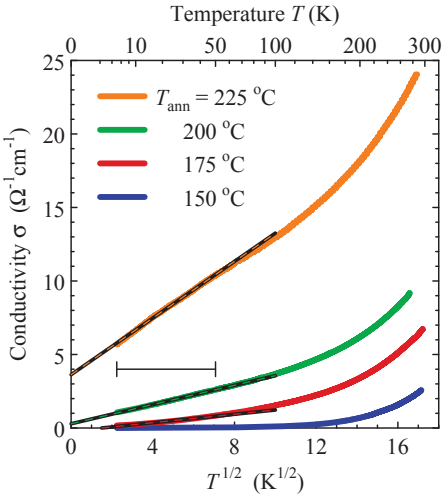

FIG. 1: Temperature dependences of the conductivity of four $GeSb_2Te_4$ films redrawn from Fig. 3 of Ref. 1. According to that plot, all these samples are considered as insulating in Ref. 1. The black straight lines, which are overlaid with colored dashes, show corresponding $\sigma = a + bT^{1/2}$ approximations. The T interval 5 to 50 K, taken into account in adjusting the respective parameters a and b, is marked by a horizontal bar.

The conflict between both the classifications of the MIT is traced back to biases inherent to the data evaluation methods. Moreover, carefully checking the justification of the respective fits uncovers inconsistencies in the experimental data on $GeSb_2Te_4$, which currently render an unambiguous interpretation impossible.

Comparing with previous experimental studies on the MIT of other disordered materials, we show that such an uncertain situation is not unusual: The consideration of the logarithmic derivative of the conductivity highlights serious inconsistencies in the interpretations in terms of a continuous MIT in the respective publications. This is demonstrated in Fig. 2, comparing experimental data to theoretical relations. In part, the discrepancies may arise from experimental problems. Thus, the challenge lies in improving the measurement precision.

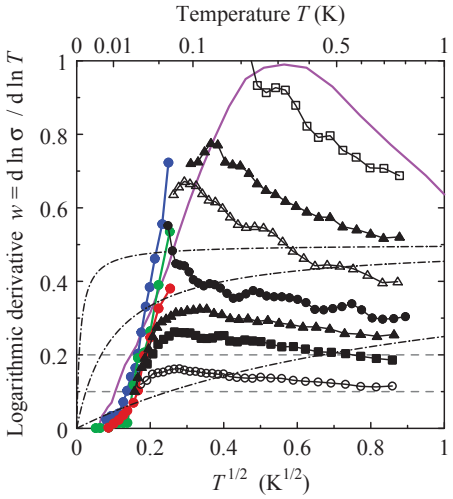

FIG. 2: Comparison of temperature dependences of the logarithmic derivative of the conductivity, w, obtained from three studies on crystalline Si:P, in which the MIT was tuned varying the P concentration: The colored filled circles were obtained by digitalization of the three upper curves in Fig. 2 of Ref. 2, always considering four neighboring points in calculating w. The magenta line was derived from the curve for the P concentration $n = 3.75 \times 10^{18}$ cm^{-3} in Fig. 1 of Ref. 3. The black symbols result from Fig. 1 of Ref. 4; from top to bottom, they refer to $n = 3.38$, 3.45, 3.50, 3.52, 3.56, 3.60, and 3.67×10^{18} cm^{-3}. According to Ref. 4, the upper three of these curves should correspond to insulating samples, whereas the lower three curves should show metallic behavior. The sample, for which the medium curve ($n = 3.52 \times 10^{18}$ cm^{-3}) is obtained, should be located very close to the MIT. The dashed-dotted lines represent the $w(T)$ resulting from hypothetical $\sigma = a + bT^{1/2}$ with $a/b = 0.01$, 0.1, and 1.

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Coherent or hopping like energy transfer in the chlorosome ?

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Chlorosomes, as part of the light-harvesting system of green bacteria, are the largest and most efficient antennae systems in nature. They are ellipsoidal sacks with dimensions in the order of 100nm x 100nm x 25 nm containing hundreds of thousands of bacteriochlorophyll pigments. Typically, strong disorder at the single chlorosome level hinders the determination of the detailed structure. Assuming strong disorder in combination with strong environmental fluctuations, however, renders the excitation energy transfer incoherent resulting in random walk like hopping transport. This scenario yields transfer times in contrast to observations. Employing scaling arguments I estimate the disorder strength under which coherent clusters, i.e. chains of pigments coherently coupled and spanning the whole chlorosome, are still possible. Within these clusters the excitations delocalize thereby speeding up the energy transfer which provides an alternative scenario to explain the fast excitation energy transfer in chlorosomes.

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Some Problems with Logarithmic Relaxation Theory, and a Few Possible Resolutions.

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There are presently several models [1-4] for relaxation of an electron glass compatible with the observed logarithmic dependence of relaxation on time. Such a dependence is observed in a large variety of systems lacking translational symmetry. For the case at hand, [1] and [2] are the more realistic models so the paper relates specifically to these.

1. A fundamental assumption in [1] and [2] is that, on a logarithmic time scale, one can assume that relaxations with rates $\Gamma>1/t$ have all occurred at time t and no relaxations with rates $\Gamma<1/t$ have yet occurred. This approximation fails to take into account that after a relaxation to a new state, *new* relaxations with large Γ become possible. A theory is presented that takes this into account. Conditions under which a logarithmic relaxation can still be expected to be observed are discussed. The theory also has a bearing on the shape of the memory dip observed in experiments with swept gate voltage.

2. Theories [2,5] relating to aging experiments that seems to fit observations very well, assumes that after a perturbing force of duration t_w is applied, the system returns to the status quo ante by *microscopically* reversing the sequence of the transition processes. Such a return implies that slow relaxation processes precede fast ones, a very unlikely constraint on the path except for very short waiting times t_w compatible with a single relaxation process during t_w.

3. It is implicitly assumed that excitation, *e.g.* by change of gate voltage, induces a change of only several percent of $G_{equilibrium}$. This however is not experimentally verified: in relaxation experiments the logarithmic decay is never observed to level off even at very long times.I shall dicuss the significance of this on the interpretation of τ, the experimental quantity associated with speed of decay [6], and on the independence of the shape of the memory dip on most experimental parameters [7].

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Fluctuation relation for weakly ergodic aging systems

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Abstract: A fluctuation relation for aging systems is introduced and verified by extensive numerical simulations [1]. It is based on the hypothesis of partial equilibration over phase-space regions in a scenario of entropy driven relaxation [2]. The relation provides a simple alternative method, amenable of experimental implementation, to measure replica symmetry breaking parameters in aging systems. The connection with the effective temperatures obtained from the fluctuation-dissipation theorem is presented. Feasible experiments in various systems are also discussed.

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Universal Superfluid Transition and Transport Properties of Two-Dimensional Dirty Bosons

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Transport properties in quantum materials are governed by a complex interplay of disorder and interactions. Dramatic effects are expected in two dimensions (2D), such as metal-insulator transitions [1–3], suppression of superfluidity [4–8], and presumably high-T_c superconductivity [9]. Possible phase transitions are however particularly elusive owing to absence of true long-range order even in extended phases [10, 11], and many questions remain open. For instance, resistivity measurements in Si-MOFSETs suggest a metal-insulator transition [1], which may be attributed to quantum localization or classical percolation [2], but experiments on GaAs heterostructures point towards a crossover behavior [3]. Studies of the superfluid Berezinskii-Kosterlitz-Thouless (BKT) transition have also been reported for ^{4}He films adsorbed on porous media [4, 5]. While the BKT transition is unaffected in the weak disorder limit [12], the question of its relevance for strong disorder is left open owing to the difficulty to identify a universal jump of the superfluid density [6–8]. Moreover, a question that is attracting much debate is whether many-body localization effects [13–17] can drive a finite-temperature metal-insulator transition in two dimensions.

Ultracold quantum gases in controlled disorder offer a unique tool to address these questions in a unified way [18]. In clean or disordered quasi-2D geometries, direct consequences of vortex pairing [19], superfluidity [20], quasi-long-range phase coherence [21, 22], and resistance measurements [23] have been reported. On the theoretical side, most knowledge rely on lattice models with uncorrelated disorder [24–28]. Conversely, little is known about the novel models of disorder introduced by ultracold atoms, which are continuous, correlated, and sustain classical percolation thresholds [29, 30].

Here we report on an *ab-initio* path-integral quantum Monte Carlo (QMC) study of the phase diagram of interacting 2D bosons in a continuous model of disorder. We show that, although the density profile exhibits large spatial modulations, the superfluid Berezinskii-Kosterlitz-Thouless transition is strongly protected against disorder, up to the zero-temperature Bose-glass transition. The critical properties of the *dirty* superfluid transition

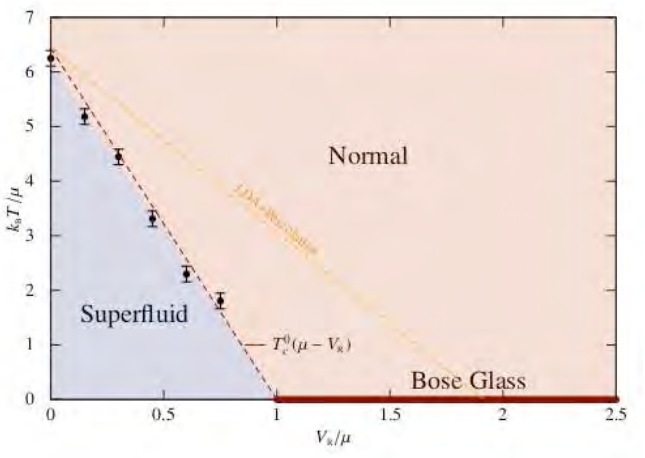

FIG. 1: Phase diagram of two-dimensional interacting bosons at fixed chemical potential and interaction strength $\tilde{g} = 0.1$. The dark dashed line is the critical temperature of the clean system with a shifted chemical potential; the lighter dashed line is the prediction of a combination of local density approximation (LDA) and percolation theory.

can be understood in terms of a universal description including a simple renormalization of the critical parameters. In particular, we find that the superfluid transition occurs while the fluid percolates with a density above the critical density of the clean system, which allows us to rule out the classical percolation scenario (see the difference between the QMC result and percolation theory on Fig. 1). Moreover, we study the conductance by means of a novel quantum Monte Carlo estimator. Deep in the strong disorder regime, we find direct evidence of an insulating behavior, characterized by a conductance that decreases with the temperature. Our data is consistent with a thermally-activated behavior of the Arrhenius type, indicating that the conductance vanishes only at zero temperature. Our results do not show any evidence of a finite-temperature localization transition, and point towards the existence of Bose bad-metal phase as a precursor of the Bose-glass phase.

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The dipolar gap in the Two-TLS model

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Tunneling two-level systems (TLSs) were introduced to explain the remarkable universality of phonon attenuation properties of glasses at low temperatures[2, 3]. Although their nature is still not clear, their generic existence in amorphous solids is well accepted, and is used to explain a plethora of phenomena ranging from 1/f noise to decoherence of superconducting qubits. Recently we have shown that inversion symmetric tunneling states dictate the low energy properties in glasses. This is a result of their weak interaction with the phonon field, and consequently their gapping of the asymmetric tunneling states at low energies[4, 5]. Here I will discuss the model, our recent results for the functional dependence of the density of states of the asymmetric tunneling states at low energies and its intriguing dependence on the form of the interaction at short distances, and new predictions regarding the possibility to detect the asymmetric tunneling states.

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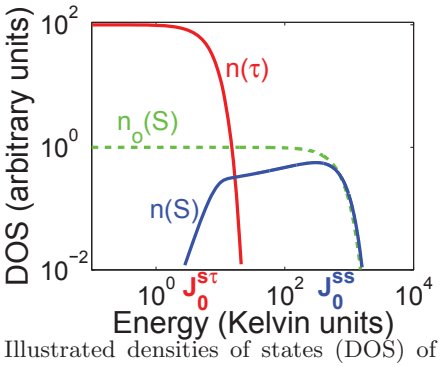

FIG. 1: Illustrated densities of states (DOS) of symmetric (τ) and asymmetric (S) TLSs. Inter-spin correlations negligibly affect $n_\tau(E)$ but considerably affect $n_S(E)$, with a sharp gap-like feature appearing at the typical energy of the $S-\tau$ interaction, where the τ-spin levels first appear. The non-correlated DOS $n_S^o(E)$ is drawn for comparison.

Termination of a Cooper-pair insulator

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Highly disordered superconductors can undergo a direct transition to an insulator under the application of a strong magnetic field (B). In this insulator Cooper-pairs are still present and participate in transport. At yet higher B the Cooper-pair insulating state terminates and a new state emerges. We investigated the transport in this new state at B-values up to 30 T and found that it is insulating with the resistance following an Efros-Shklovskii-type law. Additionally we identified a well-defined B where the transition between the two types of insulators takes place.

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The effect of Coulomb interactions on the disorder driven superconductor-insulator transition: THz versus tunneling spectroscopy

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The interplay between disorder and superconductivity has intrigued physicists for decades. Of particular interest is the influence of disorder on the superconducting energy gap Δ. We present the evolution of the energy gap through the disordered driven superconductor to insulator transition (SIT) by two different experimental methods: tunneling spectroscopy, in which a metallic electrode is placed close to the studied sample thus screening the Coulomb interactions, and terahertz (THz) spectroscopy, which probes the unscreened sample. Interestingly, with increasing disorder both methods yield different results. As shown in Fig.1, the measured superconducting gap in the THz method is dramatically suppressed compering to the results obtained by tunneling measurements.

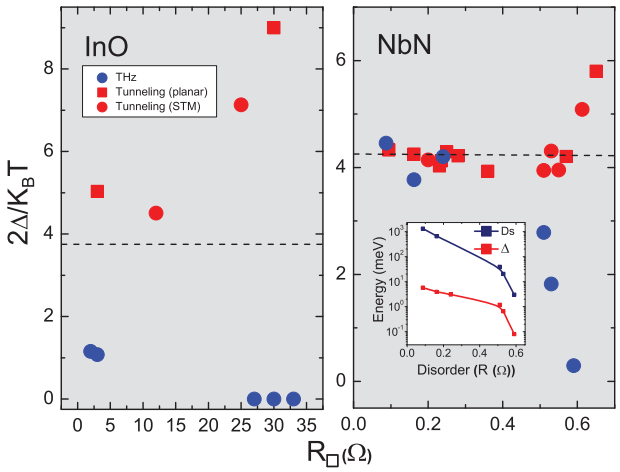

FIG. 1: **THz versus tunneling spectroscopy for series of NbN and InO films with different disorder.** $2\Delta/k_BT_c$ as a function of sheet resistance for batches of InO films (left) and NbN films (right) obtained by planar junction tunneling (red squares), STM tunneling (red circles), and THz spectroscopy (blue circles). The dashed line indicates the experimental value of clean samples. The tunneling results were taken from [3–5]. Note that the results from planar junction and STM methods agree with each-other very well. Inset: The energy gap and the superfluid stiffness as a function of sheet resistance for the NbN batch.

The comparison between the two methods demonstrate the important role played by electronic interactions in determining the nature of the phases across the SIT. To further support this reasoning we present results from a cross-check experiment in which the gap is determined from the THz experiment on films with and without a nearby metal plate. The results show that when Coulomb interactions are screened by the metal electrode a gap is recovered in the insulator. Further theoretical studies that incorporate the effects of both the emergent granularity and Coulomb interactions are essential for explaining our experimental results and for a better understanding of when the different existing paradigms are borne out in experiments.

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Electron tunneling between surface states and implanted Ge atoms in Si-MOS structure with Ge nanocrystals

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Si-MOS structures with Ge nano-crystals (NC-Ge) embedded by ion implantation in SiO_2 film preliminary grown on a p-Si substrate were studied for their capacitance-voltage characteristics (C-V). To avoid the influence of Si substrate and Si/SiO_2 interface, SiO_2 film was made sufficiently thick (600 nm), therefore implantation of Ge+ ions with energy 150 keV (projection range 100 nm, struggle 30 nm) provides location of implanted Ge atoms near the surface and far from Si/SiO_2 interface (Fig. 1). Measurements of C-V were performed at room temperature and at high frequencies (0.1-1 MHz).

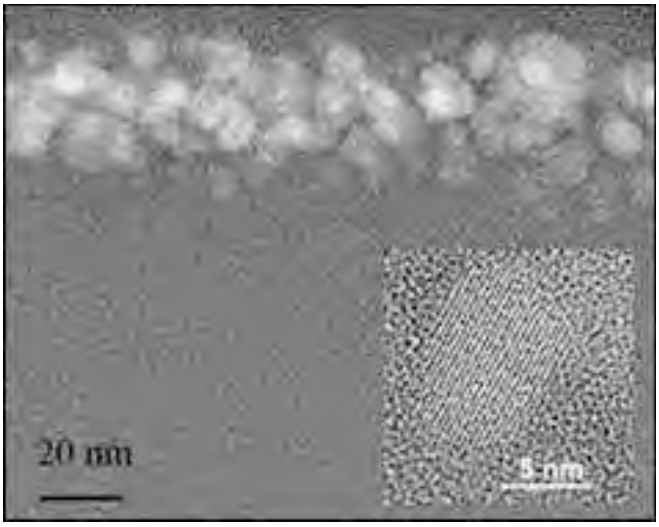

FIG. 1: HR-TEM image of NC-Ge sample.

It is shown that after Ge ion implantation, the "S-shape" of C-V, typical for MOS structures at high frequencies, is replaced by "U-shape". We explain this effect by a loss of the surface charge due to electron tunneling between surface and nearest implanted Ge atoms. Formation of Ge nanocrystals (NC-Ge) after first annealing at 800°C leads to an appearance of the hysteresis, due to charge trapping in NC-Ge (Fig. 2). Visible light illumination results in a significant decrease of the "U-dip", which implies a decrease of the surface charge loss due to discharging of NC-Ge, which is caused by the light-induced generation of electron-hole pairs. Combination of "U-shape" and hysteresis of C-V allows us to suggest a novel 4-digits memory retention unit, controlled by voltage switch or light illumination (Fig. 2).

Irradiation of NC-Ge samples with a high intensity neutron flux in a research nuclear reactor followed by annealing of radiation damage (second annealing at 800°C) leads unexpectedly to recovering of "S-shape" of C-V. Within the framework of suggested model, this recovering could be interpreted as a result of suppression of electron tunneling between the surface and Ge atoms. In turn, this implies that NC-Ge nanocrystals are no longer present in the vicinity of the surface. Indeed, the space redistribution of NC-Ge caused by neutron irradiation and second annealing was confirmed by direct observations using high resolution transmission electron microscopy (HR-TEM), energy dispersive X-ray elemental spectroscopy(EDS) and X-ray photoelectron spectroscopy (XPS).

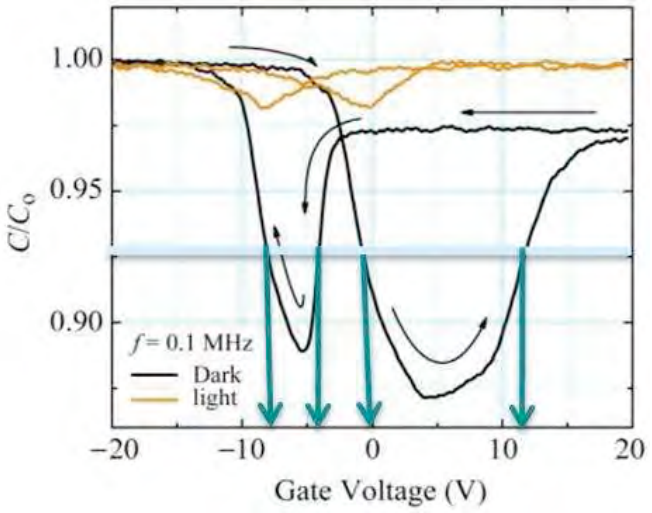

FIG. 2: C-V of NC-Ge sample

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Photo-induced conductance fluctuations in mesoscopic Ge/Si systems with quantum dots

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The characteristic feature of hopping transport in a QD layer is an extremely strong dependence of the conductance on the occupation of QDs by carriers. It was shown [2] that the conductance in a Ge/Si QD layer is changed non-monotonously by more than six orders of magnitude, upon variation of the average QD filling ranging from 0.5 to 6 holes per dot. Thus, adding or removing single charges from individual QDs should force the conductance to change. Previously, we showed [3] that illumination of macroscopic samples with QDs results in a photoconductance (PC), with their sign and magnitude being depended on the initial filling of the QDs with holes. The average change of the conductance under 0.9-1.55 μm wavelength illumination was 10-20%. Long-time conductance dynamics (typically, $10^2 - 10^4$ seconds at T=4.2 K) has been revealed as well as after switch on and switch off the illumination, displaying a sluggish temporal dependence. It was found that the residual photoconductance could persist for several hours after the light switching off.

Here we study the conductance in mesoscopic structures, hence the most favorable current path depends strongly on the exact realization of the random potential, i.e. on the charge state of every individual dot. Thus, under weak illumination we expect to observe a step-like change in the conductance, corresponding to the physical process of adding/removing a single charge to a dot. Indeed, employing this idea to Ge/Si QD devices with a

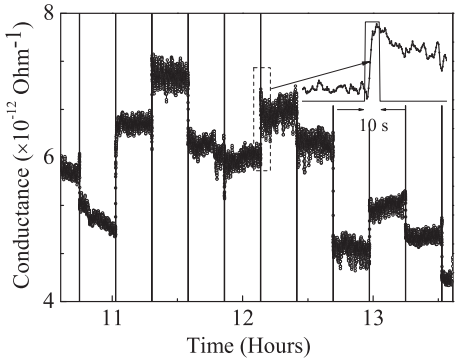

FIG. 1: Kinetics of conductance for small-area sample under pulse excitation. Inset- enlarged image of single-pulse reaction.

size, much smaller than the correlation length of the percolation network, the present work demonstrates conductance fluctuations induced by single photons. We present the experimental results of photo-induced current fluctuations in structures with conductive channel size being varied in the range of 70-200 nm.

It was shown that unlike macroscopic structures, in small-area samples, where conduction takes place through a mesoscopic size hopping network, the conductance evolves with time in discrete steps. We suggest that the redistribution of carriers among QDs of the array occurs due to absorption of a single photons. The resulting new potential landscape leads to a new conductive path providing a step like change of the conductance with time. Due to non-monotonic dependence of hopping conductance on QD occupancy, we observed both positive and negative steps in the conductance traces. Relaxation processes that are usually responsible for the appearance of downward steps have negligible contribution due to persistent PC effect, which is a characteristic feature for the structures under study. Experimental kinetics data for dark and photo-excited parts of the time-resolved conductance were analyzed in the frame of count rates at different threshold (discrimination) level. It was shown that the dark noise doesn't exceed 4-10% whereas the conductance fluctuations under illumination reach more than 70% of magnitude. To be sure that steps in the conductance are induced by the absorption of single photons the samples were subject to pulsed excitation using the pulse duration time, light intensity and the delay between pulses as parameters. It was shown (Fig.1) that every pulse causes a single step-like change of the conductance confirming single-photon operation mode.

Using SOI structure instead of Si substrate for growth of QD array, we could observe the hopping conductance and current fluctuation under illumination up to 100 K.

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On the multifractal dimensions at the Anderson transitions

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Multifractality seems to be an essential feature of wave function fluctuations at disorder driven localization–delocalization phase transitions. In most cases only a little information is available analytically. Recently[3], based on heuristic arguments, an intimate relation has been identified existing between the eigenstate multifractal generalized dimensions, D_q, which for the test case of critical random matrix ensembles read as $D_{q'} = qD_q[q' + (q - q')D_q]^{-1}$, if $0.5 < q \leq 3$.

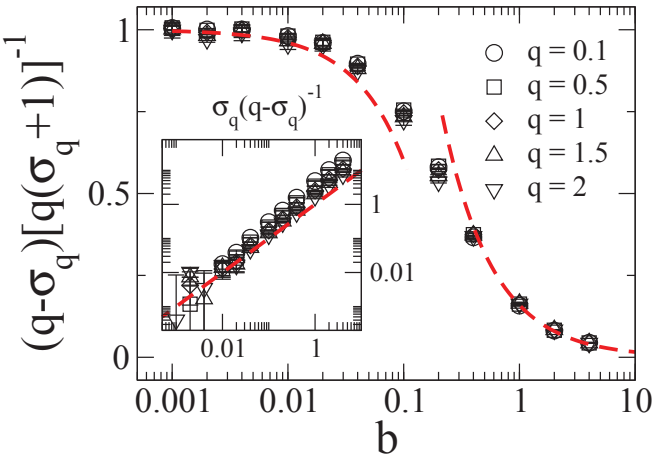

FIG. 1: Scaling of the exponents of the moments of Wigner-delay times for the power-law band random matrix model.

Here, we verify this relation by extensive numerical simulations on a wide variety of models including further random matrix ensembles, deterministic, quasiperiodic systems, etc. that provide multifractal states. The extension of our relation to $q < 1/2$ is given and we also demonstrate that for the scattering version of the power-law band random matrix model at criticality the scaling of the moments, σ_q, of the Wigner-delay time, $\langle \tau_w^{-q} \rangle \propto N^{-\sigma_q}$, can be given as $\sigma_q \approx q(1-\chi)/(1+q\chi)$, where χ is the level compressibility[4], thus providing a way to probe level correlations with the help of scattering measurements.

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Ferromagnetic ordering in Mn-doped quantum wells GaAs-AlGaAs resulting form the virtual Anderson transition

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We present our results obtained for Mn-doped GaAs quantum wells where the evidences of the ferromagnetic transition (anomalous Hall effect - AHE, peak in the temperature behavior of resistance) at relatively high temperatures were found at unusually small Mn concentrations (about an order of magnitude smaller than in earlier reported studies [2]).The temperature behavior of conductivity exhibits activation law at high temperatures. At the same time, the observed values of hopping resistance at small temperatures evidenced that the samples are deep in the insulating regime. Thus the corresponding estimates of the overlapping integrals (following from the values of the hopping conductance) can hardly explain the large values of Curie temperatures $T_c \simeq$ 100 K. We develop a theoretical model qualitatively explaining such a behavior. The model exploits a concept of virtual Anderson transition which we suggested earlier [3]. Namely, for narrow impurity bands (existing in samples with relatively low degrees of disorder) the criterion of metal-insulator transition is obeyed for impurity concentrations lower than following from standard Mott-Anderson criterion. As a result, a band of delocalized states is formed near the center of the impurity band. If the compensation degree is relatively small (which is necessary to have a low degree of disorder) the Fermi level appears to lie outside of the band of delocalized states and the temperature behavior of conductivity exhibits activation law. Such a behavior we earlier reported for GaAs quantum wells doped by Be. Here we note that the indirect exchange does not depend on the statistics of the intermediate delocalized states. Thus such an exchange between Mn atoms (leading to ferromagnetic ordering) can be supported by the states resulting from the virtual Anderson transition which explains our results. It is interesting that, experimentally, an increase of a degree of doping finally lead to a suppression of ferromagnetic ordering. We attribute such a behavior to a suppression of the virtual Anderson transition due to an increase of a degree of disorder.

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DEPENDENCE OF THE CURRENT INSTABILITY ON THE COMPENSATION DEGREE IN THE HOPPING CONDUCTIVITY REGION

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The observation of negative differential resistance in the hopping conductivity region in p-type silicon was reported in [1]. In the latter the current- voltage characteristic for the temperature saturation range of the hopping conductivity low frequency current oscillations have been discussed. It was shown that these oscillations are associated with "hopping" domain periodic formation and travel in the bulk of the sample [2,3].
In this work we present results of the investigation of the dependence of the threshold field, E_{th} , at which oscillations begin, and the relative amplitude on compensation degree K of the samples. Measurements were carried out on boron doped $(5 - 7)x10^{16}$ cm^{-3}) and very weakly compensated (compensation degree $K = (0,5 - 50) \times 10^{-4}$) silicon samples. It is shown that E_{th} increase and amplitude oscillations decrease with increasing compensation degree. At compensation degree $K \geq 10^{--3}$ the current oscillations have not been observed. The model explaining the experimental results is presented.

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Two-dimensional trapped Bose gas with correlated disorder

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Il will discuss the superfluid to normal transition of trapped Bosons in quasi two dimensions at finite temperatures, obtained thanks to accurate path-integral Monte Carlo calculations. In particular, I will show that precise measurements of the momentum distributions via usual time-of-flight expansions are able to precisely locate the *dirty* Kosterlitz-Thouless transition in trapped systems of finite size. For experimentally relevant parameters, a correlated disorder potential shifts the transition temperature to lower temperatures. For a given disorder realization, we calculate the condensate wave function, and show that islands with enhanced local coherence properties develop for strong disorder amplitudes. Extrapolating to zero temperature, we estimate the critical disorder amplitude of the quantum phase transition. The connection of the above-discussed results with the phase diagram of the homogoneneous 2D system that we have obtained elsewhere [I] will be finally discussed.

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[I] Carleo, Boeris, Holzmann and Sanchez-Palencia - Universal Superfluid Transition and Transport Properties of Two-Dimensional Dirty Bosons - To be submitted (2013)

Spin transport in helical biological systems

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The majority of existing spintronic devices are based on inorganic materials, although some work has been performed on organic molecules [3–5]. As a rule, the spin sensitivity of molecular based spintronics is rather related to the magnetic properties of the electrodes or of the used molecules, so that the recent experimental demonstration [6, 7] of spin selective effects in monolayers of double-stranded DNA oligomers have drawn a great deal of interest.

On the theoretical side two main lines can be identified: i) Studies based on scattering theory at the level of the Born approximation, including spin-orbit interactions derived from a helically shaped potential [8, 9] and ii) Approaches based on quantum transport [10, 11], which probe the electrical response of DNA self-assembled monolayers in a two terminal setup. Common to both approaches is the assumption that a molecular electrostatic field with helical symmetry can induce in the rest frame of a moving charge an effective, momentum-dependent magnetic field. This field can then couple to the electrons spin leading to a spin-orbit coupling (SOC) which encodes the helical symmetry of the molecular structure.

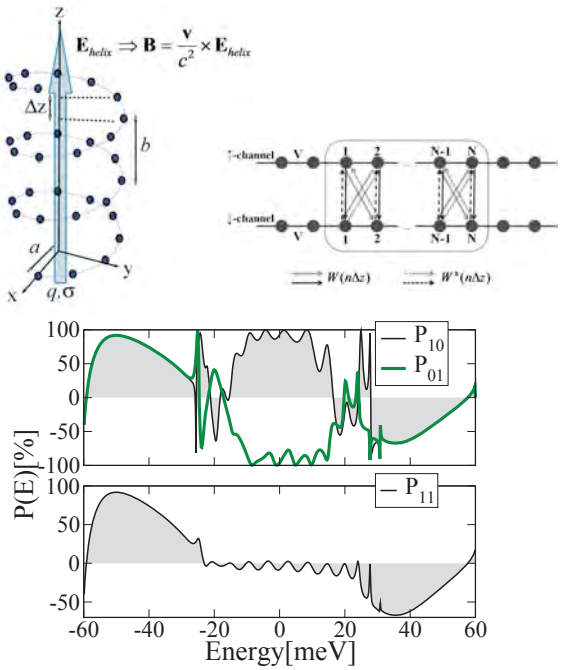

FIG. 1: *Top panel*: Sketch of the charge moving along the helical electric field and of the tight-binding model. The two channels interact via the SOC. *Bottom panel*: Energy dependence of the SP for three helical turns, and for injected electrons with their spin pointing up (P_{10}), down (P_{01}), or unpolarized (P_{11}). A spin-filter effect takes place at energies near the band edges, where all SPs have the same sign.

In our work [10], a minimal model is presented, describing electron transmission through a helical potential, see top panel of Fig. 1. Main goal of the model is to highlight the role of some crucial parameters, which will lead to a high spin-polarization (SP) while still keeping a moderate SOC strength. In short, there are two main key factors in the model allowing for a high SP: i) Lack of inversion symmetry due to the chiral symmetry of the scattering potential, and ii) Narrow electronic band widths in the helical system, i.e. the coupling between the units composing the helical structure is relatively weak.

In order to test the stability of the spin polarization against fluctuations of the electronic structure induced by static disorder, we have assumed that the site energies are random variables with a square box distribution. The results obtained by performing a configuration average over 150 realizations of the disorder show that the effect on the spin polarization turns out to be weaker at the band edges. We remark that the spin filter effect presented in the model −equal sign of the polarization for all incoming states− occurs mainly near the band edges and hence the obtained results show their stability against a perturbation of the electronic structure.

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Cryogenic calibration setup for wide band complex conductivity measurements in order to probe the dynamics of superconducting disordered systems

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Disordered superconducting systems exhibit several fascinating dynamical properties such as quantum fluctuations near the superconductor-to-insulator transition and a glassy behaviour in the mixed state [2, 3].

A powerful probe to study the dynamics is the complex impedance. The resistance is related to the quasiparticles response and the inductance gives direct access to the superfluid current density ; their frequency dependences allow the study of the characteristic timescales of the system [4]. One can measure the complex impedance on a wide frequency band for instance by probing the reflection S_{11} of an alternating GHz signal applied to the sample via a microwave line.

To fully calibrate the reflectometry setup, it is necessary to measure the reflection of three samples with known impedances in addition to the sample under study, with the circuit being under the same conditions of temperature, power and field. This procedure, simple at ambient temperature, becomes challenging at cryogenic temperatures, because one should iteratively cool and warm the cryostat to change the sample, thus potentially changing the line's response, whereas the measurements should, in principle, be made in the exact same conditions.

We are developping a unique calibration setup which allows switching in situ between the four samples at liquid helium temperature, under a broad frequency range DC-20 GHz. Here we present the cryogenic calibration setup design and the first tests.

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AC Transport in p-Ge/GeSi Quantum Well in High Magnetic Fields

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The measurements of the Surface Acoustic Wave (SAW) attenuation Γ and velocity change $\Delta v/v$ in the heterostructure p-GeSi/Ge/GeSi, containing a single quantum well with the hole density p=6×10^{11}cm^{-2}, were done at frequencies 30 and 85 MHz and a magnetic field B of up to 18 T in the temperature range 0.3 - 5.8 K. From the measured values of Γ and $\Delta v/v$ both the real, part σ_1 and imaginary part σ_2 of the high-frequency (ac) conductivity $\sigma^{\rm ac}(\omega) \equiv \sigma_1 - i\sigma_2$ could be calculated.

In this system the 2D channel forms in a compressively strained modulation doped Ge layer. Due to the strain the threefold degenerated valence band of Ge is split into 3 subbands, the highest of which is occupied by heavy holes. In relatively small magnetic fields ($B < 2$ T) the holes are delocalized, and $\sigma_2 \ll \sigma_1$. In this case the analysis of the temperature damping of the SdH oscillations allows the carrier parameters such as effective mass, Dingle temperature, and quantum relaxation time to be evaluated. These values are close to the ones which was determined for this sample from dc transport measurements. This implies the conduction is due to delocalized electrons, and dc and ac conductivities have the same mechanism.

In the integer quantum Hall effect regime realized in strong magnetic fields at low temperatures and small filling factors, $\sigma_1 < \sigma_2$ in the minima of the oscillations. This fact as well as a specific character of the experimental dependences of the ac conductivity on temperature and magnetic field in IQHE regime indicates the hopping nature of the high-frequency conductivity, which can be described within a "two-site" model.[1–3]

In this case, the mechanisms of conduction on a high-frequency and on a direct current are different. As a result, ac conductivity is standing greater than dc one $\sigma^{ac} > \sigma^{dc}_{xx}$.

We carried out the activation measurements of conductivity at odd filling factors, corresponding to the spin-split Landau levels. Dependence of the activation energy on magnetic field have given the g-factor g=4.5. We have constructed the dependence of g-factor on the Fermi energy using the value we found here as well as data of other authors.[4–6], which support the idea on significant non-parabolicity of the heavy hole energy spectrum.[7]

The acoustic effects was also measured at T=0.3 K as a function of angle of tilting the magnetic field with respect to the 2D channel normal. We determined the dependence of the real part of ac conductivity σ_1 on the tilt angle Θ. We demonstrate that for odd filling factors ν=3, 5 increase of conductivity in the minima of the oscillations with increasing Θ is a result of the in-plane field induced dependence of the g-factor on the tilt angle. The oscillations amplitude in the conductivity minima corresponding to even filling factors ν >8 is a consequence of an increase of the cyclotron effective mass in a parallel magnetic field.[8]

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Bi–functional nonlinearities in monodisperse granular ZnO slabs – Self-consistent transport theory and random lasing

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Random laser slabs made of cheap and easy to fabricate materials are most desirable, and above all, ultraviolet lasers are definitely of high interest in the optics community.

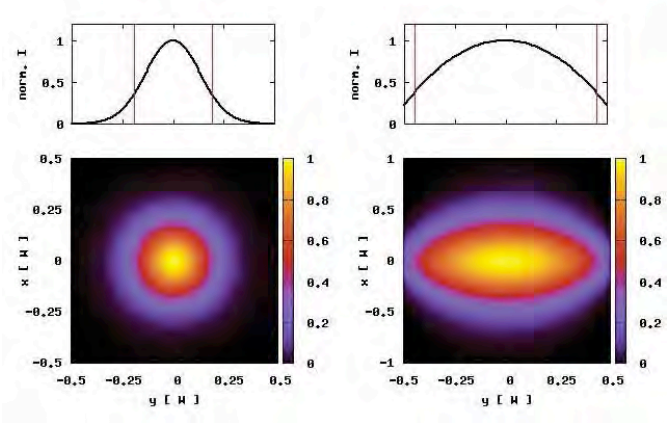

FIG. 1: Mie resonances and non-linear self-consistent gain play a key role for the tunability of random lasers made of bi–functional ZnO monodisperse powders. Further absorption and losses through open surfaces and into the substrate influence shape and intensity of coherently emitting modes. *Left panel*: The modes frequency is perfectly reflected by the substrate. Boundaries are right and left sided. *Right panel*: The mode leaks into the surrounding substrate and therefore significantly differs in shape. The profile of the emitted intensity displayed over space clearly proves the mapping of loss onto the spatially varying gain.

Alas it is not really broadly acknowledged that the functionality and principles which are all comprised within the key word 'random laser' are rather different although all footing on disorder and amplification through multiple scattering. A strong aspect is the disorder which can be present in various aspects. Experimentally often liquid laser dyes are mixed with monodisperse passive scatterers [1]. Rather unusual are bi-functional materials like ZnO which are used in polydisperse granular ensembles [2] or thin monodisperse [3] scatterer arrangements embedded in various types of substrates. The substrates may play a subtle role in the selection of the supported lasing modes by tuning their thresholds. In this paper we derive by means of quantum field diagrammatical photon transport [4–8] incorporating several loss channels an 'ab initio' theory for spatially confined and extended random laser modes. Various mode types in different gain regimes can be explained in a single framework of transport renormalized by dissipation. Dissipation processes are not only frequency selective with respect to the absorption and transmission properties of the substrate, they can be further influenced by the dispersity of the powder, and the nonlinear enhancement. We present results for thin and strongly lossy samples on silicon (SI) wavers.

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A nonmonotonic temperature dependence of the critical current in layered crystals of iron-based superconductor $Fe(Se_{0.3}Te_{0.7})_{0.82}$

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In recent years, much effort has been devoted to studying iron-based superconducting materials with high critical temperatures and magnetic fields in view of their possible wide practical application. Iron-based superconductors are typical representatives of systems lacking translational symmetry. This new class of superconductors, possessing critical (transition) temperatures up to T_c = 55 K, immediately drew the attention of researchers due to its unusual mechanism of superconductivity [1]. Indeed, in usual superconductors obeying the classical Bardeen–Cooper–Schrieffer theory, superconductivity cannot coexist with a magnetic order. In contrast, the new iron-based superconductors exhibit a fluctuational magnetic order that is believed to be responsible for the high T_c values. Among these iron-based superconductors, alloys of the $FeSe_{1-x}$ system possess the simplest structure comprising a large number of FeSe layers with $T_c \sim 8$ K [2]. The critical temperature can be controlled by partly replacing selenium (Se) atoms with tellurium (Te) atoms. For example, a $FeSe_{1-x}Te_x$ solid solution with $x = 0.5$ has $T_c \sim 14$ K. However, the complete replacement of selenium by tellurium results in loss of superconductivity and the establishment of a long-range antiferromagnetic order in the FeTe alloy. Another important process that accompanies the replacement of Se by Te is the appearance of interstitial Fe atoms in the crystalline lattice. The interstitial iron atoms are localized and involved in the magnetic interaction with Fe atoms occurring in planes of the lattice. Thus, at $T < T_c$, magnetic moments of the interstitial Fe atoms (magnetic impurity) occur between superconducting layers of $FeSe_{1-x}Te_x$. At a certain concentration of interstitial iron, a short-range ferromagnetic order can appear, such that the $FeSe_{1-x}Te_x$ solid solution in the direction perpendicular to layers can be treated as a hybrid structure of the $S–F_1–S–F_2–…F_n–S$ type (where S and F denote the superconductor and ferromagnetic, respectively). As is known, superconducting current I_s that passes via the SNS type junction (where N is a normal metal) can be described using the Josephson relation as $I_s = I_c \sin \varphi$ and, hence, varies with a period of 2π. Here, I_c is the maximum superconducting (critical) current and φ is the phase difference between two coherent ensembles of Cooper pairs belonging to the two superconductors. While the phase difference between two superconductors in the ground state in a Josephson junction of the SNS type is $\varphi = 0$, the phase in a junction with ferromagnet layer (F) will be the π-shifted due to the exchange field created by the ferromagnet [3]. In experiment, this is manifested by the behavior of critical current Ic in SFS structures, which oscillates and vanishes, depending on the temperature and thickness of the ferromagnetic layer [4].

We have studied equilibrium transport of Cooper pairs in the direction perpendicular to layers of a layered $Fe(Se_{0.3}Te_{0.7})_{0.82}$. We the first time observed: (i) the nonmonotonic variation of the critical current depending on the temperature and (ii) the enhancement of the Josephson current upon a change in the polarity of applied voltage. In the case of nonequilibrium superconductivity we observed unconventional current voltage characteristic.

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Anderson Metal-Insulator Transitions with Classical Magnetic Impurities

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We study the effects of classical magnetic impurities on the Anderson metal-insulator transition (AMIT) numerically. In particular we find that while a finite concentration of Ising impurities lowers the critical value of the site-diagonal disorder amplitude W_c, in the presence of Heisenberg impurities, W_c is first increased with increasing exchange coupling strength J due to time-reversal symmetry breaking. The resulting scaling with J is compared to analytical predictions by Wegner [2].

The results are obtained numerically, based on a finite-size scaling procedure of the typical density of states [3], which is the geometric average of the local density of states. The latter can efficiently be calculated using the kernel polynomial method [4]. Although still suffering from methodical shortcomings, our method proofs to deliver results close to established results by others [5] as shown in fig. 1, and has the potential to overcome limitations of similar approaches [6] that lack the finite-size scaling analysis.

We also discuss the relevance of our findings for systems like phosphor-doped silicon (Si:P), which are known to exhibit a quantum phase transition driven by the interplay of both interaction (Mott transition, magnetic correlations) and disorder (Anderson transition) [7].

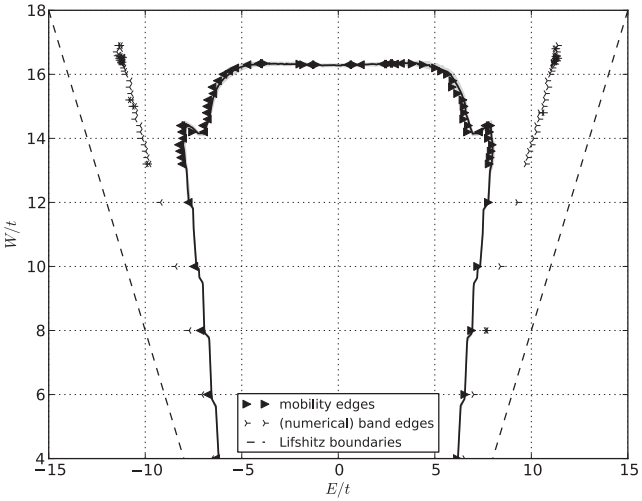

FIG. 1: Quantum phase diagram as function of energy E and disorder amplitude W for the pure Anderson tight binding model with box distribution (without magnetic impurities), given in terms of the hopping amplitude t. The triangles indicate the mobility edges for the considered values of W, pointing towards energies of localized states.

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A parallel kinetic Monte Carlo technique for the simulation of Coulomb glasses on Graphics Processing Units

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Kinetic Monte Carlo simulations of models of electron glasses are notoriously demanding, for two main reasons: elementary moves require O(N) operations because of the long-range interaction, and acceptance is very low at the temperatures of physical interest (of order $10^{-3}-10^{-2}$ of the natural energy scales of the problem). While for equilibrium Monte Carlo one can obtain exponential speedup by abandoning the physical dynamics, this is not possible for kinetic Monte Carlo.

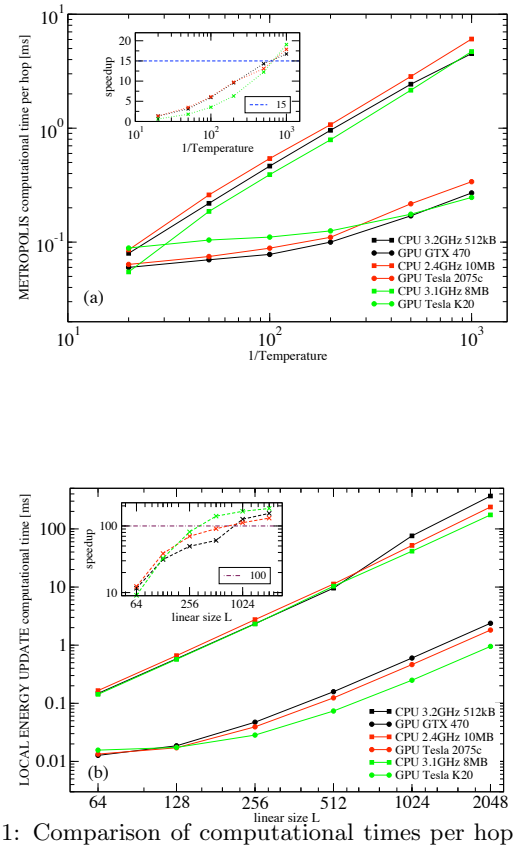

FIG. 1: Comparison of computational times per hop for the serial (CPU) and massively parallel (GPU) kinetic Monte Carlo implementations. (a) Metropolis update times as a function of temperature; (b) Local Energies Update times as a function of the linear system size. The insets show, respectively, the speedups achieved in each case.

In this work, we develop and implement a general parallel algorithm to tackle the problem of low acceptance, well suited for implementation on graphics processing units (GPU). We implement the method for the standard Coulomb glass model using the CUDA programming framework. The algorithm can be seen as a parallelization of the technique of [1]. Furthermore, for this problem we also exploit another source of parallelism, given by the massively parallel update of local energies.

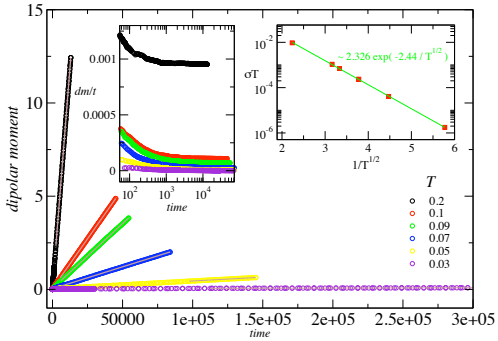

FIG. 2: Time evolution of the dipolar moment under a small applied electric field for different temperatures. The assymptotic slope (left inset) yields a conductance (right inset) obeying the Efros-Shklovskii law.

We observe an important increase of computing performance over previous numerical approaches, achieving speedups as large as 100x, thus allowing us to reach larger systems, longer simulation times, and lower temperatures (Figure 1). We perform preliminary tests of our code by verifying the Efros-Shklovskii law for conductance in 2D, also at very low temperatures (Figure 2), and quantitatively comparing our results with previous non-equilibrium results.

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Advanced Percolation Solution for Hopping Conductivity

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We show that the problem of the variable-range-hopping (VRH) in a system with exponential density of states can be mapped onto a universal geometrical problem of percolation via spheres with distributed sizes. The solution of the latter problem provided by numerical calculations allows for a highly accurate determination not only of the very pronounced exponential dependencies of the hopping conductivity on material parameters, but also of the more weakly dependent preexponential factors [1].

Our analytical results are confirmed by straightforward computer simulations and compared to former results present in the literature. Remarkably, the best performance among all results from the literature, as compared to our exact solution, is demonstrated by the result obtained by M. Grünewald and P. Thomas in 1979 [2], which, to our knowledge, was the earliest treatment of the VRH in the exponential DOS.

We also consider the case of nearest-neighbor hopping on a lattice, where the preexponential factors are provided by the percolation approach [3] for any shape of the DOS.

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Localization length and its fluctuations in an interacting fermionic system

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Using Imaginary Time Evolving Block Decimation we compute the localization length and its fluctuations for spinless electrons in the presence of disorder. We use one-dimensional systems of sizes up to 100 sites. A previous work found that repulsive interactions always enhance the effect of disorder (Physical Review B, 72, 24208, 2007), while other concluded that interactions can produce a larger localization length than the non-interacting case (Physical review letters, 81, 2308-2311, 1998). We aim to clarify this situation and to understand the behaviour of the fluctuations in the interacting system.

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Low temperature magnetic order caused by the exchange interaction in the impurity system of Si:P near the insulator- metal transition

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It is well known that the non-doped classical semiconductors (Ge, Si) are diamagnetics and the paramagnetic part of the magnetic susceptibility χ is determined in the main by the shallow impurities. This part of χ is detected by electron spin resonance (ESR) with confidence. Behavior of the paramagnetic susceptibility of the impurity spins in the semiconductor Ge:As near the insulator – metal (IM) transition was investigated in the wide temperature range [1-3]. It showed that the spin interaction in this concentration range leads to the system transformation from the Curie paramagnetic to Pauli one under the IM transition. Near the IM transition in the insulator state, spin interaction can to lead to the local magnetic order in the spin system. It was interesting to clear properties of the spin system of other semiconductors in that conditions. We investigated paramagnetic properties of Si:P near the IM transition by the ESR.
The samples with the concentration 1.3×10^{18} cm^{-3} and 3.3×10^{18} cm^{-3} were used for this purpose (critical concentration for the IM transition in Si:P $n_c = 3.5 \times 10^{18}$ cm^{-3}). Concentration was changed by the proton irradiation. It had to create irradiation centers with the concentration enough to visible compensation of the P impurity.
The temperature dependencies of the paramagnetic susceptibility χ in the non-compensated samples showed two ranges. They show Curie paramagnetic properties in the high temperature range ($\chi(T) \sim 1/T$). It means that the spin concentration in this range is constant. In the low temperature range, paramagnetic susceptibility almost not depends from the temperature. It means that the spin concentration falls due to antiparallel coupling and the sample reveals the spin glass properties. The transition temperature from the range one to the range two depends on the impurity concentration. In sample 1, the break of the curve take place at the temperature about 100 K and in the sample 2 it take place at the temperature about 10 K.
In the irradiated samples, it is shown any weak mark of the transition into the ferromagnetic state. We believe that the samples need in the much more irradiation dose.
These effects can be explained on the base of Hartree – Fok equation [4]. Decision of this one for two one electron atoms shows that the exchange interaction in this case has two parts: kinetic and Coulomb with the opposite signs. The antiferromagnetic coupling take place when the kinetic part is more then Coulomb. The ferromagnetic coupling takes place in the opposite case. The kinetic member is basic in the more high temperature range. The coulomb member becomes the basic in the low temperature range in the compensated samples when the main part of electrons falls lower then percolation level.
The authors are grateful for financial support to the Russian Foundation for Basic Research (grant no. 10-02-00629), RF Ministry of education and science (RF Presidential grant NSh-3008.2012.2), Presidium and Department of physical sciences of the Russian Academy of Sciences, and EC Research Executive Agency ("People" Programme, proposal 295180).

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Loop models with crossings

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Loop models are statistical mechanic problems whose degrees of freedom are loops or random walks. They are closely related to field theory and more conventional statistical mechanic models, and give an alternative view on critical phenomena. We study two-dimensional loop models with crossings both analytically and with extensive Monte Carlo simulations. Our main focus (the completely packed loop model with crossings) is a simple generalisation of well-known models which shows an interesting phase diagram with continuous phase transitions of a new kind.

The phase transitions considered here is a close analogue of those in disordered electronic systems – specifically, Anderson metal-insulator transitions – and provides a simpler context in which to study the properties of these poorly-understood critical points. Furthermore, results obtained for the exponents in these transitions seems to be close to those in the symplectic class of the Anderson transitions, and they encourage further studies in this direction.

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Effects of bulk charged impurities on the bulk and surface transport in three-dimensional topological insulators

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In the three-dimensional topological insulator (TI), the physics of doped semiconductors exists literally side-by-side with the physics of ultra-relativistic massless Dirac fermions. This unusual pairing creates a novel playground for studying the interplay between disorder and electronic transport. In this mini-review we focus on the disorder caused by the three-dimensionally distributed charged impurities that are ubiquitous in TIs, and we outline the effects it has on both the bulk and surface transport in TIs. We present self-consistent theories for Coulomb screening both in the bulk and at the surface, discuss the magnitude of the disorder potential in each case, and present results for the conductivity. In the bulk, where the band gap leads to thermally activated transport, we show how disorder leads to a smaller-than-expected activation energy that gives way to VRH at low temperatures. We confirm this enhanced conductivity with numerical simulations that also allow us to explore different degrees of impurity compensation. For the surface, where the TI has gapless Dirac modes, we present a theory of disorder and screening of deep impurities, and we calculate the corresponding zero-temperature conductivity. We also comment on the growth of the disorder potential as one moves from the surface of the TI into the bulk. Finally, we discuss how the presence of a gap at the Dirac point, introduced by some source of time-reversal symmetry breaking, affects the disorder potential at the surface and the mid-gap density of states.

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Finite-size effect in shot noise in hopping conduction

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Current flow in a conductor causes the increase of current fluctuations compared to the equilibrium Johnson-Nyquist noise. The excess white noise related to the discreteness of a quasiparticle charge q is called the shot noise. The shot noise value $S_I = 2FqI$ is governed by the correlations in electron motion, reaching it's maximum in the poissonian regime [3]. The Fano-factor F characterizes a non-Poissonian statistics of the current flow.

The Fano factor in the variable range hopping (VRH) regime is not universal and depends on the ratio of the sample length L and a correlation length L_c of the critical cluster, much larger than the average hop length. While available experiments [4, 5] are in a reasonable agreement with theoretical predictions for the case $L \gg L_c$, the shot noise in the opposite limit $L \sim L_c$ is not understood.

We study current shot noise in a macroscopic insulator based on a two-dimensional electron system in GaAs in a VRH regime. To define an insulating strip in the 2D channel a metallic front gate with the length of $L = 5\ \mu m$ along the current flow is used. Experimentally L_c is varied by changing either temperature or the gate voltage and it's value is estimated from transport measurements.

The conductance decreases roughly exponentially with decreasing electron density indicating the insulating regime of conduction. The conductance temperature dependence at low electron densities is best described by the 2D Mott's VRH law. The observed slow-down of T-dependencies at low temperatures may be qualitatively explained by a finite size effect, when L_c becomes comparable with L [6]. The linear dependence of threshold bias voltage on temperature also indicates the regime $L \sim L_c$ [7].

The shot noise spectral density S_I is measured at $0.5 - 4.2$ K in a frequency range $10 - 20$ MHz and is free from $1/f$ noise contribution. Our main observation is that in the regime $L \sim L_c$ shot noise becomes Poissonian (FIG. 1). This behavior can be interpreted as an observation of a finite-size effect in shot noise. At increasing temperature the shot noise decreases in a qualitative agreement with the temperature dependence of L_c.

To our best knowledge, this is the first experimental demonstration of the poissonian shot noise value in a macroscopic insulator with VRH conduction. We propose a classical approach capable to explain this result. It opens up a possibility of accurate quasiparticle charge measurement in nontrivial insulating states in charge density wave compounds, cooper pair insulators and in the bulk of a 2D system in the fractional quantum hall effect.

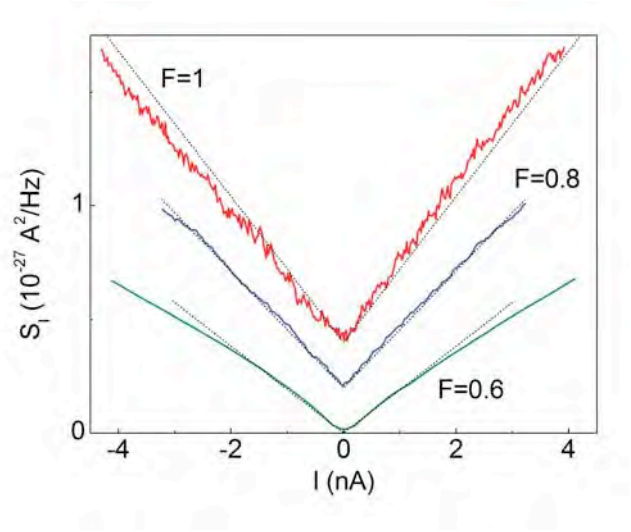

FIG. 1: Shot noise spectral density as a function of current at $T = 0.56$ K. The resistivity (the Mott temperature) from top to bottom are: $R_\square = 58$ MΩ ($T_0 \approx 300$ K),$R_\square = 8.8$ MΩ ($T_0 \approx 140$ K),$R_\square = 1$ MΩ ($T_0 \approx 40$ K). The dashed lines are fits used to extract the Fano factor. The scales on both axes are reduced by a factor of 50 (5) for the lowest (middle) curve and the two upper curves are vertically offset in steps of 2×10^{-28}A^2/Hz

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Determination peculiarities of the paramagnetic susceptibility in the semiconductors near the insulator – metal transition by electron spin resonance on the Ge:As instance

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An increase in the impurity concentration in a semiconductor leads to a stronger interaction between impurity centers and to a second-order phase transition from the insulating to metallic state (IM), with conductivity appearing at zero temperature. Together with the conductivity, the magnetic properties of the semiconductor change in the region of the IM transition. The Curie paramagnetism exhibited by noninteracting impurity electrons, characteristic of the insulating state, gives way to the Pauli paramagnetism of the metallic state. Thus, a study of the magnetic properties of a semiconductor near the IM phase transition involves estimation of the magnetic susceptibility. In principle, this can be done by means of the electron spin resonance (ESR) technique [1, 2]. However, a number of problems associated with the pronounced change in the conductivity of a sample give rise to specific features that strongly complicate an analysis of ESR spectra. They are: the cavity Q factor decreasing, the resonance Lorentzian line distort and it transformation into the Dyson line, the skin effect appearance. The least studied among the problems considered here is that of comparison of the Lorentzian and Dyson line shapes. The problem is associated with determining the magnetic susceptibility of a sample by integration of the absorption line. The comparison of the both line forms was executed on the base of the [3, 4]. It shows that the integration of the positive part of the resonance line derivative of each line gives the same result with the exactness about 15 %.
Experiments were performed on n-Ga:As samples cut-out from a single ingot with an initial impurity concentration of 3.6×10^{17} cm^{-3} and compensated by neutron transmutation doping. They confirmed that the magnetic susceptibility can be determined in the case of Dyson lines by comparing the second integrals of the positive parts of derivatives of this resonance absorption line and a line of the Lorentzian shape. The error of this procedure does not exceed 10–15 %.
A procedure for determining the magnetic susceptibility for the example of Ge:As includes three parts: *i*) use of an ESR cavity with two magnetic field antinodes, with a sample under study placed in one of these, and a reference sample into the other; *ii*) measurement of the temperature dependence of the resistivity of a sample ("poor" conductor) in order to take into account the nonuniformity of the microwave field distribution in the sample; *iii*) double integration of the measured positive part of the derivative of the Dyson resonance line. The procedure yields the magnetic susceptibility with an error not exceeding the theoretical result.
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Finite size scaling for 3D quantum percolation using multifractal analysis

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A three dimensional nearest neighbor, noninteracting hopping model is investigated, where a special kind of disorder has been introduced: every site is filled with probability p, and empty with probability $1-p$. This model is called the quantum percolation model. We use a multifractal quantity, α, to describe the scaling of the eigenstates with system size, $|\psi|^2 \sim L^{-\alpha}$. The localization–delocalization transition has been investigated based on numerical simulations of linear system sizes $24 \leq L \leq 96$ ensuring higher precision as compared to previous calculations.

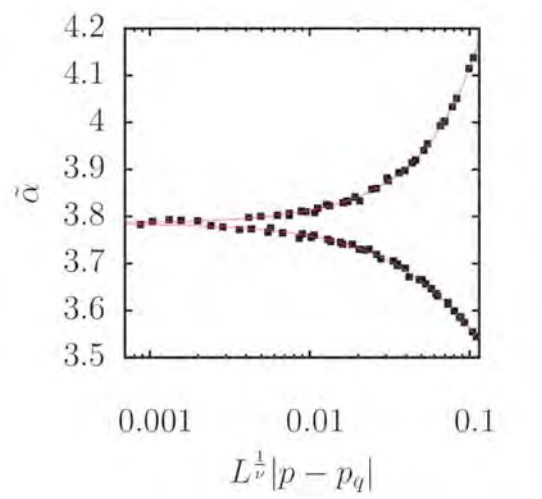

FIG. 1: Scaling function, $\tilde{\alpha}$, at energy $E = 0.1$.

The critical point and the critical exponent were calculated with the help of one parameter finite size scaling of α. The critical point was found energy-dependent, and the critical line on the $p-E$ plane (mobility edge) has been obtained. The resulting critical exponent is close to the one for the 3D Anderson transition. Details of the nature of geometrically determined localized states are presented.

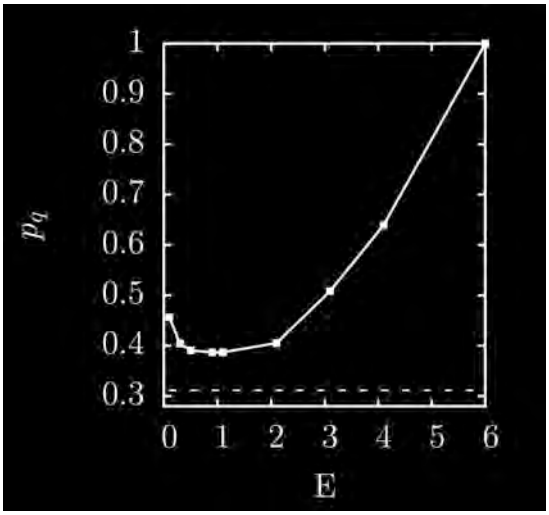

FIG. 2: The critical line on the $p-E$ plane (mobility edge). Dashed line shows the classical percolation threshold, $p_c = 0.3116 \pm 0.0002$ [1]

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Decoherence-induced conductivity in the one-dimensional Anderson model

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We examine the effect of decoherence in the one-dimensional Anderson model by a recently introduced statistical model [2–5]. In this model we introduce stochastically distributed decoherence bonds into the sample where complete loss of the phase is assumed. Afterwards the physical quantity of interest is ensemble averaged over the such obtained decoherence configurations.

Averaging the resistance of the sample, the calculation can be performed analytically. In the thermodynamic limit we find a decoherence-driven transition between quantum-coherent localized and ohmic behavior at a decoherence density determined by the second-order generalized Lyapunov exponent (GLE) [6] .

Averaging the conductance of the sample numerically, decoherence induced conductivity is found also at a critical degree of decoherence.

This means, on the other hand, that below this critical decoherence density the system remains localized, thus we find Anderson localization in presence of decoherence, i.e. many-body localization.

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Low temperature transformation from antiferromagnetic to ferromagnetic order in the impurity system of Ge:As near the insulator – metal transition

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The phenomenon of the low temperature transformation from the antiferromagnetic state to ferromagnetic one was experimentally discovered and studied in the impurity system of the nonmagnetic semiconductor Ge:As near the insulator – metal (MI) transition. It is well known that the non-doped classical semiconductors (Ge, Si) are diamagnetics and the paramagnetic part of the magnetic susceptibility χ is determined in the main by the shallow impurities. This part of χ is detected by electron spin resonance (ESR) with confidence. Near the critical concentration n_c for the IM transition, spins interact and Curie paramagnetic transforms into the Pauli paramagnetic in the metallic state of semiconductor. Near the IM transition in the insulator state, spin interaction can to lead to the local magnetic order in the spin system.
We found and studied antiferromagnetic coupling early in Ge:As on the Ge:As sample series where the electron concentration changed from 3.6×10^{17} (almost the point of the IM transition) to 1×10^{17} cm^{-3} by the impurity Ga compensation due to transmutation neutron doping [1]. This phenomenon was studied by the ESR. We measured the temperature dependence of χ, spin concentration n, g-factor and line width. The experimental results showed that the temperature dependence of χ and n had four parts. In the high temperature range 1 ($T \geq 30$ K) χ aspires to the Curie law. When the temperature decreases (range 2; $10 \leq T \leq 30$ K), $\chi(T)$ grows more slowly then Curie law. In the next temperature range 3 ($3 \leq T \leq 10$ K), $\chi(T)$ grows more slowly then Curie law, and in the range 4 ($T \leq 3$K), $\chi(T)$ submits to Curie law. We connect this behavior $\chi(T)$ with the antiferromagnetic spin coupling in the range 2, with the transition to the ferromagnetic spin coupling in the range 3 and with full ferromagnetic coupling in the range 4. The ferromagnetic state confirms by the ferromagnetic behavior of the dependencies $1/\chi(T)$, changing of the temperature dependencies g-factor and visible growth of the line width. The sample compensation plays important role in the ferromagnetic range appearance.
These effects can be explained on the base of Hartree – Fok equation [2]. Decision of this one for two one electron atoms shows that the exchange interaction in this case has two parts: kinetic and Coulomb with the opposite signs. The antiferromagnetic coupling take place when the kinetic part is more then Coulomb. The ferromagnetic coupling takes place in the opposite case. The kinetic member is basic in the more high temperature range. The coulomb member becomes the basic in the low temperature range in the compensated samples when the main part of electrons falls lower then percolation level. The preliminary results were published in [3].
The authors are grateful for financial support to the Russian Foundation for Basic Research (grant no. 10-02-00629), RF Ministry of education and science (RF Presidential grant NSh-3008.2012.2), Presidium and Department of physical sciences of the Russian Academy of Sciences, and EC Research Executive Agency ("People" Programme, proposal 295180).

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