The Abdus Salam International Centre for Theoretical Physics

Workshop on Complex Quantum Systems: Non-Ergodicity, Glassiness and Localization

27 – 31 August 2012

BOOK OF ABSTRACTS

INVITED TALKS

CONTRIBUTED TALKS

G. Aeppli (LCN London)

Quantum and classical dynamics in three-dimensional frustrated magnets

Unexpected features in the linear and non-linear response of three-dimensional, rare-earth-based frustrated magnets are described. External magnetic fields tune the relative importance of quantum and classical effects. Detailed results to be described include a dissipation-less monopole response in spin ice (1), spectral hole burning in gallium gadolinium garnet (2), and dimensional reduction in LiErF4(3).

(1) Bovo et al., submitted (2012).
(2) Kraemer et al., Science 336, 6087, 1416-1419 (2012).
(3) Ghosh et al. Phys. Rev. Lett. 101, 157205 (2008).

Ariel Amir (Harvard)

Localization-delocalization transition of phonons in disordered solids

We study, theoretically and numerically, a minimal model for phonons in a disordered system that shows rich behavior in the localization properties of the phonons as a function of the density, frequency and the spatial dimension. We use a renormalization-group-type analysis to argue for a localization-delocalization transition in dimensions higher than one. The structure of the modes reflect a divergent percolation length that arises from the disorder in the springs without being explicitly present in the definition of our model. We calculate the speed-of-sound of the delocalized modes (phonons) and corroborate it with numerics. The implications for diffusion in random environments and on the vibrational spectrum of colloidal glasses are discussed.

D. Basko (Grenoble)

On the local nature and scaling of chaos in weakly nonlinear disordered chains

The dynamics of a disordered nonlinear chain can be either regular or chaotic with a certain probability. The chaotic behavior is often associated with the destruction of Anderson localization by the nonlinearity. In the present work, it is argued that at weak nonlinearity chaos is nucleated locally on rare resonant segments of the chain. Based on this picture, the probability of chaos is evaluated analytically. The same probability is also evaluated by direct numerical sampling of disorder realizations, and quantitative agreement between the two results is found.

F. Becca (SISSA Trieste)

Localization and glassy dynamics of many-body quantum systems

When classical systems fail to explore their entire configurational space, intriguing macroscopic phenomena like aging and glass formation may emerge. Also closed quantum-mechanical systems may stop wandering freely around the whole Hilbert space, even if they are initially prepared into a macroscopically large combination of eigenstates. Here, we report numerical evidences that the dynamics of strongly interacting lattice bosons driven sufficiently far from equilibrium can be trapped into extremely long-lived inhomogeneous metastable states. The slowing down of incoherent density excitations above a threshold energy, much reminiscent of a dynamical arrest on the verge of a glass transition, is identified as the key feature of this phenomenon. We argue that the resulting long-lived inhomogeneous pattern is in turn responsible for the lack of thermalization observed in large finite size systems.
Such a rich phenomenology could be experimentally uncovered upon probing the out-of-equilibrium dynamics of conveniently prepared quantum states of trapped cold atoms which we hereby suggest.

In collaboration with G. Carleo, M. Schiro, and M. Fabrizio
[1] G. Carleo, F. Becca, M. Schiro, and M. Fabrizio, Scientific Reports 2, 243 (2012).

T. Bourdel (Palaiseau)

Effect of disorder in two-dimensional Bose gases

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We study the effects of disorder in ultracold 2D gases, well controlled systems where many parameters can be tuned. In particular, we analyze two different situations. First the expansion of non- interacting particles is quantitatively studied [1]. Diffusion and Anderson effects can be observed. Second, we focus on the physics of interacting bosons.
Interacting 2D Bose gases undergo a thermal phase transition to a superfluid phase at low temperature. It is a Berezinskii-Kosterlitz-Thouless type transition in which the interactions between particles are playing a crucial role. We study this transition through the emergence of phase coherence in the momentum distribution [2].
The influence of disorder on the 2D superfluid transition is an important open problem in condensed matter physics. It is relevant to a variety of systems such as helium films, thin metallic films, or even high temperature superconductors. Experimentally we study how microscopically correlated disorder changes the coherence properties of the 2D Bose gas close to the superfluid transition as a function of both temperature and disorder strength [3]. Our study is an experimental realization of the dirty boson problem in a well controlled atomic system suitable for quantitative analysis.

References

[1] M. Robert-de-Saint-Vincent, et al., Anisotropic 2D diffusive expansion of ultra-cold atoms in a disordered potential, Phys. Rev. Lett. 104, 220602 (2010).
[2] T.Plisson,etal.,Coherencepropertiesofa2DtrappedBosegasaroundthesuperfluidtransition, Phys. Rev. A 84, 061606(R) (2011).
[3] B. Allard, et al., Effect of disorder close to the superfluid phase transition in a two-dimensional Bose gas, Phys. Rev. A 85, 033602 (2012).

C. Castelnovo (London)

Topological Order and Glassiness

Albeit they are intrinsically different phenomena, certain aspects of topological order and glassiness exhibit intriguing similarities. For instance, if we take the view of a glassy energy landscape where phase space is broken down into statistically similar basins separated by large energy barriers, one could then view topologically ordered states as a realisation of the ultimate glassy system, where the basins are in fact statistically \emph{identical} to any local measurement. In this talk we shall explore some of these points of contact between the two areas of research. We show how exactly solvable models for topological order can inspire new models of quantum glasses where physical quantum relaxation processes (namely, finite-range tunnelling) at low temperature incur a dynamical arrest with diverging time scales displaying either strong or fragile glass behaviour. We also investigate the direct interplay of topological order and conventional (Edwards-Anderson) glassiness by introducing random fields in Kitaev's toric code. We argue that novel quantum phases appear where topological order coexists with spin glassiness.

L. Cugliandolo (LPTHE Jussieu Paris)

From non equilibrium quantum Brownian motion to impurity dynamics in exotic quantum liquid baths

Motivated by recent experiments on impurity motion in one dimensional ultra cold quantum liquids we derive the generating functional for all non equilibrium correlation functions of a quantum Brownian particle coupled to a quantum bath of harmonic oscillators. With our new method we investigate three problems of current interest: the slow relaxation dynamics of a particle confined in a harmonic potential after a position measurement; the relaxation dynamics of a particle trapped in a harmonic potential after a quantum quench realized as a sudden change in the potential parameters; the evolution of an impurity in contact with a one dimensional bosonic quantum gas. The latter problem has been recently realized in experiments with cold atoms. By using the Luttinger-Tomonaga theory we show that the quantum gas is equivalent to an exotic quantum bath of harmonic oscillators with intriguing features. The remarkable similarity between our theoretical results and experimental data is discussed.

C. Dasgupta (Bangalore)

Supersolid behavior from superfluidity along extended defects

Two studies of supersolid behavior arising from the occurrence of superfluidity along extended crystalline defects, such as dislocation lines and grain boundaries, will be discussed.
We first consider a two-dimensional polycrystalline system of bosons and show, using a standard mapping between the zero-temperature properties of this system and the statistical mechanics of interacting vortex lines in the mixed phase of a type-II superconductor, that this system exhibits nonclassical rotational inertia (NCRI) arising from superfluidity along the grain boundaries. A calculation of the NCRI from the equations of superfluid hydrodynamics shows that it increases very abruptly as the superfluid regions form a connected, system-spanning structure with one or more closed loops.
In the second study, the thermodynamics of superfluid ordering along a random network of dislocation lines is analyzed using coupled spin models in which the system of dislocation lines is represented by the line defects of one spin system and a second spin system represents the superfluid order parameter. In particular, we examine how the superfluid ordering is affected by the motion of the line segments that form the network.

M. Foster (Rutgers)

Interaction-mediated surface state instability in disordered three-dimensional topological superconductors with spin SU(2) symmetry

We show that arbitrarily weak interparticle interactions destabilize the surface states of 3D topological superconductors with spin SU(2) invariance (symmetry class CI), in the presence of nonmagnetic disorder. The conduit for the instability is disorder-induced wavefunction multifractality. We argue that time-reversal symmetry breaks spontaneously at the surface, so that topologically- protected states do not exist for this class. The interaction-stabilized surface phase is expected to exhibit ferromagnetic order, or to reside in an insulating plateau of the spin quantum Hall effect.

Reference: http://arxiv.org/abs/1204.3639

I. Hen (UCSC)

Complexity of the Quantum Adiabatic Algorithm

The Quantum Adiabatic Algorithm (QAA) has been proposed as a mechanism for efficiently solving optimization problems on a quantum computer. Here, we discuss several applications of the algorithm and analyze its efficiency by considering several hard problems. This is done mainly by studying the size dependence of the typical minimum energy gap of the Hamiltonian using quantum Monte Carlo methods. While for most problems we find that the minimum gap decreases exponentially with the size of the problem, indicating that the QAA is not more efficient than existing classical search algorithms, for other problems there is evidence to suggest that the gap may be polynomial near the phase transition.

Y. Imry (Weizmann)

Straightforward quantum-mechanical derivation of the Crooks fluctuation theorem and the Jarzynski equality [1]

Doron Cohen and Yoseph Imry

We obtain the Crooks and the Jarzynski non-equilibrium fluctuation relations using a direct quantum-mechanical approach for a finite system that is either isolated or coupled not too strongly to a heat bath.
These results were hitherto derived mostly[2] in the classical limit. The two main ingredients in the picture are the time-reversal symmetry and the application of the first law to the case where an "agent" performs work on the system. No further assumptions regarding stochastic or Markovian behavior are necessary, neither a master equation nor a classical phase-space picture are required.
The simplicity and the generality of these non-equilibrium relations are demonstrated, giving very simple insights into the Physics.

1. D. Cohen and Y. Imry, Phys Rev E86, 011111 (2012).
2. See, however, e.g. J. Kurchan, arXiv:cond-mat/0007360; P. Talkner and P. Hanggi, J. Phys. A 40, F569 (2007); C. Jarzynski and D. K. Wojcik, Phys. Rev. Lett. 92, 230602 (2004).

L. Ioffe (Rutgers)

Puzzle of the intermediate bad metal phase in Josephson junction arrays

J. Kurchan (ESPCI Paris, France)

Quantum annealing and the generic sign problem

The sign problem arises when we need to calculate averages with a canonical distribution when the energy (or action) is not real. I show how such a problem may be solved by quantum annealing, and one obtains a square-root ("Groverish") gain in computer time.

C. Laumann (Harvard)

TBA

P. LeDoussal (ENS Paris)

Universal statistics for directed polymers and the KPZ equation from the replica Bethe Ansatz

I will first review the problem of the directed polymer (DP) in a random potential and of the Kardar Parisi Zhang (KPZ) growth equation, and their mutual relation. I will introduce the replica Bethe Ansatz method and how it has allowed us to obtain the distribution of the free energy of the DP and of the height field of the KPZ equation. For large polymer size (large KPZ time) this distribution converges to the Tracy Widom distribution of the largest eigenvalue of a gaussian random matrix. I will discuss our results for both fixed and free endpoints corresponding to growth from a droplet or from an initially flat interface.

Z. Ovadyahu (Jerusalem)

Putting the Electron-Glass to Work; a test for Many-Body Localization

We describe how some of the unique properties of Electron-Glasses may be used to gain information on the fundamental nature of the Anderson-localized phase. Our experiments suggest that while the effective electron-electron interaction is long range, the electronic energy-spectrum of the system remains discrete. Therefore, electron thermalization hinges on the existence of a continuous bath (presumably, phonons). Also, the effect of non-ohmic field is not tantamount to heating; contrary to common views the conductance measured under (non-equilibrium) steady-state conditions is not a reliable thermometer. The implications of these results to the long-standing mystery of the pre-exponential term of hopping conductivity will be discussed.

D. Popovic (Tallahassee)

Emergence of superconductivity from the dynamically heterogeneous insulating state in $La_{2-x}Sr_xCuO_4$

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The properties of the insulating state and the onset of superconductivity at low doping have been key issues in the physics of cuprate high-temperature superconductors. In lightly doped, insulating $La_{2-x}Sr_xCuO_4$ (LSCO), magnetotransport and resistance noise measurements have revealed the existence of a charge glass state at very low temperatures deep within the spin glass phase (at temperatures $T \ll T_{SG}$). In particular, the hysteresis and memory in the magnetoresistance (MR) and the onset of non-Gaussian noise suggest that the charge dynamics becomes increasingly slow and correlated as *T* approaches zero. The analysis of the higher order noise statistics provides evidence for the existence of a collective ground state of charge clusters ("cluster charge glass") located in CuO_2 planes, which seem to coexist with charge-poor antiferromagnetic domains that are frozen at such low *T*.

The hysteretic positive magnetoresistance exhibited at low fields has been used as a practical tool to detect the underlying charge glassiness in $La_{2-x}Sr_xCuO_4$ for doping levels that range from the insulator to the superconductor. Moreover, by extending the MR measurements to high fields, we have been able to probe the presence of superconducting fluctuations. We find that the charge glass behavior, characteristic of the insulating state, is suppressed with doping, but it coexists and competes with superconducting fluctuations that emerge on the insulating side of the superconductor-insulator transition (SIT). Our findings are consistent with the picture of the SIT driven by phase fluctuations and localization of Cooper pairs by the competing charge order.

Keywords: cuprates, superconductor-insulator transition, charge heterogeneity

L. Sanchez-Palencia (Palaiseau)

Localization and Superfluidity of Interacting Bose Gases in the Presence of Disorder

In this contribution, we discuss many-body Anderson localization in Bose gases with weak repulsive interactions [1,2]. We show that, while the ground state is extended owing to the strong interactions, the collective excitations, i.e. the Bogolyubov quasi-particles, are Anderson localized. We develop an analytical approach, which allows us to derive exact results, and draw a clear physical picture, which reveals the relevance of screening. A consequence of the latter is that the localization properties of Bogoliubov quasi-particles are radically different from those of single particles. For instance, we find that the localization features a maximum when the healing length of the condensate is of the order of the correlation length of the disorder. Numerical calculations in support of our analytical calculations are also presented. We also discuss recent results on the superfluidity of a disordered Bose gas at finite temperature. We show that the superfluid properties show a nontrivial behavior versus temperature and disorder, and discuss its relation to localization [3].

References

[1] P. Lugan, D. Clément, P. Bouyer, A. Aspect, and L. Sanchez-Palencia, Phys. Rev. Lett. 99, 180402 (2007).
[2] P. Lugan and L. Sanchez-Palencia, Phys. Rev. A 84, 013612 (2011).
[3] S. Lellouch and L. Sanchez-Palencia, in preparation (2012).

M. Schechter (Ben Gurion)

$LiHo_xY_{1-x}F_4$ – random field Ising model beyond Imry-Ma

Recently it was shown that the random field Ising model (RFIM) can be realized in the $LiHo_xY_{1-x}F_4$ in both its spin glass and ferromagnetic phases. This has made possible the experimental study, and intrigued the theoretical study, of the RFIM in novel regimes. Here we discuss the RFIM for a ferromagnet with competing interactions and a nearby spin-glass phase, and for the dilute dipolar glass. Relation to recent remarkable experiments on the ferromagnetic $LiHo_xY_{1-x}F_4$, and to older experiments on dilute orientational glasses, will be discussed.

B. Spivak (Seattle)

Propagation of nonlinear waves in disordered media

We study the propagation of stationary waves in disordered non-linear media described by the nonlinear Schrödinger equation and show that for given boundary conditions the number of solutions of the equation increases exponentially with sample size. We discuss the ballistic case, the sensitivity of the solutions to the change of external parameters, and the similarity of this problem to the problem of spin glasses. We also discuss the relevance of our results to recent experiments on cold gases in atomic traps.

A. Tsvelik (BNL Upton, NY)

Universal Features of the Excitation Spectrum in Generalized Gibbs Distribution Ensemble

It is shown that excitation spectra of Generalized Gibbs Ensembles (GGE) of one-dimensional integrable models with isotopic symmetry contain universal features insensitive to details of the distribution. Namely, the low energy limit of the subsystem of isotopic (for instance, spin) excitations is described by the effective action of a ferromagnet at thermodynamic equilibrium with a single temperature which stiffness is determined by the initial conditions.

A. de Luca (SISSA Trieste)

The importance of being many-body: when localization and interactions meet

We investigate the ergodicity properties of a quantum wave function in presence of weak and strong disorder. Some standard indicators of the usual Anderson problem turn out to be appropriate also for the many-body case and we are able to provide a good estimation for the position of the transition in the XXX spin chain with random fields. We point out some basic ingredients of the transition by comparison with the Bethe-lattice case.

Y.J. Kao (Taipei)

Tuning the disorder in superglasses

We study the interplay of superfluidity, glassy and magnetic orders in the XXZ model with random Ising interactions on a three dimensional cubic lattice. In the classical limit, this model reduces to a *+-J* Edwards-Anderson Ising model with concentration p of ferromagnetic bonds, which hosts a glassy-ferromagnetic transition at a critical concentration $p_c^{cl} \sim 0.77$. Our quantum Monte Carlo simulation results show that quantum fluctuations stabilize the coexistence of superfluidity and glassy order ("superglass"), and shift the (super)glassy-ferromagnetic transition to $p_c > p_c^{cl}$. In contrast, antiferromagnetic order coexists with superfluidity to form a supersolid, and the transition to the glassy phase occurs at a higher p.

M. Ortuño Ortin (Murcia)

Complex quantum systems and loops models

Some quantum problems can be mapped to statistical problems, which in turn can be framed in terms of random curves. Numerical simulations of loops models can be more efficient that the equivalent quantum models. An example are network models that belong to symmetry class C, representing quasiparticle dynamics in a gapless spin-singlet superconductor without time-reversal invariance. It is a special feature of network models with this symmetry that the conductance and density of states can be expressed as averages in a classical system of dense, interacting random walks. Using this mapping, we perform a very precise numerical study of critical behavior at an Anderson transition in three-dimensions. We also study the spin quantum Hall effect and transitions between Hall plateaus in quasi-2D class C network models consisting of several coupled layers.

A small modification of the model allows us to consider magnetotransport in high-mobility 2D electron gas in a non-quantizing magnetic field. In this limiting case, there is a strong suppression of interference, and transport reduces to classical percolation. The corresponding percolation problem is bond percolation on two layers coupled by interlayer bonds.

We finally consider a class of 3D loop models that show transitions between phases with infinite loops and short-loop phases, and can be mapped to CP^(n-1) sigma models, where n is the loop fugacity. Using Monte Carlo simulations, we find continuous transitions for n=1, 2, 3, and first order transitions for n>4. The results are relevant to (2+1)-dimensional quantum magnets and to deconfined quantum criticality.

M. Tarzia (Paris Jussieu)

Difference between ergodicity, level statistics and localization transitions for the Anderson model on the Bethe lattice

I will present some results on an ongoing work on the ergodicity properties of the Anderson model defined on the Bethe lattice. Our study is motivated by the conjectured existence of a phase for intermediary disorder strength values whose ergodicity properties are distinct from the fully ergodic extended phase, as well as from the completely ergodicity broken localized one. Apart from the intrinsic interest in studying these different ergodicity regimes, the relevance of this investigation also bares on the relation of the aforementioned model to the many-body localization problem, through a mapping of the decay of quasi-particle states of the interacting system in Fock space representation onto an appropriate Anderson (single-particle) localisation problem on a tree. For an ensemble of system's realizations, we have studied eigenvalues and eigenstates statistics through exact diagonalization. In particular we analysed the neighboring gaps ratio statistics, the statistics of inverse participation ratios, including multifractality analysis. We find evidence of the presence of an intermediary delocalized non-ergodic phase and of the fact that ergodicity-level statistics and Anderson localization transitions are distinct. These results are also confirmed by the analysis of the "exact" solution of the recurrence equations for the probability distributions of local Green functions, which shows anomalous power-law decays in the intermediate phase.