ICTP SUMMER COLLEGE 2009
"Nonequilibrium Physics from Classical to Quantum Low Dimensional Systems"

SEMINARS

FIRST WEEK

Date 6/7/2009,
Time 4 p.m.

Speaker: A. Gambassi (SISSA)

Title: Non-equilibrium dynamics in classical critical systems: Aging, universality, and effective temperatures.

Abstract: The collective dynamics at critical points provides a simple instance of slow non-equilibrium evolution, with aging phenomena and a violation of the fluctuation-dissipation relation. The universality at these critical points can be conveniently exploited in order to characterize via field-theoretical methods the non-equilibrium behavior after a thermal quench. We review some of the theoretical results which have been obtained in recent years for the associated (universal) quantities, such as the fluctuation-dissipation ratios, discussing also the influence of the initial conditions and the possibility of introducing a non-equilibrium effective temperature.

Date 7/7/2009,
Time 2 p.m.

Speaker: J. Garrahan (Nottingham)

Title: Molecular Random Tilings

Abstract: We have recently shown that a small organic molecule, p-terphenyl-3,5,3',5'-tetracarboxylic acid, when adsorbed on graphite self-assembles into a two-dimensional rhombus random tiling. This tiling is close to ideal, with long range correlations punctuated by sparse localised tiling defects. This is a rare example of a molecular system displaying "Coulomb" phase behaviour and fractional excitations. I will discuss the static and dynamic properties of these kind of random tilings, and explore analogies with other dynamically arrested systems such as glasses.

Date 7/7/2009,
Time 2.45 p.m.

Speaker: S. Puri (New Delhi)

Title: Pattern Formation in the Kinetics of Phase Transitions

Abstract: Consider a system which is rendered thermodynamically unstable by a sudden change of parameters, e.g., temperature, pressure, etc. The system evolves towards its new equilibrium state via the emergence and growth of domains enriched in the preferred phase. Problems in this area of "kinetics of phase transitions" have received much research attention. In this talk, we review our understanding of this area. We conclude by mentioning novel systems (e.g., granular materials) where one observes a range of phase ordering phenomena.

Date 8/7/2009,
Time 2 p.m.

Speaker: K. Matveev (Argonne)

Title: Conductance of fully equilibrated quantum wires

Abstract: We study the conductance of a quantum wire in the presence of weak electron-electron scattering. In a sufficiently long wire the scattering leads to full equilibration of the electron distribution function in the frame moving with the electric current. At non-zero temperature this equilibrium distribution differs from the one supplied by the leads. As a result the contact resistance increases, and the quantized conductance of the wire acquires a quadratic in temperature correction. The magnitude of the correction is found by analysis of the conservation laws of the system and does not depend on the details of the interaction mechanism responsible for equilibration.

Date 8/7/2009,
Time 2 p.m.

Speaker: M. Houzet (Grenoble)

Title: Current fluctuations in Multiple Andreev Reflexion regime

Abstract: The possibility to reverse the sign of the current-current cross-correlation in multiterminal nanostructures has attracted both theoretical and experimental interest in the last decade. Indeed, while the cross-correlation is always negative in non-interacting fermionic devices, a positive cross-correlation is the signature of strong interactions in many-body systems. We will show that large positive cross correlations may arise in the case of a normal metallic island contacted to all superconducting leads. These correlations take place in the Multiple Andreev Reflexion regime, when the subgap electrons are trapped in the island and they must perform several Andreev reflections in order to gain enough energy and escape as quasiparticles in the leads.

Date 9/7/2009,
Time 2 p.m.

Speaker: R. Shekher (Goteborg)

Title: Quantum Coherent Nanoelectromechanics.

Abstract: Charge transport in electronic mesoscopic devices is strongly affected by nanoelectromechanical (NEM) coupling. Shuttling of single electrons and nanoelectromechanics of suspended nanowires are examples of such NEM phenomena. In this talk we will focus on a new functionality of NEM devices which occurs due to quantum coherence in both electronic and mechanical subsystems. Mechanically assisted superconducting weak links and mechanically induced Aharonov-Bohm effect in 1D suspended nanowire will be discussed as examples of such quantum coherent nanoelectromechanical phenomena.

Date 9/7/2009,
Time 2.45 p.m.

Speaker: F. Hekking (Grenoble)

Title: Electron Cooling in NIS tunnel junctions

Abstract: Under proper conditions, single-particle tunneling in a Superconductor (S) – Normal (N) metal tunnel junction can lead to refrigeration: heat is extracted from N and the temperature of the electronic population decreases accordingly. After a brief review of this phenomenon, we discuss the theoretical framework to describe non-equilibrium quasi-particle electric and heat currents in NIS tunnel junctions in the dirty limit. We discuss the optimal conditions for refrigeration in different situations.

We show in particular that the two-particle Andreev current generates Joule heat that is deposited in the normal metal electrode. At low temperatures this heating dominates over the single particle cooling. We also consider the effect of inelastic relaxation in the S lead. In the absence of strong relaxation the electric current and the cooling power are suppressed, which we ascribe to the effect of back-tunneling of non-equilibrium quasi-particles into the normal metal.

Finally, we show that thermal noise generated by a hot resistor *R* can, under proper conditions, also catalyze heat removal from a normal metal in contact with a superconductor via a tunnel barrier. Such a NIS junction acts as Maxwell's demon, rectifying the heat flow. We obtain analytical results for the cooling performance in an idealized high impedance environment, and perform numerical calculations for the general *R*. We conclude by assessing the experimental feasibility of the effect.

Date 9/7/2009,
Time 4 p.m.

Speaker: N. Andrei (Rutgers)

Title: Quantum Impurities out-of-Equilibrium

Abstract: We develop an exact non-perturbative framework to compute the nonequilibrium steady state properties of quantum impurities connected to leads subject to source-drain voltage. We show that in the open system limit the non-equilibrium physics is captured by open system eigenstates de¯ned with boundary conditions set by the leads. The eigenstates are current carrying and entropy producing, with the dissipation inherent in the limit. We construct these eigenstates by means of a recently introduced Scattering (or Open) Bethe Ansatz approach, a generalization to nonequilibrium of the Thermodynamic (or Closed) Bethe Ansatz. We compute the I(V) curve of the Interacting Resonance Level and observe a Fermi Edge Singularity out of equilibrium as the impurity level approaches
resonance. We then apply the approach to the quantum dot (the nonequilibrium Anderson Impurity model) and compute the nonlinear conductance as a function of the source drain voltage for any value of the gate voltage. We observe the formation of the nonequilibrium Kondo peak in the conductance as the gate voltage is decreased to mid valley and its destruction as the source-drain voltage is increased beyond the Kondo scale.

SECOND WEEK

Date 13/7/2009,
Time 2 p.m.

Speaker: F. Marquardt (Munich)

Title: Dephasing in the electronic Mach-Zehnder interferometer

Abstract: In this talk, I will first give an introduction to dephasing, i.e. the loss of quantum-mechanical phase coherence by a fluctuating environment. I will then turn to the electronic Mach-Zehnder interferometer which has become a prime tool to investigate dephasing of ballistic electrons in the solid state environment. Two aspects will be discussed in more detail: i)- when dephasing is due to the shot noise of an adjacent edge channel, the discreteness of charges implies that the potential fluctuations are non-Gaussian. We have shown that this leads to oscillations in the interference contrast of the interferometer, in contrast to naive expectations. ii)- at high bias voltages, we deal with dephasing in a strongly nonequilibrium situation. We have analyzed dephasing by electron-electron interactions in that situation using a straightforward and physically transparent 'semiclassical' approach. The Green's function (i.e. the interference contrast) of a chiral interacting one-dimensional fermion system (edge channel) obeys a power-law decay at high energies, at zero temperature. Surprisingly, we find that the exponent is universal, i.e. independent of the interaction strength, for (almost) arbitrarily shaped interaction potentials.

[1] "Controlled Dephasing of Electrons by Non-Gaussian Shot Noise", I. Neder, F. Marquardt, M. Heiblum, D. Mahalu, and V. Umansky, Nature Physics 3, 534 (2007)
[2] "Coherence oscillations in dephasing by non-Gaussian shot noise", I. Neder and F. Marquardt, New Journal of Physics 9, 112 (2007)
[3] "Universal Dephasing in a Chiral 1D Interacting Fermion System", Clemens Neuenhahn and Florian Marquardt, Physical Review Letters 102, 046806 (2009)

Date 13/7/2009,
Time 2.45 p.m.

Speaker: F. Essler (Oxford)

Title:. Slowest relaxation mode of the partially asymmetric exclusion process with open boundaries

Abstract: I consider the partially asymmetric exclusion process on a finite lattice and with the most general open boundary conditions. Using the representation in terms of the spin-1/2 XXZ Heisenberg chain I utilize the Bethe ansatz solution of the latter to determine the finite-size scaling of the spectral gap, which characterizes the approach to the stationary state at large times. I discuss boundary induced crossovers and possible interpretations of the results in terms of effective domain wall theories.

Date 14/7/2009,
Time 2 p.m.

Speaker: A. Sicilia (Paris)

Title: Classical systems crossing a phase transition: interplay between critical fluctuations and phase ordering dynamics.

Abstract: The understanding of phase transitions in terms of geometrical objects has been a fruitful framework in statistical physics which has lead to the development of powerful mathematical tools and t heoretical ideas. Although geometrical equilibrium properties are by now quite well understood, many questions are still open in the case of systems evolving out of equilibrium. The so called Kibble-Zurek mechanism introduced in the 80's quantifies the density of defects created in a passage through the critical point as a function of the velocity with which the critical point is crossed. This theory has been recently extended to the case of out of equilibrium quantum systems following an unitary evolution through the critical region. While the Kibble-Zurek theory gives a good understanding of the role played by critical fluctuations, it does not take into account the subsequent phase ordering. In our work, we extend the Kibble-Zurek ideas for classical dissipative systems in order to include the effect of phase ordering. We test these ideas with analytical calculations in the O(N) model and Monte Carlo simulations in the 2d Ising model.

Date 14/7/2009,
Time 2.45 p.m.

Speaker: S. Majumdar (Paris)

Title: Extreme Value Statistics in Real-space Condensation

Abstract: I'll discuss a class of mass transport models which reach a nonequilibrium steady state at long times and exhibit the phenomenon of real-space condensation: a macroscopic amount of mass/particles condense onto a single site in space. The important role played by extreme value statistics in determining the fluctuations of the condensate mass will also be discussed

Date 15/7/2009,
Time 2 p.m.

Speaker: E. Altman (Weizmann)

Title: Quantum steady states and phase transitions in the presence of non equilibrium noise

Abstract: Ultracold atomic, molecular or trapped ion systems offer unique possibilities to realize interesting quantum phases and phase transitions. On the other hand they are easily driven out of equilibrium by external (classical) noise sources. It is natural to expect that noise will destroy the subtle correlations underlying quantum critical behavior. This is indeed the case for thermal noise. Surprisingly we find that the 1/f noise, ubiquitous in such systems, does preserve the critical behavior. The emergent states show intriguing interplay of intrinsic quantum-critical and external noise-driven fluctuations. We demonstrate this general phenomenon with several specific examples in solid state and ultracold atomic systems. Our approach shows that genuine quantum phase transitions can be well defined even for systems driven out of equilibrium

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Date 15/7/2009,
Time 2.45 p.m.

Speaker: S. Ruffo (Firenze)

Title: Statistical mechanics and dynamics of models with long-range interactions

Abstract: Systems with long-range interactions, like gravitational, charged and dipolar systems, can be made extensive, but are intrinsically non additive. The violation of this basic property of thermodynamics is the origin of ensemble inequivalence, which in turn implies that specific heat can be negative in the microcanonical ensemble, temperature jumps can appear at microcanonical first order phase transitions, ergodicity may be broken. Realizing that such features may be present for a wide class of systems has renewed the interest in long-range interactions. In this seminar, I will present a review of the recent advances on the statistical mechanics and out-of-equilibrium dynamics of models with long-range interactions.

Date 15/7/2009,
Time 4 p.m.

Speaker: A. Lamacraft (Virginia)

Title: Low energy dynamics of spinor condensates

Abstract: The huge amount of research activity surrouding Bose and Fermi condensates of the alkali atomic gases has given rise to many new ideas, often related to the experimental setting relative to that of conventional condensed matter physics. Arguably the biggest conceptual novelty, however, compared to superfluid 4He or s-wave superconductors, is the higher spin of the particles involved. As a result, novel kinds of magnetic ordering are expected to be more common. For example, some ground states predicted by mean-field theory have zero magnetic moment but non-vanishing nematicity (quadrupole moment).
In this talk I will describe the possible magnetic orders in spinor Bose condensates and derive the low energy dynamics on the order parameter manifold, making connections to the analogous problem in conventional magnetism.

Date 16/7/2009,
Time 4 p.m.

Speaker: R. Egger (Dusseldorf)

Title: Iterative path integral simulations for nonequilbrium quantum transport in nanostructures

Abstract: In this talk, I present the iterative path integral simulation (ISPI) approach to nonequilibrium transport properties of interactingquantum dots. When convergent, this numerical technique is able to provide numerically exact result. The conditions for convergence will be discussed in detail for the Anderson dot. Besides showing results for the Anderson dot, I will also discuss the case of a dot with internal vibrational degrees of freedom.

Date 16/7/2009,
Time 4.45 p.m.

Speaker: Y. Galperin (Oslo)

Title: Many-Electron Theory of Low-Frequency Noise and Memory Effects in Hopping Insulators

Abstract: We show that 1/f-noise of conductance in the variable range hopping regime is related to transitions of many-electrons clusters (fluctuators) between two almost degenerate states. Giant fluctuation times necessary for 1/f-noise are provided by slow rate of simultaneous tunneling of many localized electrons and by large activation barriers for their consecutive rearrangements. These fluctuations in the many-electron clusters are “read out” by the hopping cluster responsible for the conductance. In a broad temperature interval, the Hooge parameter *steeply grows* with decreasing temperature because it is easier to find a slow fluctuator at lower temperatures. Our conclusions agree with the low temperature observations of 1/f-noise in p-type silicon and GaAs. We also show that transitions in many-electron clusters can be responsible also for specific memory effects observed in hopping insulators when the conductance “remembers” the gate voltage protocol. This effect is due to polarization of the clusters by electrons occupying the hopping sites and resulting decrease of the site energies.

Date 17/7/2009,
Time 2 p.m.

Speaker: I. Lerner (Birmingham)

Title: Does a bad metal become good superinsulator?

Abstract: Experimental observation of gigantic jumps in the current-voltage (I-V) characteristics of certain quasi-two-dimensional materials close to the insulator-superconductor transition led to speculation about the emergence of a new, "superinulating"state. However, similar jumps have been observed in other materials not experiencing superconducting transition. We argue that the jumps manifest bistability caused by the overheating of electrons. Our description of details of the I-V characteristics does not involve adjustable parameters and turns out to be in a quantitative agreement with the experiments. We propose experiments for more direct checks of this physical picture.

Date 17/7/2009,
Time 2.45 p.m.

Speaker: B. Doyon (Durham)

Title: The density matrix formulation for quantum impurities in steady states out of equilibrium

Abstract: Quantum impurities in metallic environments are effectively zero-dimensional objects that can exchange electrons with a surrounding conductor. It is interesting to imagine that there are in fact two conductors, isolated from each other except through the impurity, at different electric potentials and fixed temperature. Then, a current will start flowing through the impurity, and if the current is constant in time, the impurity is in a non-equilibrium steady state. The theoretical understanding of this situation is of high interest, as it combines quantum mechanics to non-equilibrium physics. I will explain how one can describe non-equilibrium steady states in impurity models through a non-equilibrium density matrix on a space of scattering states (first introduced by Hershfield in 1993). With the examples of popular impurity models, I will explain how this density matrix formulation is related both to the real-

time construction of steady states, and to scattering calculations of the non-equilibrium current and shot noise. I will then describe some of the main properties of the non-equilibrium density matrix, in particular its non-locality, and show how it can be constructed explicitly and used to calculate non-equilibrium averages perturbatively (or, perhaps if there is integrability, exactly).

Date 17/7/2009,
Time 4 p.m.

Speaker: A. Tsvelik (Brookhaven)

Title: Visual demonstration of spinon confinement in spin-1/2 ladder system: CaCu2O3

Abstract: I describe recent neutron scattering experiments on CaCuO3 which demonstrate the validity of theory of weak confinement of spinons developed earlier by Shelton, Nersesyan and myself. CaCu2O3 is a quasi-one-dimensional insulator which magnetic subsystem consists of very weakly coupled spin-1/2 ladders. The distinct feature of this material is that the rung exchange is weaker than the exchange along the ladder which makes the confinement radius large and makes it possible to observe a crossover from the weak coupling regime of fractional quantum number excitations to the strong coupling regime of singlets and triplets.

Date 17/7/2009,
Time 4.45 p.m.

Speaker: L. Arrachea (Buenos Aires)

Title: Energy transport and heat production in driven quantum systems

Abstract: A quantum system driven by ac potentials may be regarded as a quantum engine where energy is transported and dissipated in the form of heat. We present the theoretical description of such kind of systems on the basis of Keldysh non-equilibrium Green functions. We discuss the different operating modes of a quantum pump, including the mechanism of heat generation. We establish the principles of quantum

refrigeration and we show that it is possible to achieve a regime where part of the work done by some of the ac fields can be coherently transported and to be used by the other driving voltages. Finally, we define thermometers to couple to the driven system in order to determine its local effective temperature. We also discuss the relation between this temperature and the one resulting from a fluctuation-dissipation relation.

THIRD WEEK

Date 20/7/2009,
Time 2 p.m.

Speaker: G. Biroli (Paris)

Title: Thermalization and Quantum Quenches

Abstract: The understanding of thermalization phenomena and of the conditions to reach thermalization for isolated quantum systems are fundamental issues in quantum statistical mechanics. Recently, there has been a renewal of interest in these problems because of their experimental relevance for quantum quenches in cold atomic systems. In this talk I will present our recent results on this topic and contrast them to previous ones appeared in the literature.

Date 20/7/2009,
Time 2.45 p.m.

Speaker: J. Chalker (Oxford)

Title: Quantum Hall interferometers far from equilibrium

Abstract: There is great interest at present in interferometers built from quantum Hall edge states. One type of experiment, on Mach Zehnder interferometers in the integer quantum Hall regime, has produced surprising results when the interferometer is driven far from equilibrium. I will review these results and the theoretical understanding of them that has been developed over the past year.

I. Neder, M. Heiblum, Y. Levinson, D. Mahalu, and V. Umansky, Phys. Rev. Lett. 96, 016804, (2006).

J. T. Chalker, Y. Gefen, and M. Y. Veillette, Phys. Rev. B 76 085320 (2007).

Date 22/7/2009,
Time 2 p.m.

Speaker: H. Saleur (Paris)

Title: The Bethe ansatz and transport out of equilibrium: a review of some issues

Abstract: I will discuss in this talk how the `open Bethe ansatz' approach of N. Andrei and coworkers compares with the approach used by Fendley Ludwig Saleur in the study of tunneling between edge states in the quantum Hall effect. I will report on a wealth of new results for the Interacting Resonant Level Model, including detailed comparison with out of equilibrium simulations and all orders Keldysh calculations.

Date 22/7/2009,
Time 2.45 p.m.

Speaker: V. Gritsev (Freiburg)

Title: Exact methods in analysis of quantum nonequilibrium dynamics.

Abstract: I will describe various methods and approaches for studying non-equilibrium dynamics of integrable models and models which are close to integrable. These approaches include Bethe ansatz, form-factors, extended conformal symmetry, intertwining and dynamical symmetries. I will illustrate applicability of these methods on several examples of systems from cold atoms, quantum optics and mesoscopic physics.

Date 22/7/2009,
Time 4 p.m.

Speaker: M. Pustilnik (Georgia)

Title: Quantum explosion in one dimension

Abstract: In this talk we will discuss a free longitudinal expansion of a one-dimensional system of interacting bosons suddenly released from a trap. It turns out that the broken translational invariance in the initial state of the system is encoded in the correlations between the bosonic occupation numbers in the momentum space.

Date 23/7/2009,
Time 2 p.m.

Speaker: N. Israeloff (Northweastern)

Title: Macro and Nano fluctuation-dissipation-relation in non-equilibrium glass

Abstract: Experiments which probe both fluctuations and responses in rapidly quenched polymer glasses will be discussed. Dielectric degrees of freedom were probed on both macroscopic and nanoscopic scales. In both cases, interesting deviations from the predictions of the equilibrium fluctuation-dissipation relation (FDR) were found which could be characterized by effective temperatures.

Date 23/7/2009,
Time 2.45 p.m.

Speaker: L. Levitov (MIT)

Title: Quantum noise as an entanglement meter

Abstract: Entanglement entropy, which is a measure of quantum correlations between separate parts of a many-body system, has emerged recently as a fundamental quantity in broad areas of theoretical physics, from cosmology and field theory to condensed matter theory and quantum information. The universal appeal of the entanglement entropy concept is related, in part, to the fact that it is defined solely in terms of the many-body density matrix of the system, with no relation to any particular observables. However, for the same reason, it has not been clear how to access this quantity experimentally. In this talk I shall discuss a recently derived universal relation between entanglement entropy and the fluctuations of current flowing through a quantum point contact (QPC), which opens a way to perform a direct measurement of entanglement entropy. In particular, by utilizing space-time duality of 1d systems, we relate electric noise generated by opening and closing the QPC periodically in time with the seminal S = 1/3 log L prediction of conformal field theory.

Based on: arXiv:0804.1377, arXiv:0812.0006, arXiv:0901.3391

Date 24/7/2009,
Time 2 p.m.

Speaker: M. Inguscio (Firenze)

Title: Novel quantum phases with ultracold atoms in optical potentials

Abstract: We will describe different localized quantum phases that can be experimentally realized using ultracold quantum gases in optical lattices, ranging from interaction-induced localized phase (Mott insulator) to disorder induced localized phase (Anderson localization). The powerfulness of Unique diagnostic provided by atoms and their interaction with laser light will also be illustrated.

Date 24/7/2009,
Time 2.45 p.m.

Speaker: M. Olshanii (Boston)

Title: Eigenstate Thermalization Hypothesis and Quantum Thermodynamics

Abstract: One of the open questions in quantum thermodynamics reads: how can linear quantum dynamics provide chaos necessary for thermalization of an isolated quantum system? To this end, we perform an ab initio numerical analysis of a system of hard-core bosons on a lattice and show [Marcos Rigol, Vanja Dunjko & Maxim Olshanii, Nature 452, 854 (2008)] that the above controversy can be resolved via the Eigenstate Thermalization Hypothesis suggested independently by Deutsch [J. M. Deutsch, Phys. Rev. A 43, 2046 (1991)] and Srednicki [M. Srednicki, Phys. Rev. E 50, 888 (1994)]. According to this hypothesis, in quantum systems thermalization happens in each individual eigenstate of the system separately, but it is hidden initially by coherences between them. In course of the time evolution the thermal properties become revealed through (linear) decoherence that needs not to be chaotic.