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Theory of fluctuations in disordered systems.

The thesis is devoted to the study of various aspects of disordered and glassy systems. In the first part of the thesis, we have studied the problem of characterizing the critical dynamical fluctuations of structural glasses at the dynamical transition point. A field theory approach has been developed combined with the replica method and it has been introduced an effective theory that is capable to describe the dynamical heterogeneities at the dynamical transition point. A Ginzburg criterion has been developed to understand the region of validity of the mean field approach. These results are valid for the critical behavior of the dynamics in the beta regime. To understand what happens in the alpha regime we have developed a Boltzmann Pseudodynamics approach to structural glasses that is able to capture the quasi-equilibrium nature of the glassy dynamics in the long time regime. The third part of the thesis is devoted to the study of the glass and jamming physics of hard spheres in the infinite dimension limit. In this context we show that this model displays a Gardner transition that affects deeply the jamming part of the phase diagram leaving the glass part untouched. This means that to describe correctly the jamming properties of hard spheres we need to take into account the full replica symmetry breaking effects. The last part of the thesis is devoted to study mode coupling dynamics around a quasi-continuous transition.

François Landes

10 septembre 2014 Auditorium Irène Joliot Curie

Viscoelastic interfaces Driven in Disordered Media & Application to Friction

Many complex systems respond to a continuous input of energy by an accumulation of stress over time, interrupted by sudden energy releases called avalanches. Recently, it has been pointed out that several basic features of avalanche dynamics are induced at the microscopic level by relaxation processes, which are neglected by most models. During my thesis, I studied two well-known models of avalanche dynamics, modified minimally by the inclusion of some forms of relaxation.

The first system is that of a viscoelastic interface driven in a disordered medium. In mean-field, we prove that the interface has a periodic behaviour (with a new, emerging time scale), with avalanche events that span the whole system. We compute semi-analytically the friction force acting on this surface, and find that it is compatible with classical friction experiments. In finite dimensions (2D), the mean-field system-sized events become local, and numerical simulations give qualitative and quantitative results in good agreement with several important features of real earthquakes.

The second system including a minimal form of relaxation consists in a toy model of avalanches: the Directed Percolation process. In our study of a non-Markovian variant of Directed Percolation, we observed that the universality class was modified but not completely. In particular, in the non-Markov case an exponent changes of value while several scaling relations still hold. This picture of an extended universality class obtained by the addition of a non-Markovian perturbation to the dynamics provides promising prospects for our first system.

Paul Soulé

19 septembre 2014 Salle des conseils de l'IPN

Edges of Fractional Quantum Hall Phases in a Cylindrical Geometry

Fractional Quantum Hall (FQH) phases are exotic incompressible fluids which support gapless chiral edge excitations. I will present a microscopic study of those edge states in a cylindrical geometry where quasiparticles are able to tunnel between edges.

We first study the principal FQH phase at the filling fraction $1/3$ whose ground state is well described by the Laughlin wave function. For an energy scale lower than the bulk gap, the effective theory is given by a very special one dimensional electron

fluid localized at the edge: a chiral Luttinger liquid. Using numerical exact diagonalizations, we study the spectrum of edge modes formed by the two counter-propagating edges on each side of the cylinder. We show that the two edges combine to form a non-chiral finite-size Luttinger liquid, where the current term reflects the transfer of quasiparticles between edges. Then, we estimate numerically the Luttinger parameter for a small number of particles and find it coherent with the one predicted by X. G. Wen theory.

We then analyse edge modes of the FQH phase at filling fraction $5/2$. From a Conformal Field Theory (CFT) based construction, Moore and Read (Nucl. Phys. B, 1991) proposed that this phase is well described by a P-wave paired state of composite fermions. A striking property of this state is that emergent excitations braid with non-abelian statistics. When localized along the edge, those excitations are described through a chiral boson and a Majorana fermion. In the cylinder geometry, we show that the spectrum of edge excitations is composed of all conformal towers of the IsingXU(1) model. Interestingly, the non-abelian tower is naturally observed as opposed to the usual disk geometry. In addition, with a Monte Carlo method, we estimate the various scaling dimensions for large systems (about 50 electrons), and find them consistent with the CFT predictions.

Yasar Atas

24 septembre 2014 Salle des conseils de l'IPN

Some aspects of quantum chaos in many body interacting systems. Quantum spin chain and random matrices.

My thesis is devoted to the study of some aspects of many body quantum interacting systems. In particular we focus on quantum spin chains. I have studied several aspects of quantum spin chains, from both numerical and analytical perspectives. I addressed especially questions related to the structure of eigenfunctions, the level densities and the spectral properties of spin chain Hamiltonians.

In this thesis, I first present the basic numerical techniques used for the computation of eigenvalues and eigenvectors of spin chain Hamiltonians. Level densities of quantum models are important and simple quantities that allow to characterize spectral properties of systems with large number of degrees of freedom. It is well known that the level densities of most integrable models tend to the Gaussian in the thermodynamic limit. However, it appears that in certain limits of coupling of the spin chain to the magnetic field and for finite number of spins on the chain, one observes peaks in the level density. I show that the knowledge of the first two moments of the Hamiltonian in the degenerate subspace associated with each peak give a good approximation to the level density.

Next, I study the statistical properties of the eigenvalues of spin chain Hamiltonians. One of the main achievements in the study of the spectral statistics of quantum complex systems concerns the universal behaviour of the fluctuation of measure such as the distribution of spacing between two consecutive eigenvalues. These fluctuations are very well described by the theory of random matrices but the comparison with the theoretical prediction generally requires a transformation of the spectrum of the Hamiltonian called the unfolding procedure. For many-body quantum systems, the size of the Hilbert space generally grows exponentially with the number of particles leading to a lack of data to make a proper statistical study. These constraints have led to the introduction of a new measure free of the unfolding procedure and based on the ratio of consecutive level spacings rather than the spacings themselves. This measure is independent of the local level density. By following the Wigner surmise for the computation of the level spacing distribution, I obtained approximation for the distribution of the ratio of consecutive level spacings by analyzing random 3×3 matrices for the three canonical ensembles. The prediction are compared with numerical results showing excellent agreement.

Finally, I investigate eigenfunction statistics of some canonical spin-chain Hamiltonians. Eigenfunctions together with the energy spectrum are the fundamental objects of quantum systems: their structure is quite complicated and not well understood. Due to the exponential growth of the size of the Hilbert space, the study of eigenfunctions is a very difficult task from both analytical and numerical points of view. I demonstrate that the groundstate eigenfunctions of all canonical models of spin chain are multifractal, by computing numerically the Rényi entropy and extrapolating it to obtain the multifractal dimensions.

Key words: Quantum spin chains, quantum Ising model, spectral statistics, level density, quantum chaos, random matrices, Wigner surmise, spacing distribution, multifractality, Rényi entropy.

Guillaume Roux

7 novembre 2014 Salle des conseils de l'IPN **Soutenance Habilitation à diriger des recherches**

Some numerical investigations on strongly-correlated systems: from quantum quenches to disordered models.

Andrey Lokhov

14 novembre 2014 Auditorium Irène Joliot Curie

Dynamic cavity method and problems on graphs

A large number of optimization, inverse, combinatorial and out-of-equilibrium problems, arising in the statistical physics of complex systems, allow for a convenient representation in terms of disordered interacting variables defined on a certain network. Although a universal recipe for dealing with these problems does not exist, the recent years have seen a serious progress in understanding and quantifying an important number of hard problems on graphs. A particular role has been played by the concepts borrowed from the physics of spin glasses and field theory, that appeared to be extremely successful in the description of the statistical properties of complex systems and in the development of efficient algorithms for concrete problems.

In the first part of the thesis, we study the out-of-equilibrium spreading problems on networks. Using dynamic cavity method on time trajectories, we show how to derive dynamic message-passing equations for a large class of models with unidirectional dynamics — the key property that makes the problem solvable. These equations are asymptotically exact for locally tree-like graphs and generally provide a good approximation for real-world networks. We illustrate the approach by applying the dynamic message-passing equations for susceptible-infected-recovered model to the inverse problem of inference of epidemic origin.

In the second part of the manuscript, we address the optimization problem of finding optimal planar matching configurations on a line. Making use of field-theory techniques and combinatorial arguments, we characterize a topological phase transition that occurs in the simple Bernoulli model of disordered matching. As an application to the physics of the RNA secondary structures, we discuss the relation of the perfect-imperfect matching transition to the known molten-glass transition at low temperatures, and suggest generalized models that incorporate a one-to-one correspondence between the contact matrix and the nucleotide sequence, thus giving sense to the notion of effective non-integer alphabets.