Soutenances de Thèses 2023

Flavio Nicoletti

Mardi 9 mai 2023, Université de Rome **Soutenance de thèse**

Low energy excitations of vector spin glasses

The work of this thesis concerns the problem of linear low energy excitations of vector spin glass models. An analytical and numerical study is carried out, considering a fully connected random-field Heisenberg model at zero temperature, a fully-connected vector p-spin glass model and a sparse random-field Heisenberg model. We test these models against the low temperature behavior of finite dimensional glassy systems, in particular we show that they possess phases where the density of states is gapless with quasi-localised modes. In the case of the sparse model, we show that the density of states follows a quartic law at low frequency, consistently with several recent measures of this quantity that can be found in the literature of computer glasses. In all the three models, the spin glass transition is characterised in terms of the behavior of the softest excitations. We found that in the fully connected models the zero-temperature spin glass transition in a field is a delocalisation transition of the softest modes. In the sparse case, a weaker form of delocalisation appears at the transition. These results broaden our understanding of the zero-temperature critical point, by showing how spin glass ordering affects the way the system responds to small magnetic perturbations.

Jury : Ada Altieri, Pierluigi Contucci, Silvio Franz, Andrea Gabrielli, Irene Giardina, Giacomo Gradenigo, Federico Ricci-Tersenghi, Alberto Rosso

---

Lara Koehler

Lundi 10 juillet 2023, Petit amphithéâtre Bâtiment Pascal n°530 **Soutenance de thèse**

Principles of self-assembly for particles with simple geometries and complex interactions

In living cells, proteins self-assemble into large-scale functional structures based both on the specific interactions between different spots on their surfaces. The general principles that allow complex interactions to control self-assembly are largely unknown. Here, we introduce model lattice particles with trivial geometries but highly complex interactions and study their self-assembly using numerical simulations. We find that strongly anisotropic particles produce non-trivial aggregates that fall into a few stereotypical categories. Using machine learning, we accurately predict the outcome of this aggregation based on the presence of pair interactions that locally favor periodic un-frustrated arrangements. We also show that the stereotypical aggregates are fixed-points of a numerical real-space renormalization transformation.These results offer a first overview of the rich design space associated with identical particles with complex interactions, and could inspire engineered self-assembling nano-objects as well as help understand the emergence of robust functional protein structures. In particular, we show that local interaction can robustly control the size of spherical or fibrous self-assemblies of identical particle. Finally, we suggest that it is possible to systematically identify the conditions in which proteins would self-assemble into fibrillar aggregate in X-ray crystallographic scattering measurements.

Jury : Martin Lenz (directeur de thèse), Mikhail Brenner (rapporteur), Chase Broederz (examinateur), Ralf Evenaers (rapporteur), Friedrich Simmel (examinateur), Zorana Zeravcic (examinatrice)

Lorenzo Rosso

Mardi 18 juillet 2023, Petit amphithéâtre Bâtiment Pascal n°530 **Soutenance de thèse**

Dissipative Yb gases

Ultracold atomic gases are an experimental platform to study quantum many-body physics, allowing the observation of non-trivial many-body phenomena in and out of equilibrium, thus making their theoretical understanding a priority. They usually feature a high degree of control over system parameters and allow for an almost perfect decoupling from the surrounding environment. However, despite the tremendous experimental progress, a perfect isolation has never been reached, for instance because of particle losses, causing energy relaxation and decoherence phenomena. As such, dissipation is generally seen as an enemy to be fought harshly since it tends to destroy and wash out the interesting quantum effects that can be investigated. On the other hand, a research line that developed in the last decade has shown that this is not always the case. In particular, the interplay between the coherent unitary evolution and the coupling to the environment can lead to a non-trivial dynamics and to stationary states featuring strong quantum correlations and critical behaviors. Although of primary interest to understand the limitations of the simulation of quantum many-body physics, a complete theoretical description of the effect of losses on correlated quantum gases is still lacking. Even if several experiments have studied the dynamics of correlated one-dimensional quantum gases in the presence of losses, both in the bosonic and fermionic cases, the theoretical characterisation of the interplay between the unitary and lossy dynamics has only recently emerged as an important challenge and it is currently starting to attract novel attention. This thesis aims at the study of lossy correlated gases. Our work puts a particular emphasis on the theoretical characterisation of the interplay between the Hamiltonian unitary dynamics and losses. We consider different bosonic and fermionic models in the presence of mainly two-body losses, we devise effective descriptions for the relevant degrees of freedom of such systems, capable of predicting the real time dynamics of the main observables, which we then benchmark against exact numerical simulation of the full master equation.

Jury : Leonardo Mazza (directeur de thèse), Isabelle Bouchoule (examinatrice), Andrea De Luca (examinateur), Igor Lesanovsky (rapporteur), Laurent Sanchez-Palencia (examinateur), Johannes Schachenmayer (rapporteur)

Saverio Bocini

Vendredi 22 septembre 2023, Grand amphithéâtre Bâtiment Pascal n°530 **Soutenance de thèse**

Non-equilibrium dynamics in inhomogeneous quantum many-body systems

We study the non-equilibrium dynamics of quantum spin chains described by translationally-invariant Hamiltonians with short-range interactions. Special attention is given to initial states with localized inhomogeneities. Although such scenarios are often addressed by Generalized hydrodynamics (GHD), we consider special setups that go beyond this framework. First, we investigate the system at non-local scales that are not accounted for by GHD; by deriving exact results for connected correlations in partitioning protocols, the locality conditions necessary for GHD to work in the non-interacting case are established. Second, we explore macroscopic effects from local perturbations, showing that minimal modifications, such as a spin flip, of an otherwise-stationary initial state can induce a global reconfiguration of the spin chain; this phenomenon is observed perturbing jammed states and quantum scars. Finally, inspired by the low bipartite entanglement of the states exhibiting macroscopic effects from local perturbations, entanglement properties of the spectrum in non-interacting quantum spin chains are investigated; the study reveals that at most a finite small number of eigenstates satisfy the area law, also showing that several relevant models exhibit none.

Jury : Benjamin Doyon, Viktor Eisler, Maurizio Fagotti (co-directeur de thèse), Laura Foini, Dragi Karevski, Léa F. Santos, Véronique Terras (co-directrice de thèse)

Ana Flack

Lundi 25 septembre 2023, Petit amphithéâtre Bâtiment Pascal n°530 **Soutenance de thèse**

Statistics of particles with long-ranged pairwise interactions

In this thesis, we investigate the equilibrium and dynamical properties of charged particles in one dimension interacting via long-range interactions. First, we focus on the equilibrium one-dimensional one-component plasma (1dOCP), also known as the jellium model. It consists of N harmonically confined charges on a line interacting via pairwise repulsive Coulomb interactions. First, we introduce some well-known equilibrium properties of the model. Then we present the Coulomb gas method, which we later use to analyze the behavior of large deviations of different observables in the limit of a large number of particles. We find the large deviation form for the general full linear statistics, and we derive the exact formula for its variance. We continue by computing typical as well as large deviations of the gap between two middle particles. We also analyze typical and atypical fluctuations of the number of particles inside of a symmetric interval that is in the bulk of the system. The last equilibrium observable that we study is the truncated linear statistics, which describes the sum of the positions of the N' rightmost particles. In the last chapter, we investigate the Langevin dynamics of the jellium model without the confining potential. We find that, for large times, there exists a correspondence between the dynamical system and the equilibrium 1dOCP. We use this connection to study fluctuations of the particle positions in the dynamical system.

Jury : Ada Altieri, Fabio Cunden (rapporteur), David Dean, Satya Majumdar (co-directeur de thèse), Sergei Nechaev (co-directeur de thèse), Grégory Schehr (invité), Gabriel Tellez (rapporteur), Christophe Texier.

Benjamin De Bruyne

Lundi 16 octobre 2023, Grand amphithéâtre Bâtiment Pascal n°530 **Soutenance de thèse**

Extreme value statistics and optimization problems in stochastic processes

This thesis is devoted to the study of extreme value statistics in stochastic processes and their applications. In the first part, we obtain exact analytical results on the extreme value statistics of both discrete-time and continuous-time random walks. In particular, we focus on the gap statistics of random walks and exhibit their asymptotic universality with respect to the jump distribution in the limit of a large number of steps. In addition, we compute the asymptotic behavior of the expected maximum of random walks in the presence of a bridge constraint and reveal a rich behavior in their finite-size correction. Moreover, we compute the expected length of the convex hull of Brownian motion confined in a disk and show that it converges slowly to the perimeter of the disk with a stretched exponential decay. In the second part, we focus on numerically sampling rare trajectories of stochastic processes. We introduce an efficient method to sample bridge discrete-time random walks. We illustrate it and apply it to various examples. We further extend the method to other stochastic processes, both Markovian and non-Markovian. We apply our method to sample surviving particles in the presence of a periodic trapping environment. Finally, we discuss several optimization problems in stochastic processes involving extreme value statistics. In particular, we introduce a new technique to optimally control dynamical systems undergoing a resetting policy

Jury : Eric Bertin (rapporteur), Martin Evans (examinateur), Satya Majumdar (co-directeur de thèse), Cécile Monthus (examinatrice), Kilian Raschel (examinateur), Grégory Schehr (directeur de thèse), Pierpaolo Vivo (rapporteur)

Federico Lanza

Vendredi 3 novembre 2023, NTNU, Salle C201, Kolbjørn Hejes vei 1B, 7034 Trondheim
Soutenance de thèse

Optimal path for the flow of yield stress fluid

Numerous industrial and environmental applications rely on an understanding of fluid behavior within porous materials, from remediating groundwater contamination to carbon dioxide storage. Yield stress fluids, which resist flow until a critical stress threshold is exceeded, present both unique challenges and opportunities. Capillary forces, responsible for separating immiscible fluids, significantly influence multi-phase flow in porous structures. This thesis embarks on a theoretical exploration of non-linear flow within porous media, where both forces contribute to the overall rheology, interacting with the geometrical disorder at the pore level. The present study investigates the steady-state flow of yield stress blobs in a capillary fiber bundle filled with Newtonian liquid, as well as the flow of a single Bingham fluid in a tree-like pore network. We derive expressions for the pressure threshold and the average flow rate as a function of the applied pressure drop. In both problems, the non-linearity observed stems from the sequential opening of flowing paths with increasing pressure drop, and the distribution of pressure thresholds related to these paths defines the specific flow rate law. Furthermore, we explore the transition from viscous fingering to foam during immiscible drainage in a two-dimensional porous medium. We characterize this transition through numerical simulations using a dynamic pore network model, measuring the transition location, overall flow rate, and local pressure gradient as a function of imposed global pressure and viscosity ratio. We discuss potential mechanisms leading to this transition, considering local flow rate fluctuations, which we also measure and characterize. In all three cases studied, the porous medium's heterogeneity emerges as a pivotal factor.

Jury : Harold Auradou, Dag Werner Breiby, Alex Hansen, Rainer Helmig, Hans Herrmann, Marie-Laure Olivier, Alberto Rosso

---

Saptarshi Majumdar

Jeudi 16 novembre 2023, Petit amphithéâtre Bâtiment Pascal n°530 **Soutenance de thèse**

Localisation in open quantum systems

We investigate the zero-temperature phase diagram of a one-dimensional XXZ spin chain coupled with local dissipative baths composed of simple harmonic oscillators. In a finite magnetization sector, we map this system onto a two-dimensional classical action using bosonization. From this classical field theory, we find the existence of a BKT phase transition between the pre-existing Luttinger liquid phase and a new dissipative phase at zero temperature. This new phase is a gapless spin density wave with unaltered susceptibility and vanishing spin stiffness. These analytical predictions are verified against numerical Langevin dynamics simulations of the action. The local baths in the spin chain can also be interpreted as annealed disorder and they affect the transport properties. Particularly for subohmic baths, the static conductivity vanishes, which can be interpreted as a localization effect induced by the presence of dynamical disorder. Moreover, we analyze the model at zero magnetization and argue that in that case, the gapless spin density wave is replaced by a gapped antiferromagnetic phase.

Jury : Rosario Fazio (rapporteur), Laura Foini (co-directrice de thèse), Edmond Orignac (rapporteur), Alberto Rosso (directeur de thèse), Inès Safi, Grégory Schehr.

Vincenzo Schimmenti

Jeudi 23 novembre 2023, Grand amphithéâtre Bâtiment Pascal n°530 **Soutenance de thèse**

Temporal and spatial correlations in earthquake dynamics: physical modeling and data analysis

In seismology, aftershocks are smaller earthquakes originating from the destabilised crust in the regions close to a larger earthquake, the mainshock. In this thesis we study this phenomenon from three distinct perspectives. In the first one we unveil the connections between simple models of aftershocks occurrence and record statistics of stochastic processes. The second approach builds up on the similarities between earthquake sequences and mainshock-aftershocks groups with the creep dynamics of a domain wall expanding in a thin magnetic film. Finally, we use machine learning tools to construct a forecasting method for aftershock occurrence by exploiting measurements of surface deformation coming from Global Positioning System (GPS) satellites. As an addendum, in the last part of the thesis, we discuss the physics of yield-stress fluids in porous media and its links to the physics of disorder systems and directed polymers in random media.

Jury : Aurélien Decelle, François Landes (co-directeur de thèse), Cécile Monthus, Alberto Rosso (directeur de thèse), Herbert Spohn (rapporteur), Jérôme Weiss (rapporteur)

Li Gan

Jeudi 7 décembre 2023, **Petit amphithéâtre Bâtiment Pascal n°530** Soutenance de thèse

Algebraic Area of Lattice Random Walks and Exclusion Statistics

We focus on the enumeration of closed lattice random walks according to their algebraic area, with connections to quantum exclusion statistics, as well as the combinatorics of generalized Dyck and Motzkin paths. First, taking the closed square lattice walks as an example, we review the concept of the algebraic area and its connections to the Hofstadter model. Then, we introduce two approaches for the algebraic area enumeration. The first approach relies on the computation of the secular determinant of the Hofstadter Hamiltonian and its relation to the exclusion statistics. Precisely, the coefficients of the secular determinant are interpreted in terms of partition functions with exclusion parameter $g=2$. The algebraic area enumeration is obtained in terms of the associated cluster coefficients. The second approach involves a direct computation of the trace of the nth power of the Hofstadter matrix, where n is the length of the walks. We study the combinatorics of periodic Dyck paths and obtain explicit expressions for counting Dyck paths with a fixed number of up steps starting from each floor, which provide a combinatorial interpretation to the factor in the algebraic area enumeration formula obtained in the first approach. Then, we study the closed random walks on a honeycomb lattice and establish a correspondence to a system of particles obeying a mixture of $g=1$ (fermions) and $g=2$ exclusion statistics, together with the connection to the combinatorics of periodic Motzkin paths. Furthermore, we extend the algebraic area concept to closed cubic lattice walks and map the enumeration onto the cluster coefficients of three types of particles obeying $g=1$, $g=1$, and $g=2$ exclusion statistics, respectively, with the constraint that the numbers of $g=1$ exclusion particles of the two types are equal.

Jury : Cyril Banderier, Cyril Furtlehner, Brian Hopkins (rapporteur), Stéphane Ouvry (directeur de thèse), Valentina Ros, Clément Sire, Stephan Wagner (rapporteur).