Laboratoire de Physique et Modélisation des Milieux Condensés – UMR 5493

Theoretical physics laboratory : condensed matter, quantum physics, statistical physics

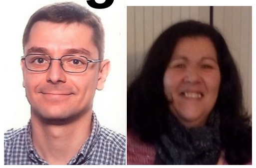
lanef Laboratoire d'Alliances Nanosciences-Energies du futur

CPTGA Centre de Physique Théorique Grenoble-Alpes

14 Chercheurs et EC

10 doctorants, 2 postdocs

2 gestionnaires



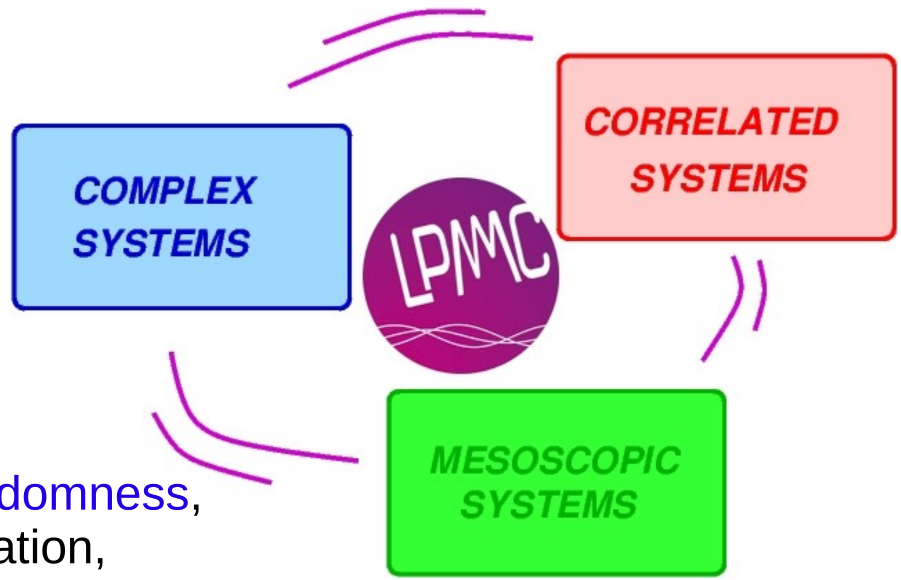
(mutualisés avec le CPTGA)

1 informaticien

LPMC

Research at LPMMC : facing novel challenges in condensed matter physics

- **Three research axes**



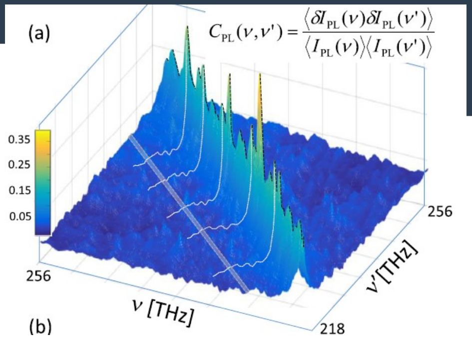
- Interacting quantum systems, macroscopic quantum coherence, superconductivity, ultracold gases
  → quantum information and quantum technologies
- Emergence of collective phenomena and new correlated states of matter → Wigner crystal, Cooper pairs, ferromagnetism,...

- Disorder and randomness, Anderson localization, interplay of disorder and interactions → random laser, seismology,…
- Out-of-equilibrium systems, critical phenomena and phase transitions, driven-dissipative and open quantum systems

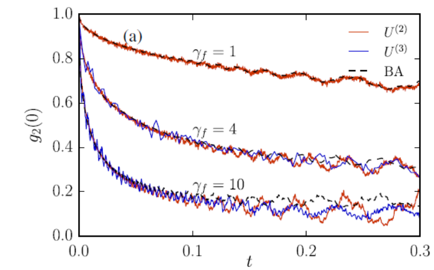
- 2D systems under magnetic field, topological aspects → Quantum Hall effect, fractional Chern insulators…
- Properties of materials and devices at nanometric scale
  → thermal machines, nanorefrigeration..

LPMMC: tools, techniques, results

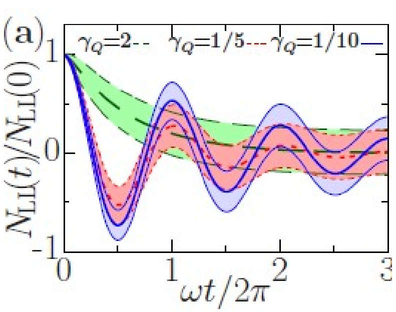
- Self-consistent approaches
- Random matrix theory
- Non-perturbative renormalization group
- Correlation functions
- Quantum Monte Carlo
- Quantum field theories, Luttinger liquids
- Exact solutions (Bethe Ansatz, Tonks-Girardeau)
- Exact diagonalization methods
- Density-Matrix Renormalization Group
- Diagrammatic approaches
- Keldysh formalism, out-of-equilibrium Green's functions
- ...



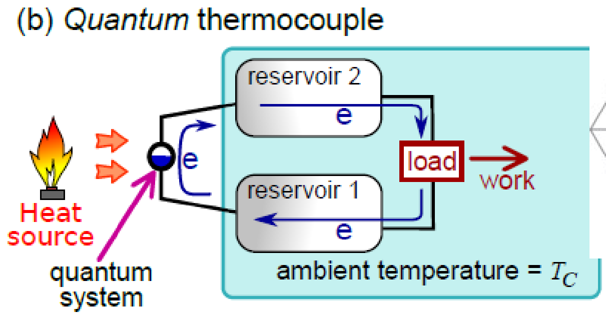
PRL 119, 043902 (2017)



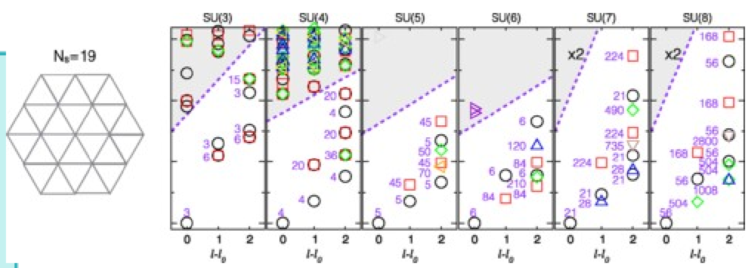
Phys. Rev. X 7, 031026 (2017)



PRL 113, 025301 (2018)



Phys. Rep. 694, 1 (2017)

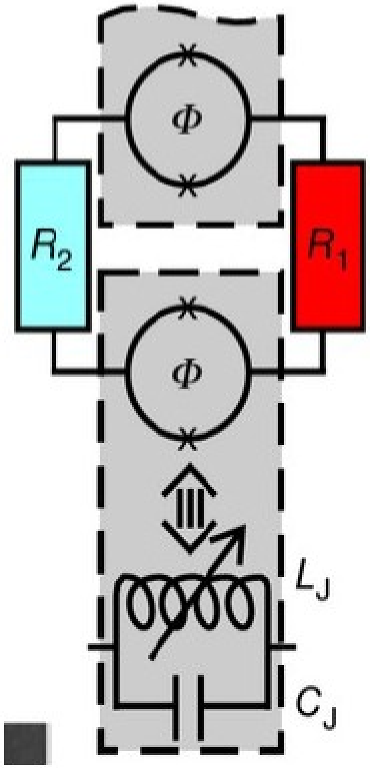


PRL 117, 167202 (2016)

Stages 2021 – Fluctuations de transfert radiatif de la chaleur dans un nano-dispositif

Denis Basko

Description : Nous allons étudier le transfert de la chaleur dans un système simple constitué de deux petits îlots métalliques maintenus à deux températures différentes et couplés par un seul mode photon. Un tel système a été réalisé à Aalto, où le mode photon était représenté par un résonateur supraconducteur (la figure à droite). À des températures inférieures au Kelvin, le transfert de chaleur par les phonons ou les quasi-particules électroniques est inefficace. Alors, le mécanisme photonique est dominant : les électrons dans l'îlot chaud émettent des photons dans le résonateur, qui sont absorbés par les électrons dans l'îlot froid. Dans ce système, la géométrie ne joue aucun rôle, le transfert de chaleur est donc quantifié par la puissance transférée P (t) qui fluctue dans le temps....

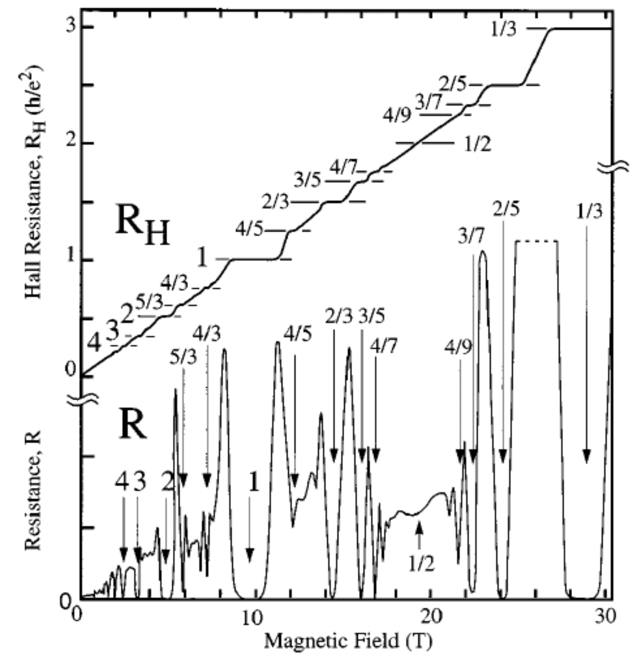


Mots-clé/ methodes : mécanique quantique, calculs analytiques, fonctions de Green hors équilibre

Stages 2021 –
Detection of topological order in ultracold atoms

Cecile Repellin

The fractional quantum Hall effect (FQHE) is a prime example of a strongly correlated phenomenon in solid state. At low temperature and large magnetic field, 2D electron gases aquire a quantized Hall conductivity $\sigma_H = \frac{p}{q}\frac{e^2}{h}$ where p and q are coprime integers, and $\frac{e^2}{h}$ is the quantum of conductance. A key feature of the FQHE is to host anyons, collective excitations whose statistics is intermediary between bosonic and fermionic. Theoretically, the FQHE can also occur for strongly interacting bosons. To explore bosonic FQH states requires engineered quantum systems: for example, it is possible to create artificial magnetic fields which act on the neutral atoms of an ultracold gas, and to tune the interactions to the strongly interacting regime. While some experimental groups are making progress towards the realization of FQH phases in cold atoms, the question of how to detect these phases in cold atoms is not fully settled.

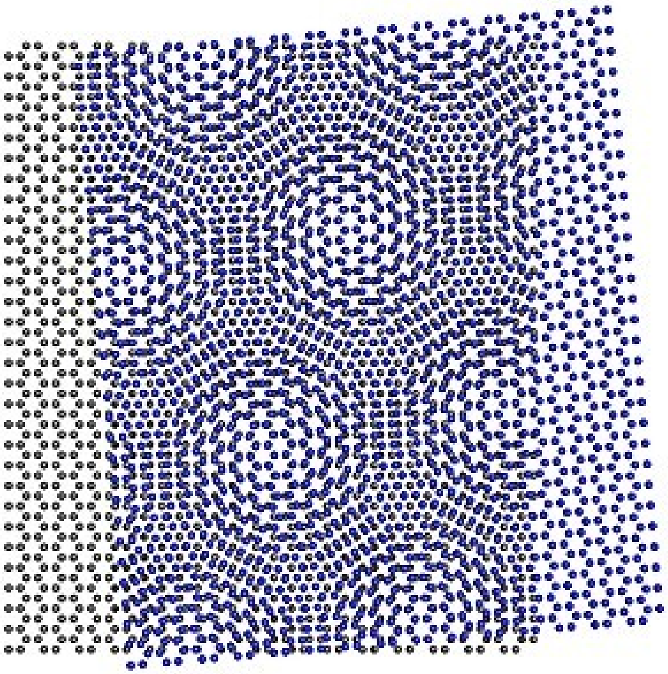


For this project, you will study the phase diagram of a FQH system on a lattice upon varying the magnetic field at constant atomic density….

Keywords/methods : fractional quantum Hall effect, DMRG, many-body physics

Stages 2021 – Strong correlations in graphene Moiré structures

Cecile Repellin



Layers of two-dimensional materials such as graphene can be stacked in a controlled way to create new properties that do not exist in monolayer graphene. More specifically, the controlled misalignment of two layers results in a superlattice potential which modifies the band structure of the device. In bilayer graphene, a slight (or 'magic') rotation angle (1.1 degrees) between the two layers results in perfectly flat conduction and valence bands. The vanishing kinetic energy in these bands gives a central role to Coulomb interactions; at partial filling of these bands, the many-body ground state is characterized by strong correlations. The most striking consequence is the experimental observation of superconductivity as well as correlated insulators in magic angle twisted bilayer graphene in 2018 [2, 3]. In the past two years, a plethora of other strongly correlated phenomena has been observed in twisted bilayer graphene and other moiré structures combining three or four layers of graphene. These observations call for an in-depth theoretical study of strong correlations in graphene moiré structures.

The aim of this internship is to investigate the possibility of quantum phases combining symmetry breaking and topology in flat-band graphene moire materials….

Keywords/methods : Many-body systems, graphene bilayer, exact diagonalization

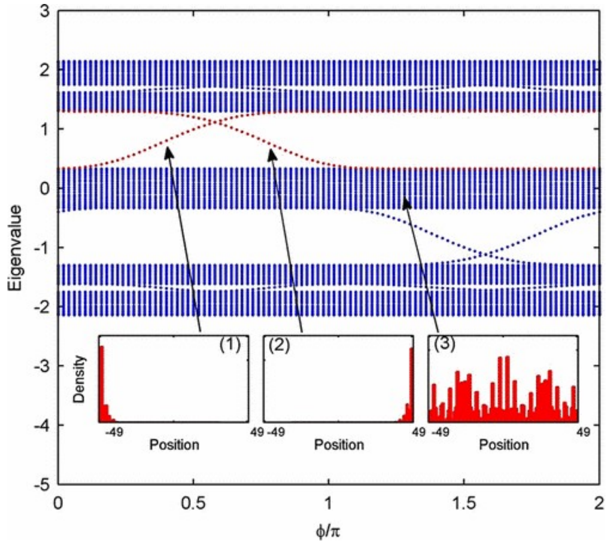
Stages 2021 – Interplay of topology and disorder in wave physics

Sergey Skipetrov

Summary:

Topological concepts play an important role in condensed matter physics [1]. Topological invariants, such as the Chern number, for example, are robust with respect to sample imperfections and weak interactions between particles, which makes them good reference points when comparing idealized theoretical models with experiments. In addition, thinking in terms of topology provides an alternative view of complex physical phenomena and can be very beneficial for the interpretation of experiments. The quantum Hall effect is a paradigmatic example of phenomenon that is best understood with the help of topological concepts.

The topological characterization of physical systems and phenomena is restricted neither to intrinsically quantum systems nor to electrons (i.e., charged fermions). Topological concepts arise in optics [2], in acoustics [3] and even in Earth science [4]. The aim of this **theoretical** internship is to explore the role played by the topological phenomena in the wave physics of disordered systems. The simplest example of such a system is a one-dimensional periodic or quasi-periodic chain to which a small amount of disorder is added. We know that the topological invariants associated with the chain's spectrum are robust.....



Keywords/methods : Anderson localization, topology, analytical and numerical calculations

Stages 2021 – Electromagnetic waves in strongly disordered systems

Sergey Skipetrov

Summary:
Scattering of electrons by impurities in metals gives rise to a diffusive transport which is at the origin of Ohm's law. At low temperatures, this diffuse propagation is prevented by quantum interferences. This is "Anderson localization" known for more than 60 years [1]. The phenomenon of scattering also exists for electromagnetic waves, and many efforts have been made to observe Anderson localization of light [2,3].

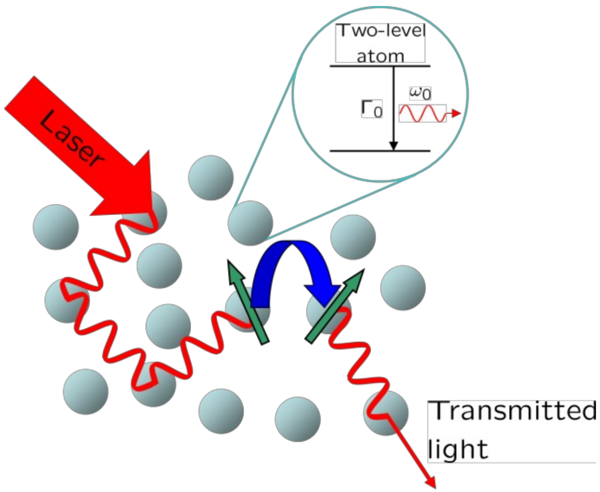


Figure : Sketch the propagation of light in a disordered medium represented by an ensemble of two-level atoms (blue spheres). In addition to the transverse waves that propagate at long distances (wavy red lines), there is dipole-dipole coupling between atoms in the near field via longitudinal fields (blue arrow).

Our numerical simulations have demonstrated the absence of Anderson localization for electromagnetic waves propagating in disordered media composed of dipolar scatterers. This unexpected and surprising absence is undoubtedly due to the near-field phenomena and, in particular, to the existence of longitudinal electromagnetic waves. In strongly disordered media, these waves will contribute to energy transport and will be decisive for key observables such as the mean free path (the distance between two scattering events), the diffusion coefficient, the energy transport velocity, and the density of states [5] (see Figure). The existence of longitudinal waves makes radiative transport very different from the transport of matter waves (electrons or cold atoms). Their inclusion in transport theory is the main objective of this internship.

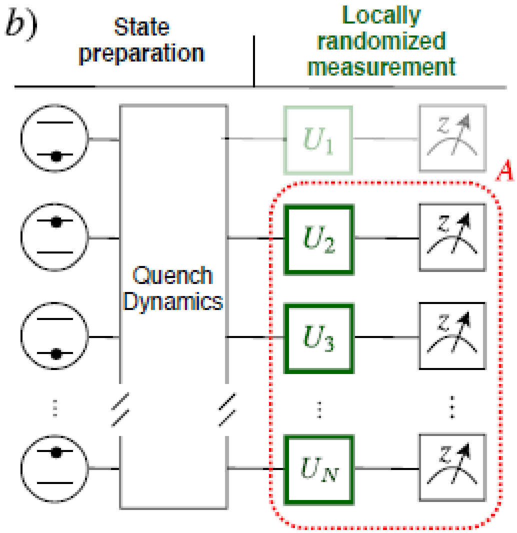
As part of this **theoretical and numerical** internship, we propose to study the role of longitudinal waves in optical transport using two approaches: 1) diagrammatic perturbation theory and 2) numerical simulations of a model of immobile dipolar scatterers often used to model cold atoms. The two approaches are strongly complementary. While analytical theory guides simulations and allows us to come up with simple yet approximate formulas, simulations provide the opportunity to perform quasi-exact calculations and to test the

Keywords/methods : Anderson localization, wave propagation, diagrammatic methods and numerical simulations

Stages 2021 – Verification of quantum computation by randomized measurements

Benoit Vermersch

Synthetic quantum systems of Rydberg atoms, trapped ions, superconducting qubits, quantum dots, etc, have reached a new era: Programmable coherent interactions can be implemented between tens of particles, and in highly tunable geometries. These systems can be used as quantum simulators to understand unique features of quantum phases of condensed matter or high-energy physics. Synthetic quantum systems can also implement quantum computers . These devices offer the prospect to outperform classical computers, in particular to solve "hard" classical optimization problems .
A central aspect for the future of quantum simulation and computation is the development of experimental tools to probe a new generation of many-body quantum states, which could not be realized so far . While standard measurement techniques give typically access to low-order correlation functions, accessing experimentally true quantum features, such as entanglement, was considered for many years as an outstanding challenge for quantum technologies. Recently, we have developed and demonstrated protocols known as randomized measurements (RM), that have the potential to address this challenge.
The internship consists in implementing a verification protocol for quantum computers.....



Keywords/methods : quantum technologies, quantum computer, verification protocol, numerical script

Stages 2021

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- Detection of topological order in ultracold atoms (Cecile Repellin)
- Strong correlations in graphene Moiré structures (Cecile Repellin)
- Interplay of topology and disorder in wave physics (Sergey Skipetrov)
- Electromagnetic waves in strongly disordered systems (Sergey Skipetrov)
- Verification of quantum computation by randomized measurements (Benoit Vermersch)

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