

# Experimental PhD in ultracold atomic quantum gases: Simulating disordered quantum systems – many-body effects and topology

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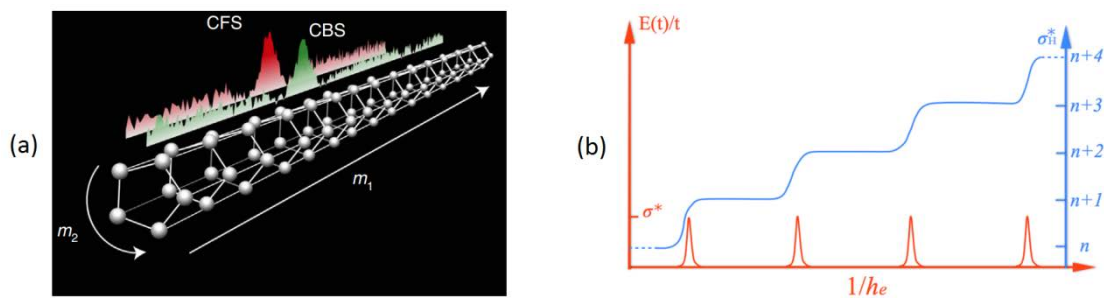
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It is today possible to cool gases of atoms to only a fraction of a  $\mu\text{K}$  above absolute zero. These ultracold gases manifest a wave-like (quantum) behavior, ideal for many fundamental physics experiments. They allow, for example, the experimental study of quantum phase transitions between a metal and an insulator in presence of a disordered potential. This is generically called the Anderson transition and is found in many fields involving waves propagating in disordered media: optics, acoustics, microwaves... Our team has acquired an international renown in this domain, with the first experimental observation of the Anderson transition in 3 dimensions (3D). The experimental apparatus is extremely versatile and can also simulate physics in one, two, or even four dimensions!

Using matter waves, we were recently able to provide a first direct ‘microscopic’ smoking gun of the Anderson Localization, the so-called “Coherent Forward Scattering” phenomenon – thus confirming its very recent theoretical prediction. Moreover, this interference signature, in conjunction with its weak-localization counterpart, the “Coherent Backscattering”, can be extremely valuable tools for probing novel phenomena, such as the interplay of many-body effects or symmetry properties with the Anderson physics.



**Fig. 1** (a) Experimental observation of the CBS and CFS interference peaks using the time-reversal properties of a quasi-1D dynamical system (see [2] for details). (b) Schematic representation of the Integer Quantum Hall Effect for a quasiperiodic Kicked Rotor system, showing sharp peaks of the energy-growth rate, and corresponding Quantum Hall conductance plateaus (from the theoretical proposal [5]).

These experimental advances open interesting possibilities, beyond the current state-of-the-art, to probe the coherence properties of quantum disordered systems. This PhD thesis will start in the fall of 2019, around two new research lines, both using a Potassium BEC apparatus scheduled to be ready during the first year of the thesis. The first objective is the study of interaction effects on the transport properties (localization, Anderson transition, etc.) in disordered systems close to quantum degeneracy

– in relation, e.g. with the ‘hot topic’ of the Many-Body Localization (MBL). The second direction is related to the investigation of topological effects in periodically-driven (“Floquet”) systems. Recent theoretical proposals [5] have shown the possibility of studying a variant of the Integer Quantum Hall effect using techniques similar to our setup.

The thesis is experimentally-oriented, but will be complemented with numerical simulations aimed at a better understanding of the underlying physics. The work will be realized in collaboration with several theory groups, in Paris (LKB group of D. Delande, N. Cherroret), Toulouse (G. Lemarié) and Beijing (C. Tian).

*Recent publications in the group:*

- [1] C. Hainaut et al. *Phys. Rev. Lett.* **121**, 134101 (2018)
- [2] C. Hainaut et al. *Nat. Commun.* **9**, 1382 (2018)
- [3] C. Hainaut et al. *Phys. Rev. A* **97**, 061601(R) (2018)
- [4] C. Hainaut et al. *Phys. Rev. Lett.* **118**, 184101 (2017)

*Bibliography:*

- [5] C. Tian et al. *Phys. Rev. B* **93**, 075403 (2016)
- [6] J-C. Garreau, *C. R. Phys.* **1**, 31 (2017)
- [7] C. Muller, D. Delande *arXiv:1005.0915*
- [8] J. Chabé et al. *Phys. Rev. Lett.* **101**, 255702 (2008)

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