PhD position (Theory): Nonequilibrium thermodynamics of many-body quantum systems

Keywords *: Quantum thermodynamics, numerical methods, many-body quantum systems*
Laboratory : Laboratoire de Physique et Chimie Théorique (LPCT), UMR 7019.
Location : Nancy, France.
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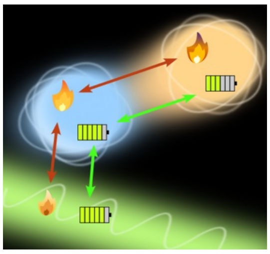
Group webpage : https://qthermo.wordpress.com/
Funding: ERC Starting Grant project “QARNOT”.



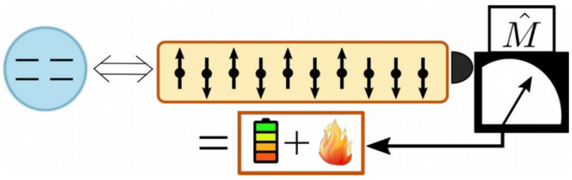


Figure : Left: *Recent progress in quantum thermodynamics allows to define and analyze work and heat exchanges between quantum systems. However, applying those definitions require to keep track of the full state of the systems, which is intractable for large quantum systems [3].* Right*: The PhD student will join the effort of the group to build a formalism for nonequilibrium quantum thermodynamics involving only a few macroscopic observables, relevant for numerical or experimental analysis of many-body systems.*

Can we use the concepts from thermodynamics to better understand complex quantum dynamics ?

Context: In the 90s, the scope of thermodynamics broadened to include small systems and far-from equilibrium transformations. Building on these advances, the emerging field of q**uantum thermodynamics** has recently lead to breakthroughs formulating nonequilibrium thermodynamics in the quantum regime. Motivations range from the search of quantum advantages in heat engines (for instance based on entanglement or quantum measurement [1]) or batteries based on quantum systems, to the expression of global constraints on many-body quantum dynamics stemming from the Second Law, or its generalizations to stochastic systems called *Fluctuation Theorems* [2]. One of the recent successes of the field was to overcome foundational difficulties in defining work and heat exchanged between quantum systems, and express the Second law in a fully quantum context [3].

However, utilizing those frameworks require to keep track (to measure or to simulate) the full quantum state of the systems under study (the density operator). In particular, the later is needed to compute the von Neumann entropy of the system. While this is tractable for an elementary quantum system, e.g. a two-level system or a harmonic oscillator weakly coupled to their environment, it becomes quickly impossible for many-body quantum systems. Instead, it would be very valuable to have statements similar to macroscopic thermodynamic laws, which provide constraints on how energy exchanges occur in many-body quantum systems, and which could be used without solving the total dynamics exactly (as it is the case in classical macroscopic thermodynamics). To reach this goal, new frameworks for quantum thermodynamics are currently being developed to exploit information contained in only a few macroscopic (i.e. coarse-grained) observables of the system, expected to play the role of state variables (see for example [4]).

The goal of the PhD ptoject is to participate into the development of those novel methodologies by testing the novel approaches developed in the Nonequilibrium Thermodynamics group of the Université de Lorraine over paradigmatic examples of many-body quantum systems. Examples include spin-chains or ensembles of quantum emitters (atoms) coupled to an electromagnetic field. The master student will work in close collaboration with a postdoc of the group involved in the development of those new framework.

Work environment: The PhD student will join the Dynamics and Symmetry Axis of the LPCT lab in Nancy (Université de Lorraine) and will be supervised by Cyril Elouard (Junior Professor CPJ). The project is funded by the European ERC Starting Grant project "QARNOT".
The LPCT is an equal opportunity laboratory with a working environment actively promoting equality, diversity, and inclusion.

Candidate profile : We are looking for excellent candidates with strong background in theoretical physics and numerical methods. Previous internships or courses in numerical methods for many body system (such as tensor networks) will be appreciated, as well as experience in quantum dynamics or quantum open systems.

For more information and application, please contact : cyril.elouard[at]univ-lorraine.fr

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