Lab project M2 PPN

Monday & Tuesday from Nov. 2026 to March 2027

Title of the project: Autonomous quantum devices

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Laboratory / Department / Team : ICB / ICQ / DiTeQ

Collaborations: Mohammed Bilal (DiTeQ), Mohamed Boubakour (Université Lorraine), Cyril Elouard (Université Lorraine)

Summary: Autonomous quantum devices are ensembles of interacting quantum systems without external classical drive. Their total Hamiltonian is therefore time-independent. Their autonomous nature brings an important practical advantage: a great reduction of external noise, usually brought by transmission lines and driving wires. Such autonomous quantum devices are currently attracting a lot of attention [1] with promising experimental applications like autonomous quantum refrigerators [2] and quantum computing powered by quantum batteries [3].
The overall aim of the project is to analyze the performances of autonomous quantum devices in the light of recent thermodynamic frameworks [4,5]. The thermodynamic analysis should explore the possibilities and limits of such autonomous quantum devices. The successful candidate will work on some of the following topics:

(i) Optimizing autonomous quantum devices. Focusing on a simple design of a quantum refrigerator made of a qubit interacting with a harmonic oscillator, the aim will be to optimize the initial state of the harmonic oscillator in order to maximize the performance of the refrigerator. Tools from optimal control theory will be used.

(ii) Apply the framework [5] to autonomous quantum refrigerators. In particular, since such devices operate without work source, the aim would be to understand which resource substitute the work. Other possible applications: thermodynamic computing [6], or autonomous error correction.

(iii) Apply an extended version of the framework [5] to quantum computation powered by quantum batteries [3].

(iv) Study the role of initial quantum coherences on the evolution of central thermodynamic quantities like heat flow, work flow, and entropy production. The study will compare to kind of dynamics (the so-called secular versus non-secular master equations [7]).

[1] J. A. M. Guzmán, P. Erker, S. Gasparinetti, M. Huber, N. Y. Halpern: Key issues review: useful autonomous quantum machines. Rep. Prog. Phys. 87, 122001 (2024).
[2] M. A. Aamir, P. Jamet Suria, J. A. Marín Guzmán, C. Castillo-Moreno, J. M. Epstein, N. Yunger Halpern, S. Gasparinetti: Thermally driven quantum refrigerator autonomously resets a superconducting qubit. Nat. Phys. 21, 318 (2025).
[3] Y. Kurman, K. Hymas, A. Fedorov, W. J. Munro, J. Quach: Powering Quantum Computation with Quantum Batteries. Phys. Rev. X 16, 011016 (2026).
[4] M. Esposito, K. Lindenberg, C. Van den Broeck: Entropy production as correlation between system and reservoir. New J. Phys. 12, 013013 (2010).
[5] C. Elouard, C. Lombard Latune: Extending the Laws of Thermodynamics for Arbitrary Autonomous Quantum Systems. PRX Quantum 4, 020309 (2023).
[6] Patryk Lipka-Bartosik, Martí Perarnau-Llobet, Nicolas Brunner, Thermodynamic Computing via Autonomous Quantum Thermal Machines, Science Advances 10, eadm8792 (2024).
[7] M. Boubakour, T. Szikman, C. Elouard: A refined thermodynamic analysis of nonsecular master equations. arXiv:2606.13504 (2026).

Type of project (theory / experiment): Theory

Required skills: good analytical skills, interest in open quantum systems, good programming skills.