Open Quantum Systems (Theory Group)

Project title: Thermal state preparation in qubits and many body systems

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Background: Our research efforts are focused on advancing methods to treat open quantum systems; such quantum systems couple to many "environmental" degrees of freedom. Instead of describing their dynamics with the unitary Schrodinger equation, the dynamics of open systems is often described by non-unitary dissipative quantum master equations, which are differential equations for the density operator [1]. We apply our methods to study dissipative quantum materials, quantum energy conversion devices, quantum sensing, and computing. We have been collaborating with other theoreticians and with experimentalists realizing quantum dissipative systems in e.g., Nitrogen Vacancy (NV) centres and superconducting qubits.

I am looking for one student to work on the project described below, or other projects in my group (please check out my group's recent publications).

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Project Description:

Quantum state preparation is a central challenge in quantum science and technology, as quantum algorithms, simulations, and sensing protocols depend on the ability to initialize systems in well-defined target states. In practice, state preparation is hindered by limited control, environmental noise, decoherence, and the exponential growth of Hilbert space with system size, making high-fidelity preparation increasingly difficult for many-body systems. These challenges motivate the development of new theoretical frameworks and practical protocols that balance accuracy and efficiency. A summer project on this topic would explore different approaches to quantum state preparation.

The repeated interactions (RI) model [2] is a class of microscopic system-bath models that mimics open quantum systems dynamics. Quantum algorithms can implement the repeated interaction model [3] to study quantum thermalization, dynamics, and quantum energy transfer. **Objectives**: Study, assess and develop quantum protocols and algorithms for open quantum system dynamics and specifically thermal state preparation; explore tradeoffs between internal and external dynamics for fast thermalization; test fundamental cooling limits [4].

Requirements: Students do not need to come with prior knowledge in the research field. I am looking for curious and motivated students who enjoy challenges and are interested in getting involved in projects combining theory and computer simulations. Students will be directed by the PI (Segal) and by graduate students. They will learn in-house codes and write their own programs. Final note: We have a good coffee machine.

[1] The theory of open quantum systems. H.P. Breuer, F. Petruccione 2002.

[2] F. Ciccarello, S. Lorenzo, V. Giovannetti, G. M. Palma, Quantum collision models: Open system dynamics from repeated interactions, Physics Reports, 954, 1 (2022).

[3] C. Ramon-Escandell, A. Prositto, D. Segal, Thermal state preparation by repeated interactions at and beyond the Lindblad limit, Physical Review Research 7, 043012 (2025).

[4] L. Bassman Oftelie, A. De Pasquale, and M. Campisi, Dynamic Cooling on contemporary quantum computers, PRX Quantum **5**, 030309 (2024).