

MASTER 2
Internship Proposal 2026–2027

Host institution	Laboratoire de Physique de l'École Normale Supérieure (LPENS)
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Entanglement sudden death and revival in quantum spin liquids

Keywords: Quantum magnetism, quantum information, open quantum systems

Scientific project

Quantum entanglement is a central resource for quantum technologies, yet it is fragile against interactions with an environment. Surprisingly, the entanglement between two qubits can disappear completely in a finite time even when their individual coherences decay gradually. This phenomenon, known as *entanglement sudden death*, need not be irreversible: an environment with memory can return quantum information to the qubits and allow entanglement to revive [1]. Understanding when a quantum many-body environment destroys or preserves entanglement is the motivation for this project.

Quantum spin liquids provide an unusual setting for this question. Kitaev models describe magnets whose excitations involve mobile Majorana fermions and discrete gauge fluxes [2]. We will consider a two-leg Kitaev ladder, which has an exact fermionic description in the absence of impurities. At finite temperature, thermally excited fluxes act as an effective source of disorder for the mobile excitations and can induce localization [3]. Such localization could restrict the spread of quantum information into the environment and enhance memory effects. This raises a counterintuitive possibility: **can heating help preserve quantum entanglement?**

This internship will investigate two spin-1/2 impurity qubits coupled by exchange interactions to different sites of the ladder. Starting from an entangled pair, the student will calculate its reduced dynamics and quantify entanglement through the *concurrence*. The objective is to determine how entanglement decay, survival and possible revivals depend on temperature, coupling strength and the structure of the environment. Particular attention will be paid to distinguishing genuine memory effects from recurrences caused by a finite system size.

The work will combine analytical calculations with numerical simulations in Python. Initial steps will involve simple limits and exact diagonalisation of small systems. The study can extend to weak-coupling master equations and finite-temperature spin correlations of the ladder, using its solvable structure to connect the qubit dynamics to the properties of the magnetic environment.

Methods and candidate profile. The project offers training in quantum magnetism, open quantum systems, entanglement dynamics and computational physics. A good understanding of quantum mechanics and basic programming skills are expected. Prior knowledge of quantum spin liquids is not required. Informal enquiries are welcome.

Selected references

- [1] T. Yu and J. H. Eberly, “Sudden Death of Entanglement”, *Science* **323**, 598–601 (2009).
- [2] A. Kitaev, “Anyons in an exactly solved model and beyond”, *Annals of Physics* **321**, 2–111 (2006).
- [3] A. Metavitsiadis and W. Brenig, “Thermal transport in a one-dimensional $\mathbb{Z}_2$ spin liquid”, *Phys. Rev. B* **96**, 041115(R) (2017).