

MASTER 1
Internship Proposal 2026–2027

Host institution	Laboratoire de Physique de l'École Normale Supérieure (LPENS)
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Probing quantum skyrmions with diamond spin sensors

Keywords: Magnetic skyrmions, quantum sensing, NV centres, quantum tunnelling.

Scientific project

Magnetic skyrmions are nanoscale textures in which spins form a swirling pattern. In frustrated magnets, their *helicity*, the angle describing the orientation of the in-plane spins, can behave as a quantum degree of freedom. Theory predicts discrete helicity levels and tunnelling between distinct configurations, motivating proposals to encode a qubit in a single skyrmion [1,2]. A central challenge is to identify measurable signatures of this collective quantum dynamics. **Can a diamond spin sensor reveal quantised skyrmion helicity?**

This project will explore this question using a nitrogen-vacancy (NV) centre in diamond, an atomic-scale spin sensor placed above a magnetic film [3]. Fluctuations of the skyrmion's stray magnetic field can induce transitions of the NV spin and modify its relaxation time T_1 . By tuning the sensor frequency and varying temperature or magnetic field, NV relaxometry could reveal the spectrum of helicity fluctuations. The goal is to establish which quantum features are detectable and under what conditions.

Starting from an effective quantum-rotor Hamiltonian for the helicity, the student will calculate energy levels and transition matrix elements, then relate them to the magnetic noise seen by the NV. The resulting predictions for $1/T_1$ will be studied as functions of temperature, field, sensor position and orientation. Particular attention will be paid to selection rules that can make some transitions invisible, and to how quantum predictions differ from classical helicity fluctuations and contributions from other skyrmion modes. This will help identify promising measurement geometries and the spectral resolution needed to separate the signals.

The work will combine analytical calculations with numerical simulations in Python. For an **M1 internship**, the core will be the helicity spectrum and stray-field coupling for a simple skyrmion profile. At **M2 level**, the study can extend to master equations for the sensor dynamics, dissipative broadening of the helicity transitions, and the influence of background magnetic noise. The scope and balance between analytical and numerical work will be adapted to the student's background.

Methods and candidate profile. The project offers training in quantum magnetism, quantum sensing, open quantum systems and computational physics. A good understanding of quantum mechanics and basic programming skills are expected. Prior knowledge of skyrmions or NV centres is not required. Informal enquiries are welcome.

Selected references

- [1] C. Psaroudaki and C. Panagopoulos, "Skyrmion Qubits: A New Class of Quantum Logic Elements Based on Nanoscale Magnetization", *Phys. Rev. Lett.* **127**, 067201 (2021).
- [2] C. Psaroudaki and C. Panagopoulos, "Skyrmion helicity: Quantization and quantum tunneling effects", *Phys. Rev. B* **106**, 104422 (2022).
- [3] F. Casola, T. van der Sar and A. Yacoby, "Probing condensed matter physics with magnetometry based on nitrogen-vacancy centres in diamond", *Nat. Rev. Mater.* **3**, 17088 (2018).