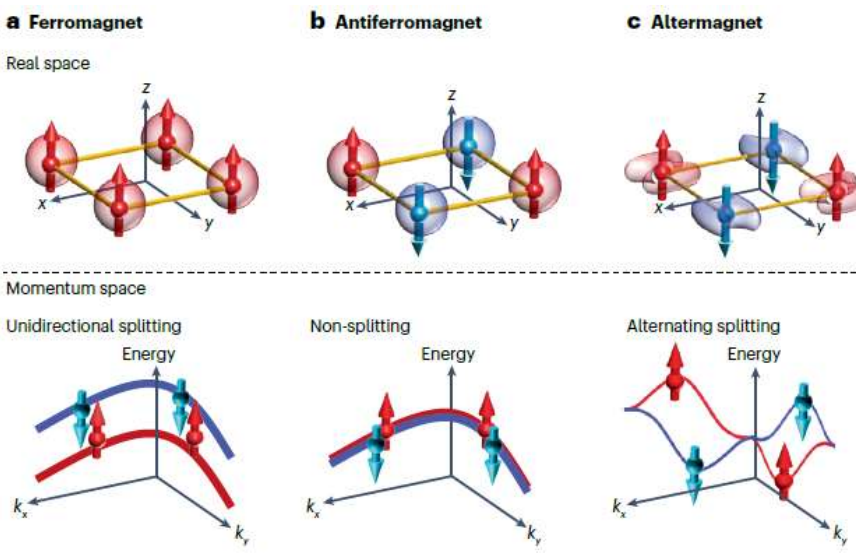
Proximity effects in superconductor/altermagnet interfaces

laboratoire Albert Fert

Scientific Context

Altermagnets (AMs)[1,2] form a recently proposed third class of magnetic materials. Unlike ferromagnets, which exhibit parallel spin alignment and net magnetization, or antiferromagnets, which have antiparallel spins and no net magnetization, AMs combine alternating spin alignment with unique symmetry connections (e.g., mirror or rotation). This results in spin-momentum locking in their energy bands, enabling anisotropic spin transport and spin-polarized currents without net magnetization. Thus, from a technological perspective, AMs merge the advantages of ferromagnets (spin polarization of conduction electrons) and antiferromagnets (vanishing stray fields and high-frequency spin dynamics), making them promising for applications in spintronics and magnonics[3]. Since their theoretical proposal in 2022, AMs have attracted significant research attention, with experimental efforts focused on identifying materials that exhibit their subtle properties. However, their demonstration is challenging, often requiring sophisticated probes to distinguish AM responses from other effects, such as spin-orbit coupling. Thus key challenges include developing efficient probes for AMs and leveraging their unique spin properties for novel functionalities. We propose that exploring the interaction between superconductors (Ss) and AMs could provide a powerful approach to address these challenges. S/AM interfaces have seen rapid theoretical growth, with new papers proposing phenomena like topological superconductivity, spin currents, and diode effects. Superconductivity may also serve as a sensitive probe for altermagnetism[4] . However, experimental studies are scarce, motivating this proposal. We will explore three main mechanisms of interaction: proximity effect (penetration of superconducting correlations can in the AM), the effect of the exchange field on superconductor's properties, and the dynamic interaction between magnetization dynamics in the altermagnet and the superconducting state. This will be debe via magneto transport and spin-pumping experiments in S/AM heterostructures grown in the lab.



Spin configurations in ferromagnets, conventional collinear antiferromagnets and altermagnets. a, Spins are parallel in real space. In momentum space, the energy bands show unidirectional splitting, with the sign generally independent of momentum. **b**, spins are antiparallel with isotropic spin density. The energy bands do not show splitting **c**, each sublattice displays anisotropic spin density. Opposite sublattices are connected by symmetries that are not inversion or translation symmetry. The energy bands exhibit alternating spin splitting, forming a *C*-paired spin-momentum/valley locking. Taken from [3]

1. Šmejkal *et al. Phys. Rev. X* **12**, 040501 (2022).
2. Krempaský *et al. Nature 2024 626:7999* **626**, 517–522 (2024).
3. Song *et al. Nature Reviews Materials 2025 10:6* **10**, 473–485 (2025).
4. Mazanik *et al.* https://arxiv.org/pdf/2603.06188 (2026).

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Work program & skills acquired during internship

The experimental work involves growth (via Pulse laser deposition) and nanofrication (lithography) of S/AM devices, and their characterization using transport measurements, FMR experiments, and advanced magnetic imaging (MFM, NV center microscopy) in a cryogenic environment. The student will interact and work with postdocs, permanent researchers, as well collaborators experts in theoretical modeling.

Applicant skills: Excellent team player, rigorous and enthusiastic, the candidate has a strong scientific curiosity. Experience and basic knowledge of superconductivity, magnetism and condensed matter physics in general are considered a great asset.

Work environment

The work will be developed at Laboratoire Albert Fert. Created and under the scientific direction of the 2007 Nobel Prize Laureate Prof. Albert Fert, this laboratory specializes in spintronics, nanomagnetism, complex oxides, and unconventional superconductors.

The laboratory is a joint endeavor of the CNRS –the largest research institution in France, the Univeristy Paris-Saclay, and the technological industrial THALES. The PhD student will evolve in a very rich intellectual environment in which academics and industrials work together, and fundamental research and technological developments advance hand in hand. From a more global perspective, the PhD project is circumscribed within a national effort on spintronics (PEPR SPIN), and within joint projects between the Laboratoire Albert Fert and various French laboratories (IJL Nancy, SPINTEC Grenoble, LPS Orsay, CINaM Marseille, PHELIQS Grenoble) and European Laboratories (UCM Spain, CSIC San Sebastian, CHALMERS Sweden, WWU Germany) on superconducting spintronics. Thus, PhD student will have access to a large network of excellent collaborators in France and Europe.

The supervisors will be Dr. **Javier E. Villegas (javier.villegas@cnrs-thales.fr) and Santiago Carreira (santiago.carreira@cnrs-thales.fr)**

Further information on the laboratory and the group can be found here:

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Requested background : Master 2
Duration : 4-6 months
Start period : from Feb 2027
Possibility of the PhD thesis: YES
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