M2 internship & PhD: 2D Superconducting Spintronics

Superconducting spintronics (and spin caloritronics) lies at the intersection of spin(-orbit) physics and superconductivity, traditionally studied in metals. Van der Waals materials, which can be exfoliated down to the monolayer limit have opened up new perspectives for the field.

We study the interplay of magnetism and superconductivity in heterostructures based on few-layer van der Waals (vdW) superconductors (SC) and magnetic (M) materials, taking advantage of the recently established possibility of obtaining atomically clean interfaces between such materials and integrating these stacks into devices. Such systems provide a novel, highly-tuneable platform for superconducting spintronics. Our collaboration has shown that semiconducting transition metal dichalcogenides (TMDs) and (anti)ferromagnet CrSBr are excellent tunnel barriers. Thus, we have obtained spectral evidence for a possible equal-spin triplet superconducting (ESTS) state in the TMD $NbSe_2$. Recently, we have demonstrated control of CrSBr's magnetism in all possible applied field directions.

Building on work by previous students Pierre-Eloi Paret and Maya Klang, the internship will focus on benchmarking and the demonstration of new functionality (energy-independent spin-filtering, gate tuneability…) in SC/M devices, where SC is a thin-film metal such as aluminium.

Next, probably during the PhD, the candidate will focus more on vdW magnetic materials and TMD superconductors; the latter have strong Ising spin-orbit coupling at the ultrathin limit. We aim to elucidate the spin- and valley-active roles of SC/M interfaces, including possible symmetry mismatch effects, as well as the effect of Ising spin-orbit coupling on spinful quasiparticle eigenmodes. Finally, we propose to demonstrate tuneable SC/M proximity effects, e.g. Edelstein and Yu-Shiba-Rusinov physics, and the all-electrical control of unconventional spinful SC states.

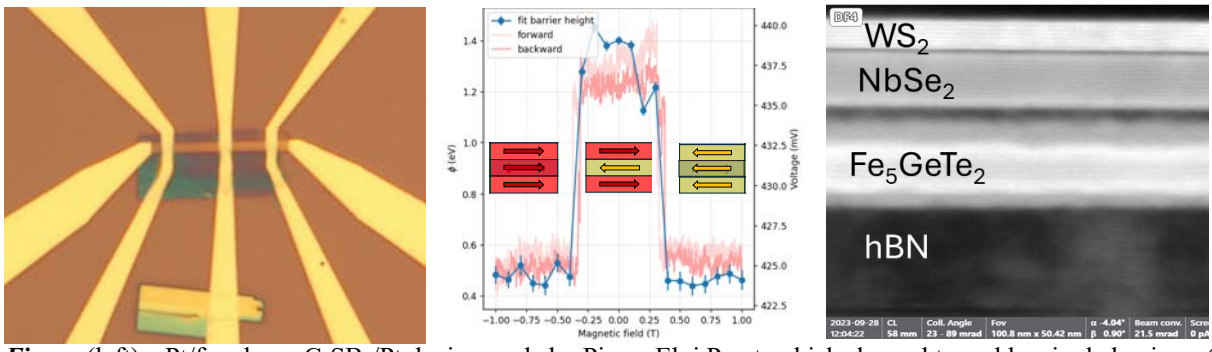


Figure (left) a Pt/few-layer CrSBr/Pt device made by Pierre-Eloi Paret, which showed tunnel barrier behaviour. (centre) Fine control of the CrSBr magnetisation with an applied magnetic field along the *b* axis. (right) TEM cross-section of a SC/M device made by Maya Klang, showing clean interfaces between the materials.

Candidates should have a strong background in quantum mechanics and condensed matter physics, and solid laboratory experience. Familiarity with nanofabrication, vdW materials and low-noise low-temperature electronic transport would be a plus. This co-supervised project is part of a long-standing collaboration between the Université Paris-Saclay (Charis Quay *et al.*) and the Hebrew University (Hadar Steinberg *et al.*). The student will have the opportunity to interact with other colleagues in the field, including theorists.

References

H Steinberg *et al.*, 'Transition Metal Dichalcogenide Superconductor Tunneling Devices: A Review', *Journal of Superconductivity and Novel Magnetism* **38**, 103 (2025).

M Kuzmanović *et al.*, 'Evidence for spin-dependent energy transport in a superconductor', *Nat. Commun.* **11**, 4336 (2020).

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