

INTERNSHIP PROPOSAL

(One page maximum)

Laboratory name: Institut des NanoSciences de Paris (INSP)	
CNRS identification code: UMR7588	
Internship director's surname: Tristan Cren and Marie hervé	
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https://w3.insp.upmc.fr/recherche-2/equipes-de-recherche/spectroscopie-des-nouveaux-etats-quantiques/	
Internship location: Jussieu campus	
Thesis possibility after internship:	YES
Funding: NO	If YES, which type of funding:

Superconductivity in Stamped Misfit Crystals

Keywords: Superconductivity, Transition-metal dichalcogenides, Scanning tunnelling spectroscopy, Ising spin orbit coupling.

Scientific description:

Transition-metal dichalcogenides (TMDs), particularly monolayer NbSe₂ and NbS₂ are ideal candidates to host topological superconductivity. Their broken in-plane inversion symmetry and heavy transition metal atoms generate a strong out-of-plane effective magnetic field. This so-called Ising spin-orbit coupling (SOC) not only protects superconductivity against in-plane magnetic fields far beyond the Pauli limit, but also naturally favours unconventional pairing since Ising SOC locks spins out of plane and allows mixed singlet–triplet pairing. However, accessing a topological phase might require extreme shifts in the chemical potential of the single layer, one must push the Fermi level close to the top of the band (several hundreds of meV of chemical potential shift compared to pristine NbSe₂). Misfit layer compounds bypass standard limitations by sandwiching transition metal dichalcogenides (TMDs) between charge-donating rock-salt layers. In particular, in the misfit layer compound (LaSe)_{1.14}(NbSe₂)₂, the large work-function of the TMD compared to the rock-salt drives a huge charge transfer (up to 0.6e⁻/Nb), while preserving the band structure and Ising SOC of the NbSe₂.

Recently we exploited this unique tunability to track the superconducting state of NbSe₂ across a remarkably wide doping range using the newly grown misfit layer compound (La_xPb_{1-x}Se)_{1.14}(NbSe₂)₂. We discovered a strongly non-monotonic phase diagram marked by an abrupt collapse of superconductivity at a critical composition (x=0.4). This boundary sharply separates a conventional s-wave regime at low doping (x<0.4) from a disorder-sensitive, unconventional state at high doping (x>0.4). Crucially, orientation-selective in-gap modes emerge at atomic step edges in the highly doped phase. These signatures establish a doping-driven change of pairing symmetry, and point to a crystalline-topological order in the high-doping phase. This establishes MLCs as a uniquely tunable platform to engineer and explore two-dimensional topological superconductivity.

With this internship we plan to study both bulk misfit compounds and single layers prepared by exfoliation in ultrahigh vacuum. Scanning tunnelling microscopy/spectroscopy down to 300mK will be used in order to map the local density of states of these materials for compositions close to the one at which we have observed a topological transition. We explore in particular the role of atomic defects and step edges that can shed some light on the symmetry of the Cooper pairs. This work is a first step toward an electrical control of the topological transition in a field-effect transistor geometry that will be the topic of an eventual thesis.

Related bibliography:

- *Tuning the charge transfer of transition metal dichalcogenides via misfit layer compounds*, H. Le Du et al., Adv. Funct. Mater. 36, e77636 (2026)
- *Doping tunable charge density waves in misfit layer compounds*, H. Le Du et al., arXiv:2607.19095 (2026)
- *Doping-controlled topological superconducting transition in misfit layer compounds*, H. Le Du et al., arXiv:2609.07545 (2026)
- *Misfit layer compounds: A platform for heavily doped 2D transition metal dichalcogenides*, R.T. Leriche et al., Adv. Funct. Mater. 31, 2007706 (2021)

Techniques/methods in use: Low temperature STM, Exfoliation.

Applicant skills: The candidate should have a very good background in quantum solid state matter. This is a dominantly experimental internship; however, the topic requires solid mathematical skills, in particular concerning topological aspects of the work.

Please, indicate which speciality(ies) seem(s) to be more adapted to the subject:

Condensed Matter Physics:	YES	Soft Matter and Biological Physics:	NO
Quantum Physics:	NO	Theoretical Physics:	NO