Master 2: *International Centre for Fundamental Physics*

INTERNSHIP PROPOSAL

(One page maximum)

Laboratory name: Laboratoire de Physique des Solides
CNRS identification code: UMR8502
Internship director'surname: Pascal SIMON/Andrej MESAROS
e-mail: pascal.simon@universite-paris-saclay.fr, Phone number: : +33 169156090
andrej.mesaros@universite-paris-saclay.fr
Web page: : https://equipes2.lps.u-psud.fr/pascal-simon/
Internship location: University Paris Saclay, Bat. 510, 91405 Orsay Cedex
Thesis possibility after internship: YES
Funding already obtained for a PhD: NO If YES, which type of funding:

Flat band superconductors: what is the length scale?

Recent experimental studies on twisted bilayer graphene (TBG) and other twisted materials have revealed unexpectedly complex phase diagrams with exotic phases of quantum matter [1]. Among them, they revealed highly unconventional superconducting phases with ultra-flat bands, which cannot be described by the conventional BCS theory. Due to their very low Fermi velocity, the superconducting coherence length ξ, predicted by BCS theory (which is proportional to the Fermi velocity) is more than 20 times shorter than the measured values. Recent theoretical developments [2] show that the coherence length is instead governed by the quantum metric of the Bloch states (which measures the distance between two adjacent Bloch states).

When a magnetic impurity is embedded in a superconductor, its local moment acts as a Cooper pair breaker, creating intra-gap bound state excitations whose spatial extent can be extremely large and is governed by ξ [3]. In this internship, we would like to theoretically study how the superconducting order parameter responds to inhomogeneities such as isolated or clusters of magnetic impurities. More specifically, we would like to analyze the problem of a magnetic impurity in a flat-band superconductor and decipher if and how the quantum metric shows up in the bound state equations.

In the longer term, our understanding of hybrid systems involving such flat-band superconductors needs to be completely revised: this includes all the quantum engineering that has been developed with mesoscopic superconductors.

[1] Y. Cao et al., *Unconventional superconductivity in magic-angle graphene superlattices*, Nature 556, 43 (2018).
[2] S. A. Chen and K. T. Law, *Ginzburg-Landau Theory of Flat-Band Superconductors with Quantum Metric*, Phys. Rev. Lett. 132, 026002 (2024).
[3] G. C. Ménard et al., *Coherent long-range magnetic bound states in a superconductor*, Nature Physics 11, 1013 (2015).

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: YES Theoretical Physics: YES