Master 2: *International Centre for Fundamental Physics*

INTERNSHIP PROPOSAL

Laboratory name: Laboratoire de Physique des Solides
CNRS identification code: UMR 8502
Internship director'surname: MESAROS Andrej & SIMON Pascal
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Internship location: Orsay
Thesis possibility after internship: YES
Funding: NO If YES, which type of funding:

Title: **New topological states from inhomogeneous spin-orbit coupling**

Topological matter became a central research topic because it has exotic electronic states that are protected against many material imperfections. Two key examples are that (A) topological insulators exhibit conducting edge states, which are promising for future spintronics/electronics [1], and (B) topological superconductors can host Majorana bound states (MBS), which are localized quasiparticles with non-Abelian statistics, possibly useful for quantum computing [1]. Building topological matter is generally expected to require both magnetic fields and spin-orbit coupling (SOC) to control the electron's spin. The SOC is a fundamental interaction that entangles the electron momentum and spin, but up to now has been treated only as constant in space. A crucial experimental route to topological matter however uses SOC-dominated substrates or adatoms to induce SOC in a material: the induced SOC is then inhomogeneous, and an understanding of topological matter that could arise is therefore urgently needed.

In this proposal, we want to theoretically study the use of inhomogeneous SOC for creating topological insulators and superconductors, and their protected propagating or localized electron states. Firstly, motivated by ongoing experiments [2], this internship will focus on two-dimensional lattices, e.g., graphene, with periodic and quasi-periodic patterns of SOC such as induced by a substrate lattice. In order to get familiar with the physics, the student will start with numerical calculations based on exact diagonalization of tight binding Hamiltonians.

Secondly, this internship offers a challenge to the motivated theory student by focusing on a deeper physical relationship between inhomogeneous SOC and inhomogeneous magnetic fields. In one dimension, the fact that a spiral-like magnetic field can be mathematically mapped to constant SOC is being exploited in experiments for creating MBS [3]. Yet, there is no general understanding of the non-unique mapping, nor of the possible topological matter. Promise is shown by a few studies predicting MBS in two-dimensional magnetic skyrmion textures [4]. Finding magnetic textures that reproduce examples of inhomogeneous SOC introduced above is a direction we plan to deepen.

Along the same lines, special attention will be paid to inhomogeneous SOC configurations with a point-like singularity. One such vortex-like singularity in SOC was found to explain experimental findings of topological superconductivity and MBS in a monolayer with magnetic atoms [5]. In the long run, we would like to study the stability of such singular SOC by solving Ginzburg-Landau field theories.

[1] M.Z. Hasan&C.L. Kane, arXiv:1002.3895; J. Alicea, arXiv:1202.1293.
[2] T. Wakamura *et al.*, arXiv:1809.06230.
[3] B. Braunecker et al., arXiv:1004.0467; J. Klinovaja *et al.*, arXiv:1307.1442; G.L. Fatin *et al.*, arXiv:1510.08182; Experiments at LPA & LPS.
[4] G. Yang *et al.*, arXiv:1602.00968; M. Garnier, A. Mesaros, and P. Simon, submitted.
[5] G. Ménard *et al.*, arXiv:1810.09541.

Profile: Condensed matter theory, superconductivity, spin-orbit coupling and topology

Please, indicate which specialities seem to be more adapted to the subject:

Condensed Matter Physics:	YES	Macroscopic Physics and complexity:	NO
Quantum Physics:	YES	Theoretical Physics:	YES