Master 2: *International Centre for Fundamental Physics*

INTERNSHIP PROPOSAL

Laboratory name: Laboratoire de Physique des Solides
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Internship location: Orsay
Thesis possibility after internship: YES
Funding: Not yet secured If YES, which type of funding: ANR

Title: **Exotic topological superconducting states with 2D Dirac materials**

Much interest in topological superconducting matter has emerged in the past years, partly because such superconductors can host exotic low-energy excitations such as Majorana bound states. The interest in Majorana fermions is mainly motivated by their non-Abelian statistics which may be useful for quantum computing [1]. Despite most of the research on Majorana fermions focusing on one-dimensional systems, a few recent experimental works report topological superconductivity in two dimensions [2]. However, the present systems seem difficult to handle experimentally and are not easily scalable. New platforms compatible with nanoelectronics are therefore strongly required. In this proposal, we want to study theoretically the topological superconductivity in 2D materials with a Dirac-like low energy spectrum.

Transition metal dichalcogenides (TMDs) are quasi-2D Dirac materials like graphene and are considered candidates for the next generation of low-energy-dissipation electronics. However, unlike graphene, they have a strong spin-orbit coupling and are experimentally found to be superconducting under certain conditions. These key differences make them ideal materials for the study of topological phases.
It was recently discovered that superconductivity found in monolayer TMD materials is of a new type called Ising superconductivity [3] as a consequence of the strong spin-orbit coupling. Our goal is to study how TMDs can be used to engineer topological superconductivity sustaining Majorana edge excitations.

Motivated by experiments realized in Paris, we will investigate heterostructures made by stacking magnetic layers and a monolayer of TMD. In order to get familiar with the physics, the student will start with numerical calculations based on exact diagonalization of tight-binding Hamiltonians exhibiting Ising topological superconductivity. In this direction, a special attention will be paid to defects which can pin Majorana bound states in their core. In the long run, we would like to: (1) Engage in more microscopic many-body calculations to study the possible superconducting orders able to emerge in TMDs (by directly solving microscopically the superconducting gap equation), and (2) Develop effective Landau field theories to describe these new types of exotic multi-component superconducting orders.

This work is motivated by on-going experiments carried out in the Paris area, and can also lead to extensive collaboration with foreign universities (for example, in Hong Kong).

[1] J. Alicea, , Rep. Prog. Phys. 75, 076501 (2012) or arXiv:1202.1293.
[2] G. Ménard et al., Nat. Comm. 10, 2587 (2019); D. Wang et al., Science 362, 333 (2018)
[3] J. M. Lu, et al., Science 350, 1353 (2015). X. Xi, et al., Nature Phys. 12, 139–143 (2016).

Profile: Condensed matter theory, superconductivity, Dirac matter and topology

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

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