PhD Thesis Proposal 2017

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Title: **Novel superconducting states with magnetic domains in superconductors**

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 but also because these exotic particles are their own antiparticles, making them chargeless and difficult to evidence (see e.g. [1]). Many new platforms supporting Majorana quasiparticles have been advocated recently among which arrays of magnetic impurities in superconductors. This opens up a huge theoretical and experimental activity at the frontier between superconductivity, magnetism and topological considerations.

Isolated magnetic impurities in a 2D superconductor give rise to so-called Shiba bound states. The spatial extent of their long-range wave-function has been recently characterized experimentally based on theoretical support [2]. They can be regarded as elementary building blocks. In the dense limit, these bound states give rise to bands which may be in some topological phase supporting Majorana fermions. We have recently proposed that the ground state of dense chain of magnetic impurities on a superconductor can actually self tune in its topological phase [3]. During this PhD, after being acquainted with the formalism, we will extend this study to large magnetic domains embedded in 2D superconductors which offer a new route to realize topological superconductivity as we demonstrated recently in collaboratio[4]. We want to better characterize the interplay between macroscopic magnetic cluster and superconductivity. In order to tackle this issue, we plan to use a combination of microscopic approaches, some numerical calculations based on exact diagonalization and also to study an effective Ginzburg Landau free energy valid for long length scales.

All the aforementioned considerations are based on a classical treatment of magnetic impurities valid for large spins. Treatin arrays of quantum spins in a superconducting host constitutes a challenging task we plan to attack in the longer run. Along this road, it would be worth properly analyzing the case of a single multi-orbital quantum impurity. This will be done using numerical renormalization group approach. The lattice of quantum impurity will be tackled using a combination of numerical techniques such as density matrix renormalization group and also analytical approaches based on low-energy field theory.

[1] J. Alicea, , Rep. Prog. Phys. 75, 076501 (2012) or arXiv:1202.1293.
[2] G. Ménard, S. Guissart, et al., Nature Physics (2015) or arXiv :1506.06666.
[3] B. Braunecker, P. Simon, Phys. Rev. Lett. 111, 147202 (2013).
[4] G. Ménard, S. Guissart, et al., arXiv:1607.06353

Profile: Condensed matter theory, superconductivity, magnetism, topology, many-body physics.