Alexandra PALACIO MORALES
Associate Professor (Maître de Conférences)
alexandra.palacio-morales@universite-paris-saclay.fr
tél. : 01 69 15 80 11

- PhD Offer -
Quantum dynamics of a single spin on a superconductor

Keywords: YSR states, Unconventional superconductivity, High frequency -STM, UHV growth

The use of two-level systems as qubits are central to quantum information and simulation. The archetype of a two-level system is a spin-½ object in a magnetic field. A simple solid-state example is a magnetic atom in an insulator. The physical implementation of quantum computers has at its heart two requirements, which appear to be in competition: long coherence times to preserve quantum states and scalability for the implementation of more complex circuits. The first requires weak interactions and hence isolated systems, while the second leads to densification and the risk of increased interactions. One way to resolve this is to use substrates with energy gaps (i.e. zero density of states in the energy range of the qubits) and even better, topological protection. Both of these are possible in superconductors: conventional superconductors have an energy gap devoid of low-lying excitations, while spins in interaction with the superconductor are predicted to give rise to topologically protected states.

Bottom-up magnet-superconductor hybrid systems have been studied with scanning tunneling microscopy (STM), which is ideal for visualising, manipulating and measuring at the atomic scale. So far, spectroscopy on single spins has revealed the existence of Yu-Shiba-Rusinov (YSR) states; Bogoliubov excitations with electron-hole parity; i.e., a two-level system protected from the continuum by the superconducting gap [1]. The main strategy for attempting to create robust qubits has been to engineer the band structure of magnetic arrays by modifying their orientation on, or coupling to, the underlying superconductor [2,3]. Under certain conditions, these hybrid systems show topologically protected zero-energy collective modes at the edge of the magnetic structures; called Majorana Bound States [4,5,6,7].

To date, these studies have only been performed in the classical and static limits. The first goal of this PhD thesis is to address the quantum dynamics of single spins on a superconducting surface; i.e., to analyze the spin coherence lifetime and the Rabi oscillations, which might evolve with the effective exchange coupling of the spin with the superconductor, see Fig. 1a. A smooth control of the exchange coupling from weak to strong will bring the magnetic-superconductor hybrid systems through a quantum phase transition; i.e., from Kondo doublet to Kondo singlet states [8,9], see Fig. 1b. The second goal is then to address the competition of the Kondo and the superconductivity and the spin splitting of Kondo doublet ground state.

To achieve this, the PhD will perform Electron Spin Resonance (ESR), which consists of resonantly driving the spin of an adatom by means of a microwave field applied across the impurity [10,11]. The platforms of the studies for this project are spin-1/2, such as CoPc or CuPc molecules, on $NbSe_2$ [12] or Nb(110) thin films on which the exchange coupling of the impurities with respect to the superconductor is controlled by adjusting tip-sample distance on top of the molecule [8]. These research activities needs from ESR-STM instrumentation. The PhD will be involved in the final setting of one-of-a-kind Electron Spin Resonance (ESR) STM, called MHz-ESR-STM, based on our finite-frequency (shot-noise) STM [13]. Particularly, the novel excitation and readout implemented in our MHz-ESR-STM will enhance an order of magnitude the spin coherence phase to $\sim\mu s$ (i.e., long qubit coherence times) and will allow a fast qubit reading and writing.

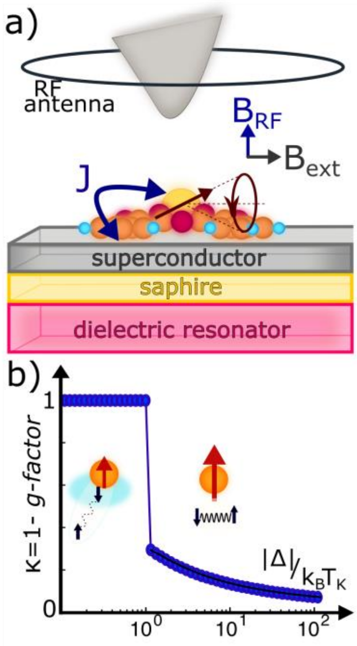

Figure 1.a) Spin dynamics on molecules on a superconductor using a novel instrumentation: a MHz-ESR-STM. b) Evolution of the compensation factor κ through the Quantum phase transition (QPT). The schematics show spin-superconducting interactions at both sides of the QPT [9].

[1] U. Thupakula et al., Phys. Rev. Lett. **128**, 247001 (2021)
[2] K. Franke et al., Science **332**,940-944 (2011)
[3] M. Ruby et al., Phys. Rev. Lett. **120**, 156803 (2018)
[4] S. Nadj-Perge et al., Science **346**, 6209 (2014)
[5] H. Kim et al., Science Adv. **4**, eaar5251 (2018)
[6] G. Menard et al., Nat. Comm. **8**, 2040 (2017)
[7] A. Palacio-Morales et al., Science Adv. **5**, aav6600 (2019)
[8] L. Farinacci et al. Phys. Rev. Lett. **121**, 196803 (2018)
[9] C. P. Moca et al. Phys. Rev. Lett. **127**, 186804 (2021)
[10] S. Baumann et al., Science **350**, 417-420 (2015)
[11] K. Yang et al., Sciences **366**, 509-512 (2019)
[12] S. Kezilebieke et al. Nano Lett. **19**, 4614-4619 (2019)
[13] F. Massee et al., Rev. Sci. Instrum. **89**, 093708 (2018

How to apply? Interested candidates should contact Dr. Alexandra Palacio Morales via email (alexandra.palacio-morales@universite-paris-saclay.fr) by submitting a short motivation letter and a CV.