A Yu-Shiba-Rusinov Qubit

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Magnetic impurities in s-wave superconductors lead to spin-polarized Yu-Shiba-Rusinov (YSR) in-gap states and a chain of magnetic impurities offers one of the most viable routes for the realization of Majorana bound states. They hold a promise for topological quantum computing, but this ambitious goal looks distant since no quantum coherent degrees of freedom have yet been identified in these systems. To fill this gap we propose an effective two-level system, a YSR qubit, stemming from two nearby impurities. Using a time-dependent wave-function approach, we derive an effective Hamiltonian describing the YSR qubit evolution as a function of distance between the impurity spins, their relative orientations, and their dynamics. We show that the YSR qubit can be controlled and read out using the state-of-the-art experimental techniques for manipulation of the spins. Finally, we address the effect of the spin noises on the coherence properties of the YSR qubit, and show a robust behavior for a wide range of experimentally relevant parameters. Looking forward, the YSR qubit could facilitate the implementation of a universal set of quantum gates in hybrid systems where they are coupled to topological Majorana qubits.

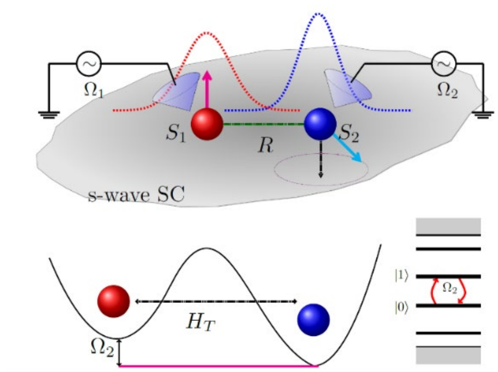

Fig: Two classical spins, target (red) and test (blue), respectively, are placed on top of a 2D s-wave superconductor at a distance R inducing a double-well potential that accommodates two in-gap states for a given parity: the odd parity states |0> and |1> define the YSR qubit states. The asymmetry of the potential stems from the slightly different coupling parameters at the two sites. Driving the test spin effectively tunes the potential bias, and when at resonance with the qubit splitting, it allows for coherent rotations of the qubit, while the target spin is interrogated off-resonantly for quantum non-demolition detection.

References:

[1] Archana Mishra, Pascal Simon, Timo Hyart, Mircea Trif (arXiv: 2106.01188)

*[2] Archana Mishra, So Takei, Pascal Simon, Mircea Trif, Phys. Rev. B **103**, L121401 (2021)*