

Magnetic resonance of single biomolecules with quantum superconducting circuits

Superconducting qubits, developed for quantum computing, can also serve as sensitive detectors for probing the magnetic properties of individual molecules. The Quantronics group has demonstrated the detection of individual electron spins in crystals by counting the microwave photons they emit [1], as well as the coherent control of neighbouring nuclear spins [2]. This internship will contribute to our ongoing work on molecular spins in frozen solution, with the aim of performing magnetic resonance spectroscopy on individual spin-labelled biomolecules.

Electron spin resonance (ESR) provides information about the local electronic and magnetic environment of molecules. In structural biology, interactions between spin labels can also be used to measure distances within proteins. Conventional experiments average over many molecules, obscuring their individual properties and limiting spectroscopic resolution. Measuring molecules individually could overcome this ensemble broadening and reveal local environments and spin couplings that are otherwise unresolved, opening access to more detailed structural information.

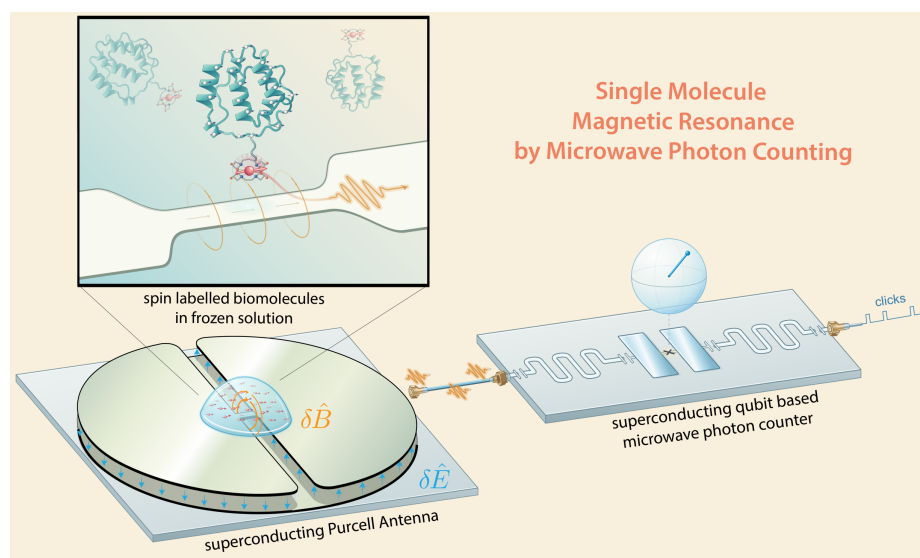


Figure 1

Proposed experiment. Spin-labelled biomolecules in frozen solution are coupled to a superconducting antenna (left; molecular detail in inset). Following microwave excitation, the antenna enhances and collects the radiation emitted by the spins. The photons travel to a separate circuit, where a superconducting qubit detects their arrival (right).

Internship project

The internship will bring together superconducting quantum computing and molecular spectroscopy. Our aim is to extend microwave photon counting from individual spins in pristine crystals to molecular spin labels, particularly Gd-DOTA, in frozen solution. A central challenge is whether radiative emission can compete with faster non-radiative relaxation in these molecular environments. New superconducting Purcell antennas and low-noise qubit-based photon counters provide the tools to explore this regime.

The student's first objective will be to establish a reproducible procedure for depositing molecular samples on a superconducting resonator, combining surface preparation, controlled deposition and microscopy. Alongside this work, they will learn to operate the superconducting-qubit photon detector, including microwave pulse calibration, dispersive readout and reset: the same control and measurement techniques used in quantum computing. Depending on progress, they will combine photon counting with pulsed ESR to search for the molecular spin signal and, if detected, begin characterising its relaxation dynamics. The project will establish the experimental foundations for detecting individual spin-labelled biomolecules.

Candidate profile and PhD

We seek a Master's student with a strong background in quantum mechanics and a pronounced interest in experimental physics. Programming experience is desirable; prior expertise in biochemistry is not required. The internship is intended to continue into a PhD in the group, developing single-molecule magnetic resonance with superconducting quantum circuits.

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