

INTERNSHIP PROPOSAL

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CNRS identification code: UMR 8023
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Internship location: Quantic team, LPENS, 24 rue Lhomond, 75005 Paris
Thesis possibility after internship: YES
Funding: YES Type of funding: INRIA grant

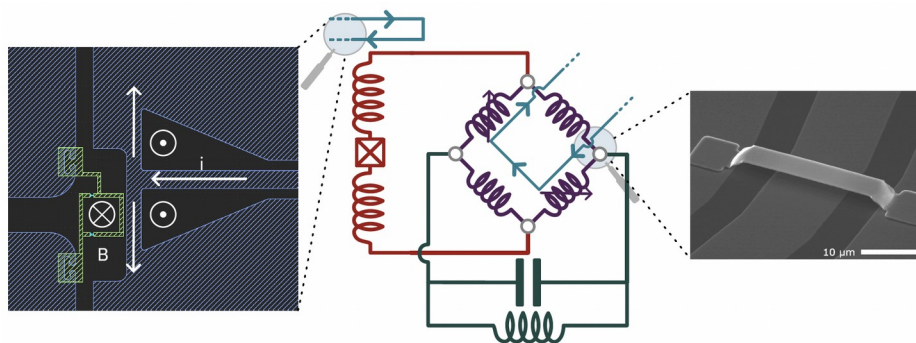
Simulating light–matter interactions with superconducting circuits

We will build a superconducting circuit to simulate light–matter interaction beyond the strong-coupling limit: the coupling between an artificial atom and a microwave resonator is tuned in situ, from zero up to the deep-strong coupling regime, where it exceeds the bare frequencies of both.

In atomic systems, light–matter interaction is weak, set by the fine-structure constant $\alpha \approx 1/137$. In high-impedance superconducting circuits, the coupling rate instead reaches the atom and photon frequencies [1,2]. The ground state then becomes an entangled atom–field superposition, a Schrödinger cat, and the Dicke and spin-boson models predict quantum phase transitions driven by the interaction itself. Measuring these states remains an open challenge: once atom and photon hybridize, one can no longer read them out separately.

Our approach relies on a new coupler: a Wheatstone bridge of Josephson inductances (figure, center). When the bridge is balanced, the coupling vanishes by symmetry; a magnetic flux unbalances it and tunes the coupling in magnitude and sign, with no intermediate mode in the spectrum. One prepares the system at weak coupling, ramps it into the deep-strong regime, and switches the coupling off within a nanosecond: this quench projects the hybridized state onto the uncoupled basis, where standard qubit and cavity readout apply.

The student will first design the device – a fluxonium qubit coupled to a lumped-element resonator through the bridge – using circuit quantization and numerical simulations, quantify how fabrication asymmetries limit the off state, and develop in the ENS clean room the superconducting air bridges that route the flux lines. Depending on progress, the student will then fabricate the full circuit and perform its first spectroscopy at 10 mK, mapping the spectrum from the dispersive to the deep-strong coupling regime. The internship can be continued as a PhD on quench protocols and bosonic qubits.



Left: on-chip flux line: a current i in a coplanar line shorted to ground threads a field B through the SQUID loop (green). **Center:** fluxonium (red) coupled to a lumped-element resonator (green) through the bridge coupler (purple); flux lines (blue) bias qubit and coupler independently and cross over air bridges. **Right:** electron micrograph of an air bridge [3].

[1] P. Forn-Díaz et al., Rev. Mod. Phys. 91, 025005 (2019); [2] F. Yoshihara et al., Nat. Phys. 13, 44 (2017); [3] N. Janzen et al., Appl. Phys. Lett. 121, 094001 (2022).

Condensed Matter Physics: YES
Quantum Physics: YES

Soft Matter and Biological Physics: NO
Theoretical Physics: NO