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Towards strong coupling between a heavy fluxonium qubit and a phononic crystal membrane resonator

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Owing to recent advances in phononic engineering, chip-scale mechanical resonators with lifetime and coherence time in the order of seconds in a thermal environment at 10 mK have been achieved [1]. The non-linearity of a superconducting circuit could bring this highly-coherent mechanical system in the regime of macroscopic quantum superpositions. [2]. From a fundamental perspective, by providing full control over the quantum state of the macroscopic mechanical system, this hybrid platform would be ideal to test gravitational collapse models [3]. However, the main difficulty against a strong coupling scheme is the large frequency difference between the two quantum systems. An interesting direction towards strong elechtromechanical coupling consists in applying a DC-bias to a pair of mechanically compliant capacitors to create a motion-to-charge conversion. With this approach, the Boulder group has demonstrated a sizeable interaction between a superconducting qubit in the GHz range and a mechanical resonator with frequency $\Omega = 25\ MHz$ [4]. Nevertheless, the ubiquitous transmon had to be replaced by a Cooper-pair box (CPB), a strongly anharmonic qubit but very sensitive to low-frequency environmental charge noise. This situation prevented the coherent manipulation of the mechanical system. Our group has proposed a new approach by coupling the mechanical resonator to a radically different qubit architecture that will enable direct and resonant strong coupling: the heavy fluxonium qubit. This circuit is composed of a Josephson junction (E_J) shunted to a large capacitance (E_c) and an extremely large inductance (E_L), fulfilling the conditions $E_L < E_c$ and $E_c \ll E_J$. As recently demonstrated by Schuster's group, the heavy-fluxonium is able to reach frequencies as low as 14MHz and outperform all the other qubit architectures in terms of both energy relaxation and dephasing rates, while the low-frequency qubit manifold can be efficiently readout and manipulated using microwave transitions towards higher qubit excited states [5].

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