PhD Thesis Topic

Laboratory: Institut Néel/CNRS
Address: 25 rue des Martyrs ; Grenoble
Thesis director: Andrew Fefferman
Tel: 04.76.88.90.92
e-mail: andrew.fefferman@neel.cnrs.fr

Ultra-Coherent Nanomechanical Resonators

Scientific project: The unparalleled sensitivity of quantum sensors will yield many important applications. In particular, resonators with mechanical coherence times of order 10 to 100 milliseconds at 10 mK have recently been demonstrated.[1] These devices could be used as quantum memories in hybrid systems for quantum communication and computation. They could also be used for testing fundamental aspects of quantum mechanics. At the same time, nuclear demagnetization refrigeration (NDR), yielding microkelvin cryostat temperatures, has been applied to microwave optomechanics, yielding passive ground state cooling of ~10 MHz mechanical modes.[2] However, researchers in these two fields have not yet combined NDR and ultra-high Q mechanical resonators with mechanical coherence times exceeding 10 ms. Since the mechanical damping rate Γ_m of these devices decreases with cooling even at 10 mK, the mechanical coherence time $\sim 1/(\Gamma_m \bar{n}_{\mathrm{th}})$ for thermal phonon occupation $\bar{n}_{\mathrm{th}}$ should be greatly increased by cooling to lower bath temperatures.

1. A. Youssefi *et al*. *Nature Physics* (2023) https://doi.org/10.1038/s41567-023-02135-y
2. D. Cattiaux *et al*. *Nature Communications*, 12, 6182 (2021) https://doi.org/10.1038/s41467-021-26457-8

Methods and techniques: We will use state-of-the-art optomechanical devices fabricated by the Kippenberg group at EPFL for the project. The devices are known to have exceptionally low mechanical dissipation near 10 mK and relatively strong optomechanical coupling. Using the microkelvin microwave optomechanics cryostats of the Néel Ultra-Low Temperatures group[3], which are unique in the world, we will cool the devices to temperatures below 1 mK in order to achieve a record mechanical quantum coherence times. We will then apply this extreme coherence to quantum memory protocols and experiments probing the implications of general relativity in quantum mechanics.

3. M. Raba *et al*. Phys. Rev. Applied (2024) https://doi.org/10.1103/PhysRevApplied.22.024027

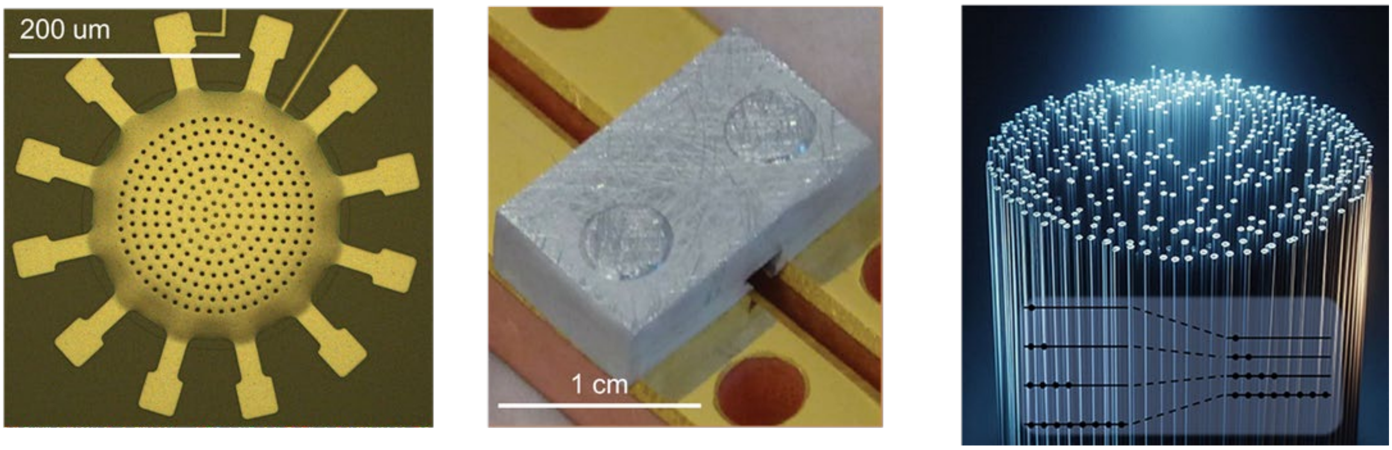

Figure: (left) One of the ultracoherent nanomechanical drums, (center) the ultra-low resistance superconducting heat switch for nuclear demagetization refrigeration, (right) artist's impression of the aluminum wire bundle nuclear refrigerant with inset depicting the population of the Zeeman levels at two magentic fields.