Superfluid Helium-4 as an Ultra-low Loss Optomechanical Element
Coupling the motion of superfluid and superconducting condensates

L. De Lorenzo and K. C. Schwab

Applied Physics, Caltech, Pasadena CA, USA

Frictionless motion at zero frequency is a hallmark of superfluidity, which has led us to consider the superfluid state of helium-4 as an ultra-low loss mechanical element for the study of the quantum limits of motion. At temperatures below 500 mK, acoustic loss in first sound at low frequencies occurs through the non-linear mechanical response which leads to a T^4 dependance of the acoustic attenuation coefficient. Our estimates suggest that the quality factor for a kilohertz frequency resonator can approach 10^{11} for temperatures below 10 mK and with a helium-3 isotopic impurity fraction less than 10^{-10}. To detect the superfluid motion with quantum-limited backaction, we have coupled the acoustic motion of a centimeter scale volume of helium-4 to the TE_{011} mode of a cylindrical superconducting niobium microwave resonator (11 GHz resonance with an internal Q of $3.5 \cdot 10^8$), through the pressure dependent modulation of the permitivitty. Using a properly designed microwave detection circuit (sideband resolved, shot noise limited), detection of the motion near the standard quantum limit appears possible. Our first low temperature measurements with this system have demonstrated the parametric coupling between the acoustic motion and the microwave cavity frequency. Realization of an optimized system may allow for careful studies of the lifetimes of quantum states of motion with massive gram scale objects, probing quantum decoherence mechanisms which are speculated to exist for massive objects, and the detection of very weak continuous wave inertial and gravitational forces.

Section: QF - Quantum Fluids

Keywords: quantized motion, optomechanical system