An optomechanical quantum memory implemented in a membrane-in-the-middle system

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The same principles that enable the detection of gravitational waves also allow cooling mechanical resonators to their quantum ground state and using them as building blocks for the dissemination of quantum resources. In this context, a quantum memory addresses one of the central challenges of quantum information science: preserving fragile quantum states long enough for them to be processed, transmitted, or distributed across a quantum network. One promising approach is offered by cavity optomechanics, in which an optical field is coupled to the motion of a mechanical resonator through radiation pressure.

This seminar presents an introduction to the fundamental concepts of cavity optomechanics, beginning with the operation of a Fabry-Pérot optical cavity and the role of radiation pressure. The membrane-in-the-middle configuration is discussed as a versatile implementation that allows the independent optimization of optical and mechanical properties. The interaction between optical and mechanical modes is examined through Stokes and anti-Stokes scattering processes, demonstrating how laser detuning gives rise to sideband cooling of the mechanical resonator. Building on these concepts, optomechanically induced transparency is discussed as a means of storing the quantum state of light in the mechanical degree of freedom in this system. Finally, it is shown how a membrane-in-the-middle optomechanical cavity can serve as a platform for implementing the Duan-Lukin-Cirac-Zoller protocol for entanglement swapping. The discussion concludes with an overview of current challenges and future research directions pertaining to optomechanical quantum memories and their role in quantum communication networks.

Keywords: cavity optomechanics, Fabry-Pérot cavity, membrane-in-the-middle, sideband cooling, quantum memory