

Optomechanical cooling with coherent and squeezed light: the thermodynamic cost of opening the heat valve

Juliette Monsel^{a,*}, Nastaran Dashti^a, Sushanth Kini Manjeshwar^a, Jakob Eriksson^{a,b}, Henric Ernbrink^a, Ebba Olsson^a, Emelie Torneus^a, Witlef Wieczorek^a et Janine Splettstoesser^a

- a. Department of Microtechnology and Nanoscience (MC2), Chalmers University of Technology, S-412 96 Göteborg, Sweden
 b. University of Gothenburg, S-412 96 Göteborg, Sweden

* email : monsel@chalmers.se

Ground-state cooling of mechanical motion by coupling to a driven optical cavity has been demonstrated in various optomechanical systems. In our work, we provide a so far missing thermodynamic performance analysis of optomechanical sideband cooling in terms of a heat valve (see Fig. 1(a)). As performance quantifiers we examine not only the lowest reachable effective temperature (phonon number), but also the evacuated-heat flow as an equivalent to the cooling power of a standard refrigerator, as well as appropriate thermodynamic efficiencies, which all can be experimentally inferred from measurements of the cavity output light field. Importantly, in addition to the standard optomechanical setup fed by coherent light (see Fig. 1(b)), we investigate two recent alternative setups for achieving ground-state cooling: replacing the coherent laser drive by squeezed light [1,2] or using a cavity with a frequency-dependent (Fano) mirror [3]. We study the dynamics of these setups within and beyond the weak-coupling limit and give concrete examples based on parameters of existing experimental systems. By applying our thermodynamic framework, we gain detailed insights into these three different optomechanical cooling setups, allowing a comprehensive understanding of the thermodynamic mechanisms at play [4].

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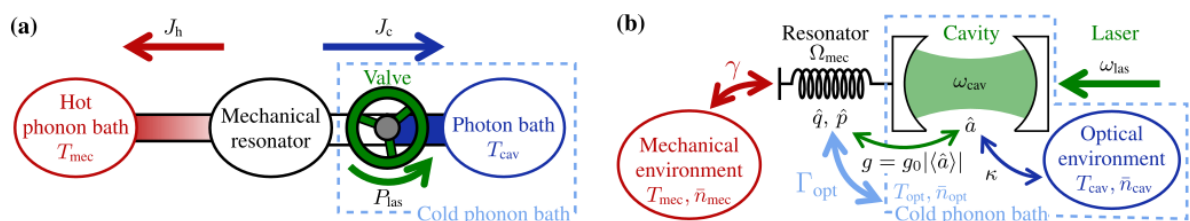


Figure 1 : (a) Thermodynamic framework: a mechanical resonator (in black) is in contact with a hot phonon bath (in red). To cool it down, it is coupled to a photon bath (in blue) whose temperature is much smaller than the relevant photon energies. The coupling can be regarded as opening a valve (in green), allowing heat to flow to the cold bath. (b) Standard setup for optomechanical cooling: a cavity with a moving-end mirror is driven by a laser. The mechanical resonator is in contact with a thermal phonon reservoir and the cavity with a photon reservoir. The light blue dashed box represents the effective phonon bath that can be identified in the weak-coupling regime.