Department of Physics,
Koc University, Istanbul.

Ground-state cooling of mechanical resonators by quantum reservoir engineering

Muhammad Tahir Naseem

Introduction

- Simultaneous cooling of multiple mechanical resonators is challenging in the optomechanical setting due to dark-mode formation.
- We propose a scheme for simultaneously cooling multiple resonators using only incoherent thermal sources.
- We employ bath spectrum filtering to engineer reservoirs for cooling.

Model System

Our advantageous cooling scheme can be realized by systems where the cooling agent and target systems are coupled via *energy-field* interaction. For illustration, we consider a typical multimode optomechanical system

$$\hat{H}_s = \omega_a \hat{a}^\dagger \hat{a} + \sum_{i=1}^{2} [\omega_i \hat{b}_i^\dagger \hat{b}_i - g_i \hat{a}^\dagger \hat{a}(\hat{b}_i + \hat{b}_i^\dagger)]$$

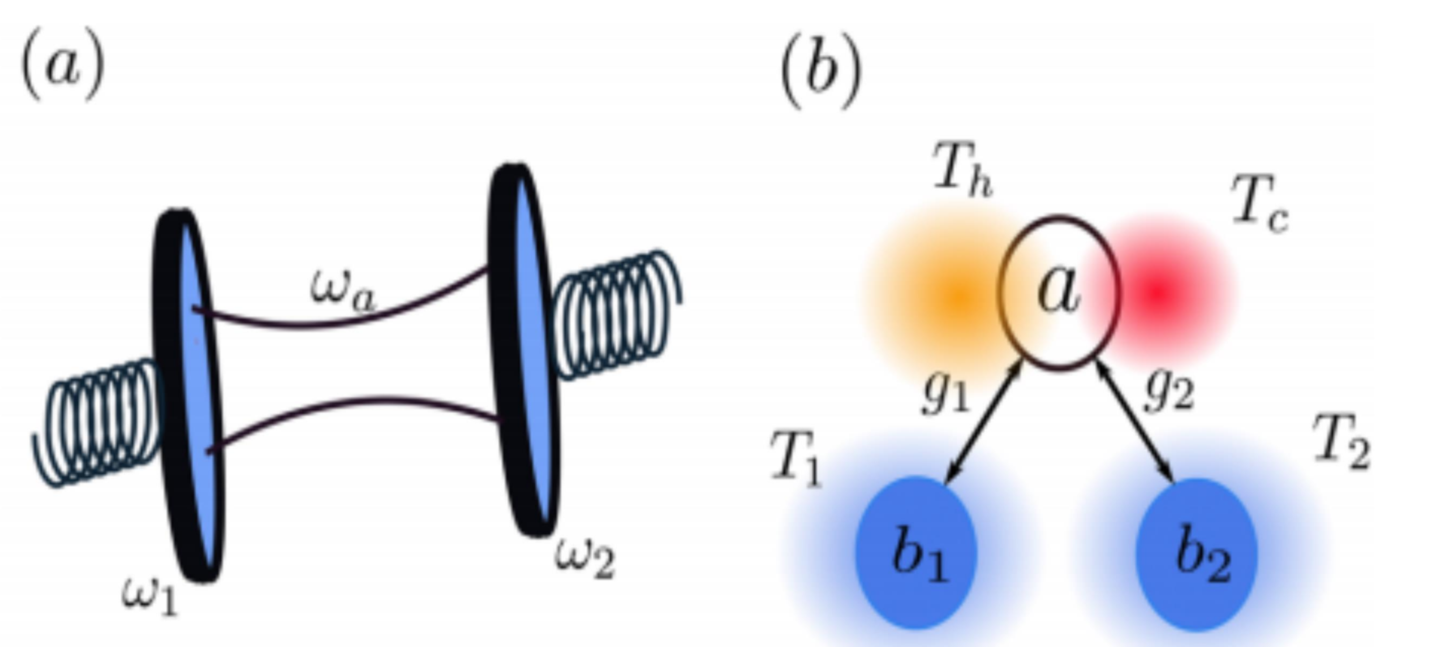

Fig. (a) Schematic illustration of an optomechanical system in which two mechanical resonators are coupled to a single optical cavity mode. (b) Two thermal baths are coupled to the cavity, and each resonator is unavoidably coupled to its own environment.

Methods

- We derive the *global* master equation for the analysis of the system.
- In the master equation, both heating and cooling terms are present. We employ bath spectrum filtering to suppress the heating terms.
- The analytical expression for steady-state mean phonon number is given by deriving the rate equations.

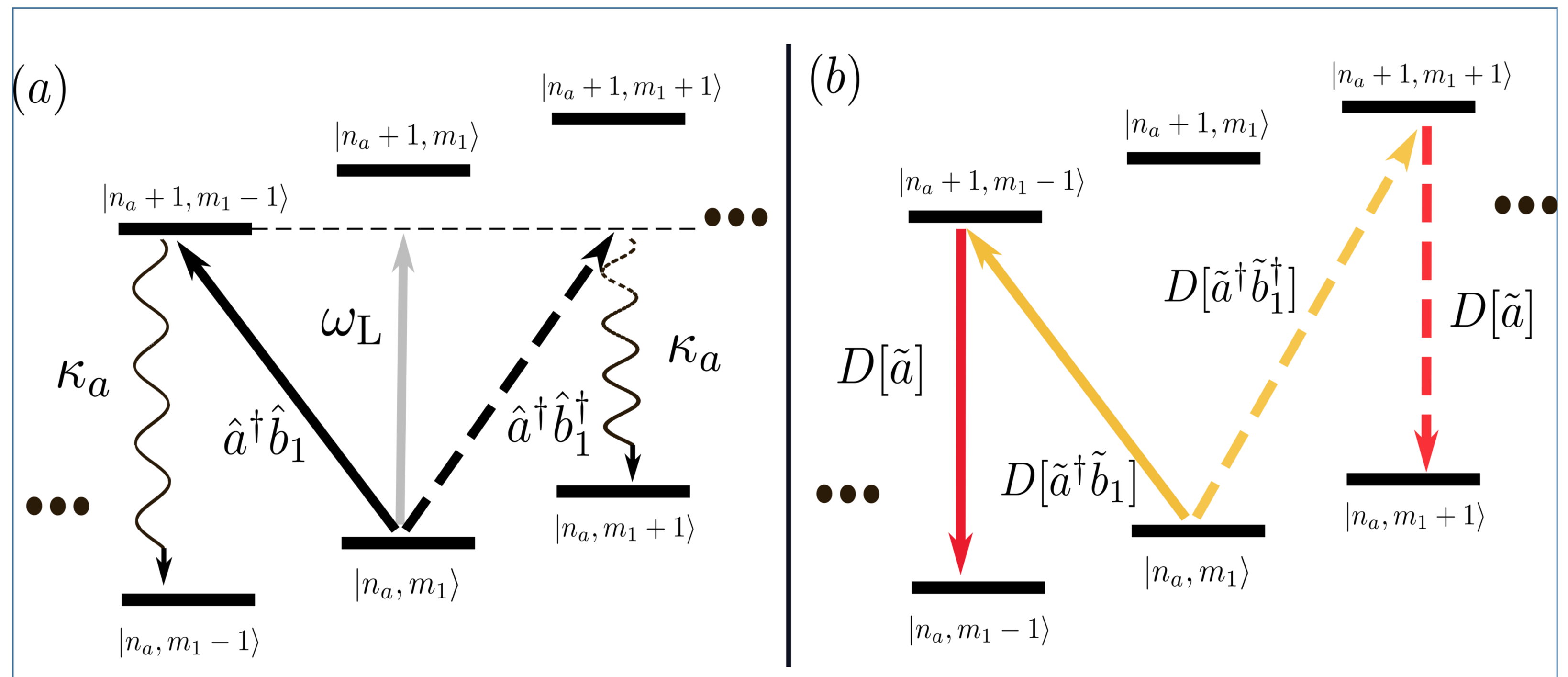

Fig. (a) The cooling mechanism in a standard laser sideband cooling scheme. (b) The cooling mechanism in our scheme.

Cooling Mechanism

- We explain our scheme's cooling mechanism by drawing a direct connection with the typical laser sideband cooling scheme.
- By the analogy of sideband cooling, we drive the cavity with an incoherent hot thermal bath at the lower sideband and suppress the upper sideband.
- The equation for the mean phonon number in both cases is similar.

Results

- We show that simultaneous cooling of two degenerate or near-degenerate mechanical resonators is possible, which is otherwise a challenging goal to achieve.

$$\langle \tilde{n}_1 \rangle_{ss} = \frac{A_c^+ + \kappa_1 \bar{n}_1}{\tilde{\Gamma}_c + \kappa_1}$$

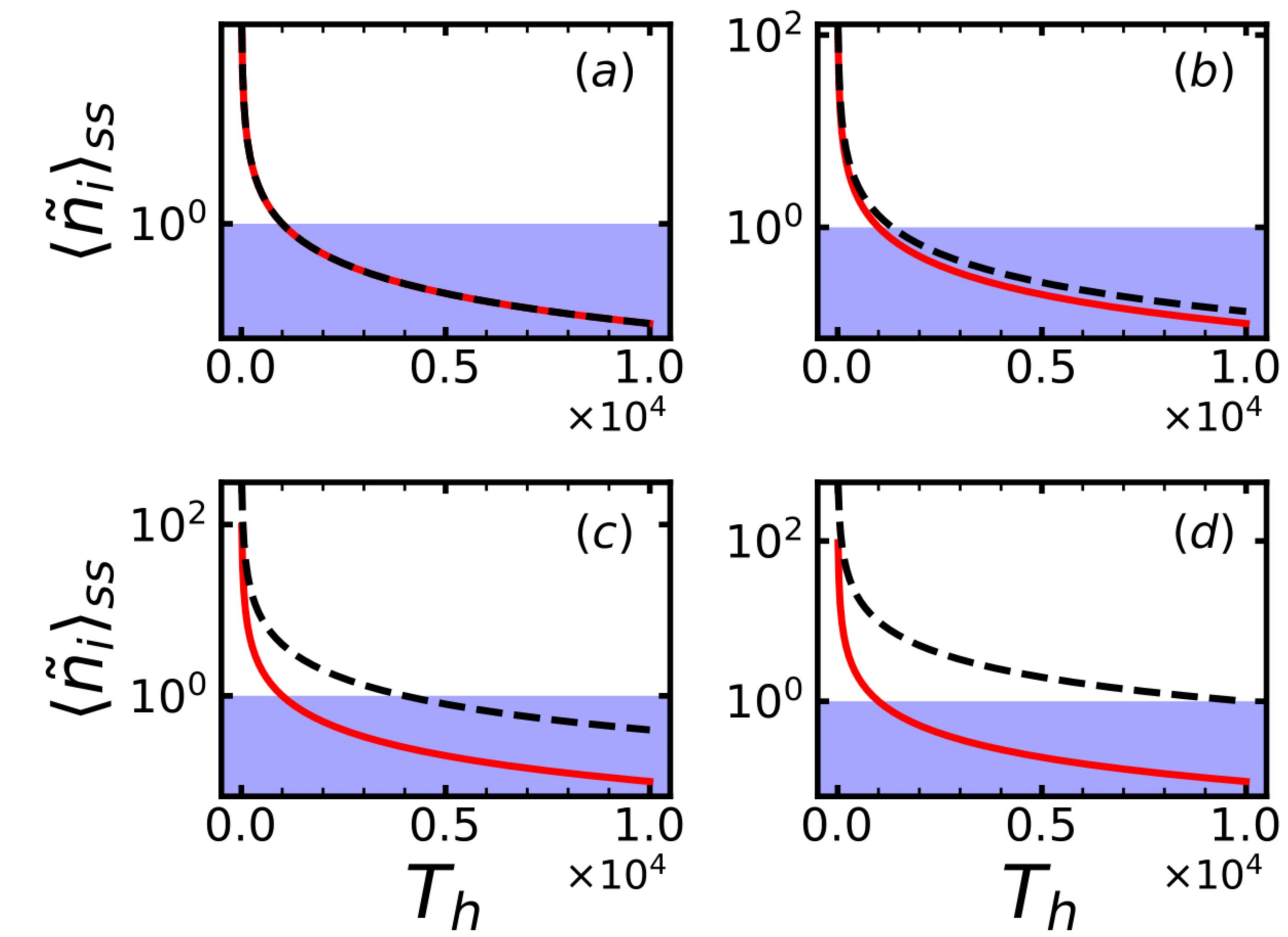

Fig. The steady-state mean phonon number as a function of hot bath temperature. The solid and dashed curves are for two different mechanical resonators with the same frequency.

Conclusions

We propose a scheme for the simultaneous cooling of degenerate mechanical resonators using only incoherent thermal sources, which is otherwise a challenging goal to achieve.

References: Naseem, M.T., Müstecaplıoğlu, Ö.E. Ground-state cooling of mechanical resonators by quantum reservoir engineering. *Commun Phys* **4**, 95 (2021).