Engineered entropic forces allow ultrastrong dynamical backaction

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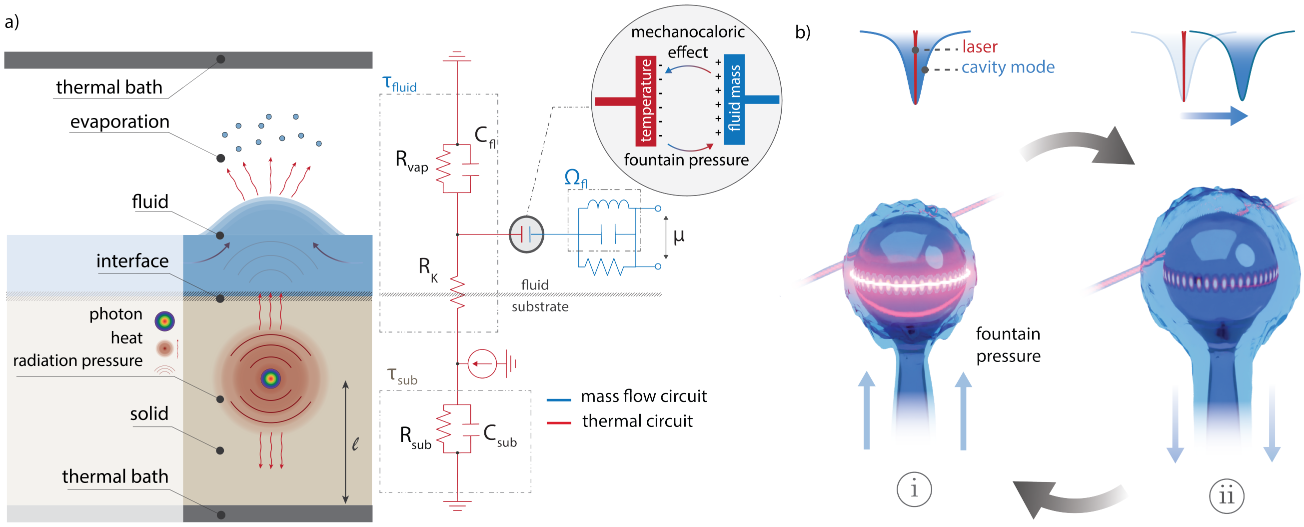
When confined within an optical cavity, light can exert strong radiation pressure forces. Combined with dynamical backaction, where the resulting motion back-acts on the cavity, this enables important processes such as laser cooling, and applications ranging from precision sensors to quantum memories and interfaces [1]. However, the magnitude of radiation pressure forces is constrained by the energy mismatch between photons and phonons. Optical forces can, alternatively, be applied via entropy, rather than energy, gradients. Entropic forces are common in nature, for example, explaining many molecular forces and the restoring force of a stretched rubber band. Here, we overcome this energy mismatch using entropic forces arising from the absorption of light. We show that entropic forces can exceed the radiation pressure force by eight orders of magnitude, and demonstrate this using a superfluid helium third-sound resonator [2]. We develop a framework to engineer the dynamical backaction from entropic forces, applying it to achieve optomechanical phonon lasing with a threshold power of only ~ 2 picowatts, a factor of 2000 lower than has been shown before [3]. This phonon laser can be viewed as a microscale thermodynamic heat engine. We show that its efficiency—while low due to the small temperature differential introduced by photon absorption—is nonetheless around a hundred times higher than previous nanomechanical heat engines. Our results present a pathway to exploit entropic forces in quantum devices, and to study nonlinear fluid phenomena such as turbulence and solitons.



[1] M. Aspelmeyer, T. Kippenberg and F. Marquardt, Rev. Mod. Phys. 4 86 (2014)

[2] G. Harris, et al, Nat. Phys. 12 8 (2016); Y. Sachkou, et al, Science 366 6472 (2019); X. He, et al, Nat. Phys. 16 4 (2020); Y. Sfendla, et al, npj Quantum Inf. 7 62 (2021).

[3] A. Sawadsky, et al, *in preparation.*