Light-mediated interactions in atomic and optomechanical systems

Philipp Treutlein

Department of Physics, University of Basel, Switzerland
philipp.treutlein@unibas.ch

Many of the breakthroughs in quantum science and technology rely on engineering strong Hamiltonian interactions between quantum systems. Typically, strong coupling relies on short-range forces or on placing the systems in high-quality electromagnetic resonators, which restricts the range of the coupling to short distances. In these lectures I will show how a loop of laser light can generate Hamiltonian coupling over a distance [1] and report experiments using this approach to strongly couple a nanomechanical membrane oscillator and an atomic spin ensemble across one meter in a room-temperature environment [2]. We observe spin-membrane normal mode splitting, coherent energy exchange oscillations, two-mode thermal noise squeezing, and dissipative coupling with exceptional points [2]. We furthermore realize an optical coherent feedback loop and use it for cooling of the membrane vibrations [3,4]. Our experiments demonstrate the versatility and flexibility of light-mediated interactions, a powerful tool for quantum science that offers many further possibilities and is readily applicable to a variety of different systems.

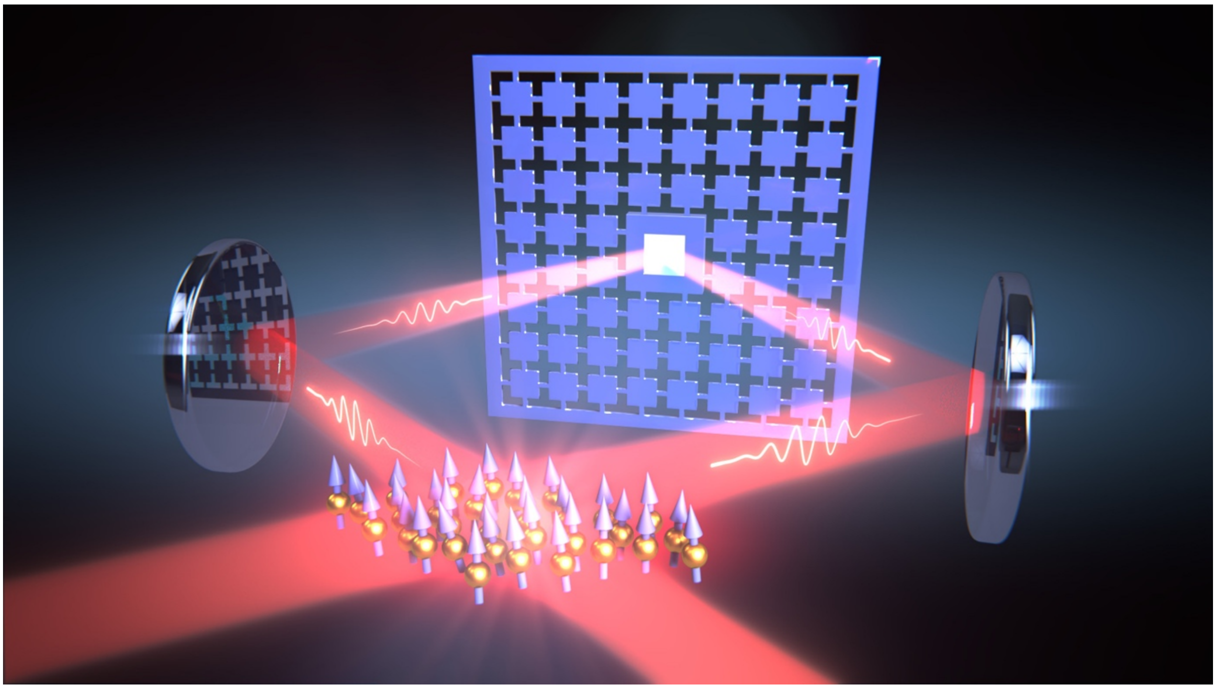

Figure: A loop of laser light couples the vibrations of a nanomechanical membrane to the spin of a cloud of atoms.

References

[1] T. M. Karg, B. Gouraud, P. Treutlein, and K. Hammerer, *Remote Hamiltonian interactions mediated by light*, Phys. Rev. A **99**, 063829 (2019).
[2] T. M. Karg, B. Gouraud, C. T. Ngai, G.-L. Schmid, K. Hammerer, and P. Treutlein, *Light-mediated strong coupling between a mechanical oscillator and atomic spins one meter apart*, Science **369**, 174 (2020).
[3] G.-L. Schmid, C. T. Ngai, M. Ernzer, M. Bosch Aguilera, T. M. Karg, and P. Treutlein, *Coherent feedback cooling of a nanomechanical membrane with atomic spins*, Phys. Rev. X **12**, 011020 (2022).
[4] M. Ernzer, M. Bosch Aguilera, M. Brunelli, G.-L. Schmid, T. M. Karg, C. Bruder, P. P. Potts, and P. Treutlein, *Optical coherent feedback control of a mechanical oscillator*, arXiv:2210.07674