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Light-mediated strong coupling of ultracold atoms and a nanomechanical oscillator

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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. We show how a loop of laser light can generate Hamiltonian coupling over a distance and report experiments using this approach to strongly couple a nanomechanical membrane oscillator and an ultracold atomic spin ensemble across one meter in a room-temperature environment [1]. We observe spin-membrane normal mode splitting, coherent energy exchange oscillations, two-mode thermal noise squeezing, dissipative coupling with exceptional points, and coherent feedback cooling of the membrane [1,2,3]. Our experiments demonstrate the versatility and flexibility of light-mediated interactions, a powerful tool for building hybrid quantum systems that offers many further possiblities and is readily applicable to a variety of different systems.

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