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Tunable cavity optomechanics with ultracold neutral atoms

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Optomechanical systems are typically implemented in solid state, with significant environmental couplings, thermal occupation of the mechanical resonator mode, and optomechanical parameters fixed during device fabrication. Here we present a widely tunable optomechanical system, in which the mechanical resonator is the collective motion of an ensemble of ultracold neutral atoms, trapped in the ground state of a harmonic oscillator potential. The atoms can be positioned anywhere along a strongly coupled cavity optical probe field, allowing access to both linear and quadratic optomechanical couplings, with contrast in coupling as large as 80%. Varying the optical fields provides high-dynamic- range control of both the mechanical resonator natural frequency (over a factor of 10) and the strength of the per-photon optomechanical coupling (over a factor of more than 1000). We demonstrate highly tunable cavity shifts and optical bistability. We also discuss experiments to explore wave mixing, squeezing, and spin-opto-mechanical interactions in our system.