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N-atom cavity QED: from cavity protection to quantum simulations with long-range interactions

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Photon-mediated interactions between atoms coupled to an optical cavity are emerging as a powerful tool for engineering entangled states and many-body Hamiltonians. In a next-generation cavity QED (CQED) experiment currently approaching completion at LKB, we combine a strong-coupling fiber Fabry-Perot microcavity with state-of-the-art atomic tweezer techniques for single-atom addressing and detection. The cavity mode gives rise to an effective long-range interaction, which can couple any combination of ~100 atoms in a 1D chain using the tweezers. In a first experiment with this new setup, we introduce controlled disorder in the atomic frequency distribution to simulate the surprising effect of cavity protection that has been observed in solid-state cavity QED, where a narrow normal-mode doublet emerges in spite of a much broader frequency distribution of the emitters. We find that the concentration of photonic weight of the coupled light–matter states is a key parameter for the transition to the protected state, and demonstrate that a simple parameter based on the statistics of transmission count spectra provides an experimental proxy for this theoretical quantity. Moreover, we realize a dynamically modulated Tavis–Cummings model to produce a comb of narrow polariton resonances protected from disorder, with potential applications to quantum networks.

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