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Atomic physics meets nanophotonics: creating complex quantum states of matter and light

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Significant efforts have been made to interface cold atoms with micro- and nano-photonic systems in recent years. Originally, it was envisioned that the migration to these systems from free-space atomic ensemble or macroscopic cavity QED experiments could dramatically improve figures of merit and facilitate scalability for applications such as quantum information processing. However, a more interesting scenario would be if nanophotonic systems could yield new paradigms for controlling quantum light-matter interactions, which have no obvious counterpart in macroscopic settings. Here, we describe one paradigm for novel physics, based upon the coupling of atoms to photonic crystal structures. In particular, we show that atoms can become dressed by localized photonic "clouds" of tunable size. This cloud behaves much like an external cavity, but which is attached to the position of the atom. This dynamically induced cavity can then mediate long-range spin interactions or forces between atoms, yielding an exotic quantum material where spins, phonons, and photons are strongly coupled.