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Strongly Interacting Rydberg Slow Light Polaritons

Synthetic quantum materials offer an exciting opportunity to explore quantum many-body physics and novel states of matter under controlled conditions. In particular, they provide an avenue to exchange the short length scales and large energy scales of the solid state for an engineered system with better control over the system Hamiltonian, more accurate state preparation, and higher fidelity state readout. Here we propose a unique platform to study quantum phases of strongly interacting photons. We introduce ideas for controlling the dynamics of individual photons by manipulating the geometry of a multimode optical cavity, and combine them with recently established techniques to mediate strong interactions between photons using Rydberg atoms. We demonstrate that this approach gives rise to crystalline- and fractional quantum Hall- states of light, opening the door to studies of strongly correlated quantum many-body physics in a photonic material.