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Building Synthetic Quantum Systems with Atoms and Photons –From Waveguide QED with Neutral Atoms to Many-Body Physics with Rydberg-Dressed Lattice Gases

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Quantum networks are composed of quantum nodes that interact coherently through quantum channels, and open a broad frontier of scientific opportunities. An exciting frontier in this endeavor is the integration of otherwise 'simple'quantum elements into complex quantum networks. In this context, there is active research to achieve lithographic quantum optical circuits, for which atoms are trapped in nanoscopic dielectric structures and 'wired'together by photons propagating through circuit elements. Exemplary experimental platforms include photonic crystal waveguides and cavities. Owing to their small optical loss and tight field confinement, these nanoscale dielectric devices are capable of mediating long-range atom-atom interactions using photons propagating in their guided modes. In a complimentary fashion, long-range interactions between photons can be mediated by an underlying lattice of atoms. Such systems have the potential to provide new tools for scalable quantum networks, quantum phases of light and matter, and quantum metrology. I will discuss the designers'approach to "few-body physics"of ultracold atoms interfaced with nanophotonic waveguides, and a recent experimental demonstration of collective band-edge nonlinearity with localized atoms in 1D photonic crystal waveguides. By trapping single atoms within vacuum spaces of a photonic crystal, tantalizing opportunities emerge for novel quantum transport phenomena, tunable long-range atomic interactions, and control of quantum vacuum forces. By extension, I will describe the theoretical aspects of novel "many-body" phenomena with Rydberg-dressed spin models.

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