

Quantum Spin Lenses in Atomic Arrays

Wed, 2018-02-14 23:04 - [Manfred Mark](#) [1] **Date:** 2017-09-20

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Reference:

Phys. Rev. X 7, 31049 (2017)

URL:

<https://journals.aps.org/prx/abstract/10.1103/PhysRevX.7.031049> [2]

We propose and discuss quantum spin lenses, where quantum states of delocalized spin excitations in an atomic medium are focused in space in a coherent quantum process down to (essentially) single atoms. These can be employed to create controlled interactions in a quantum light-matter interface, where photonic qubits stored in an atomic ensemble are mapped to a quantum register represented by single atoms. We propose Hamiltonians for quantum spin lenses as inhomogeneous spin models on lattices, which can be realized with Rydberg atoms in 1D, 2D, and 3D, and with strings of trapped ions. We discuss both linear and nonlinear quantum spin lenses: in a nonlinear lens, repulsive spin-spin interactions lead to focusing dynamics conditional to the number of spin excitations. This allows the mapping of quantum superpositions of delocalized spin excitations to superpositions of spatial spin patterns, which can be addressed by light fields and manipulated. Finally, we propose multifocal quantum spin lenses as a way to generate and distribute entanglement between distant atoms in an atomic lattice array.

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