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Rydberg Excitation and Crystallization in Ultracold Gases

When cold atoms are laser-excited to high-lying Rydberg states a dramatic inversion of time- and energy-scales takes place. The resulting interactions give rise to interaction energies that can exceed the translational energy of the atoms, and induce a fast excitation dynamics during which atomic motion is practically frozen out.
In small, ultracold ensembles, a single Rydberg atom may entirely blocks any further excitation, and, thus, acts as a mesoscopic "superatom" with collective enhanced coupling to light. This dipole blockade enables the production of highly entangled collective states with potential applications for fast quantum information processing as well as single-photon sources.
In this talk, I will describe how this mechanism can be extended to the regime of multiple Rydberg atoms, permitting the coherent manipulation of strongly correlated, many-body states and the formation of crystalline structures of Rydberg atoms out of a disordered frozen gas. The presented calculations reveal the existence of an excitation number staircase, which closely resembles the Coulomb blockade staircase in nano-scale solid state devices. It will further be demonstrated how such excitations can be transfered to crystalline, non-classical photonic states, i.e. a pulse train of localized single photons, with tunable delay times and photon numbers.

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