Ultrahigh-precision Rydberg atomic localization using standing waves and optical vortices

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Atom localization has been of continuous interest in quantum mechanics, with many practical applications in nanolithography, laser cooling and trapping, and other areas of atomic physics. Rydberg atoms are hard to localize due to the difficulty of confining them in a small region with high density. On the other hand, their enhanced nonlinear properties open new opportunities for quantum optics and information [1], making the experimental realization of precise Rydberg localization important.
In out work we propose theoretical schemes for such strongly confined localization using interacting Rydberg atoms in a ladder configuration, where a standing-wave or an optical vortex is used in the second step of the ladder. Depending on the degree of compensation of the Rydberg level energy shift (induced by the van der Waals interaction) by the coupling field detuning, two antiblockade regimes, i.e., a partial (PA) and a full antiblockade (FA) are distinguished. When a standing wave is used as a coupling field, a periodic pattern of tightly localized regions can be achieved for both regimes. However, the PA allows for much faster convergence of spatial confinement, yielding a high resolution Rydberg state-selective super localization to a sub-nanometer scale [2]. Applying a doughnut-shaped optical vortex in the second step of the ladder [3] results in ultraprecise two-dimensional localization solely in the zero-intensity center down to the nanometer scale. Auxiliary modulation to the two-photon detuning allows for a three-dimensional confinement of the Rydberg atoms. Our results pave one-step closer to the development of new subwavelength localization techniques to the nanometer scales, representing feasible experimental applications.
This work is partly supported by the COST action CA16221 “Quantum Technologies with Ultracold Atoms” (AtomQT).

References:

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