Accurate Rydberg quantum simulations of spin-1/2 models

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Using non-perturbative calculations of the interaction potentials between two Rydberg atoms taking into account both electric and magnetic fields, we can simulate a broad range of two-atom Rydberg systems. Benchmarks against varied experimental data show an excellent agreement between the simulations and experiments. We apply our simulation procedure to investigate under which experimental conditions spin-1/2 models can be accurately quantum simulated using Rydberg atoms. More specifically, we determine experimental parameters for which a system of atoms that are laser driven to $nD_{3/2}$ Rydberg states and interacting via the van der Waals interaction can be mapped accurately to an Ising-like spin-1/2 model, despite the large number of Rydberg levels involved. Our investigations show the importance of a careful selection of the experimental parameters in order not to break the Rydberg blockade mechanism which underlies the mapping. By selecting appropriate experimental parameters, even in a large system of 49 Rydberg atoms, an excellent agreement is achieved between the measured time evolution and the numerically calculated dynamics of the Ising-like spin-1/2 model. This result opens exciting prospects for the realization of high-fidelity quantum simulators of spin Hamiltonians.