Simulating Strongly Correlated Phases in One-Dimensional Rydberg Systems

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Platforms based on neutral Rydberg atoms are highly practical quantum simulators as their large dipole moments provide tunable strong interactions with different characters and ranges. In this work, we consider a system of neutral atoms that are modeled as two-level systems with a pair of Rydberg states, leading to both van der Waals and dipolar interactions among the atoms. Focusing on one-dimensional systems, we provide two examples where we leverage the van der Waals and dipolar interactions of the Rydberg atoms to study ground states with rich properties.

The first example considers a dimerized chain of Rydberg atoms where the competition between long/short-range processes is illustrated. We identify bond-ordered-density-wave (BODW) phases that simultaneously exhibit density wave and bond orders [1]. Including on-site density modulation is shown to help stabilize symmetry-protected topological BODW phases at certain fillings [2]. We also find a unique non-topological BODW phase without any analog in the non-interacting model. The second example includes the strong nearest-neighbor interaction limit where a constrained model with non-local fluctuations from interacting Rydberg atoms alongside local fluctuations is considered. The combined effect of such fluctuations drives the system from a disordered phase to an intrinsically quantum-ordered Rydberg crystal, which was not previously reported in one dimension. We provide an intuitive explanation of the underlying physics and a variational ansatz that describes both the ordered and disordered regimes.

Our findings show that Rydberg atoms offer an exceptional platform even in a simple setup such as a one-dimensional lattice for exploring the interplay between short/long-range interactions and fluctuation-driven phenomena that are otherwise only possible to probe in higher-dimensional and complicated systems.

References

[1] Z. Zeybek, R. Mukherjee, and P. Schmelcher, Phys. Rev. Lett. 131, 203003 (2023).
[2] Z. Zeybek, P. Schmelcher, and R. Mukherjee, arXiv:2403.06649 (2024)