Ultrafast electron dynamics beyond mean-field in a strongly-correlated ultracold Rydberg gas

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Many-body interactions govern a variety of physical and chemical phenomena such as the emergence of magnetism and superconductivity as well as solvent effects on chemical reactions. Understanding those interactions beyond mean field is one of the holy grails of modern sciences. Atomic, molecular, and optical physics with advanced laser technologies has recently emerged as a new platform to study many-body systems. One of its latest developments is the study of long-range interactions among ultracold particles such as atoms in an optical lattice clock [1], polar molecules [2], magnetic atoms [3], ions [4], and Rydberg atoms [5]. Advantages of Rydberg atoms over the other systems include their large dipole moments and excellent tunability of interactions, which can be switched on and off actively. Most of the relevant Rydberg experiments have so far been performed with narrow-band lasers in a regime referred to as "Rydberg blockade", in which only one Rydberg atom can exist in a sphere whose radius is typically on the order of several microns. Here we demonstrate a new strategy to realize a strongly-correlated Rydberg gas, in which we have circumvented the Rydberg blockade with a broadband picosecond (ps) laser pulse to increase the interaction by several orders of magnitude. The property of this strongly-correlated Rydberg gas has been investigated by time-domain Ramsey interferometry with attosecond precision. Our ps laser pulse allows for the real-time observation of coherent and ultrafast electron dynamics evolving more rapidly than expected for two-body correlations by several orders of magnitude. This observation is well reproduced by a theoretical model beyond mean-field approximation. Finally we have actively controlled such ultrafast many-body dynamics by tuning the principal quantum number and population of the Rydberg state and the atom density. Our new approach opens a new avenue to observe and manipulate the nonequilibrium dynamics of strongly interacting many-body systems on the ultrafast timescale.

References

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[4] See, for example, P. Richerme *et al.*, Nature **511**, 198 (2014).
[5] See, for example, P. Schauß *et al.*, Nature **491**, 87 (2012).