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Quantum many-body localization in a strongly coupled ultracold plasma

A many-body system of quantum particles quenched on a disordered potential can undergo a transition to a localized, non-ergodic phase with the properties of a quantum glass.[1, 2, 3, 4, 5] Well-isolated ensembles of ultracold atoms have provided an important proving ground for such phenomena.[6, 7] Rydberg atoms in particular offer the advantage of highly tuneable, very long range interactions.[8, 9] Here we present experimental evidence suggesting a novel route to a state of many-body localization beginning from a quantum-selected initial state in a Rydberg gas of nitric oxide. Laser-crossed molecular-beam excitation forms an ellipsoidal excitation volume. Prompt Penning ionization releases electrons in the dense core of this Rydberg gas. The resulting electron-impact avalanche forms a plasma that spontaneously bifurcates and cools by disposing electron thermal energy to the momentum of separating, strongly coupled ultracold plasma volumes. This disposal of energy to mass transport quenches the plasma, relaxing the electrons on a disordered ion potential that remains stationary on the timescale of electron motion. These cooling dynamics give rise to an extremely robust ensemble of Rydberg and quasi-Rydberg molecules, which seems spatially and energetically immobilized in a band of states very near the ionization continuum. Under natural, delocalized conditions, classical simulations call for this highly excited ensemble of molecular ions and electrons to decay by well-defined, readily accessible channels of recombination, relaxation and fragmentation to form neutral dissociation products and a hot, expanding electron gas. Instead, we observe free-flying, localized ultracold plasma volumes with projected lifetimes of milliseconds, perhaps tens of milliseconds.

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