Imaging the interface of a qubit and its quantum-many-body environment

S. Rammohan,[1] S. Tiwari,[1] A. Mishra,[1] A. Pendse,[1] A. K. Chauhan,[1,2] R. Nath,[3] A. Eisfeld,[4] and S. Wüster[1]

[1] *Department of Physics, Indian Institute of Science Education and Research, Bhopal, Madhya Pradesh 462 066, India*
[2] *Department of Optics, Faculty of Science, Palacký University, 17. listopadu 1192/12, 77146 Olomouc, Czechia*
[3] *Department of Physics, Indian Institute of Science Education and Research, Pune 411 008, India*
[4] *Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Strasse 38, 01187 Dresden, Germany*

We show that two major facets of the decoherence paradigm are experimentally accessible for a single impurity atom embedded in a Bose-Einstein condensate when the impurity is brought into an electronic superposition of two Rydberg states [1]. Not only can the electronic decoherence of the Rydberg atom be read out by microwave interferometry[2, 3], the platform also provides unique access to the accompanying entangled state of the environment. We theoretically demonstrate signatures of the latter in total atom densities during the transient time in which the impurity is becoming entangled with the medium but the resultant decoherence is not complete yet. The Rydberg impurity thus provides a handle to initiate and read-out mesoscopically entangled superposition states of Bose atom clouds affecting about 500 condensate atoms. We find that the time-scale for its creation and decoherence can be tuned from the order of nanoseconds to microseconds by choice of the excited Rydberg principal quantum number ν and that Rydberg decoherence dynamics is typically non-Markovian [4].

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