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A mesoscopic Rydberg impurity in an atomic quantum gas RICHARD SCHMIDT, HOSSEIN SADEGHPOUR, ITAMP, Harvard University, EUGENE DEMLER, Harvard University — Impurity problems have been at the forefront of research in condensed matter physics for several decades. In this talk, we show that Rydberg impurity excitations in ultracold quantum gases present a new frontier in impurity research. Here vastly different energy scales compete, signified in deeply bound Rydberg molecules of mesoscopic size. This situation poses a new challenge for theoretical physics and necessitates the confluence of methods ranging from mesoscopic to atomic physics. In our work, we develop a novel many-body theory for the non-equilibrium dynamics of giant impurity excitations Bose gases. Such single Rydberg impurity excitations have recently been observed, and we demonstrate that the observations can be understood from our theoretical approach which incorporates atomic and many-body theory.The crossover from few-body dynamics to quantum many-body collective behavior - manifest in the appearance of a novel superpolaronic state - is elucidated in our unified functional determinant approach, valid at zero and finite temperature. The time-dependent formalism is not restricted to Rydberg systems but can be generally applied to impurities in bosonic and fermionic environments and opens new possibilities to study impurity dynamics in mesoscopic systems.

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