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Tailoring the Phonon Environment of Embedded Rydberg Aggregates

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State-of-the-art experiments can controllably create Rydberg atoms inside a Bose-Einstein condensate (BEC) [1]. The large Rydberg electron orbital volume contains many neutral atoms, resulting in electron-atom scattering events. The number of atoms within the orbit, and hence the Rydberg-BEC interaction, can be tuned by choice of principal quantum number or condensate density. This makes the hybrid system a fascinating platform for quantum simulation. My poster presentation will discuss the physics of the interaction and corresponding dynamics of single or multiple Rydberg atoms in two internal electronic states embedded inside a BEC, to assess their utility for controlled studies of decoherence and quantum simulations of excitation transport similar to photosynthetic light-harvesting.

The poster will initially include the theoretical framework that we developed to calculate the open quantum system input parameters like the bath correlation function and the spectral density, initially for a single Rydberg atom, possibly in two internal states with angular momentum quantum numbers $l = 0$ ($|s\rangle$) and $l = 1$ ($|p\rangle$) [2], in BEC and then for a chain of Rydberg atoms, forming an aggregate. The electron-atom contact interactions lead to Rydberg-BEC coupling, which creates Bogoliubov excitations (phonons) in the BEC.

Using this spin-boson model with the calculated parameters, we examine the decoherence dynamics of a Rydberg atom in a superposition of $|s\rangle$ and $|p\rangle$ states, resulting from the interaction with its condensate environment. Further, the poster will discuss the emergence of non-Markovian features in the system in the presence of a microwave external drive of the Rydberg atom using a stochastic computational technique for non-Markovian open quantum systems [3].

Finally, the poster will preview the results for the aggregate case, where one of the atoms in the aggregate is in the state $|p\rangle$, while the rest are in the state $|s\rangle$, resulting in excitation transport via dipole-dipole interaction [4]. We investigate the effects of non-Markovianity and decoherence on the excitation transport based on an effective model described by a Holstein Hamiltonian, allowing us to set up the dynamics similar to those found in light-harvesting complexes, but at a different time and energy scales.

References:

[1] J. B. Balewski, et. al.; Nature 502 664 (2013).

[2] S. Rammohan, et. al.; Phys. Rev. A 103, 063307 (2021).

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[4] D. W. Schönleber, et. al.; Phys. Rev. Lett. 114 123005 (2015).

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