Effect of Coupling Geometries on the Multi-mode, Open Dicke Model

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In the open Dicke model, which describes the collective coupling of N two level atoms to a single cavity mode, there is a well known phase transition in the steady-state behaviour of the system, as the light-matter coupling strength is varied, from a normal phase to a superradiant phase [1][2] . Multi-mode versions of this model, where several distinct clusters of N atoms are coupled to the degenerate modes of a confocal cavity, have been studied in the context of spin glass and associative memory regimes [3][4], for which the couplings between different clusters of atoms and different modes are chosen effectively randomly, without the choice of a particular geometry.

In this theoretical work, we are investigating the multi-mode Dicke model in a 'nearest-neighbour' geometry, where there are M clusters of atoms and $M-1$ cavity modes arranged so that each cavity mode couples to two neighbouring clusters of atoms. In particular, we characterize the steady state solutions, and show that beyond the superradiant transition there are additional stable steady-state solutions, the number of which increases with the number of atomic clusters in the system. We show that some of these stable steady-state solutions correspond to persistent oscillations in the mean-field limit, and investigate the fate of these oscillations for finite sized clusters. Our work demonstrates that there is rich new physics possible when considering different coupling geometries in the multimode Dicke model.

References [1] F. Dimer et al., Phys. Rev. A. **75** 013804 (2007) [2] P. Kirton et al., Adv. Quantum Technol. **2** 1800043 (2019) [3] B. Marsh et al., Phys. Rev. X. **14** 1 (2024) [4] B. Marsh et al., Phys. Rev. X. **11** 021048 (2021)

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