Strong-coupling effects in the relaxation dynamics and steady state of a qubit

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We study the effects that are neglected in the conventional weak-coupling approaches for open quantum systems. Using numerically exact methods, we solve the relaxation dynamics and the steady state of the reduced density operator of a qubit interacting bilinearly with a thermal bath[1]. We find that the ideal Boltzmann distribution at the bare qubit frequency is obtained only in the limit of vanishing bath coupling. The deviation is caused by the downward Lamb shift of the qubit transition frequency leading to excess thermal occupation, and by the entanglement of the qubit and the bath, which is present even in the zero-temperature limit. We also find that the qubit decay is superexponential at short time scales, contrary to the result from standard Markovian approaches. Our results are important in the development of quantum protocols[2] based on engineered environments with a tunable bath-coupling strength[3].

[1]J. Tuorila, J. Stockburger, T. Ala-Nissila, J. Ankerhold, and M. Möttönen *System–environment correlations in qubit initialization and control*, arXiv:1901.06209 (2019).
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