Simulation of Jaynes-Cummings Model with Time-delayed Coherent Feedback Using Matrix Product States

N. Nemet*, V. Canela and S. Parkins

The Dodd-Walls Centre for Photonic and Quantum Technologies,
Department of Physics, University of Auckland, New Zealand

Coherent feedback is an efficient and topical way of altering the usual Markovian system-environment interaction in open quantum systems in order to enhance the intrinsic quantum behaviour of the system. Thus, it can be a quite valuable addition to an existing quantum network. Previously, using a feedback loop, rapid convergence to a controlled steady-state [1], controllability of optical squeezing for a degenerate parametric amplifier [2], recovered Rabi oscillations in the single-excitation limit [3], etc. were shown analytically. Moreover, the coherence-preserving benefits of quantum feedback in solid-state systems have been found significant even at finite temperature [4].

Due to the feedback loop, correlations between different times emerge for the infinite degrees of freedom of the considered environment. For linear systems, an analytical description is still possible, however for non-linear systems numerical methods are required [5, 6]. Based on the calculations performed in the context of spin chains using an efficient representation of the whole system called Matrix Product States (MPS) [7] a resource-effective method has also been developed for quantum systems with time-delayed feedback [6].

Applying this numerical technique, we show that Rabi oscillations can be recovered for the open Jaynes-Cummings model for a given phase of the feedback loop (Fig. 1). We also comment on how the observed spectrum and the bunching properties of the system (Fig. 2) change with the introduction of time-delayed coherent feedback.

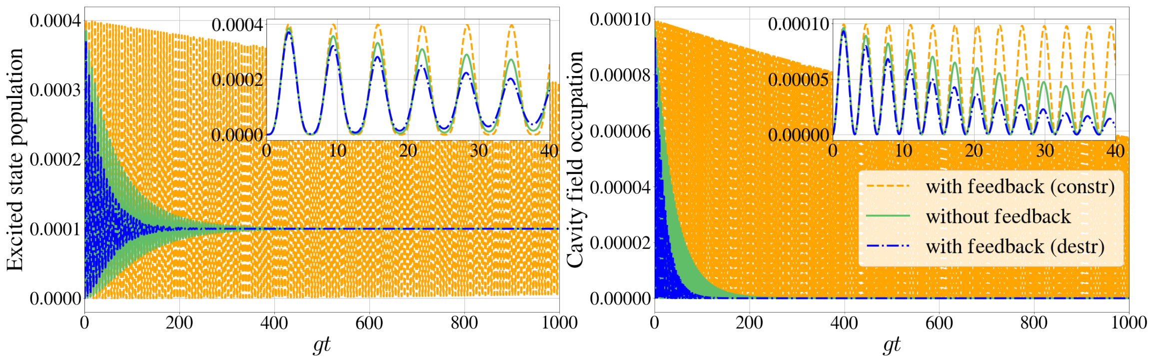

Figure 1: Time-dependent dynamics of the Jaynes-Cummings model for weak driving with the system is initially in its ground state. The Rabi oscillations are damped without feedback (green solid), which effect is enhanced for destructive feedback (blue dash-dotted) and suppressed for constructive feedback (orange dashed). Cavity damping coefficients: $\gamma_L = \gamma_R = g/40$, cavity driving strength on cavity and atomic resonance: $\Omega_c = g/100$.

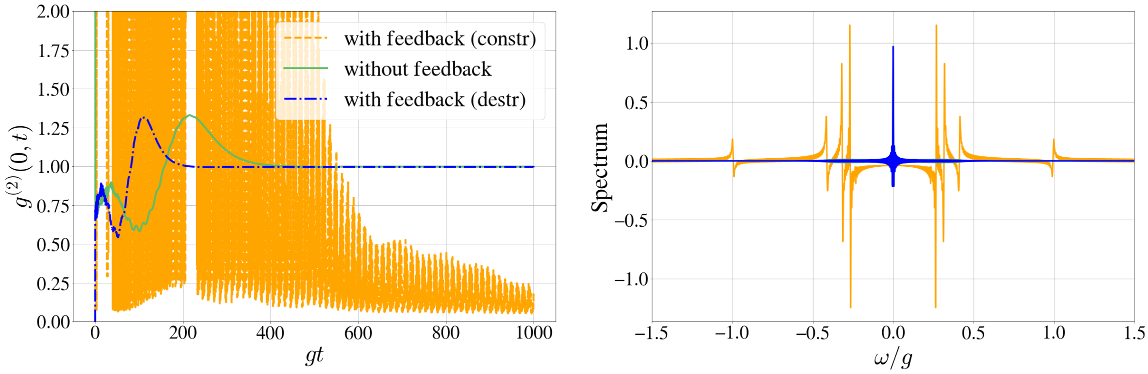

Figure 2: Preliminary results for the spectrum and equal time $g^{(2)}$ function for the Jaynes-Cummings model with direct atomic driving without feedback (green) and with constructive (orange) and destructive (blue) feedback. Cavity damping coefficients: $\gamma_L = \gamma_R = g/40$, atomic driving: $\Omega_e = g/10$, the system is initially in the 3-photon Fock state for the cavity.

References

[1] A. L. Grimsmo, A. S. Parkins and B. S. Skagerstam, New J. Phys. **16**, 065004 (2014).
[2] N. Német and S. Parkins, PRA **94**, 023809 (2016).
[3] J. Kabuss, D. O. Krimer, S. Rotter, K. Stannigel, A. Knorr and A. Carmele1, Phys. Rev. A. 92, 053801 (2015).
[4] N. Német, S. Parkins, A. Knorr and A. Carmele, manuscript in preparation.
[5] A. L. Grimsmo, A. S. Parkins and B. S. Skagerstam, New J. Phys. **16**, 065004 (2014).
[6] H. Pichler and P. Zoller, Phys. Rev. Lett. **116**, 093601 (2016).
[7] U. Schollwöck, Ann. Phys. **326**, 96 (2011).

*Contact email: nnem614@aucklanduni.ac.nz