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A classical simulation of nonlinear Jaynes–Cummings and Rabi models in photonic lattices: reply to comment

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Abstract: We regret that such a misleading comment [Opt. Express (2013)] has been made to our paper. First Lo states in his abstract that "However, the nonlinear Rabi model has already been rigorously proven to be undefined" to later recoil and use the contradictory statement "(...) regarding the BS model with the counter-rotating terms (...) Lo and his co-authors have proven that the model is well defined only if the coupling stregth g is smaller than a critical value $g_c = \omega/4$". While Lo focuses on the validity of the quantum optics Hamiltonians and gives a misleading assesment of our manuscript, the focus of our paper is the method to map such a set of Hamiltonians from quantum optics to photonic lattices. Our method is valid for the given class of Hamiltonians and, indeed, precaution must be exerted on the paramater ranges where those Hamiltonians are valid and where their classical simulation is feasible. These parameter ranges have to be specified in for each particular case studied. Furthermore, we gave as example the Buck-Sukumar model including counter-rotating terms which is a valid Hamiltonian for some coupling parameters.

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References and links

1. B. M. Rodríguez-Lara, F. Soto-Eguibar, A. Z. Cárdenas, and H. M. Moya-Cessa, "A classical simulation of nonlinear Jaynes–Cummings and Rabi models in photonic lattices," Opt. Express **21**, 12888–128981 (2013).
2. C. F. Lo, "A classical simulation of nonlinear Jaynes–Cummings and Rabi models in photonic lattices: comment," Opt. Express (2013).
3. C. F. Lo, K. L. Liu, and K. M. Ng, "The multiquantum Jaynes–Cummings model with the counter-rotating terms," Europhys. Lett. **42**, 1–6 (1998).
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In a recent paper we have shown a method to simulate nonlinear Jaynes-Cummings (JC) and Rabi models in photonic lattices [1]. Lo disputes that "the proposed classical simulation is actually not applicable to the nonlinear Rabi model and the simulation results are completely

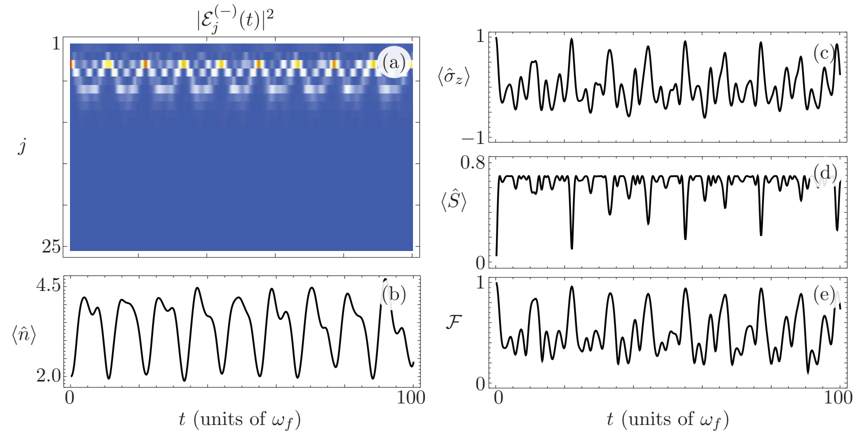

Fig. 1. The classical simulation of the time evolution for the separable initial state $|\psi(0)\rangle = |2,e\rangle$ under the Buck-Sukumar model plus counter-rotating terms on resonance, $\omega_0 = \omega_f$, and coupling parameters $g_- = g_+ = 0.249\omega_f$. (a) Propagation of the initial field in the corresponding negative parity photonic lattice of the classical simulator. The time evolution of the (b) mean photon number, (c) mean atomic excitation energy, (d) mean von Neumann entropy, and (e) fidelity reconstructed from the classical simulation. The lattice is composed by two hundred coupled photonic waveguides.

invalid" [2]. While it is true that attention must be paid to the parameter set where the quantum models are valid and where the corresponding photonic lattices are experimentally feasible, our method to map nonlinear Rabi models into the classical propagation of light through photonic lattices is valid and we encourage the reader to consult our manuscript on this regard. Unfortunately we were not aware of the work done by Lo and his coauthors which, besides enriching our article by adding appropriate boundaries for the set of parameters where the Buck-Sukumar model including counter-rotating terms is valid, would have allowed us to cite him. Let us start by the simplified version of our Hamiltonian that is related to his comment,

$$\hat{H} = \omega\hat{n} + \frac{\omega_0}{2}\hat{\sigma}_z + g\left(\hat{a}\frac{f(\hat{n})}{\sqrt{\hat{n}}} + \frac{f(\hat{n})}{\sqrt{\hat{n}}}\hat{a}^\dagger\right)\hat{\sigma}_x, \tag{1}$$

with well-behaved real function $f(\hat{n})$ such that $f(\hat{n})|0\rangle = 0$ in terms of the number operator, $\hat{n} = \hat{a}^\dagger\hat{a}$, and the Pauli matrices $\hat{\sigma}_i$ with $i = z,x$. Clearly, the use of an auxiliary function $f(\hat{n}) = \sqrt{\hat{n}}$ reduces the problem to the Jaynes-Cummings (JC) Hamiltonian including counter-rotating terms which is well defined for any given parameter set as discussed by Lo and coauthors in [3]. Furthermore, setting the auxiliary function to $f(\hat{n}) = \hat{n}$ reduces the Hamiltonian to the Buck-Sukumar model including counter-rotating terms which is well defined for $g < \omega/4$ as discussed by Lo and coauthors in [4].

In conclusion, the statement "Hence, the proposed classical simulation is actually not applicable to the nonlinear Rabi model and the simulation results are completely invalid" is misleading as it should not refer to the classical simulation. The mapping from the quantum models to the classical analog is correct. The quantum Rabi model with any given parameter set [3] and the Buck-Sukumar model with counter-rotating terms for $g < \omega/4$ [4] are valid as stated by Lo [2].

We only agree with Lo that the numerical simulation presented in Fig. 3 of our paper [1] should have been done for an adequate value of g in which the Buck-Sukumar Hamiltonian including counter-rotating terms is valid; for example $g = 0.249\omega_f$ in Fig. 1 here. However, it is true also that for large g's the first neighbor interaction is not valid any more for large n's, and at least second neighbor interactions should be considered. As in every classical simulation, any particular instance of $f(\hat{n})$ in our model should be studied with care in order to choose a parameter range where both the quantum model is valid and the photonic lattice is experimentally feasible.

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