Single Photon Blockade in Nanocavities with Weak Kerr Nonlinearity (Application)

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Outline

- Background
  - Cavities
  - Kerr Nonlinearity
  - Photon Blockade with nonlinear cavities
- Model for Si
  - Limitations on System
  - Calculating Nonlinear Coupling Strength (U) for Si
- Results
- Future Work
- Acknowledgements
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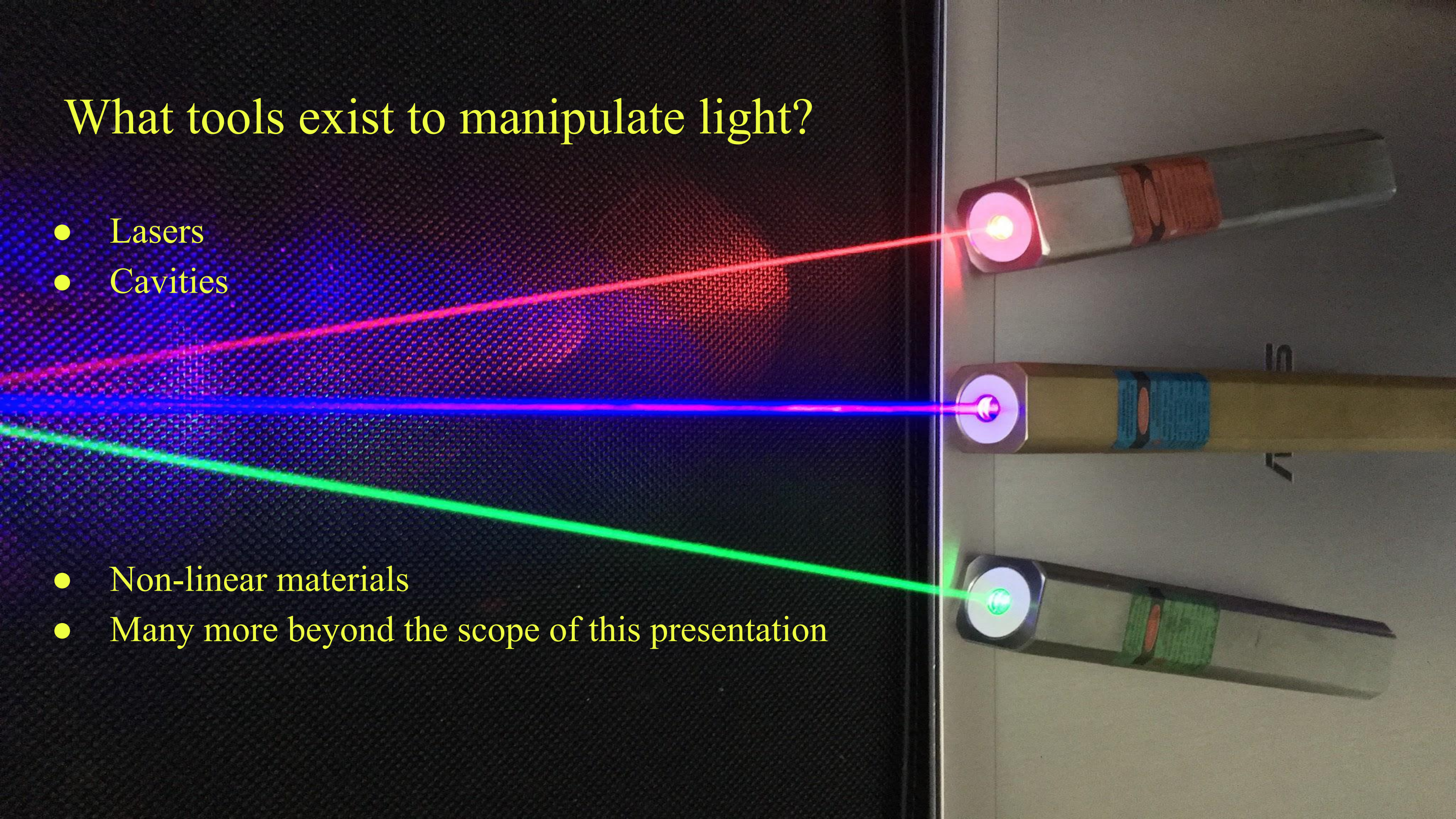
Background

What tools exist to manipulate light?

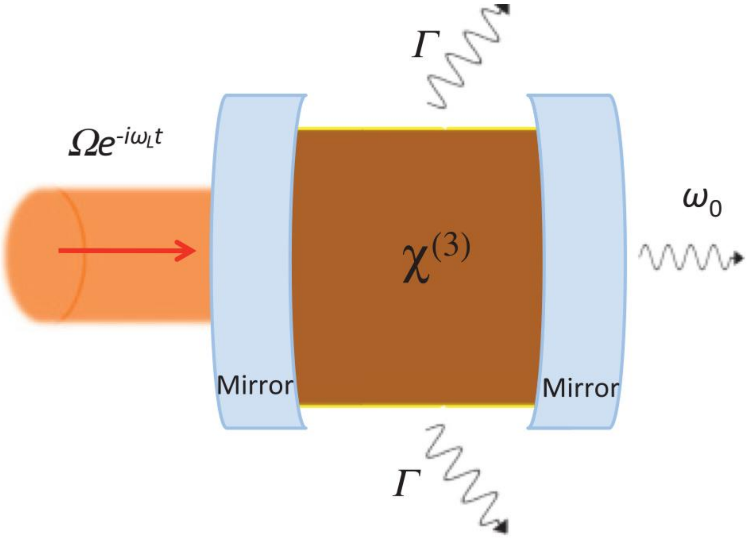
- Lasers
- Cavities

- Non-linear materials
- Many more beyond the scope of this presentation



What are cavities?

- A resonator for E-M radiation
- Can trap photons



Ferretti & Gerace, 2012

Maxwell's Equations in Matter

Where **D** is given by the following:

$$\mathbf{D} = \varepsilon_0 \mathbf{E} + \mathbf{P}$$

In linear media, we have the following:

$$\mathbf{P} = \varepsilon_0 \chi \mathbf{E}$$

$$\nabla \cdot \mathbf{D} = \rho$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

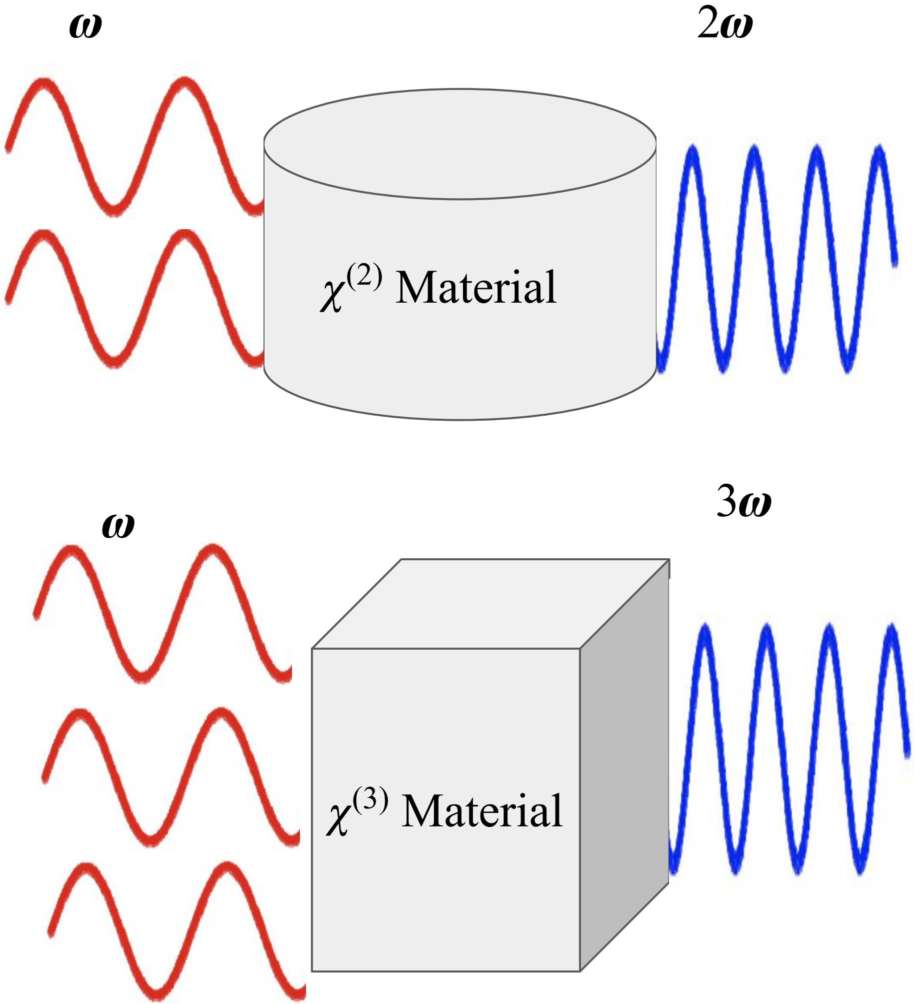
$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

Kerr Nonlinearity

The polarization can be generalized to…

$$\mathbf{P} = \epsilon_0[\chi\mathbf{E} + \chi^{(2)}\mathbf{E}^2 + \chi^{(3)}\mathbf{E}^3 + ...]$$

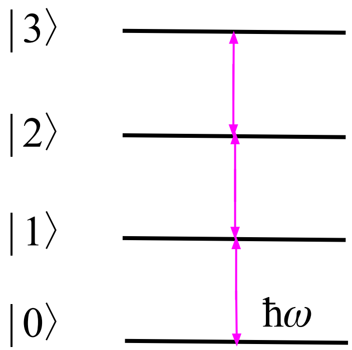
- The properties of the incident light are changed due to the material's response
- Can be applied to **cavities, quantum optics**, fiber optic systems, and more

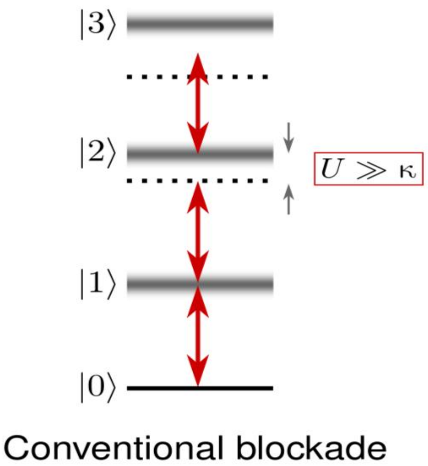


Photon blockade with nonlinear cavities

Basic Ingredients:

- Nonlinear Coupling Strength (U)
- Source of light (laser)





Lingenfelter et al. 2021

Model for Si

Overview for Simulation

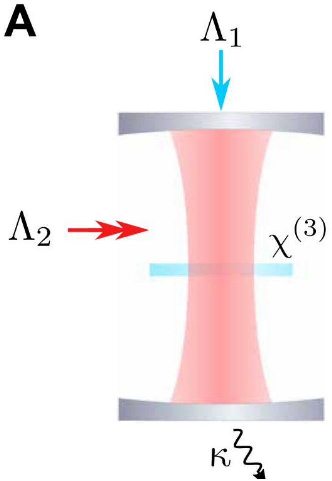
- Used QuTIP to model a photon blockade with a Si nonlinear cavity

$$\frac{d}{dt}\hat{\rho} = -i[\hat{H}, \hat{\rho}] + \kappa\mathcal{D}[a]\hat{\rho}$$

Lingenfelter et al. 2021

Limitations on System

- Light can escape the cavity or cavity can absorb photons and can be modeled by the cavity decay rate ($\boldsymbol{\kappa}$)
- Displacement errors



Lingenfelter et al. 2021

Calculating Nonlinear Coupling Strength (U) for Si

Parameters:

$$\chi^{(3)} = 0.45 \times 10^{-18}\ \frac{\mathrm{m}^2}{\mathrm{V}^2}$$

$$V_{\text{eff}} = 10^{-20}\ \mathrm{m}^3$$

$$\epsilon_{\mathrm{r}}^2 = n^4 = (3.4)^4$$

$$\hbar\omega_0 = \frac{hc}{\lambda} = \frac{1240\ \mathrm{nm\ eV}}{1550\ \mathrm{nm}} = 0.8\ \mathrm{eV}$$

Calculating U:

$$\begin{aligned} U &= \frac{3(\hbar\omega_0)^2}{4\epsilon_0 V_{\text{eff}}}\frac{\chi^{(3)}}{\epsilon_{\mathrm{r}}^2} \\ &= 4.68 \times 10^{-28}\ \mathrm{J} \\ &= \frac{4.68 \times 10^{-28}\ \mathrm{J}}{10^6 \times 6.63 \times 10^{-34}\ \mathrm{Js}} \\ U &\approx 0.705\ \mathrm{MHz} \end{aligned}$$

Ferretti and Gerace, PRB, 85, 033303 (2012)

Results

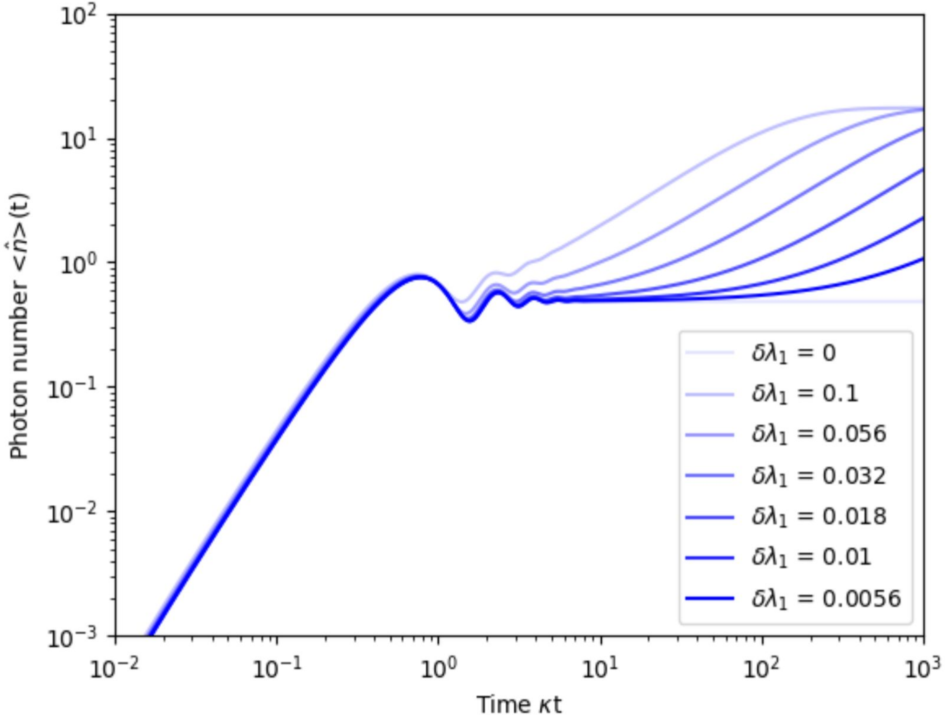
Simulation of Mismatched Drive Amplitude on Blockade Dynamics for Si

Drive Mismatch:

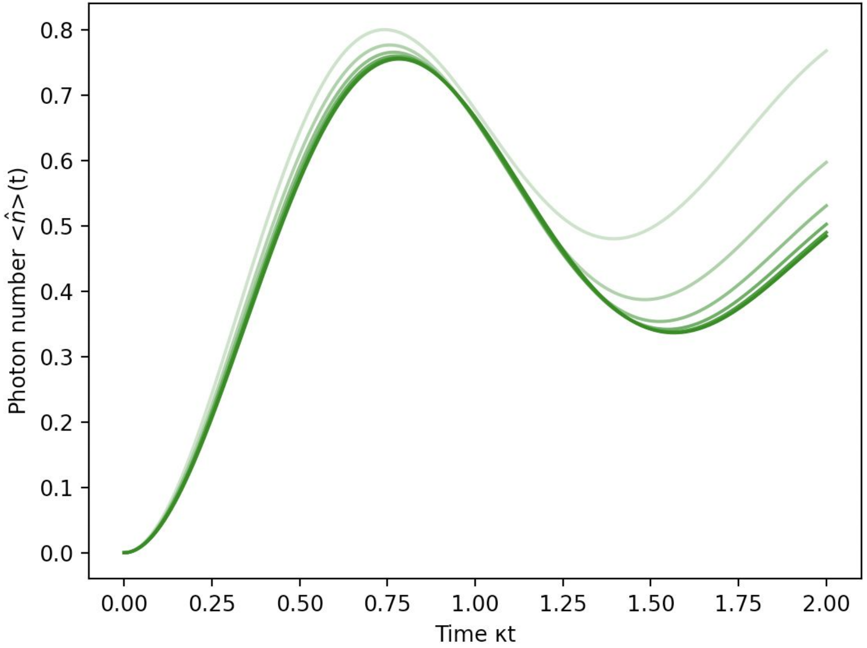
$$\tilde{\Lambda}_1 = -\tilde{\Lambda}_3(1+\delta\lambda_1) = -\tilde{\Lambda}_3 r$$

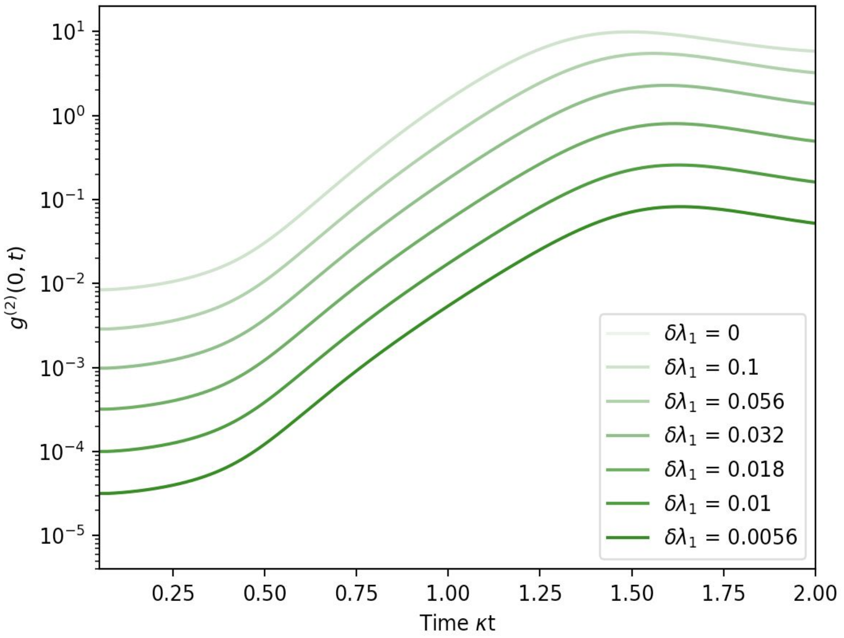
Parameters used for simulation:

- κ = 1 MHz
- U = 0.705 MHz
- N = 60 states



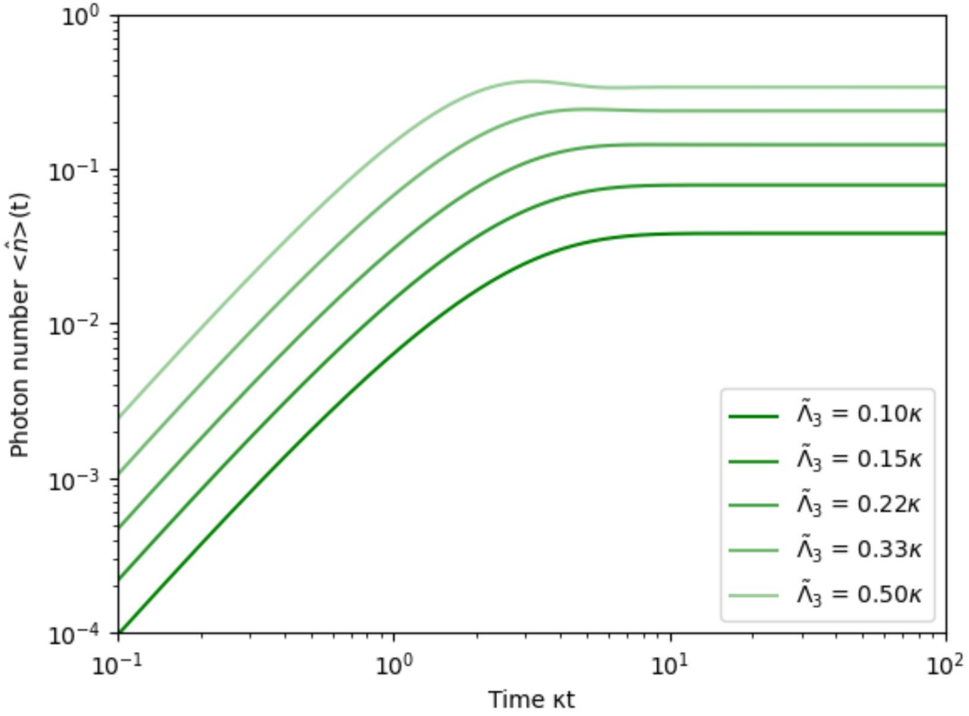
Simulation of Mismatched Drive Amplitude on Blockade Dynamics for Si cont.





Blockade Dynamics with Weak $\tilde{\Lambda}_3$ drive for Si

- Parameters used for simulation:
  - $\boldsymbol{\kappa}$ = 1 MHz
  - U = 0.705 MHz
  - N = 60 states



Conclusion/Future Prospects

- Implement this in a lab setting
- Write paper discussing results

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References

[1] Lingenfelter et al., Sci. Adv. 7, eabj1916 (2021)

[2] Sara Ferretti and Dario Gerace Phys. Rev. B **85**, 033303

[3] M. Fox, ***Quantum Optics: An Introduction*** (Oxford University Press)