Multi-Mode Array Filtering of Resonance Fluorescence

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Fluorescence and correlation filtering is a field that has long been studied [1-3]. In this work we develop an efficient theoretical approach to better filter fluorescence from a target system. To demonstrate this, we model a resonantly driven two-level atom atom coupled as a cascaded system into an array of tunable single-mode cavities [4]. This allows us to derive a set of moment equations for the atomic and cavity mode operators, building upon the uncoupled Maxwell-Bloch equations:

$$\frac{\mathrm{d}}{\mathrm{d}t}\langle\hat{\boldsymbol{\sigma}}\rangle = \boldsymbol{M}\langle\hat{\boldsymbol{\sigma}}\rangle + \boldsymbol{B}, \quad \langle\hat{\boldsymbol{\sigma}}\rangle = \begin{pmatrix}\langle\hat{\sigma}_-\rangle \\ \langle\hat{\sigma}_+\rangle \\ \langle\hat{\sigma}_z\rangle\end{pmatrix}, \quad \boldsymbol{B} = \begin{pmatrix}0 \\ 0 \\ -\gamma\end{pmatrix}, \quad \boldsymbol{M} = \begin{pmatrix}-\gamma/2 & 0 & i\Omega/2 \\ 0 & -\gamma/2 & -i\Omega/2 \\ i\Omega & -i\Omega & -\gamma\end{pmatrix}, \tag{1}$$

where γ is the atomic decay rate and Ω is the driving field Rabi frequency. These moments then act as source terms for the cavity field operator moments; for example,

$$\frac{\mathrm{d}}{\mathrm{d}t}\langle\hat{a}_j\rangle = -\left(\kappa + i\omega_j\right)\langle\hat{a}_j\rangle - \mathcal{E}_j\langle\hat{\sigma}_-\rangle, \tag{2a}$$

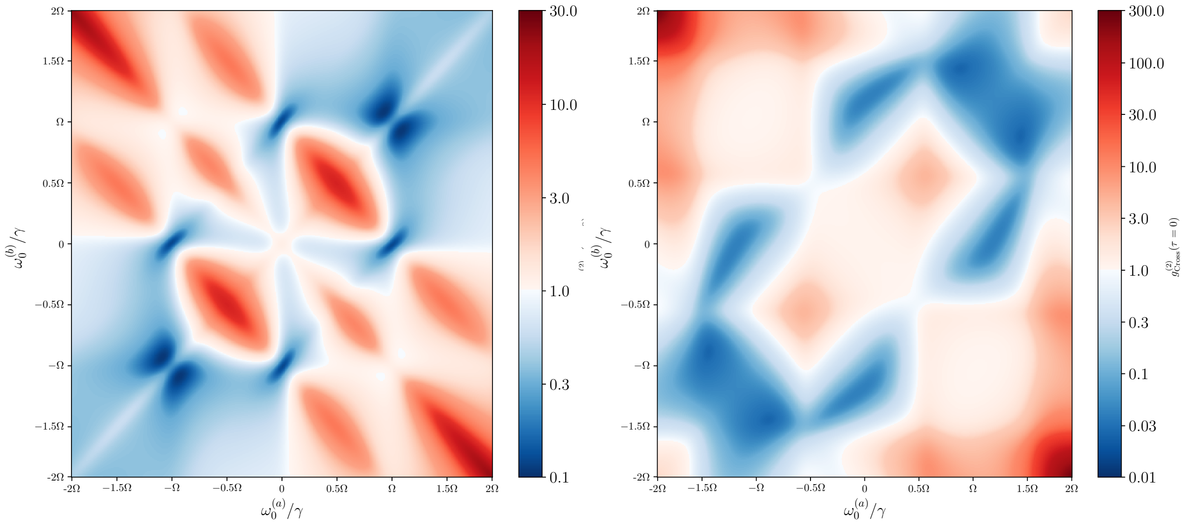
$$\frac{\mathrm{d}}{\mathrm{d}t}\langle\hat{a}_j\hat{\boldsymbol{\sigma}}\rangle = \left(\boldsymbol{M} - \kappa - i\omega_j\right)\langle\hat{a}_j\hat{\boldsymbol{\sigma}}\rangle + \left(0, -\frac{1}{2}\mathcal{E}_j\left(\langle\hat{\sigma}_z\rangle + 1\right), -\gamma\langle\hat{a}_j\rangle + \mathcal{E}_j\langle\hat{\sigma}_-\rangle\right)^T, \tag{2b}$$

where ω_j is the resonance frequency of the j^{th} mode and $\mathcal{E}_j$ is the cascaded systems coupling rate for the j^{th} mode.

In this talk we will discuss how the structure of these coupled equations gives us a natural path to computing frequency filtered first- and second-order correlation functions as well as cross-correlations, using quantum regression equations, with

$$G^{(1)}_{ss}(\tau) = \langle\hat{A}^\dagger(\tau)\hat{A}(0)\rangle_{ss}, \quad G^{(2)}_{ss}(\tau) = \langle\hat{A}^\dagger(0)\hat{A}^\dagger\hat{A}(\tau)\hat{A}(0)\rangle, \quad G^{(2)}_{\mathrm{cross}} = \langle\hat{A}^\dagger(0)\hat{B}^\dagger\hat{B}(\tau)\hat{A}(0)\rangle_{ss}, \tag{3}$$

where $\hat{A} = \sum_{j=-N}^{N}\hat{a}_j$ is the collective mode operator. Figure 1 shows the initial value of cross-correlated frequency-filtered photons for a range of different filter detunings; a calculation which was too computationally expensive when solving the master equation due to the large Hilbert space of the coupled system. We will also discuss how this filtering technique can be applied to other more complex systems.



(a) Single-mode $N = 0$ with $\kappa = \gamma$.

(b) Multi-mode $N = 10$ with $\kappa = \gamma, \delta\omega = 0.8\gamma$.

Figure 1: Initial cross-correlation values for different frequency detunings of filters A and B, with $\Omega = 5\pi\gamma$.

References

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