Unraveling open quantum system dynamics with time and frequency resolved photon correlations

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The quantum theory of optical coherence developed by Glauber in the 60s [1, 2] revolutionized the field of Quantum Optics by identifying photon correlations as the fundamental characterization of light. Theoretically, the Glauber correlator must be upgraded to the so-called time and frequency resolved photon correlations, [3–5]:

$$g^{(2)}_{\Gamma_1,\Gamma_2}(\omega_1,\omega_2;\tau) = \lim_{t\to\infty} \frac{\langle {A^\dagger}_{\omega_1,\Gamma_1}(t) {A^\dagger}_{\omega_2,\Gamma_2}(t+\tau) A_{\omega_2,\Gamma_2}(t+\tau) A_{\omega_1,\Gamma_1}(t)\rangle}{\langle ({A^\dagger}_{\omega_1,\Gamma_1} A_{\omega_1,\Gamma_1})(t)\rangle \langle ({A^\dagger}_{\omega_2,\Gamma_2} A_{\omega_2,\Gamma_2})(t+\tau)\rangle}, \quad (1)$$

where $A_{\omega_i,\Gamma_i}(t) = \int_{-\infty}^{t} dt_1 e^{(i\omega_i - \Gamma_i/2)(t-t_1)} a(t_1)$ is the field detected at frequency ω_i, within a frequency window Γ_i, at time t. Despite being a common practice experimentally in many contexts such as cavity-QED [6] or resonance fluorescence [7, 8], their computation has remained a theoretical challenge only manageable for $N = 2$ and simple systems [9, 10].

In this talk, we present our recently developed theory of frequency-filtered and time-resolved N-photon correlations or N-photon spectra [11] , sketched in Fig. 1(a), that measure the probability of emission of N photons at times $T_1, ...T_N$ into the frequency domain. With this formalism, we are able to study the two-photon spectra (TPS) of a variety of systems of increasing complexity: single mode emitters and the various coupling combinations, under incoherent and coherent excitation [12]. We find that even the simplest systems display a rich dynamics of emission, not accessible by the standard single photon spectroscopy as shown in Fig. 1(b). In more sophisticated systems, such as the strong light-matter coupling achieved in cavity-QED experiments, two-photon emission processes involving virtual states are revealed (see Fig. 1(c), that can be exploited for perfect two-photon state generation [13]. Moreover, we will show how by using a streak camera set-up we were able to capture the first complete TPS for an out-of-equilibrium polariton condensate [14].

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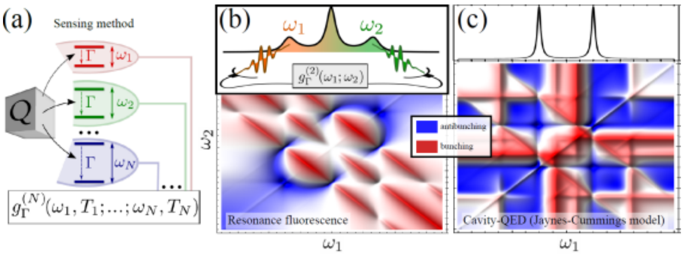

FIG. 1. (a) Sketch of our method to compute frequency-filtered and time-resolved N-photon correlations, based on the intensity-intensity cross correlations between N two-level sensors weakly coupled to the system of interest, Q. We use this method to compute the two-photon spectrum (in the steady state, $T1 = T2$) of different cases such as (b) the resonance fluorescence, a qubit scattering light from a laser or (c) cavity-QED, the Jaynes-Cummings model of quantum light-matter coupling. The two-photon spectra reveal, out of the one-photon spectrum shown above, regions of enhanced single photon emission (antibunching, in blue) or two-photon emission (bunching, in red).

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