Coloured Quantum Cascades

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A recent proposal for a one-way quantum cascade [1], where a single excitation circulates around a ladder of energies [cf. Fig. 1(a)], promised to qualitatively improve the quality of single-photon sources. The photons emitted from such a circular cascade are not only perfectly antibunched (i.e., the probability to find two photons at the same time is *exactly* zero), but their correlation function also displays a temporal gap around zero, guaranteeing that the photons are separated from each other by a finite gap $\delta\tau$. Moreover, as the number of energy levels included in the ladder increases, the internal dynamics of the quantum cascade induces temporal order in the photon emission, and their correlations start to resemble the spatial correlations between atoms in a liquid [2], as shown in the dashed black line in Fig. 1(c). The appearance of such a temporal ordering has been coined as the *photon liquefaction in time*.

Here, we take a step forward in the analysis of the liquefied photons, and address a fundamental question that concerns every quantum system: its observation. This is an important consideration, because every physical observer (which in our case could be a detector or an optical target) is bounded by the Heisenberg uncertainty principle, which means that there is an interplay between its temporal and spectral resolution. Using the theory of frequency-resolved correlations [3] we have access to the correlations of the photons from the cascade *as observed* with finite resolution. As expected, we find that the perfect antibunching of the emission is spoilt as the linewidth of the detector is reduced. However, the degradation of the correlations becomes less prominent as the number of quantum states involved in the ladder increases. Figures 1(b) and 1(c) show that while a linewidth $\Gamma/\gamma_1 = 1$ drastically reduces the antibunching in the $N = 2$ cascade, it barely modifies it in the $N = 26$ one. In fact, in the latter, the temporal structure of the correlations is maintained, even with detectors whose linewidth is narrower than the emission line of the cascade, i.e., $\Gamma/\gamma_1 \leq 1$, implying that the liquefaction of light is highly resilient to observation.

Our results show that one-way quantum cascades are indeed a strong system upon which single-photon sources could be developed. Even when observed with finite temporal resolution, their correlations display strong antibunching and a plateau around zero delay, indicating that photons are indeed emitted one by one. Furthermore, our findings allow us to propose a novel criterium to identify and classify single-photon sources, based on the analysis of the correlation function $g^{(2)}(\tau)$ on the vicinity of $\tau = 0$ and consider both the power dependence of the short-time correlations as well as the presence of oscillations or at least bunching (elbows) past the first coherence time, as these mark the onset of short-time photon ordering.

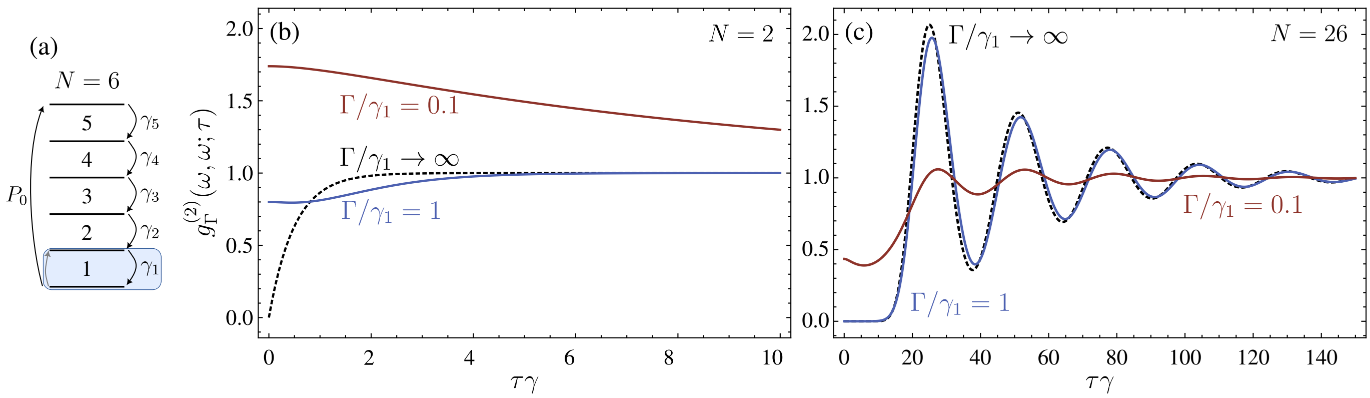

Figure 1: (a) N-level cascade for $N = 6$, with five radiative transitions at rates γ_i ($1 \leq i \leq 5$) plus one reloading P_0. The two-level system is in the dark-shaded (blue) box. (b, c) Observed correlations $g_\Gamma^{(2)}(\omega, \omega; \tau)$ from an $N = 2$ and an $N = 26$ cascade, respectively. The limiting case $\Gamma/\gamma_1 \to \infty$ corresponds to the emission without filtering.

References

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