Comment on "Deterministic Single-Photon Source for Distributed Quantum Networking"

A recent Letter [1] describes an experiment to generate single photons within the setting of cavity QED. The authors claim that "a sequence of single photons is emitted on demand" and that their results represent "the realization of an intrinsically reversible single-photon source." Although their work is certainly an advance towards these goals, unfortunately the observational evidence reported in Ref. [1] does not support the principal claims of the demonstration of a deterministic source for single photons, nor of emission that is suitable for the coherent transfer of quantum states over a network. The underlying difficulties are that (1) photons are emitted at random and not "on demand" due to the random arrival of atoms into the interaction region, (2) the photon stream is super-Poissonian because of fluctuations in atom number, and (3) the pulse phase is random and unknown due to the stochastic character of atomic trajectories.

The data presented in Fig. 4 of Ref. [1] display the second-order intensity correlation function $g^{(2)}_{D_1,D_2}(\tau)$ for the cross-correlation of photoelectric counting events from two detectors (D_1, D_2) as a function of time separation τ. Somewhat surprisingly, $g^{(2)}_{D_1,D_2}(\tau) \geq 1$, and, in particular, $g^{(2)}_{D_1,D_2}(0) \simeq 1$, so that the inferred photon statistics are *super-Poissonian* $\langle \Delta n^2 \rangle > \langle n \rangle$ [2]. This is in marked contrast to the behavior required for an on-demand single-photon source, for which $g^{(2)}(t_0) \simeq 0$ at predetermined times t_0, with *sub-Poissonian* photon statistics $\langle \Delta n^2 \rangle < \langle n \rangle$ [2]. The authors attribute this disparity to detection events other than those arising from photons emitted from the cavity. *However, $g^{(2)}_{D_1,D_2}(0)$ would remain greater than unity even if the background light were eliminated altogether, making $\tilde{g}^{(2)}$ in* [1] *specious.* Furthermore, neither $g^{(2)}_{D_1,D_2}$ nor $\tilde{g}^{(2)}$ incorporate nonstationarity of the underlying processes, so that conclusions about nonclassicality are not well supported.

To illustrate these points, consider the well-studied problem of resonance fluorescence from a two-state atom, with intensity correlation function $g^{(2)}_A(\tau)$ [2]. If observations are made not for a single atom but rather from a volume with a stochastic variation in atom number N, the resulting intensity correlation function $g^{(2)}_{D_1,D_2}(\tau)$ is of a markedly different form from $g^{(2)}_A(\tau)$, as illustrated in Fig. 1. *Significantly, Fig.* 1 *for free-space emission reproduces the essential characteristics of Fig.* 4 *in Ref.* [1] *for emission within a cavity, including that the light is super-Poissonian* [4]. The commonality of these two figures arises because of fluctuations in the number of "source" atoms about which there is no *a priori* knowledge. For independent single-atom emitters, the observation of sub-Poissonian *photon statistics* requires sub-Poissonian *atom statistics*, with $g^{(2)}_{D_1,D_2}(0) < 1$ in direct correspondence to the reduction $Q_A \equiv \frac{\overline{(\Delta N)^2} - \overline{N}}{\overline{N}} < 0$ [3]. Strategies to achieve $Q_A < 0$ include conditional detection, both for Fig. 1 and for Fig. 4 in Ref. [1] [2,5].

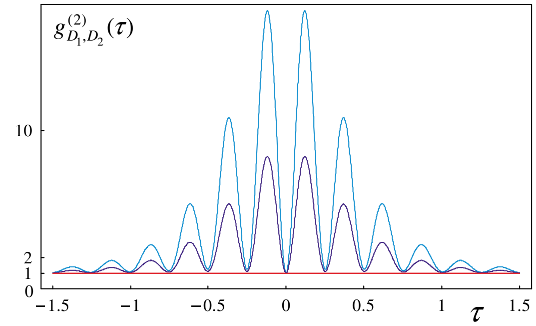

FIG. 1 (color online). $g^{(2)}_{D_1,D_2}(\tau)$ versus delay τ for the fluorescent light from a beam of atoms with average number $\bar{N} = 0.1$. The line at $g^{(2)}_{D_1,D_2}(\tau) = 1$ represents the Poisson limit for coherent light of the same mean counting rates at (D_1, D_2). τ is measured in units of the transit time t_0. The generalized Rabi frequency $\Omega' t_0 = 25$, and transverse decay rate $\beta t_0 = 0.1$. The lower trace is for background to signal ratio = 0.5 (appropriate to Ref. [1]), while the upper trace has no background [3].

In addition to fluctuations in arrival time and atom number, the experiment of Ref. [1] suffers from a lack of atomic localization with respect to the spatially varying coupling coefficient $g(\vec{r})$. As as result, the output pulse shapes and phases for photon emissions vary in a random fashion. A typical atom in [1] moves $\pm \frac{\lambda}{4}$ along the cavity axis during its transit, leading to an unknown phase ϕ for the emitted field, which varies from one pulse to the next. *Such randomness in ϕ makes the field unsuitable for the quantum network protocols cited in Refs.* [3,16–19] *of Kuhn et al.* [1]. Moreover, reversible transmission to a second atom-cavity system requires knowledge of the actual time of the initial emission, as well as an "event" ready atom at the remote location. Neither of these capabilities follows from the experiment reported in Ref. [1].

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[3] H. J. Kimble, M. Dagenais, and L. Mandel, Phys. Rev. A **18**, 201 (1978), Eq. (31); see quant-ph/0210032.
[4] Quantitative differences (e.g., around $\tau = 0$) could be resolved by a three-state model with pumping and recycling.
[5] In [1] the mean number of photoelectric events per atom per pumping cycle is $\bar{n} \sim 0.04 \ll 1$. This low efficiency and the high background rate severely limit any sub-Poissonian effect via conditional detection [2].

