Reply to "Comment on 'Phase-sensitive population decay: The two-atom Dicke model in a broadband squeezed vacuum' "

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We clarify the nature of phase sensitivity in atomic decay in a broadband squeezed light field.

In a recent paper,[1] we analyzed the dynamics of two atoms decaying in a broadband squeezed light field. We showed that the population decay depended on the uneven distribution of noise between the two quadratures of the field and referred to this as "phase-sensitive population decay." Ficek and Drummond[2] (preceding Comment) state that this expression may be misleading as it might imply that the population decay rate can depend on the phase of the squeezing. Of course, we had no intention of implying any such dependence in our article and, indeed, explicitly state that the phase of the squeezing can be set to zero without loss of generality. Nevertheless, it is worthwhile to examine the various meanings of the concept of phase sensitivity.

The squeezing transformation is characterized by the complex parameter $\eta = r\exp(i\phi)$: the amplitude r governs the radii of the squeezed state phase-space density ellipse, and the phase ϕ its orientation with respect to some reference phase. Ficek and Drummond concentrate on the effects of ϕ; we are concerned with the effects of r which dictates the quadrature noise variances. This is our meaning of phase sensitivity. Following Caves and Schumaker,[3] we write the field in terms of time-stationary quadrature components $E_1(t), E_2(t)$ as

$$E(t) = E_1(t)\cos\Omega t + E_2(t)\sin\Omega t \ , \tag{1}$$

where Ω is the carrier frequency of the broadband squeezed radiation field. If this field is mixed in a heterodyne detection system, then the radiation is said to be phase or amplitude squeezed depending on which quadrature carries the noise reduction. Heuristically we often speak of reduced phase fluctuations, but strictly we are concerned only with the unequal partition of the quantum noise between the quadratures. In a two-photon device such as the parametric amplifier, correlated pairs of photons at frequencies $\Omega \pm \epsilon$ are created by the strong pump field which oscillates at 2Ω. The pumping excites Fourier components at frequency E of the field amplitudes $E_1(t), E_2(t)$ given by[3]

$$E_m(t) = \int d\epsilon [E_m(\epsilon)e^{-i\epsilon t} + E_m^*(\epsilon)e^{i\epsilon t}] \ , \tag{2}$$

and we assume, following Ref. 3, that the noise in each component $E_m(\epsilon)$ is Gaussian, and that the fluctuations in each sideband at frequency ϵ are independent of those in other modes. In general the amount of noise in $E_1(\omega)$ and $E_2(\omega)$ need not be the same. In this way we see the noise is phase sensitive.

If we study the interaction of an atomic system resonant with the carrier frequency of the broadband squeezed light, the atoms see a time-stationary noise which is anisotropic in phase space in a frame rotating at Ω. In the case we considered, of a two-atom Dicke model, the interatomic dipole-dipole correlations *are* sensitive to the phase ϕ of the squeezing, i.e., to the orientation of the noise ellipse. The overall population decay rate, however, is not, so as we stated we can set $\phi = 0$ without loss of generality. We, therefore, reemphasize that the population decay is sensitive to the phase dependent noise, and not, of course, to ϕ.

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