

The Private Lives of Photons: Asking particles where they spent the night

Aephraim Matthew Steinberg¹, Daniela Angulo¹, Kyle Thompson¹, Vida-Michelle Nixon¹,
Andy Jiao¹, and Howard M. Wiseman²

¹*University of Toronto, 60 St. George Street, Toronto M5S 1A7, Canada*

²*Centre for Quantum Dynamics, Griffith University, Yuggera Country, Brisbane, Queensland
4111, Australia*

The interaction of a resonant electromagnetic field with a cloud of two-level atoms is so well studied that one would hardly expect it to hold any more mystery, and yet it turns out to still have surprises in store when one considers the effect of post-selection. While photons famously don't follow definite trajectories, there are interesting questions one can ask - experimentally as well as theoretically - about where they have spent their time before being observed. This raises thorny issues about how to talk about the past of a quantum system.

I will describe an experiment we initially built to observe optical nonlinearity at the single-photon level, aiming towards applications such as QND and quantum computing. I will pay particular attention to some of the strange effects we observed when post-selecting on the final state of a photon. In one, we could in a sense “amplify” the phase shift an individual photon wrote on a probe beam. Most recently, we began using this apparatus to probe how much time atoms are caused to spend in the excited state by a resonant photon. Specifically, we investigated whether the answer depends on whether the photon in question is transmitted or reflected. Not only was the answer yes, but the result for transmitted photons turned out to be quite unexpected. I will present both theory and experiment supporting a simple, yet disturbing, connection between the delay time experienced by a pulse and the time atoms spend in the excited state. Finally, I will address the question of how to think about a photon which is prepared in a narrow frequency mode, but later observed at a particular time.