MAR17-2016-020241

Abstract for an Invited Paper
for the MAR17 Meeting of
the American Physical Society

Quantum State Smoothing: what did an open quantum system do when you weren't watching?

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For a classical system that is subject to unobserved forces, and monitored imperfectly (i.e. yielding a noisy measurement record) the optimal way to estimate its properties at a certain time t is by smoothing. This means making use of the measurement record obtained both before t and after t. Generalizing this idea to the quantum domain is not straightforward. One can restrict to estimating an unknown classical process influencing a quantum state [Tsang, Phys. Rev. Lett 102, 250403 (2009)] or to estimating the unknown result of a measurement at time t [Gammelmark *et al.*, Phys. Rev. Lett. 111, 160401 (2013)]. We propose instead quantum state smoothing [Guevara and Wiseman, Phys. Rev. Lett. 115, 180407 (2015)]: we consider a quantum system that is coupled to two environments, observed respectively by Alice and Bob. It is the nature of quantum mechanics that such measurements yield a noisy measurement record, and subject the system to back-action forces. The true state of the system given Alice's and Bob's records is, under some assumptions, pure. But say Alice does not have access to Bob's noisy record – then she cannot know the true state. We show that she can better estimate the true state of the system at time t using her record in the future of t as well as the past. However, the state she should use to estimate the true state depends on what is meant by the 'best' estimate. We show that the 'standard' smoothed quantum state introduced by Guevara and Wiseman in 2015 is the one that minimizes the expected trace mean square error with the true state. Maximizing the expected fidelity with the true state, on the other hand, yields a different, 'lustrated', smoothed state.