

Post-processed estimation of quantum evolution

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Weak quantum measurements enable real-time tracking and control of dynamical quantum systems, producing quantum trajectories – evolutions of the quantum state of the system conditioned on measurement outcomes. For classical systems, the accuracy of trajectories can be improved by incorporating future information, a procedure known as smoothing. Here we apply this concept to quantum systems, generalising a formalism of quantum state smoothing for an observer monitoring a quantum system exposed to environmental decoherence, a scenario important for many quantum information protocols. This allows future data to be incorporated when reconstructing the trajectories of quantum states. We experimentally demonstrate that smoothing improves accuracy using a continuously measured nanomechanical resonator, showing that the method compensates for both gaps in the measurement record and inaccessible environments. We further observe the signature of a key predicted departure from classical smoothing: quantum noise renders the trajectories nondifferentiable. These results establish that future information can enhance quantum trajectory reconstruction, with potential applications across quantum sensing, control, and error correction.