Absolute Irreversibility and Continuous Quantum Measurement: A Fluctuation Theorem Perspective

Sreenath K. Manikandan, Cyril Elouard[a,b], and Andrew N. Jordan[a,b,c]

[a]Department of Physics and Astronomy, University of Rochester, Rochester, NY 14627, USA
[b]Center for Coherence and Quantum Optics, University of Rochester, Rochester, NY 14627, USA
[c] Institute for Quantum Studies, Chapman University, Orange, CA, 92866, USA

The out-of-equilibrium fluctuations of thermodynamic quantities like entropy production for a small system in contact with a thermal reservoir are constrained beyond the second law using relations known as fluctuation theorems. Here we show that, in the absence of a thermal reservoir, the dynamics of continuously measured quantum systems can also be described by a fluctuation theorem, where the fluctuations originate from inherently probabilistic quantum measurement dynamics. This theorem captures the emergence of an arrow of time in the measurement process, from microscopically reversible quantum state dynamics in continuous quantum measurements. We also demonstrate that the measurement-induced wave-function collapse exhibits absolute irreversibility, such that Jarzynski and Crooks-like equalities are violated. We apply our results to different continuous measurement schemes on a qubit: dispersive measurement, homodyne and heterodyne detection of qubit's fluorescence.