Stochastic excursions: Counting observables and noise

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Understanding fluctuations of observables across stochastic trajectories is essential for various fields of research, from quantum thermal machines to biological motors. We introduce a framework to analyze the statistics of counting observables in sub-trajectories (dubbed as stochastic excursions) of processes out of equilibrium. Given a partition of the state space into two sets A and B, an excursion is defined as the segment of the trajectory that starts with a transition from A to B and ends upon the first return from B to A. Our approach offers analytical expressions for the full distribution of counting observables (such as currents, heat, work, entropy production, and dynamical activity) and the excursion duration, capturing their correlations and finite-time fluctuations. As our main result, we uncover a nontrivial fundamental relation between fluctuations of counting observables at the single-excursion level and the steady state noise obtained from full counting statistics, offering a tool to inspect noise sources.