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Quantitative characterization of detailed balance breaking in linear noise-driven dynamical systems AKHIL GHANTA, JOHN NEU, STEPHEN TEITSWORTH, Duke University — In non-equilibrium dynamical systems, the breaking of detailed balance is often manifested by the appearance of *fluctuation loops*, whereby the most probable fluctuation path to a particular state and the relaxation path from it form a loop-like structure in phase space. Such phenomena are present in a diverse array of systems, including noise-driven micromechanical oscillators, coupled electronic circuits, beating cellular flagella, and neuron models. The direct experimental observation of such loops is often challenging, requiring extensive ensemble-averaging of individual stochastic trajectories. Here, we utilize a time-dependent area tensor $A(t)$ - computed from any two independent dynamical variables - to quantitatively characterize the breaking of detailed balance and associated fluctuation loops in linear noise-driven dynamical systems. Analytically, we find that the ratio $A(t)/t$ approaches a constant at long times. This constant can be calculated exactly in terms of system parameters and vanishes precisely when the system satisfies detailed balance. Simulations of model systems are consistent with theoretical results and reveal robust convergence behavior which supports the utility of the area tensor in analyzing experimental data.

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