Unified Hierarchy of Fluctuation-Response Identities and Inequalities in Nonequilibrium Markovian Dynamics

Hyun-Myung Chun[1], Euijoon Kwon[2], Hyunggyu Park[2], Jae Sung Lee[1,2]
[1]*School of Physics, Korea Institute for Advanced Study*
[2]*Quantum Universe Center, Korea Institute for Advanced Study*

Understanding the relationship between fluctuations and response is a central problem in nonequilibrium statistical physics. While the fluctuation-dissipation theorem provides this connection near equilibrium, a general framework valid far from equilibrium remains incomplete. In this talk, I present a unified fluctuation-response framework for nonequilibrium Markovian dynamics. For discrete-state systems described by Markov jump processes, we derive fluctuation-response identities and inequalities that relate fluctuations of general observables to their responses to perturbations of transition rates. Extending these ideas to continuous-state systems, we establish a fluctuation-response theory for Langevin dynamics that connects global fluctuations of observables to their responses to perturbations in force, mobility, and temperature. Together, these results reveal a unified hierarchical structure linking various identities and inequalities, in particular clarifying the relationship between the fluctuation-dissipation theorem and thermodynamic uncertainty relations.

References

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