Stochastic thermodynamics: From concepts to model-free inference

Udo Seifert

University Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart, Germany

Stochastic thermodynamics provides a universal framework for analyzing nano- and micro-sized non-equilibrium systems. Prominent examples are single molecules, molecular machines, colloidal particles in time-dependent laser traps and biochemical networks. Thermodynamic notions like work, heat and entropy can be identified on the level of individual fluctuating trajectories. They obey universal relations like the fluctuation theorem.

Thermodynamic inference as a general strategy uses consistency constraints derived from stochastic thermodynamics to infer otherwise hidden properties of non-equilibrium systems. As a paradigm for thermodynamic inference, the thermodynamic uncertainty relation discovered in 2015 provides a lower bound on the entropy production through measurements of the dispersion of any current in the system [1]. Likewise, it quantifies the cost of temporal precision for biomolecular processes and provides a model-free bound on the thermodynamic efficiency of molecular motors and microscopic heat engines. Generalizations allow us to apply it to time-dependently driven systems like the unfolding of proteins under mechanical force [2]. Waiting time distributions between observable events yield even better bounds on entropy production and the topology and driving affinity of the underlying network [3,4].

[1] A. C. Barato and U. Seifert, PRL 114, 158101, 2015

[2] T. Koyuk and U. Seifert, PRL 125, 260604, 2020

[3] J. van der Meer, B. Ertel, and U. Seifert, PRX 12, 031025, 2022

[4] J. van der Meer, J. Degünther, and U. Seifert, PRL 130, 257101, 2023