# Energy Conversion and Fluctuation Relations in Levy Active Matter

Yuanfei Huang[1], Jong-Min Park[1],

[1]*Asia Pacific Center for Theoretical Physics, Pohang*

Stochastic thermodynamics successfully quantifies energy exchange in fluctuating environments, yet its standard formulation relies crucially on continuous Gaussian noise. Here, we establish a stochastic thermodynamic framework for systems driven by non-Gaussian pure-jump Levy fluctuations, which naturally arise in strongly intermittent biological and synthetic active matter. By extending trajectory-level energetics to discontinuous dynamics, we identify an active entropy production that quantifies irreversibility induced solely by jump-driven probability redistribution [1]. Using a conditioning path-integral formulation for jump processes, we derive non-trivial generalized forms of the Clausius inequality, Crooks fluctuation theorem, and Jarzynski equality. We further show that active entropy production systematically modifies the thermodynamic bounds of cyclic energy converters, yielding generalized power-efficiency trade-off relations and enhanced apparent efficiencies relative to passive thermal engines. These predictions are further illustrated numerically for an active Brownian particle driven by Poisson shot noise. Our results establish heavy-tailed active fluctuations as a genuine thermodynamic resource for nonequilibrium energy conversion.

[1] Y. Huang, C. Liu, B. Miao, X. Zhou. Phys. Rev. Lett. 136 (6), 068302 (2026).
[2] Y. Huang, J-M. Park, Energy Conversion and Fluctuation Relations in Levy Active Matter. Soon in arXiv.