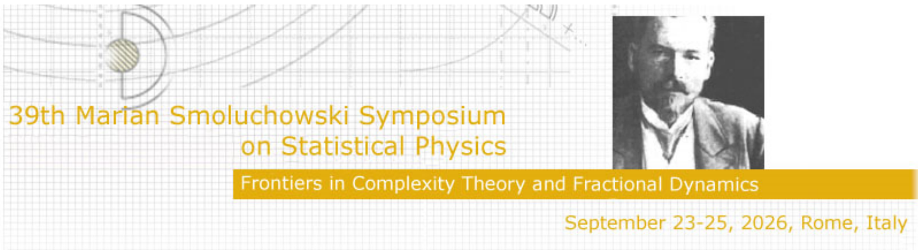

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Strong Violation of the Thermodynamic Uncertainty Relation in a Minimal Autonomous Heat Engine

Thursday, 24 September 2026 15:30 (1h 30m)

Thermodynamic uncertainty relations (TURs) bound the precision of thermodynamic currents in autonomous nonequilibrium steady states and constrain the trade-off between power, efficiency, and constancy in heat engines. We study a minimal autonomous heat engine composed of a discrete ratchet that performs work against a constant bias and an underdamped harmonic oscillator acting as an internal stochastic controller. The oscillator autonomously switches the ratchet between hot and cold phases without external periodic driving. In the regime of time-scale separation, the model becomes exactly solvable. We derive analytical expressions for the average current, its fluctuations, and the TUR ratio, showing that the effect of the continuous degree of freedom is fully captured by the Fano factor of oscillator zero crossings. As the internal control becomes more regular, current fluctuations are strongly suppressed and the TUR ratio can approach zero. We also identify regimes where the engine operates near maximal current and high efficiency while exhibiting pronounced TUR violations. These results show that strong TUR violations can arise already in a simple autonomous hybrid system with underdamped control.

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