# COLLECTIVE ADVANTAGES IN FINITE-TIME THERMODYNAMICS

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## ABSTRACT

A central task in finite-time thermodynamics is to minimize the excess or dissipated work $W_{\text{diss}}$ when manipulating the state of a system in contact with a thermal bath. We consider this task for an $N$-body system whose constituents are identical and uncorrelated at the beginning and end of the process. In the regime of slow but finite-time processes, we show that $W_{\text{diss}}$ can be dramatically reduced by considering collective protocols in which interactions are suitably created along the protocol. This can even lead to a sub-linear growth of $W_{\text{diss}}$ with $N$: $W_{\text{diss}} \propto N^x$ with $x < 1$; to be contrasted to the expected $W_{\text{diss}} \propto N$ satisfied in any non-interacting protocol. We derive the fundamental limits to such collective advantages and show that $x = 0$ is in principle possible, however it requires long-range interactions. We further explore collective processes with spin models featuring two-body interactions and achieve noticeable gains (sub-linear scaling of the dissipation) under realistic levels of control in simple interaction architectures. As an application of these results, we focus on the erasure of information in finite time and prove a faster convergence to Landauer's bound. Fig. 1(a) summarizes the results of our publication [1]: we show the minimal dissipation one can obtain for the erasure of $N$ bits for different degrees of control on the system. In red we apply our main result: a fundamental (tight) bound in the full control scenario. The other curves correspond to different architectures of two-body interaction models (depicted in Fig. 1(b-e)) with a varying degree of realism in the required control.

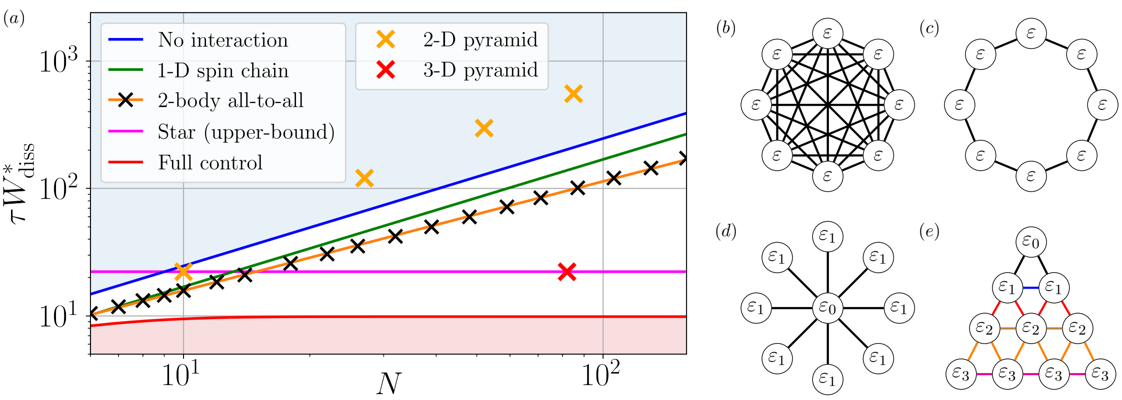


Figure 1: (a) Minimal dissipation $W^*_{\text{diss}}$ for the erasure of $N$ spins for different control designs analyzed in this work. These are compared with the dissipations that are achievable with no interactions (blue-shaded area), and with the dissipations that are not achievable regardless of the protocol (red-shaded area). We find $\tau W^{*,\text{chain}}_{\text{diss}} \approx 1.69N$, $\tau W^{*,\text{all}}_{\text{diss}} \approx 2.20N^{0.857}$, while $\tau W^{*,\text{Star}}_{\text{diss}} \leq 9\pi^2/4$ . Single points are provided for 2-D and 3-D Pyramids with few layers and an aperture of 8. (b-e) Depiction of the geometries of the interactions of the studied systems (equal colors/labels correspond to equal values of the local fields). (b) all-to-all model with $N = 8$, (c) 1-D spin chain with $N = 8$, (d) the Star model with $N = 9$, (e) 2-D Pyramid model with 4 layers and an aperture of 1.

## REFERENCES

[1] A. Rolandi, P. Abiuso and M. Perarnau-Llobet, Collective Advantages in Finite-Time Thermodynamics, *Physical Review Letters*, vol. 131, 210401, 2023.