Optimizing autonomous thermal machines powered by energetic coherence

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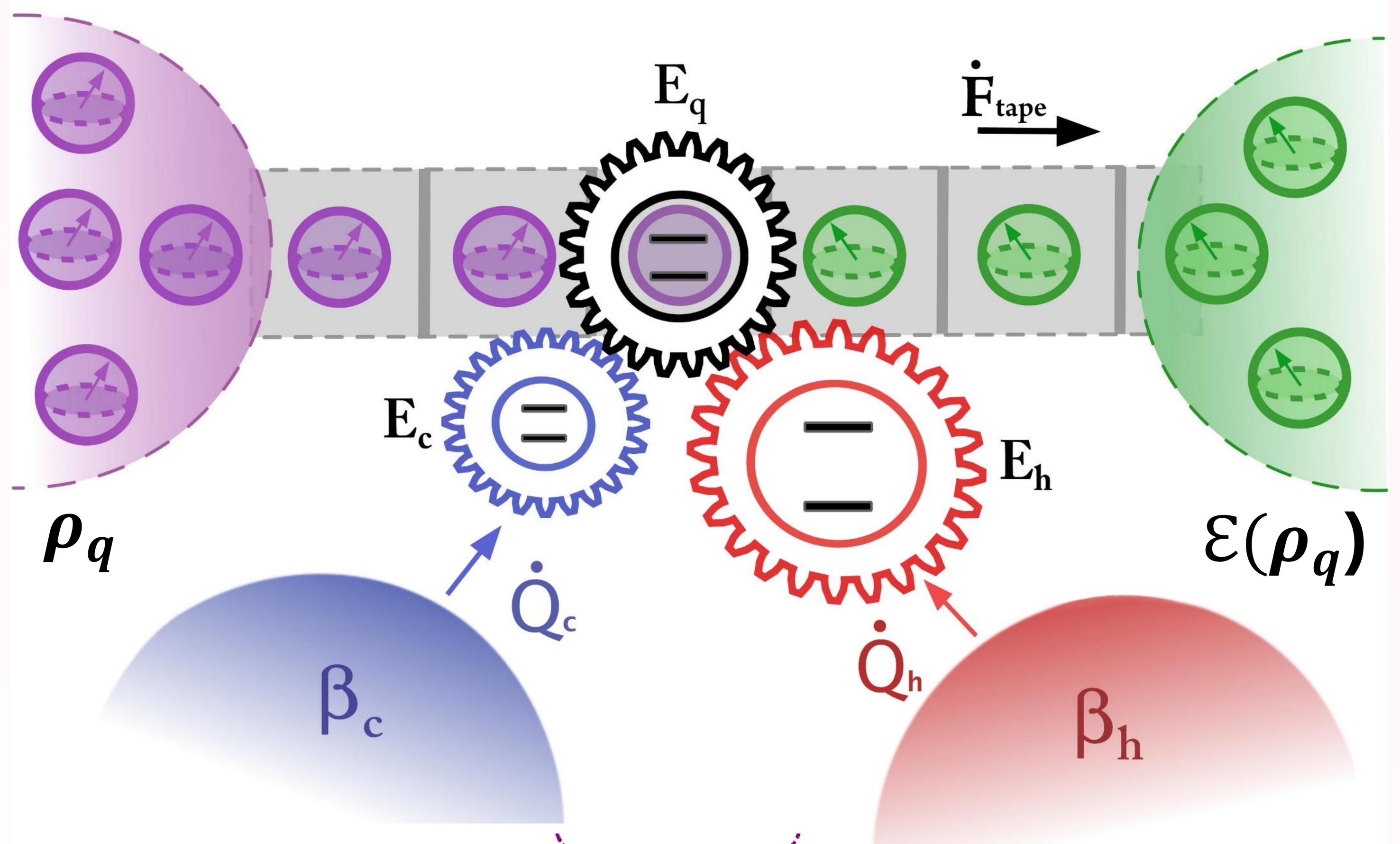
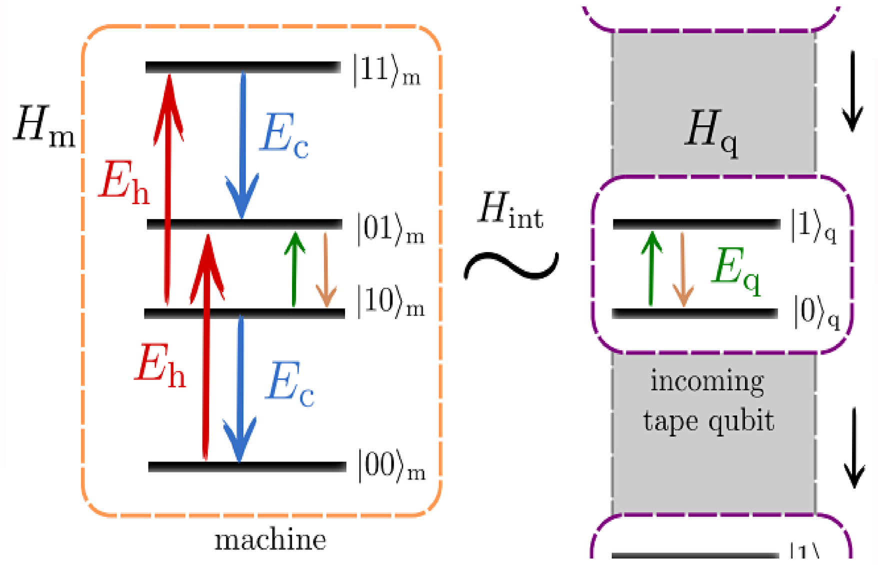
Abstract

The characterization and control of quantum effects in the performance of thermodynamic tasks may open new paths for small thermal machines working in the nanoscale. In this work, we measure and optimize the effect of energetic coherence,i.e coherence between states with different energies on the performance of a small autonomous quantum thermal machine. We demonstrate that the input coherence may enhance the power of the machine and may enable it to operate in otherwise impossible regimes. On the other hand, our results also show that, in some cases, coherence may also be detrimental, rendering optimization of particular models a crucial task for benefiting from coherence-induced enhancements.

Coherent Machine Model

We consider a quantum thermal machine that consists of two qubits with energy spacing $E_h \geq E_c$ which are weakly coupled to thermal reservoirs with different inverse temperatures ($\beta c \geq \beta h$).





Tape Qubit

$$E_q = E_h - E_c$$

$$\rho_q = \begin{pmatrix} p_0 & c \\ c^* & p_1 \end{pmatrix}$$

Then a stream of qubits in a tape with a fixed energy E_q which are prepared in the same initial state ρ_q interacts sequentially one by one with the machine through energy preserving Interactions $[H_{int}, H_m + H_q] = 0$.

GKLS master equation:

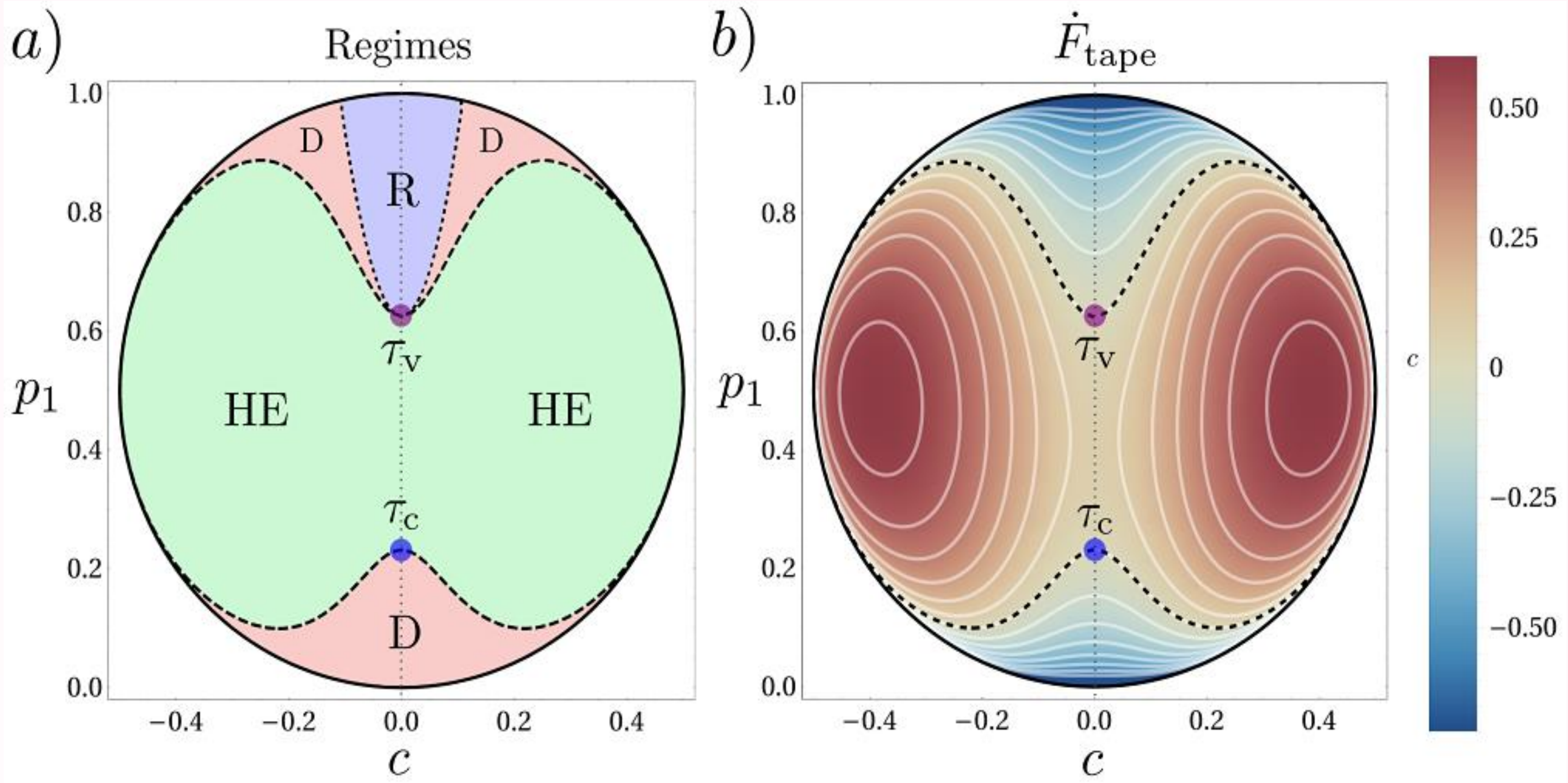
$$\dot{\rho}_m = -i\,[V,\rho_m] + \gamma^q_\downarrow \mathcal{D}[\sigma_c^+\sigma_h^-]\rho_m + \gamma^q_\uparrow \mathcal{D}[\sigma_c^-\sigma_h^+]\rho_m + \mathcal{L}_c(\rho_m) + \mathcal{L}_h(\rho_m) \equiv \mathcal{L}_{tot}(\rho_m),$$

Steady State $\pi_m = \begin{pmatrix} \pi_{00} & 0 & 0 & 0 \\ 0 & \pi_{10} & \pi_c & 0 \\ 0 & \pi_c^* & \pi_{01} & 0 \\ 0 & 0 & 0 & \pi_{11} \end{pmatrix}$

Regimes of Operation

In the steady state regime we derive the bounds on the performance of the machine by combining the first and second law:

- **First Law:** $\dot{E}_{tape} = \dot{Q}_c + \dot{Q}_h$
- **Second Law:** $\dot{S}_{tape} - \beta_c \dot{Q}_c - \beta_h \dot{Q}_h \geq 0$



I.Free energy Heat Engine (HE):

$$\boxed{\dot{F}_{tape} > 0 \quad \dot{Q}_h > 0 \quad \dot{Q}_c < 0}$$

II.Refrigerator (R):

$$\boxed{\dot{Q}_c > 0 \quad \dot{F}_{tape} < 0 \quad \dot{Q}_h < 0}$$

III.Dissipator (D):

$$\boxed{\dot{Q}_c < 0 \quad \dot{F}_{tape} < 0 \quad \dot{Q}_h > 0}$$

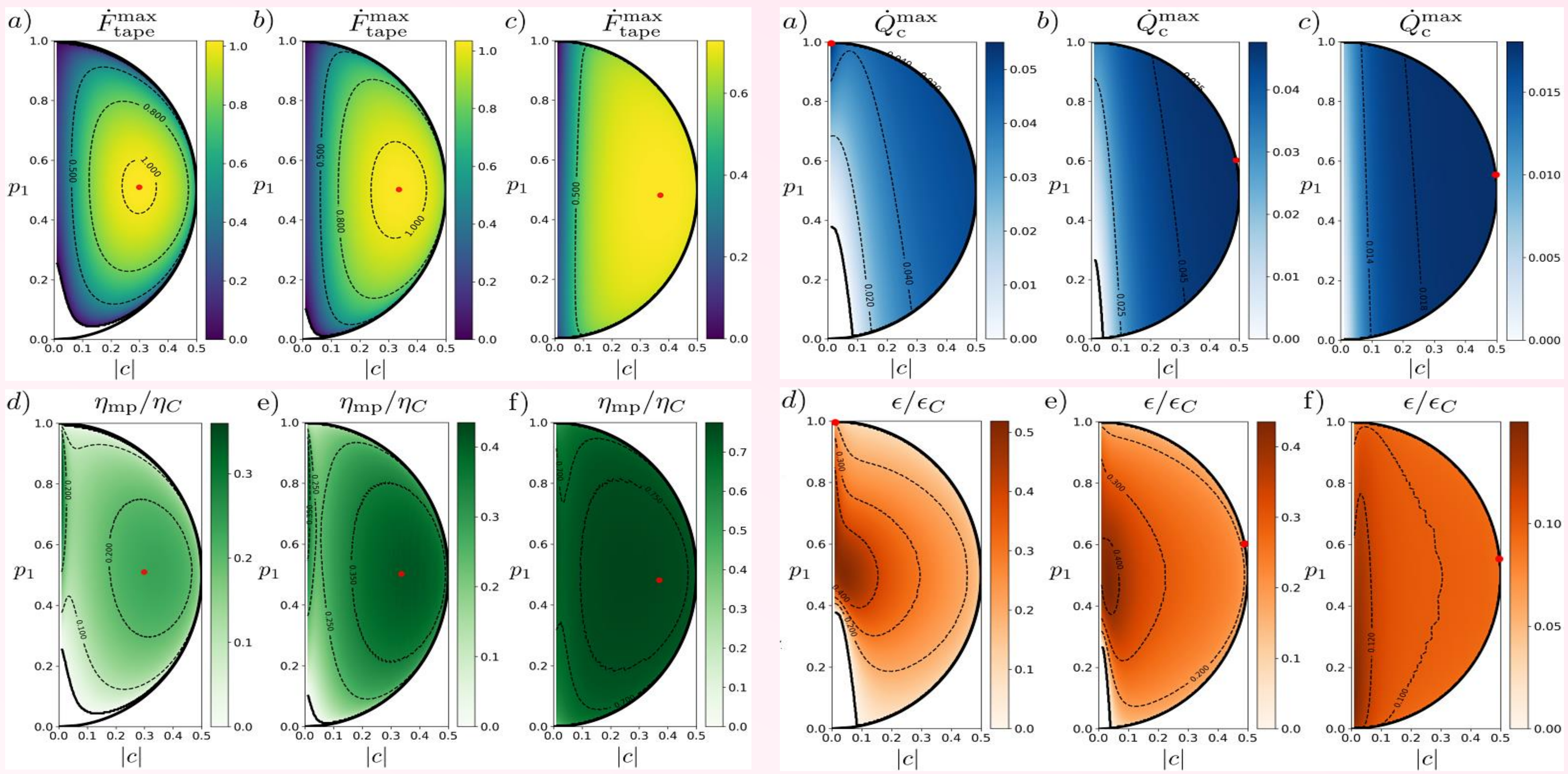
Efficiency of (HE):

$$\eta \equiv \frac{\dot{F}_{tape}}{\dot{Q}_h} \leq 1 - \frac{\beta_c}{\beta_h} \equiv \eta_C$$

COP of (R):

$$\epsilon \equiv \frac{\dot{Q}_c}{-\dot{F}_{tape}} \leq \frac{\beta_c}{\beta_c - \beta_h} \equiv \epsilon_C$$

Optimization of the performance



Conclusion

1- The advantageous effects of coherence require the optimization over the initial state of the tape and the machine's design.

2- For lower temperatures coherence can enhance both the power and efficiency of the heat engine (HE)

3- Detrimental effect of coherence: enhanced cooling doesn't not coincide with improved efficiency

For more information:

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