



# Finite-time optimization of a quantum Szilard heat engine

Tan-Ji zhou, Yu-Han Ma, and Chang-Pu Sun

1 Graduate School of China Academy of Engineering Physics, Beijing 100193, China

2 School of Physics and Astronomy, Beijing Normal University, Beijing 100875, China

3 Key Laboratory of Multiscale Spin Physics (Ministry of Education), Beijing Normal University, Beijing 100875, China

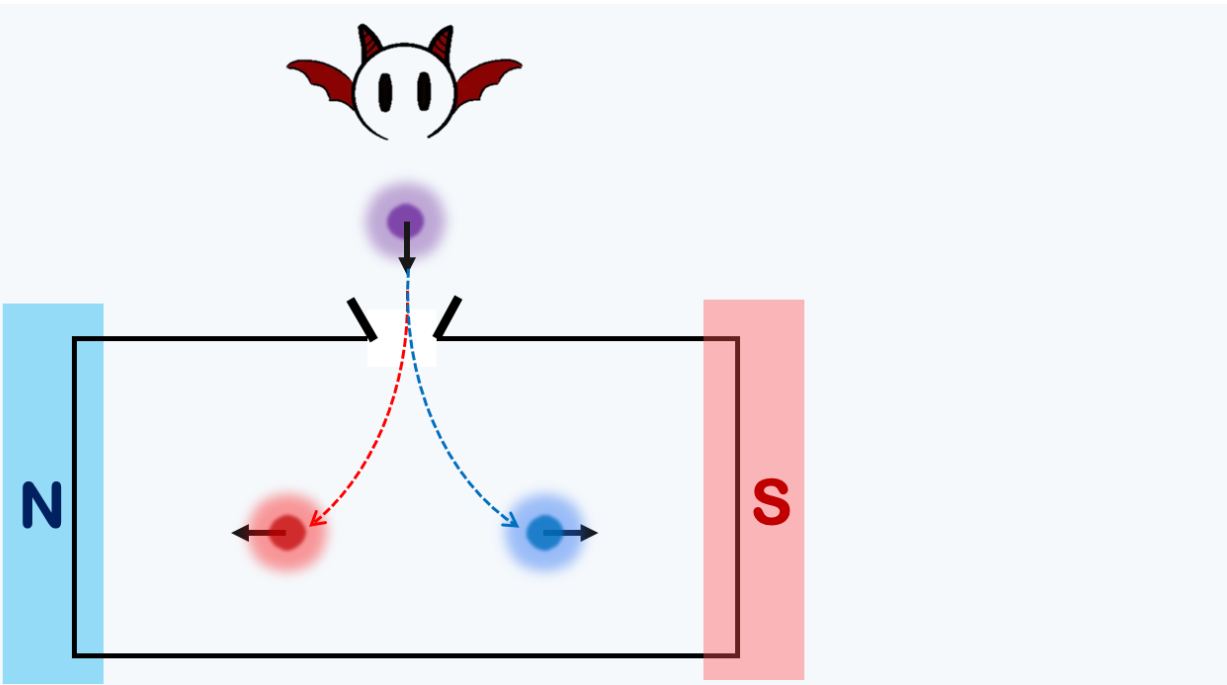


## 1. Introduction

To bridge the gap between information thermodynamics and finite-time thermodynamics, we propose and study a finite-time quantum Szilard engine model to analyze the influence of nonideal quantum measurement on engine performance. We investigate the information correlation between the particle and Maxwell's demon during quantum measurement and analyze the dynamics of the which-way information recorded by Maxwell's demon. Our results demonstrate the fundamental tradeoff between the power and efficiency of information engine due to nonideal measurement.

## 2. Finite-time Information engine

Stage I



✓ **Recording of information:**  
Correlation between demon and particle

$$I(t_M) = I_{DP} \equiv S_D + S_p - S_{DP}, \quad (1)$$

✓ **Work output**

$$W_O \leq k_B T_H I(t_M), \quad (2)$$

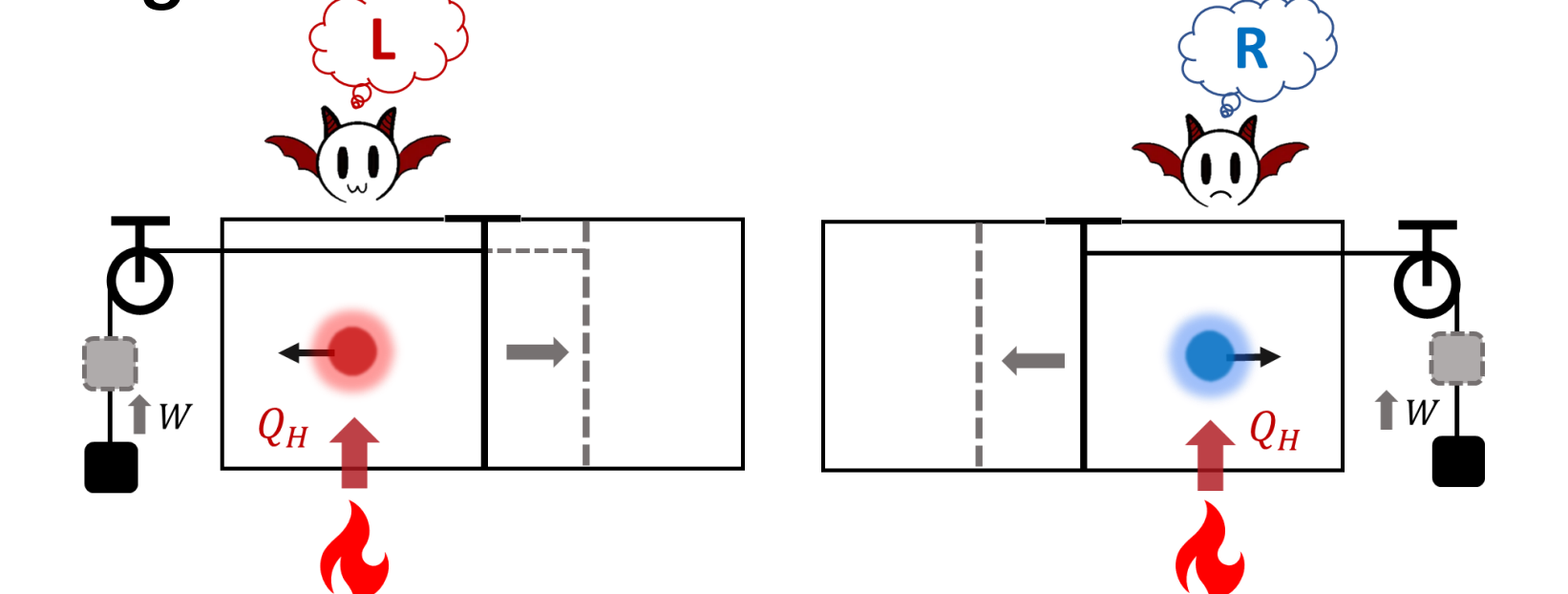
✓ **Measurement ideality**  $\mathcal{M} \equiv I/\ln 2$

$$\mathcal{M}(\tilde{t}) = 1 + \frac{p(\tilde{t}) \ln p(\tilde{t}) + [1 - p(\tilde{t})] \ln [1 - p(\tilde{t})]}{\ln 2} \quad (3)$$

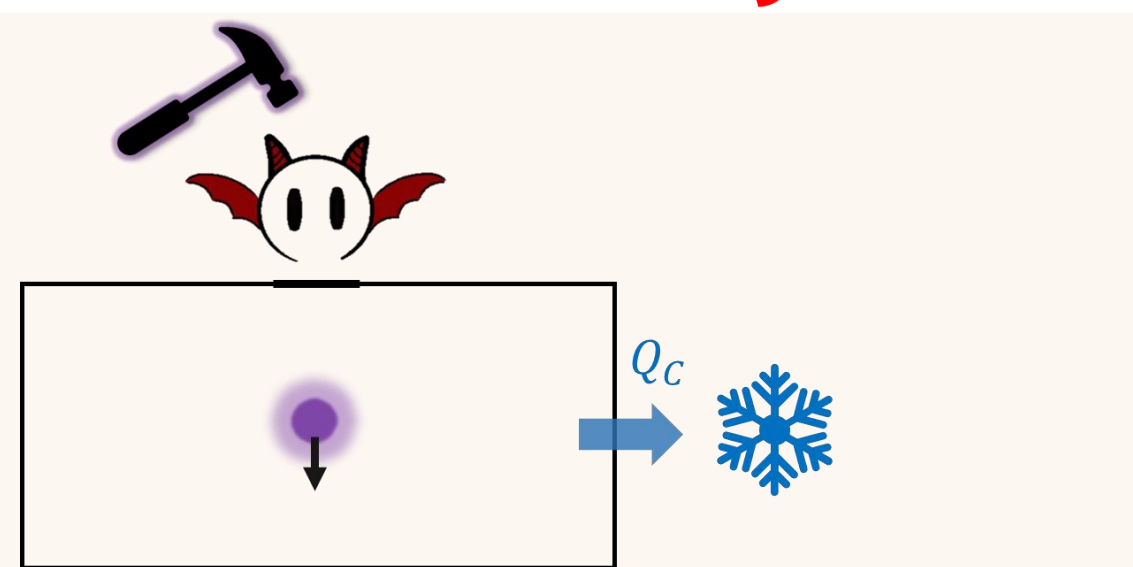
with

$$p(\tilde{t}) = \frac{1}{2} \left[ 1 + \operatorname{erf} \left( \frac{\alpha \tilde{t}^2}{\sqrt{2\tilde{t}^2 + 8}} \right) \right] \quad (4)$$

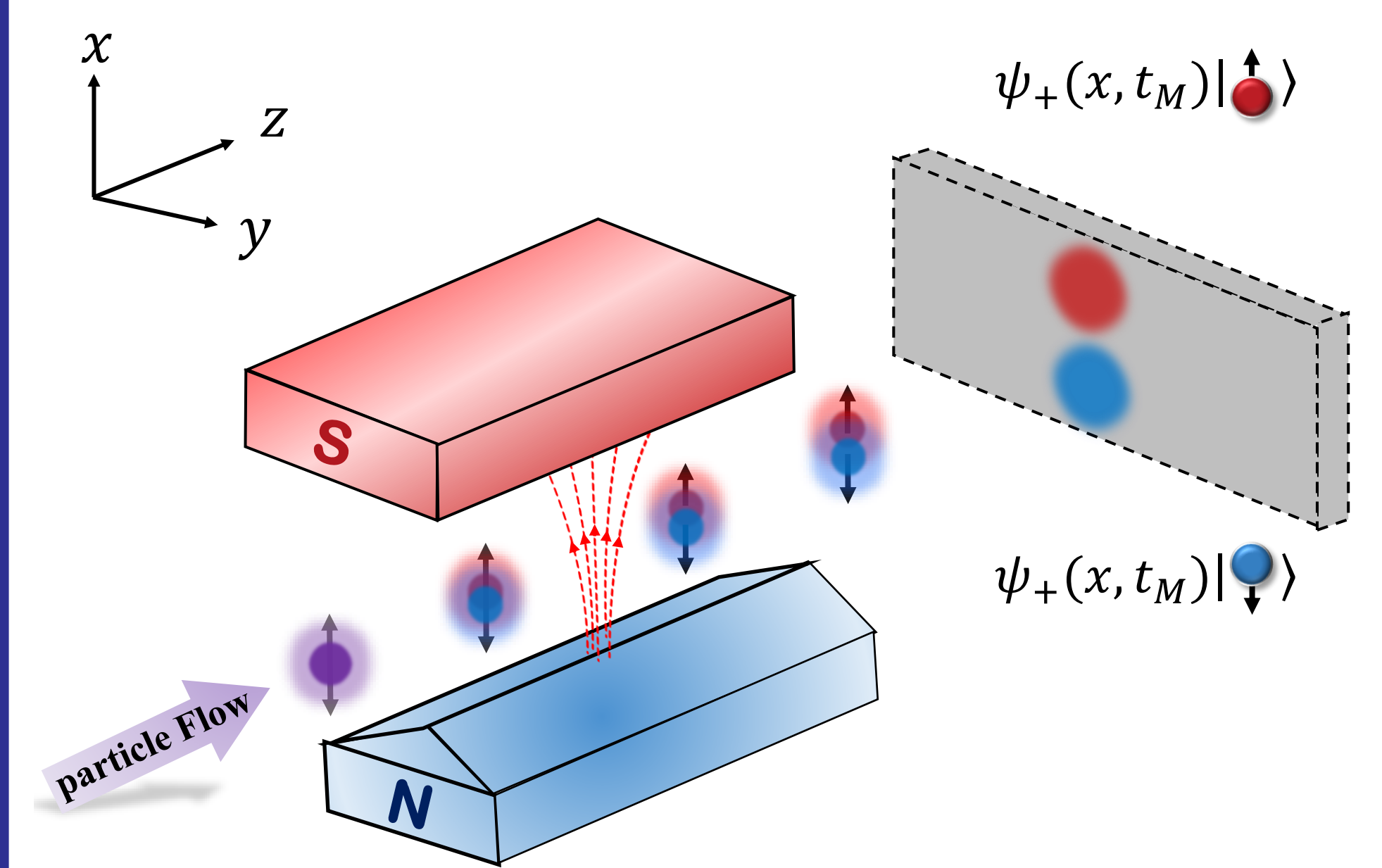
Stage II



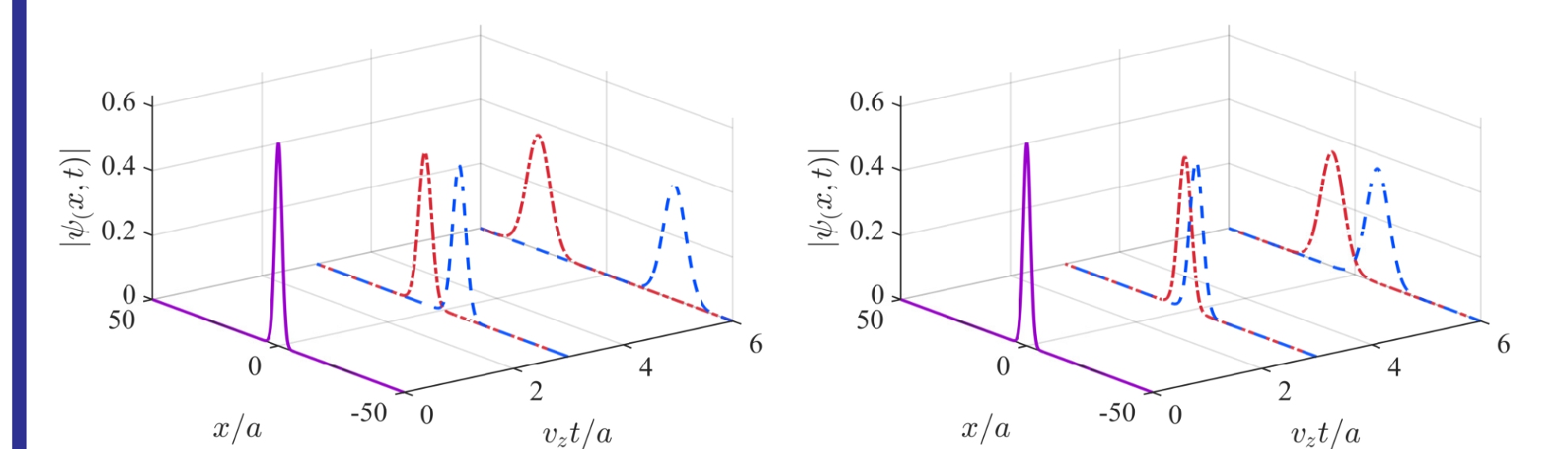
Stage III



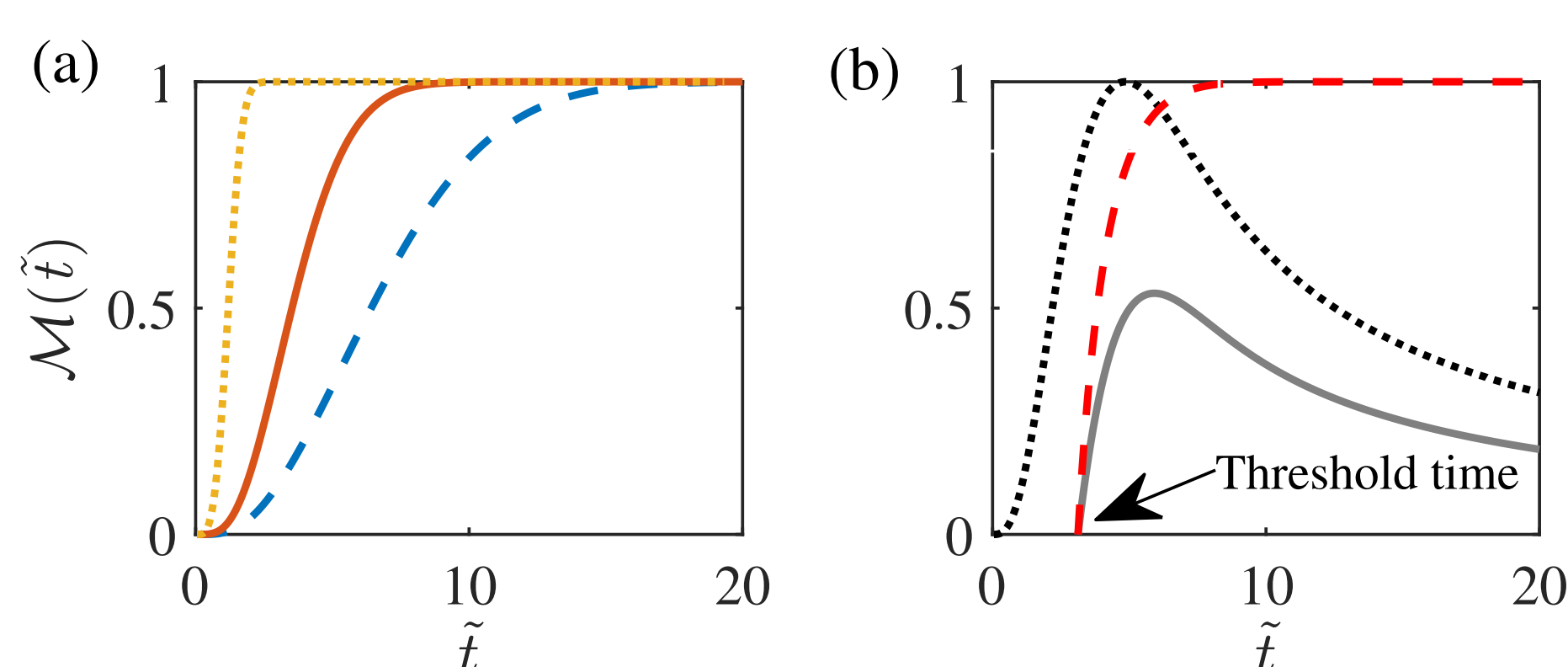
## 3. "Stern-Gerlach" Demon



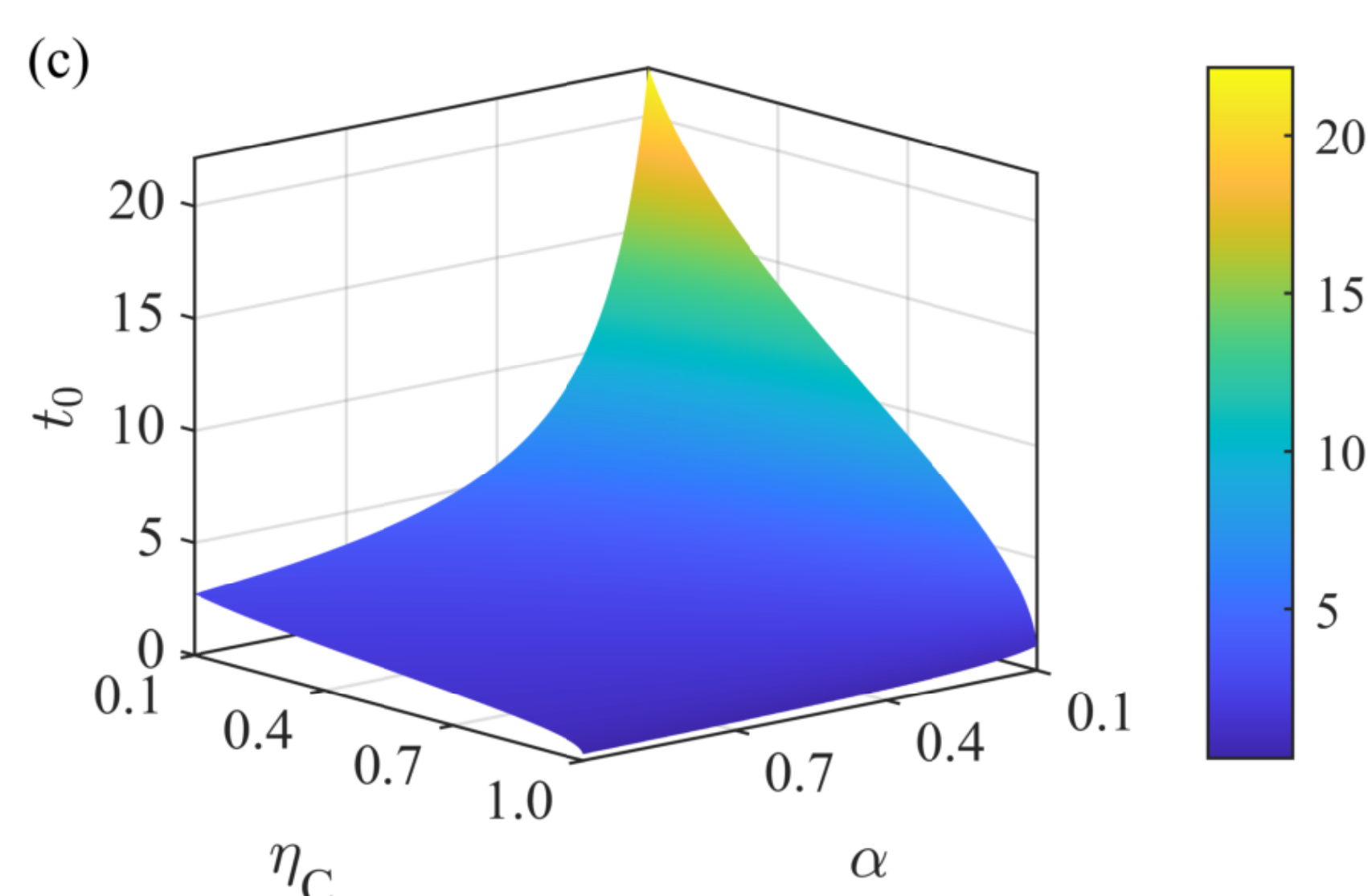
✓ **The accuracy of the demon's discrimination of the particle's position depends on the memory time (measurement duration) and the memory capacity (coupling strength)**



## 4. Information Recording



(a) Measurement ideality with different  $\alpha = 0.2, 0.4, 2$  (blue, orange, yellow). (b) Efficiency and power as functions of measurement time  $\tilde{t}$ .



The threshold time  $t_0$  as a function of the Carnot efficiency  $\eta_C$  and  $\alpha$ .

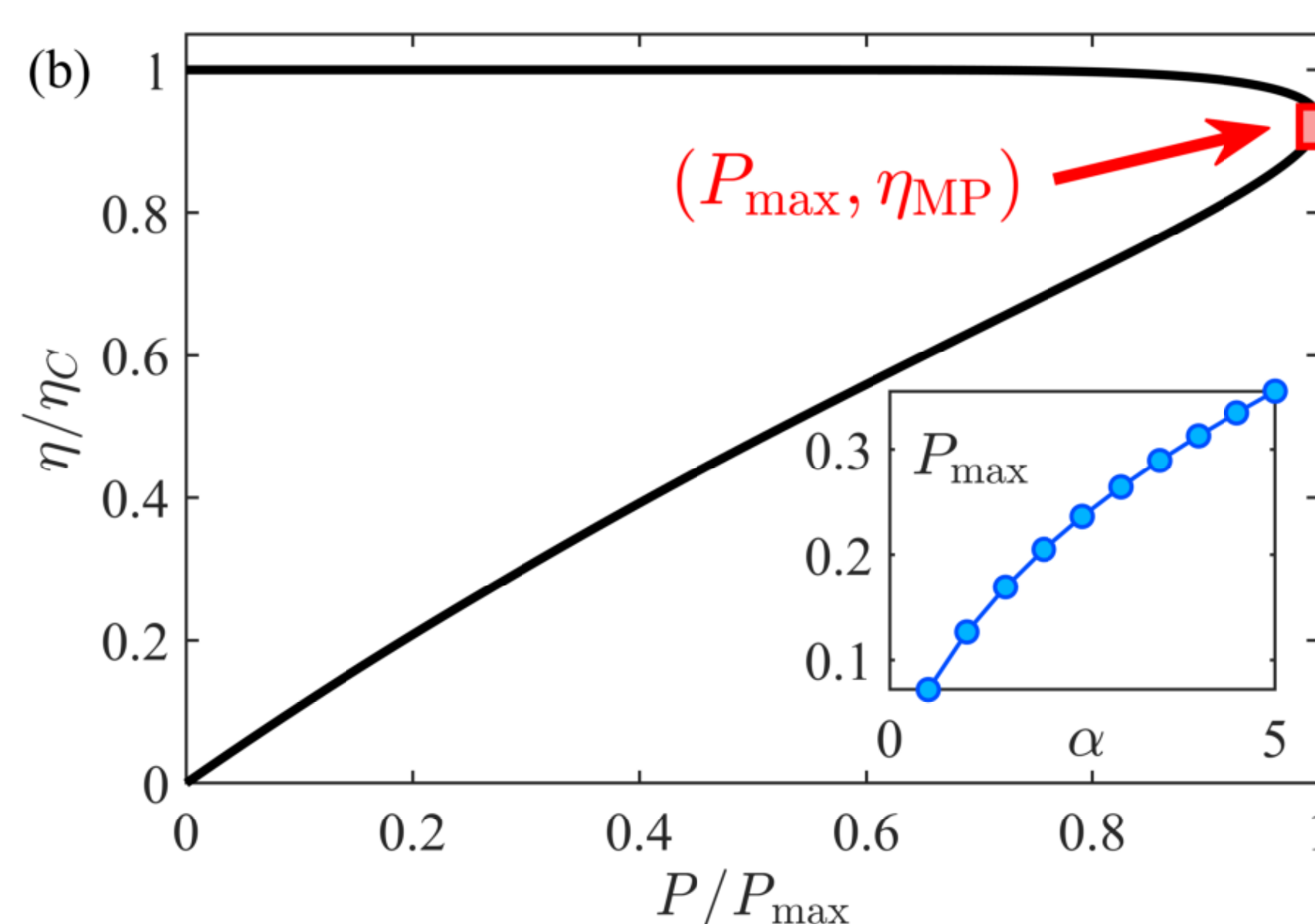
## 5. $P - \eta$ Trade-off

✓ **Efficiency is bounded by measurement ideality**

$$\frac{1 - \eta_C}{1 - \eta} \leq \mathcal{M} \quad (5)$$

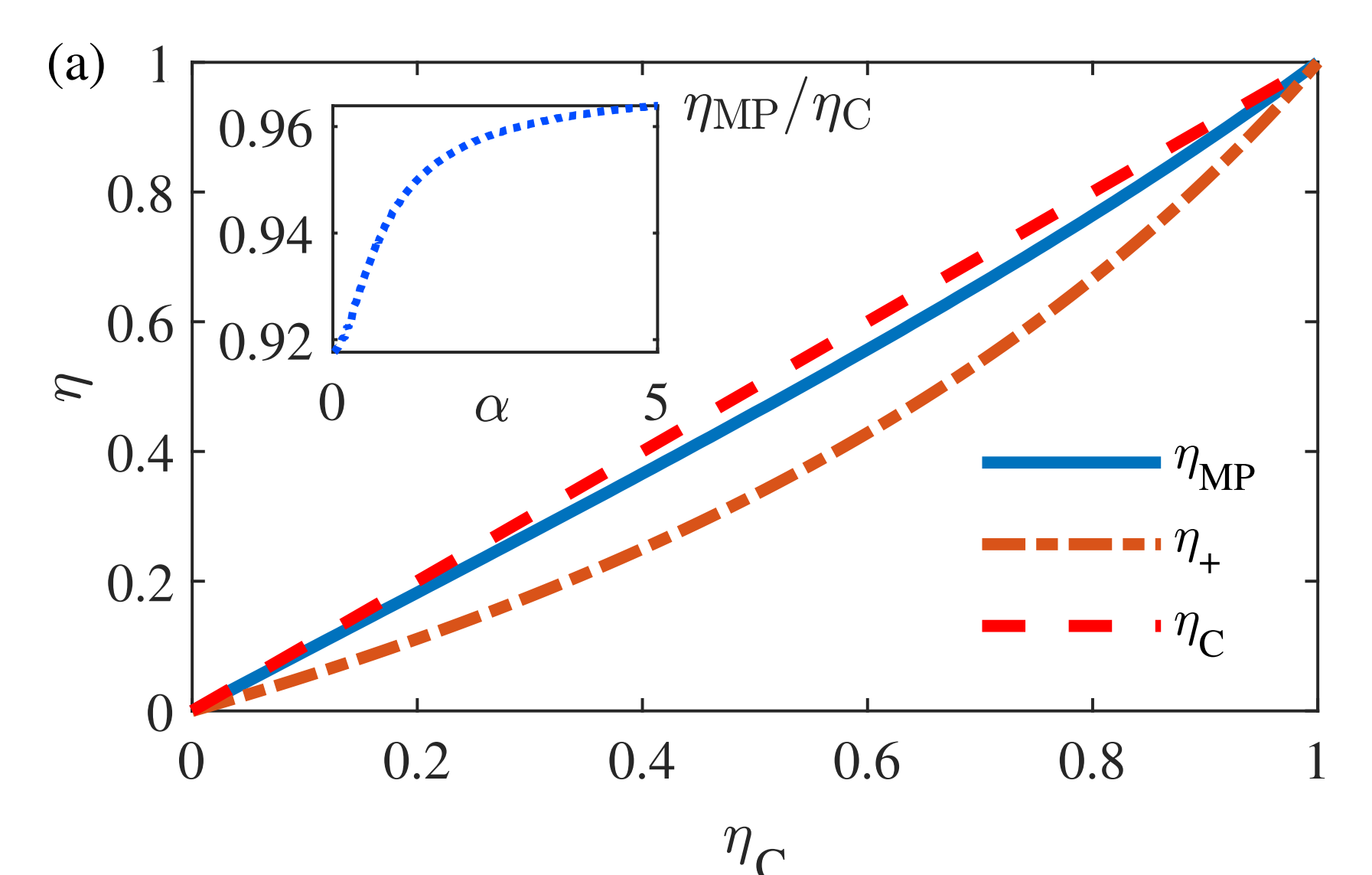
✓ **Power**

$$P = \frac{\eta(\tilde{t}) k_B T_H I(\tilde{t})}{\tau_M \tilde{t}} \quad (6)$$



## 6. EMP

(a) Efficiency at maximum power as a function of Carnot efficiency.  $\eta_+ = \eta_C / (2 - \eta_C)$  (Esposito et al, PRL2010)



## Key Findings

- Nonideal measurement by the demon allows the engine to run fast with **high power at the expense of efficiency**
- EMP of the engine can exceed that of the low-dissipation Carnot heat engine at a certain range of  $\eta_C$
- Provide **thermodynamic evidence for quantum measurement**

## Further Explorations

- Optimal control protocol and the **geometric optimization of the engine**
- Thermodynamic criterion** for different interpretation of quantum measurement
- Thermodynamic consequences of **finite-time memory of intelligent life**

## References

Tan-Ji zhou, Yu-Han Ma, and Chang-Pu Sun, *Finite-time optimization of a quantum Szilard heat engine*, Phys. Rev. Res. 6 (2024) 043001

## Contact and Acknowledgments

† Email: yhma@bnu.edu.cn

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