Quantum Measurement Cooling

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Editors' Suggestion | Featured in Physics

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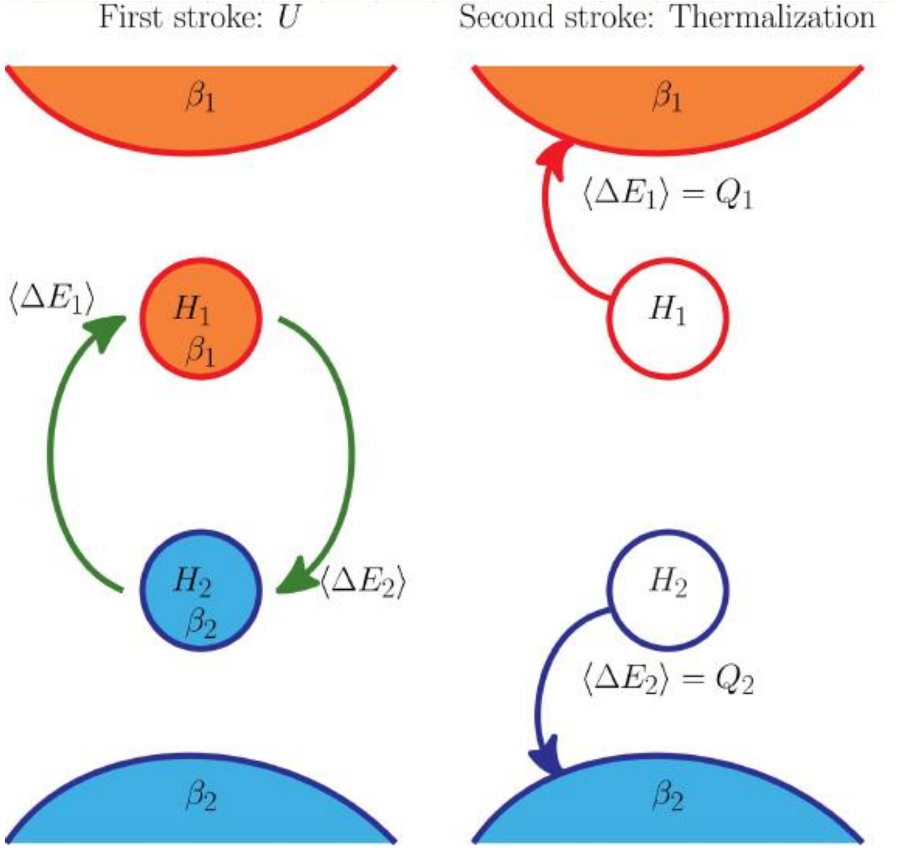
Quantum engines driven by unitaries



Campisi, Pekola, Fazio, NJP **17** 035012 (2015)

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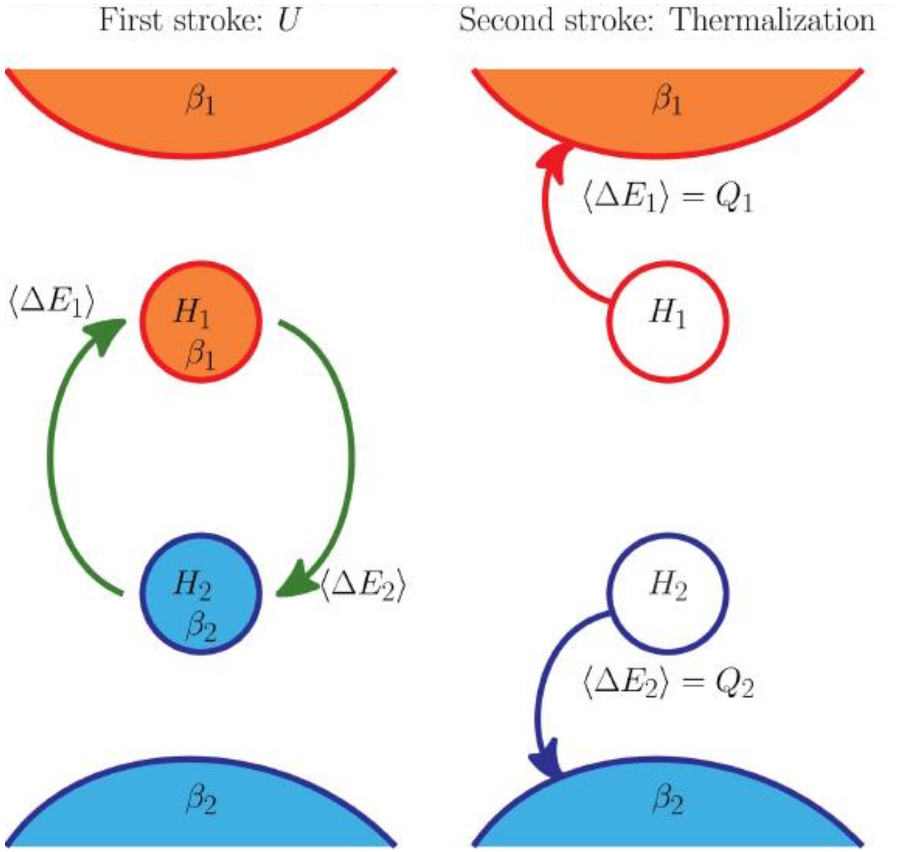

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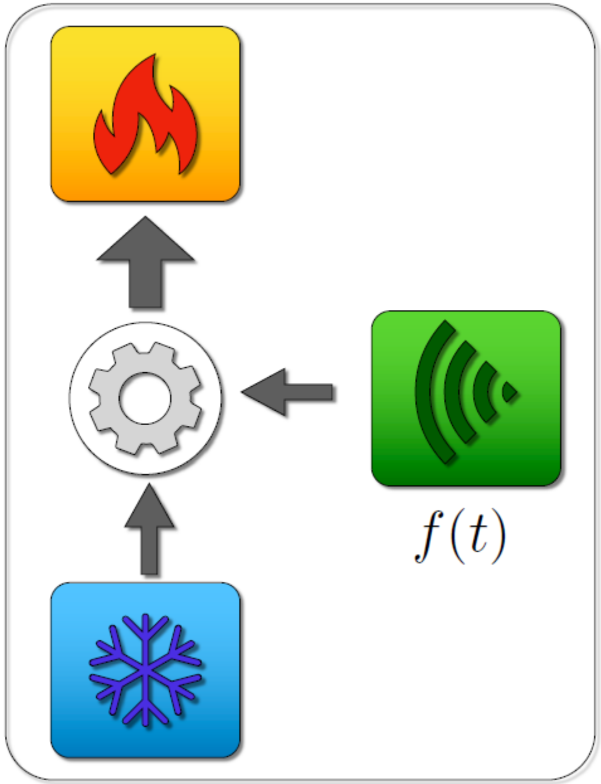
$$\rho = \frac{e^{-\beta_1 H_1}}{Z_1} \otimes \frac{e^{-\beta_2 H_2}}{Z_2}$$

$$\rho' \longrightarrow U\rho U^+$$

$$\langle \Delta E_1 \rangle = Tr[H_1(U\rho U^+ - \rho)]$$
$$\langle \Delta E_2 \rangle = Tr[H_2(U\rho U^+ - \rho)]$$

$$\langle \Delta E_1 \rangle + \langle \Delta E_2 \rangle = \langle W \rangle$$

Using quantum measurements



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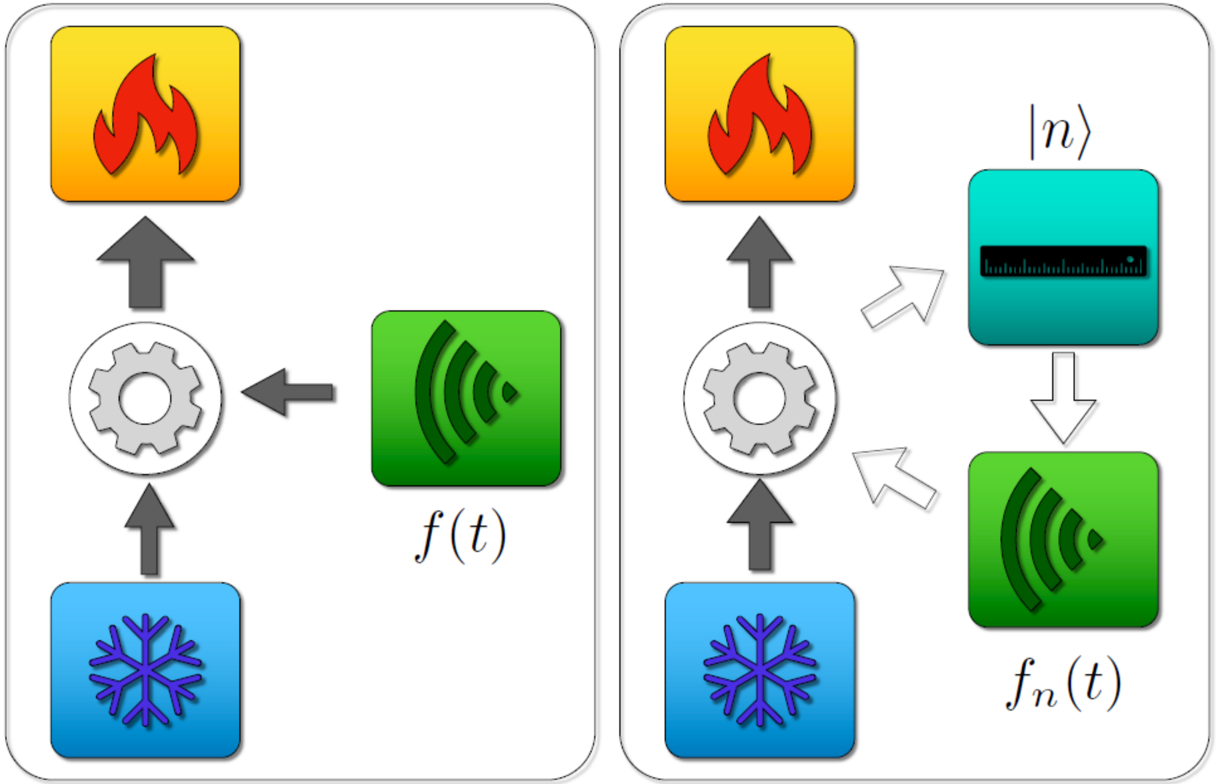

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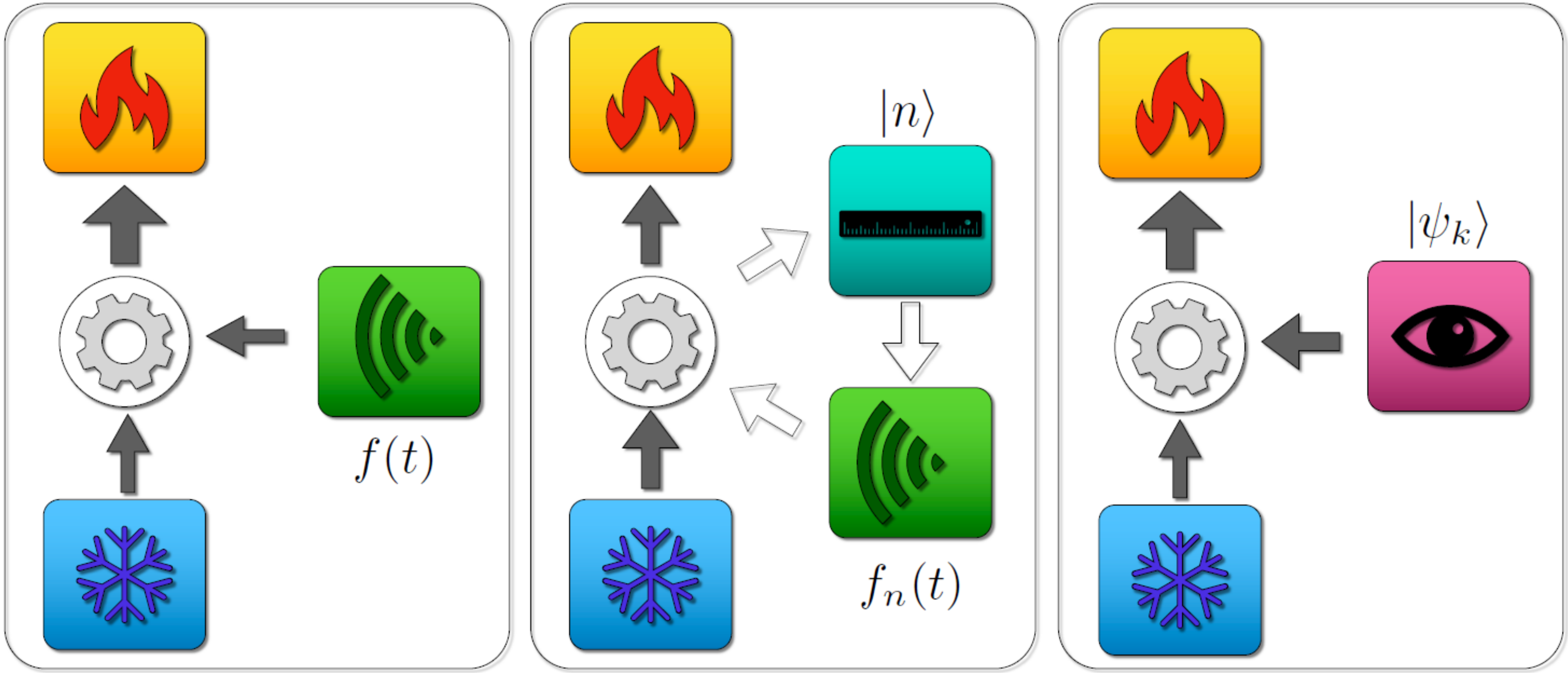
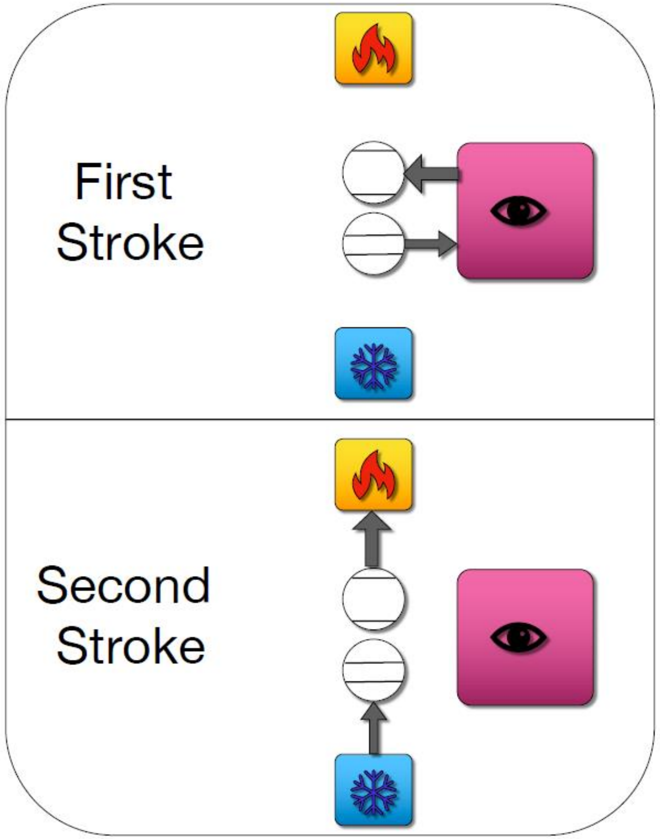


Engine powered by measurements



$$\Pi_k = |\psi_k\rangle\langle\psi_k|$$

$$\rho = \frac{e^{-\beta_1 H_1}}{Z_1} \otimes \frac{e^{-\beta_2 H_2}}{Z_2}$$

$$\rho' \longrightarrow \sum_k \Pi_k \rho \Pi_k$$

$$\langle \Delta E_1 \rangle = Tr[H_1(\rho' - \rho)]$$
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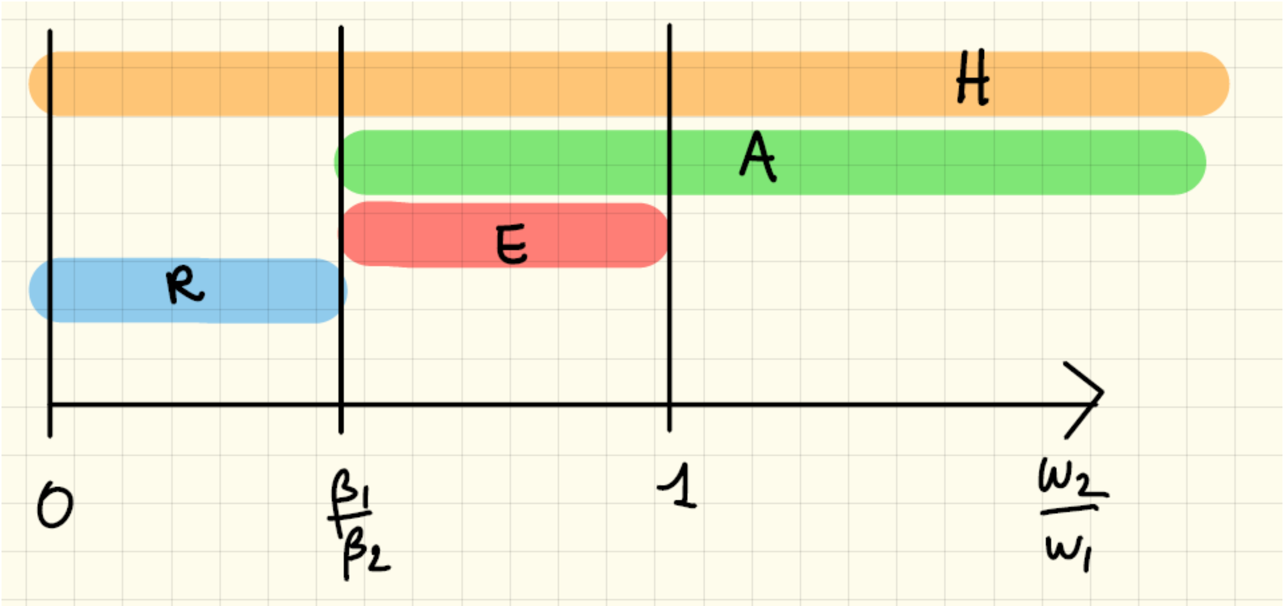
Operation ranges of a 2-qubit engine

Parameters to change:

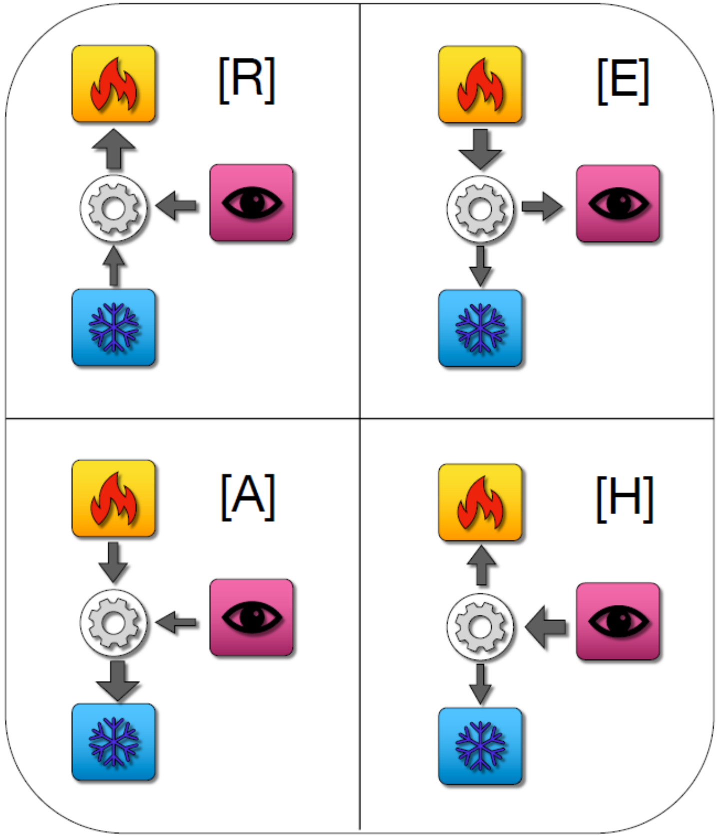
- Temperatures of the baths: β_1, β_2
- Energy splitting of qubits: ω_1, ω_2

Precisely the ratios $\frac{\beta_1}{\beta_2}$ and $\frac{\omega_2}{\omega_1}$

Operation ranges of a 2-qubit engine



Andrea Solfanelli, B.Sc. Thesis UniFi (2018).



Optimal regime

Unitary

$$U = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Maximizes:

- Efficiency and work output in [E] regime
- Efficiency and cooling in [R] regime
- Maximum work output $\mathcal{W}$ ergotropy [Allahverdyan et al., *Europhys. Lett.* **67** (2004)]

Measurements

$$|\psi_k\rangle \begin{cases} |\psi_1^*\rangle = |\uparrow\uparrow\rangle \\ |\psi_2^*\rangle = \frac{|\uparrow\downarrow\rangle+|\downarrow\uparrow\rangle}{\sqrt{2}} \\ |\psi_3^*\rangle = \frac{|\uparrow\downarrow\rangle-|\downarrow\uparrow\rangle}{\sqrt{2}} \\ |\psi_4^*\rangle = |\downarrow\downarrow\rangle \end{cases}$$

Maximizes:

- Efficiency and work output in [E] regime
- Efficiency and cooling in [R] regime
- Maximum work output $\mathcal{E} \leq \mathcal{W}/2$ metrotropy [Solfanelli et al., arXiv:1905.10262 (2019)]

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See poster from Andrea Solfanelli for details!

Is it practically feasible?

$$\rho' = \sum_k \Pi_k \rho \Pi_k = \sum_k U P_k U^+ \rho U P_k U^+$$

- 2-qubits at thermal equilibrium
- Perform a global unitary
- Measure in canonical basis
- Perform the inverse unitary
- Thermalization

All these operations can be implemented using circuit QED and circuit QTD tools!

Two additional questions:
- How small is the «good» region of SU(4)?
- Is it robust to noise?

Uniform (Haar) MonteCarlo sampling

- Sample U uniformly according to the SU(4) Haar measure[1].

$$U_{\boldsymbol{\alpha}} = e^{i\lambda_3\alpha_1}e^{i\lambda_2\alpha_2}e^{i\lambda_3\alpha_3}e^{i\lambda_5\alpha_4}e^{i\lambda_3\alpha_5}e^{i\lambda_{10}\alpha_6}e^{i\lambda_3\alpha_7}e^{i\lambda_2\alpha_8}e^{i\lambda_3\alpha_9}e^{i\lambda_5\alpha_{10}}e^{i\lambda_3\alpha_{11}}e^{i\lambda_2\alpha_{12}}e^{i\lambda_3\alpha_{13}}e^{i\lambda_8\alpha_{14}}e^{i\lambda_{15}\alpha_{15}}$$

$$\boldsymbol{\alpha} = (\alpha_1, \alpha_2, \dots, \alpha_{15})$$

[1] Tilma, T., Byrd, M., & Sudarshan, E. C. G. (2002). A parametrization of bipartite systems based on SU(4) Euler angles. *Journal of Physics A: Mathematical and General*, *35*(48), 10445.

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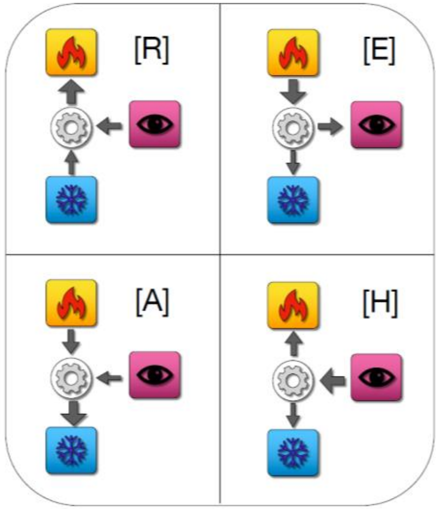

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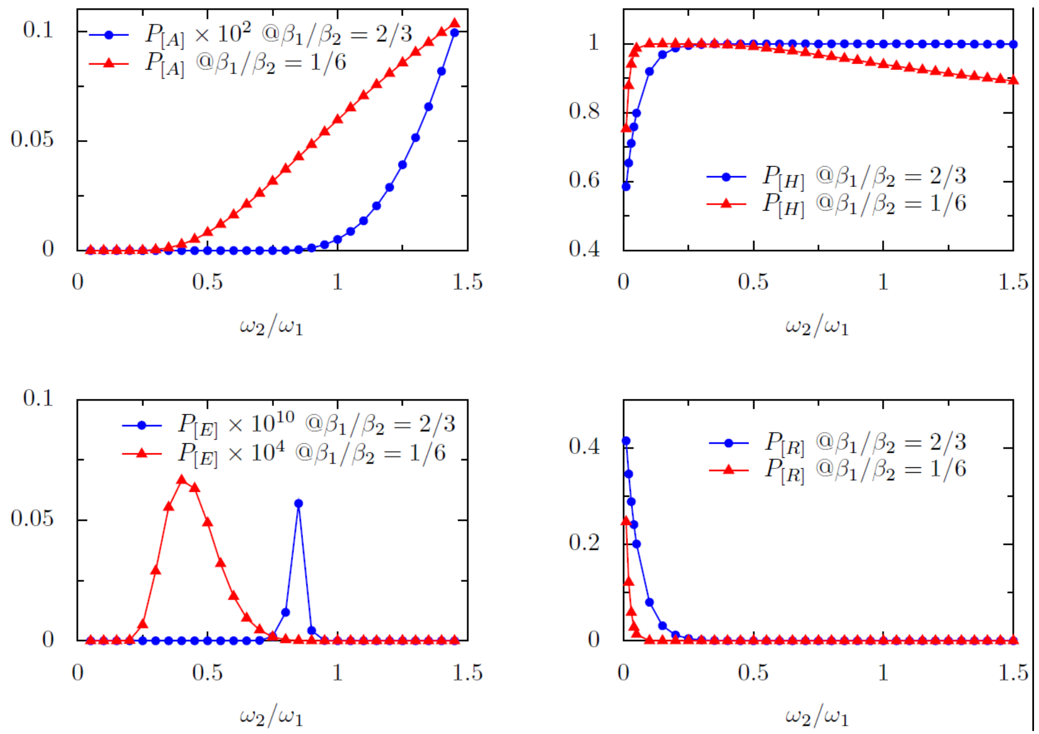
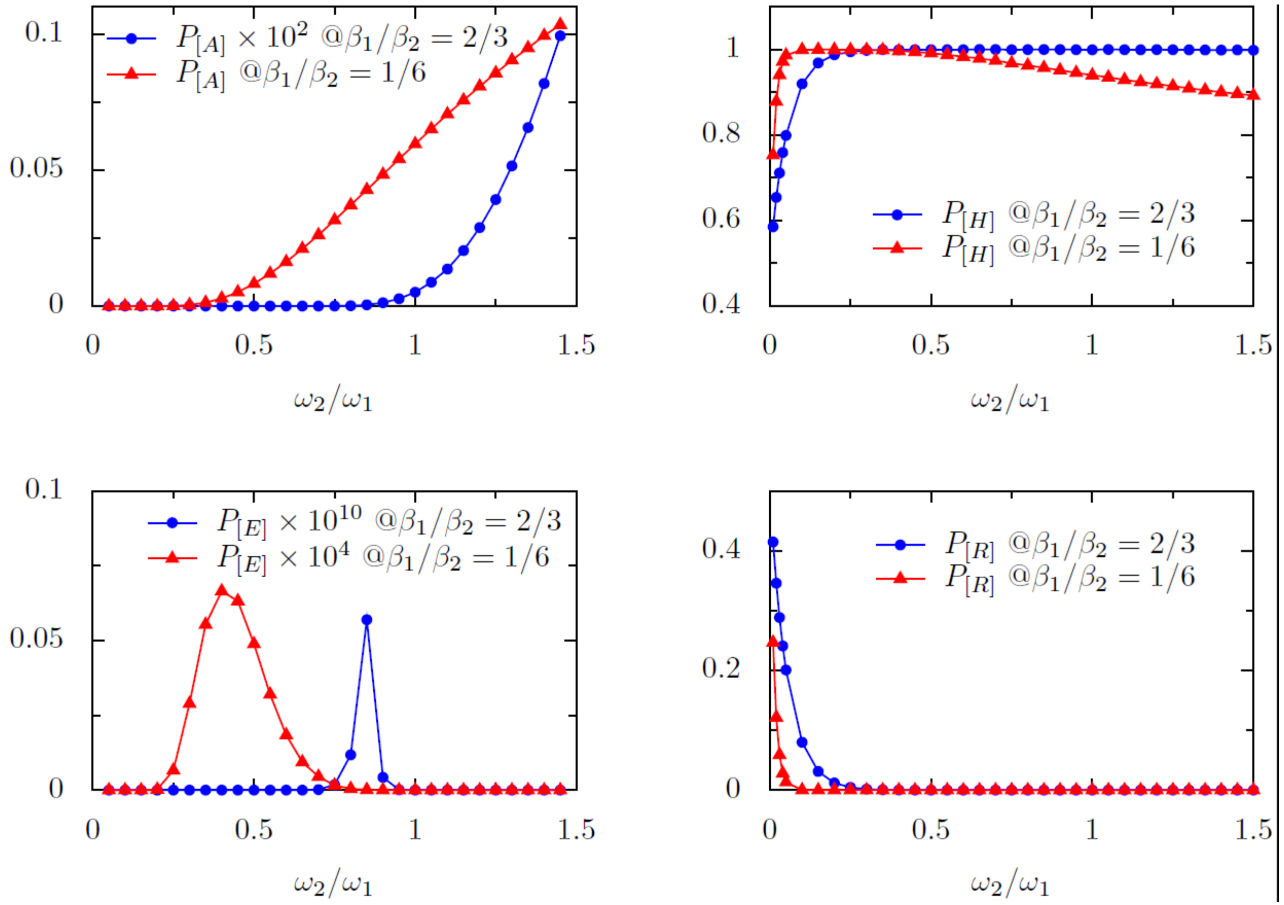


Uniform (Haar) MonteCarlo sampling

The volume of each type of engine in Haar space is non zero!

There's a finite volume of measurement basis that can implement QMC.



An insight into noise using t-SNE

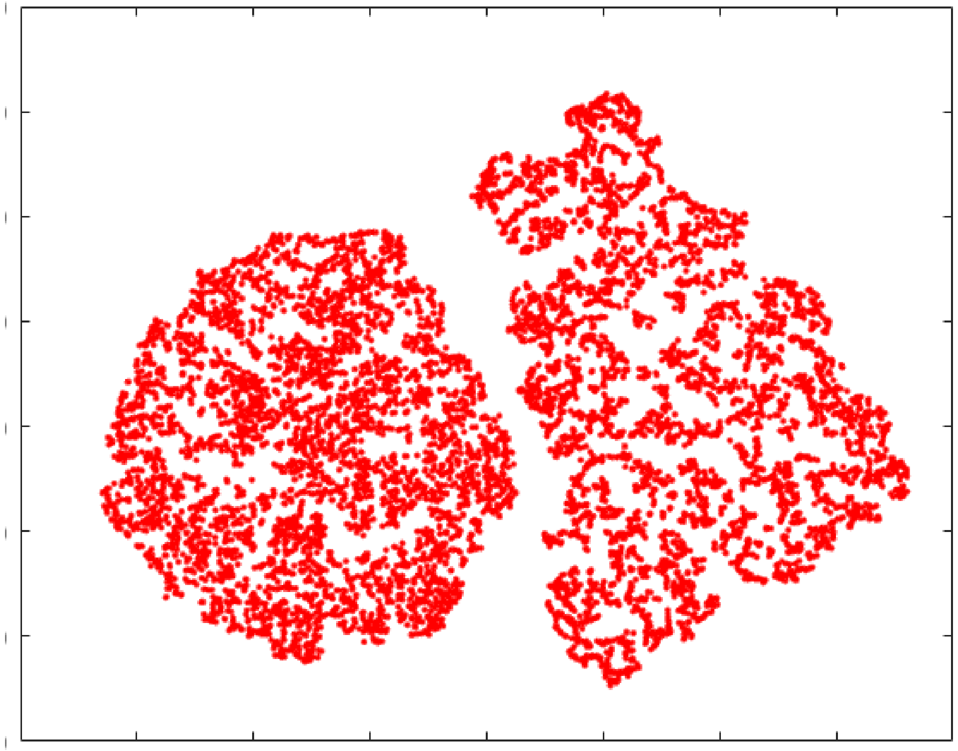
t-SNE = t-distributed Stochastic Neighbor Embedding [1]

Popular dimensionality reduction technique used in ML to visualize points in high-dimensional spaces.

[1] van der Maaten, Hinton, *Journal of Machine Learning Research*, vol. 9, Nov 2008, pp. 2579–2605

An insight into noise using t-SNE

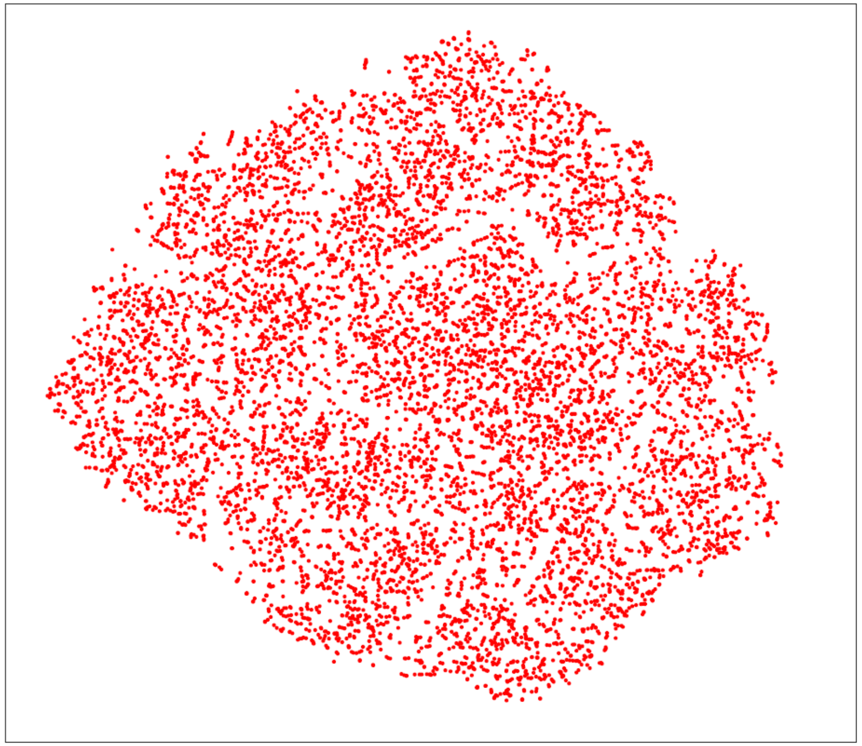
Example: disconnected regions in SU(4) space.



t-SNE tries to preserve the geometry of the data in the high dimensional space.

An insight into noise using t-SNE

We can use the same technique to visualize the space of SU(4) that realizes QMC.



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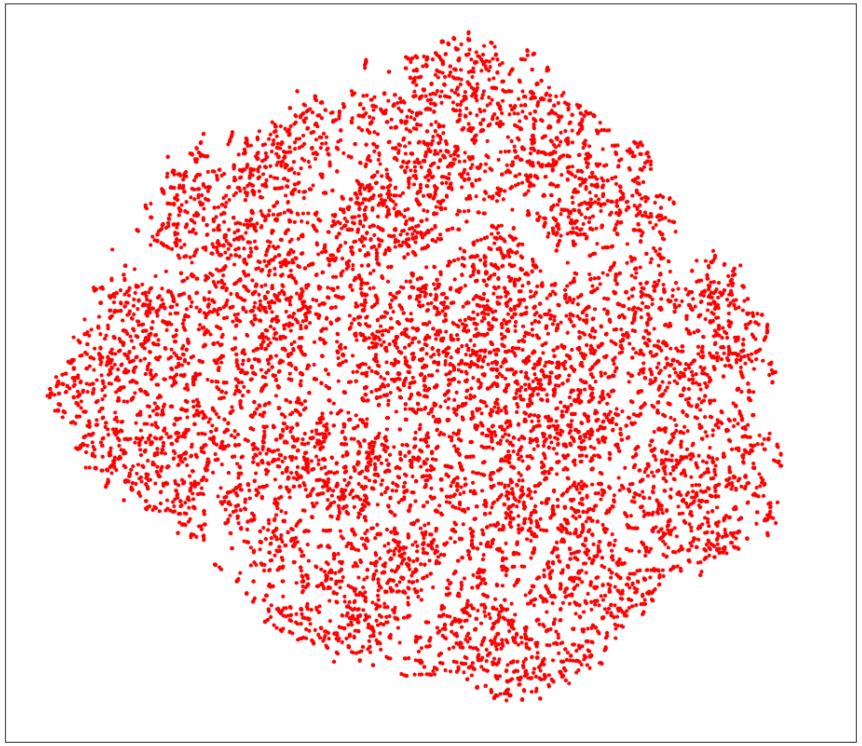

~~Proof~~ Hint that the subspace of QMC is connected thus is robust to perturbations/noise.

Thanks to…

Andrea Solfanelli (POSTER!)

Michele Campisi

Paola Verrucchi

Alessandro Cuccoli

qtif.weebly.com

www.qdab.org

Summary

- Theoretical formulation of a cooling engine based on quantum measurements.
- Proposal for an experimental realization.
- Works for a non negligible volume of SU(4) space.
- It is robust to noise.