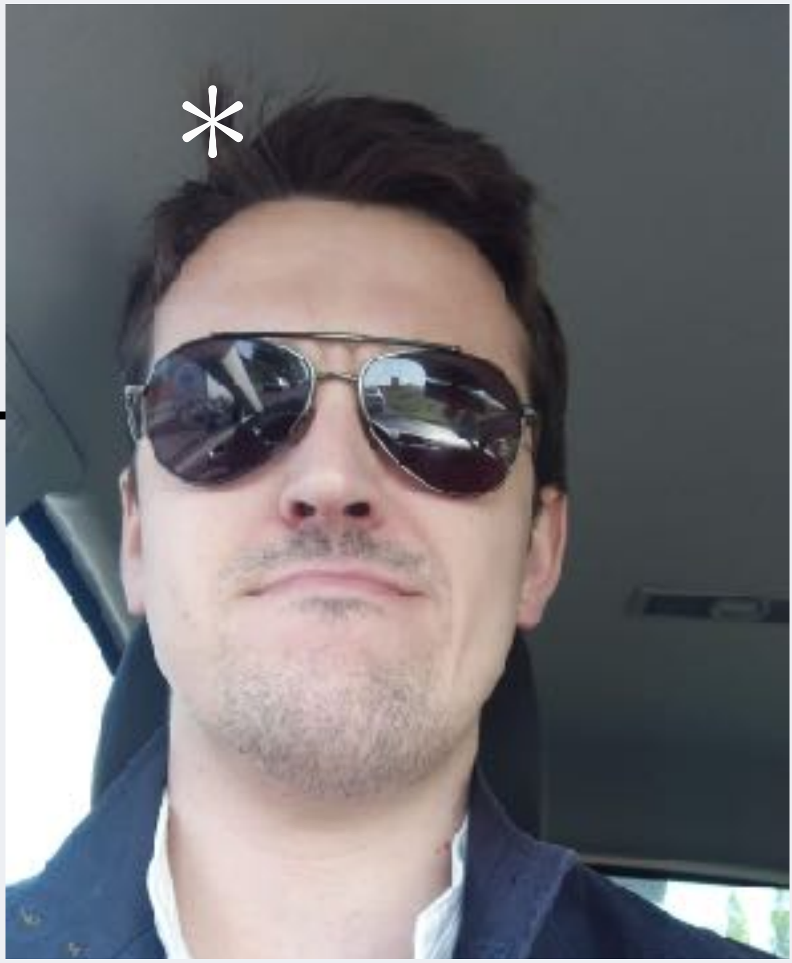
QTEQ
QUANTUM TECHNOLOGY at QUEEN'S

A self-contained quantum harmonic engine



- *Dr Brendan Reid*- QTEQ, Queen's University Belfast*
- *Dr Simon Pigeon - Laboratoire Kastler Brossel, Université Pierre et Marie Curie, Paris*
- *Dr Mauro Antezza - Laboratoire Charles Coulomb, Université de Montpellier*
- *Dr Gabriele De Chiara - QTEQ, Queen's University Belfast*

Aims of the talk

Project in a nutshell:

Using three quantum harmonic oscillators, we aim to realise an Otto cycle

Project in a slightly bigger nutshell:

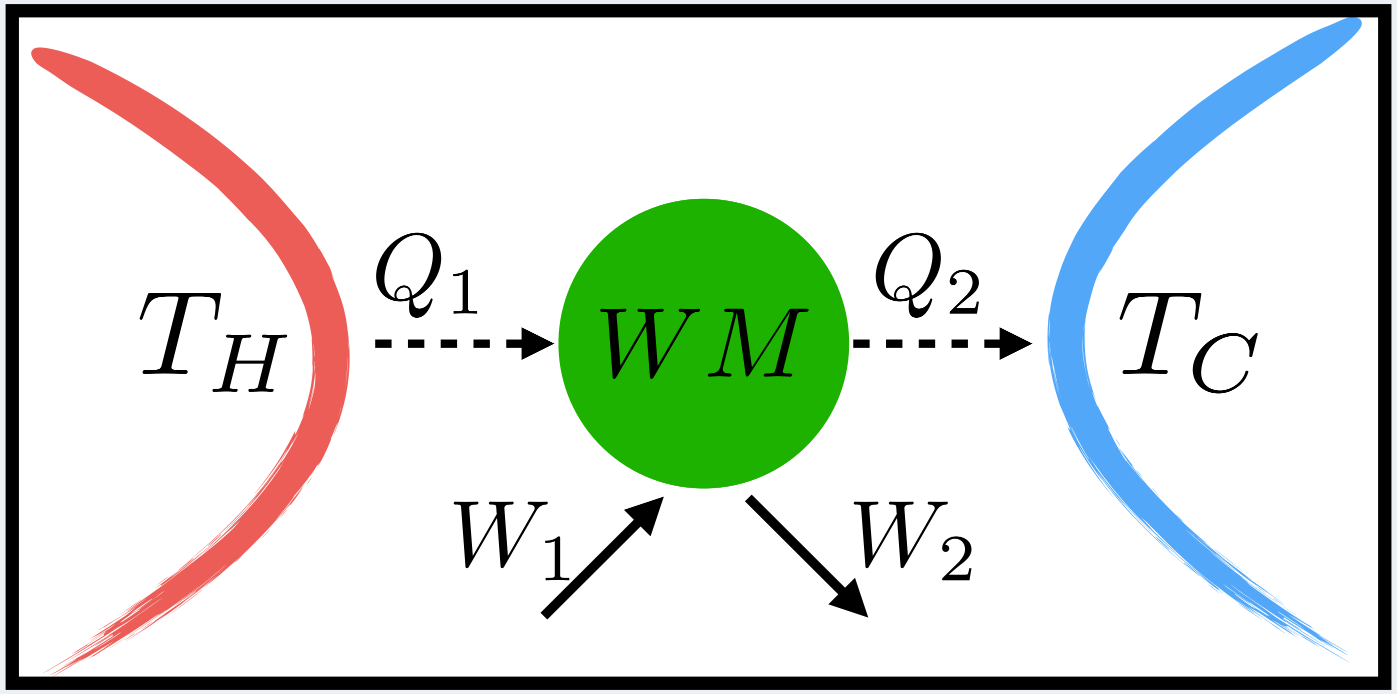
Can we replicate a thermodynamic engine (i.e. extract work) from a quantum system consisting of only three QHO?

Okay, fine, but why?

Quantum thermodynamics is a study of how the laws of thermodynamics apply at the microscopic quantum level

Up until recently quantum engines were studied **exclusively** with infinitely sized reservoirs

Dephasing and dissipation destroyed quantum coherences!



The state of the thermal reservoirs is assumed constant for all t — however the WM state necessarily changes.

Okay, fine, but why? cont.

Technological implications—work extraction in a localised region of space.

Finitely sized system evolves unitarily—no Markovian approximation!

Built-in protection for non-classical features: any entanglement or discord will remain

Can we find a connection between engine performance and non-classical features?

Quantum heat engine literature (is extensive)

- Kosloff & Rezek, NJP **8**, 86 (2006) - *harmonic oscillators*.
- Friedenberger & Lutz, arXiv:1508.04128 (2015) - *trapped ions*
- Nori et al, PRE **76**, 031105 (2007) - *qubits*.
- Skrzypczyk et al, PRL **105**, 130401 (2010) - *qubits*.
- Singer et al, Science **352**, 6283 - *trapped ions*
- Matsukevich et al, arXiv:1702.08672 - *trapped ions*

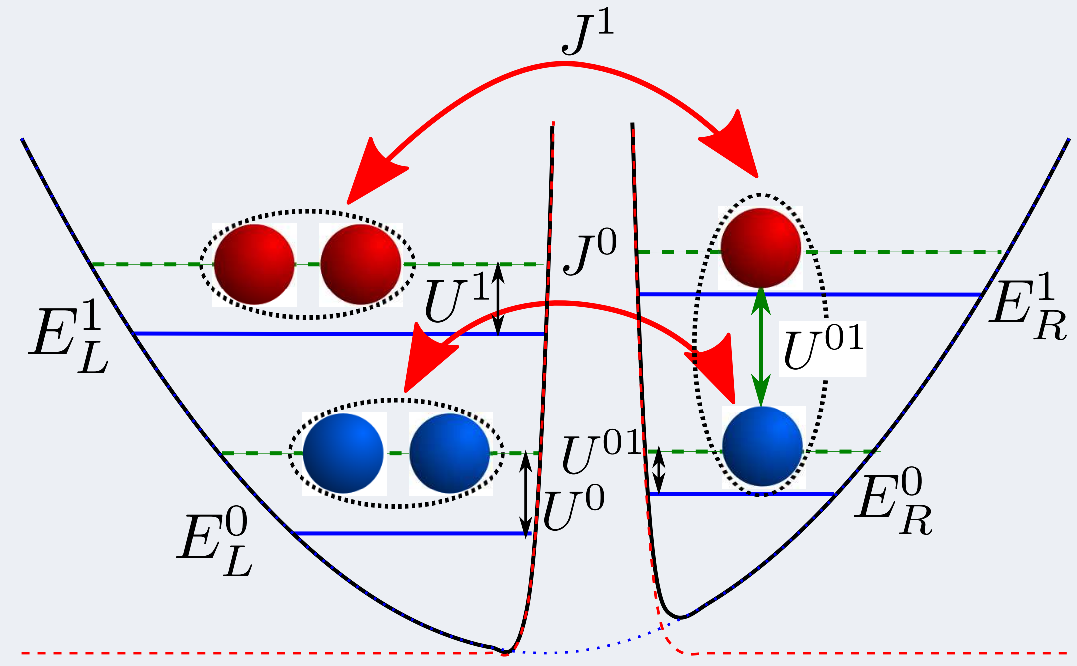
All of these papers use infinitely sized baths

Papers exploring engines with finite baths

Fialko & Hallwood: PRL **108**, 085303 2012

"First demonstration of a heat engine with finite heat baths"

…however there is no discussion on thermodynamic quantities!



Uzdin et al.: arXiv:1610.02671

Small number of spins acting as a bath for an engine spin — artificially induced dephasing

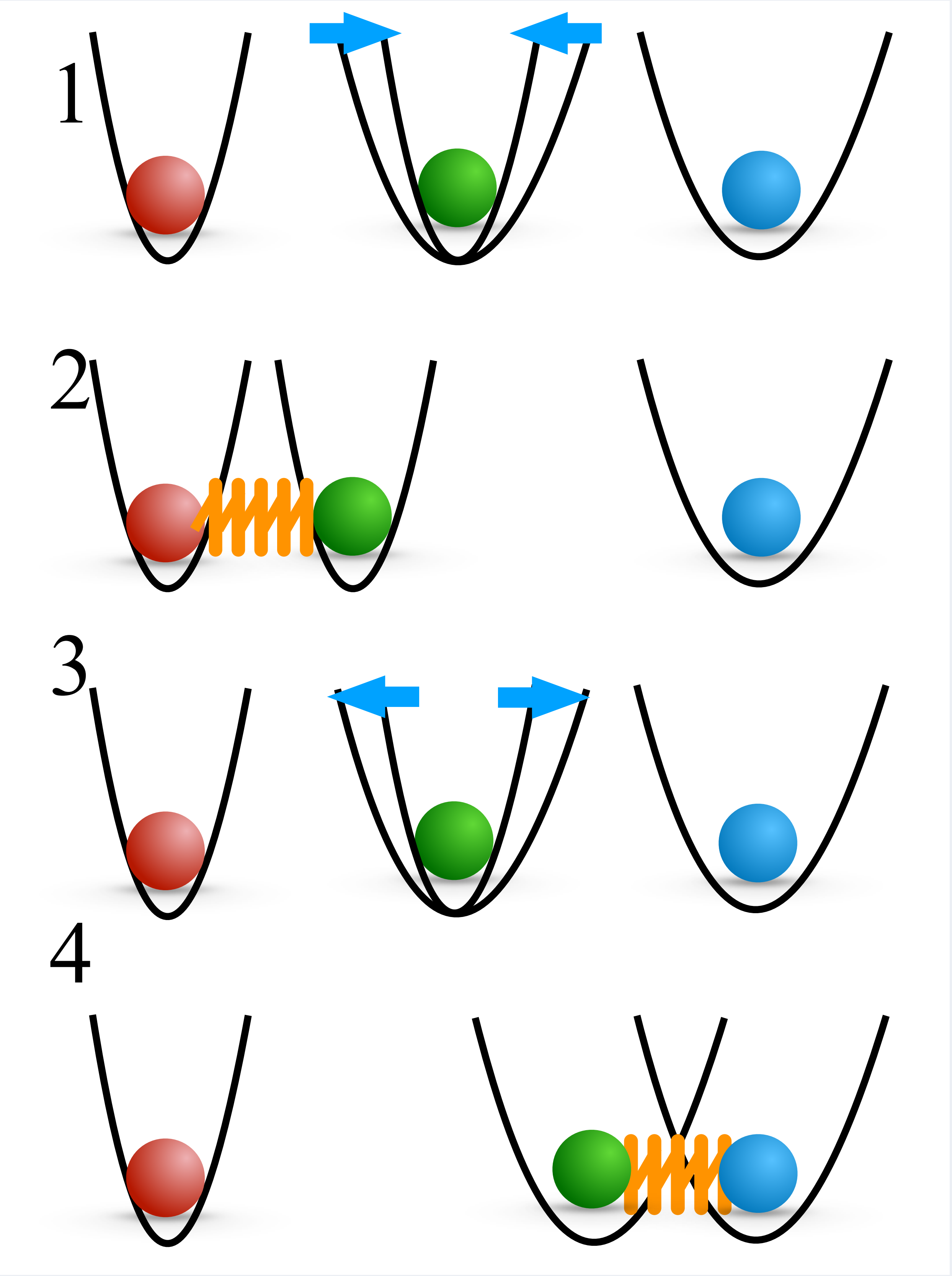
Aspects of finite bath engines not discussed; solely aiming to simulate Markovian dynamics

Our setup

Three oscillators: hot bath, working medium, cold bath

Otto cycle:

1. *Compression*
2. *Heating*
3. *Expansion*
4. *Cooling*



Necessary but boring details

$$H_i = m\omega_i^2 x_i^2 + p_i^2/m$$

$$H_{ij} = \alpha_{ij}\left(a_i a_j^\dagger + a_i^\dagger a_j\right)$$ ***(Heating, cooling strokes)***

If two oscillators are resonant…

$$\omega_i = \omega_j = \omega \rightarrow [H_i + H_j, H_{ij}] = 0$$

(compression/expansion strokes)

$$\omega_2(\omega_i, \omega_f) = \sqrt{\omega_i^2 + (\omega_f^2 - \omega_i^2)t/\tau_R}$$

Parameter Count:

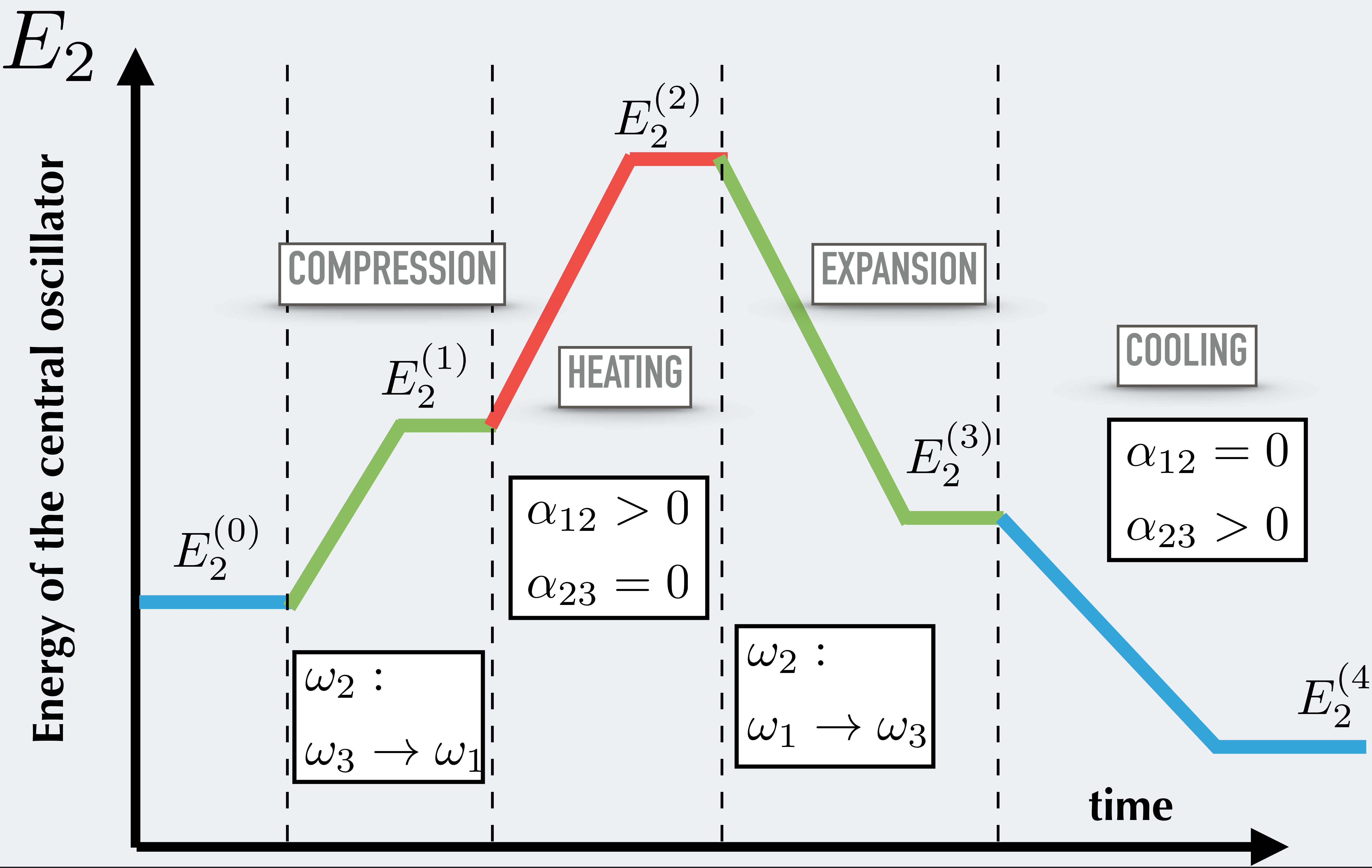
~~ω_1~~ ~~ω_2~~ ω_3

α_{12} α_{23}

τ_H τ_C

τ_R

The Otto cycle in oscillators



More details

Ordered operator basis $R = \{x_1, x_2, x_3, p_1, p_2, p_3\}$

Covariance matrix $\sigma_{ij} = \frac{1}{2}\langle R_i R_j + R_j R_i \rangle - \langle R_i \rangle \langle R_j \rangle$

Lyapunov Equation $\dot{\sigma}(t) = A\sigma(t) + \sigma(t)A$

$$A = \Omega H$$

Covariance matrix is the matrix of your unknowns - if you know it, you know everything!

More details

How are we measuring work?

$$\mathcal{W} = \mathrm{Tr}\left[H\left\{\sigma[n\tau] - \sigma[(n-1)\tau]\right\}\right]$$

Work defined on a per cycle basis as the energy of the system decreases every cycle

The baths are 'finite'…no thermalisation! As a result every cycle is different!

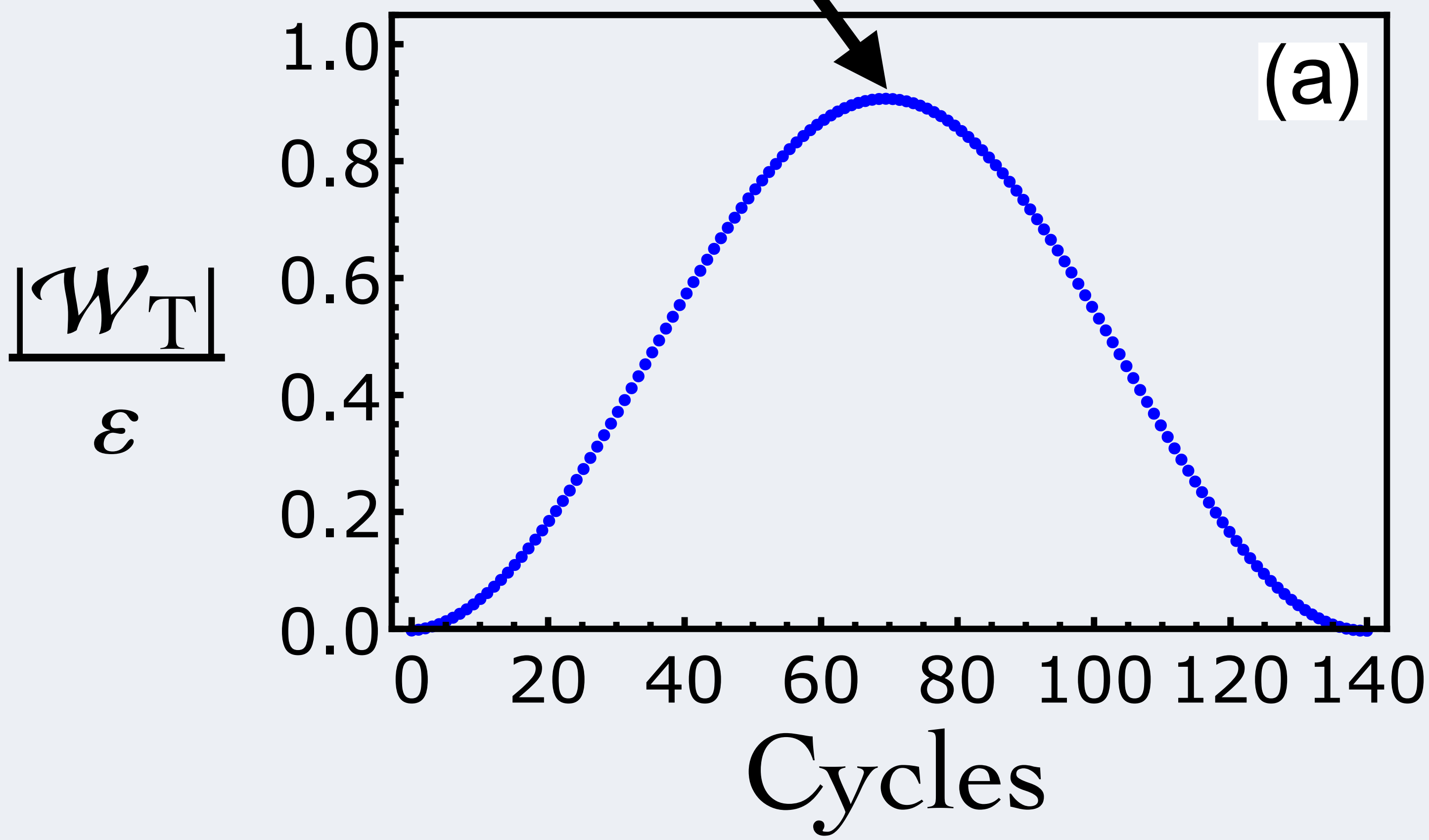
Thermal states **v** ***Squeezed states***

$$\bigotimes_{i=1}^{3} \frac{\exp\left(-\beta_i H_i\right)}{Z_i}$$

$$\bigotimes_{i=1} S(r_i)\left|0\right\rangle\left\langle 0\right| S^{\dagger}(r_i)$$

Engine stops here

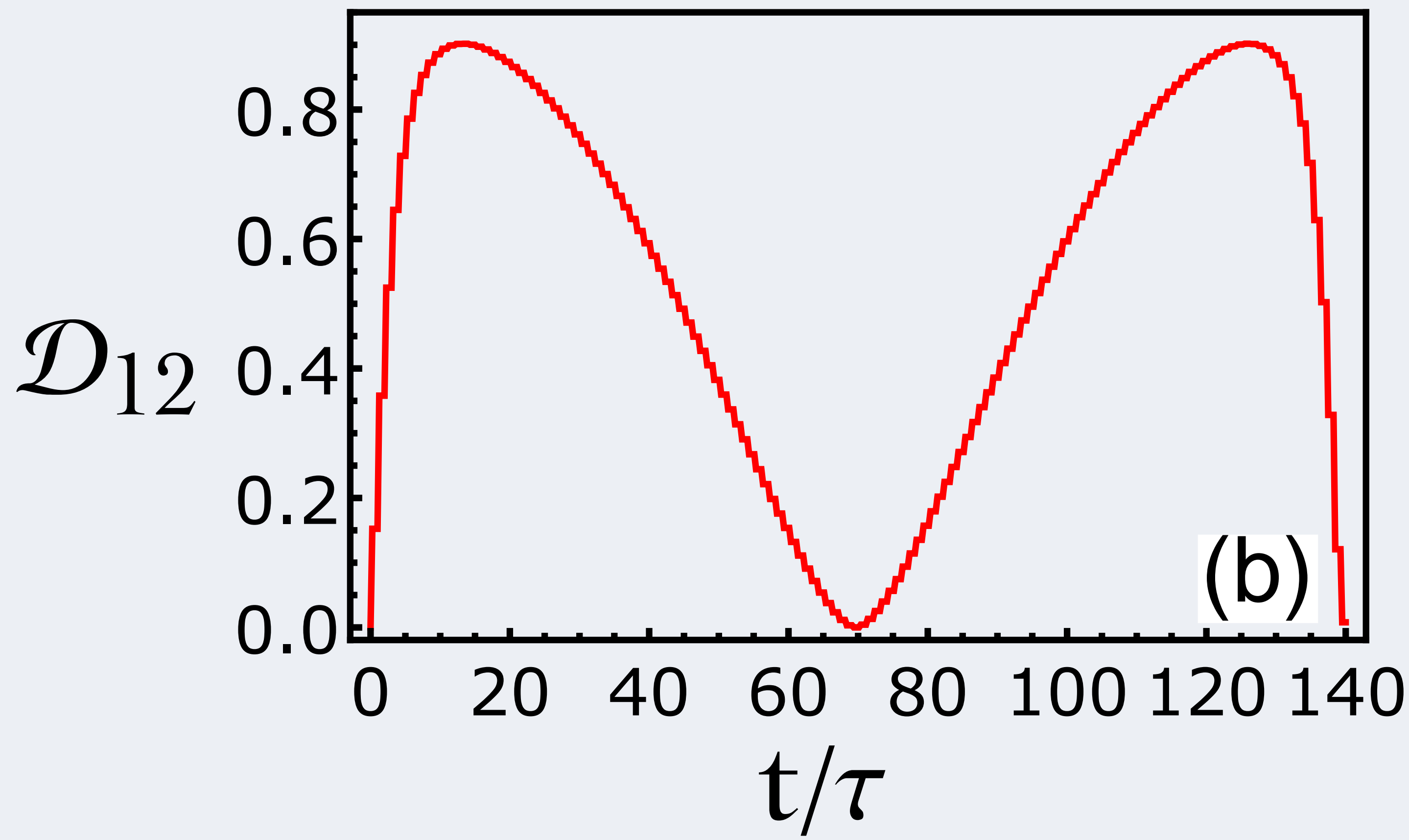
$\omega_3 = 0.1\omega_1 \qquad \beta_{2,3} \to \infty$



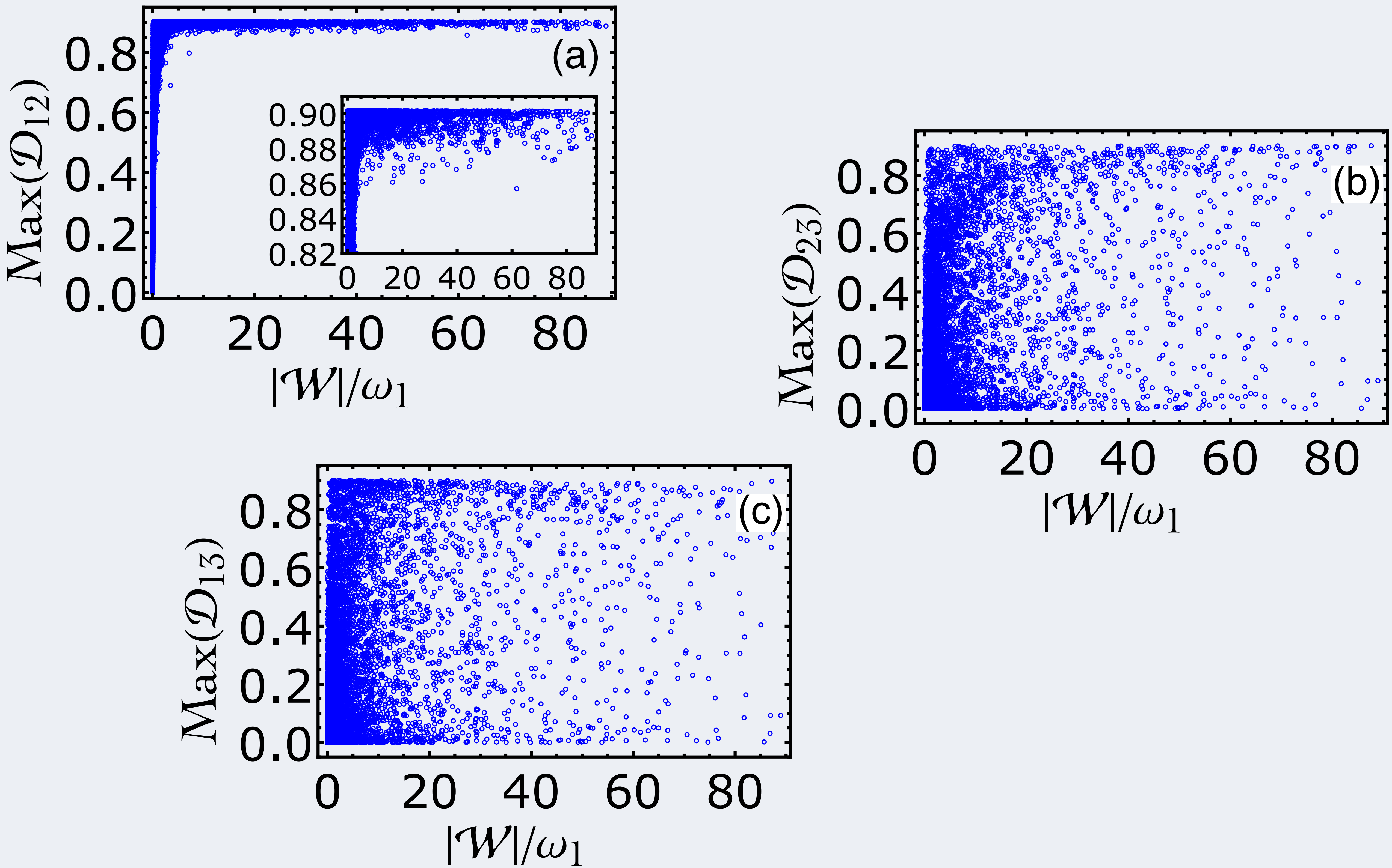
Ergotropy is the maximum extractable work

No entanglement for thermal states!

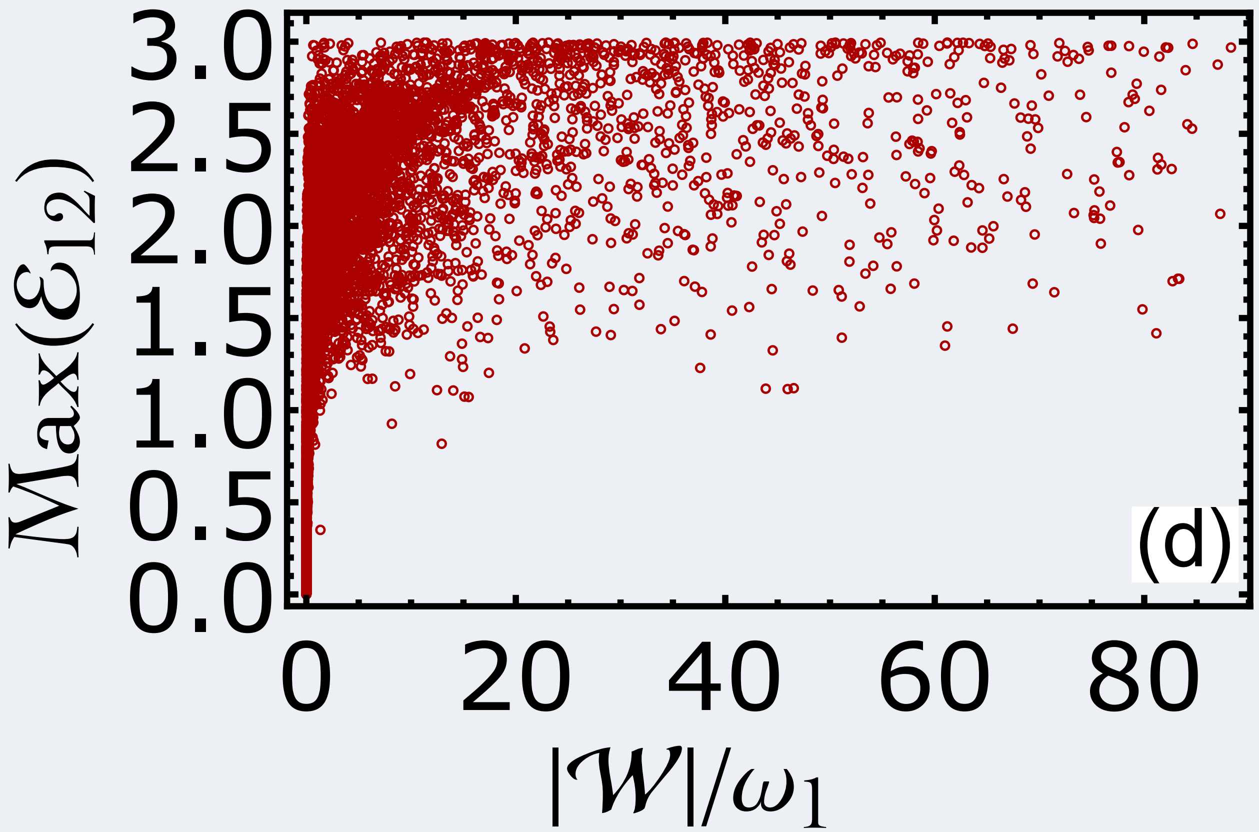
Only non-zero discord is between oscillators 1 and 2

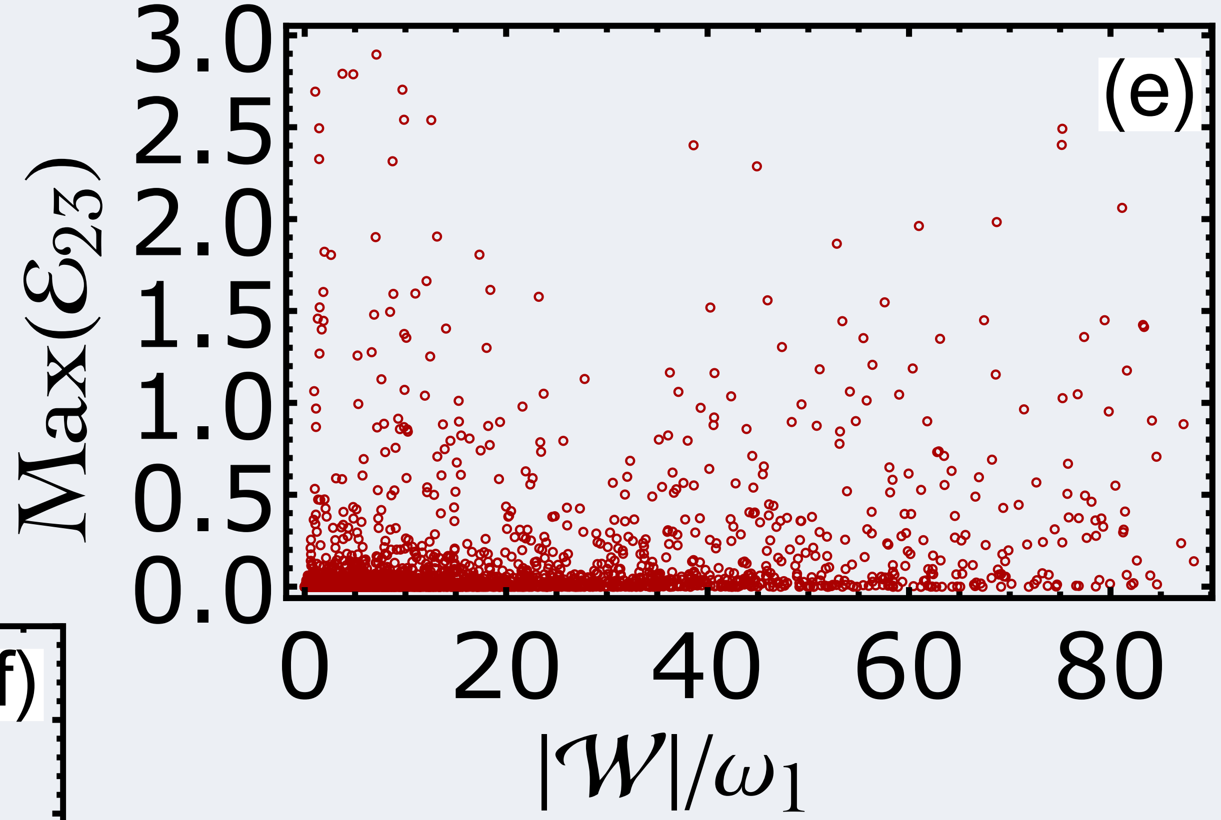


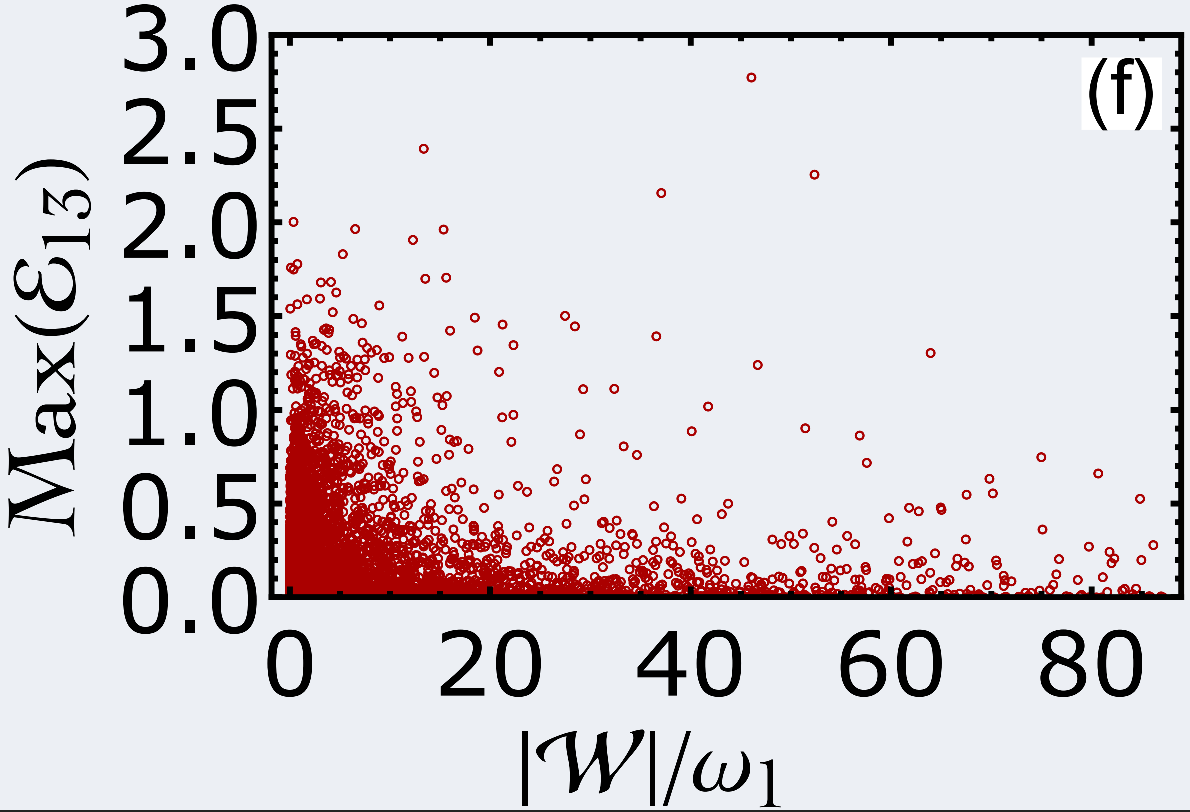
Thermal states — randomised variables



Squeezed states —random variables







Natural extension: bigger baths!

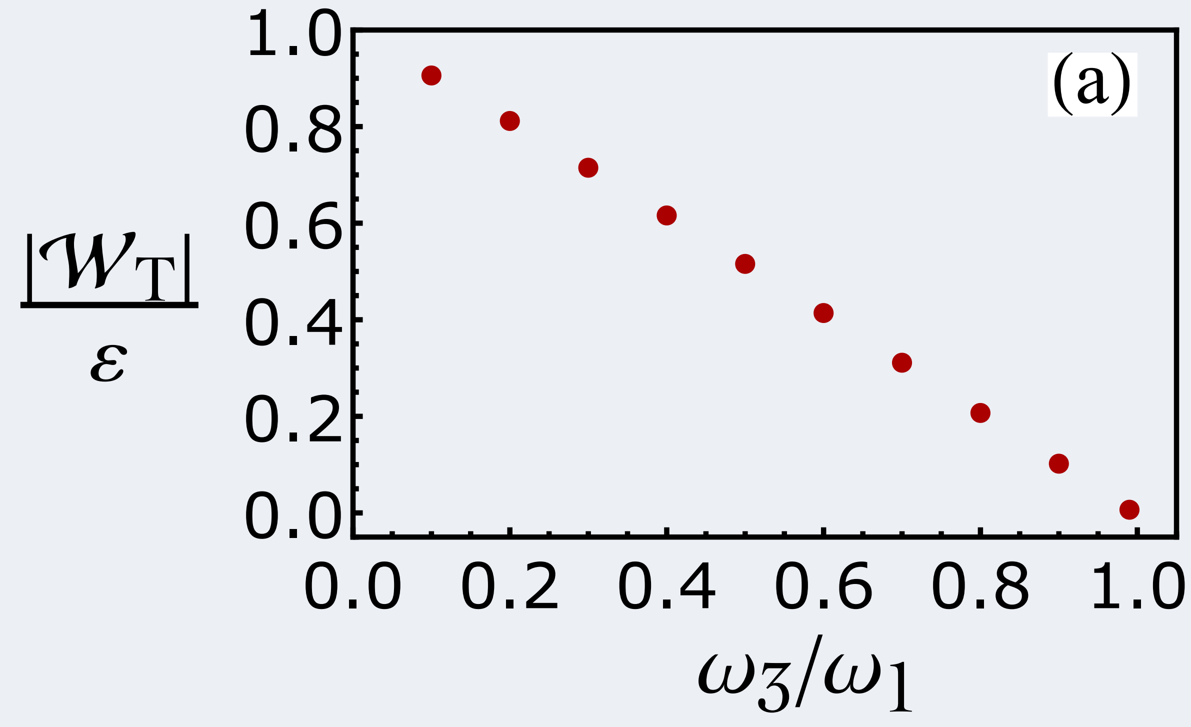
Pozas-Kerstjens et al. NJP **20** 043034

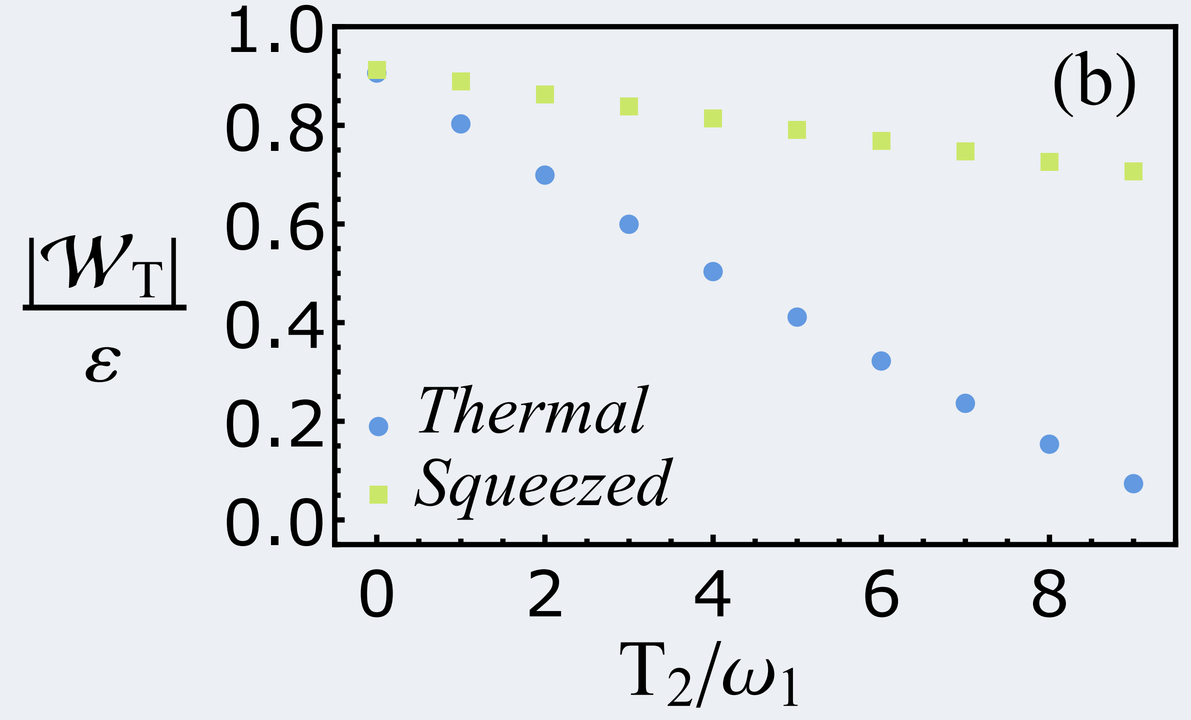
Large but finite baths allow for emulation of infinite baths

To mention:

Third oscillator kind of useless — not necessary for work extraction!!!

Other results





Optimised, maximum work extraction

Two Italians and a Frenchman walk into a bar

Gabriele De Chiara
Queen's University Belfast

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Brossel (Paris)

Mauro Antezza
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