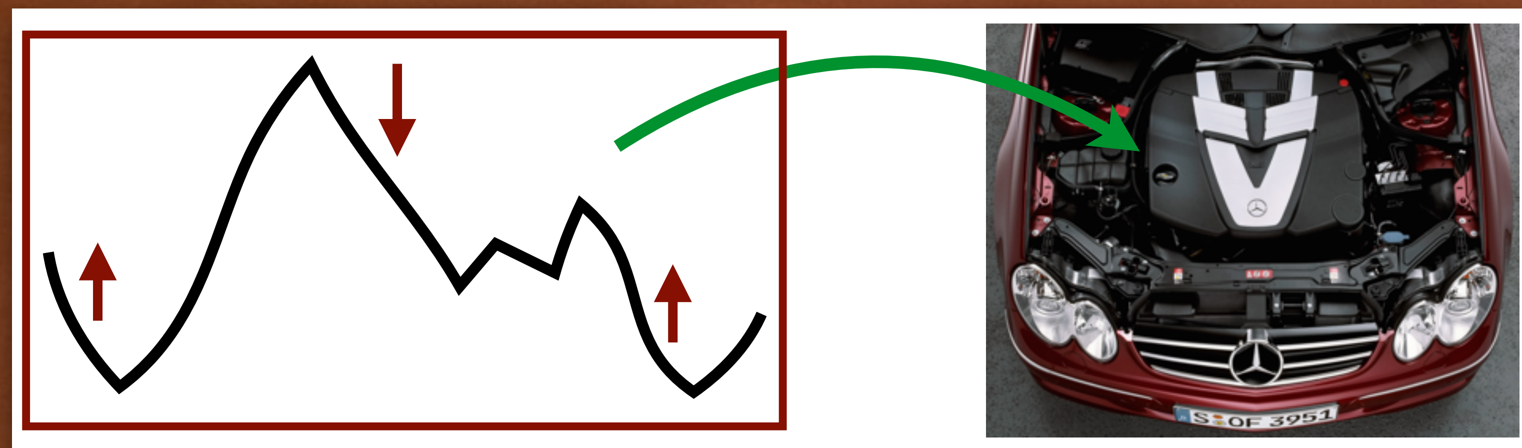
MBL-MOBILE: MANY-BODY-LOCALIZED ENGINE



Nicole Yunger Halpern

Caltech, Institute for Quantum Information & Matter

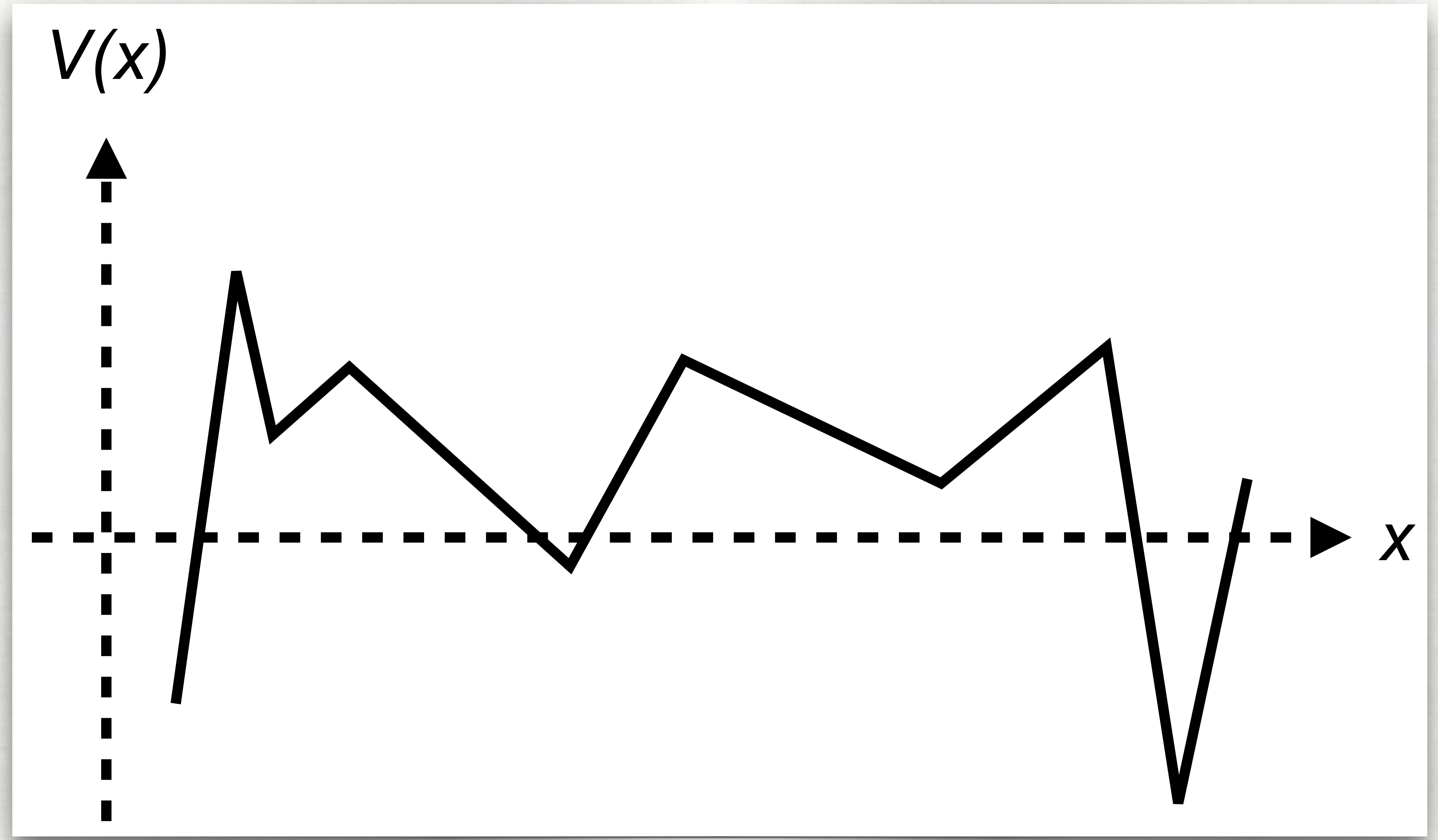
arXiv:1707.07008

With C.D. White, S. Gopalakrishnan, and G. Refael

KITP "Quantum Thermodynamics" conference; June 2018

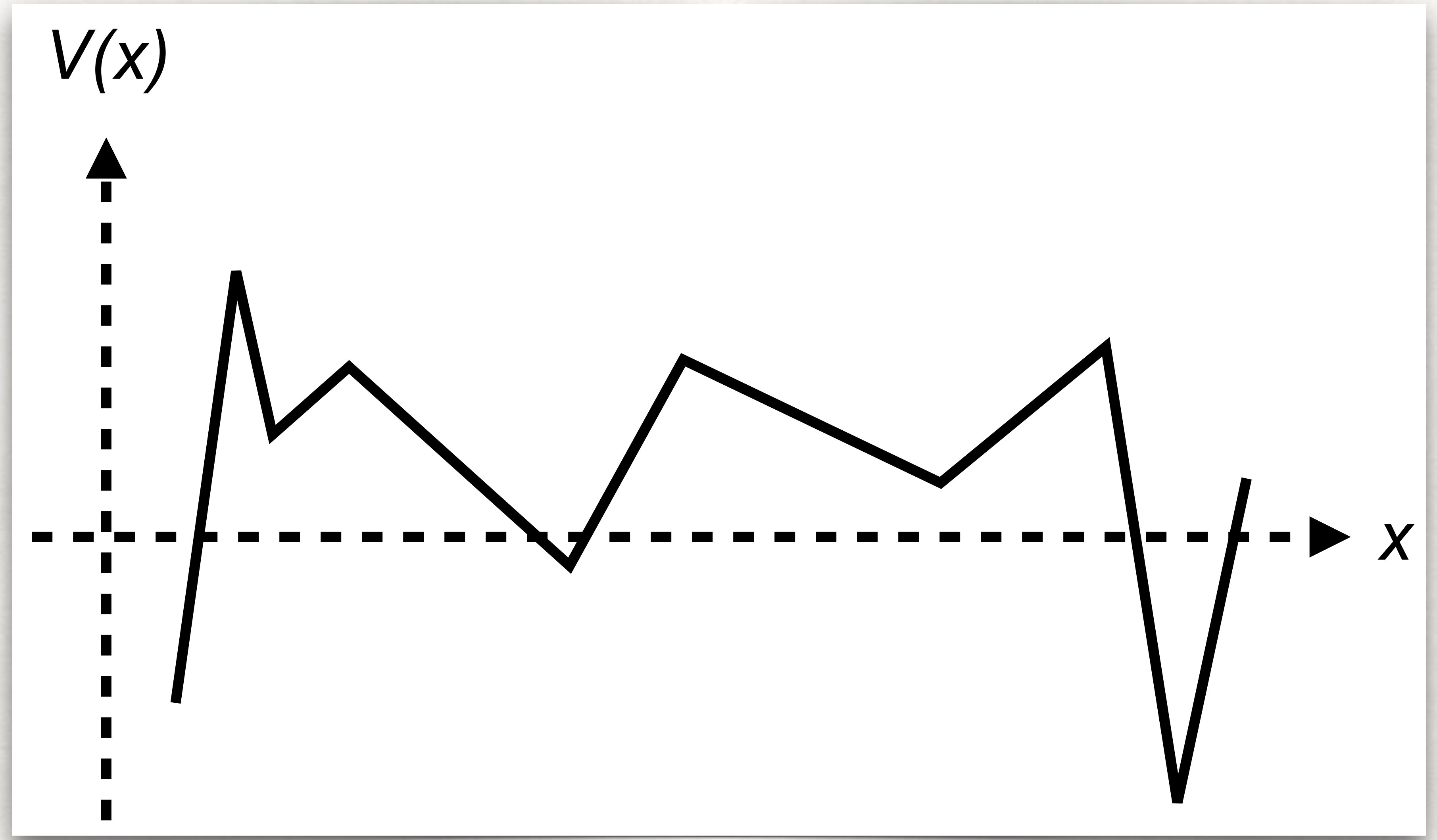
Caltech

Crap



Crap

(AKA random disorder potential)



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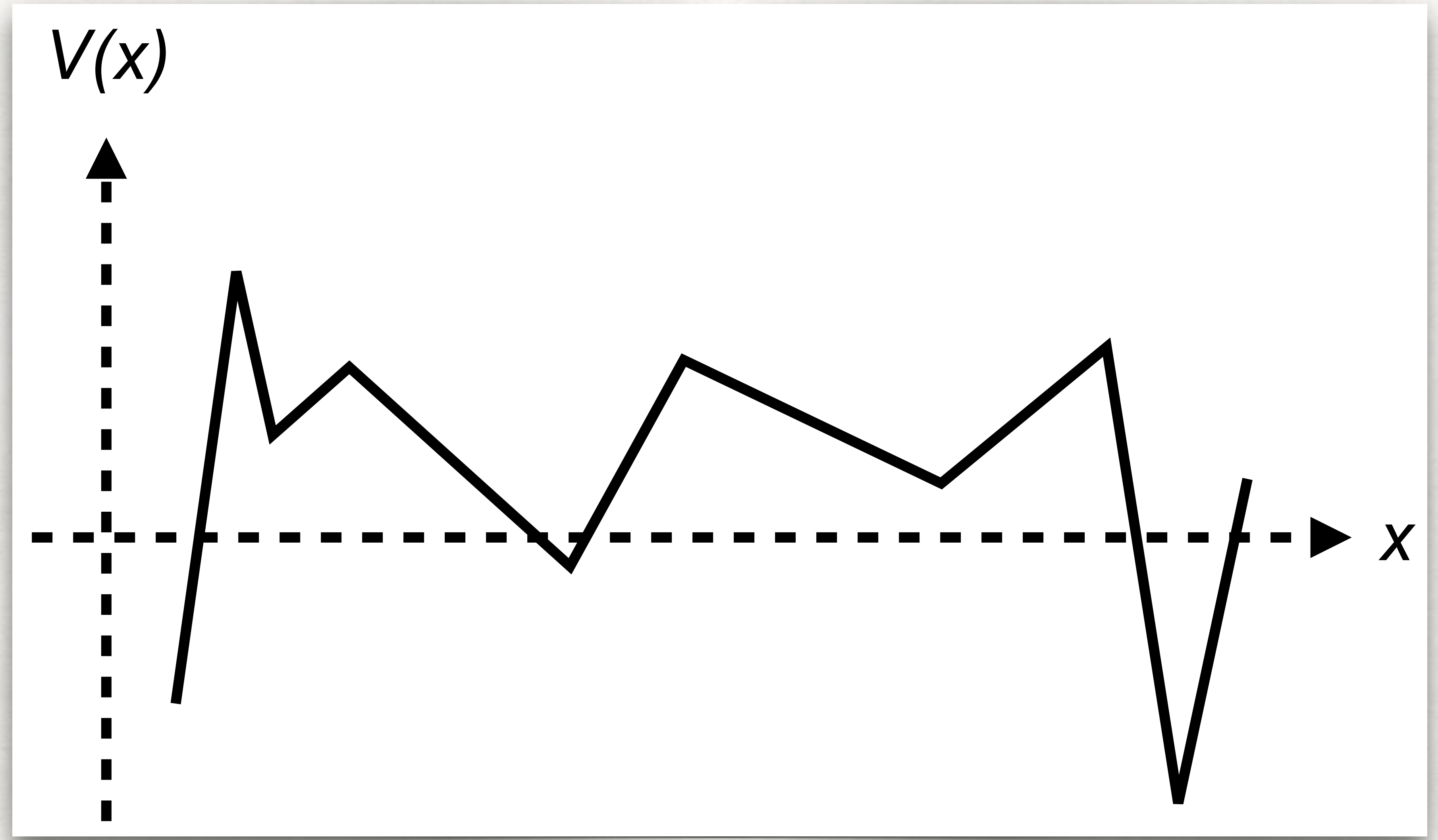

Random crap + interactions

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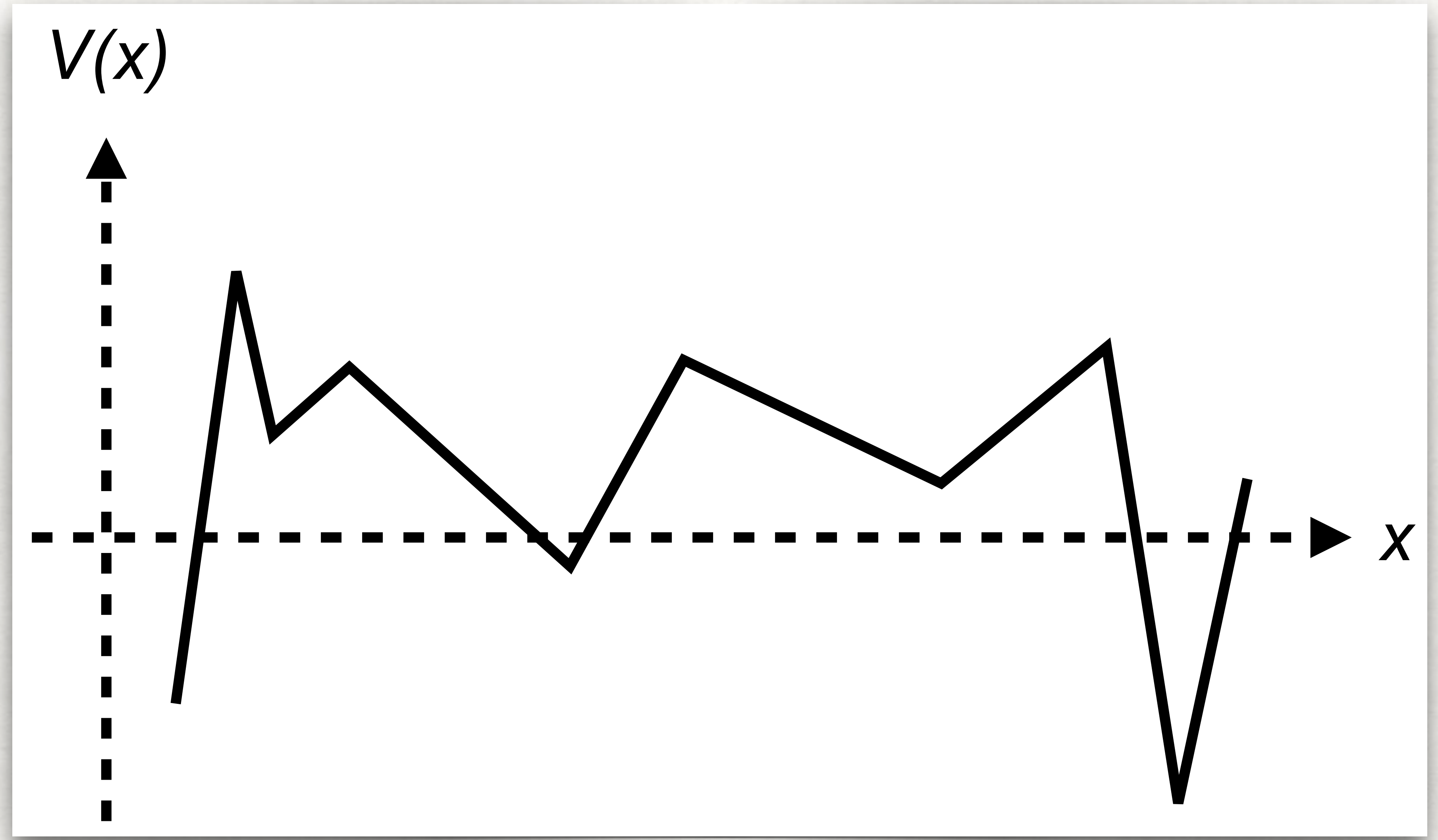

Random crap + interactions → phase of quantum many-body systems:

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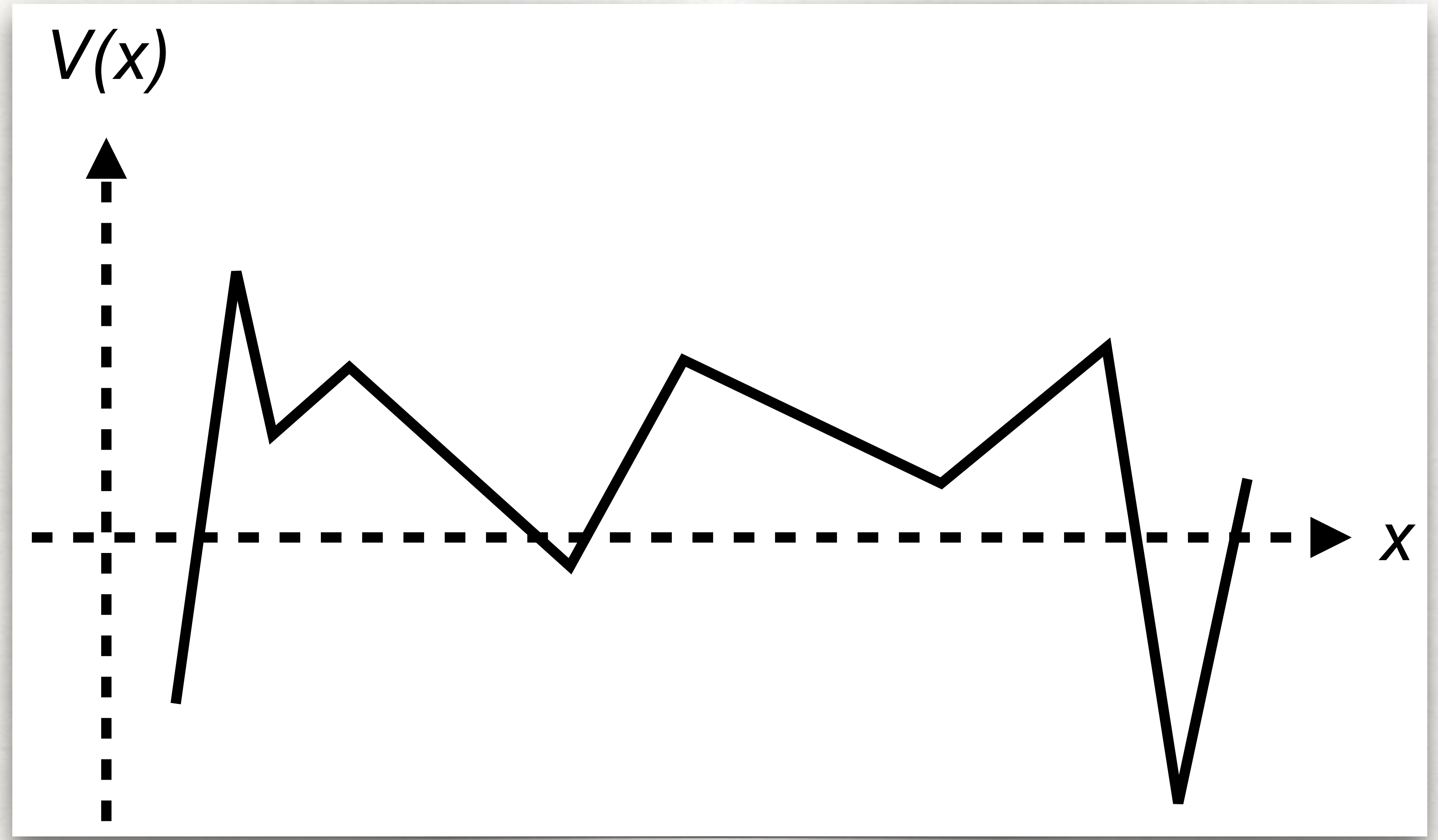

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Many-body localization (MBL)

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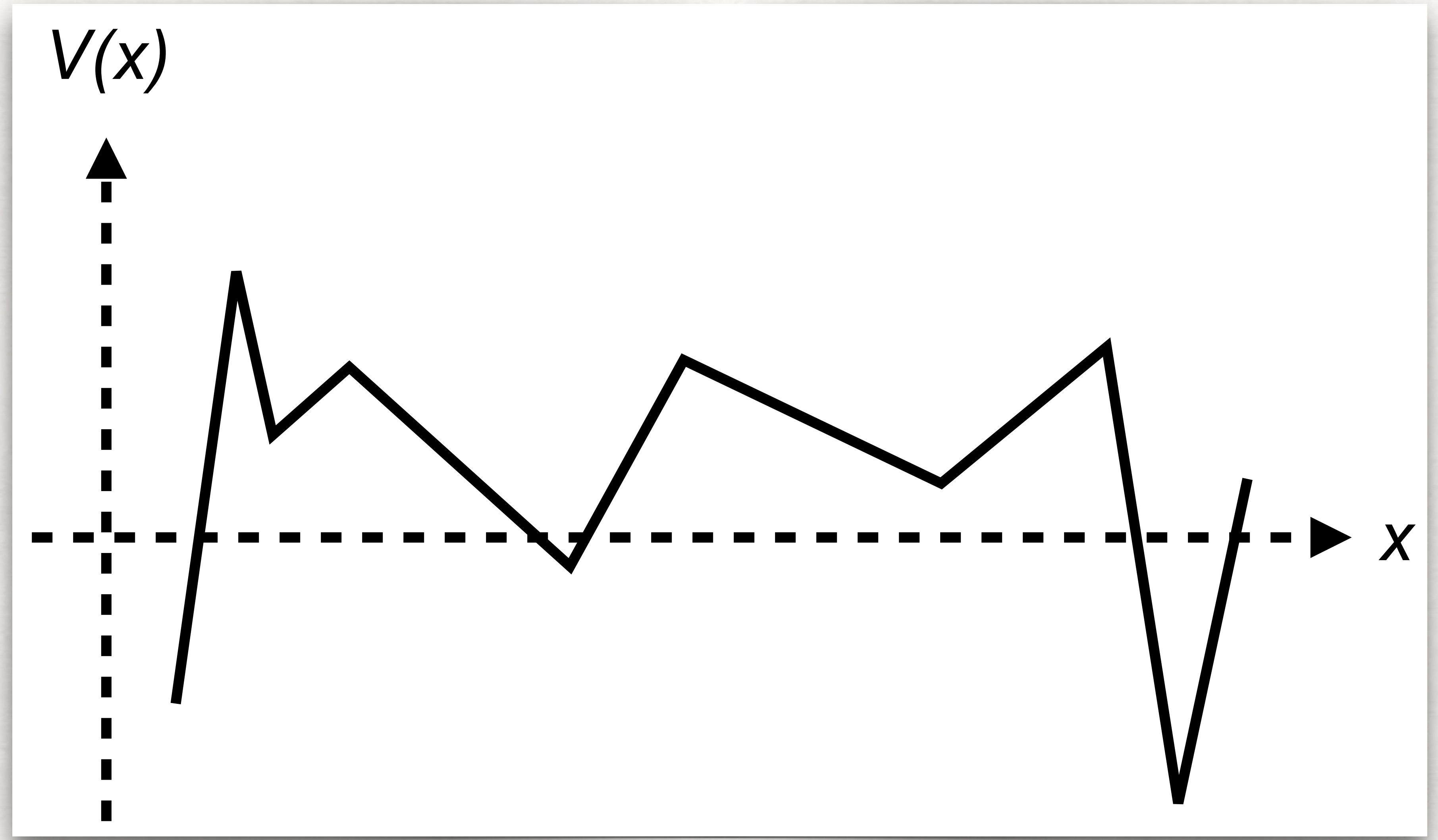

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→ Acts athermally

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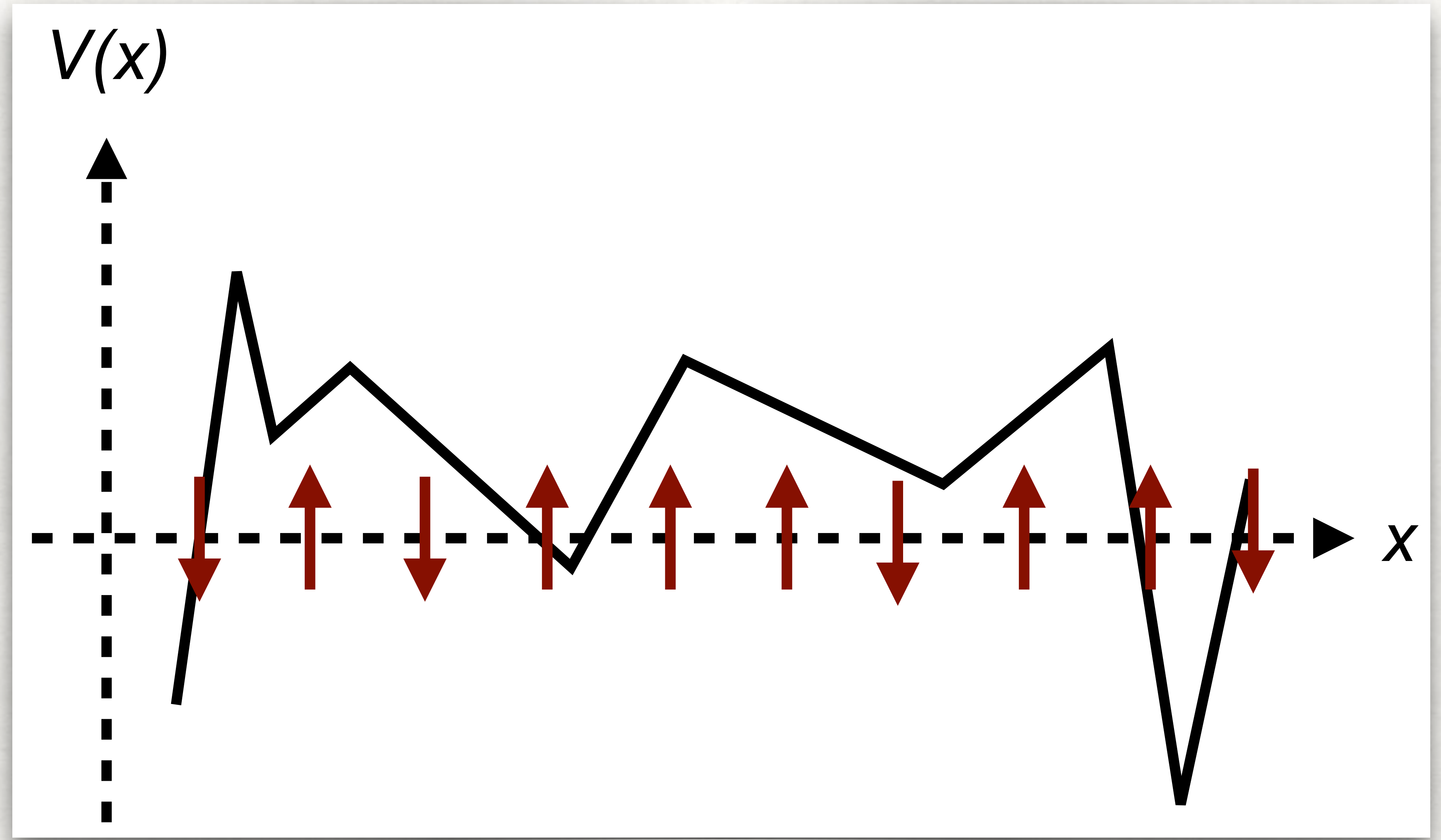

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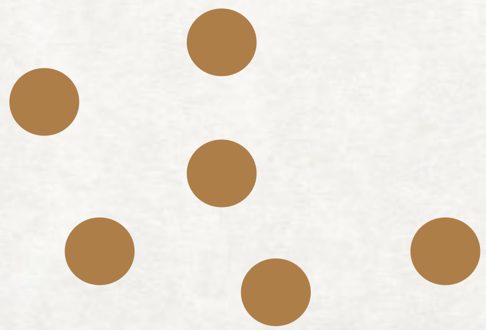
Contrast: thermalizing classical gas



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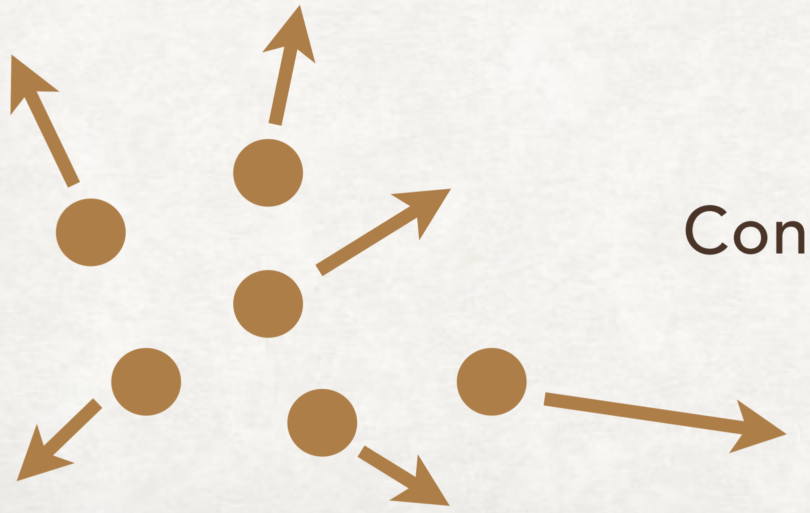
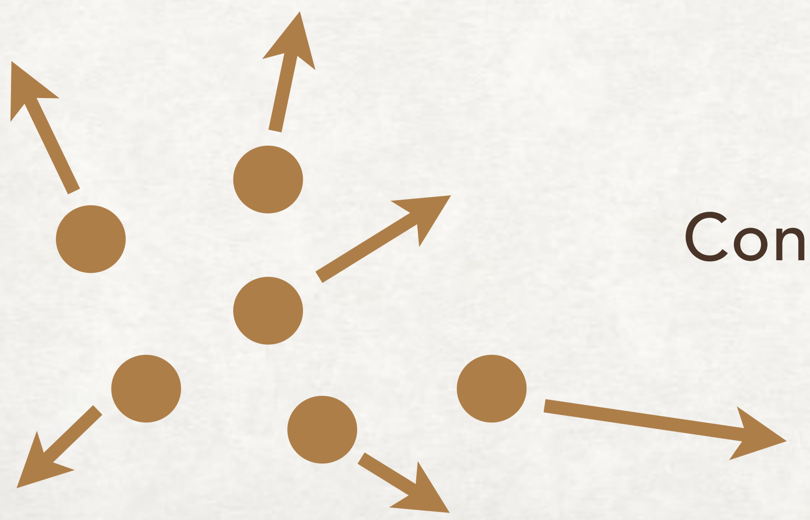


Contrast: thermalizing classical gas

Random crap makes quantum many-body systems behave athermally.



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Many-body localization (MBL)

- Review: Abanin *et al.*, arXiv:1804.11065 (2018).

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But what's it good for?

Athermality as a resource

Athermality as a resource

T_H

Athermality as a resource

T_H

$T_C << T_H$

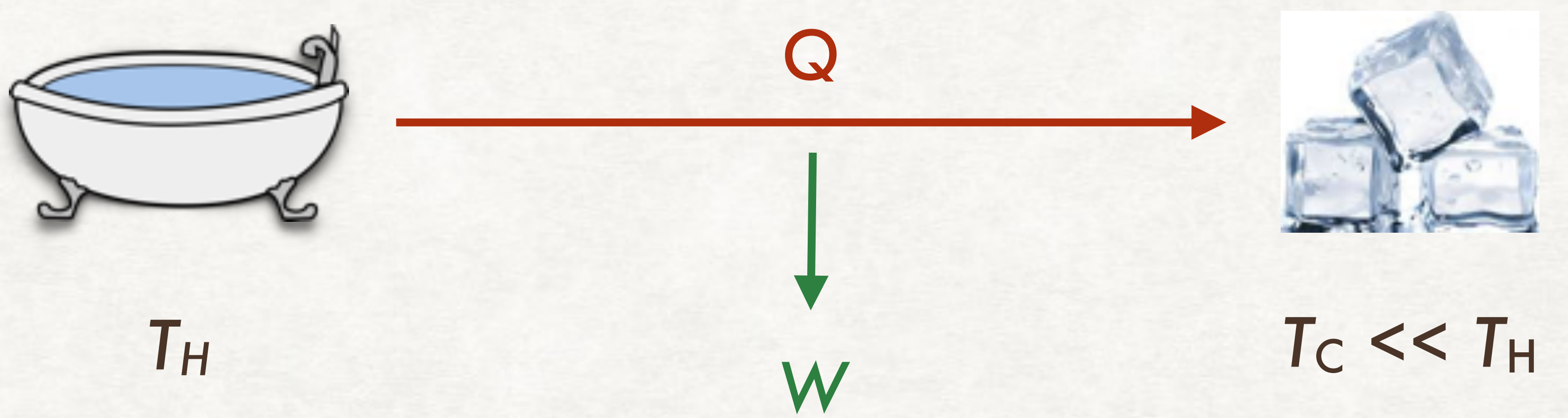
Athermality as a resource

Q →

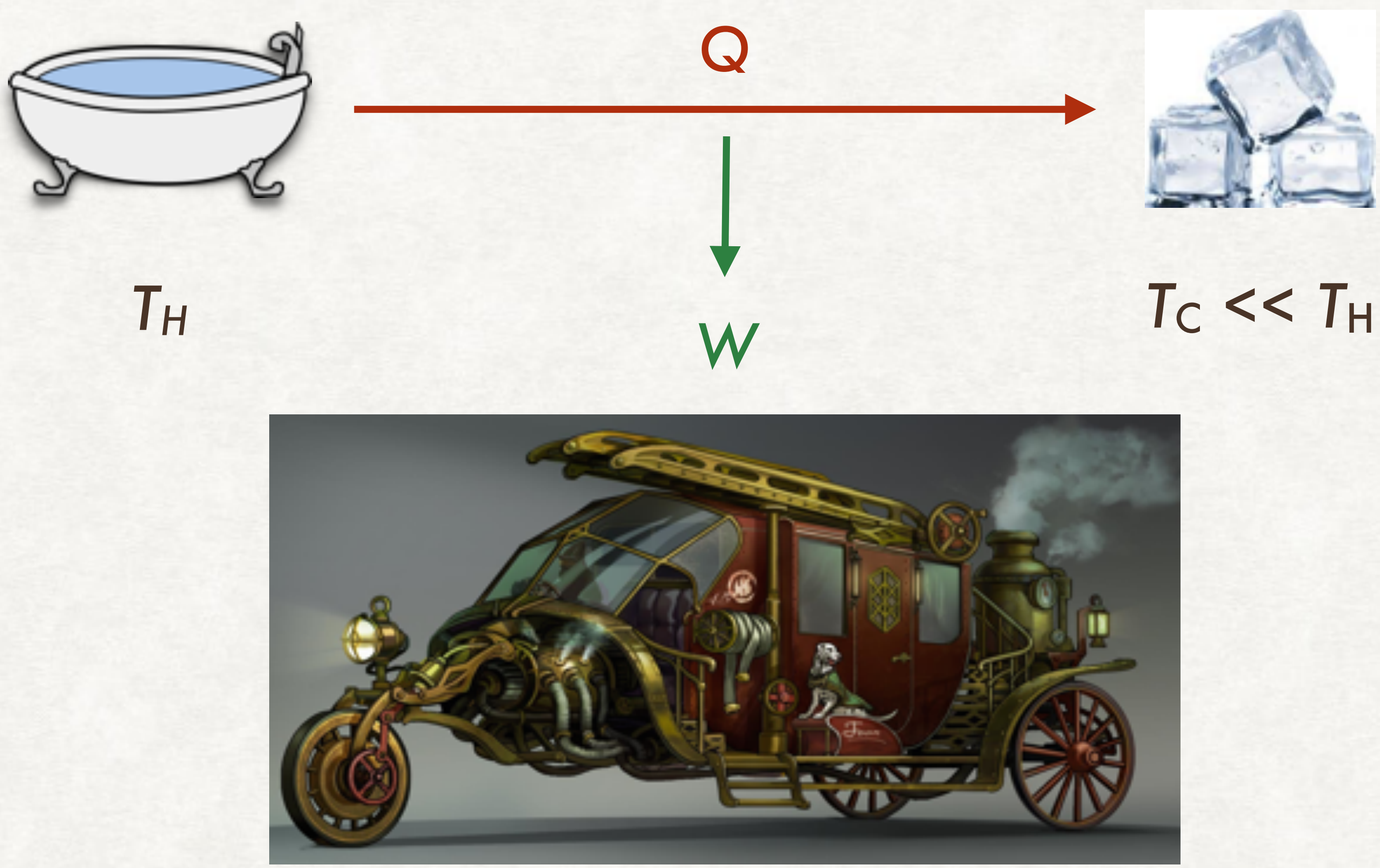
T_H

$T_C << T_H$

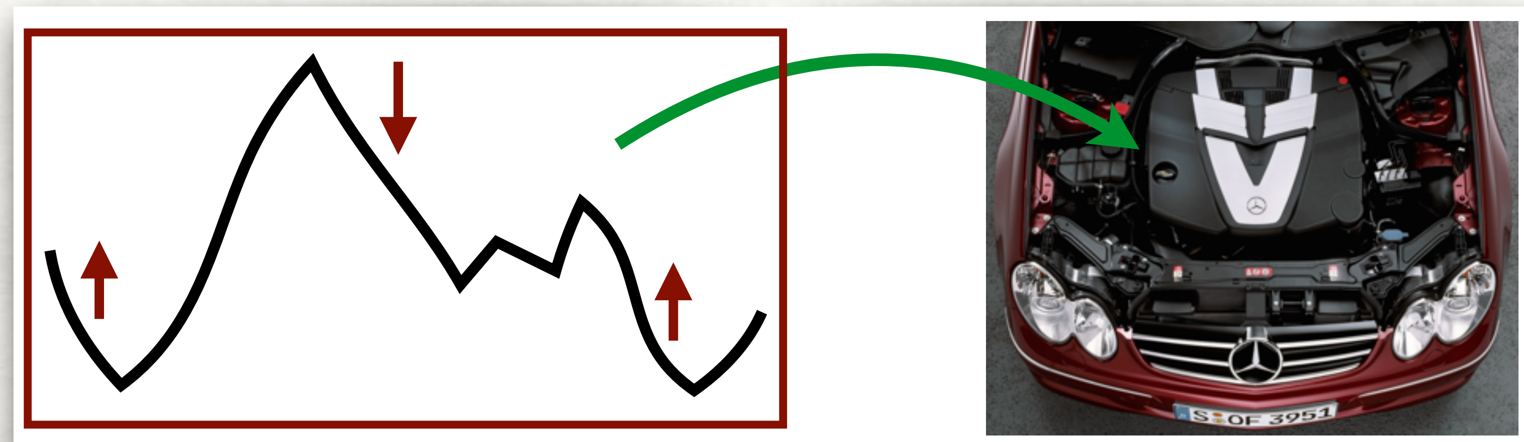
Athermality as a resource



Athermality as a resource



MBL-mobile



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With C.D. White, S. Gopalakrishnan, and G. Refael

Where we're headed

Where we're headed

- Set-up

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- MBL as an "athermal phase"

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- Evaluating performance

Where we're headed

- Set-up
- MBL as an "athermal phase"
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- Evaluating performance
- Opportunities

Set-up

- Qubit chain:

Set-up

- Qubit chain:

- Disordered Heisenberg model

    - $H(\alpha_t)$

Set-up

- Qubit chain: 

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  - $H(\alpha_t)$

  - 

Set-up

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  - $H(\alpha_t)$

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✦ Very localized

Set-up

- Qubit chain: 

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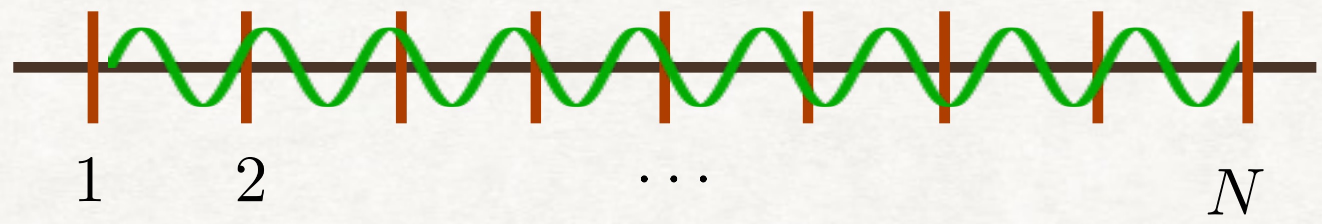
    ✦ "Thermal" ✦ Very localized

Set-up

- Qubit chain: 

- <u>Disordered Heisenberg model</u>

  - $H(\alpha_t) = \sum_{j=1}^{N-1} \sigma_j \cdot \sigma_{j+1}$

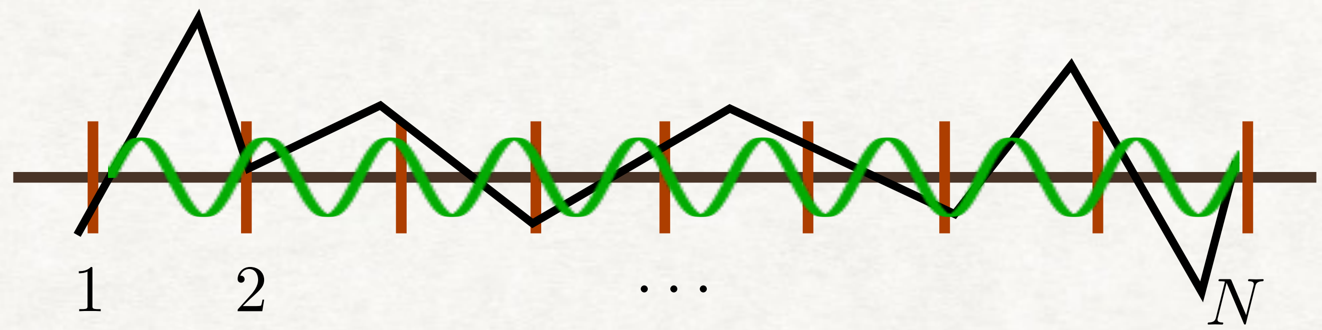
  - 

    $\alpha_t = 0$ $\alpha_t = 1$

    ✦ "Thermal" ✦ Very localized

Set-up

- Qubit chain:



- <u>Disordered Heisenberg model</u>

- $$H(\alpha_t) = \sum_{j=1}^{N-1} \sigma_j \cdot \sigma_{j+1} + h(\alpha_t) \sum_{j=1}^{N} h_j \sigma_j^z$$

- 

  - ✦ "Thermal"
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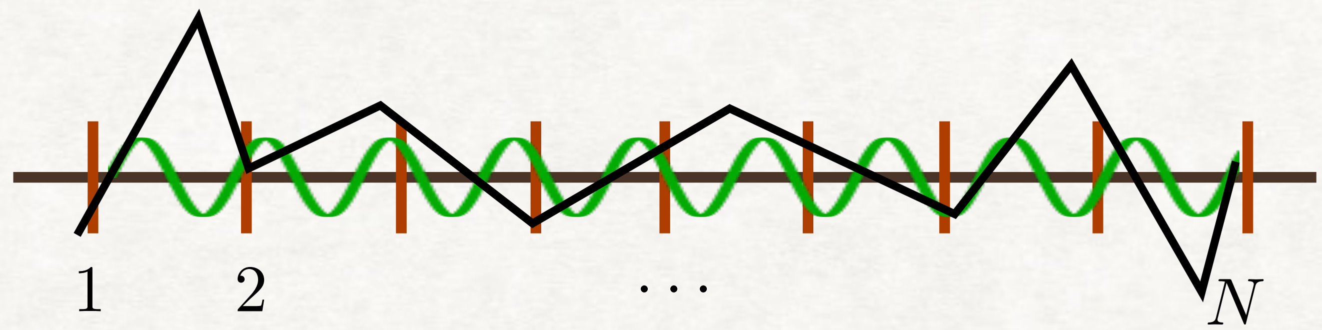
Set-up

- Qubit chain:



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✦ Disorder dominates

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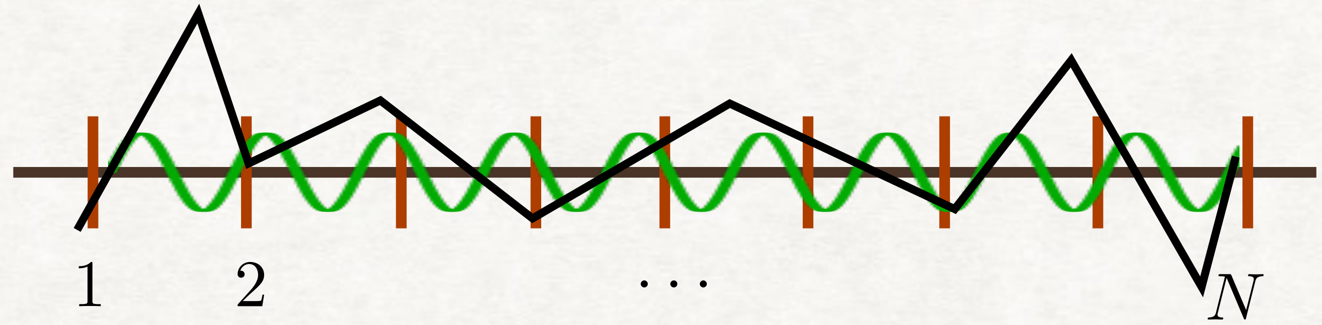
- Qubit chain: 

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    - ✦ Hopping dominates
    - ✦ Very localized
    - ✦ Disorder dominates

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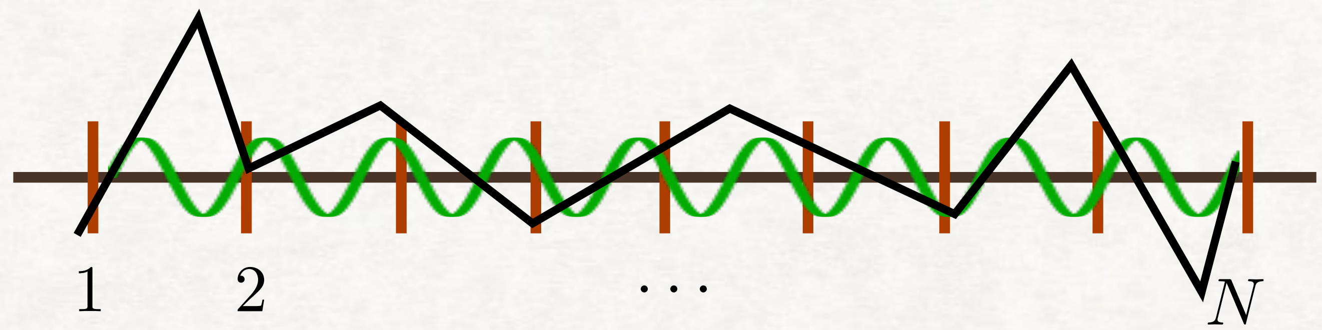

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- 

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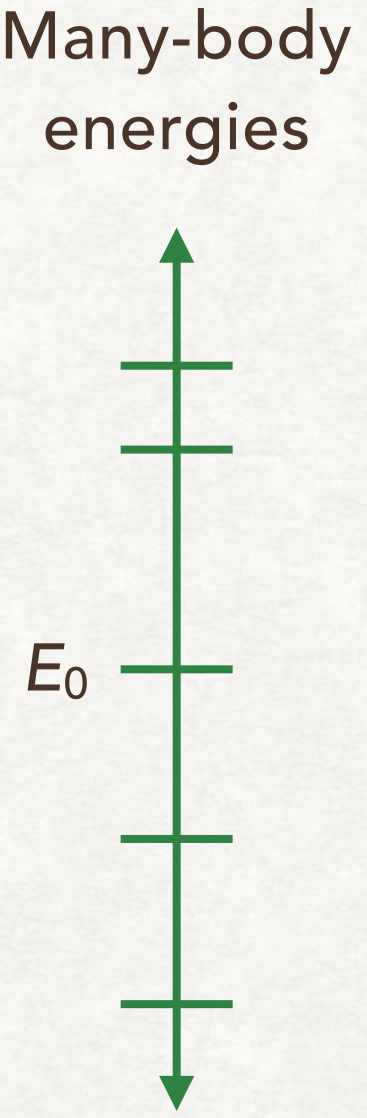
2 regimes

2 regimes



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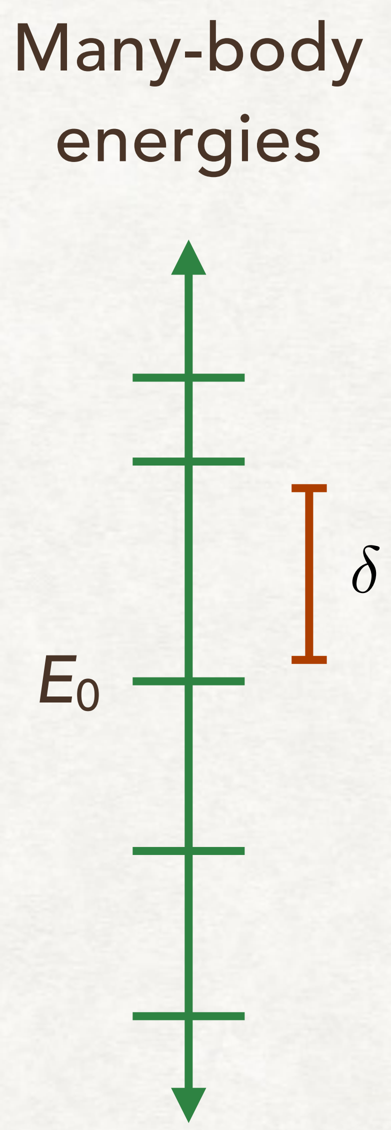
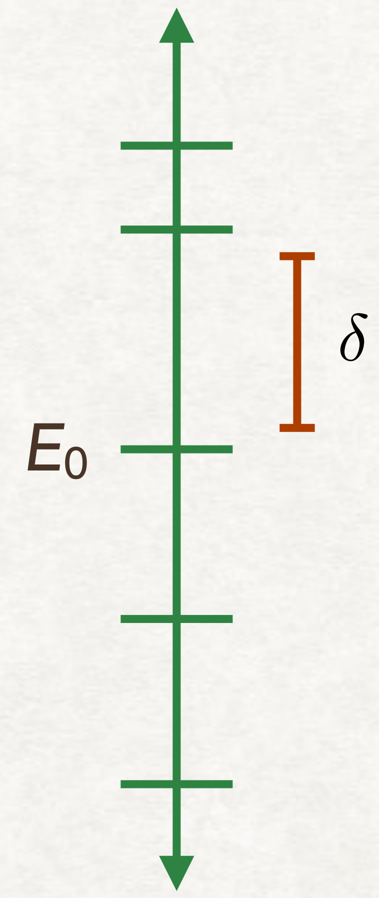


2 regimes

Gap distribution

$P(\delta)$ = probability that any given gap is of size δ

Many-body energies



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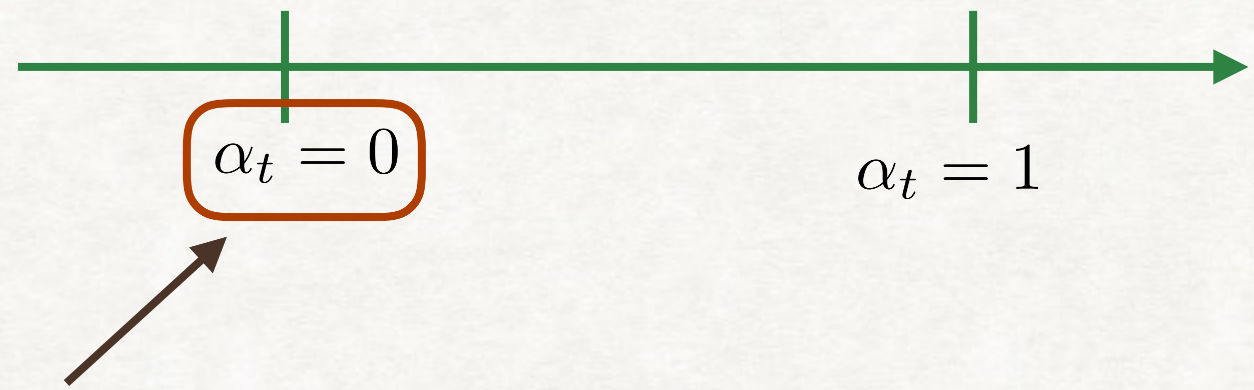

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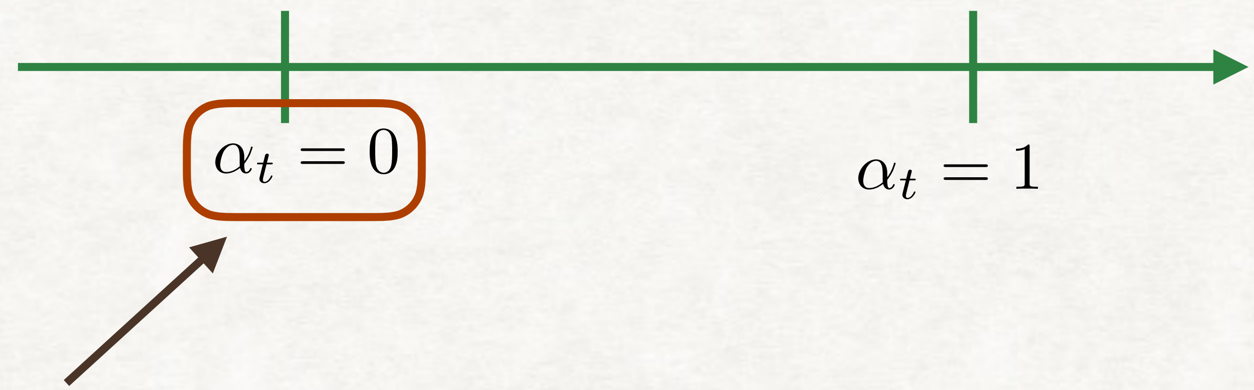
2 regimes



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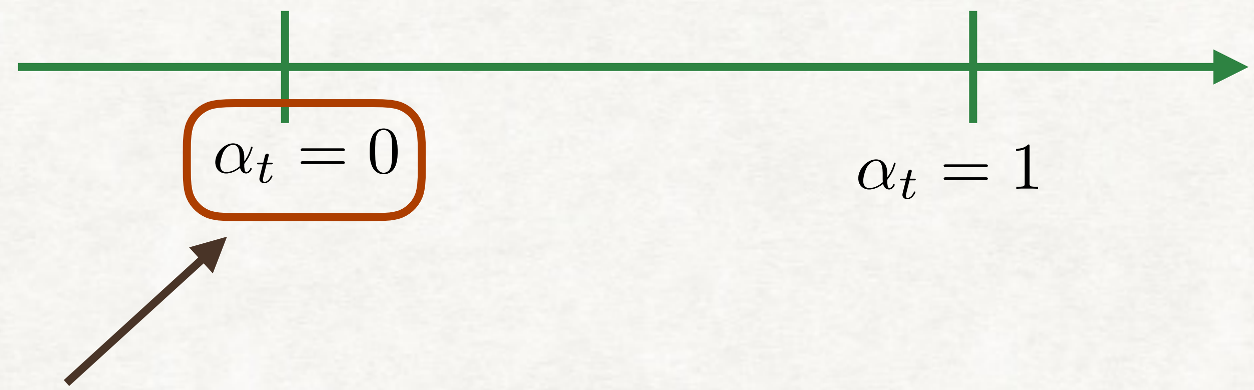
2 regimes



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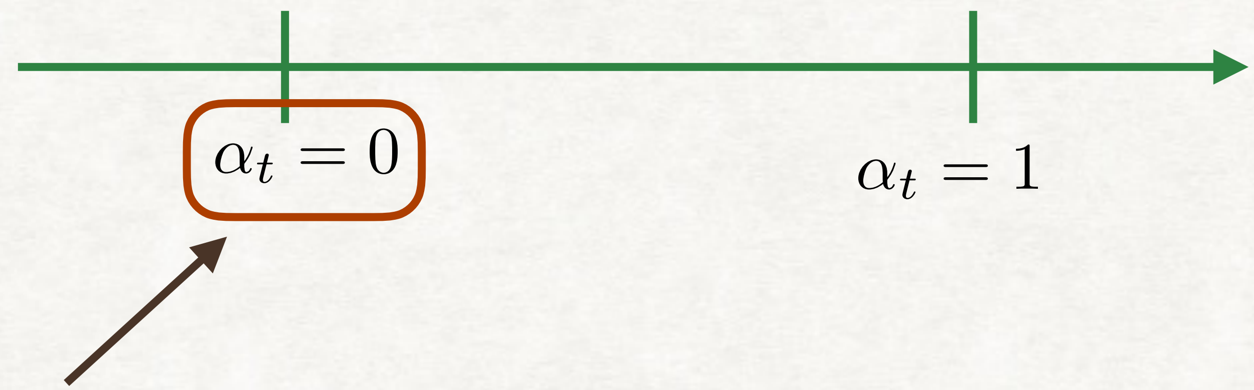

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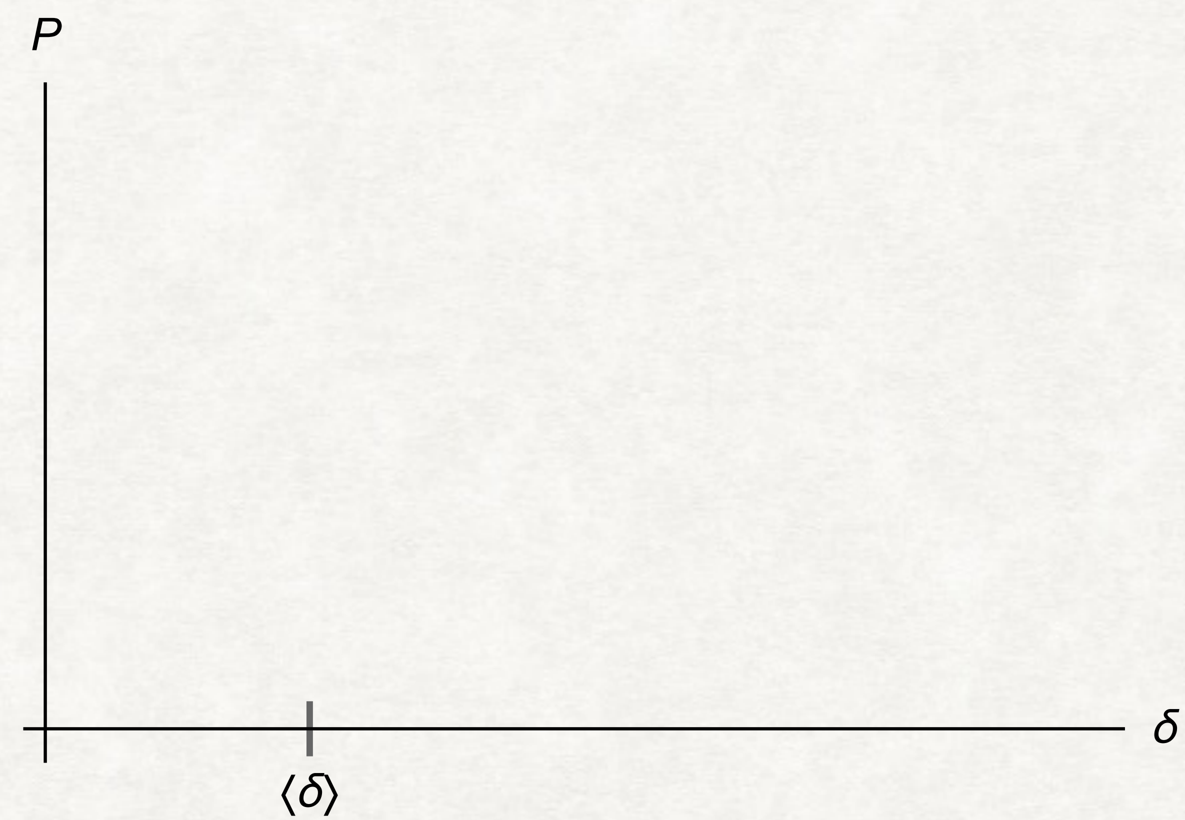
Average gap

2 regimes



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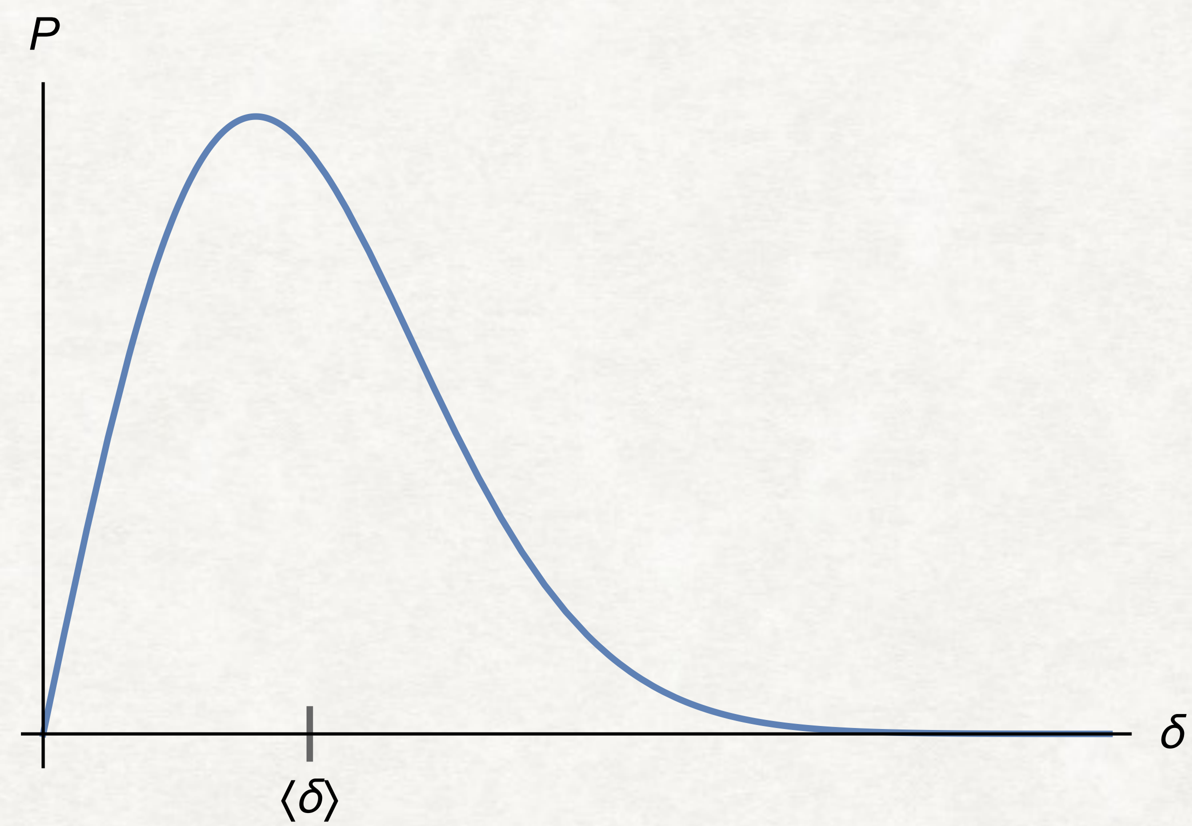

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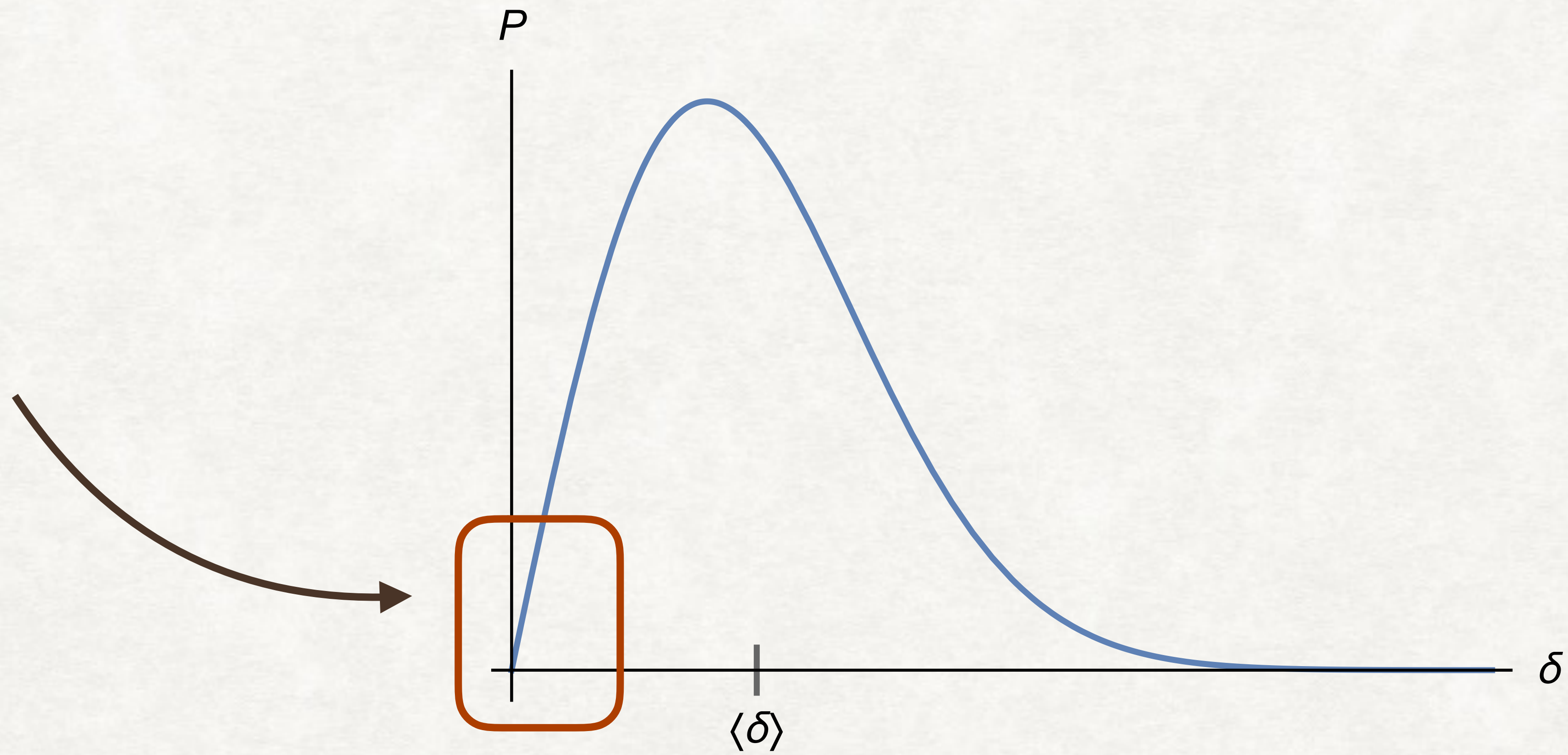
- $\delta \to 0$



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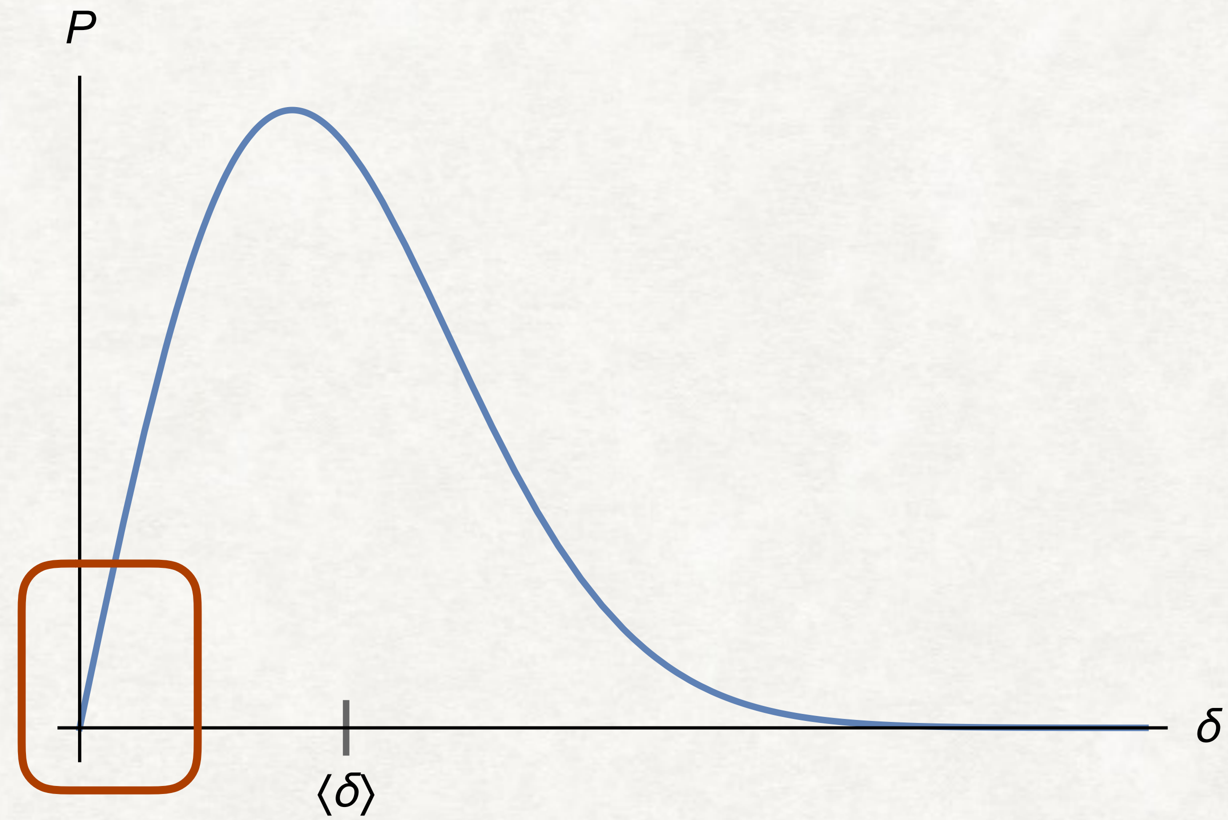

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Average gap

2 regimes

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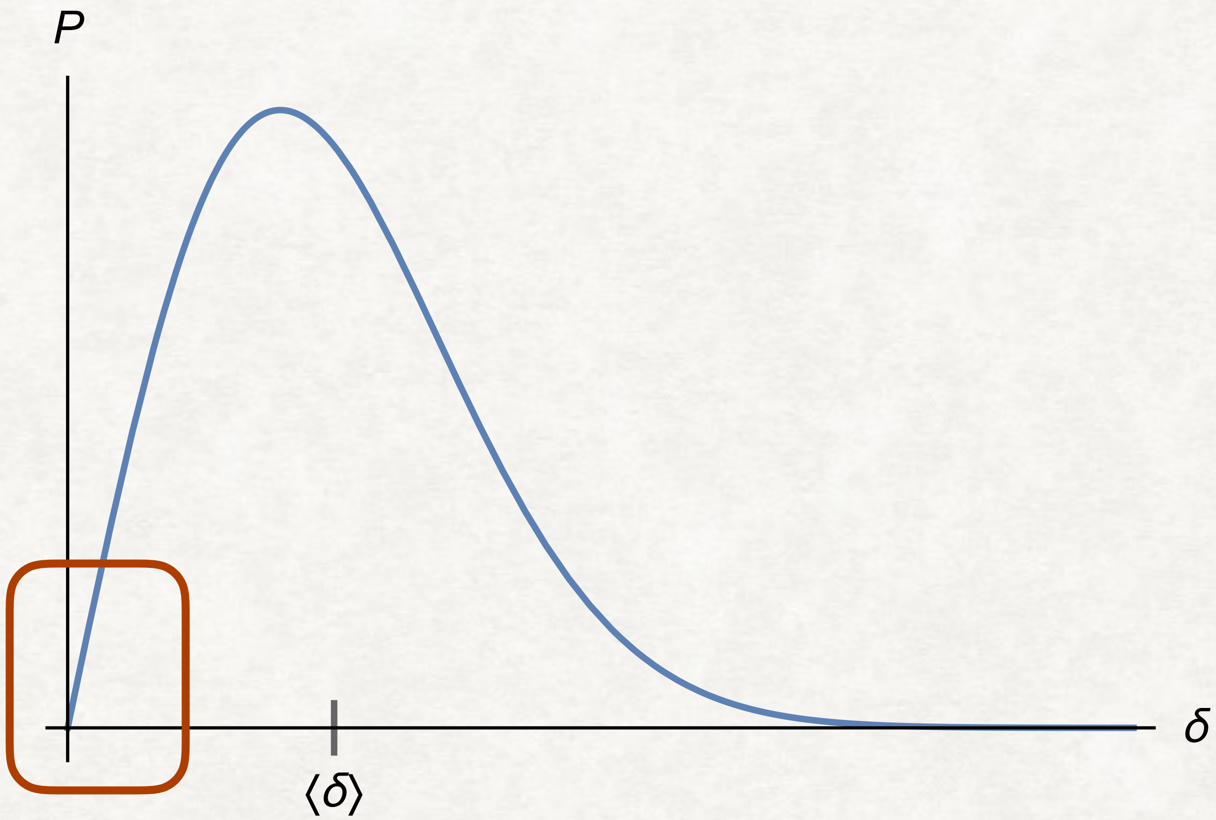
- Level repulsion



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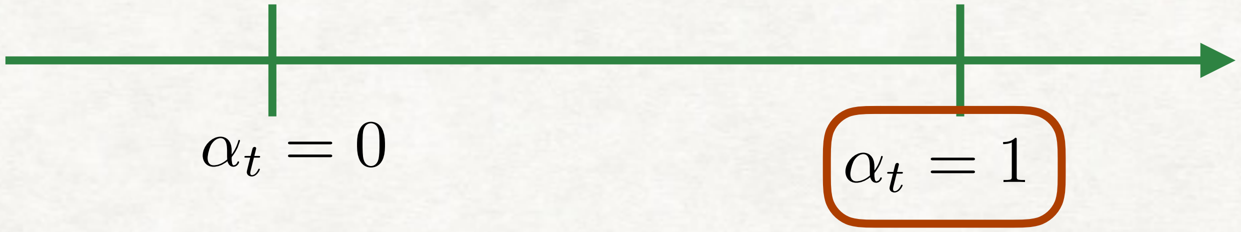
Average gap

2 regimes

- Deeply localized (MBL) regime

2 regimes



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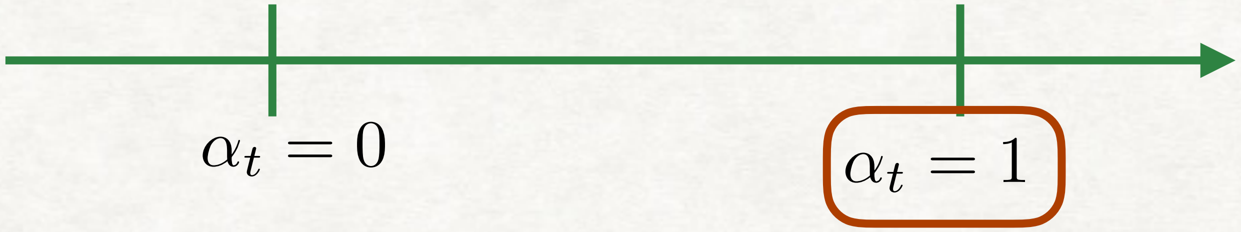

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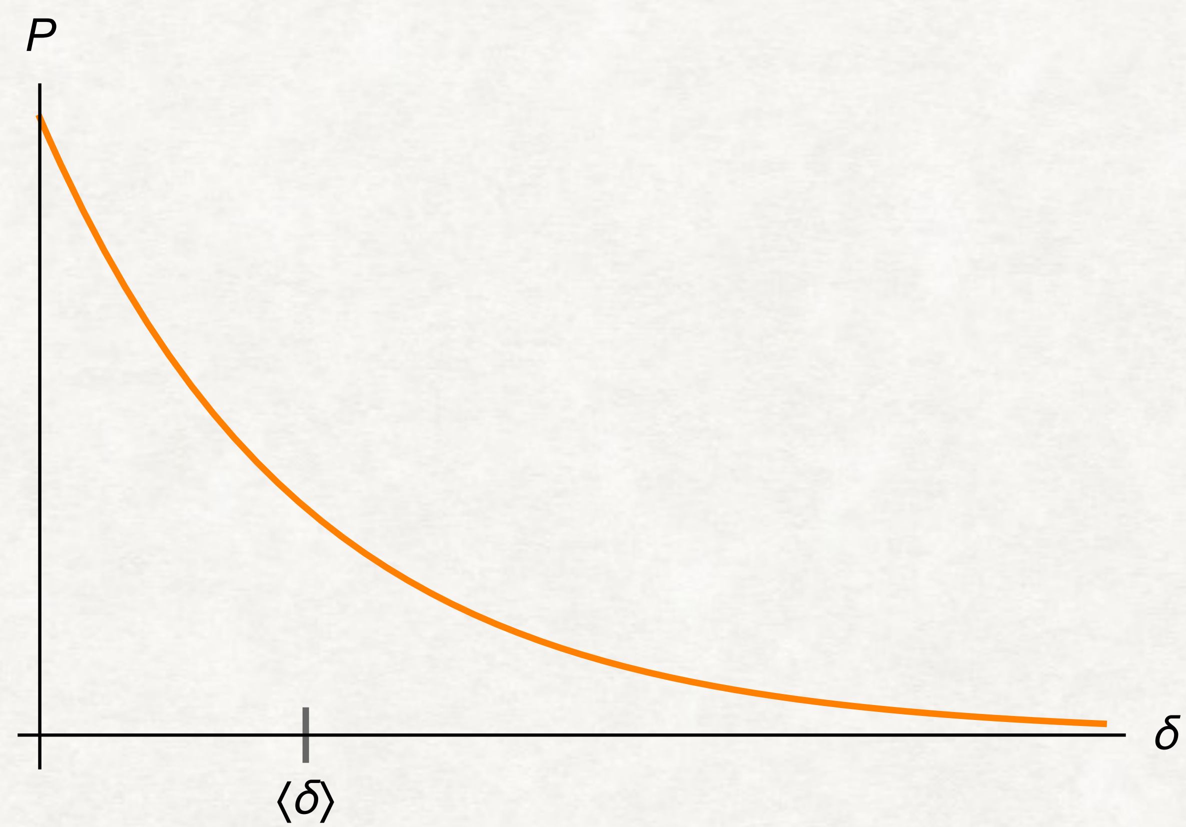

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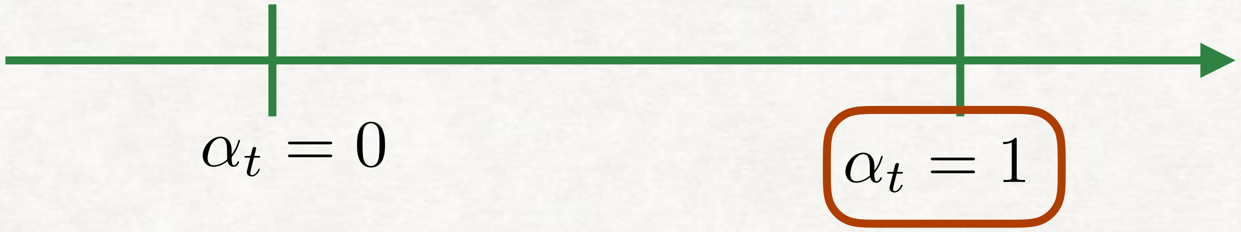

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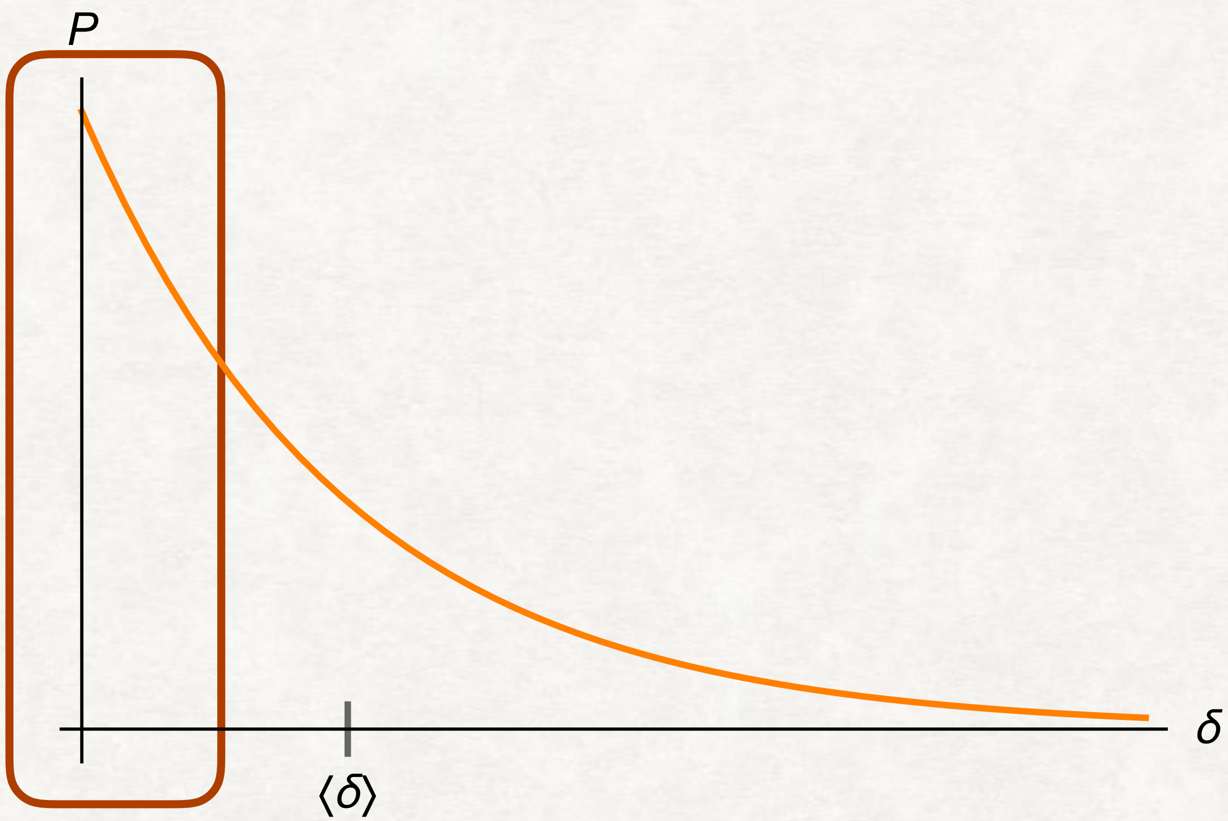

- $\delta \to 0$

2 regimes

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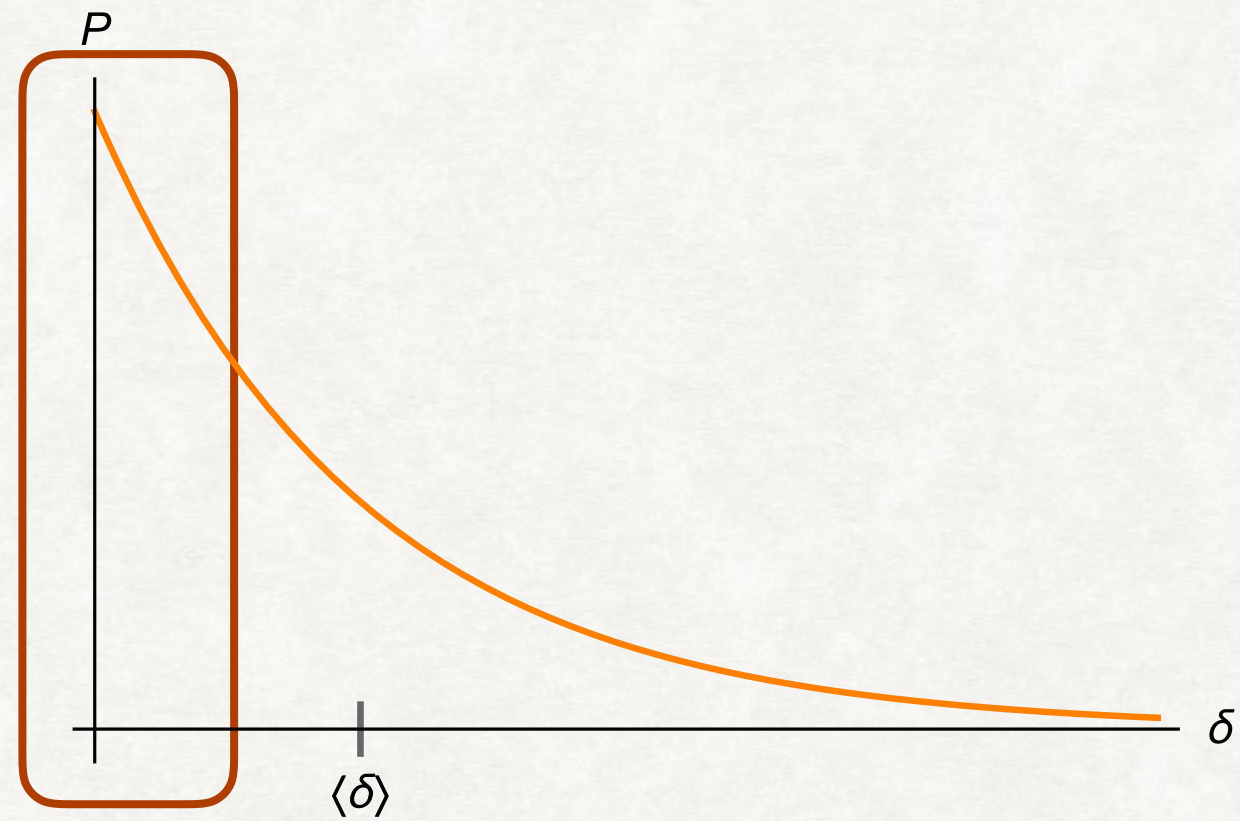

- $\delta \to 0 \quad \Rightarrow \quad P_{\mathrm{MBL}}(\delta) > 0$

2 regimes

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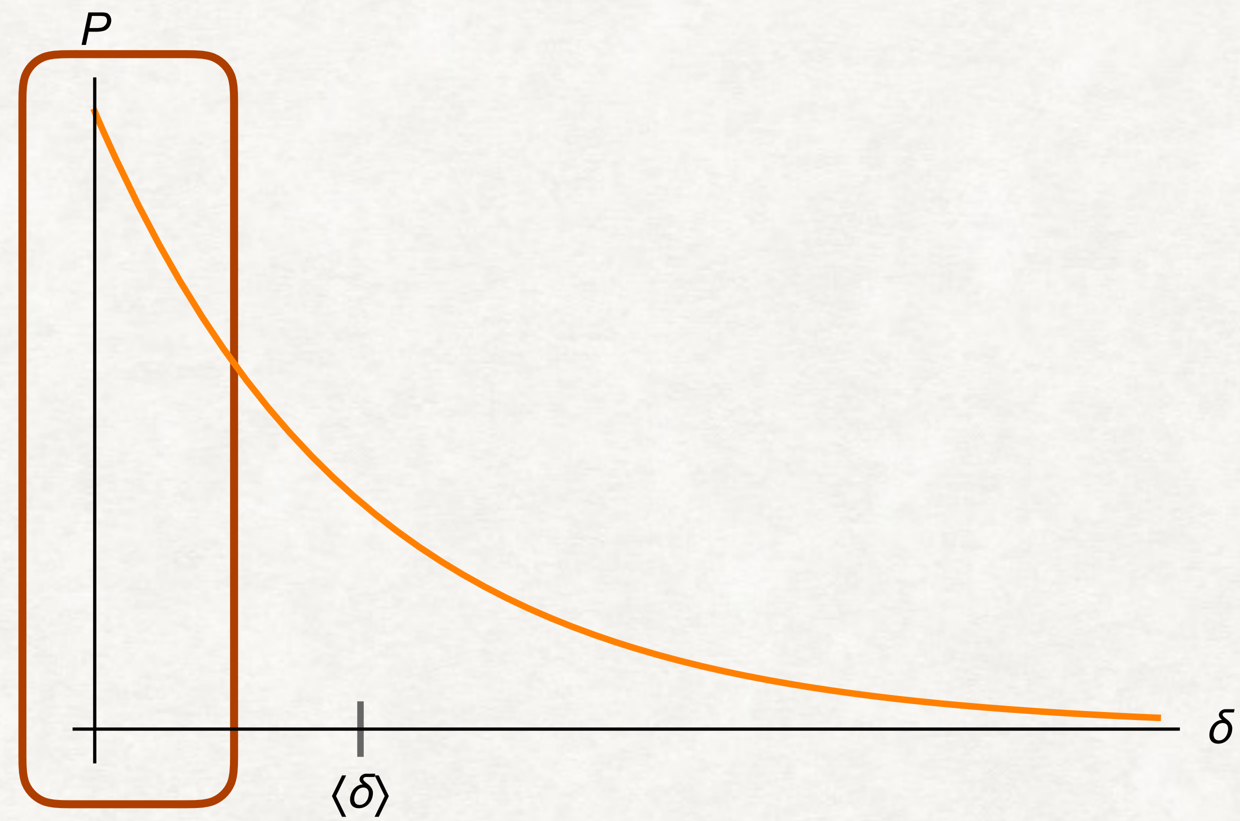

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2 regimes

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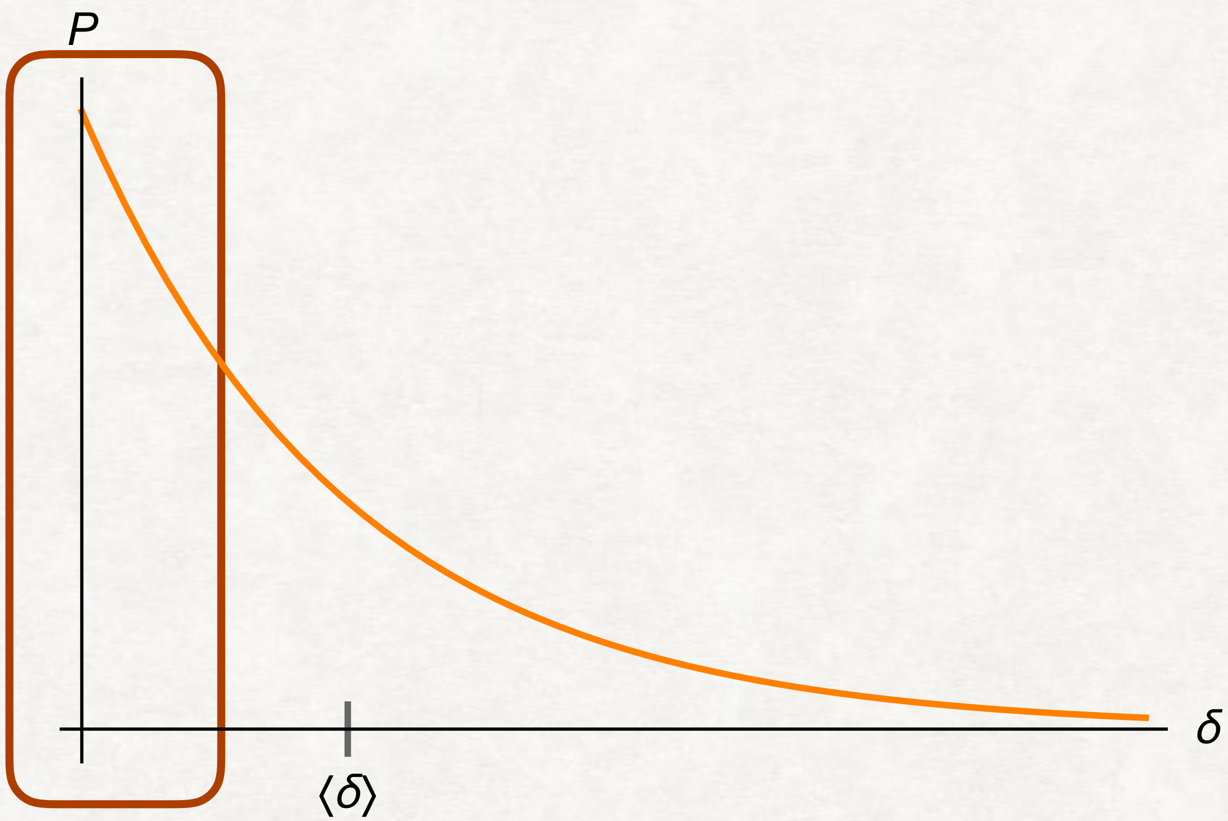

- $\delta \to 0 \quad \Rightarrow \quad P_{\mathrm{MBL}}(\delta) > 0$
- Lack of level repulsion
- **MBL has athermal gap statistics.**

MBL Otto cycle

MBL Otto cycle → 4 strokes

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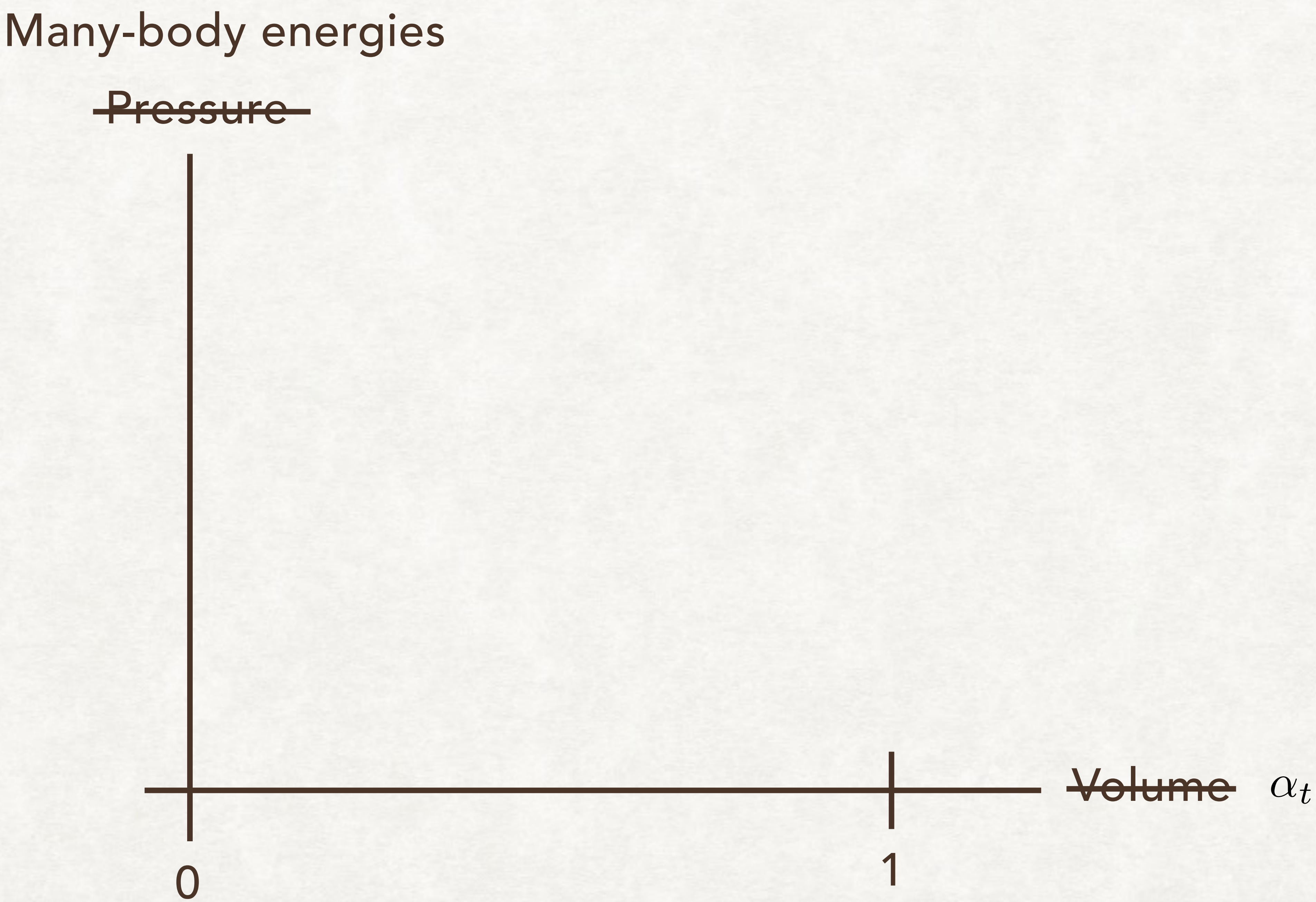
Many-body energies

~~Pressure~~

~~Volume~~ α_t

MBL Otto cycle → 4 strokes



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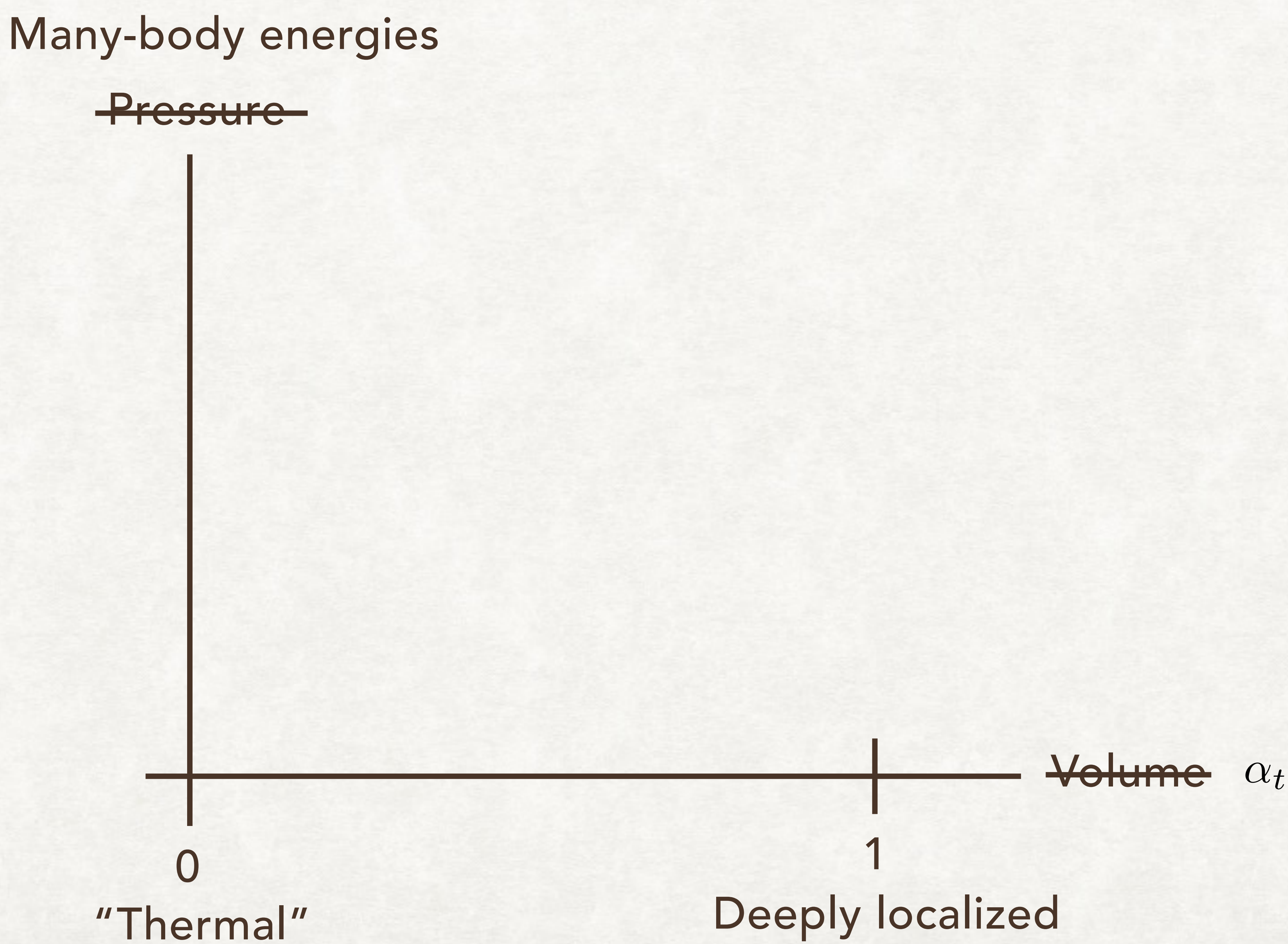

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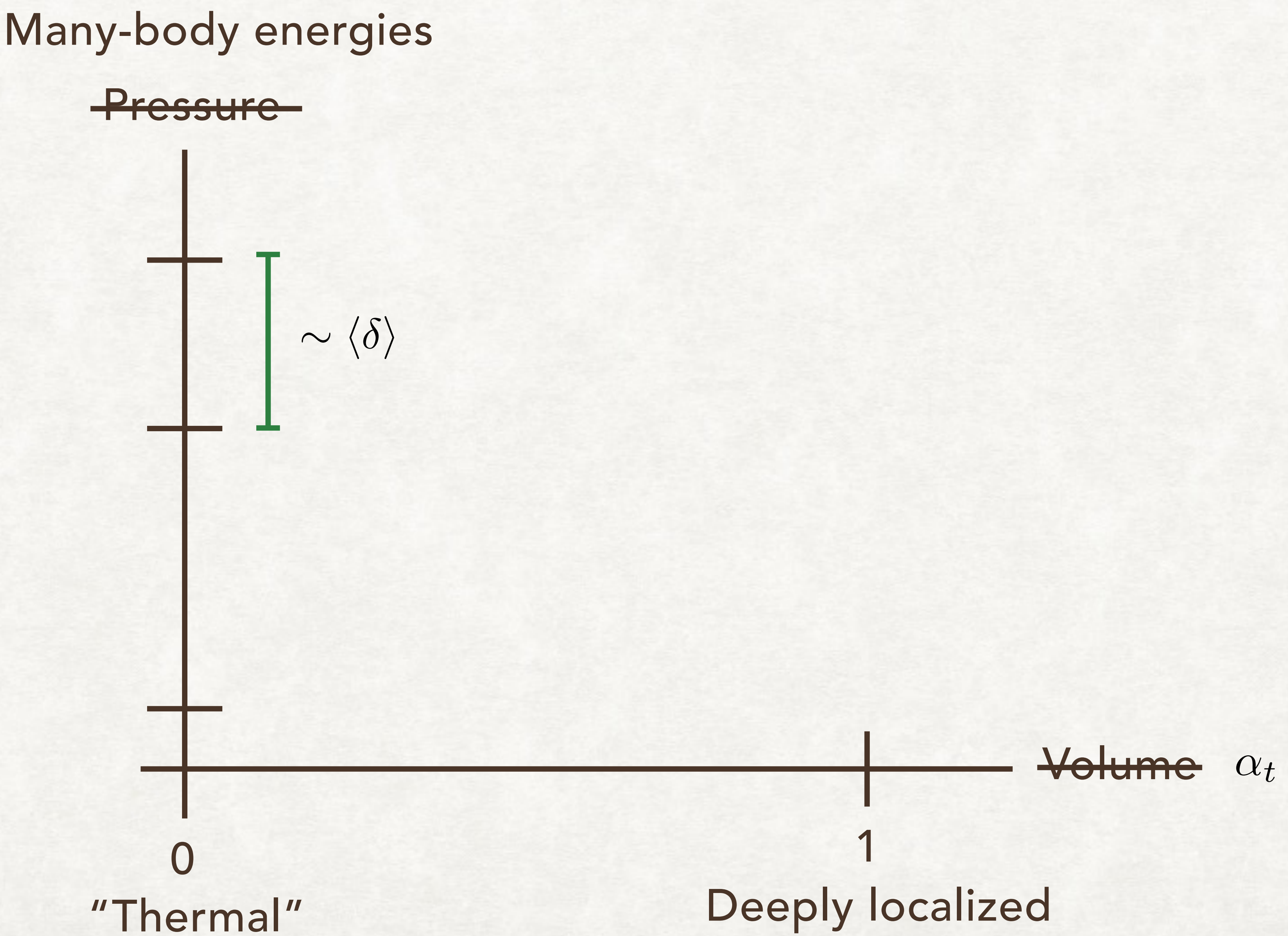

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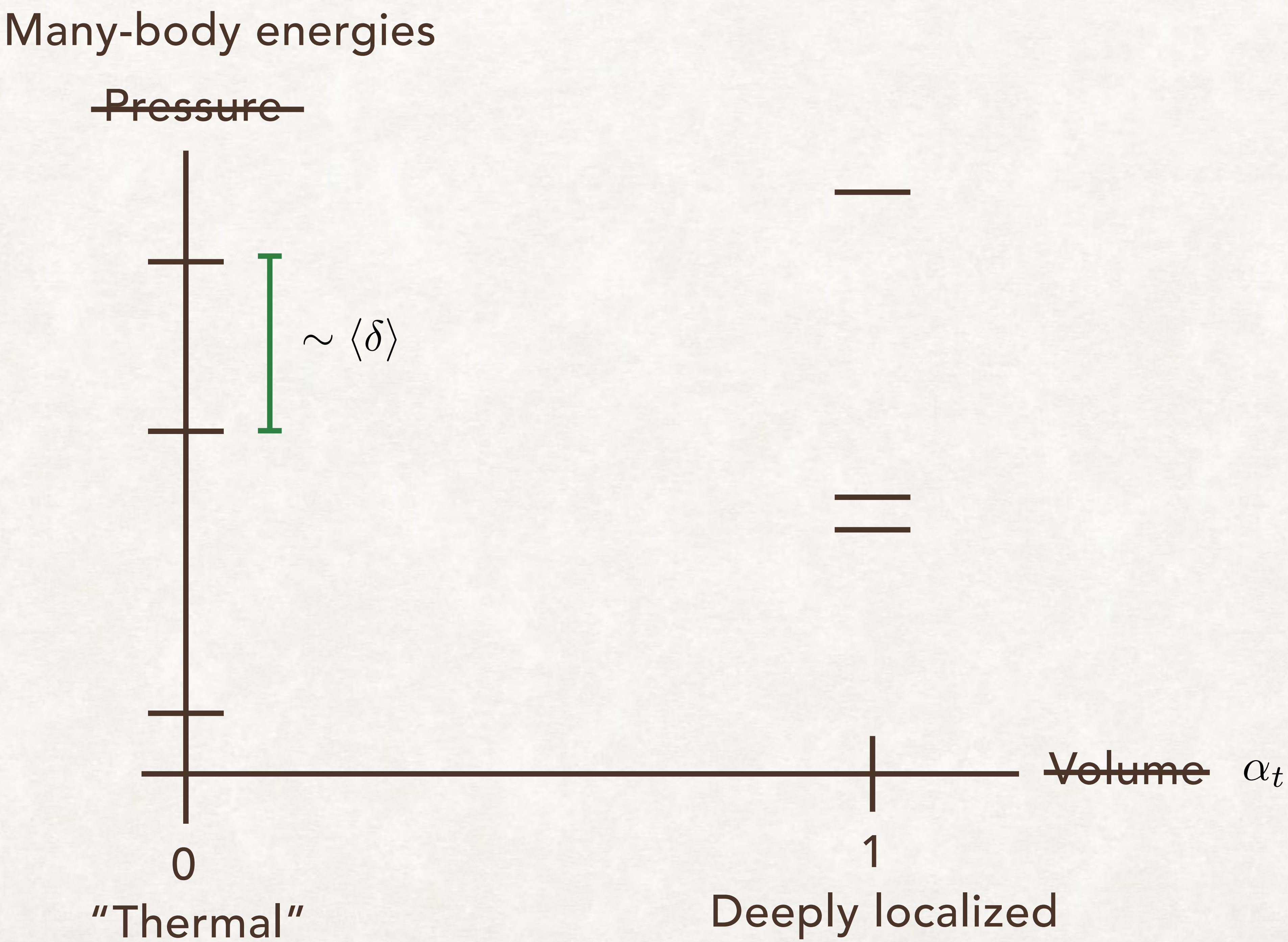
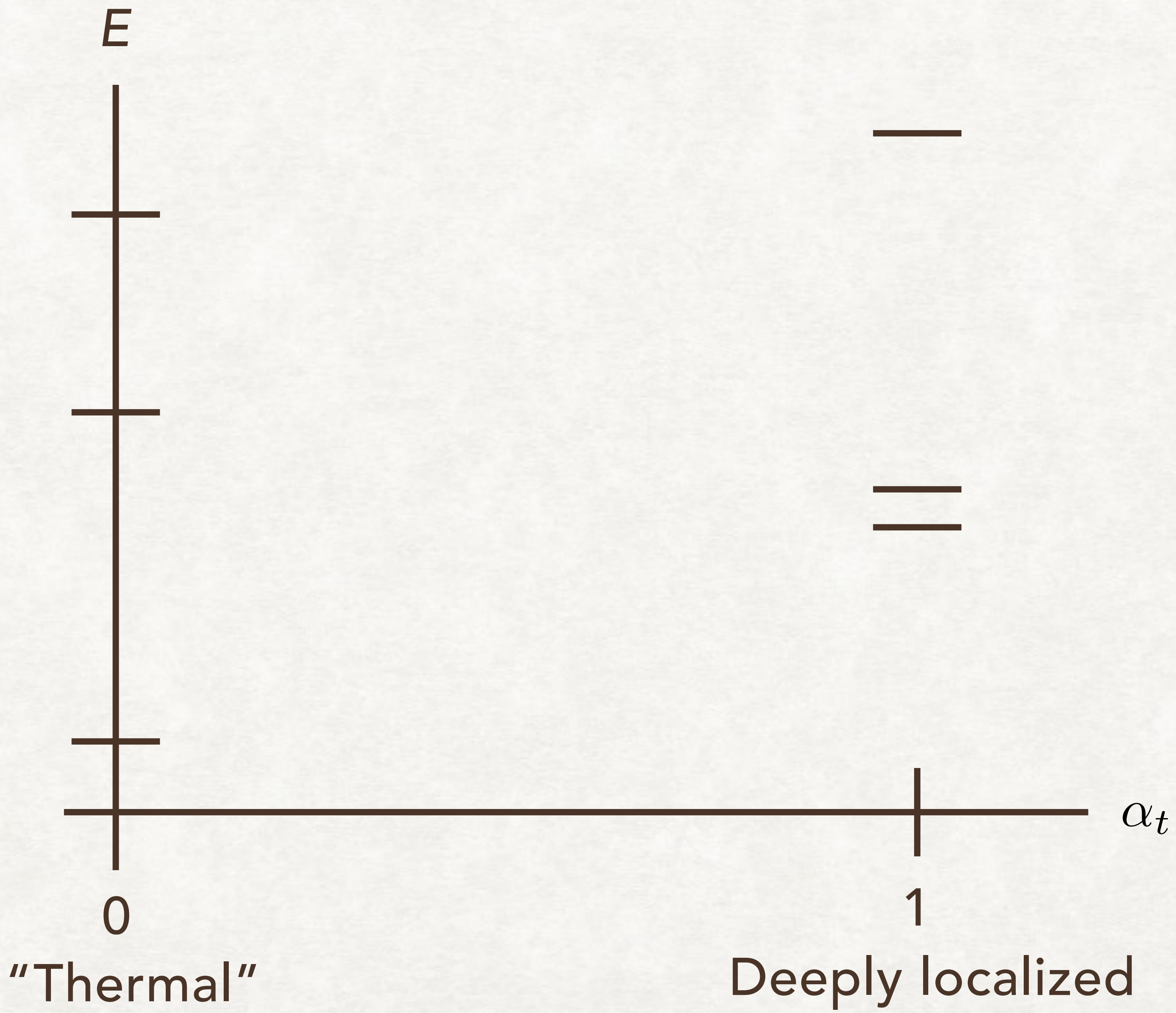


MBL Otto cycle

- Initialize $H(\alpha_0) \equiv H_{\text{ETH}}$



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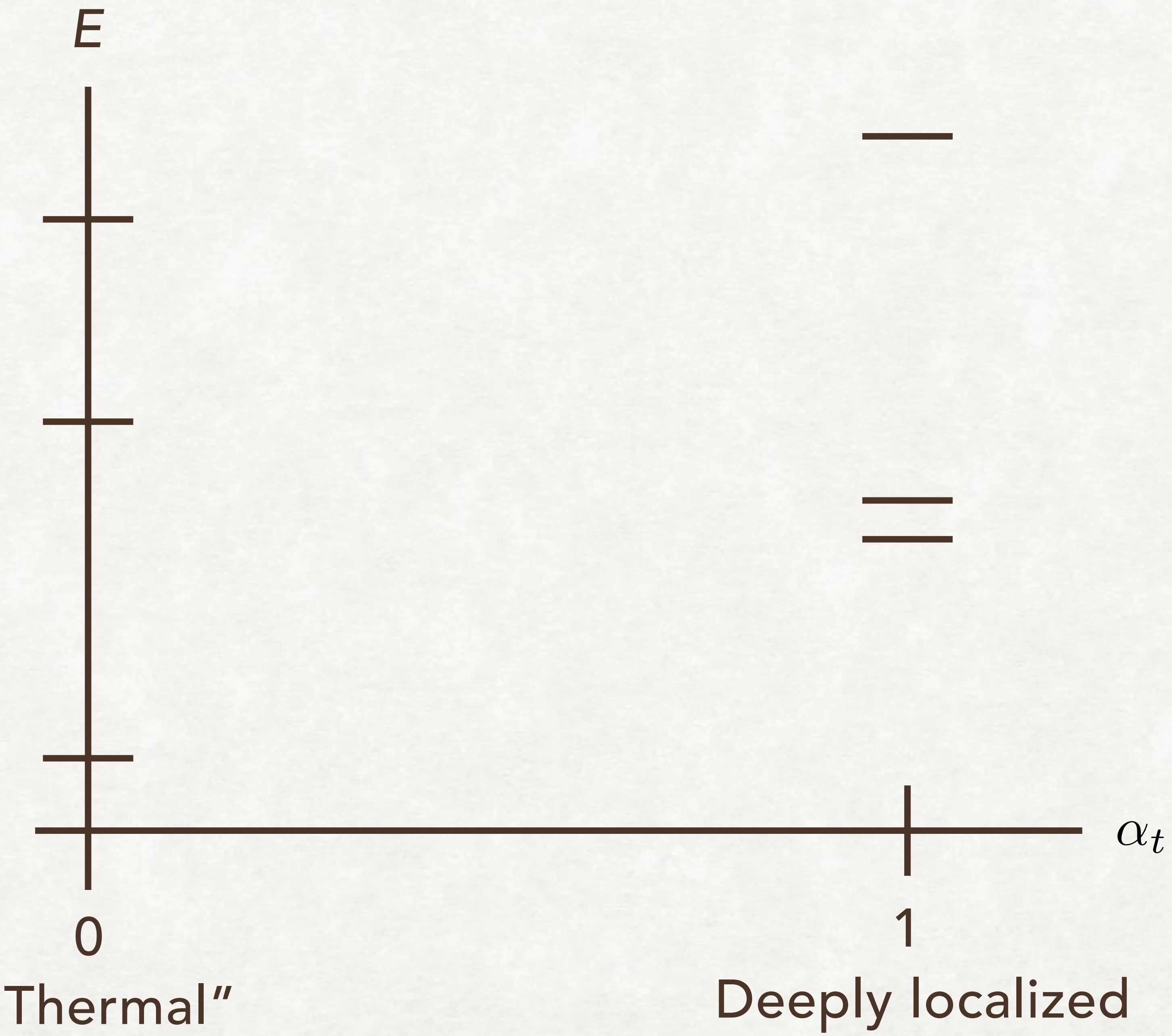
- $\rho(0) = \dfrac{e^{-H_{\mathrm{ETH}}/T_{\mathrm{H}}}}{Z_{\mathrm{ETH}}}$



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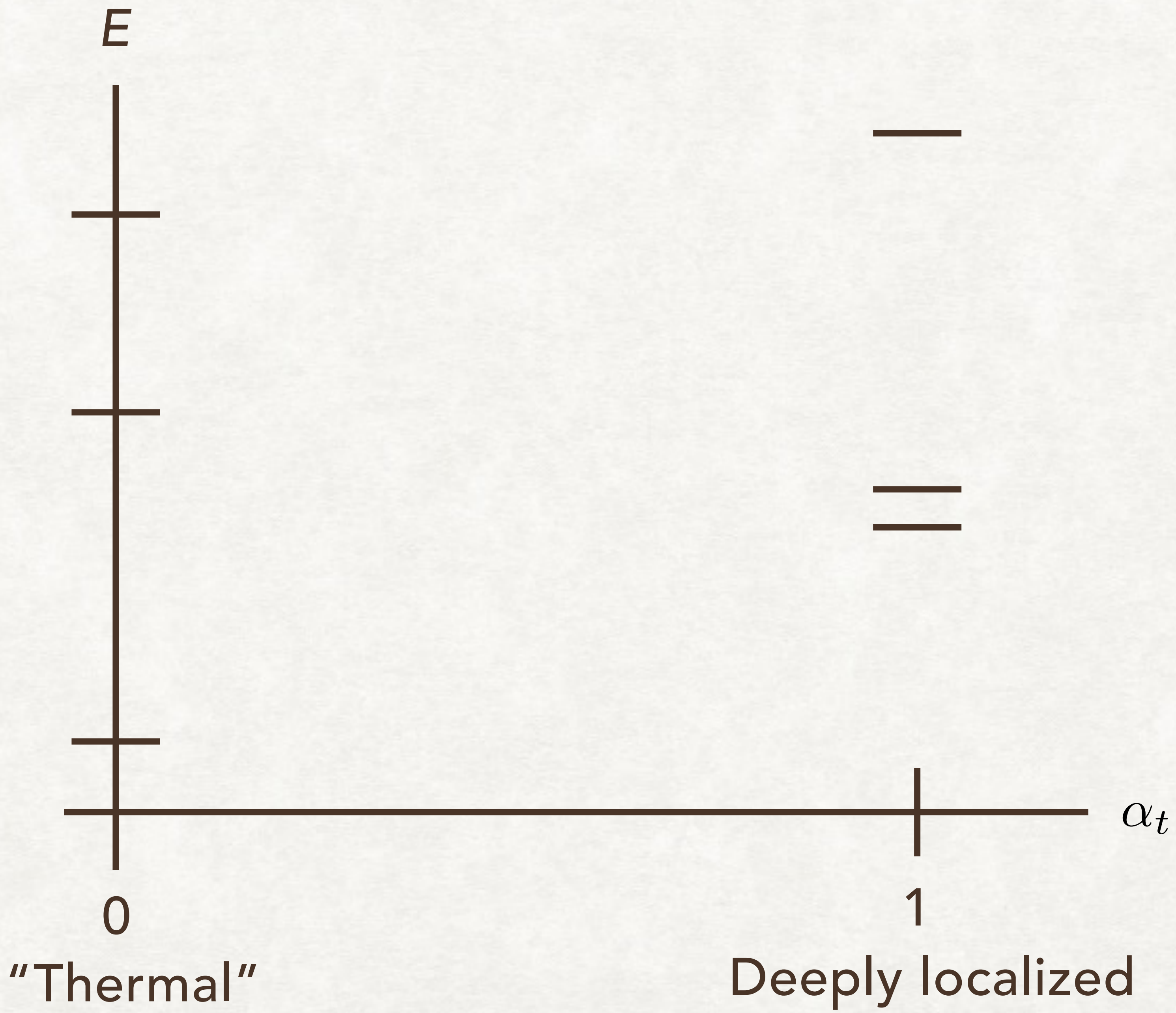
- $\rho(0) = \frac{e^{-H_{\mathrm{ETH}}/T_{\mathrm{H}}}}{Z_{\mathrm{ETH}}}$
- Disconnect from bath



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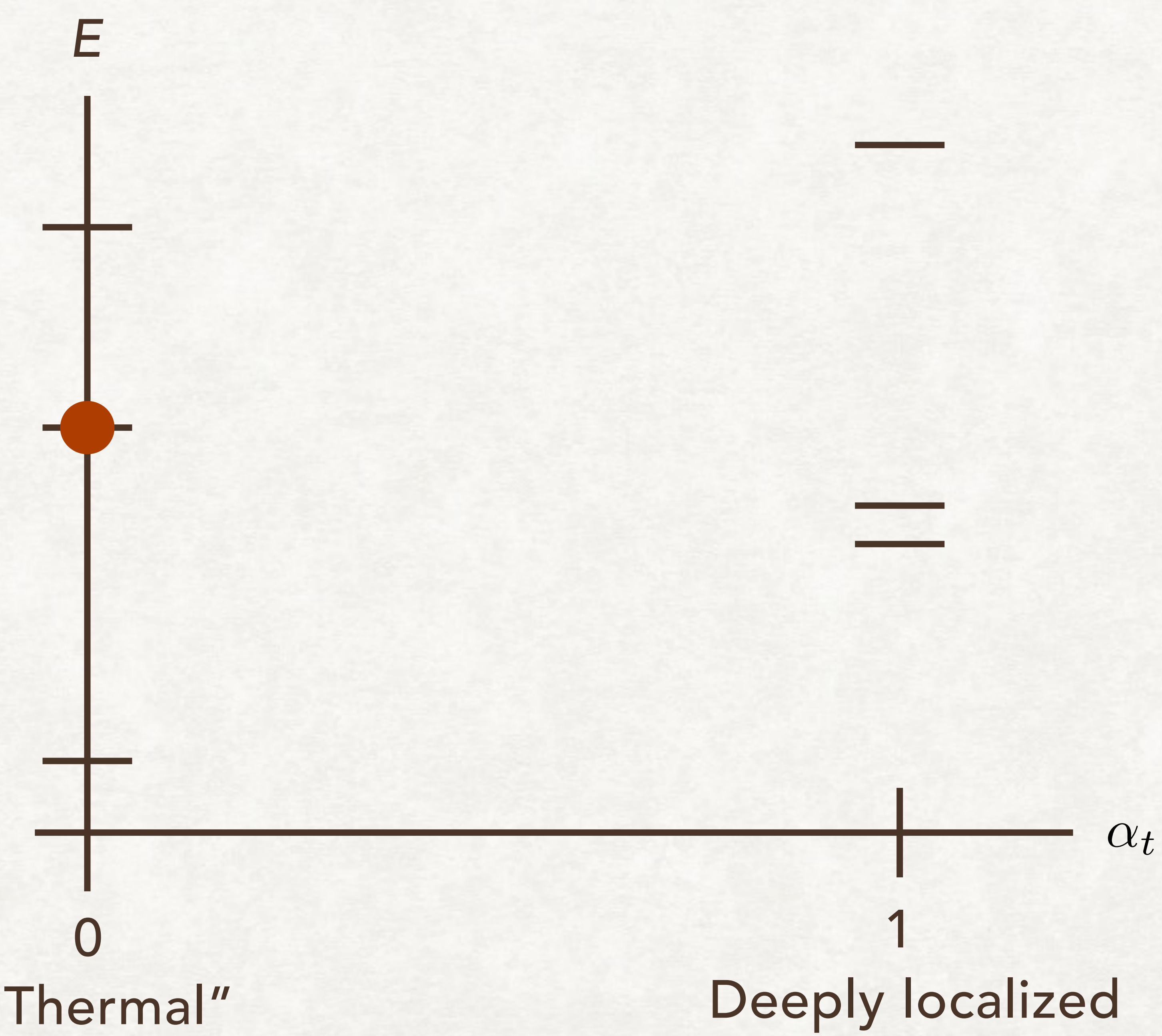
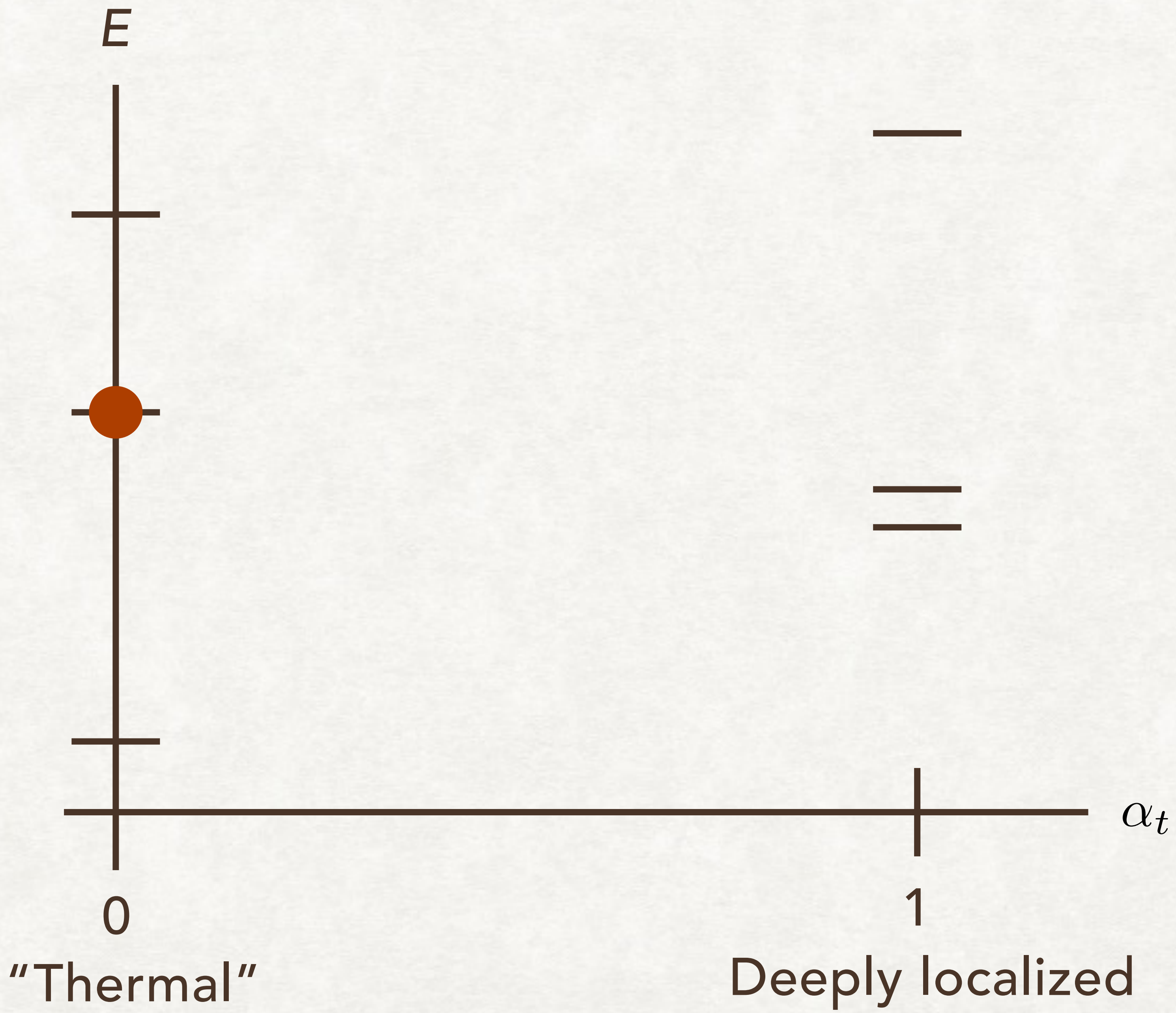


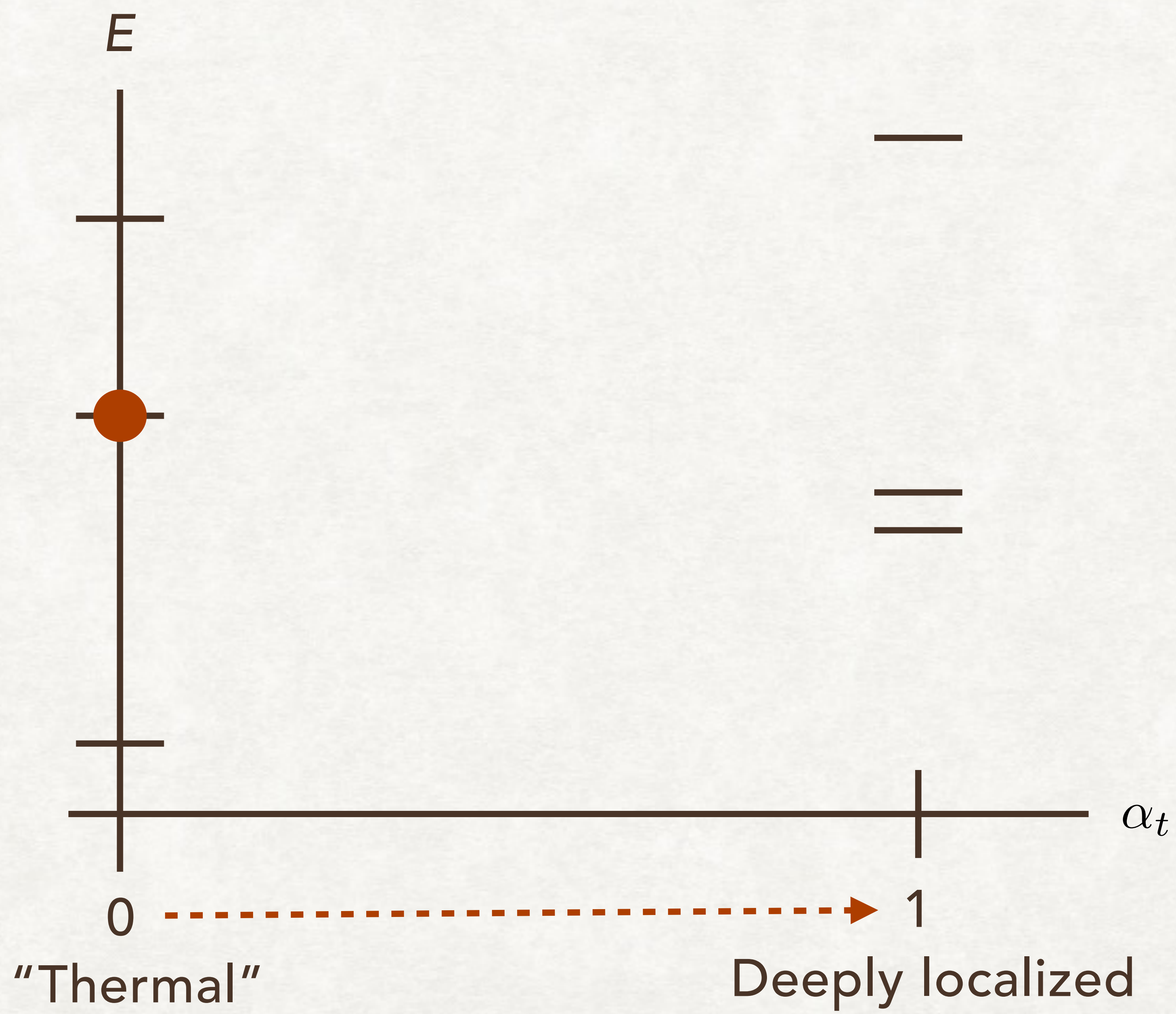
MBL Otto cycle

- Stroke 1: isoentrope



MBL Otto cycle

- Stroke 1: isoentrope
- $H_{\text{ETH}} \mapsto H_{\text{MBL}}$



MBL Otto cycle

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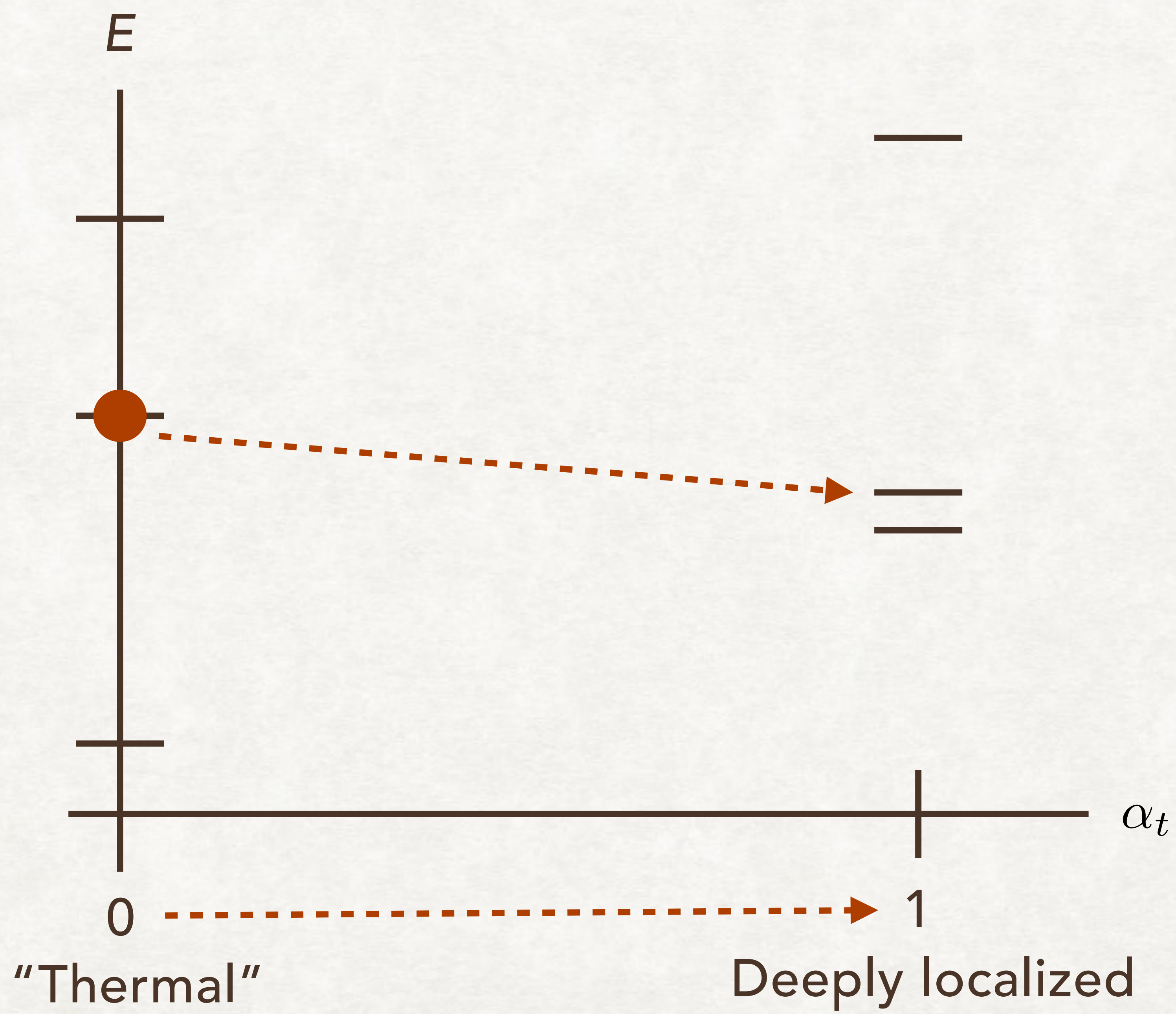

MBL Otto cycle

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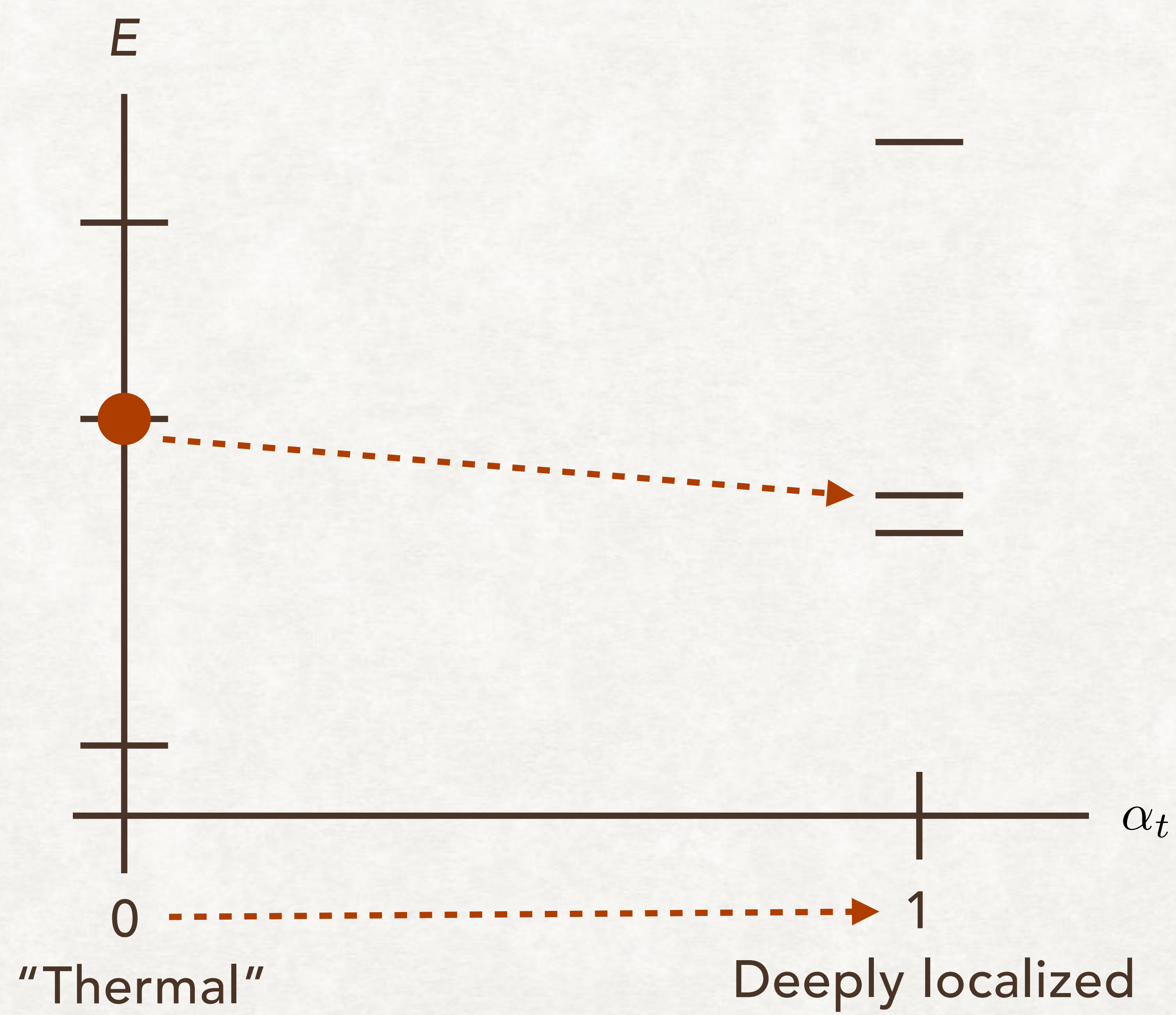

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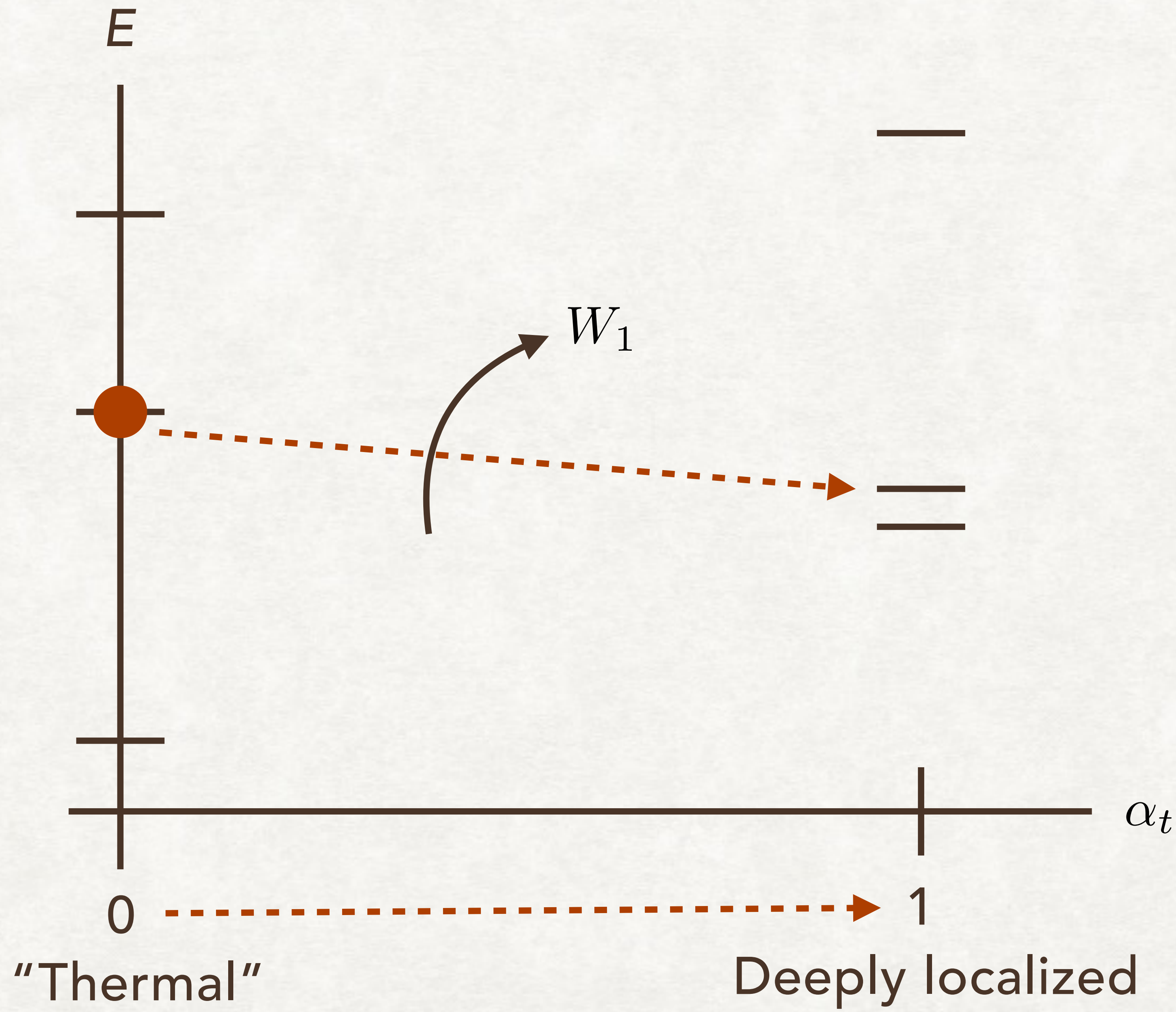
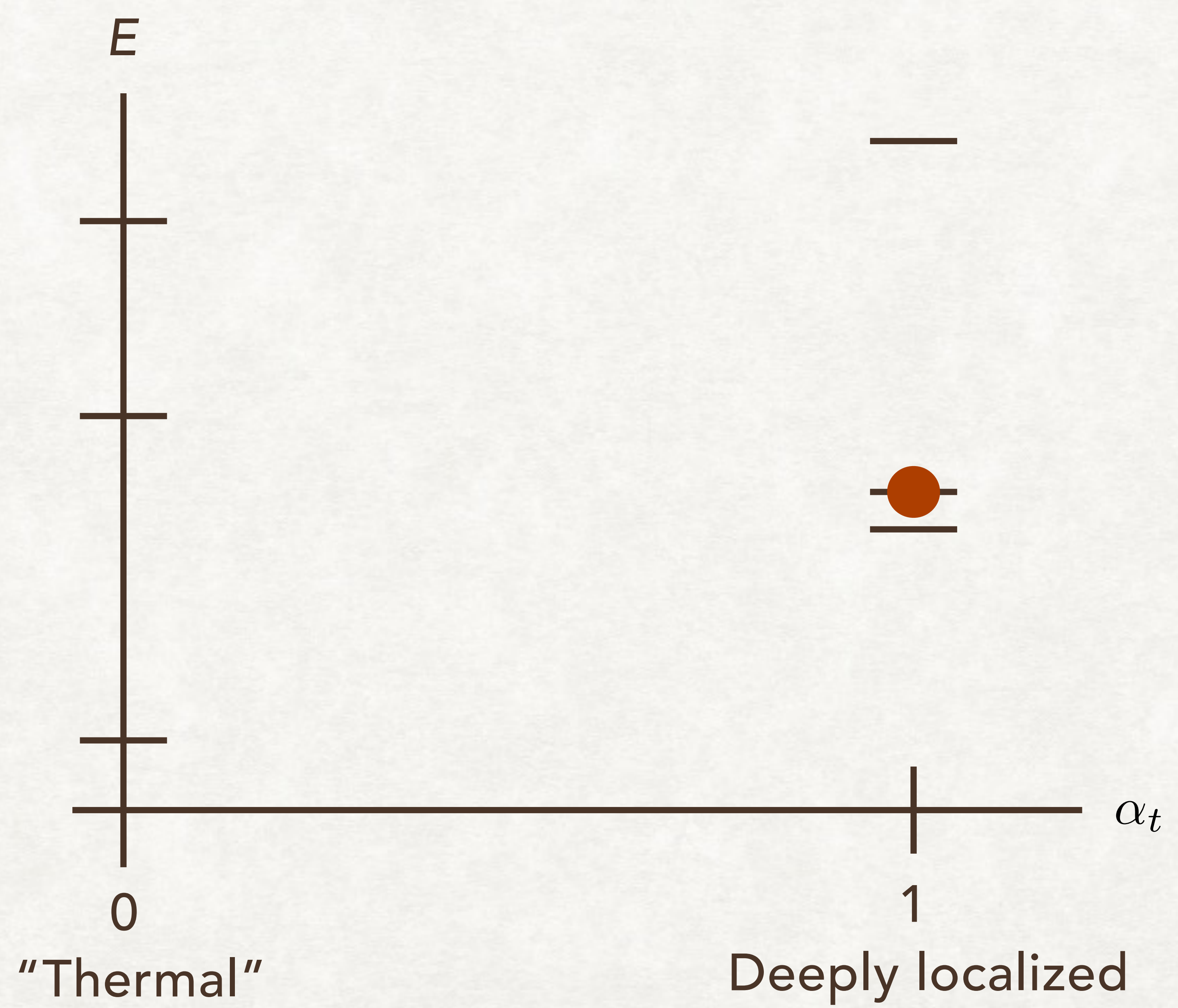


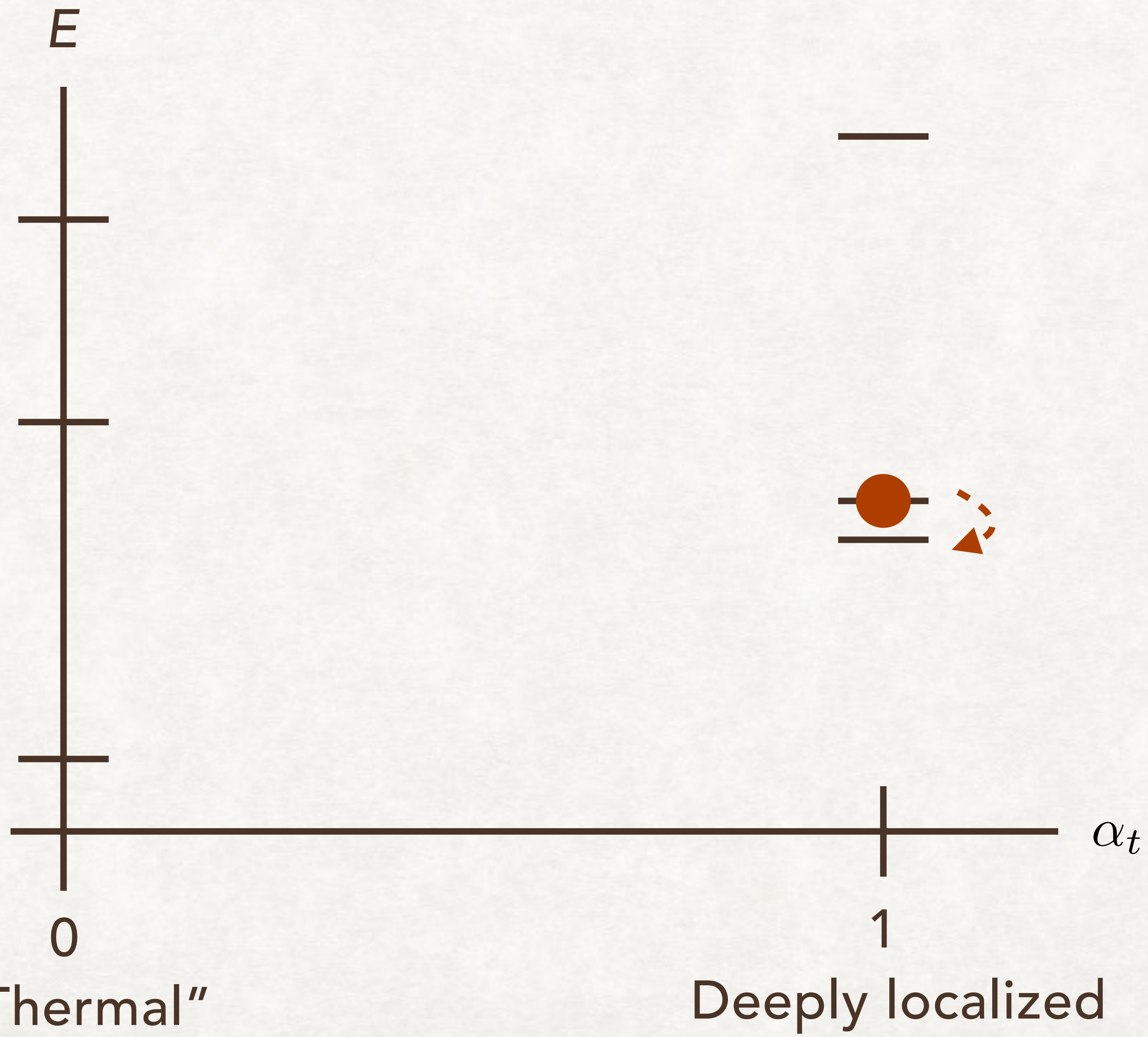
MBL Otto cycle

- Stroke 2: isotherm



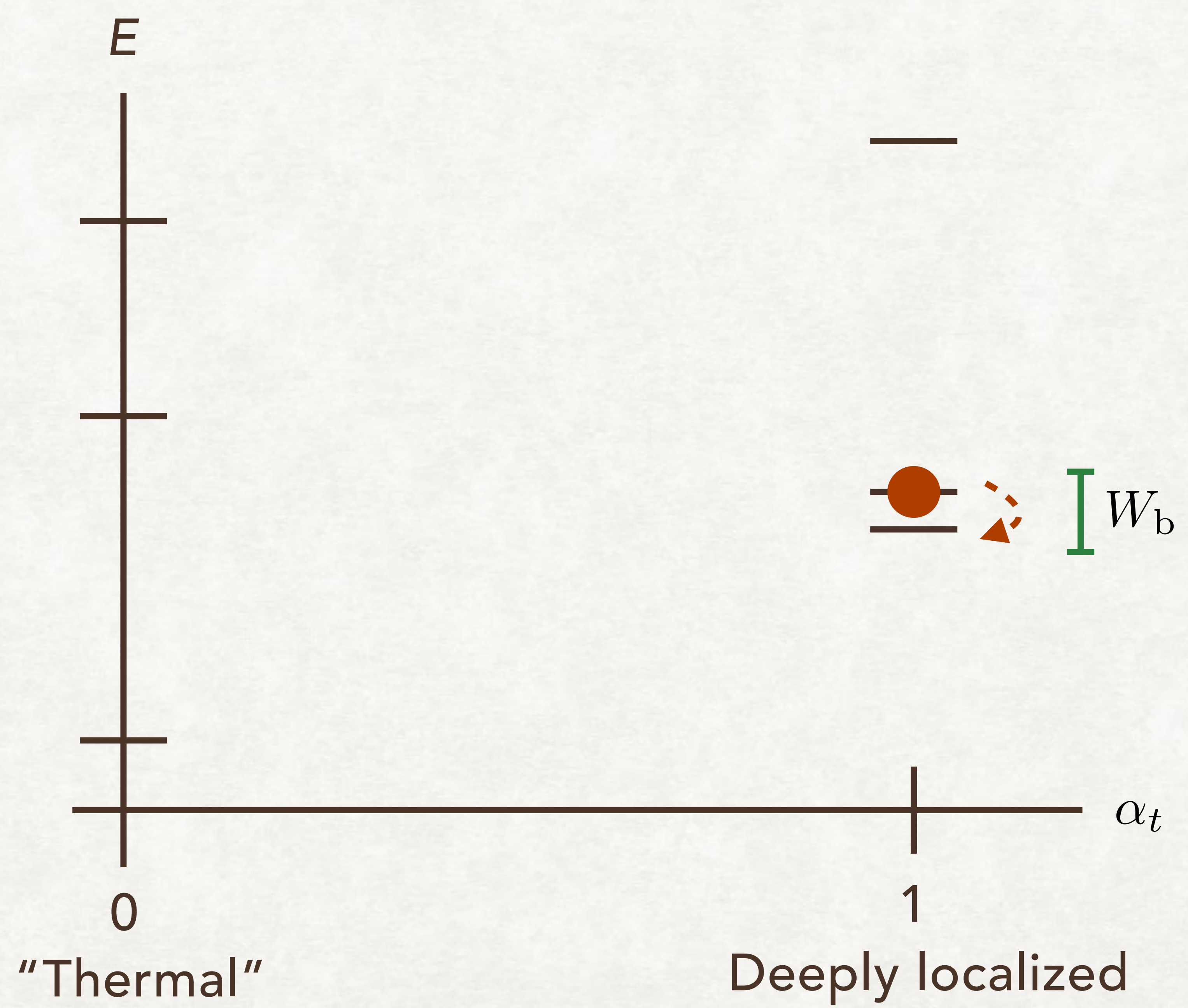
MBL Otto cycle

- Stroke 2: isotherm
- $T_\mathrm{C} \ll T_\mathrm{H}$



MBL Otto cycle

- Stroke 2: isotherm
- $T_C \ll T_H$
- Small bandwidth
  - $W_b \ll \langle \delta \rangle$



MBL Otto cycle

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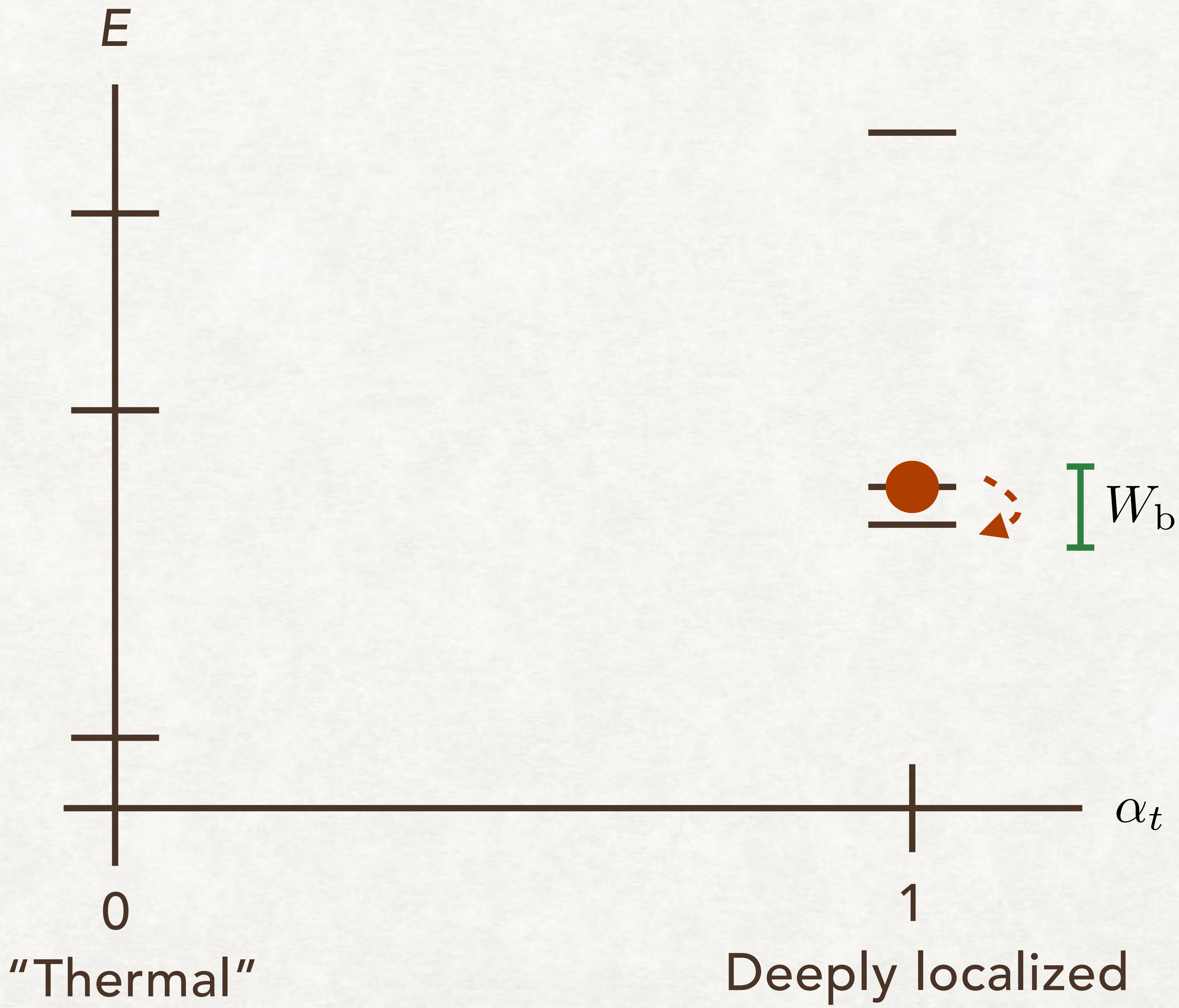

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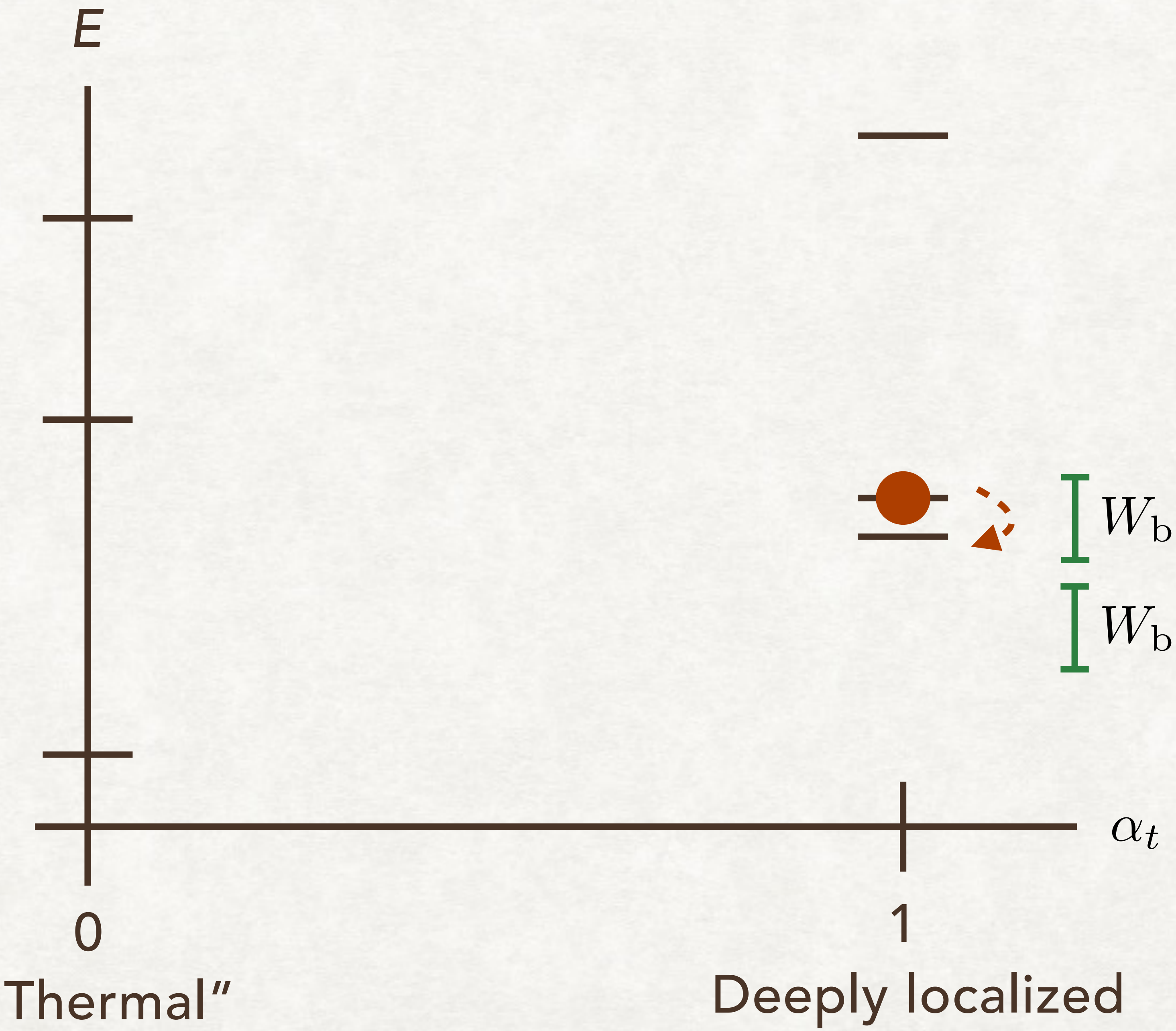

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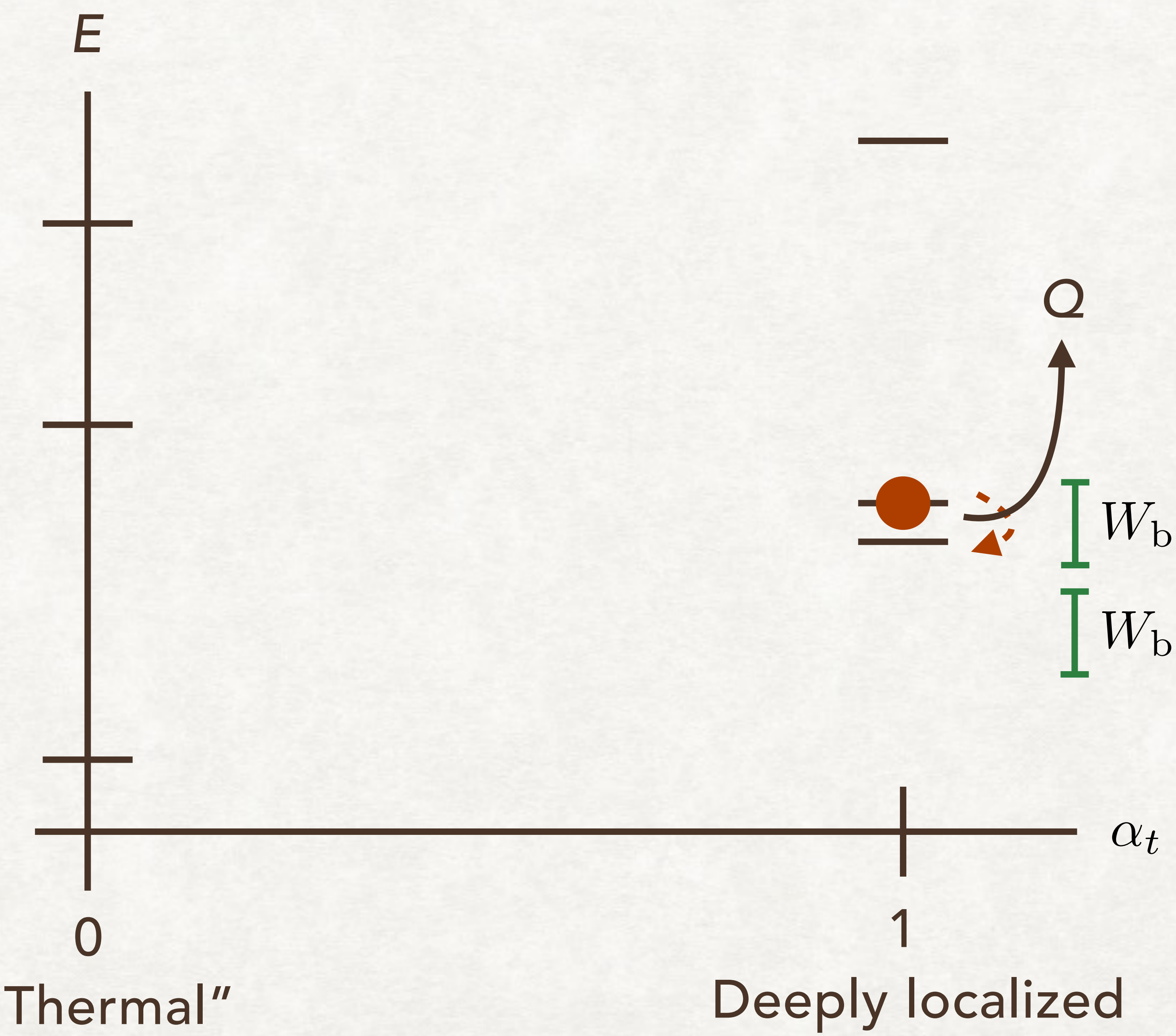
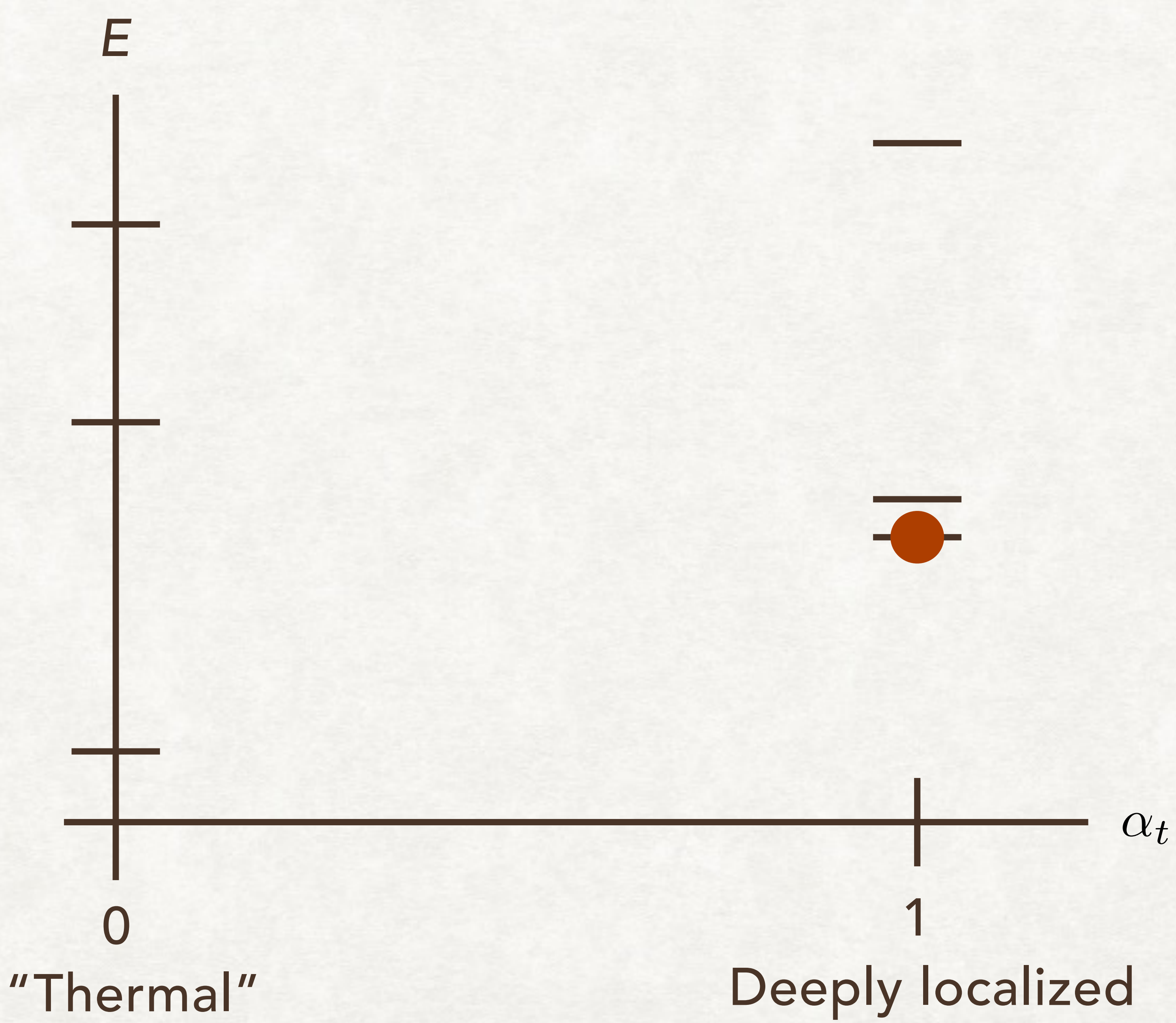


MBL Otto cycle

- Stroke 3: isentrope



MBL Otto cycle

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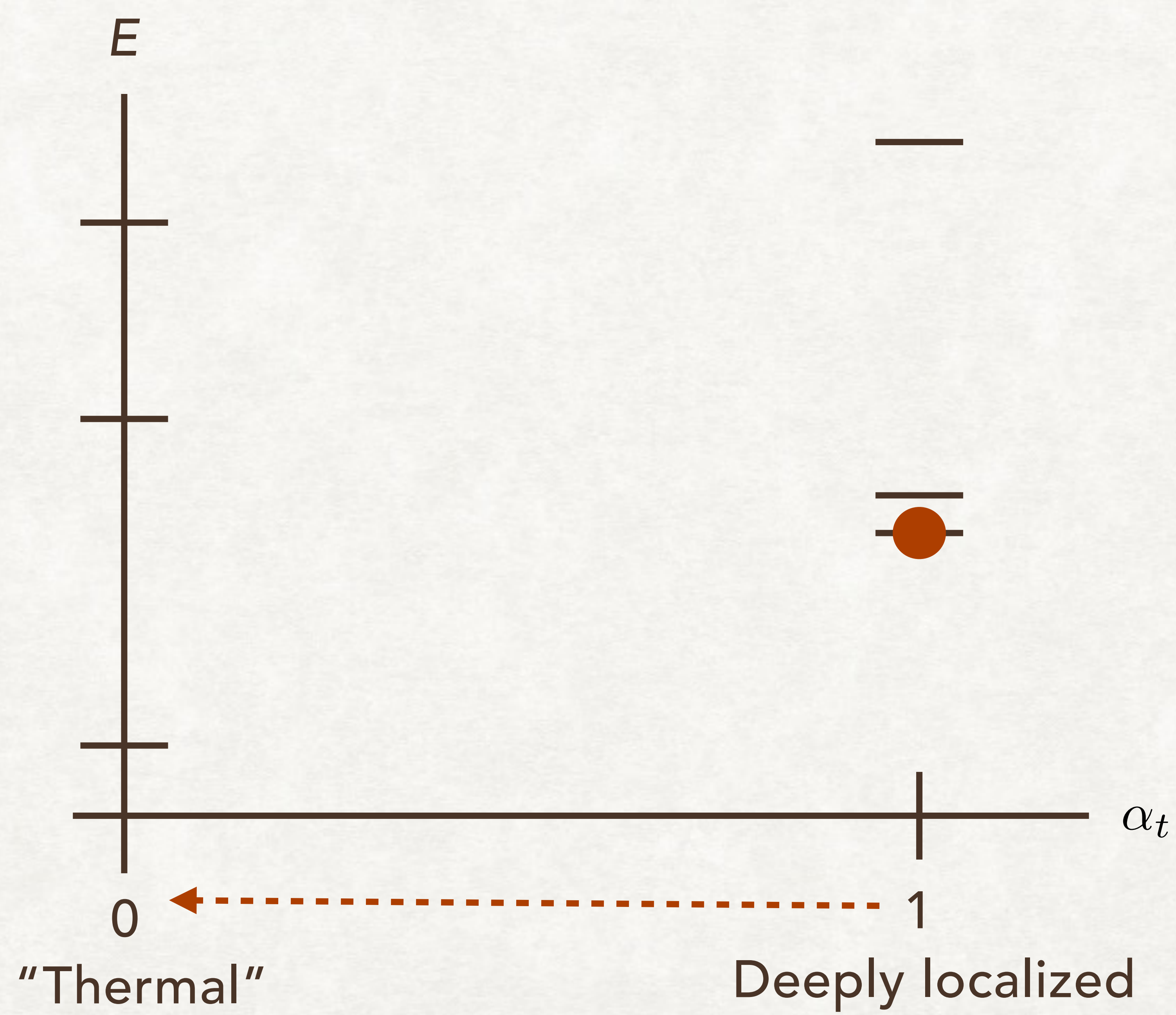

MBL Otto cycle

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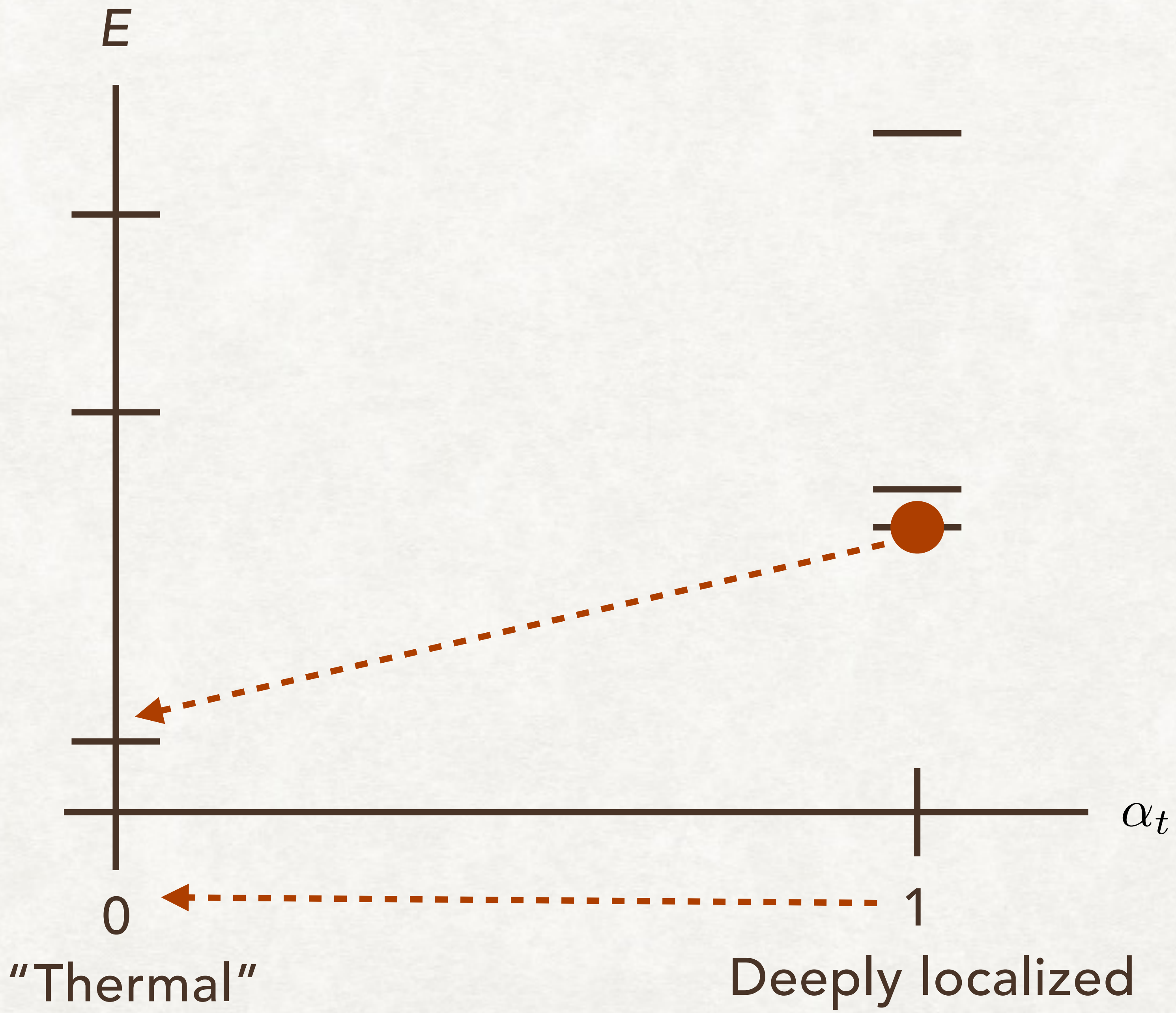

MBL Otto cycle

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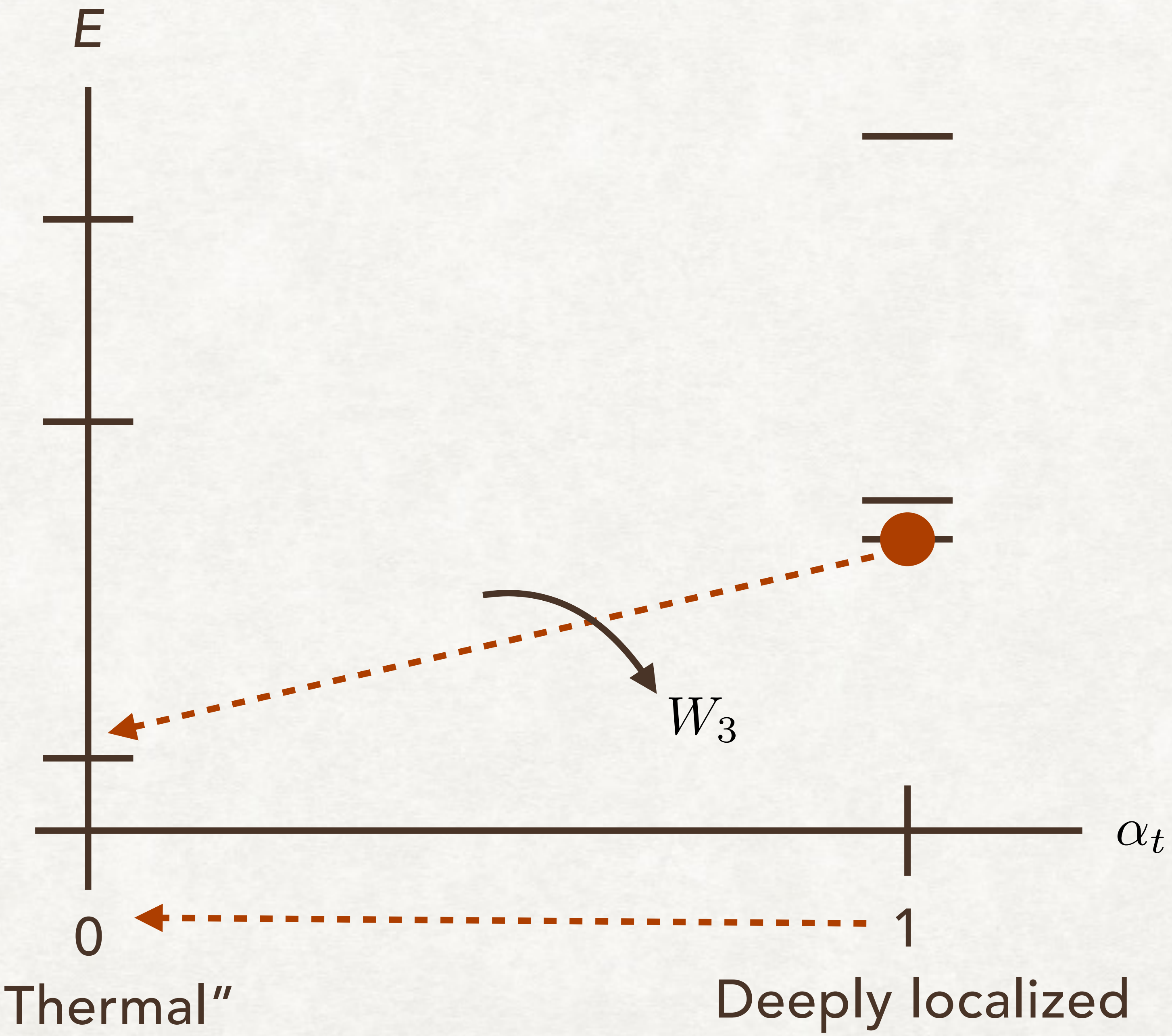
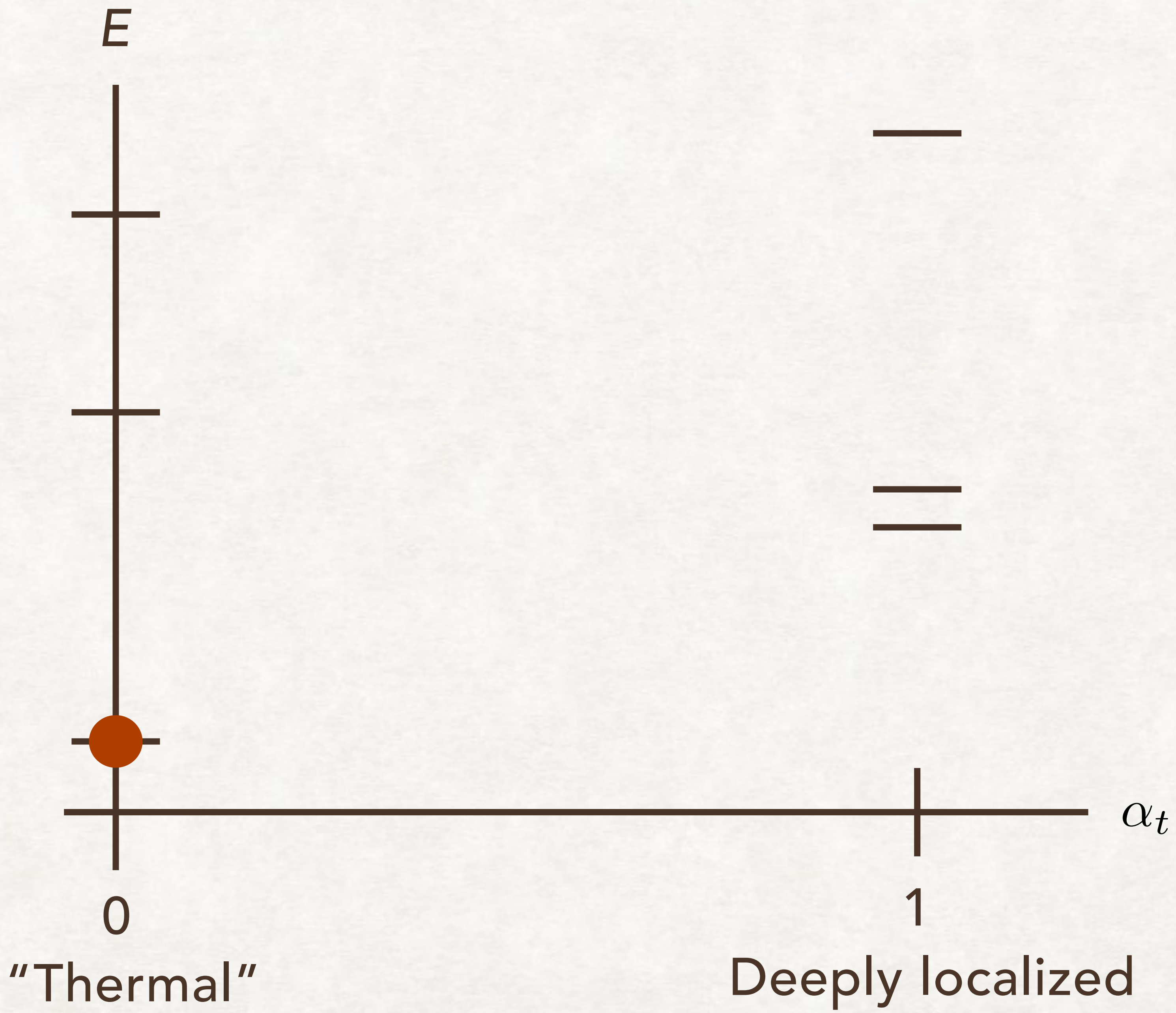


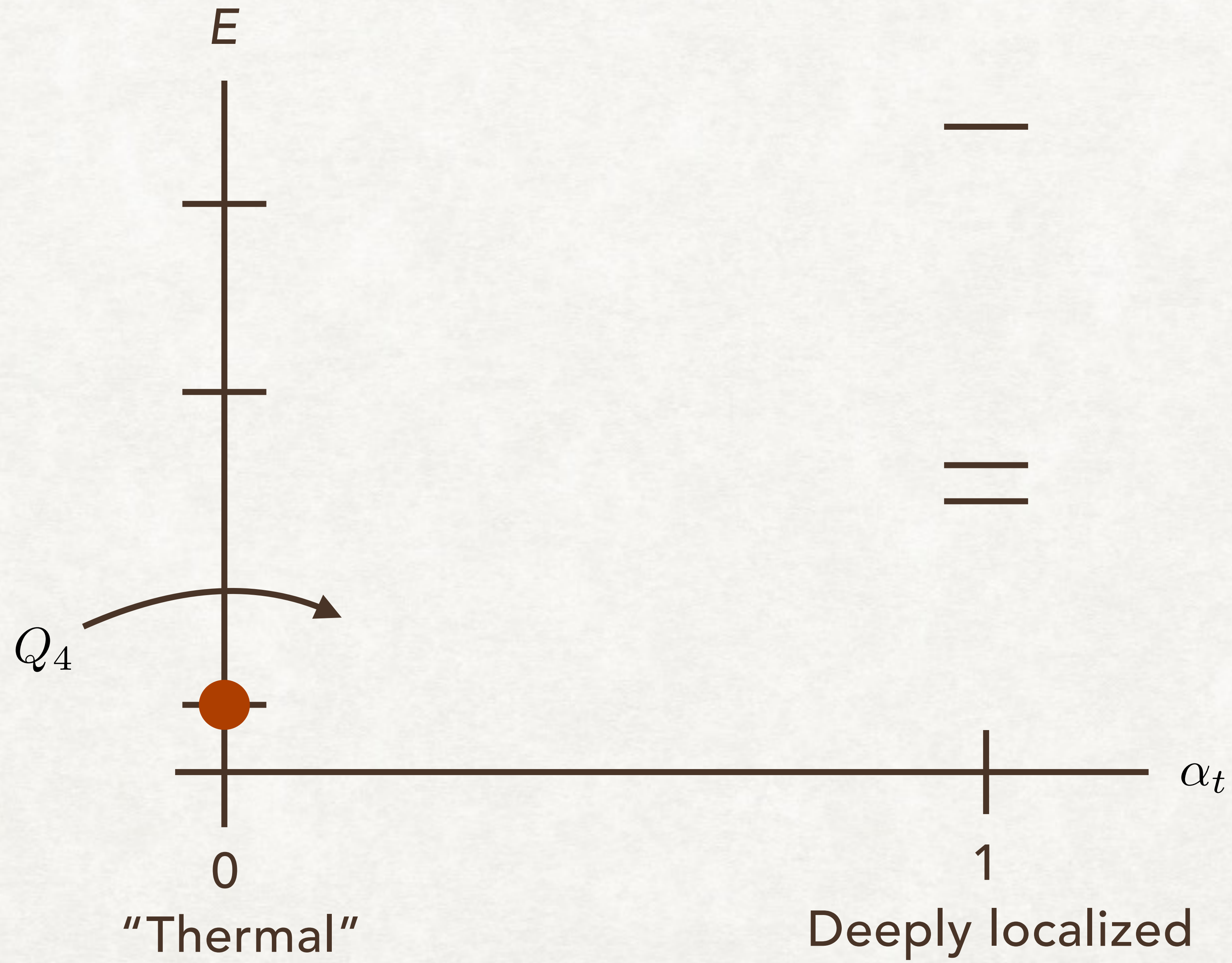
MBL Otto cycle

- Stroke 4: isotherm



MBL Otto cycle

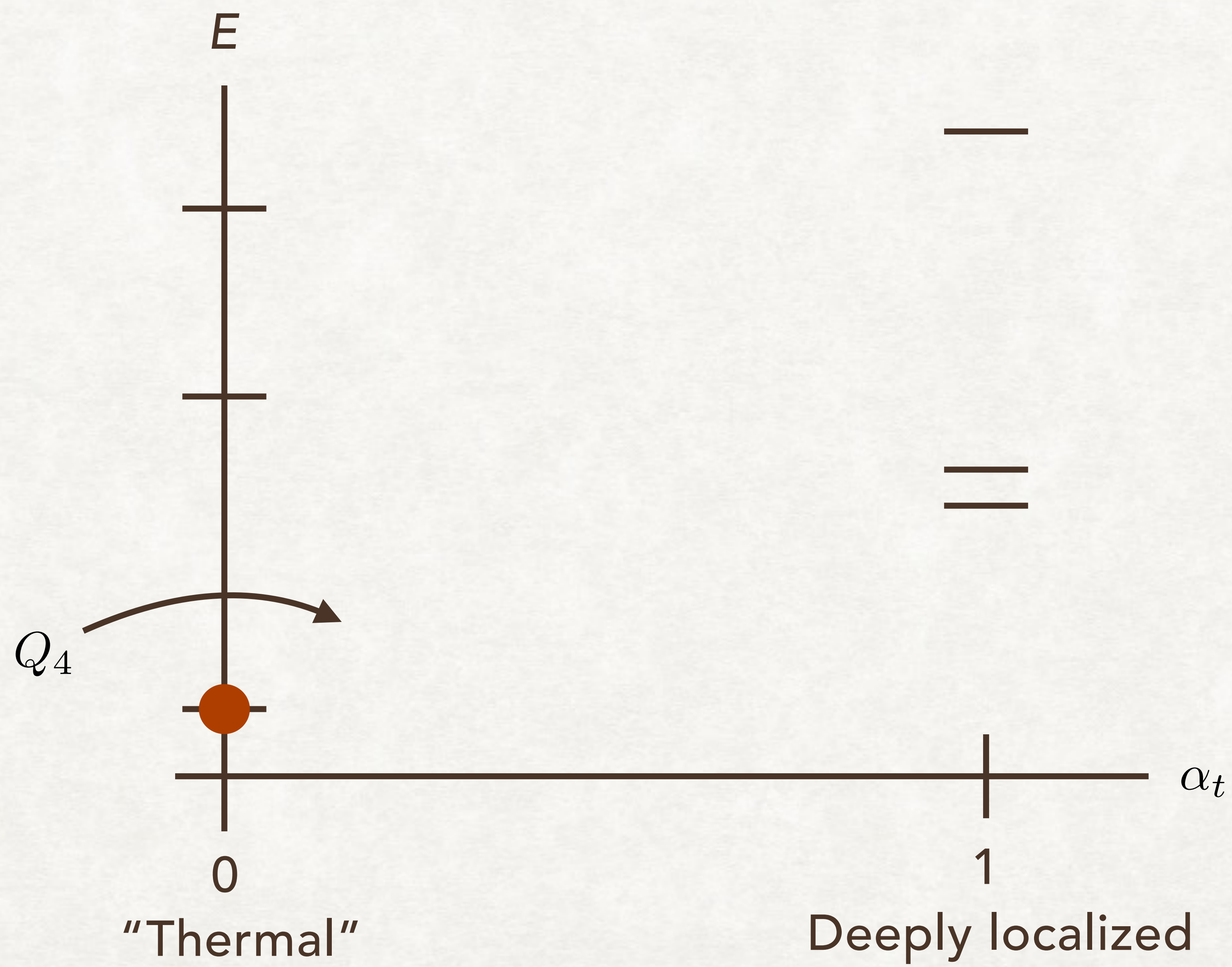
- Stroke 4: isotherm



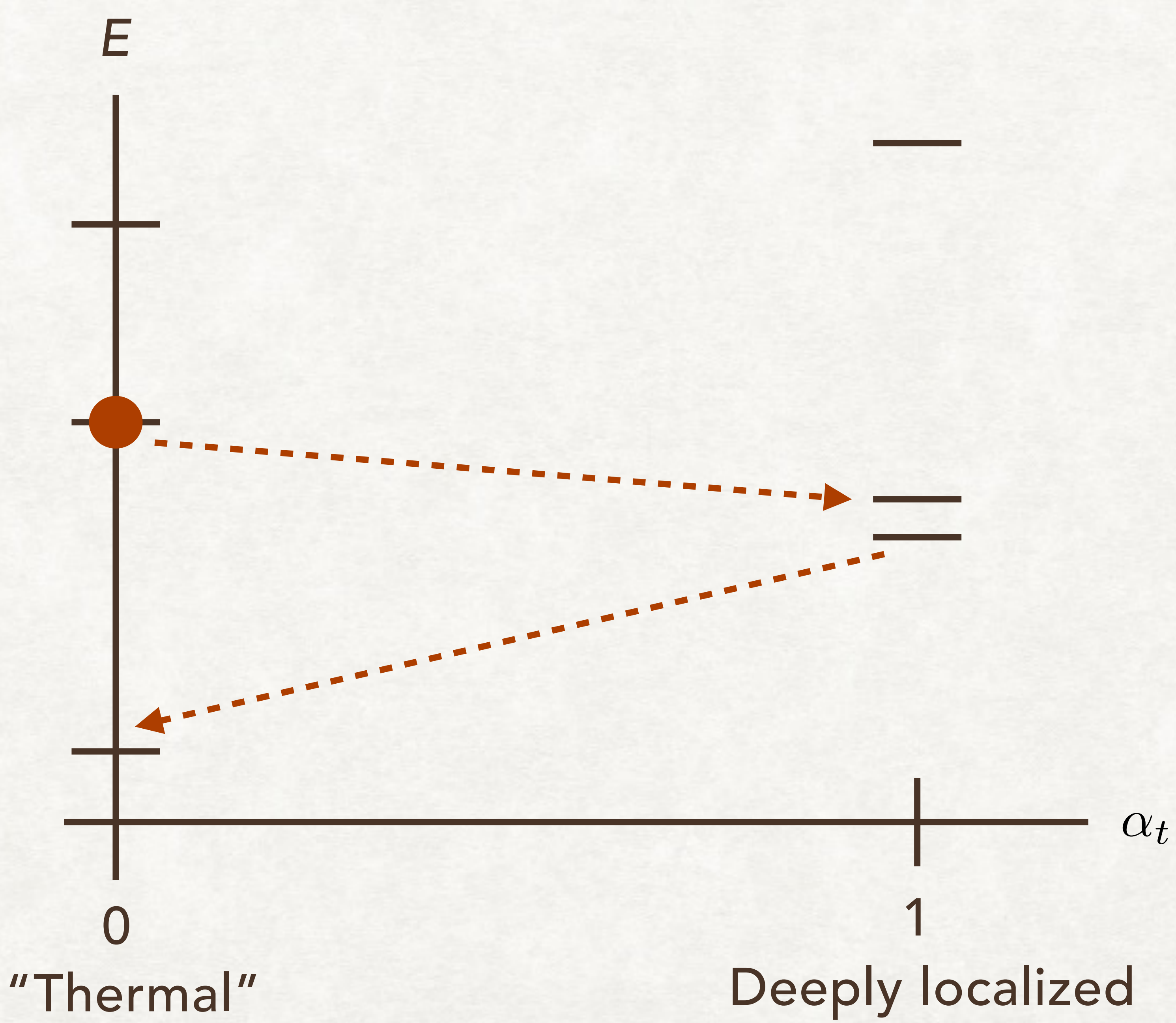
MBL Otto cycle

- Stroke 4: isotherm
- Reset to

$$\rho(0) = \frac{e^{-H_{\text{ETH}}/T_{\text{H}}}}{Z_{\text{ETH}}}$$

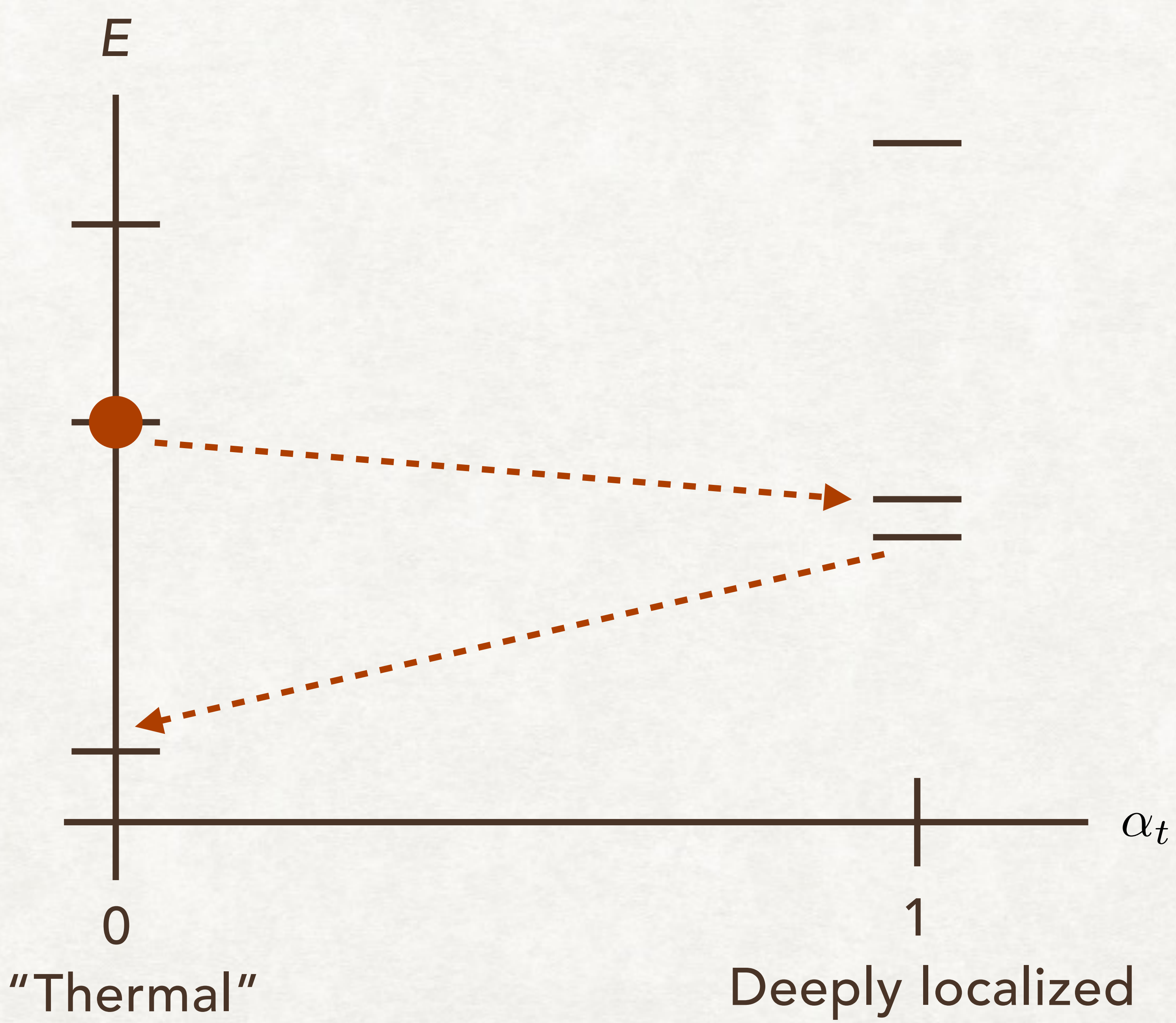


MBL Otto cycle



MBL Otto cycle

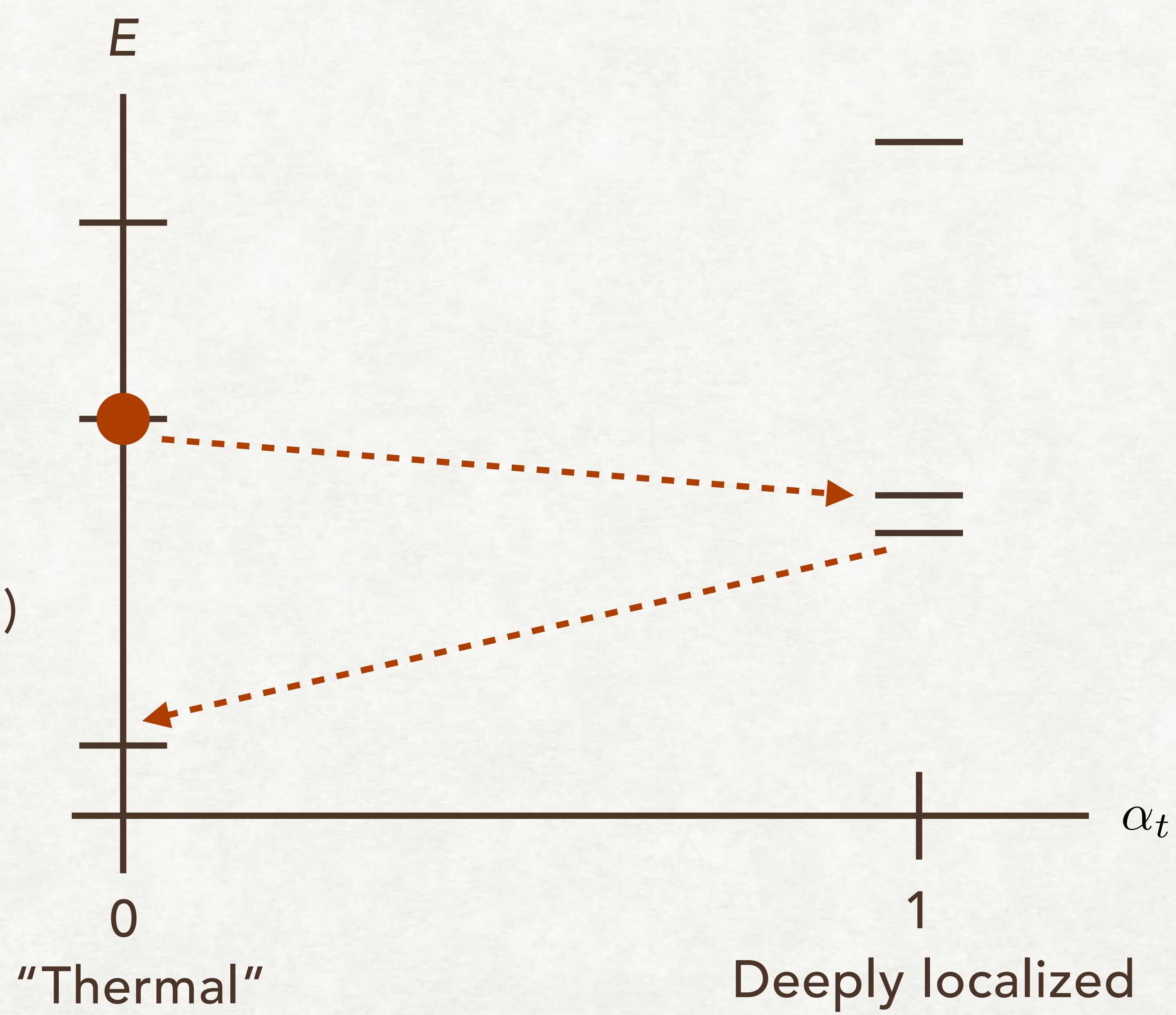
Why net work $\langle W_{\rm tot} \rangle > 0$



MBL Otto cycle

Why net work $\langle W_{\text{tot}} \rangle > 0$

- $W_{\text{b}} \ll \langle \delta \rangle$
- Prob(small MBL gap) > Prob(small ETH gap)



Evaluating the MBL Otto cycle

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$$\langle W_{\text{tot}} \rangle , \quad \eta_{\text{MBL}}$$

Evaluating the MBL Otto cycle

$$\langle W_{\text{tot}} \rangle \,, \quad \eta_{\text{MBL}}$$

Strategy

Evaluating the MBL Otto cycle

$$\langle W_{\text{tot}} \rangle \,, \quad \eta_{\text{MBL}}$$

<u>Strategy</u>

- Integrate over many-body energy spectra

Evaluating the MBL Otto cycle

$$\langle W_{\mathrm{tot}} \rangle \, , \quad \eta_{\mathrm{MBL}}$$

<u>Strategy</u>

- Integrate over many-body energy spectra
  - Average gaps over *P*(δ)'s

Evaluating the MBL Otto cycle

$$\langle W_{\text{tot}} \rangle \, , \quad \eta_{\text{MBL}}$$

<u>Strategy</u>

- Integrate over many-body energy spectra
    - Average gaps over $P(\delta)$'s
- Average energies over quantum states

Evaluating the MBL Otto cycle

$$\langle W_{\text{tot}} \rangle \,, \quad \eta_{\text{MBL}}$$

<u>Strategy</u>

- Integrate over many-body energy spectra
- Average gaps over *P*(δ)'s
- Average energies over quantum states
- Check with numerical simulations

Evaluating the MBL Otto cycle

(I) Per-cycle power:

Evaluating the MBL Otto cycle

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Uh-oh.

Evaluating the MBL Otto cycle

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Localization to the rescue!

Evaluating the MBL Otto cycle

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N

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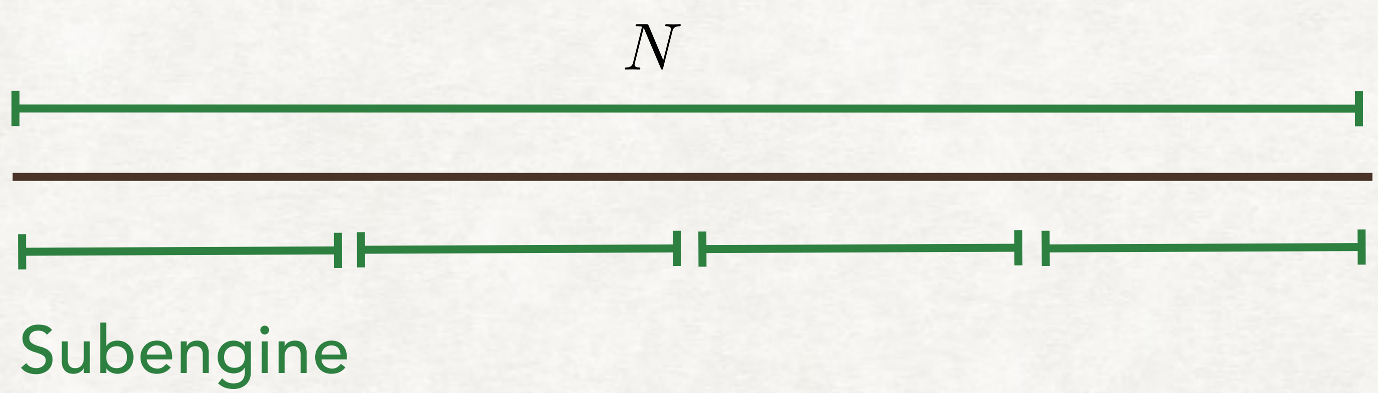

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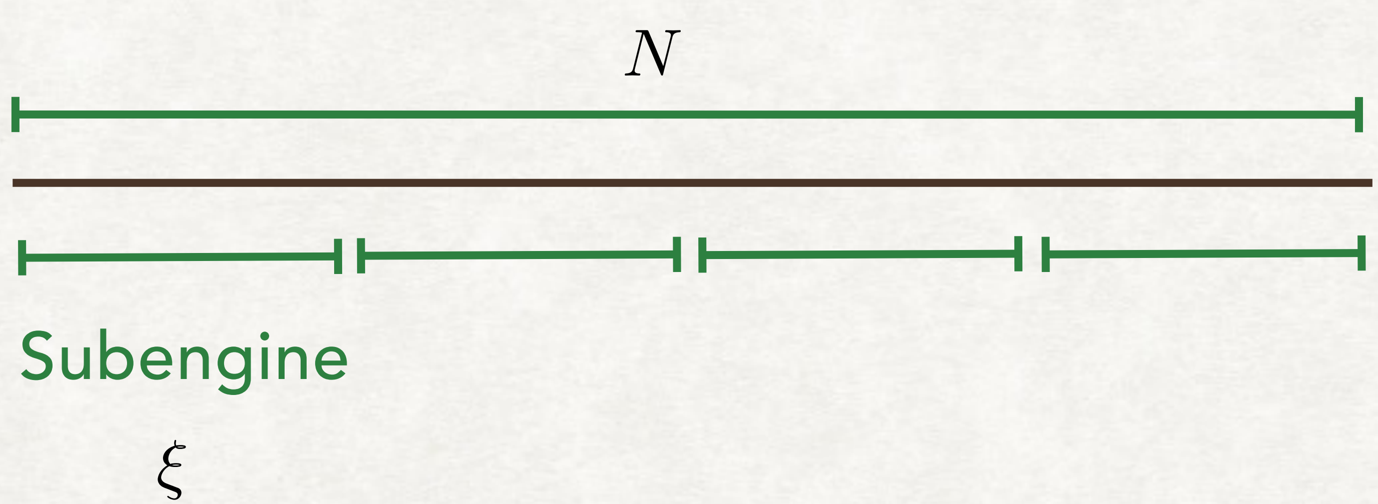

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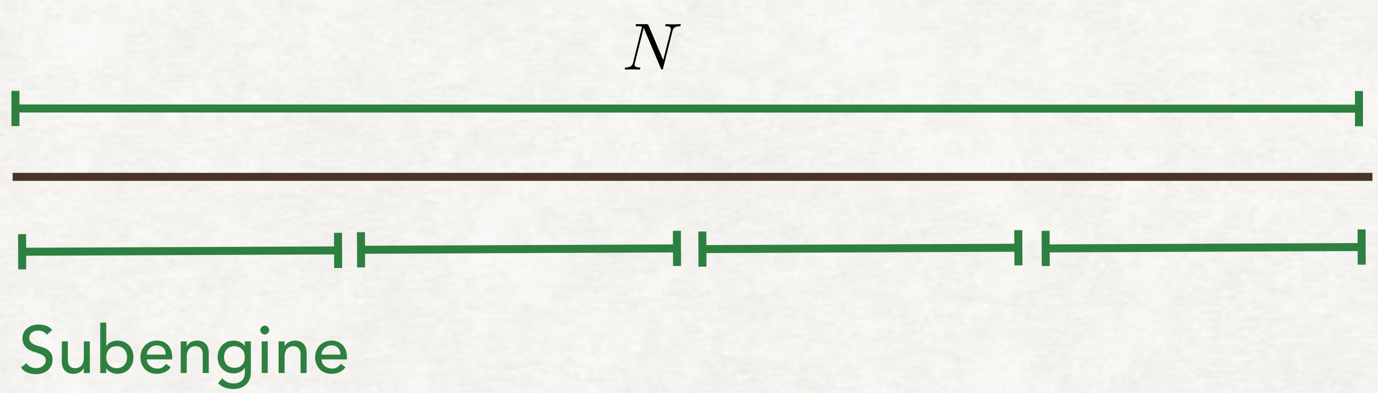

$\xi \longrightarrow \langle \delta \rangle_{\rm sub} \sim 2^{-\xi}$

Evaluating the MBL Otto cycle

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Uh-oh.

Localization to the rescue!

N

Subengine

$\xi \longrightarrow \langle \delta \rangle_{\rm sub} \sim 2^{-\xi}$

a subengine

a subengine.

Evaluating the MBL Otto cycle

(II) Efficiency:

Evaluating the MBL Otto cycle

(II) Efficiency: $\eta_{\text{MBL}} \sim 1 - \frac{W_{\text{b}}}{2\langle \delta \rangle}$

Evaluating the MBL Otto cycle

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Evaluating the MBL Otto cycle

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Compare

Evaluating the MBL Otto cycle

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Compare

$$\eta_{\mathrm{gas}} = 1 - \left(\frac{V_{\mathrm{large}}}{V_{\mathrm{small}}} \right)^{\frac{C_{\mathrm{p}}}{C_{\mathrm{V}}} - 1}$$

$$\eta_{\mathrm{QHO}} = 1 - \frac{\omega_{\mathrm{small}}}{\omega_{\mathrm{large}}}$$

Review: R. Kosloff and Y. Rezek, Entropy 19, 136 (2017).

Evaluating the MBL Otto cycle

(III) Order-of-magnitude estimates

Evaluating the MBL Otto cycle

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- Platform: silicon doped with phosphorus

Evaluating the MBL Otto cycle

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Evaluating the MBL Otto cycle 

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Evaluating the MBL Otto cycle

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  - Bacterial flagellar motor:  $P \sim$ 1 order of magnitude less

Evaluating the MBL Otto cycle

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Evaluating the MBL Otto cycle

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Evaluating the MBL Otto cycle 

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Evaluating the MBL Otto cycle

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- Compare: array of qubits (e.g., quantum dots)

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  - $P/V \sim 1$ kW/m^3


OPPORTUNITY
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(I) Experimental realizations

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  Kondov, McGehee, Xu, and DeMarco, Phys. Rev. Lett. 114, 083002 (2015).
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(II) More applications of MBL as an athermal resource 

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(III) Shortcuts to adiabaticity

- Re: Adolfo del Campo's talk

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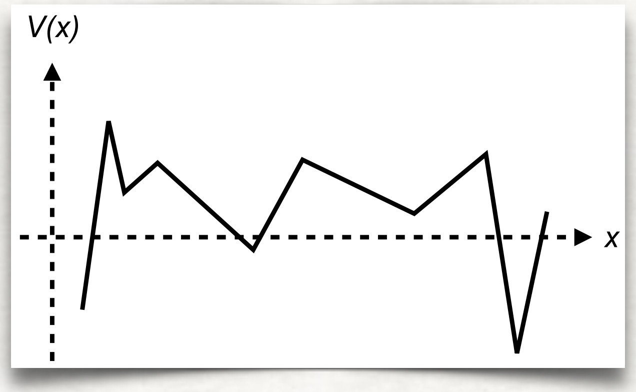
- Re: Adolfo del Campo's talk

(IV) Athermality beyond density operators →

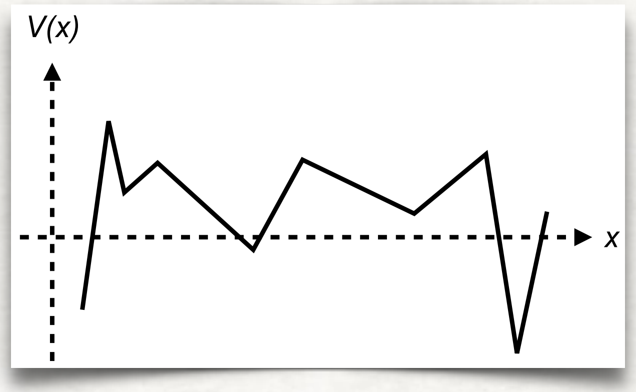
Recap

Recap

- Motivations →



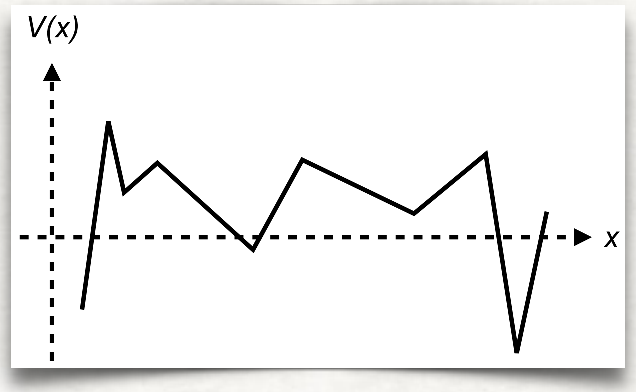
Recap

- Motivations → 

- Set-up

Recap

- Motivations



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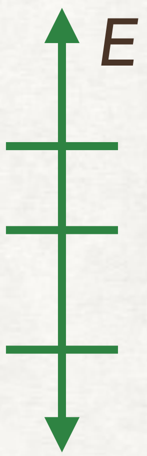
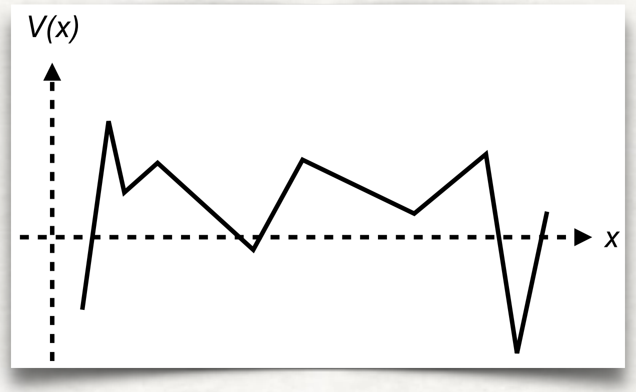
- MBL as an "athermal phase"



Recap

- Motivations → 

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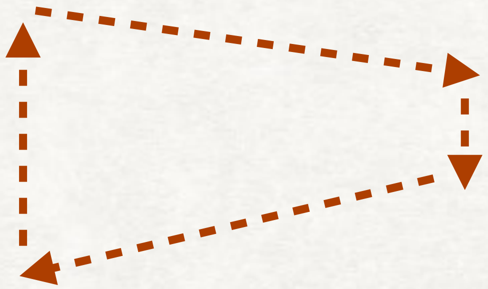
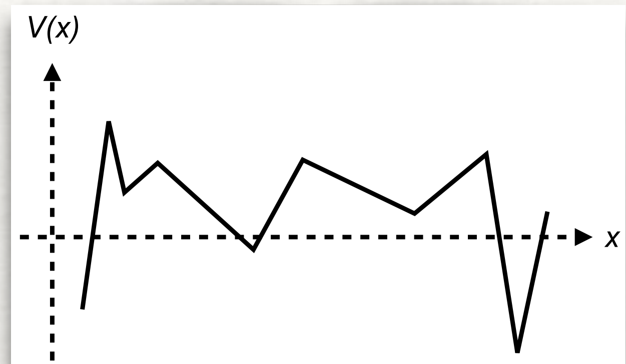
- MBL Otto cycle → 

Recap

- Motivations



- Set-up
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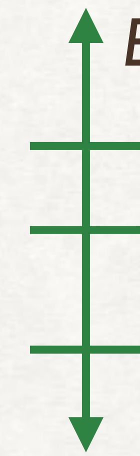
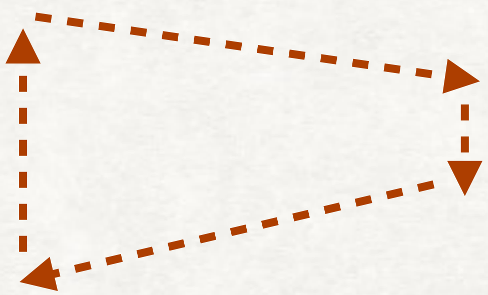


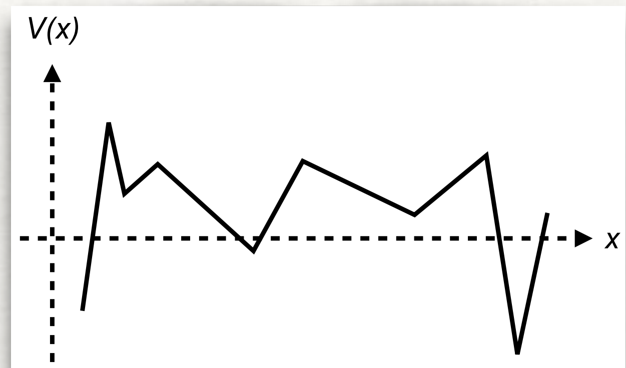
- MBL Otto cycle



- Evaluate performance

Recap

- Motivations →



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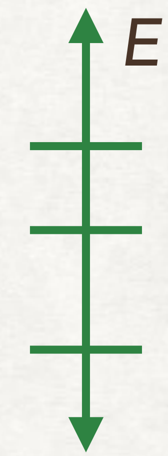
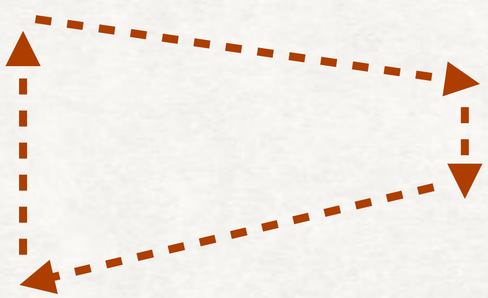


- MBL as an "athermal phase" →
- MBL Otto cycle →

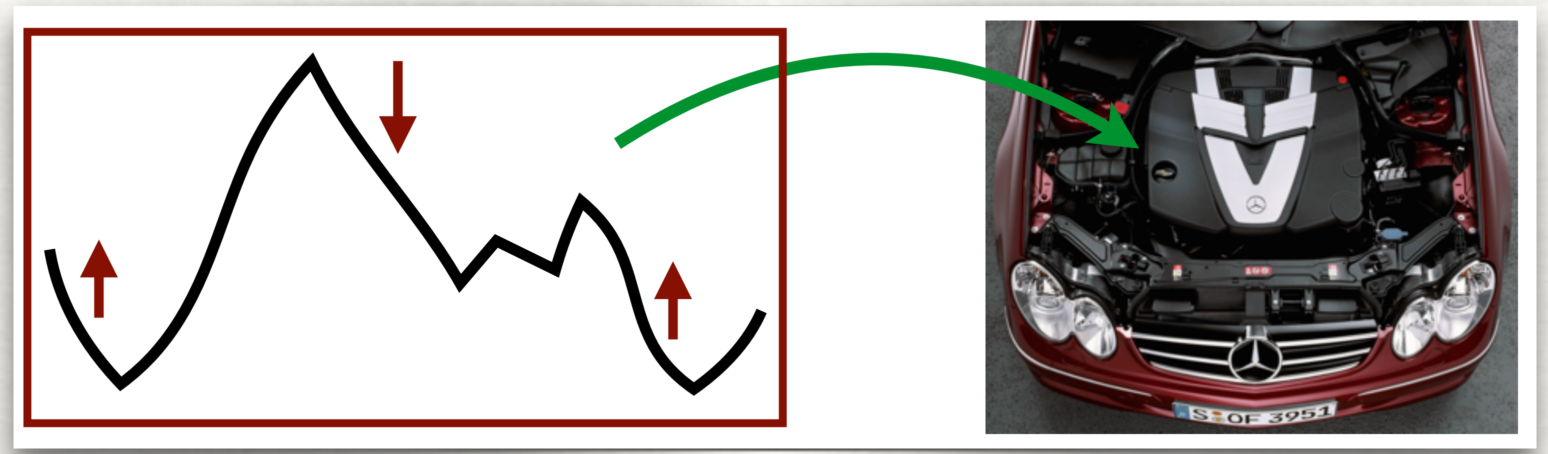


- Evaluate performance →

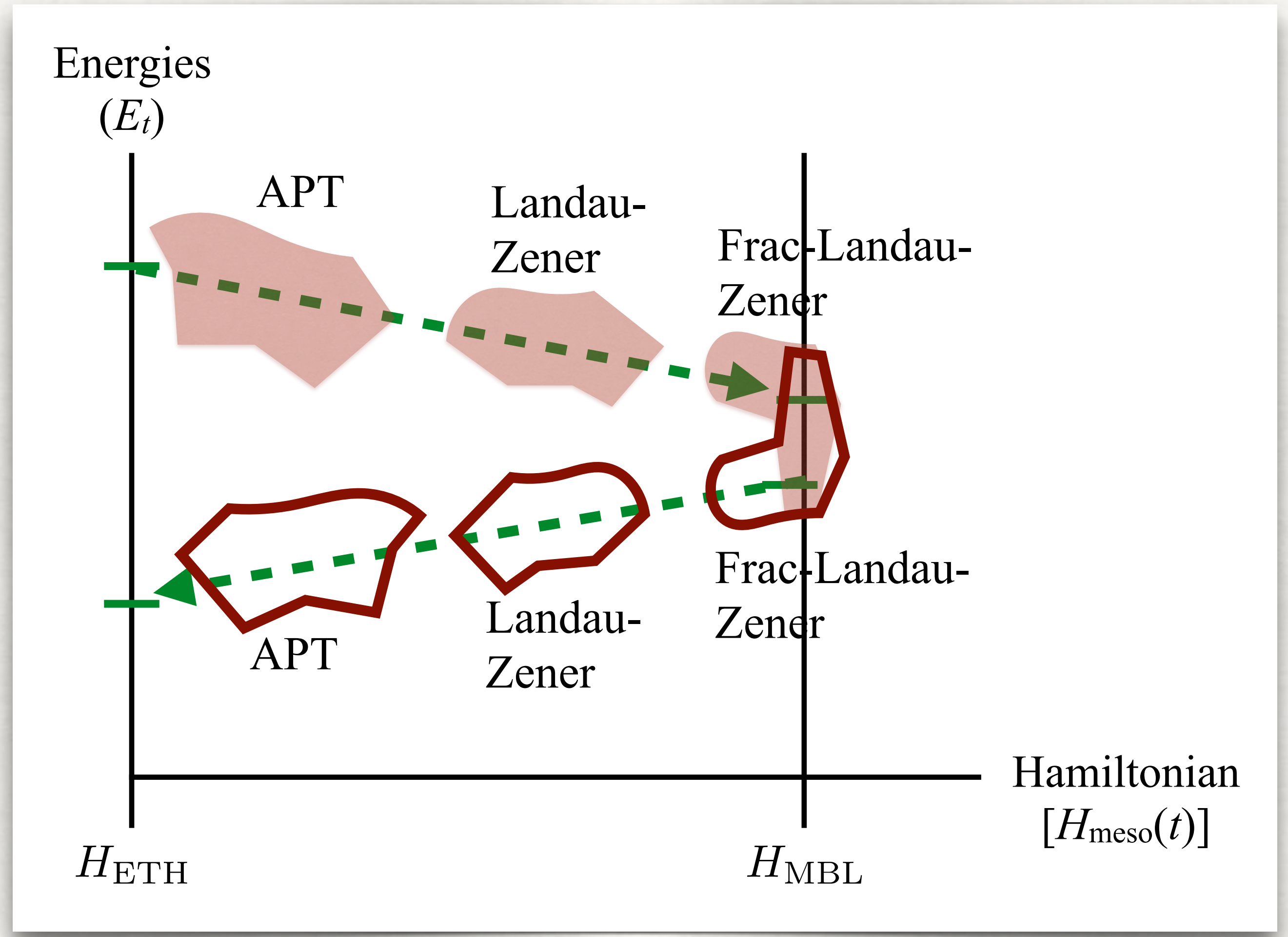
- Opportunities

Isn't it amazing, what we can achieve with random crap?

arXiv:1707.07008



Diabatic corrections



$$\langle W_{\text{frac}-\text{LZ}} \rangle \sim (v\delta_{-})^{1/3} \qquad \langle W_{\text{LZ}} \rangle \sim (1-\theta) W_{\text{b}}$$