Converting long-range entanglement into mixture: a tensor network approach to local equilibration

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arXiv: 2308.04291

MAX PLANCK INSTITUTE
OF QUANTUM OPTICS

Entanglement growth in non-equilibrium scenarios limits the applicability of TN

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Hinders simulations that could resolve both fundamental and practical questions

Entanglement barrier

White and Feiguin, 2004
Vidal, 2004
Haegeman et al., 2011

Unitary evolution

$$U(t) = e^{-iHt}$$

Low entangled
state or operator

$t = 0$ $\longrightarrow$ $t = \infty$

Entanglement barrier

White and Feiguin, 2004
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Unitary evolution

$$U(t) = e^{-iHt}$$

Low entangled state or operator

Simple macroscopic behavior

$t = 0$ $\longrightarrow$ $t = \infty$

Entanglement barrier: global quench

White and Feiguin, 2004
Vidal, 2004
Haegeman et al., 2011

Unitary evolution

$$U(t) = e^{-iHt}$$

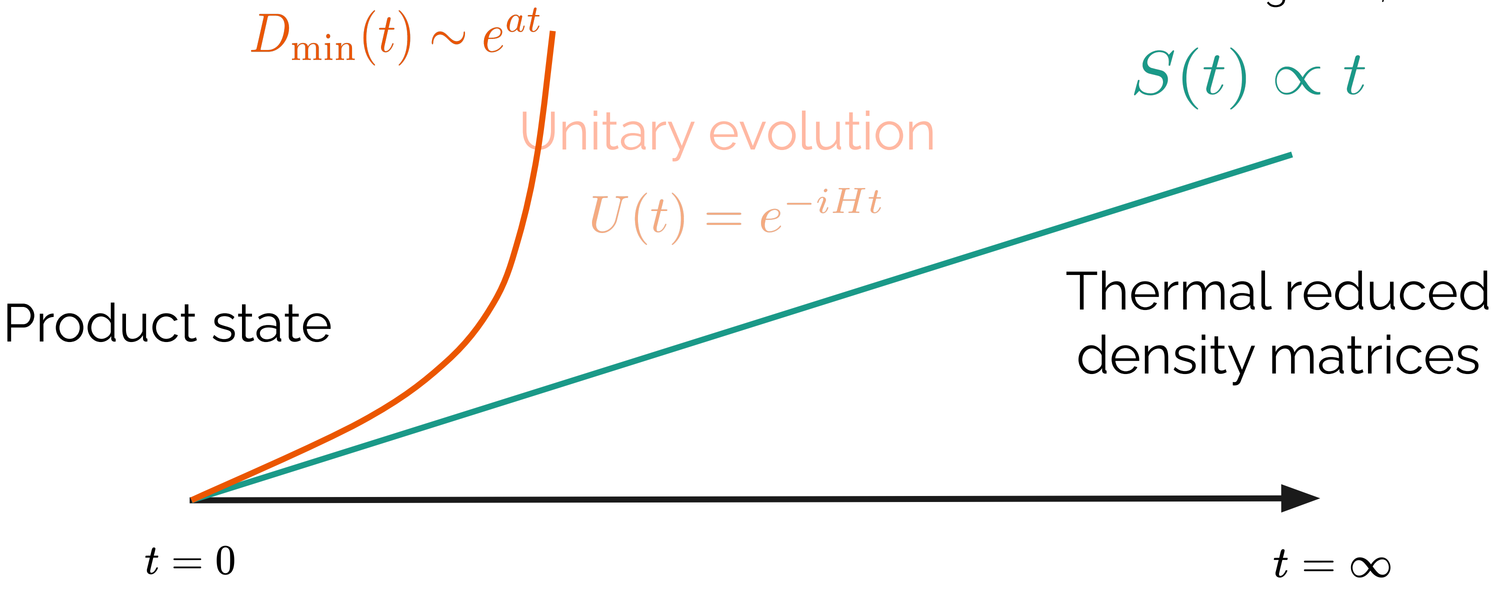
Product state

Thermal reduced density matrices

$t = 0$ $\qquad$ $t = \infty$

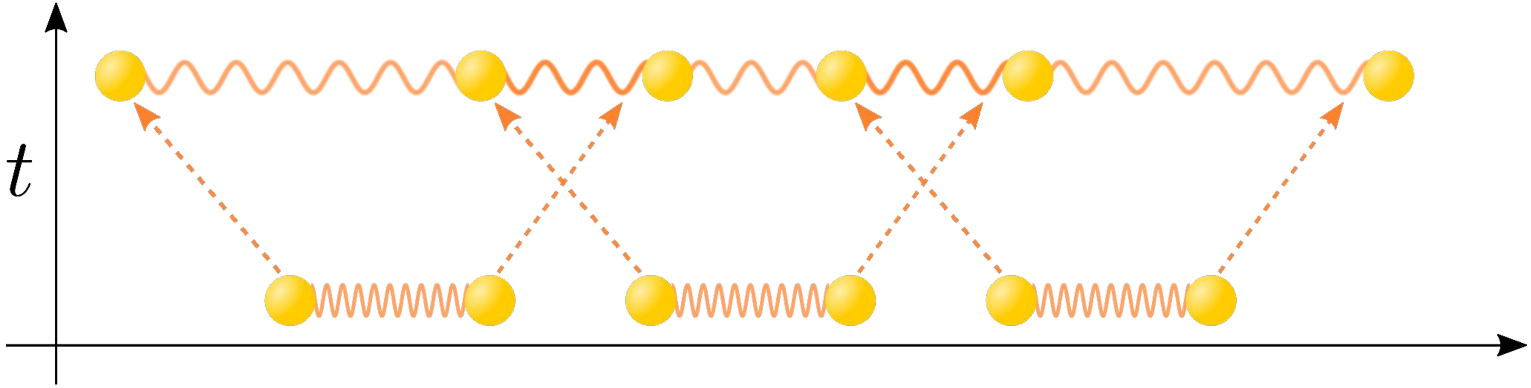
Entanglement barrier: global quench

Leviatan et al., 2017
White et al., 2018
Rakovszky et al., 2022
Kvorning et al., 2022

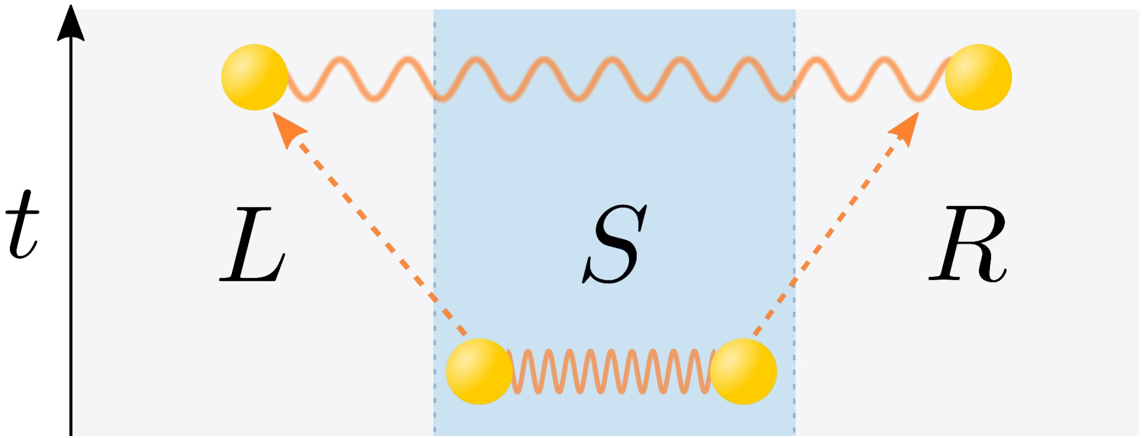


Quasiparticle picture

Calabrese and Cardy, 2005



Quasiparticle picture



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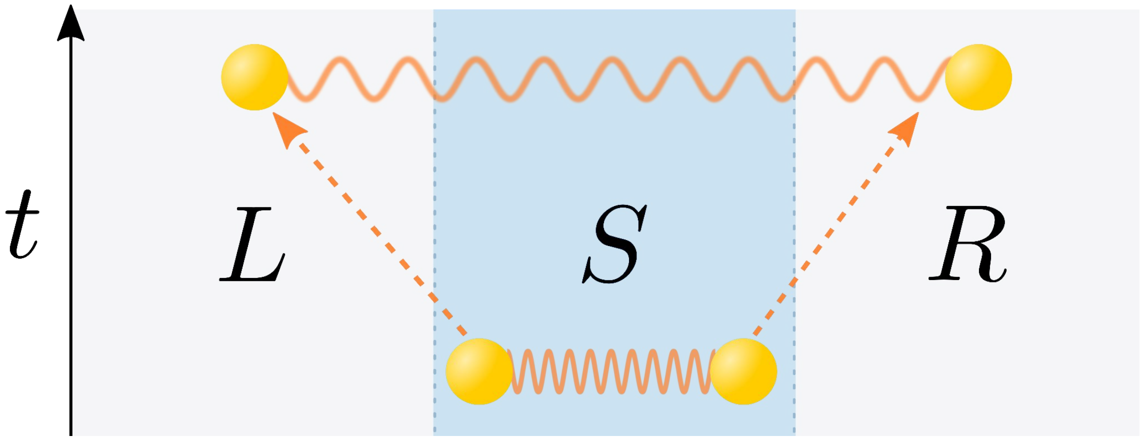
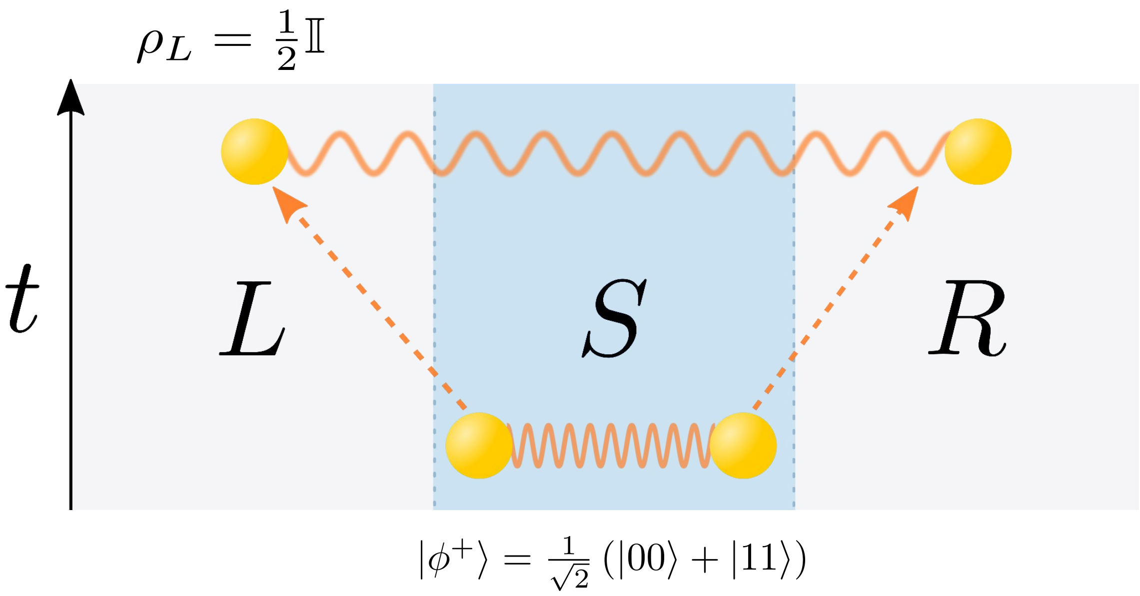
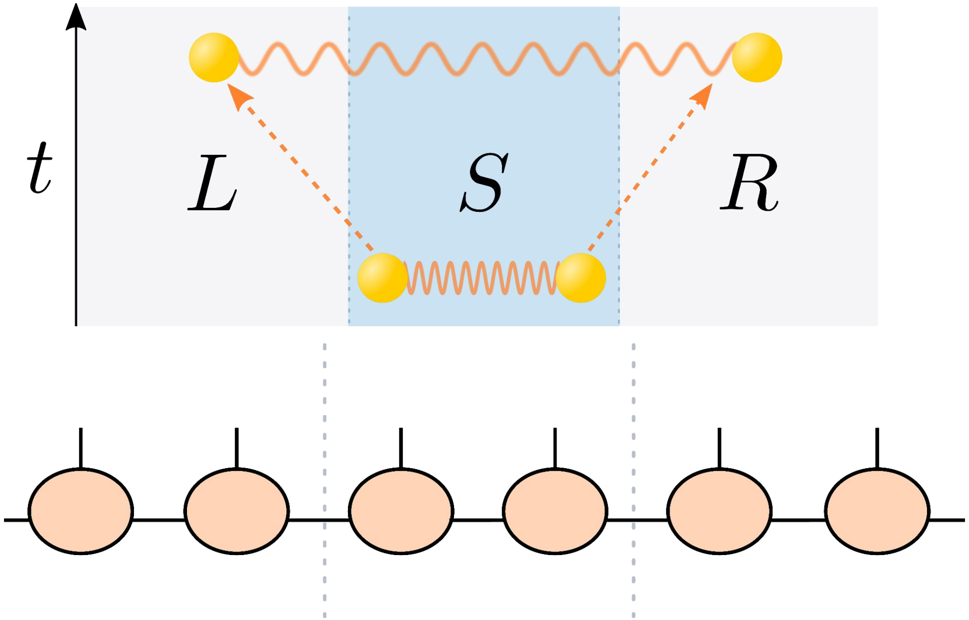


$$|\phi^+\rangle = \frac{1}{\sqrt{2}}\left(|00\rangle + |11\rangle\right)$$

Quasiparticle picture



Tensor network picture



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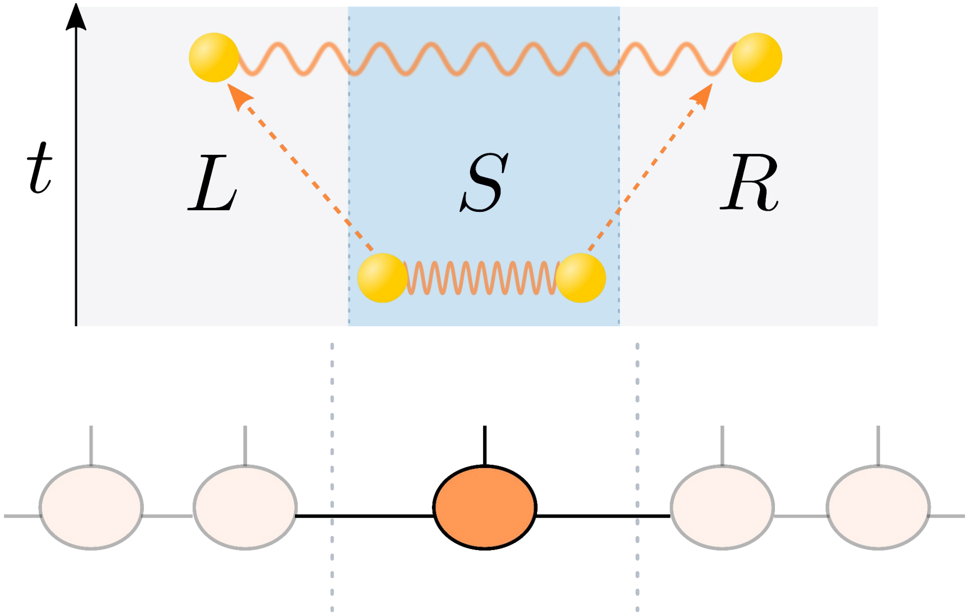

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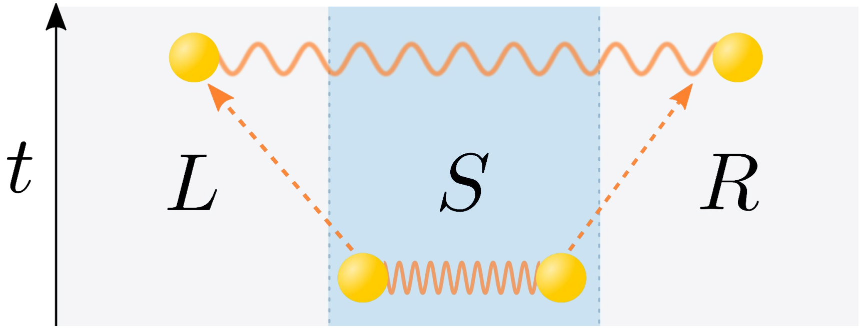

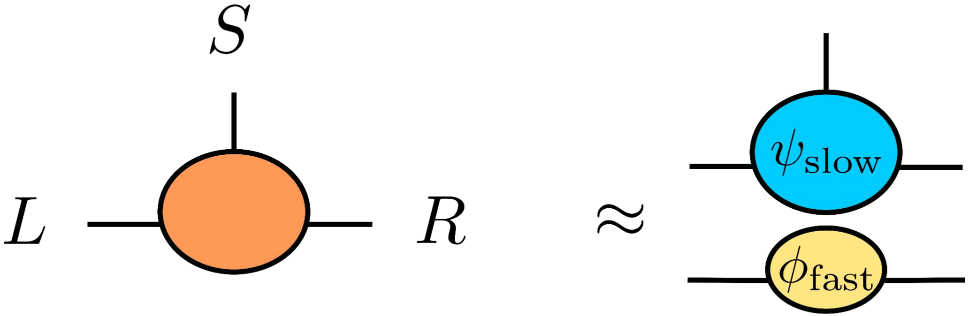

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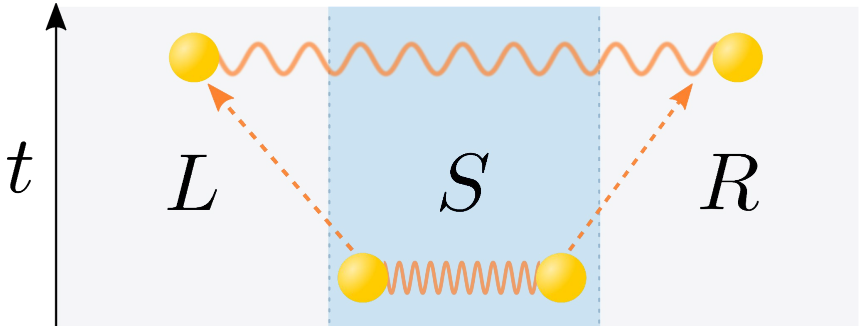
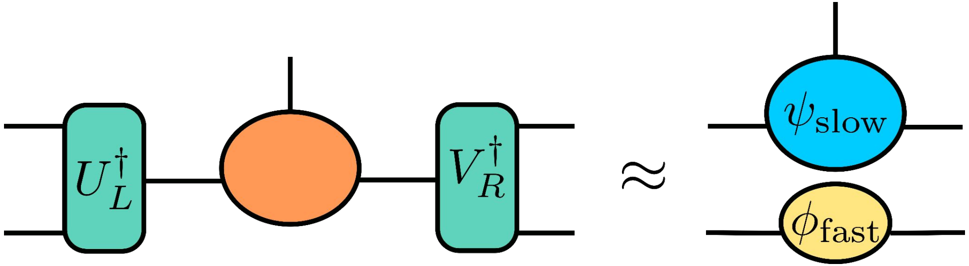
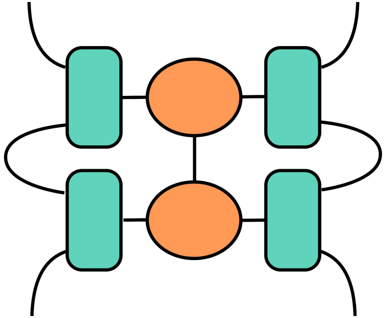
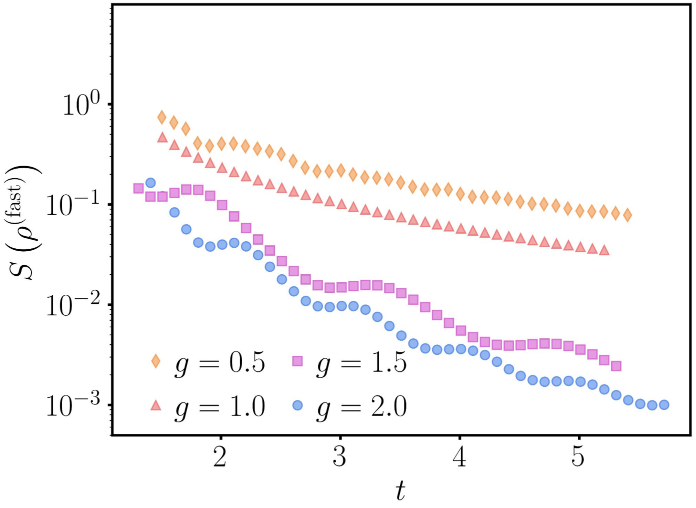




Long-range entanglement decoupling (integrable)

$$H = -\sum_n \left(\sigma_n^z \sigma_{n+1}^z + g\sigma_n^x\right)$$





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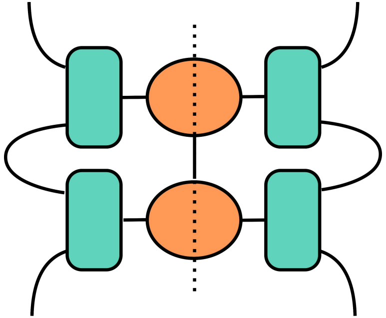
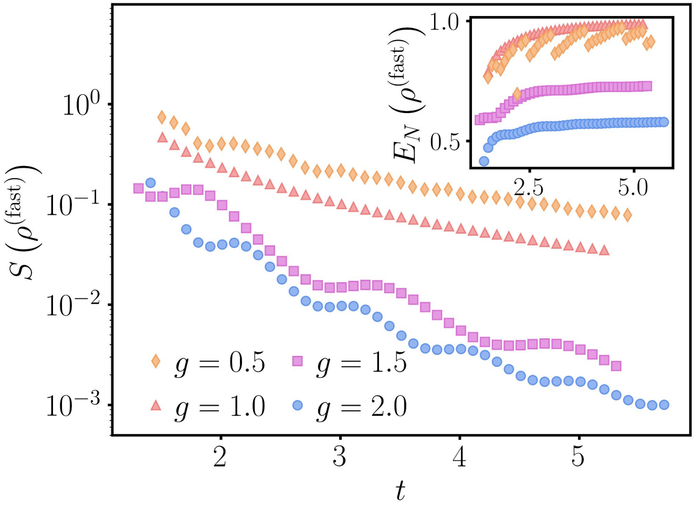
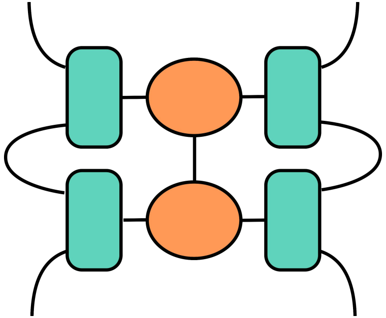
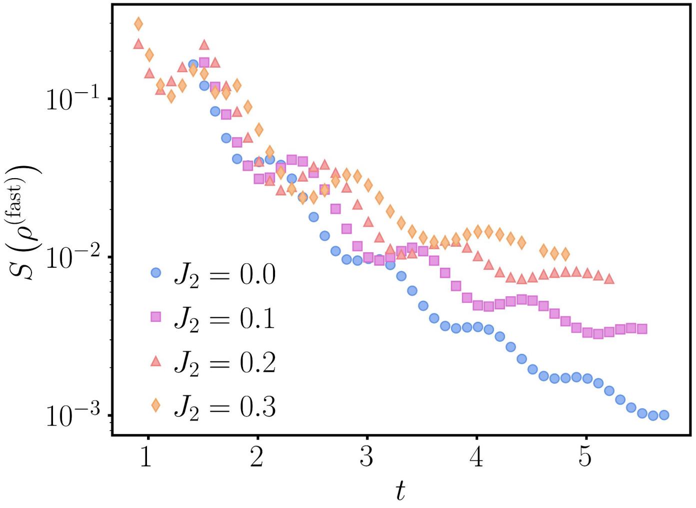




Long-range entanglement decoupling (non-integrable)

$$H = -\sum_n \left(\sigma_n^z \sigma_{n+1}^z + g\sigma_n^x + J_2 \sigma_n^z \sigma_{n+2}^z\right)$$





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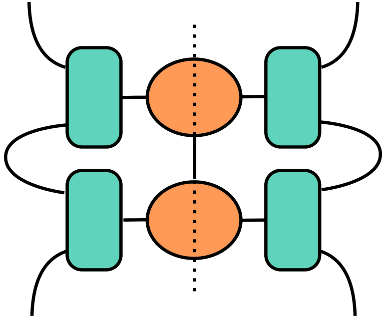
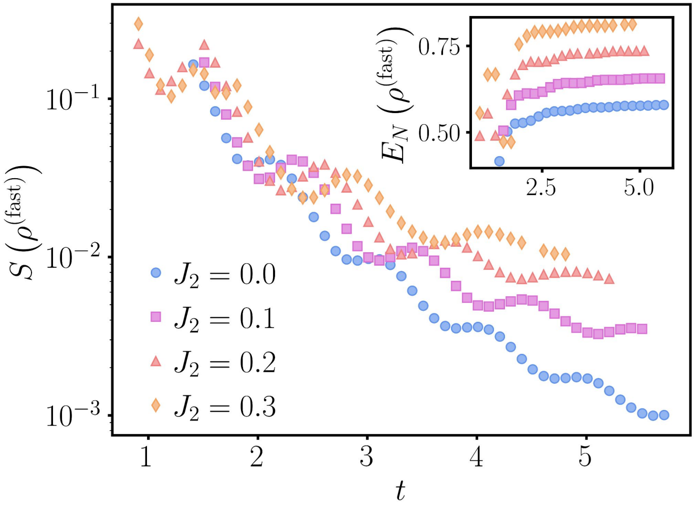
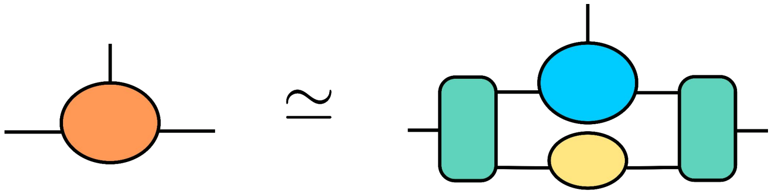


$E_N(\rho_{\text{fast}})$

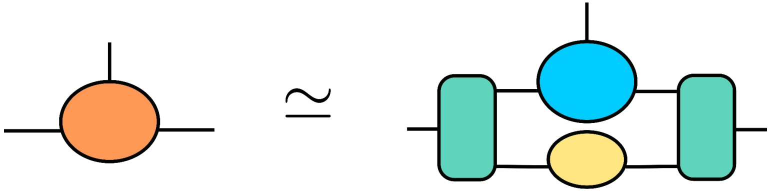


Mixing the long-range degrees of freedom



Fast degrees of freedom contribute via their reduced density matrices to the local observables in the neighbouring blocks

Mixing the long-range degrees of freedom



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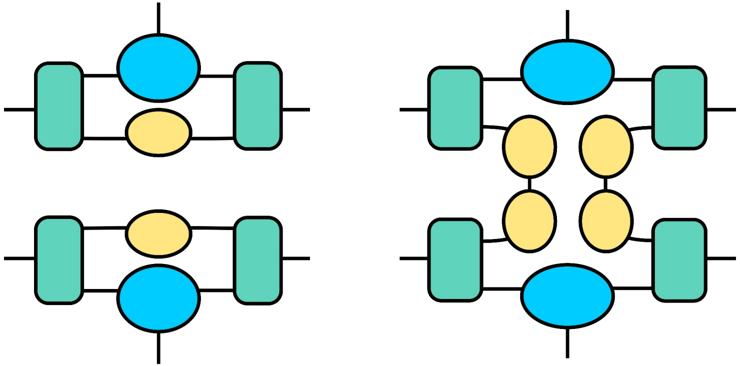
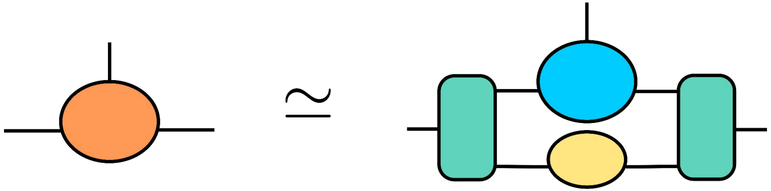


Substitute them by the product of their marginals

Mixing the long-range degrees of freedom



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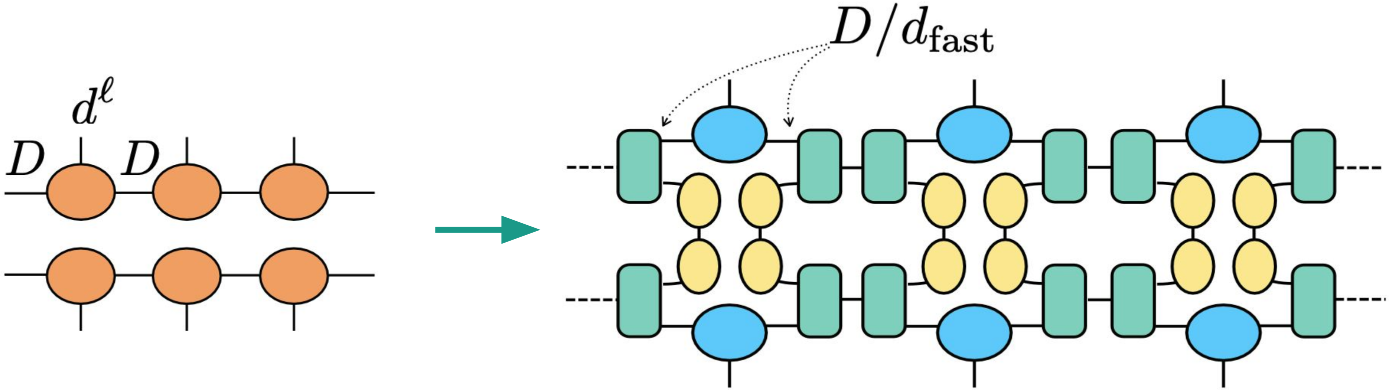
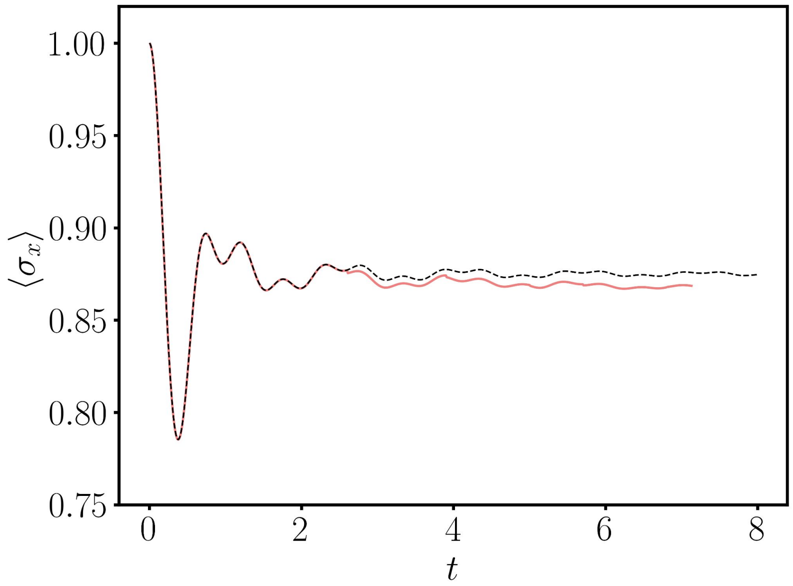


Truncation results

$$H = -\sum_n \left(\sigma_n^z \sigma_{n+1}^z + g\sigma_n^x\right)$$



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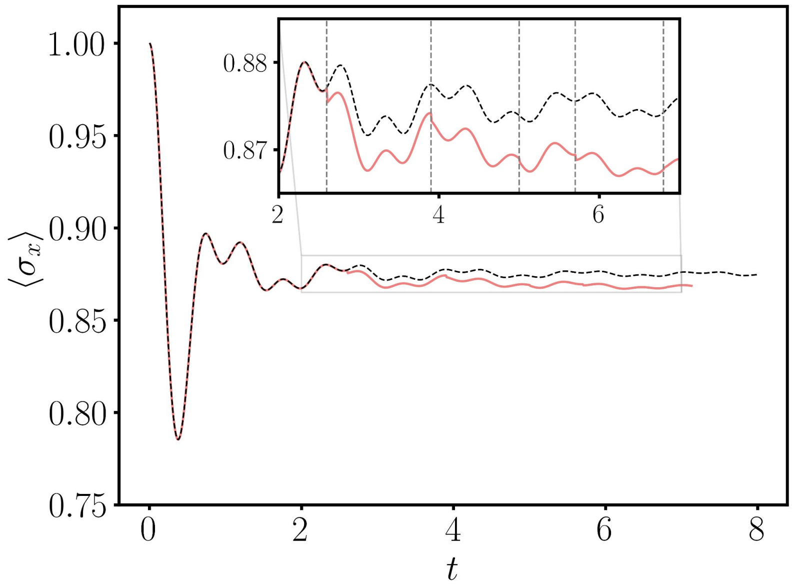
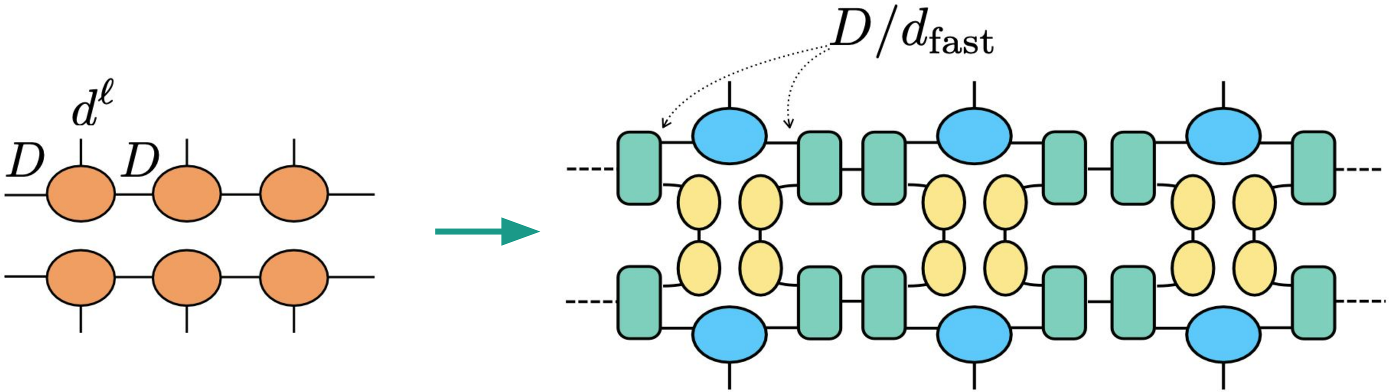


Improved heuristic algorithm



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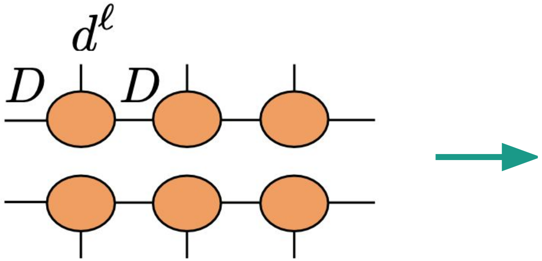
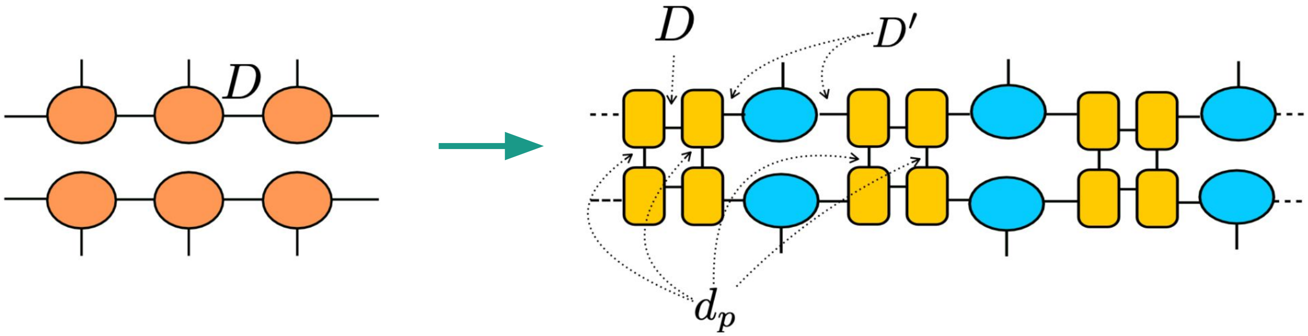
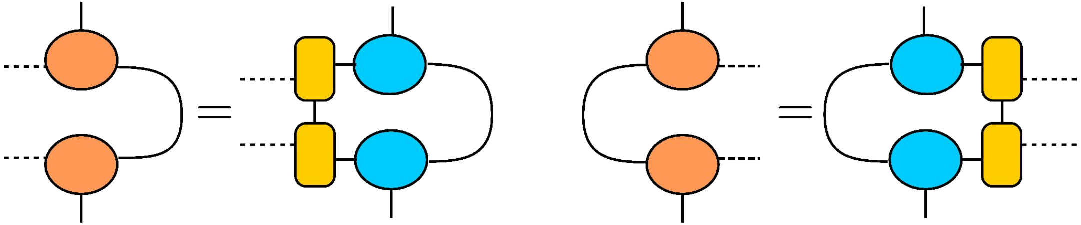


The original decomposition was a constructive way to construct states that preserved the marginals. We can also variationally look for states with smaller bond dimension that preserve them.

Improved heuristic algorithm

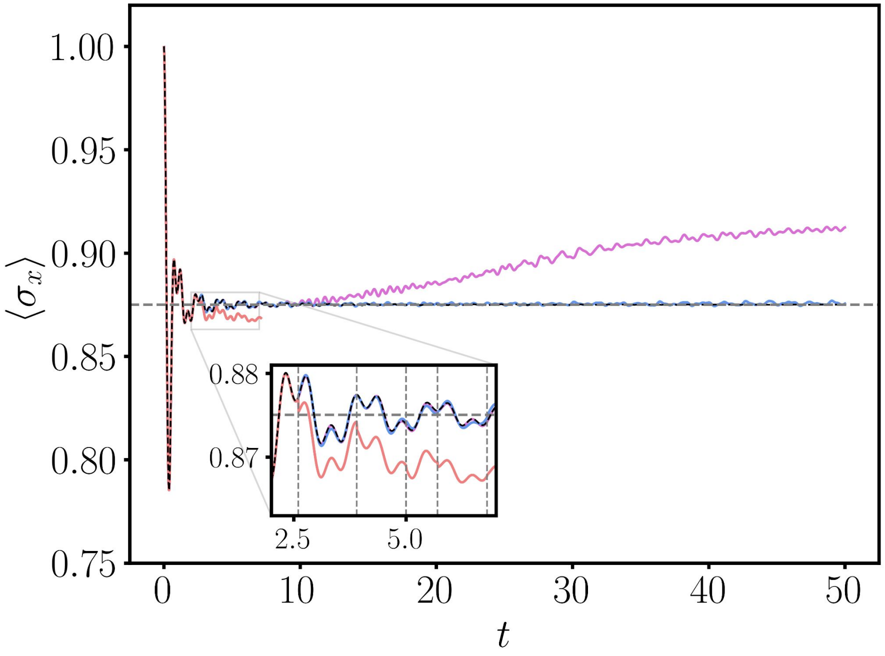


such that



Results integrable

$$H = -\sum_n \left(\sigma_n^z \sigma_{n+1}^z + g\sigma_n^x\right) \qquad g = 2$$



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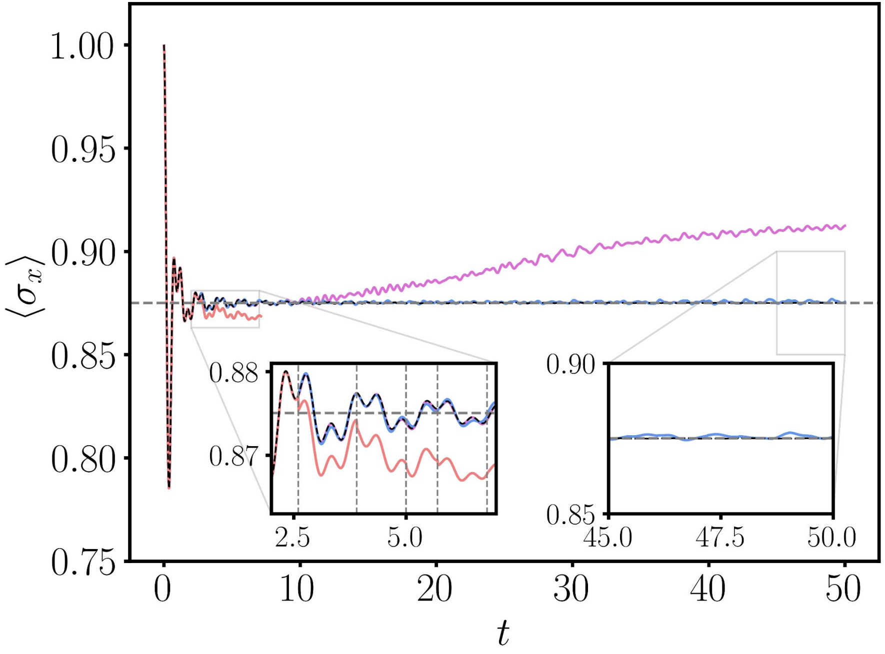

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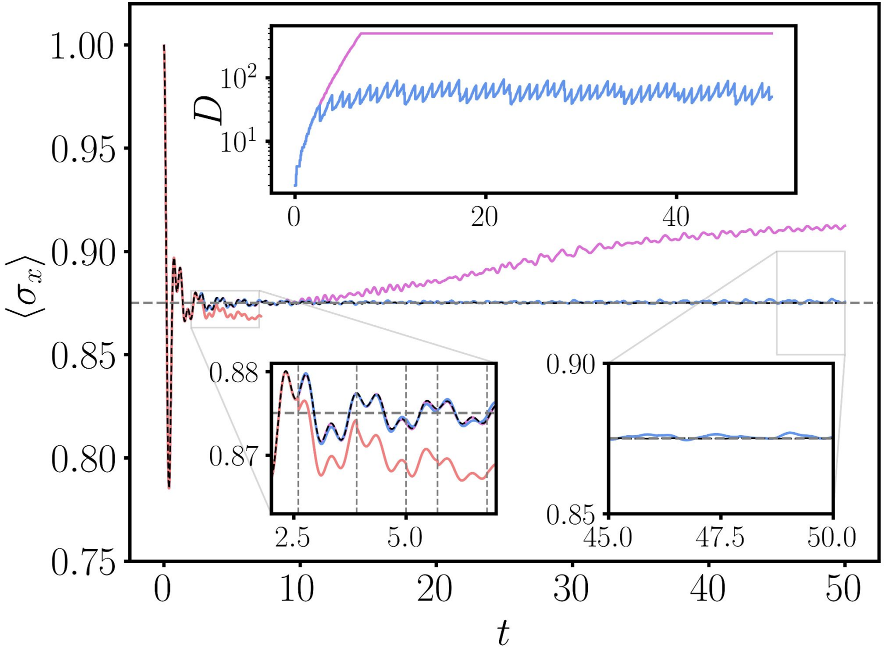
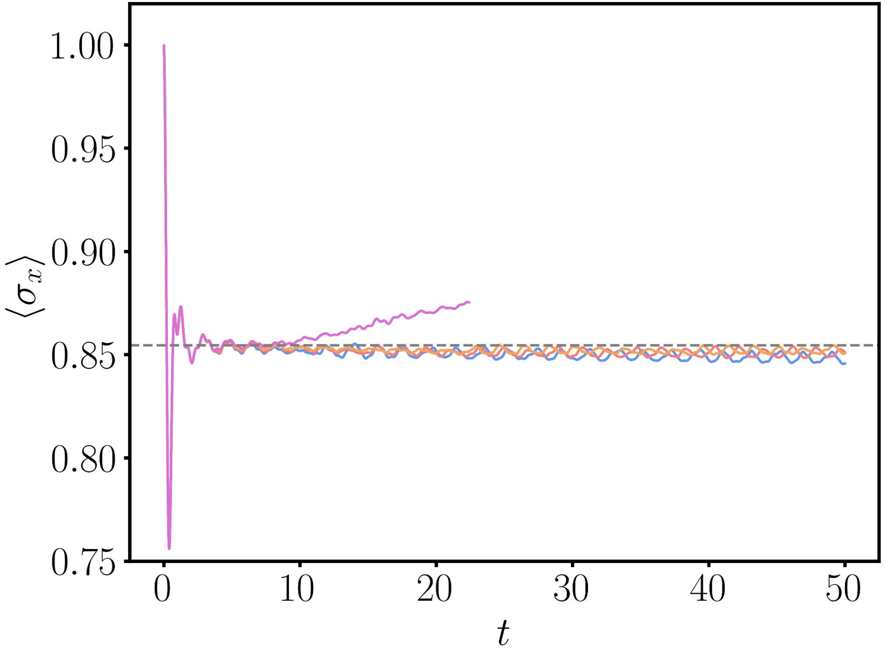


Results non-integrable

$$H = -\sum_n \left(\sigma_n^z \sigma_{n+1}^z + g\sigma_n^x + J_2 \sigma_n^z \sigma_{n+2}^z\right)$$

$$g = 2$$
$$J_2 = 0.1$$



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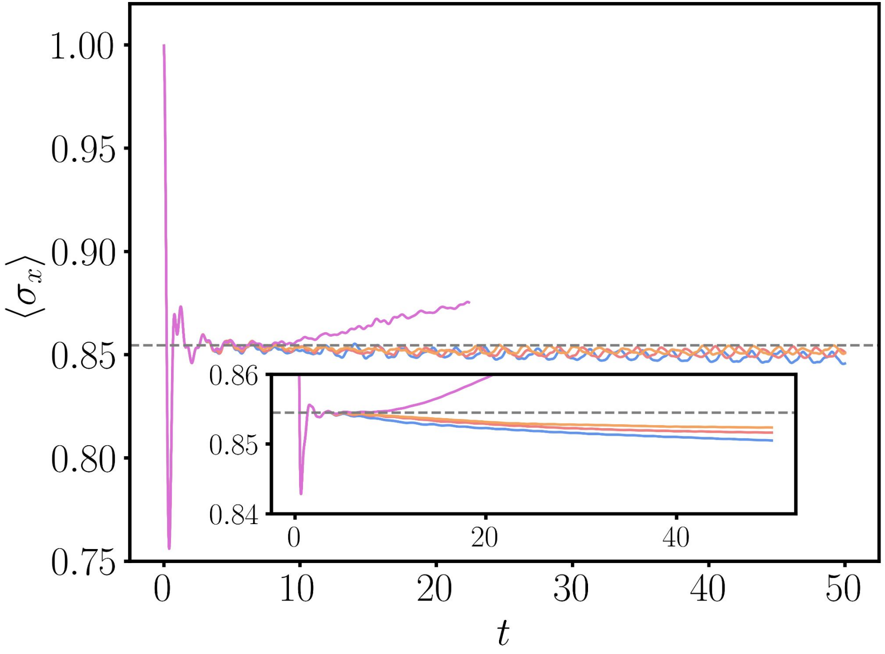

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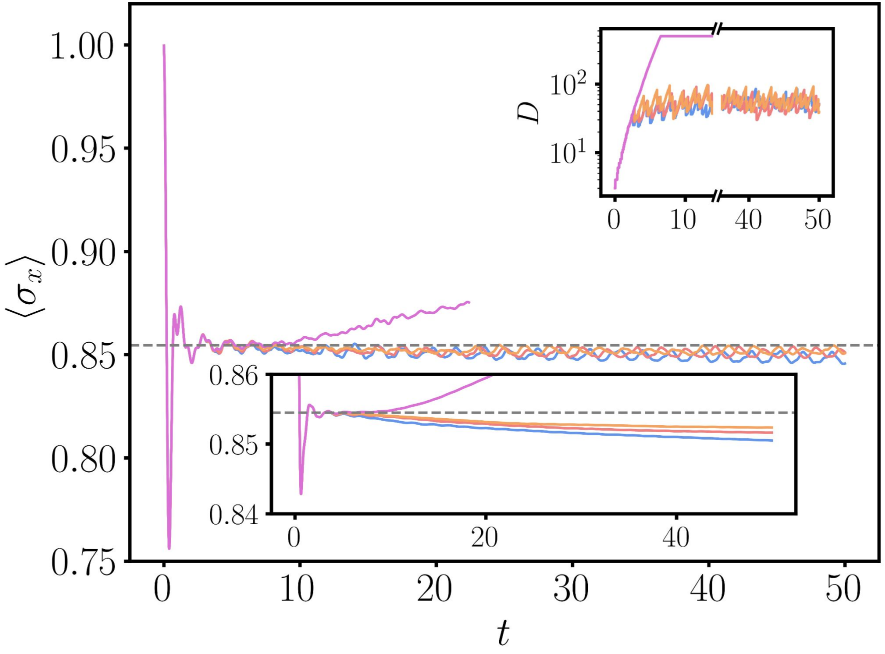

Conclusions

- We identify the long-range entanglement produced after a quantum quench and propose a technique to convert it into mixture
- Our approach is inspired by the intuitive understanding of entanglement dynamics in terms of the radiation of quasiparticles
- We have generalized our intuition to an algorithm that goes beyond the quasiparticle regime

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Thank you for your attention!

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