Advanced tensor network methods for many body physics

Quantum dynamics in two dimensions etc.

Luka Pavešić, University of Padova

Quantum many body problems from the viewpoint of tensor network methods

2+ D models

long-range interactions

1D models

long time dynamics (thermalization)

nearest-neighbour interactions

generic quantum chaotic systems

volume-law entangled systems

easy → unreasonable

Quantum many body problems from the viewpoint of tensor network methods

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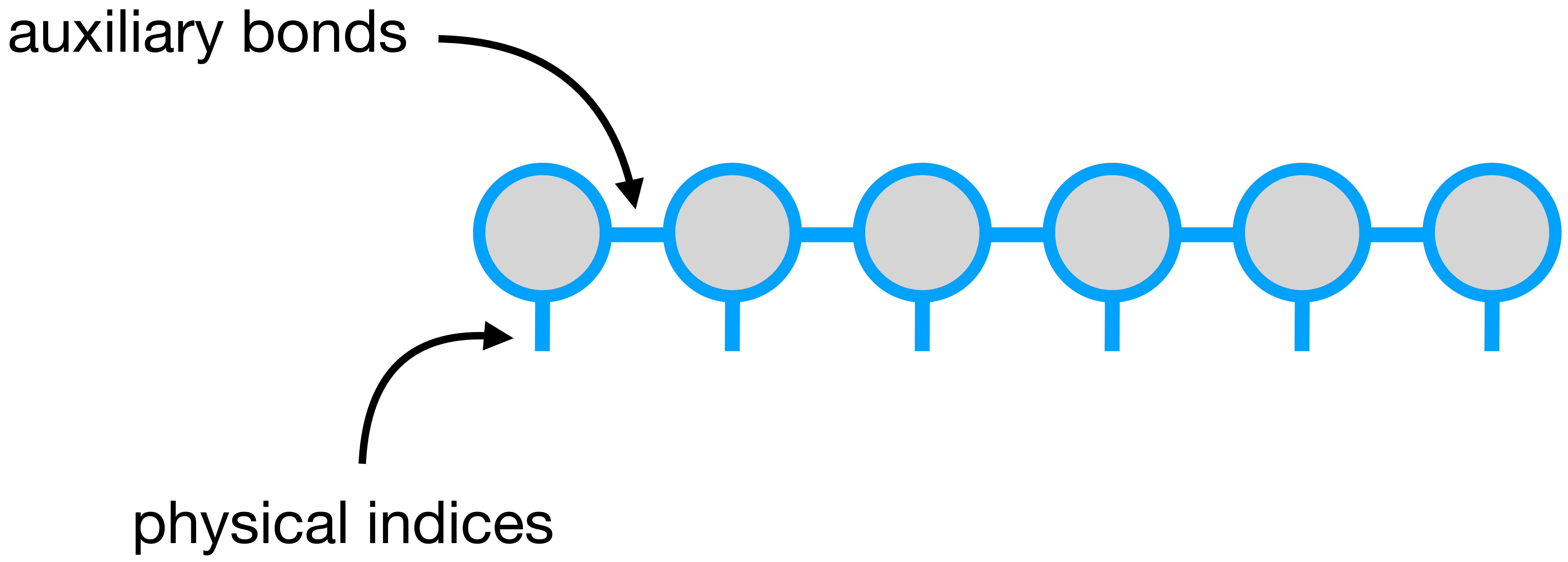
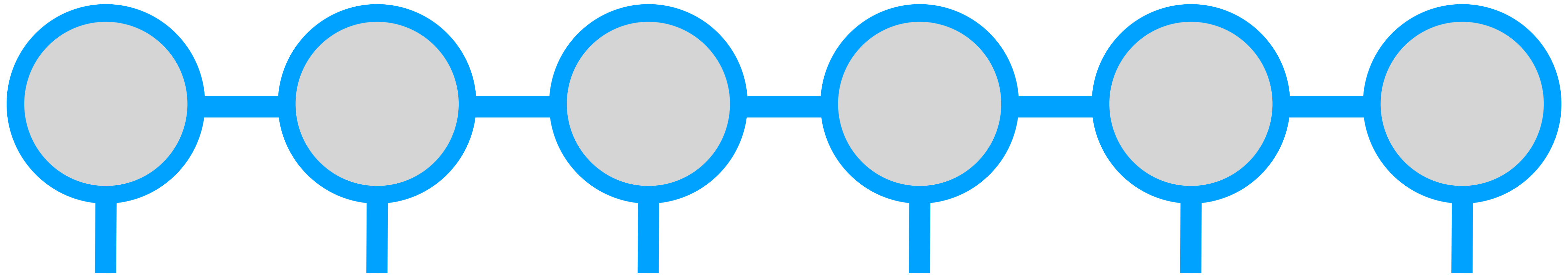
Tensor networks

are an efficient way to compress the wavefunction.



There is a fundamental relation between the ***size of the auxiliary bonds (compression)*** and the **amount of correlations captured**.

Why does it work?



(1) Ground states of systems with short range interactions have dominantly short-range correlations.

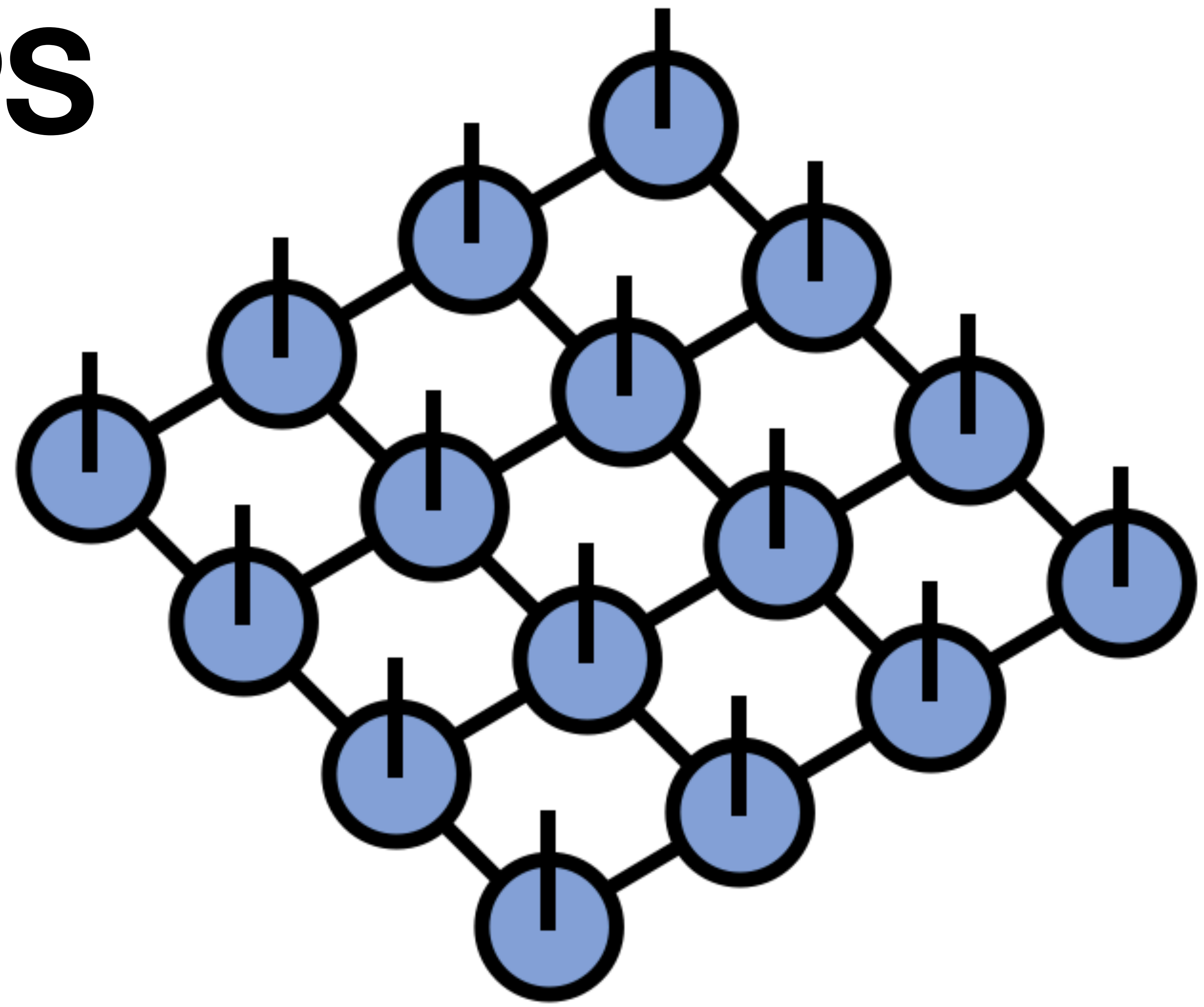
(2) Efficient algorithms for ground state search and time evolution.

(3) Mimics the connectivity of the system being represented.

Tensor networks in 2D: PEPS

(projected entangled pair state)

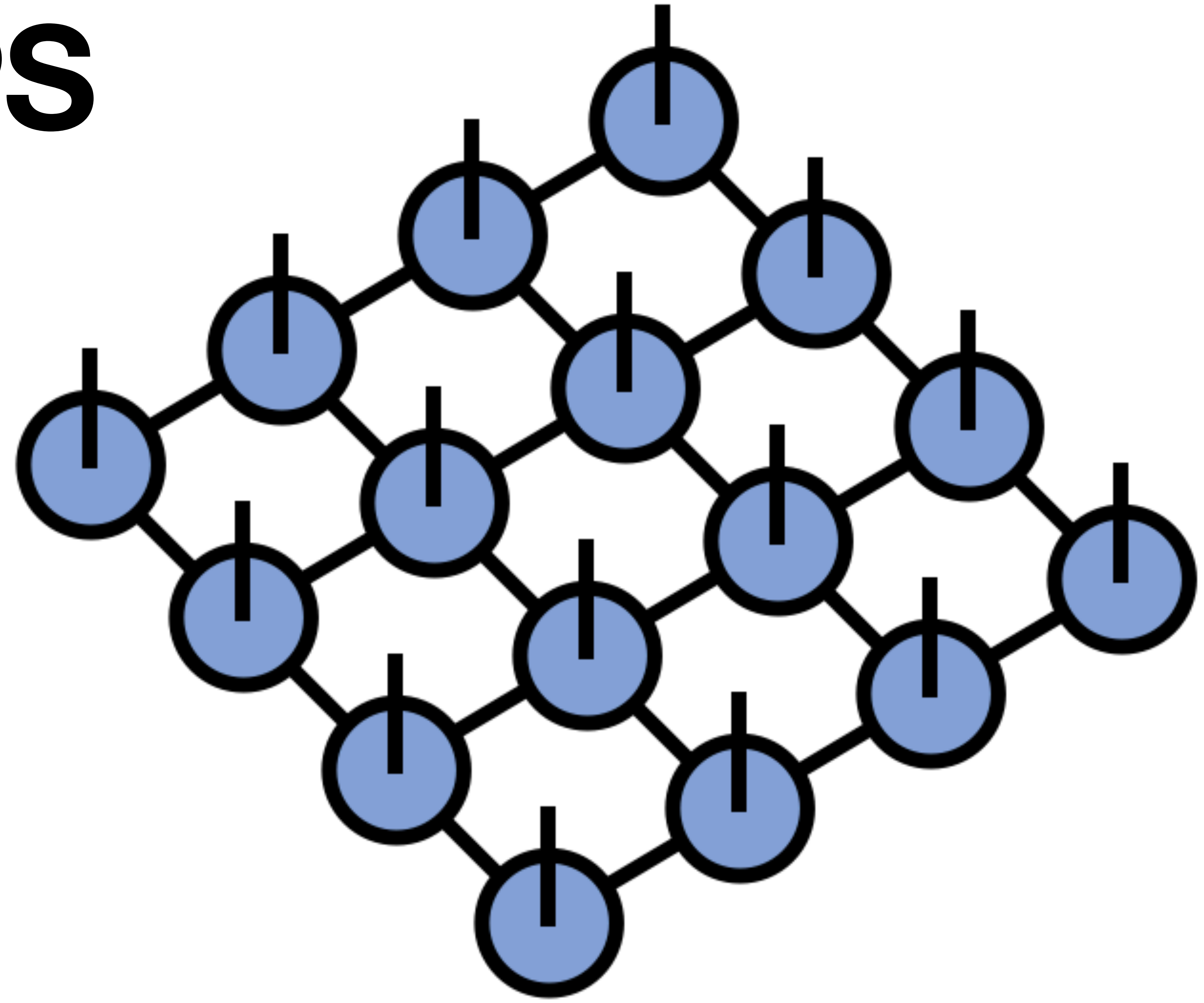
Can represent area-law entangled states.



https://tensornetwork.org/peps/

Tensor networks in 2D: PEPS

(projected entangled pair state)



Can represent area-law entangled states.

BUT:

Cannot be efficiently contracted. $O(\chi^L)$

Approximate optimization is unfeasible: $O(\chi^{10})$

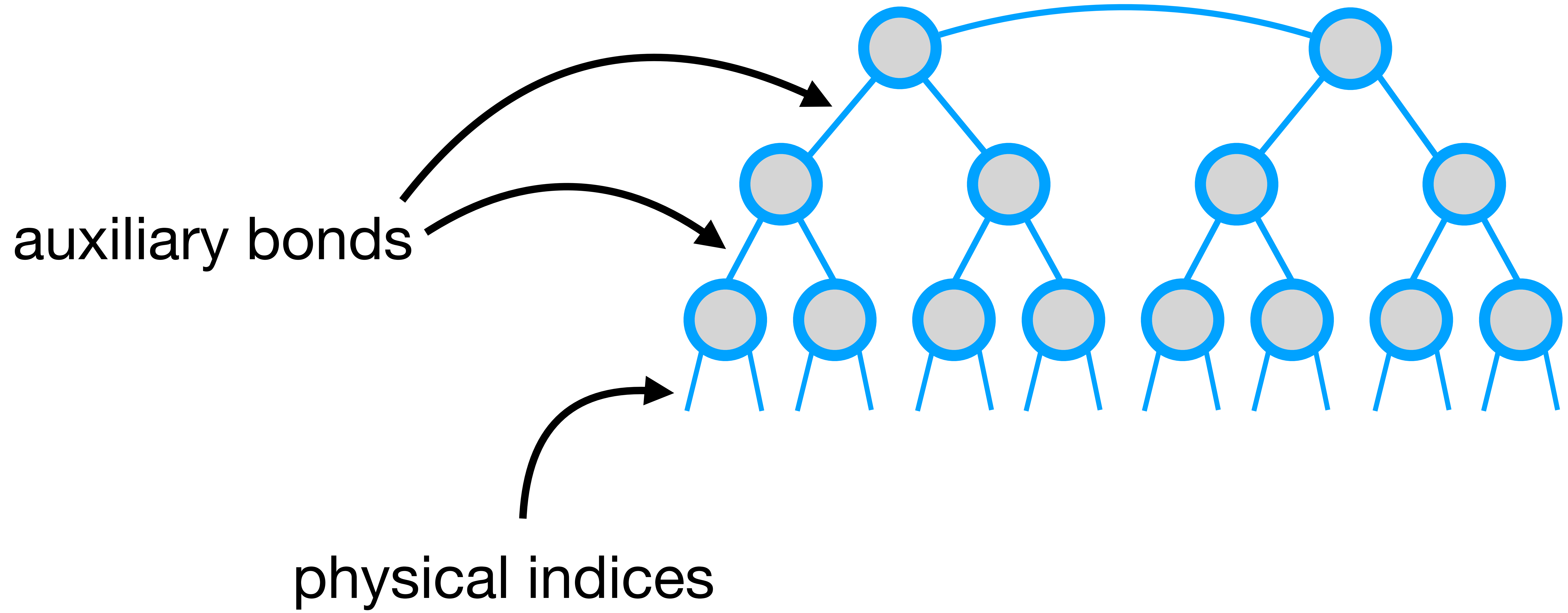
*This is all because PEPS has **loops**!*

https://tensornetwork.org/peps/

A compromise: tree tensor networks

A network with ***as many links*** as possible,
without any ***loops***.

(DMRG and TDVP map directly from MPS)

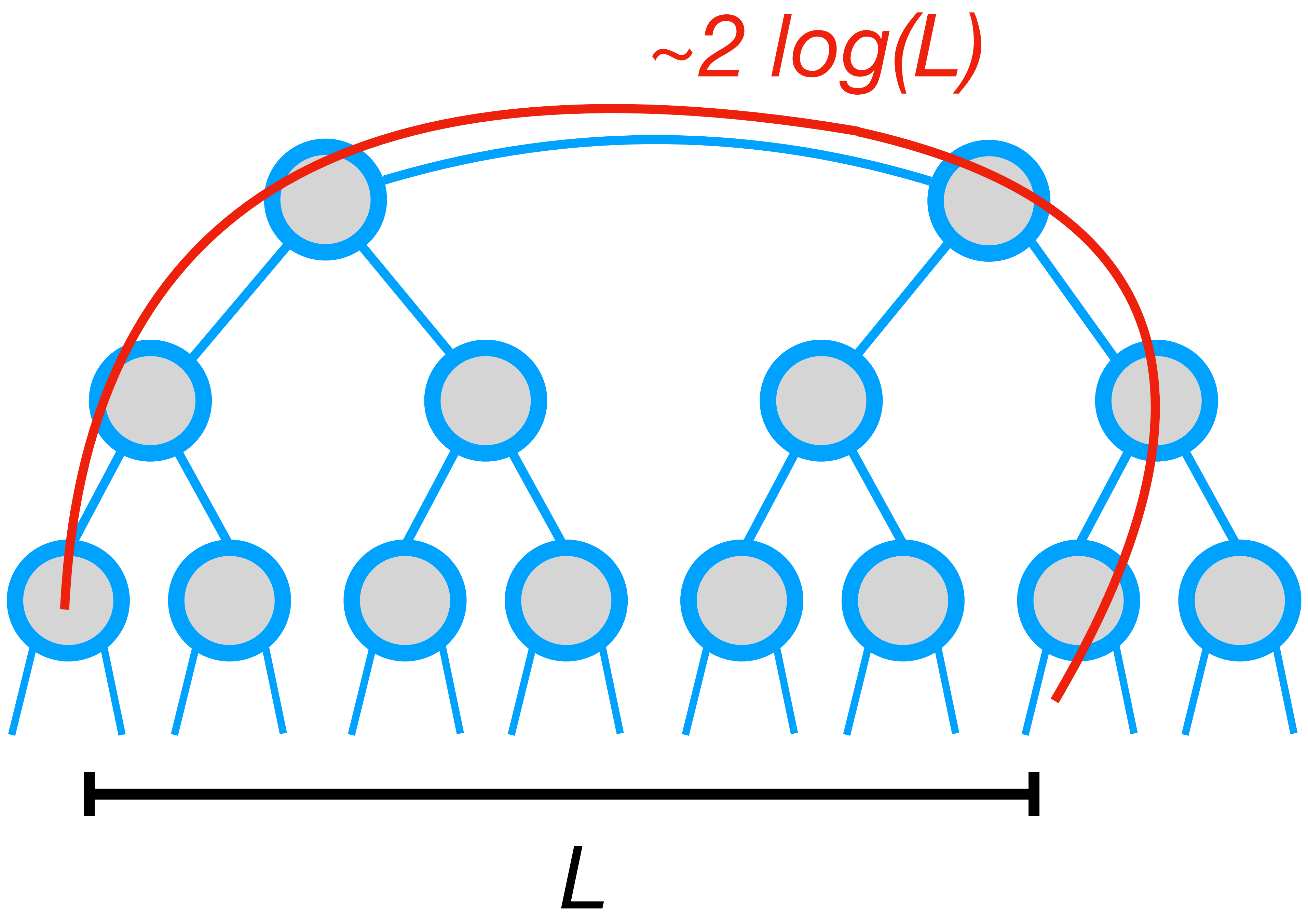


A compromise: tree tensor networks

A network with ***as many links*** as possible,
without any ***loops***.

(DMRG and TDVP map directly from MPS)

It is better than MPS at
encoding long-range interactions:



We expect ~log(N) better results
than with MPS.

physics

Systems with dynamical constraints

where the dynamics is *(approximately)* constrained
to a subspace of the Hilbert space

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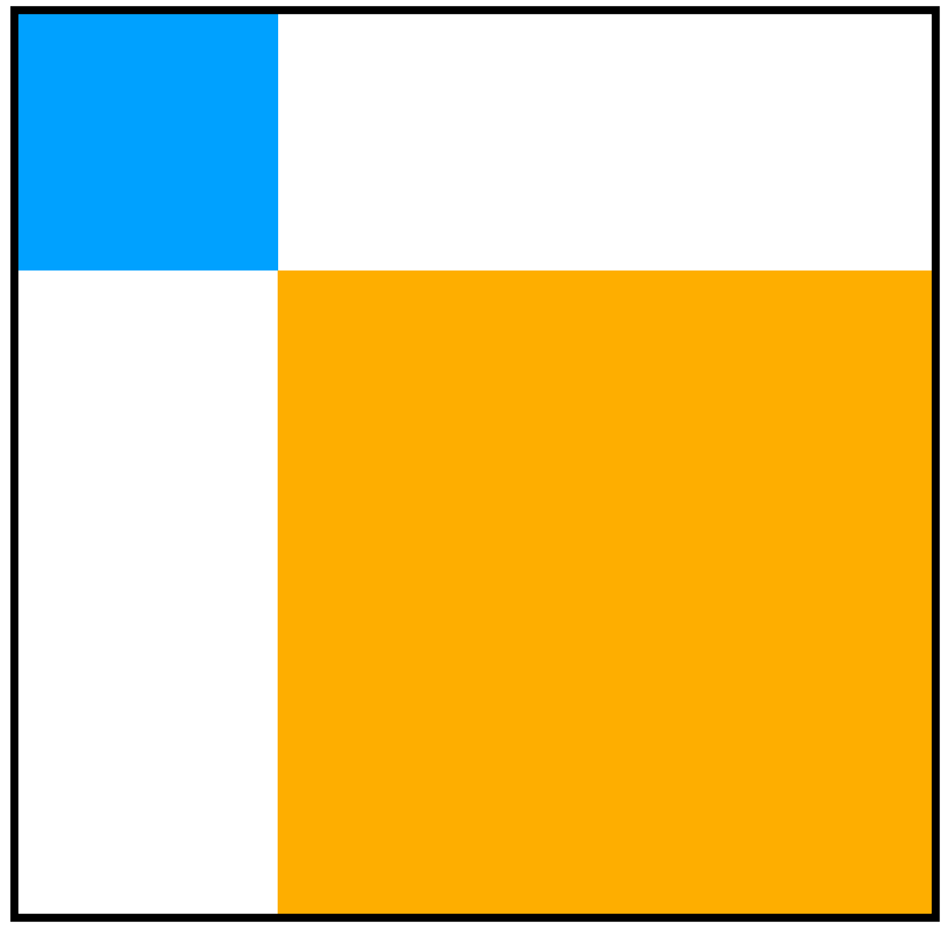
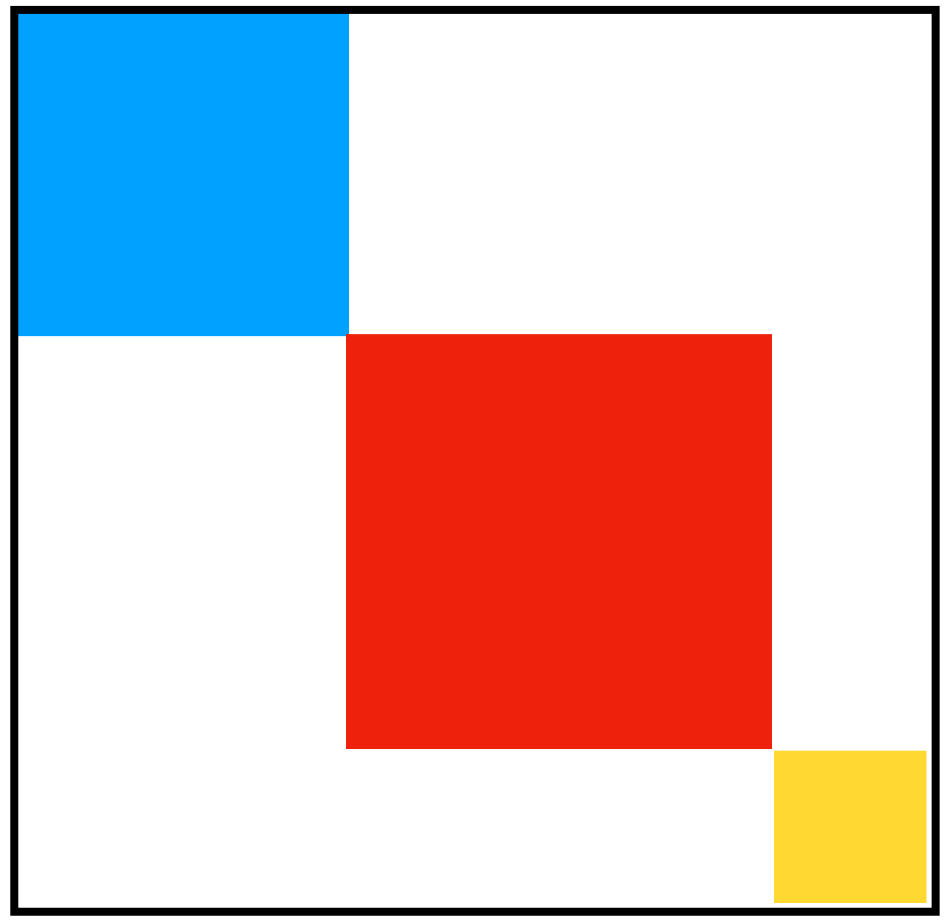
quantum scars



emergent dynamical constraints



2D quantum Ising on a square lattice

$$H = -J \sum_{\langle i,j \rangle} Z_i Z_j - g \sum_i X_i$$ with $g < g_c = 3J$

energy cost of domain walls

spin flipping

2D Ising on a square lattice

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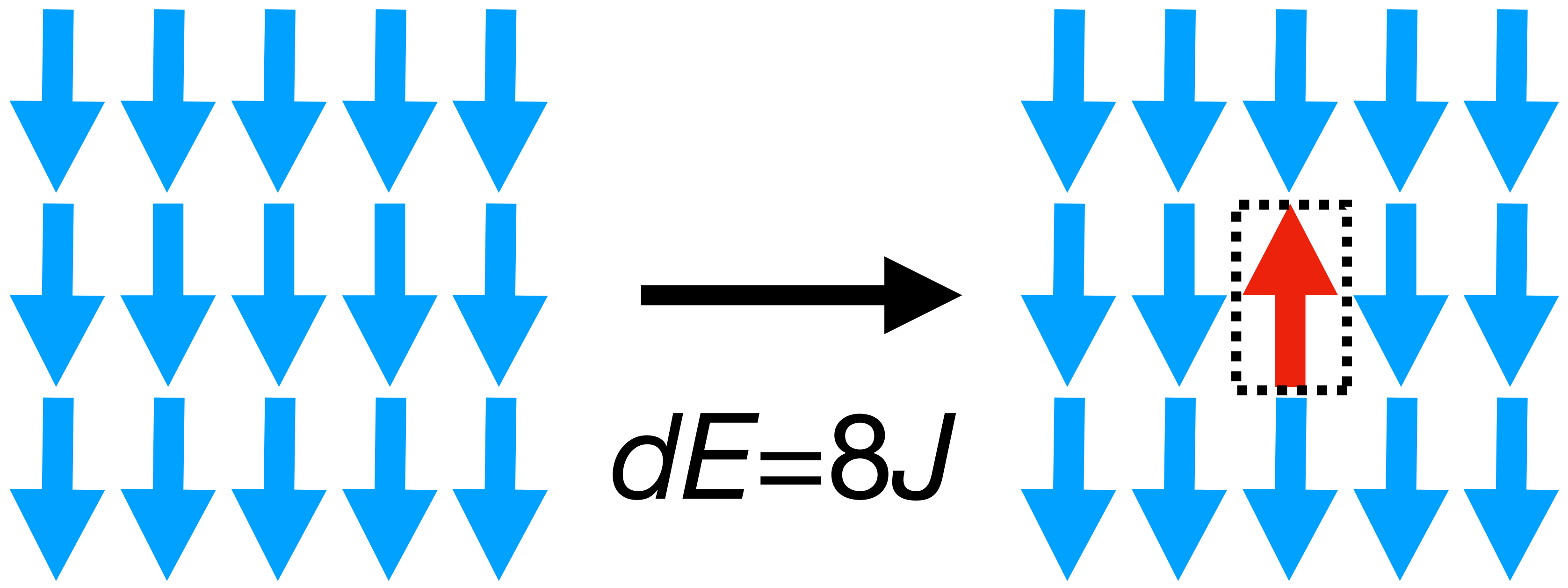
Creating domains is energetically expensive:



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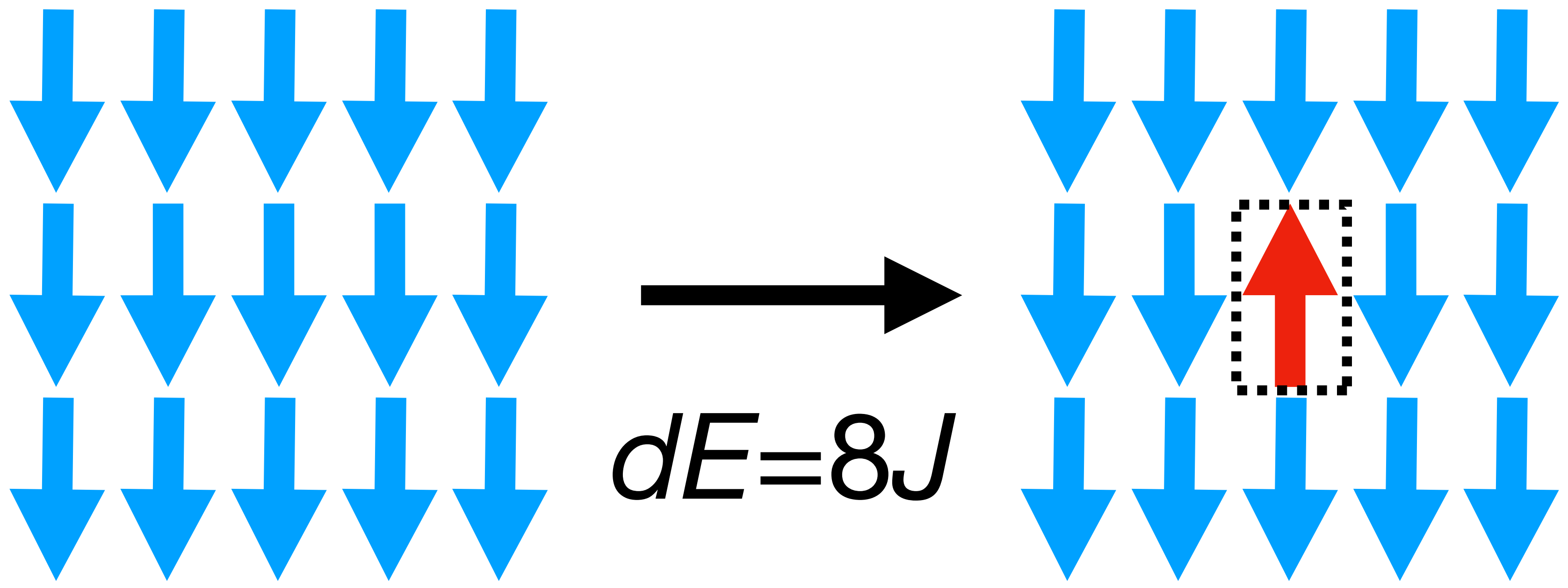
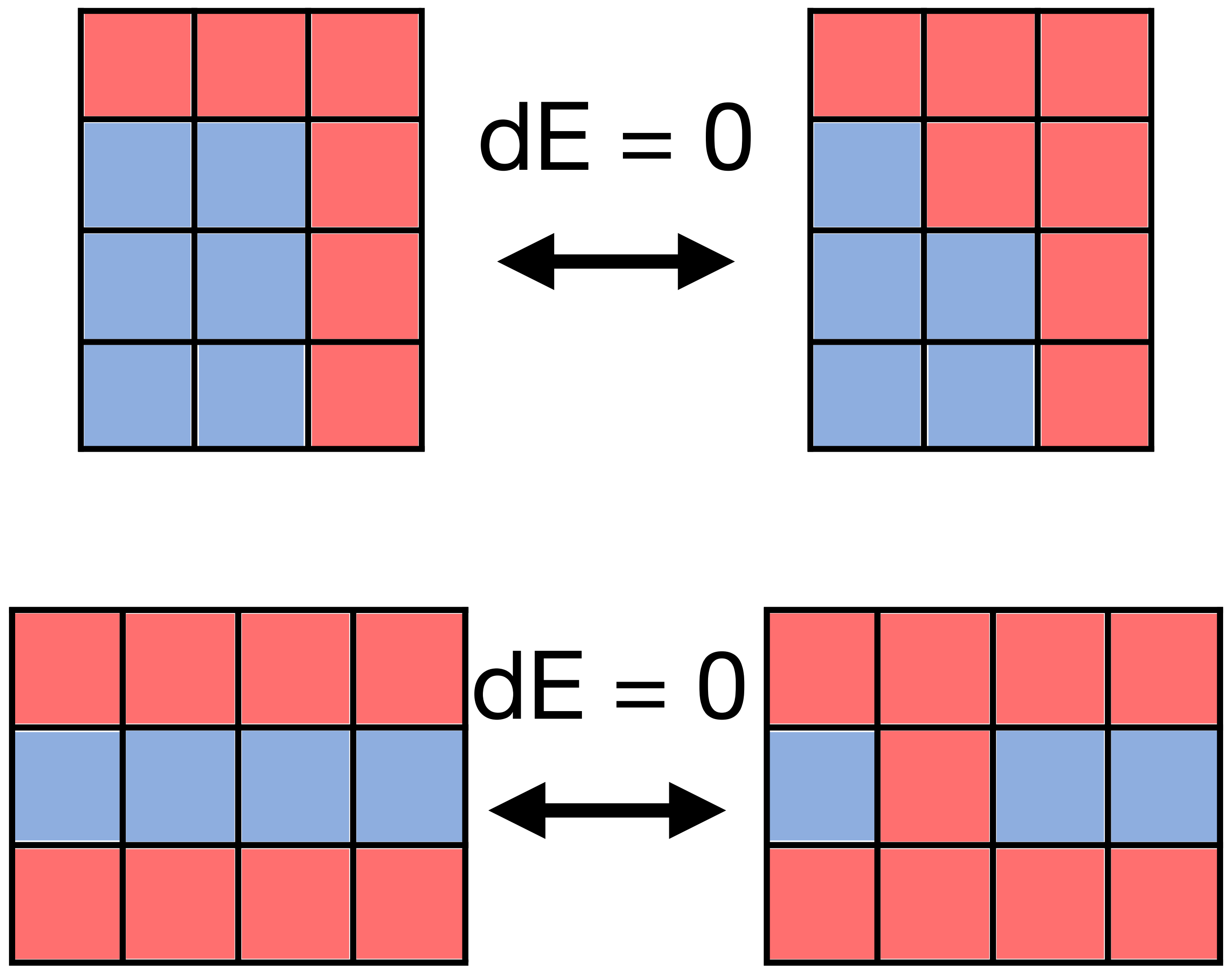


But, there are **resonant** processes:



Resonant processes conserve the length of the domain wall

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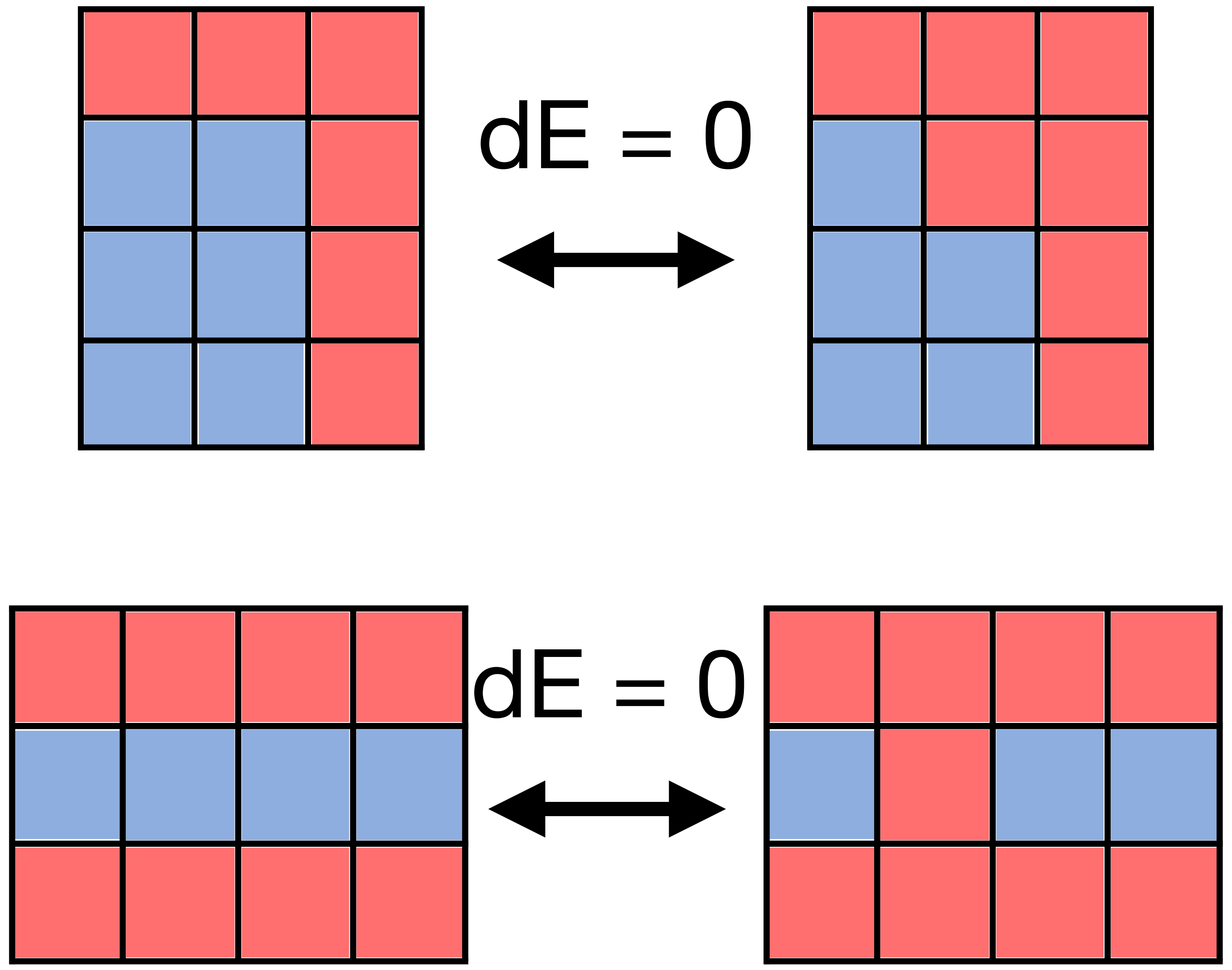
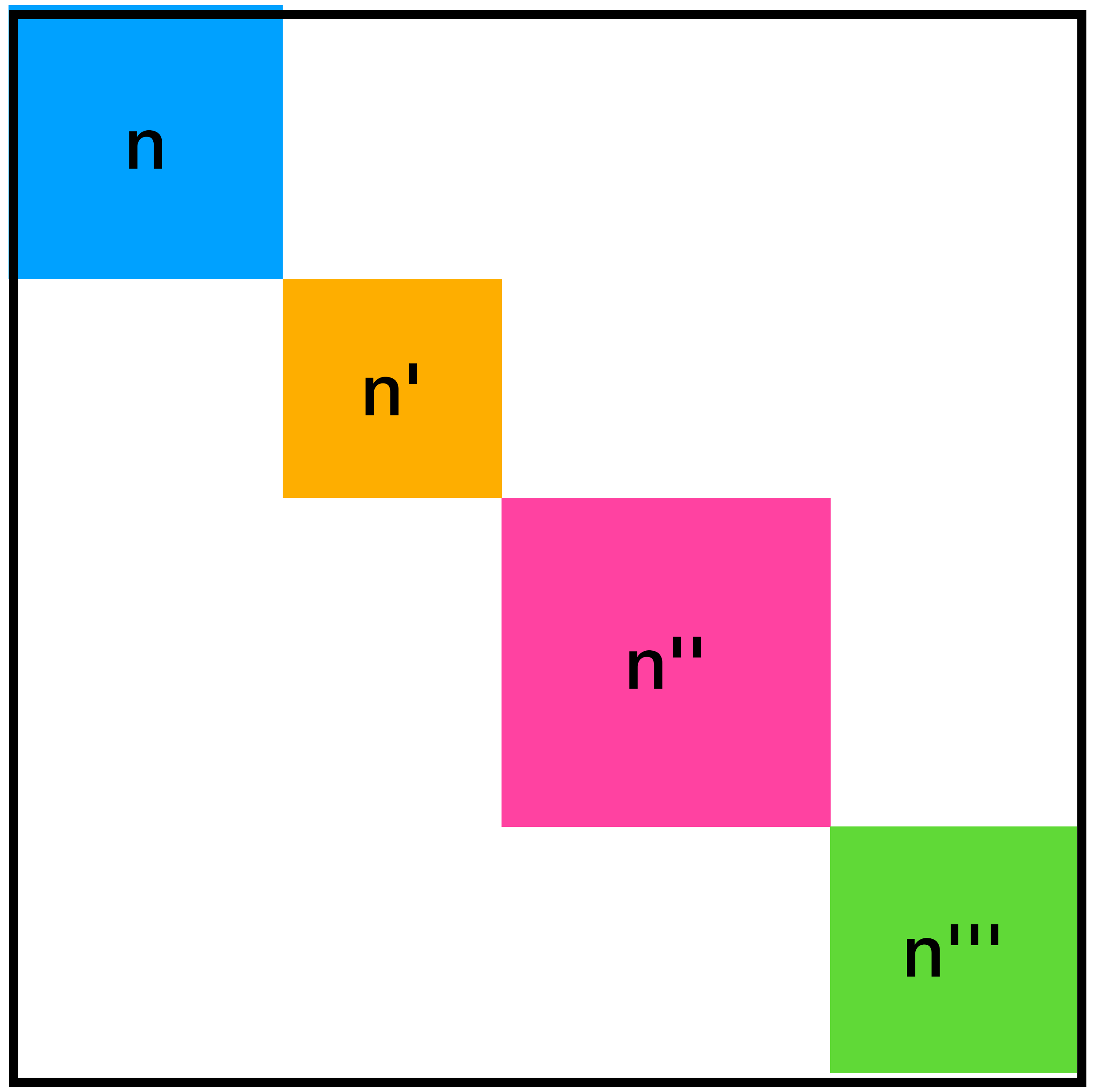
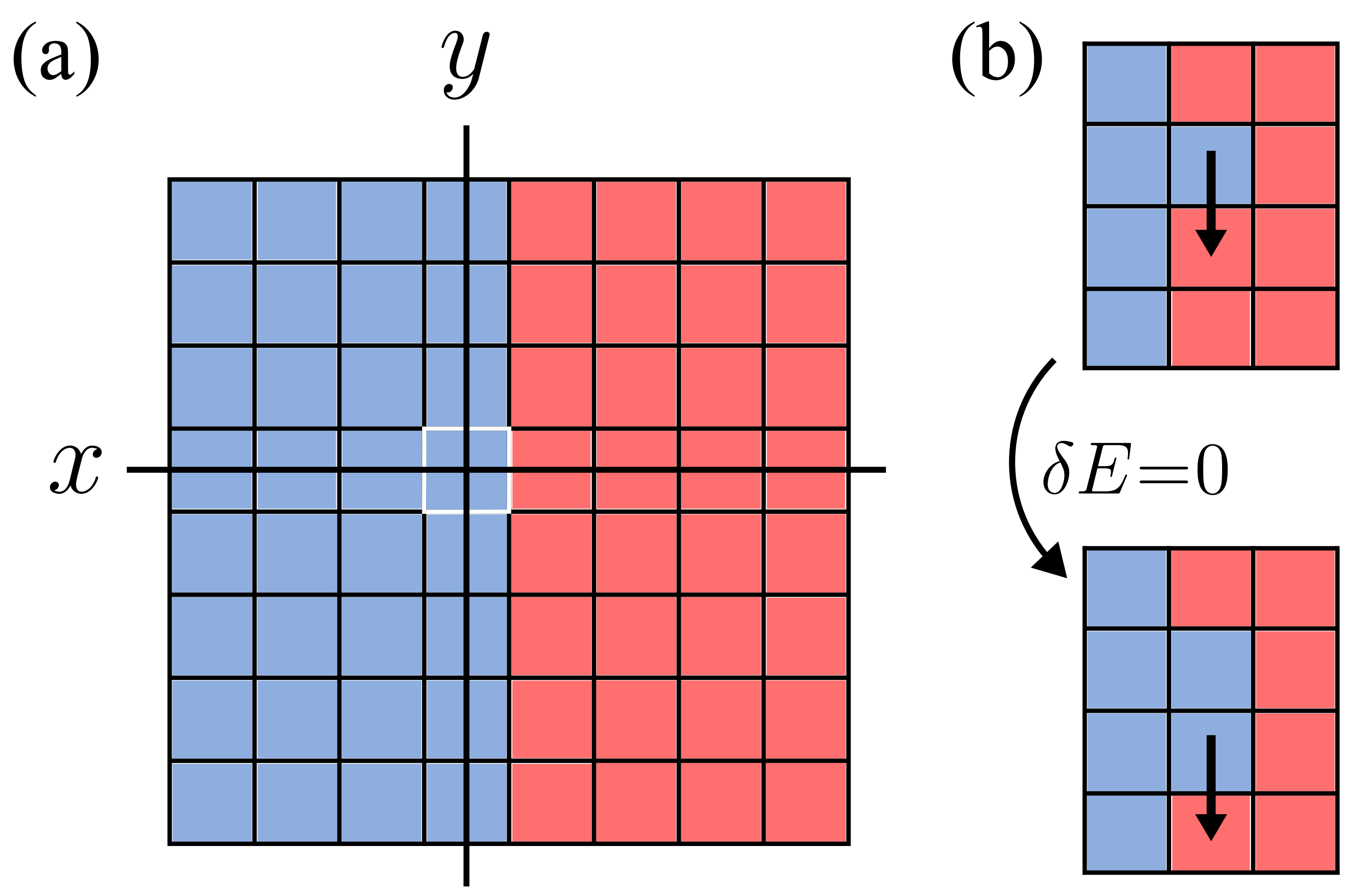


Fragmentation into sectors with same **total domain wall length** *n.*

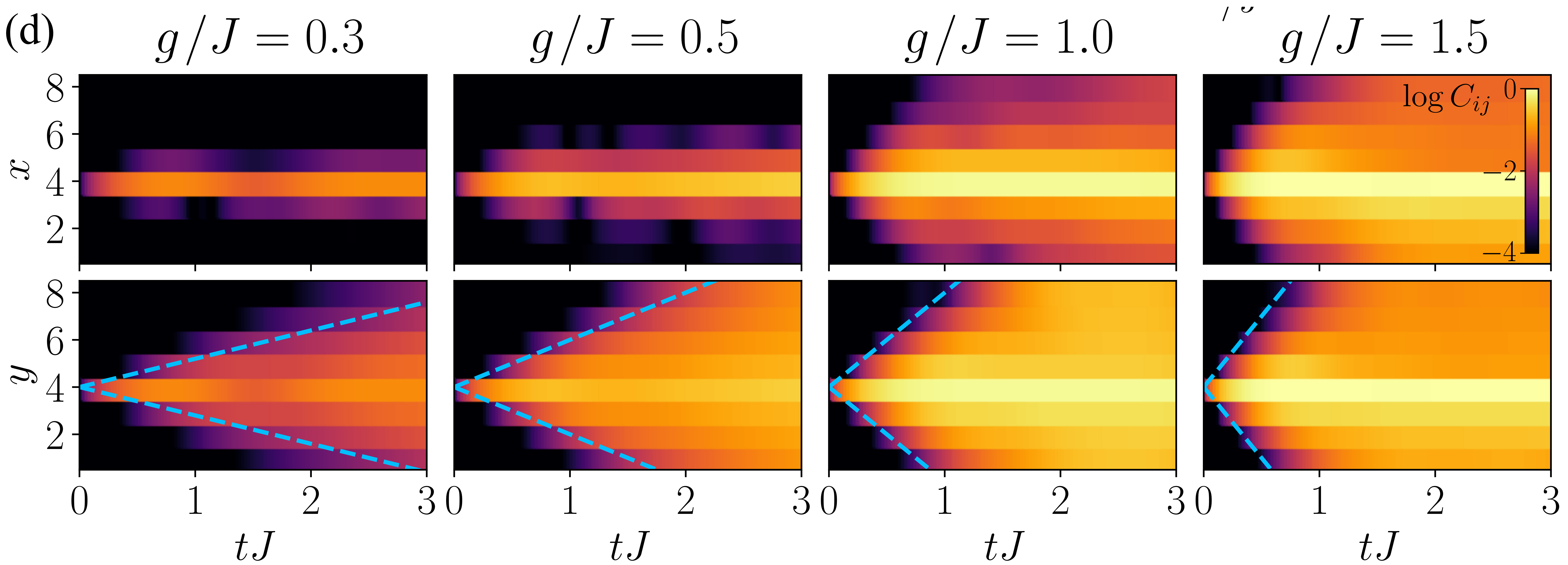


Yoshinaga et al. Emergence of Hilbert Space Fragmentation in Ising Models with a Weak Transverse Field, PRL **129**, 090602, 2022

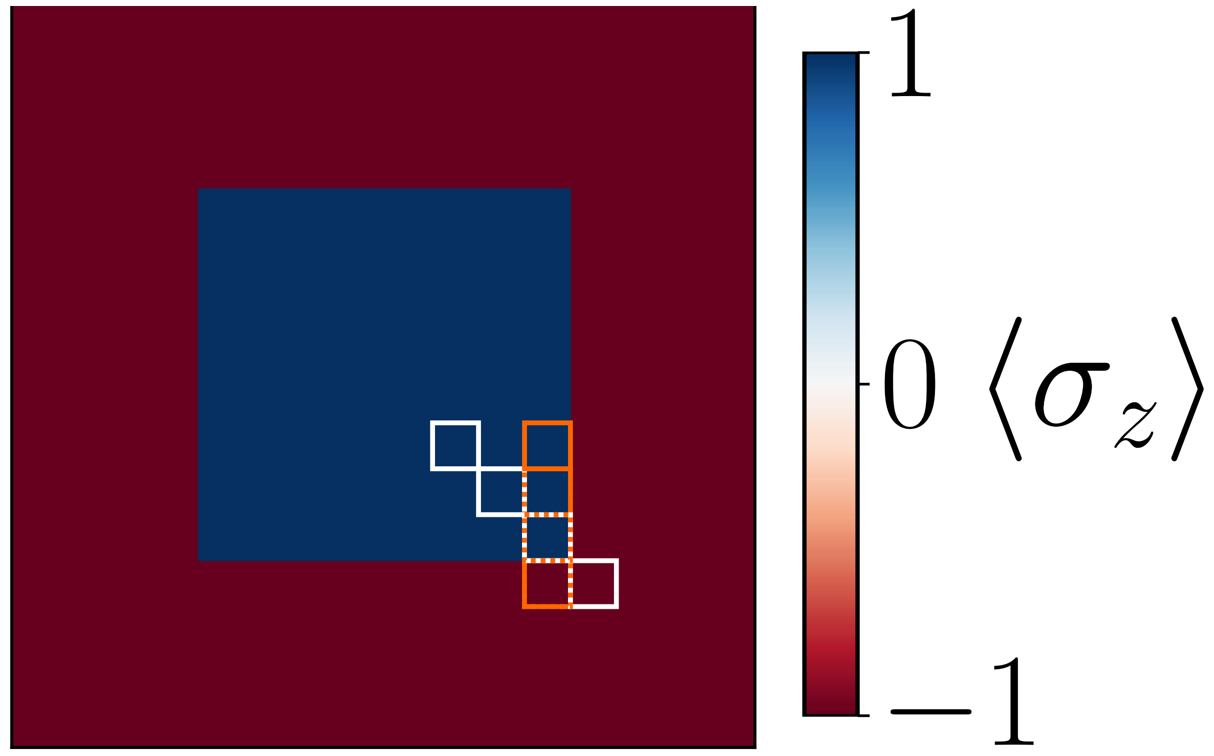
Dynamics from a domain wall?



Cij = <Zi Zj> - <Zi><Zj>



Melting of a square



arXiv:2406.11979

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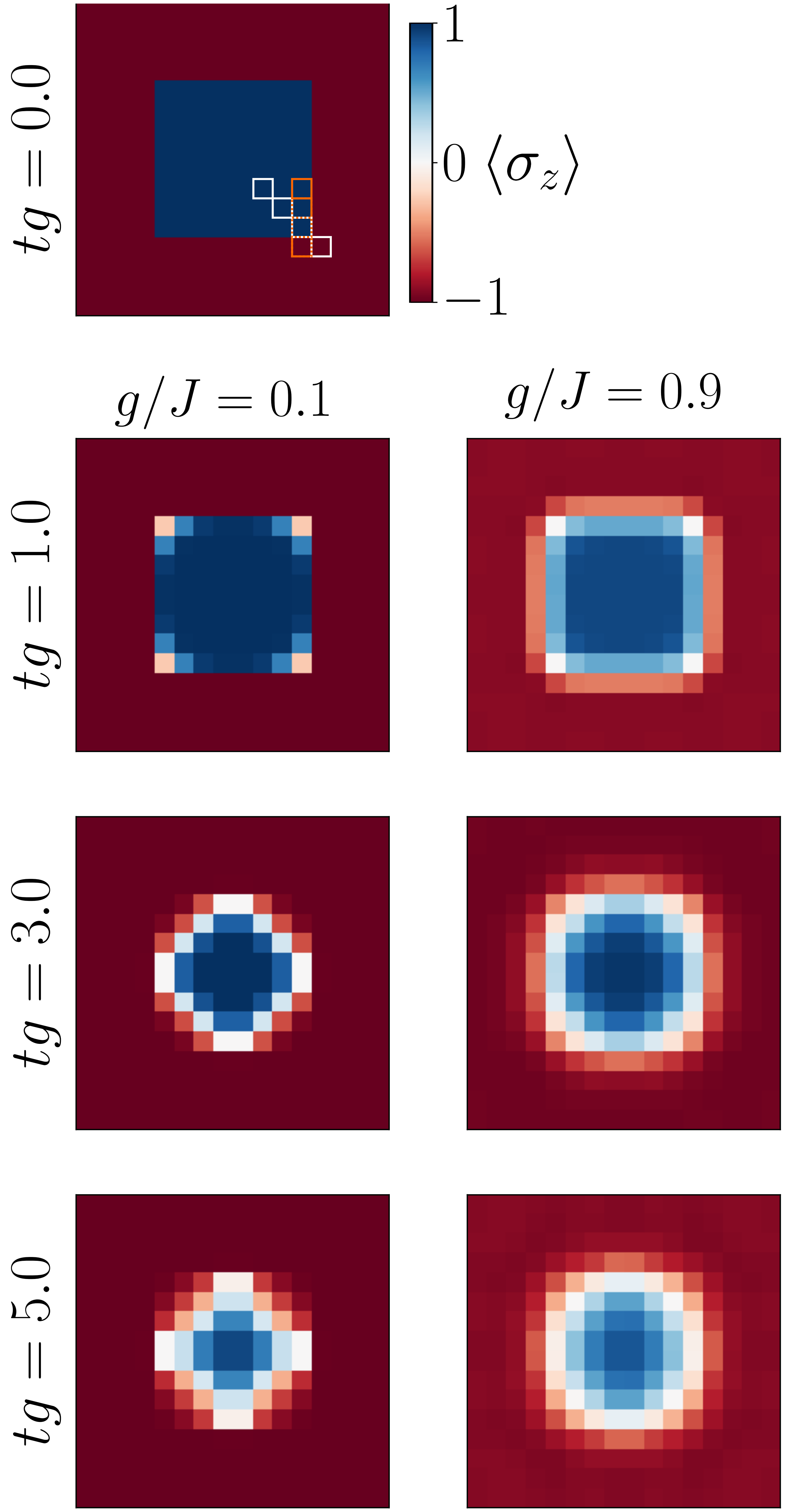


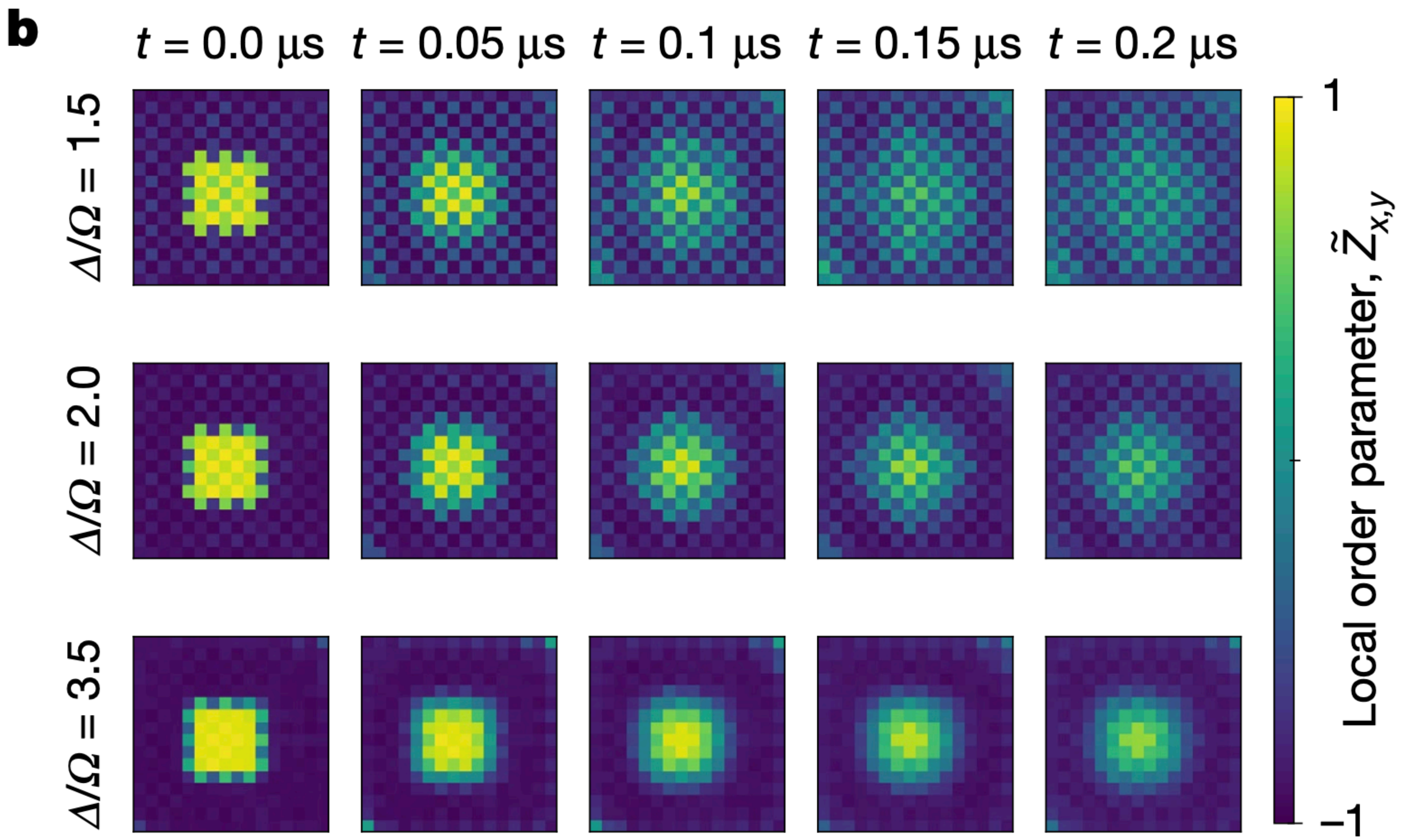
arXiv:2406.11979

So what?

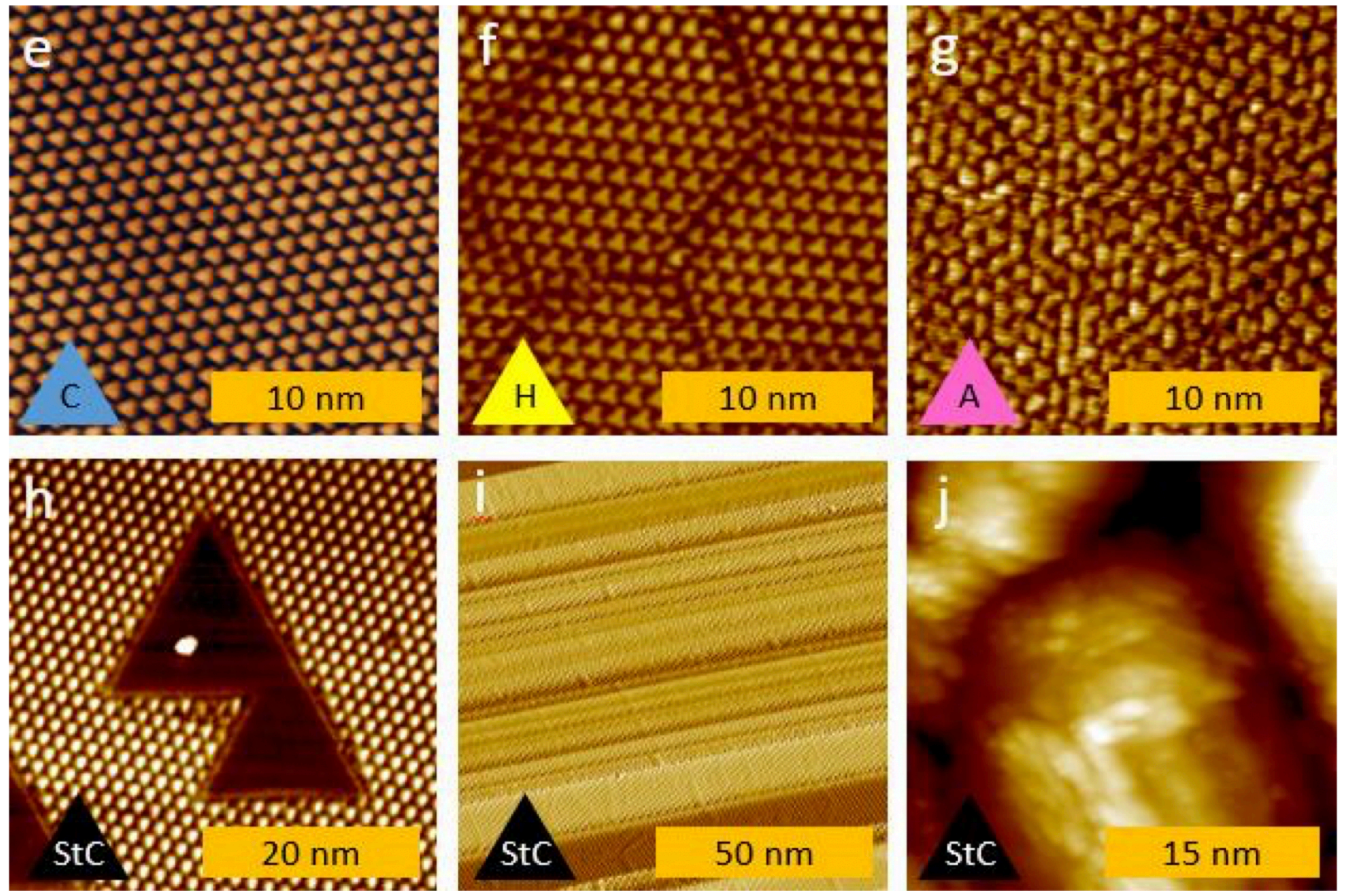
Quantum coarsening and collective dynamics on a programmable simulator

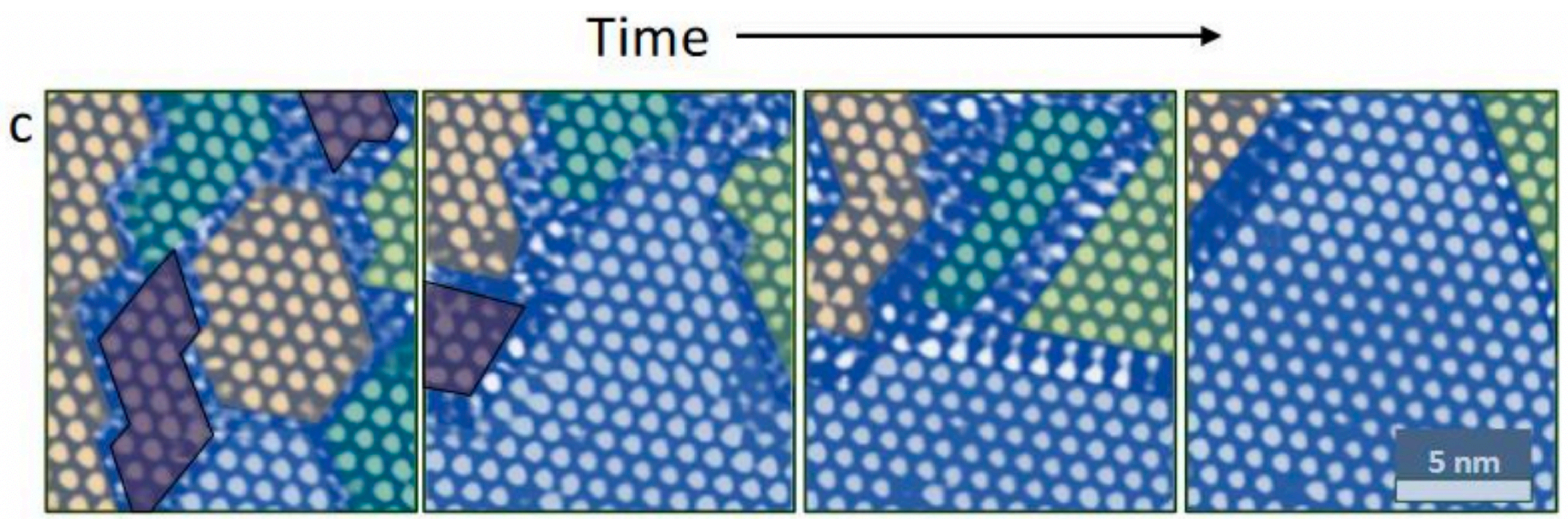
Tom Manovitz, Sophie H. Li, Sepehr Ebadi, Rhine Samajdar, Alexandra A. Geim, Simon J. Evered, Dolev Bluvstein, Hengyun Zhou, Nazli Ugur Koyluoglu, Johannes Feldmeier, Pavel E. Dolgirev, Nishad Maskara, Marcin Kalinowski, Subir Sachdev, David A. Huse, Markus Greiner, Vladan Vuletić & Mikhail D. Lukin

Nature **638**, 86–92 (2025) | Cite this article



Ravnik et al. A time-domain phase diagram of metastable states in a charge ordered quantum material, Nat. Commun. 12 2323, 2021





Fun fact

Article

Evidence for the utility of quantum computing before fault tolerance

https://doi.org/10.1038/s41586-023-06096-3
Received: 24 February 2023
Accepted: 18 April 2023

Youngseok Kim[1,6✉], Andrew Eddins[2,6✉], Sajant Anand[3], Ken Xuan Wei[1], Ewout van den Berg[1], Sami Rosenblatt[1], Hasan Nayfeh[1], Yantao Wu[3,4], Michael Zaletel[3,5], Kristan Temme[1] & Abhinav Kandala[1✉]

vs.

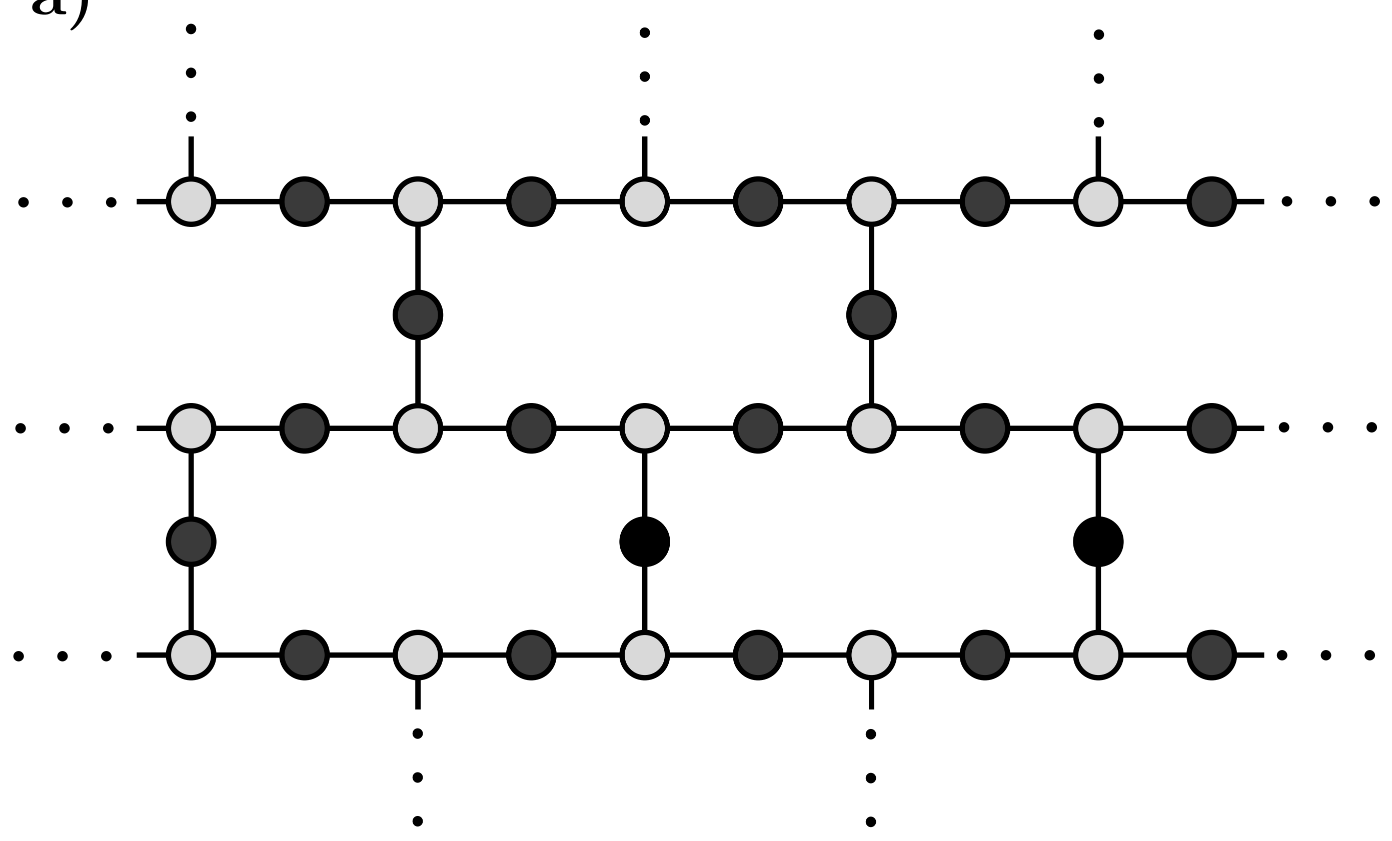
Efficient Tensor Network Simulation of IBM's Eagle Kicked Ising Experiment

Joseph Tindall[1,*], Matthew Fishman[1], E. Miles Stoudenmire[1] and Dries Sels[1,2]
[1] Center for Computational Quantum Physics, Flatiron Institute, New York, New York 10010, USA
[2] Center for Quantum Phenomena, Department of Physics, New York University, 726 Broadway, New York, New York 10003, USA

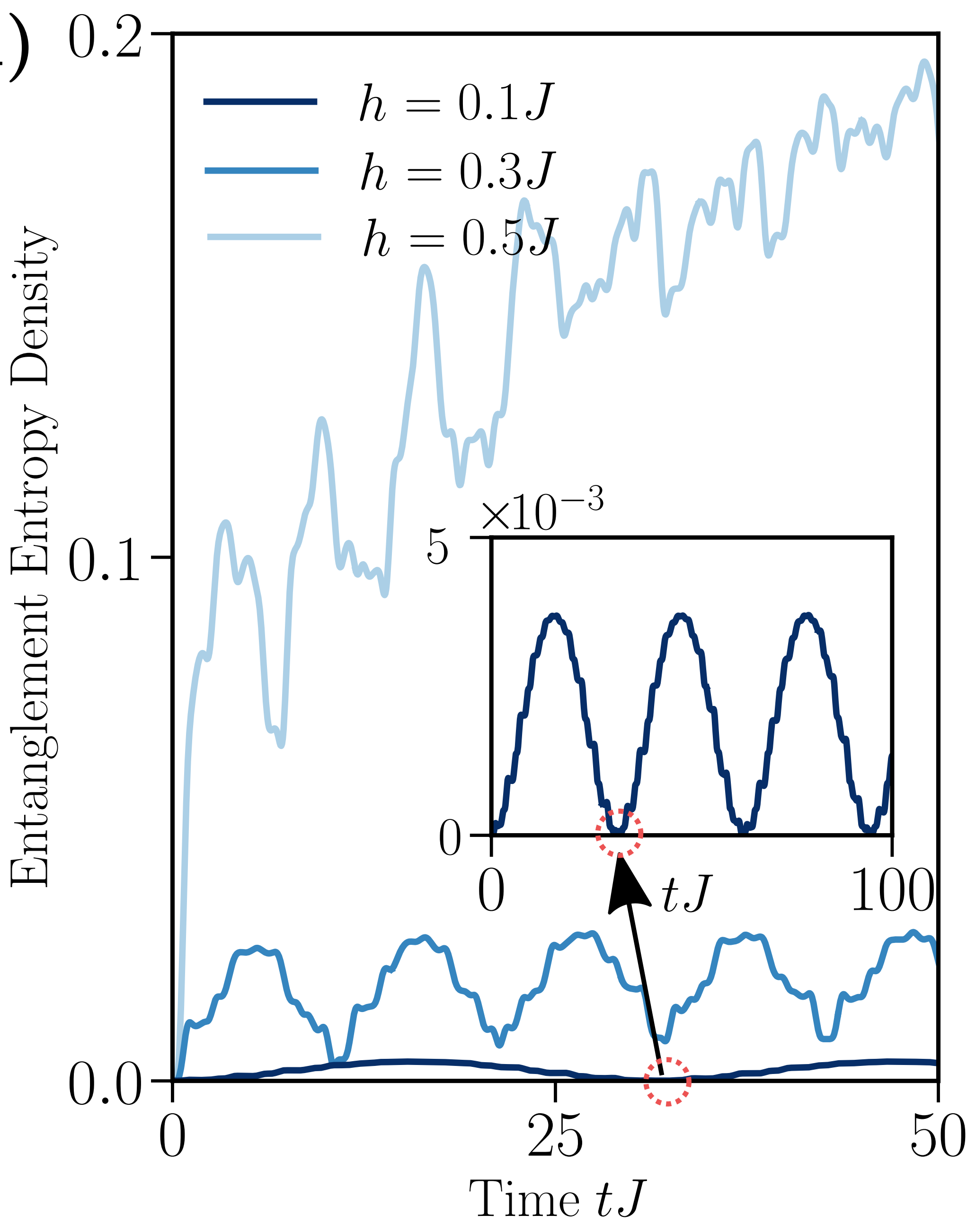
Confinement in the Transverse Field Ising model on the Heavy Hex lattice

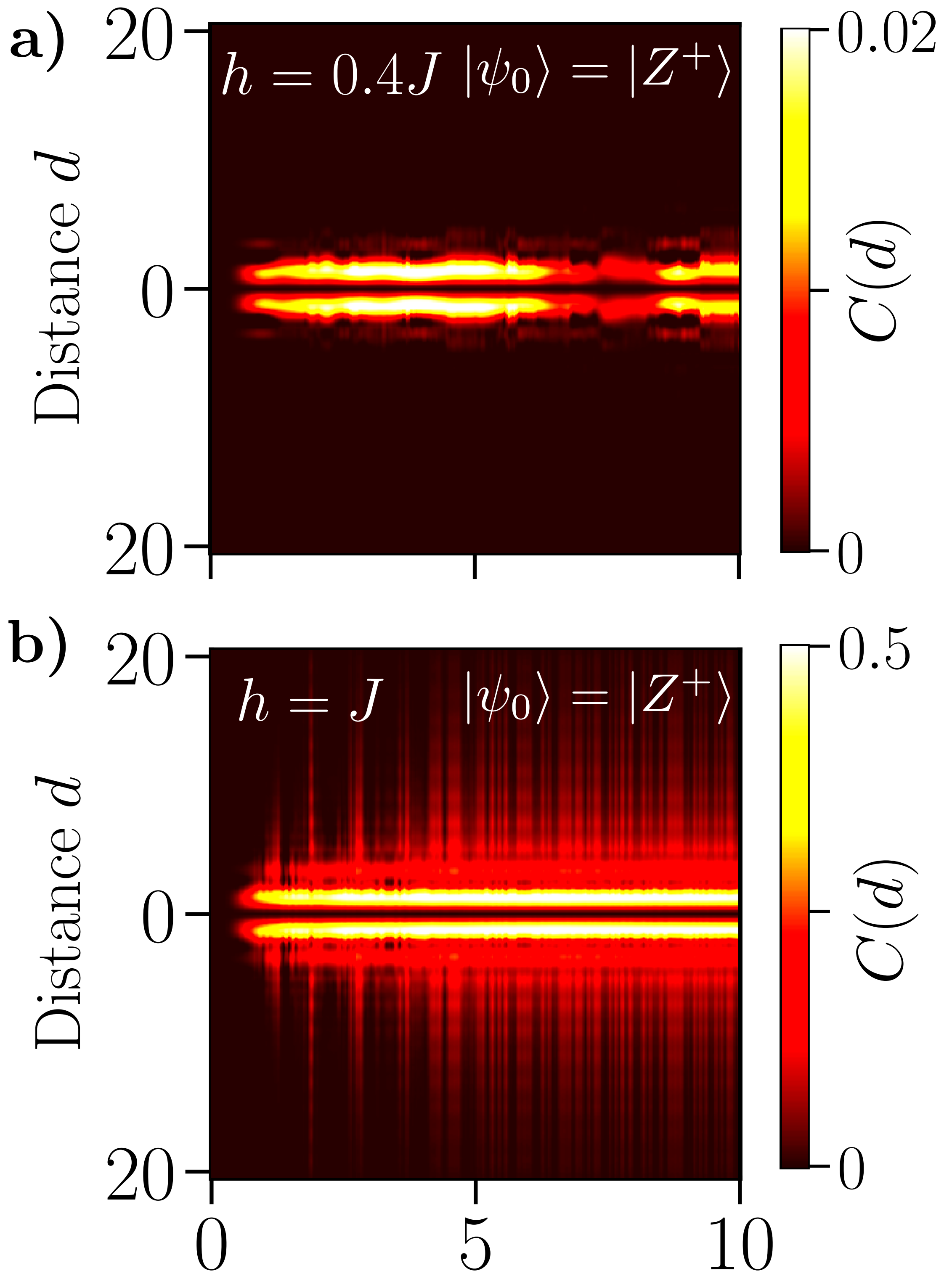
Joseph Tindall[1] and Dries Sels[1,2]
[1] Center for Computational Quantum Physics, Flatiron Institute, New York, New York 10010, USA
[2] Center for Quantum Phenomena, Department of Physics, New York University, 726 Broadway, New York, NY, 10003, USA
(Dated: March 6, 2024)

a)

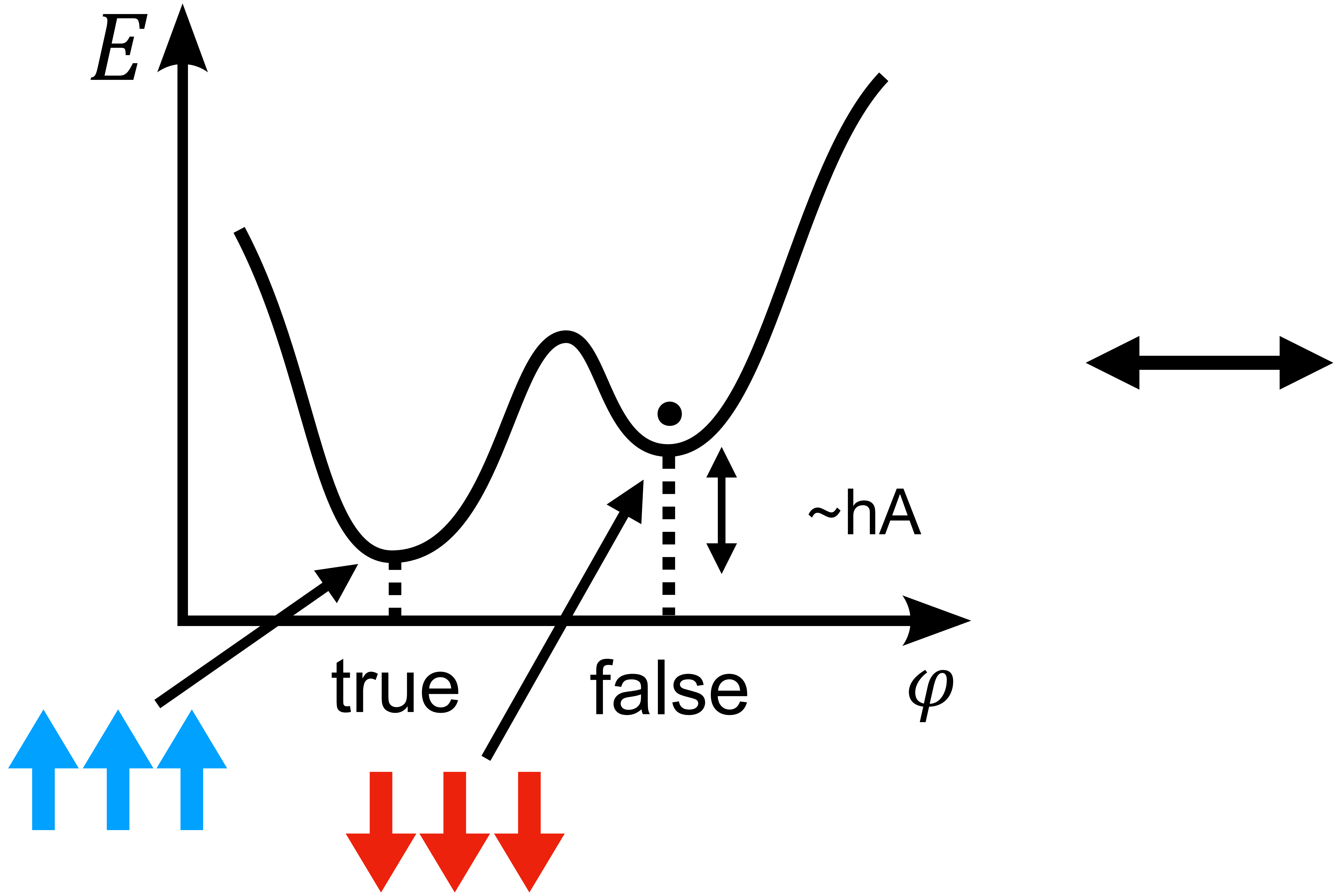


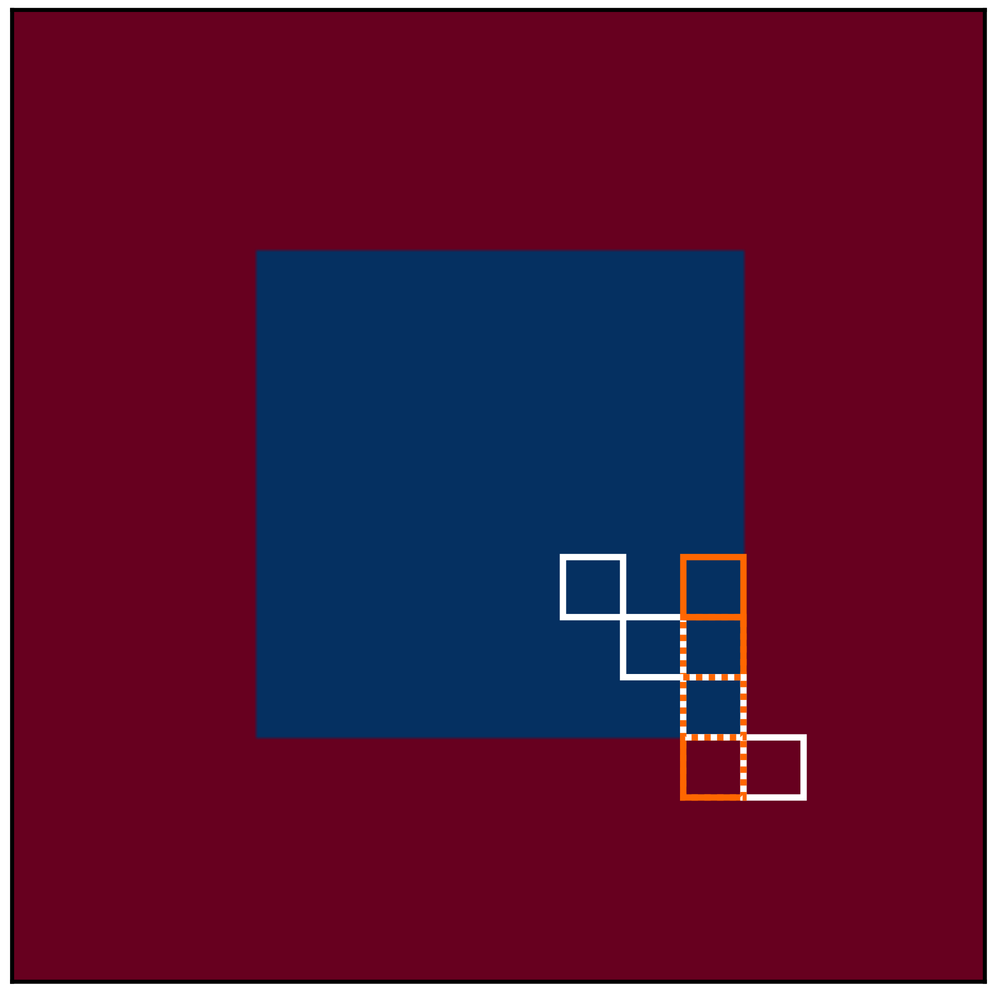
d)



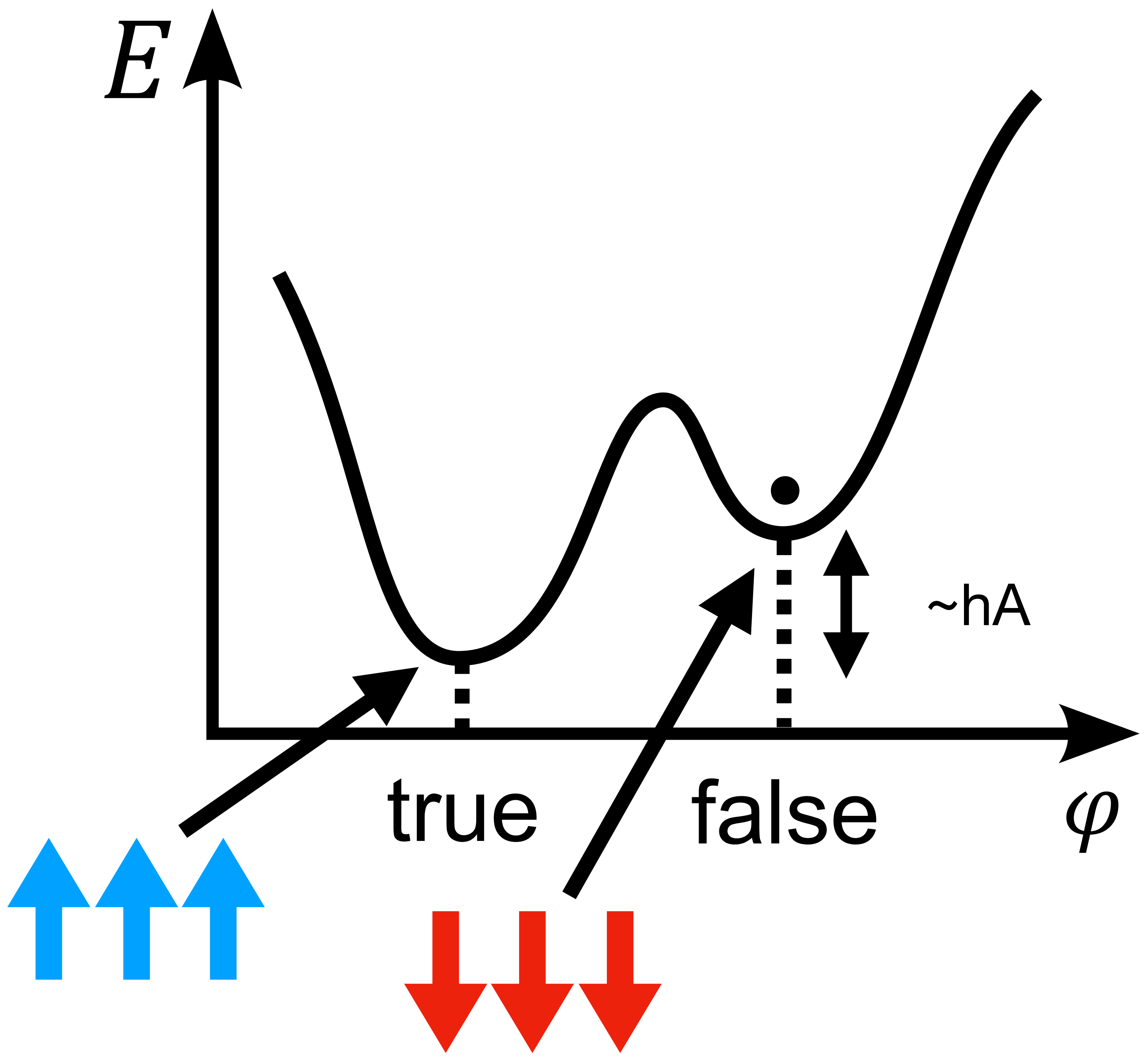


False vacuum decay

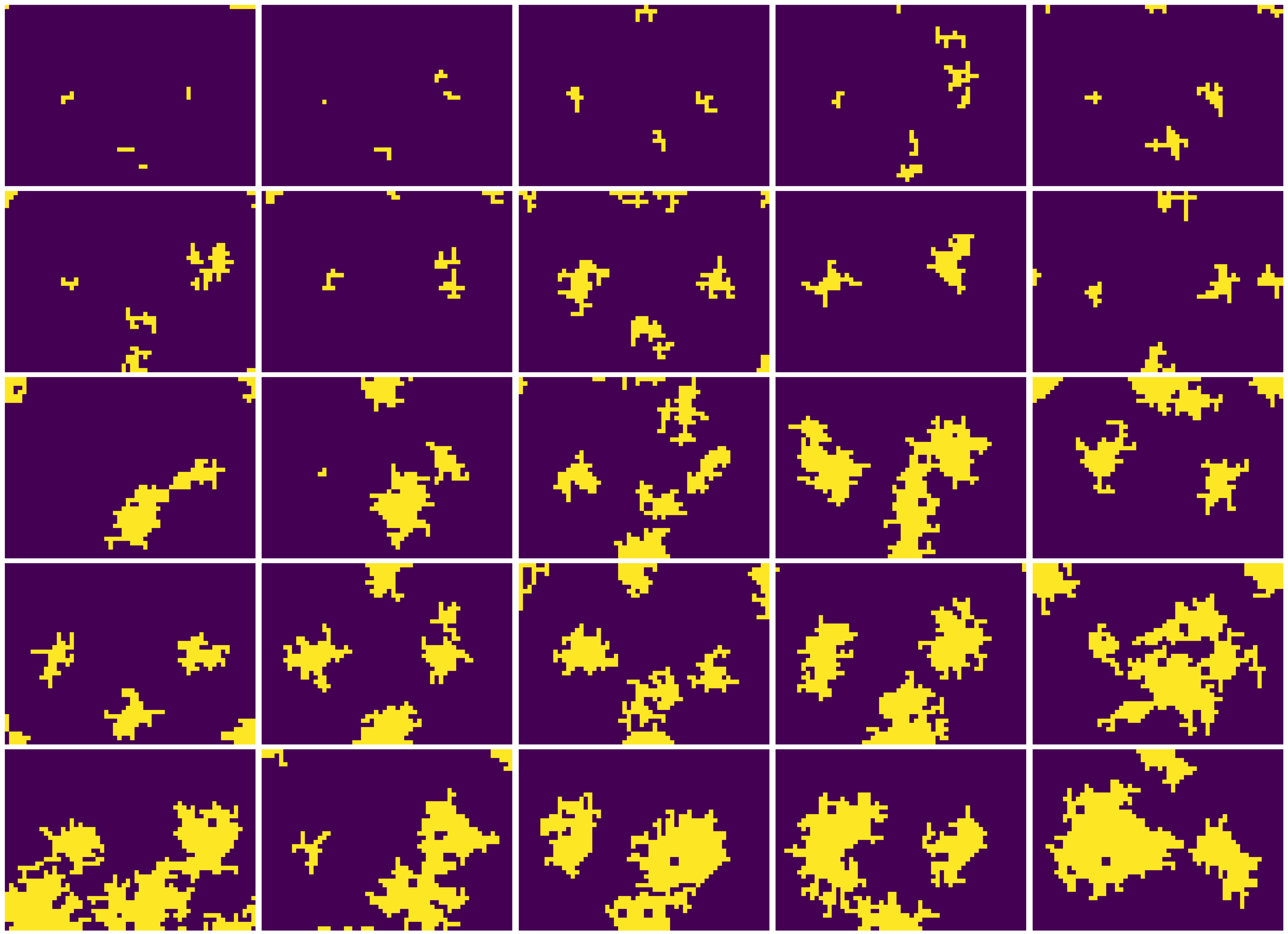




Outlook2: false vacuum decay & metastable states



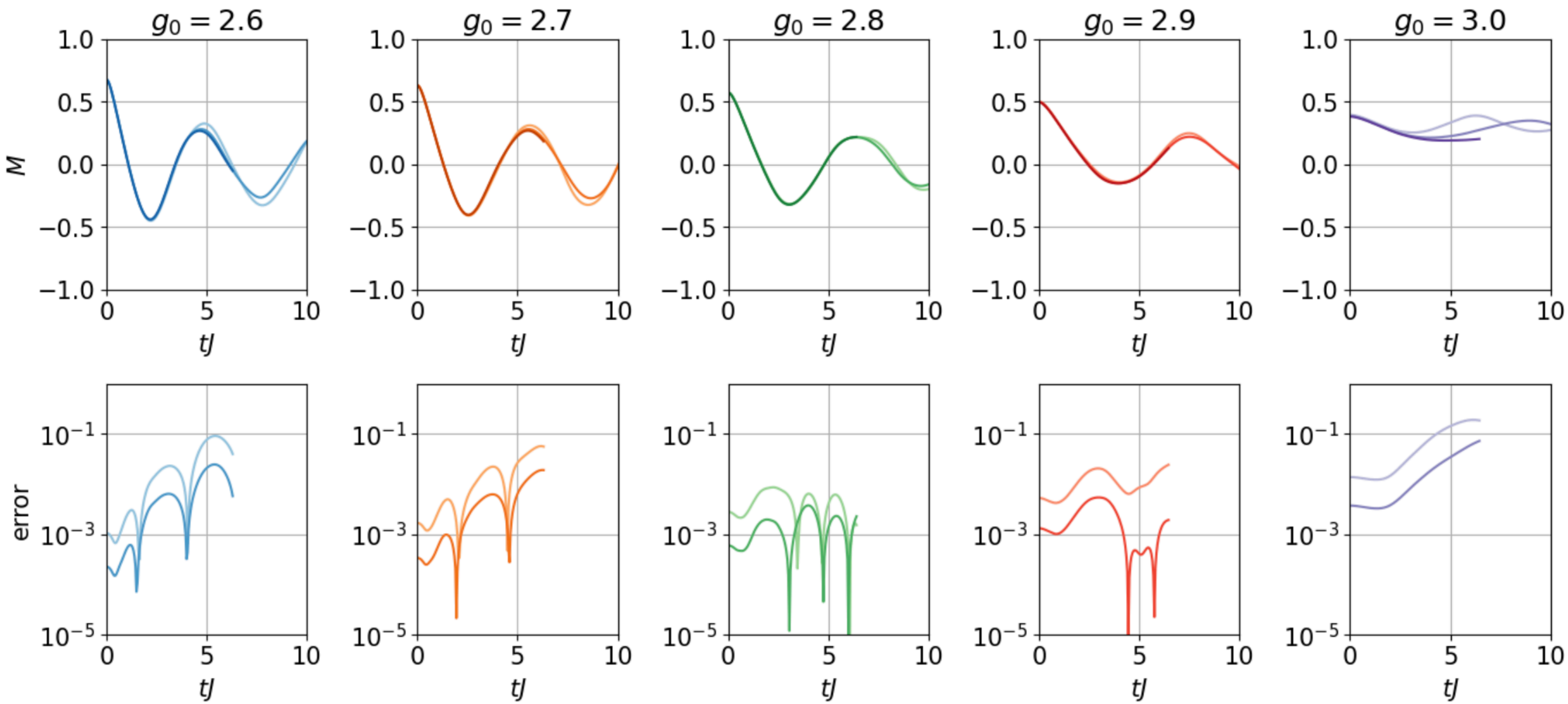
False vacuum decay @dWave? Yes!(?)



Jaka Vodeb, Gregor Humar, Marko Ljubotina, Jean-Yves Desaules, Zlatko Papič

2D Ising at the critical point and adS/CFT

$N = 32 \times 32; \quad \chi = 200,\ 300$



Scattering in 2D

TTN
MPS
2+ D models
long-range interactions
long time dynamics (thermalization)
generic quantum chaotic systems
volume-law entangled systems
constrained dynamics
metastable states
locally entangled
dynamics
1D models
nearest-neighbour interactions
easy
unreasonable