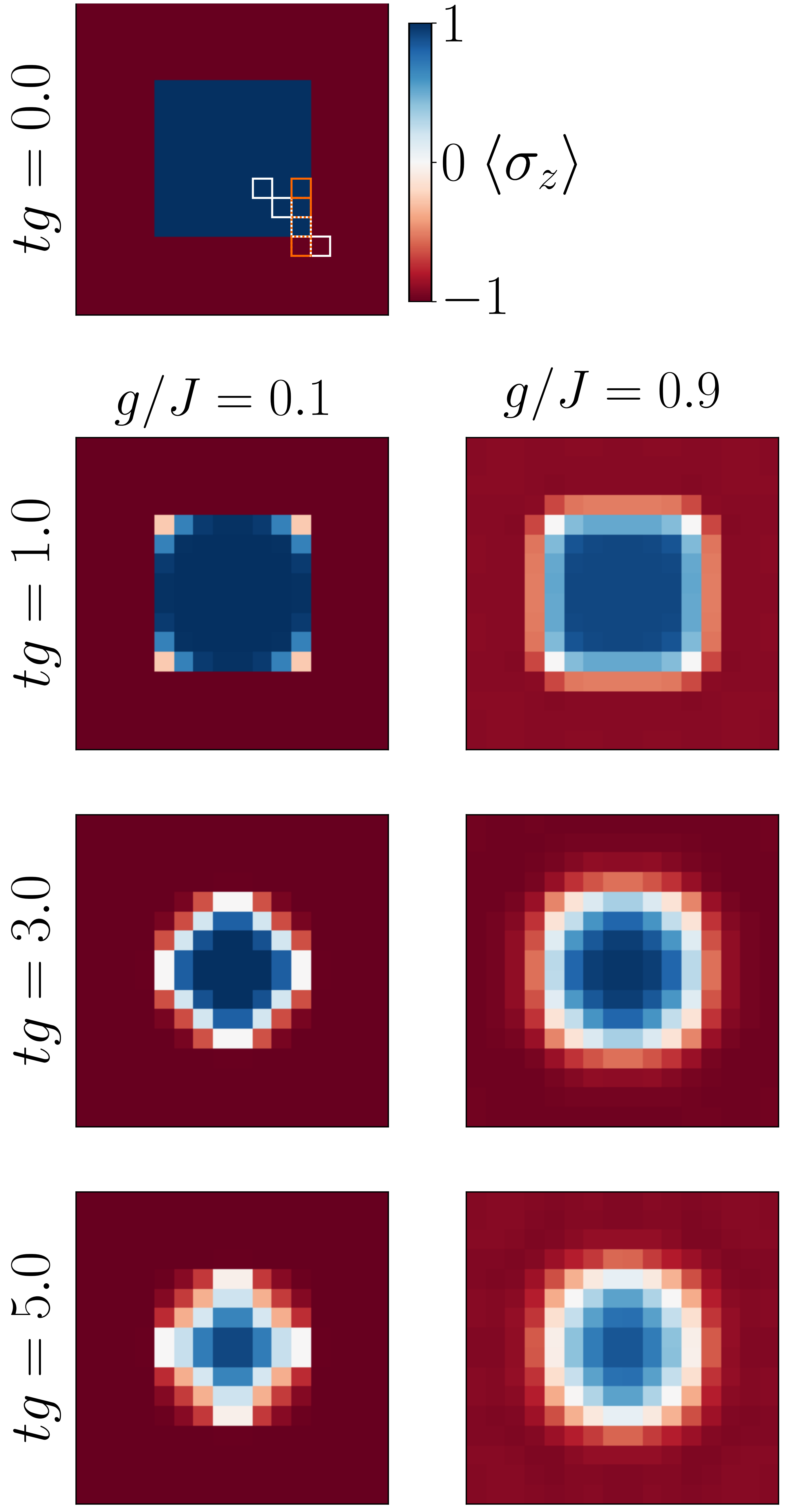
Constrained dynamics in the 2D quantum Ising model

Luka Pavešić, Daniel Jaschke, Simone Montangero
University of Padova

arXiv:2406.11979



Generic interacting systems thermalize.

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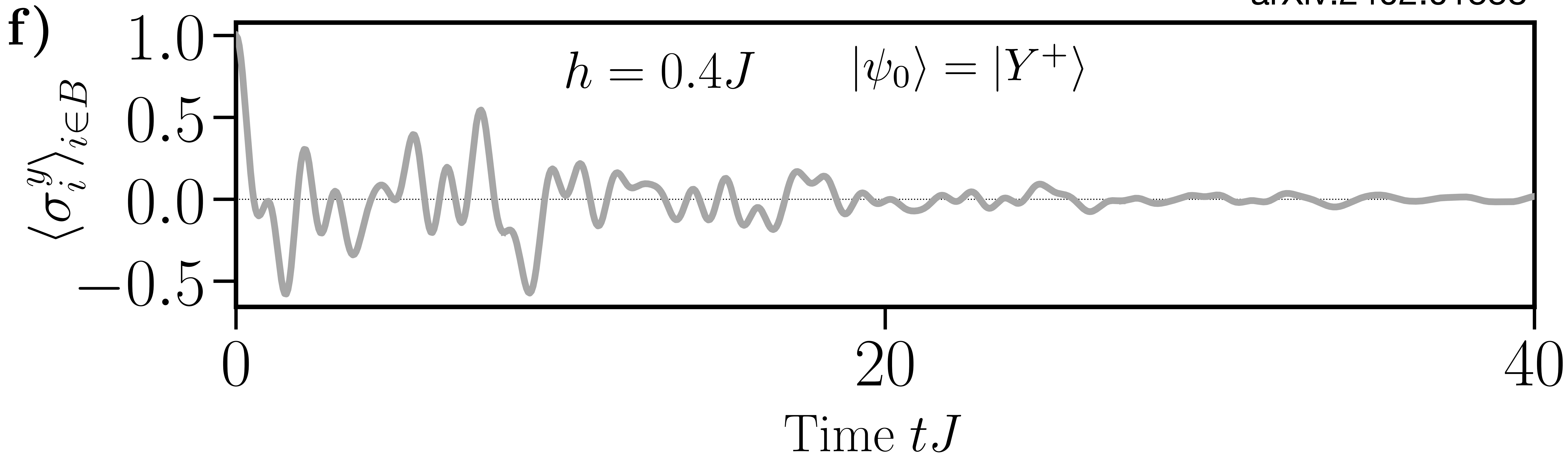
In **closed quantum** systems, explained by the *eigenstate thermalization hypothesis:*

For local observables, the rest of the system acts as a thermal environment.

arXiv:2402.01558



Sometimes, thermalization is very slow

... and that is interesting!

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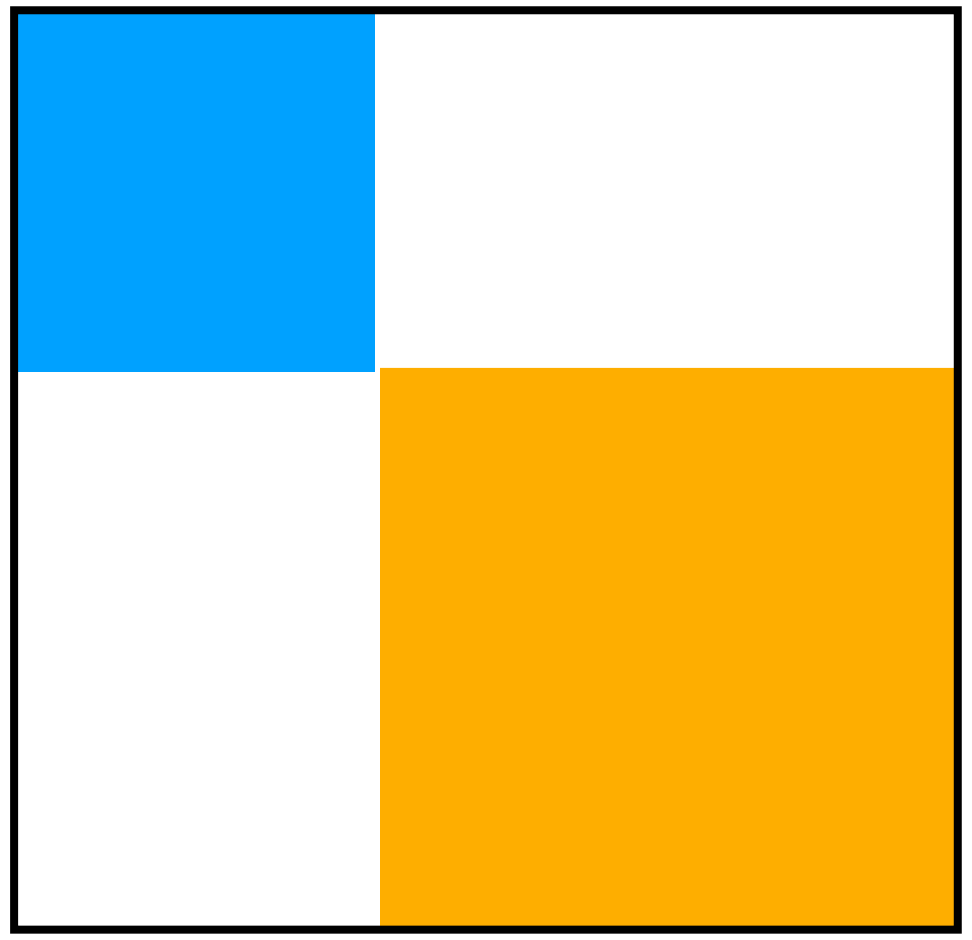
Reason: some kind of separation of subspaces of the Hilbert space.

$H =$ 

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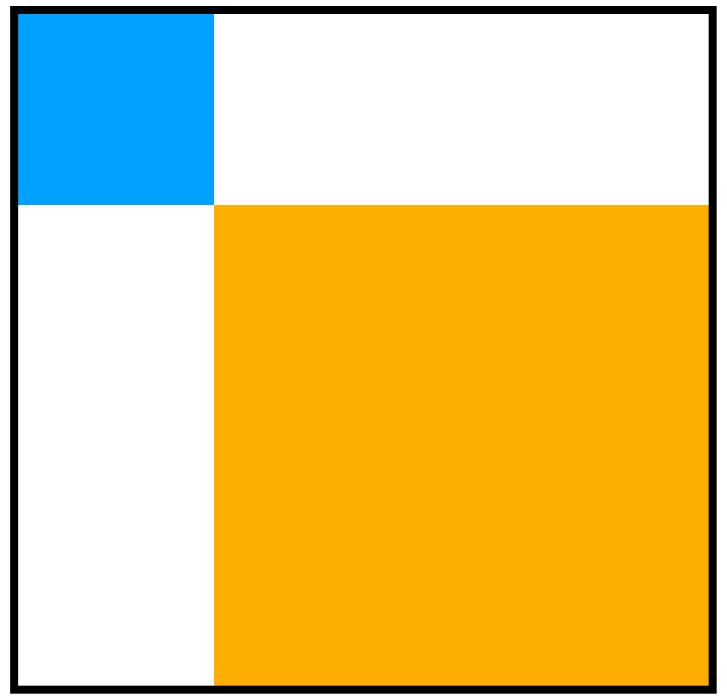
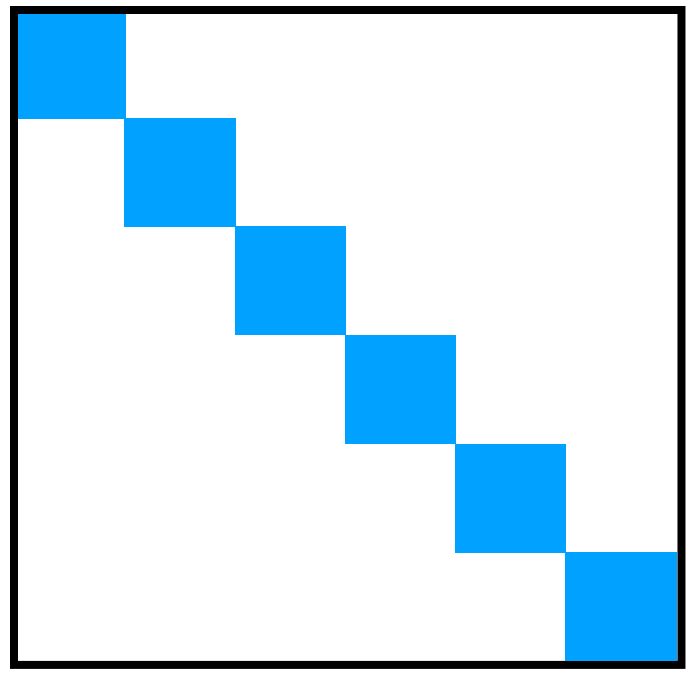
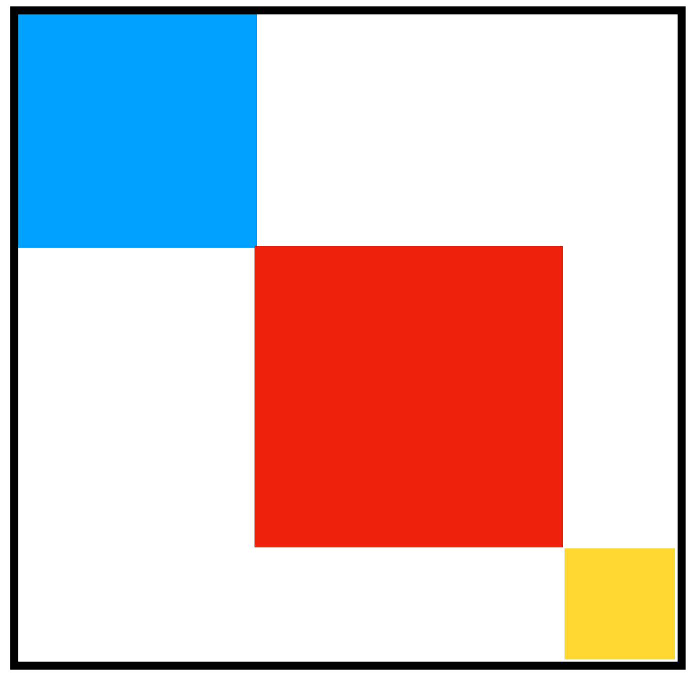
(i) quantum scars



(ii) integrable systems



(iii) emergent dynamical constraints



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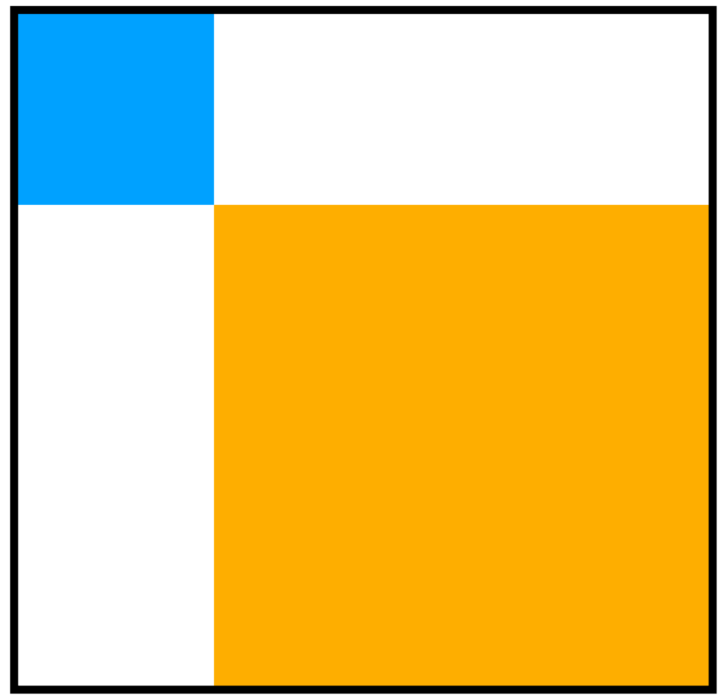

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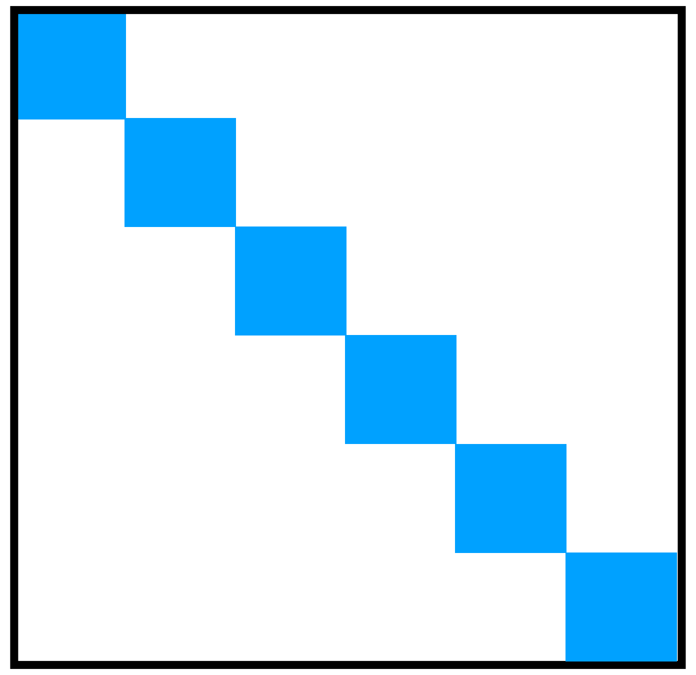

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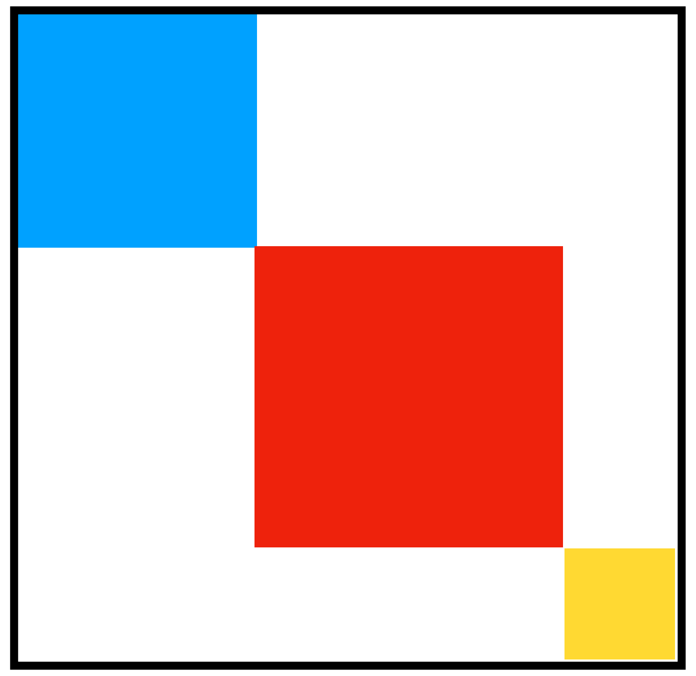


Today!

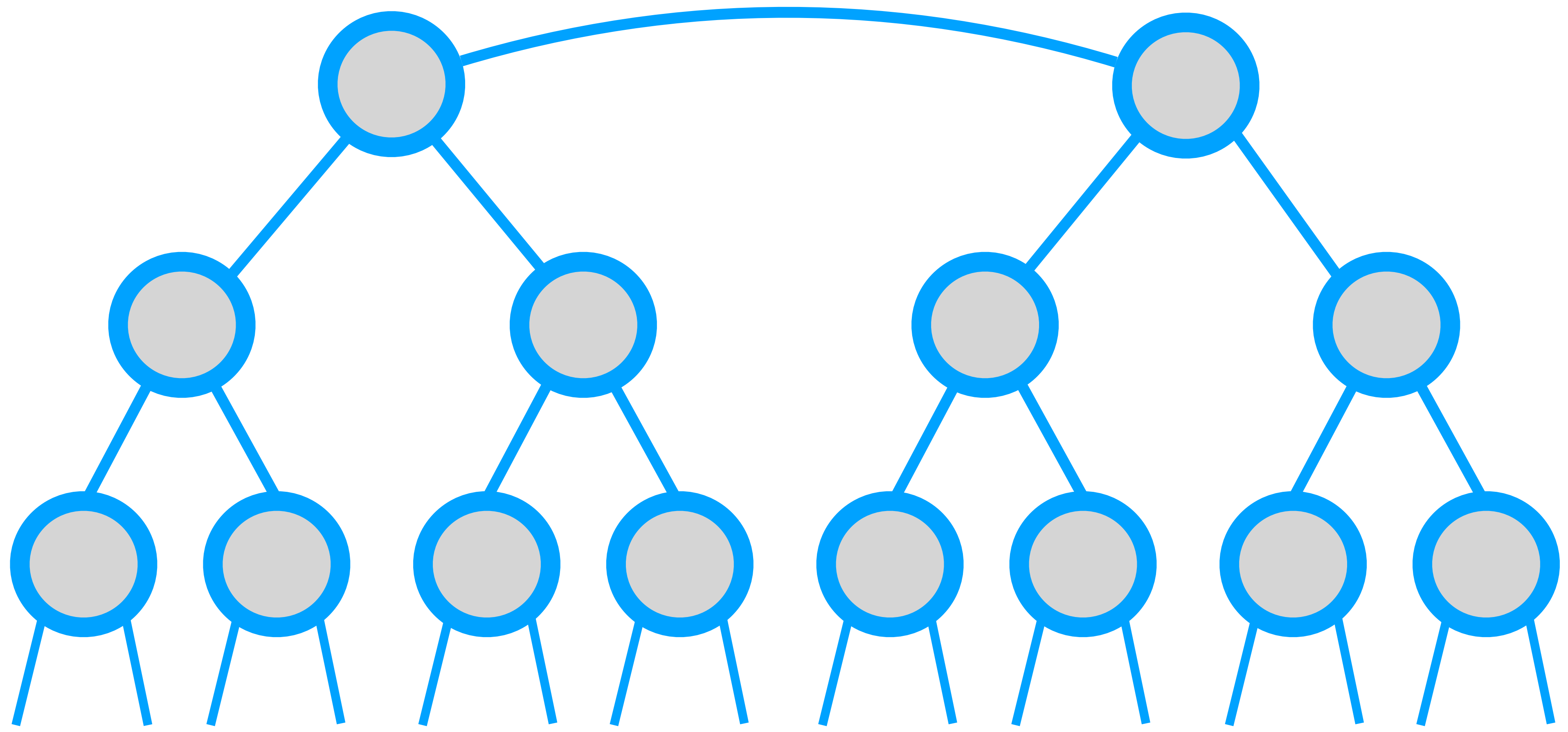
Transverse field Ising model

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

In the regime: $J = 1$

$$g < g_c = 3J$$

Transverse field Ising model



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

In the regime: $J = 1$

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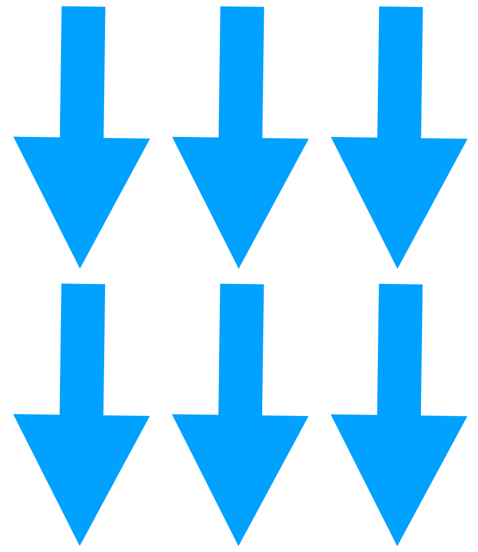
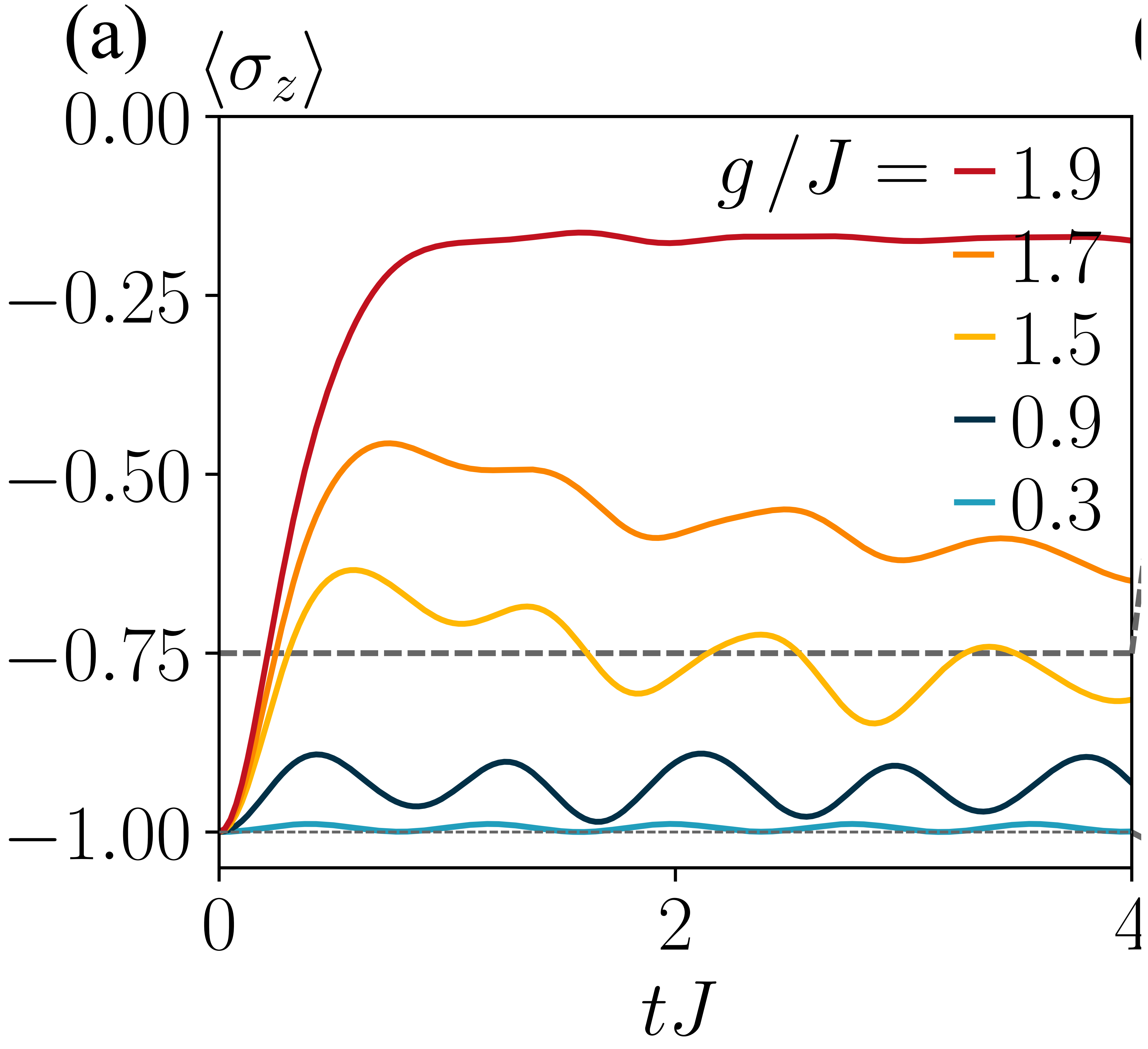
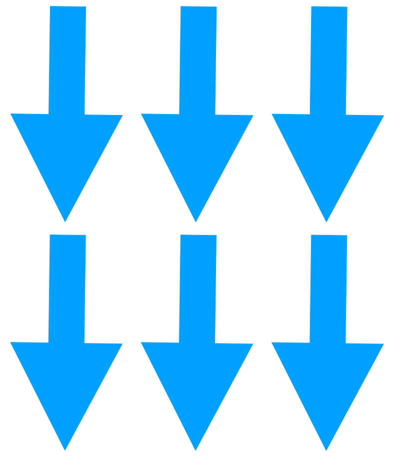
We look at quenches of product states $\psi_0 =$  to finite *g*.

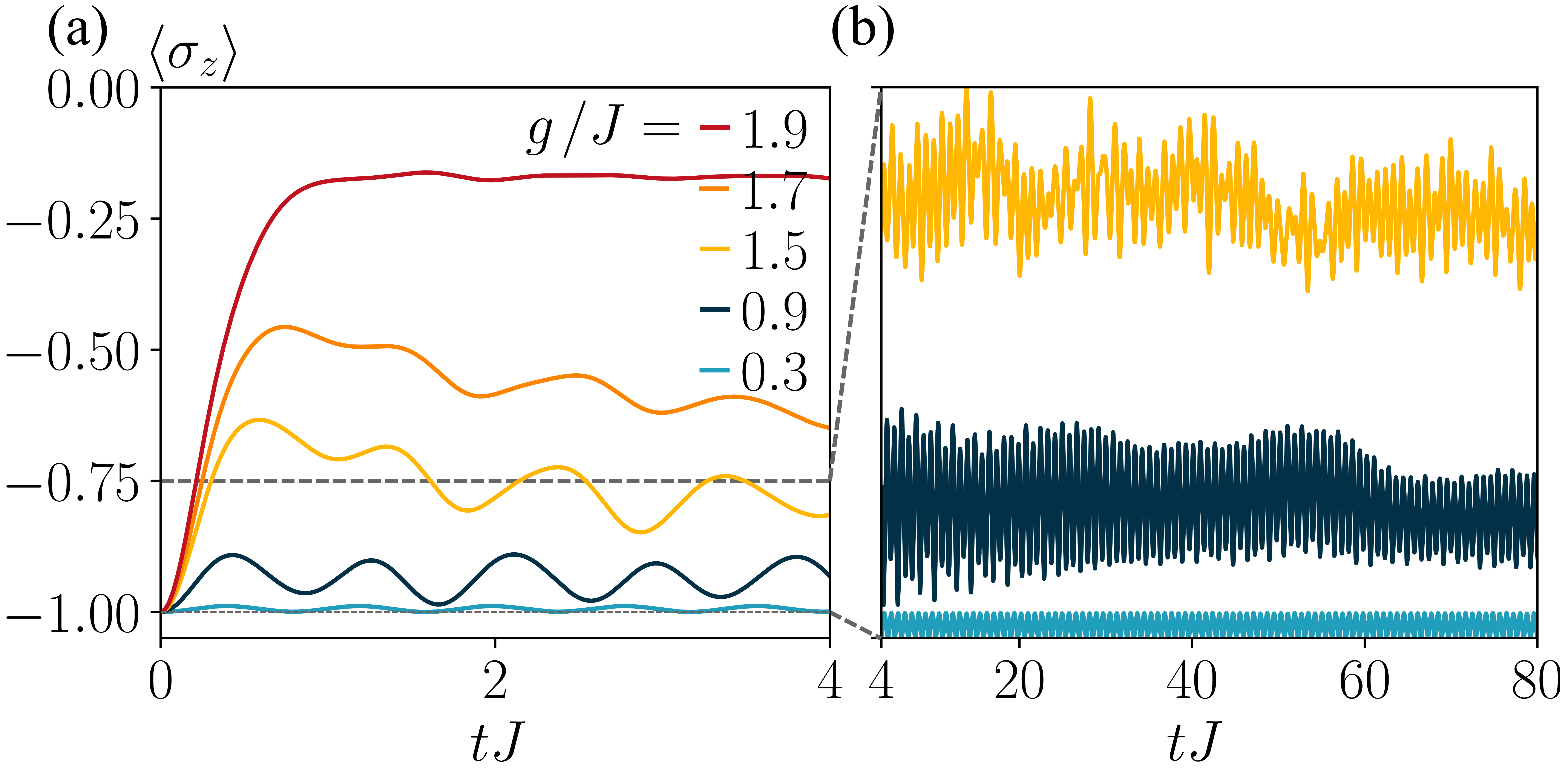
Quench of $\psi_0 =$ ↓↓↓ ↓↓↓ to finite *g*

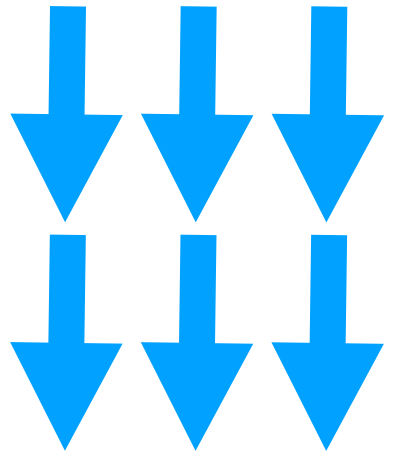


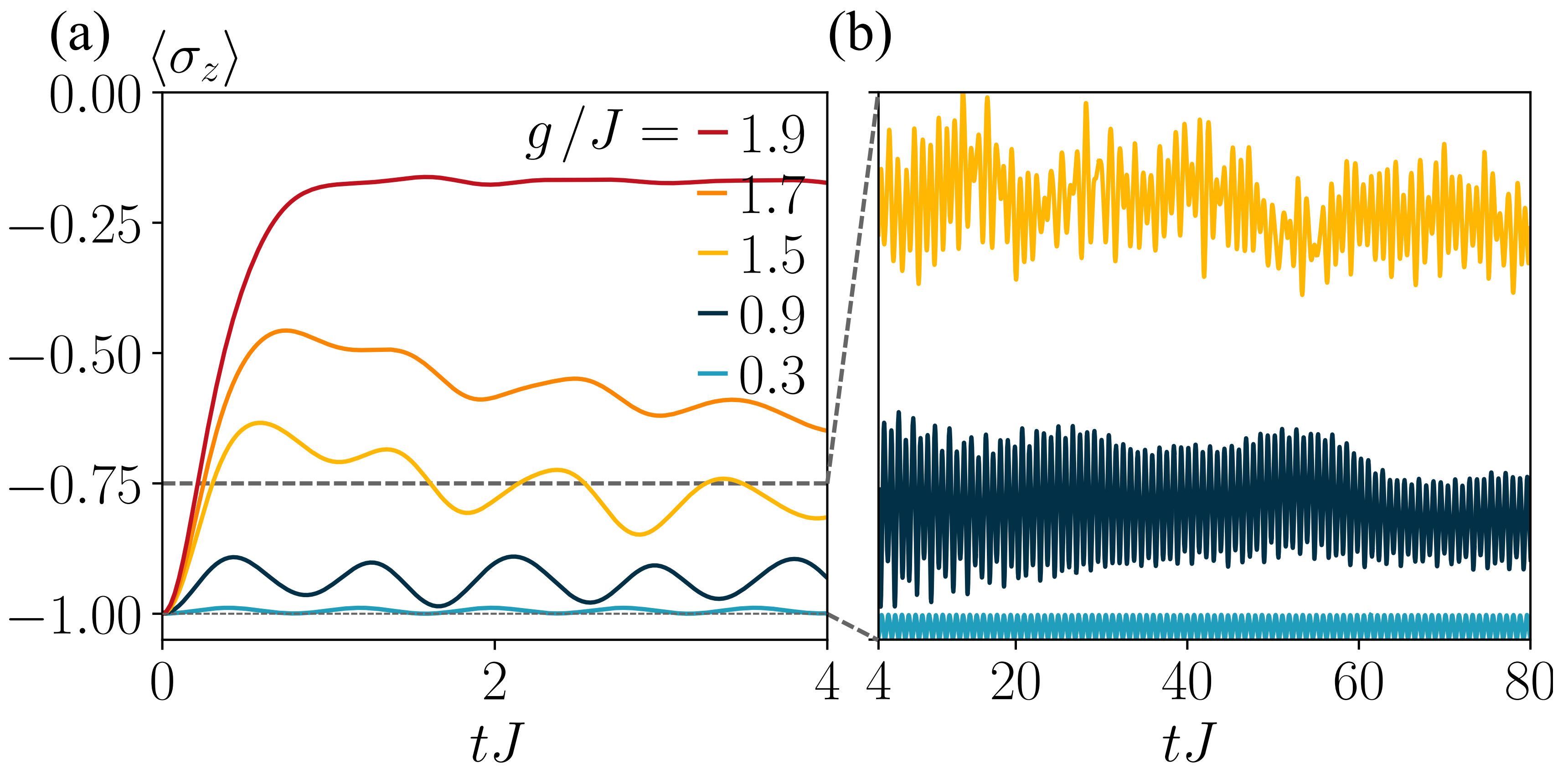
thermalizing at g/J ~ 2

NOT thermalizing at smaller g

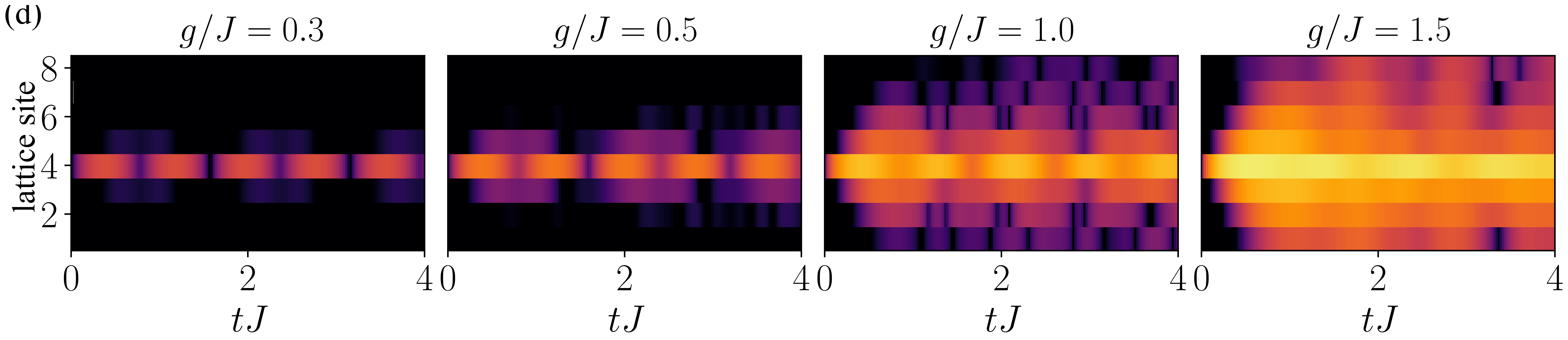
Quench of $\psi_0 =$  to finite *g*



Quench of $\psi_0 =$  to finite *g*

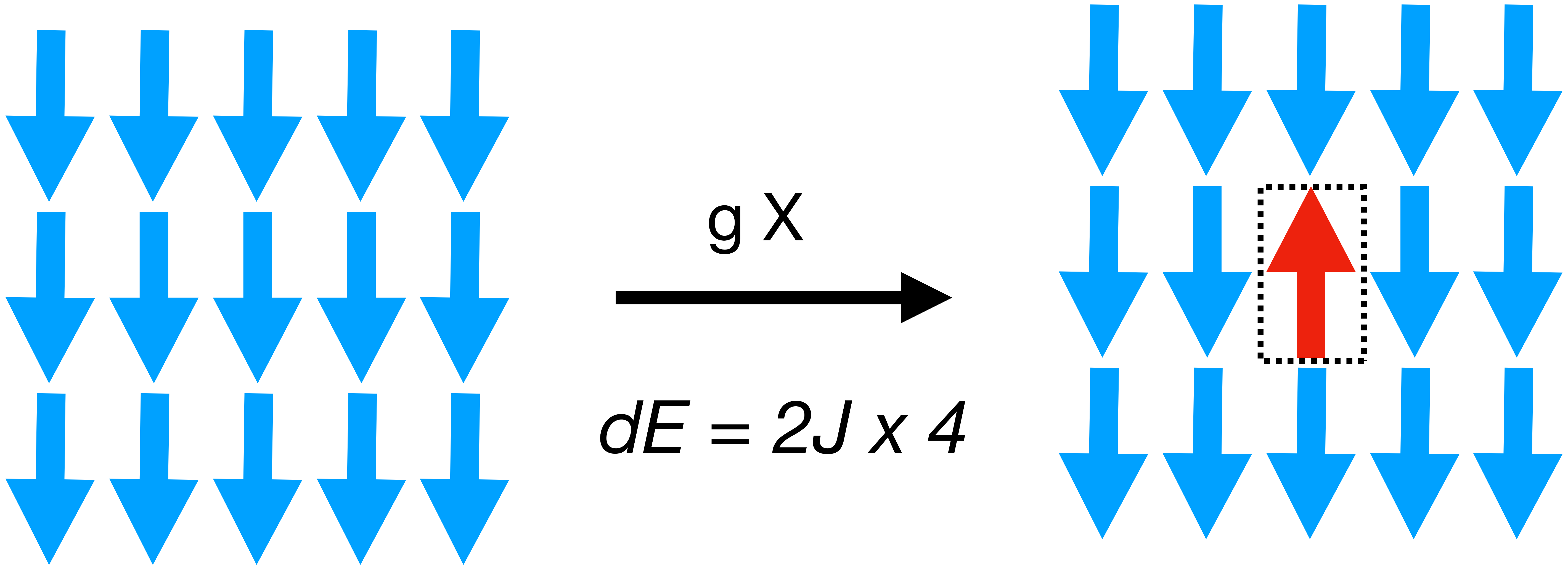


Cij = <Zi Zj> - <Zi><Zj>



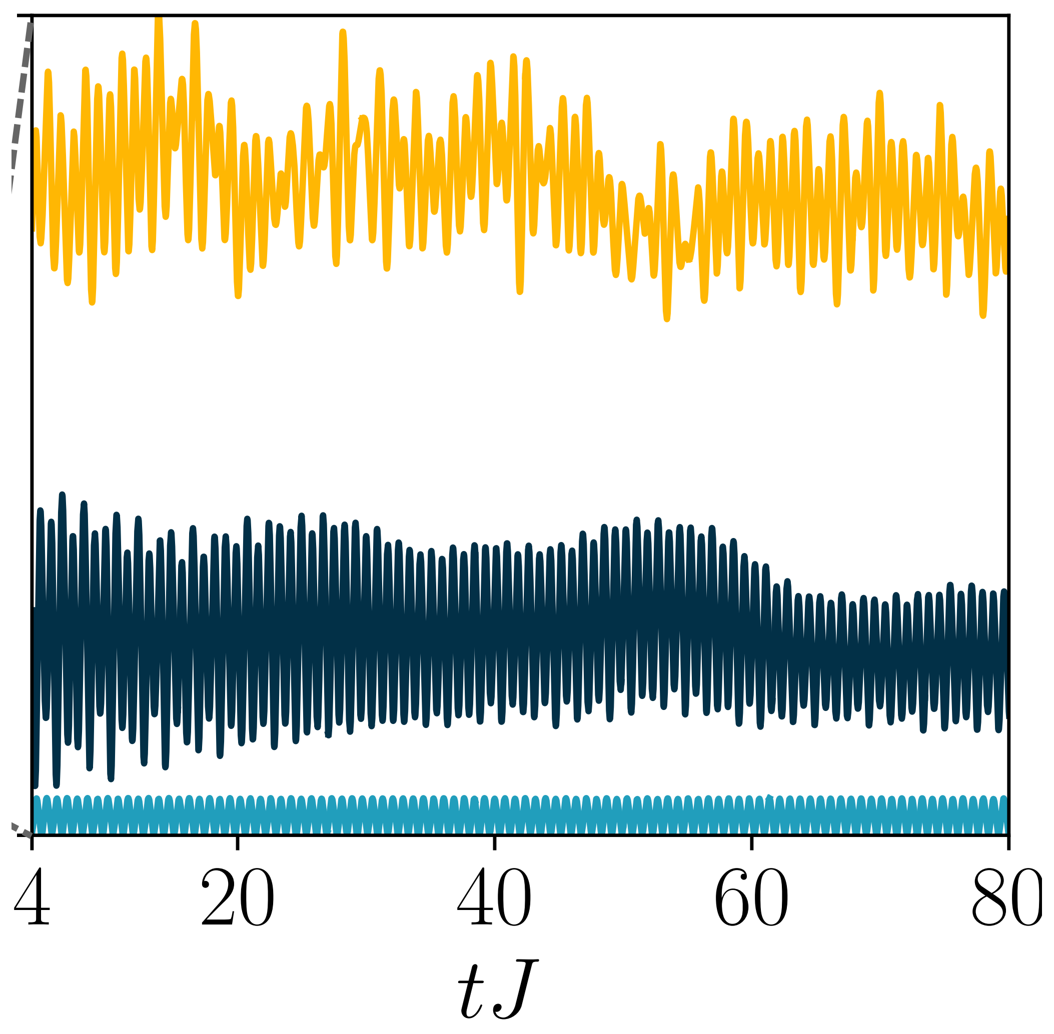
What is going on?

Creating elementary excitations is prohibitively expensive:

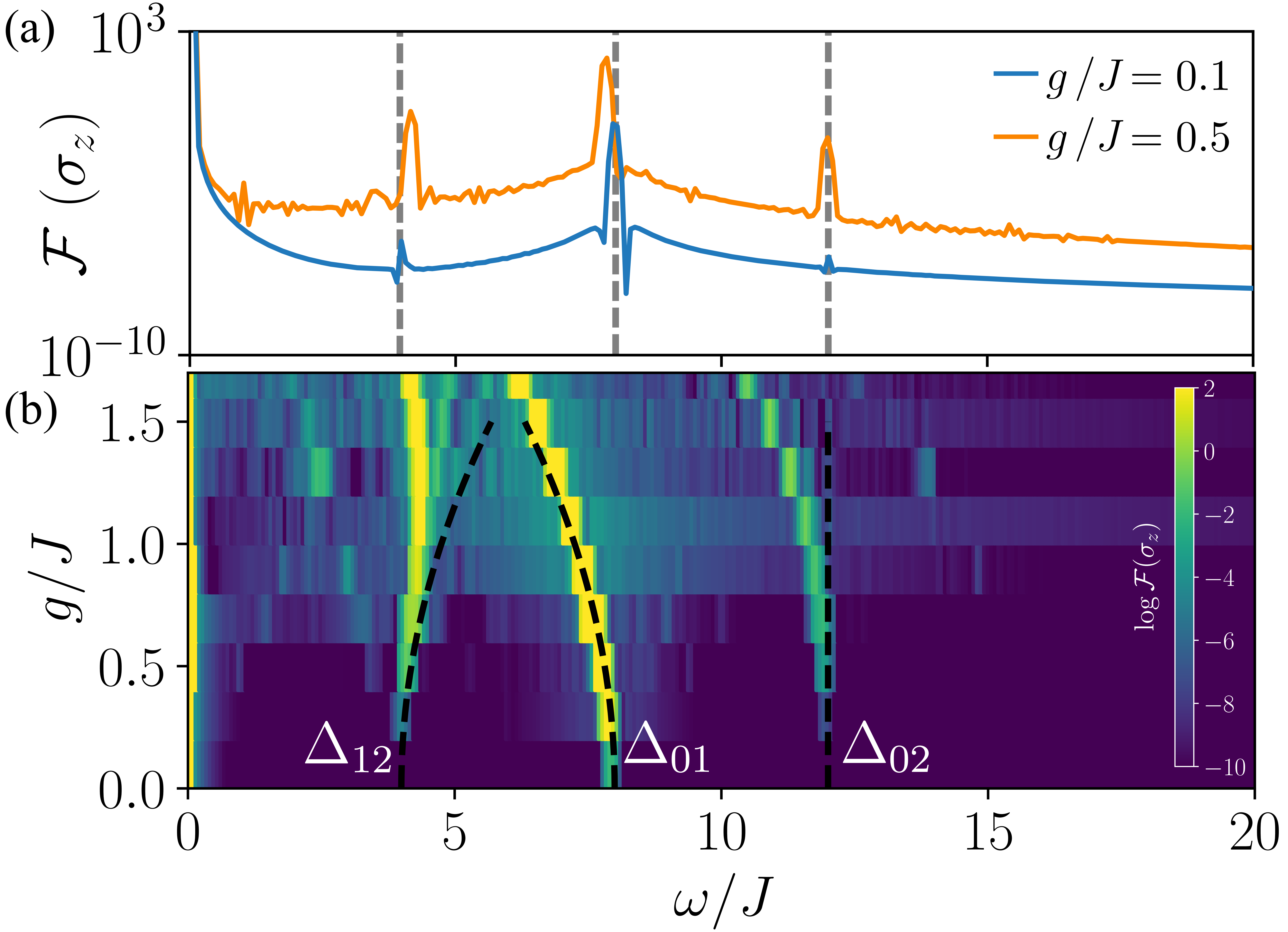


The *amplitude* is given by g^2/8J.

Nature of excitations



FT



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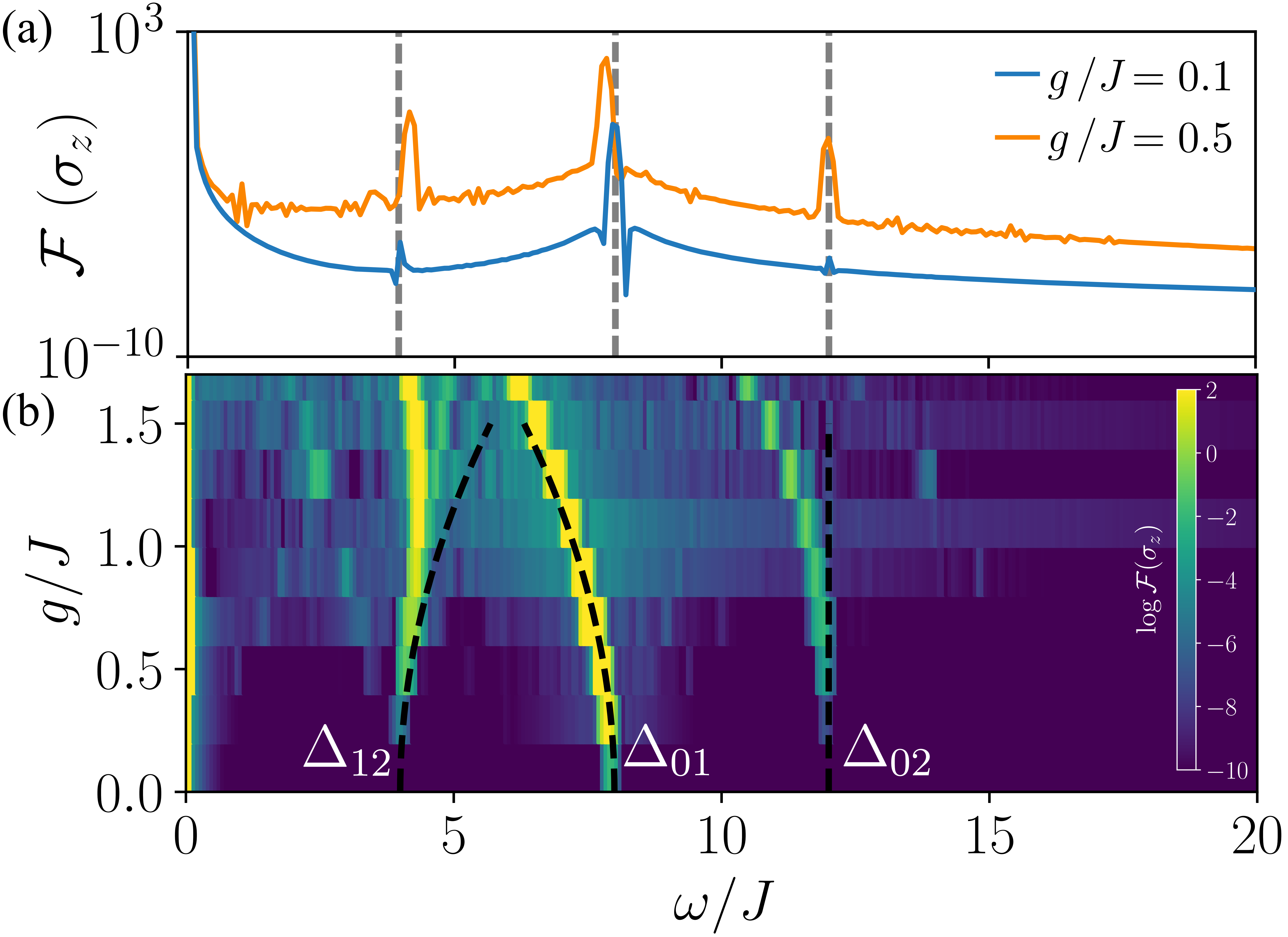

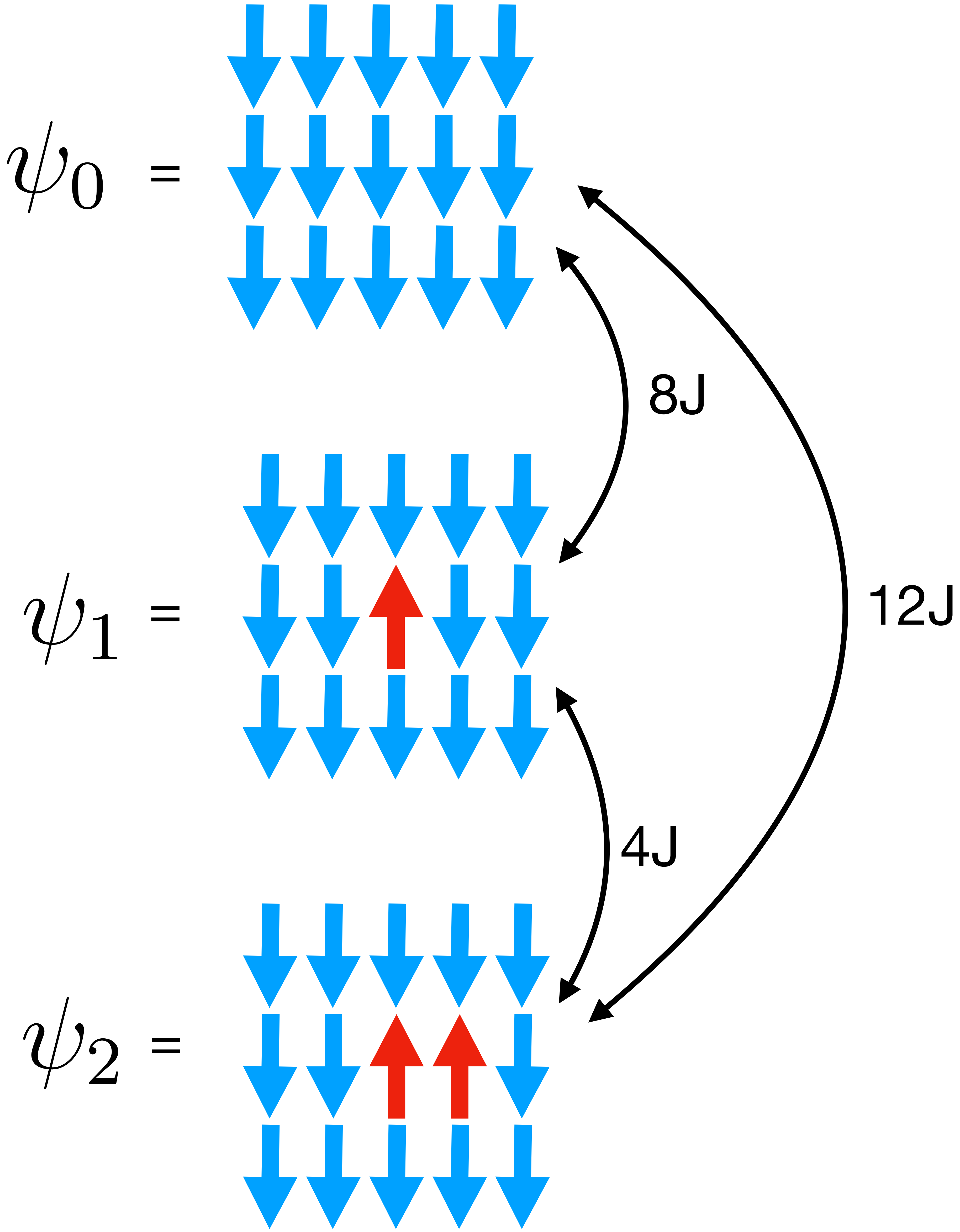

Fragmentation more generally?

(in presence of domain walls)

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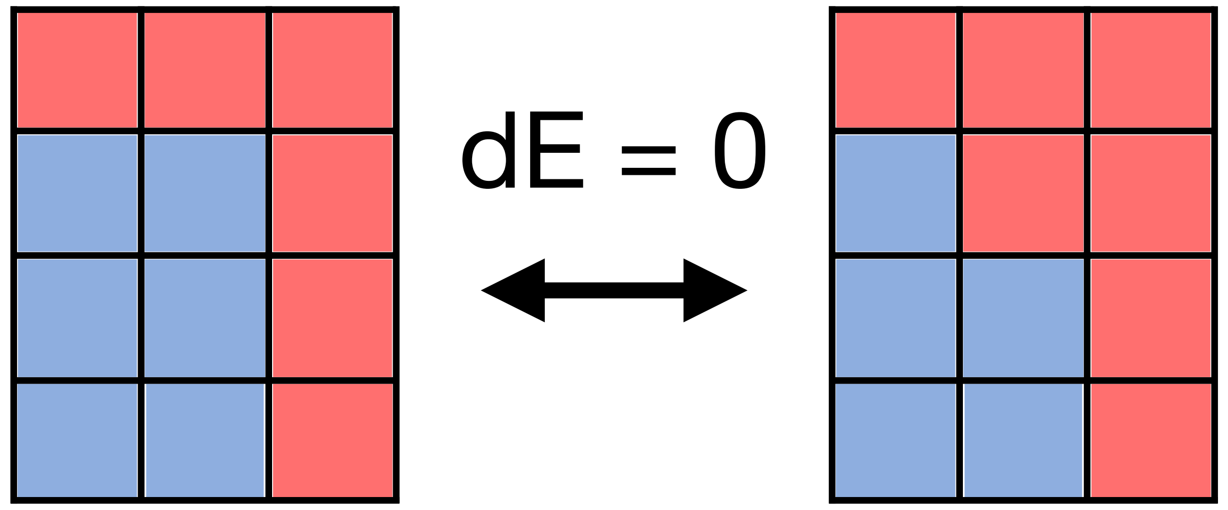
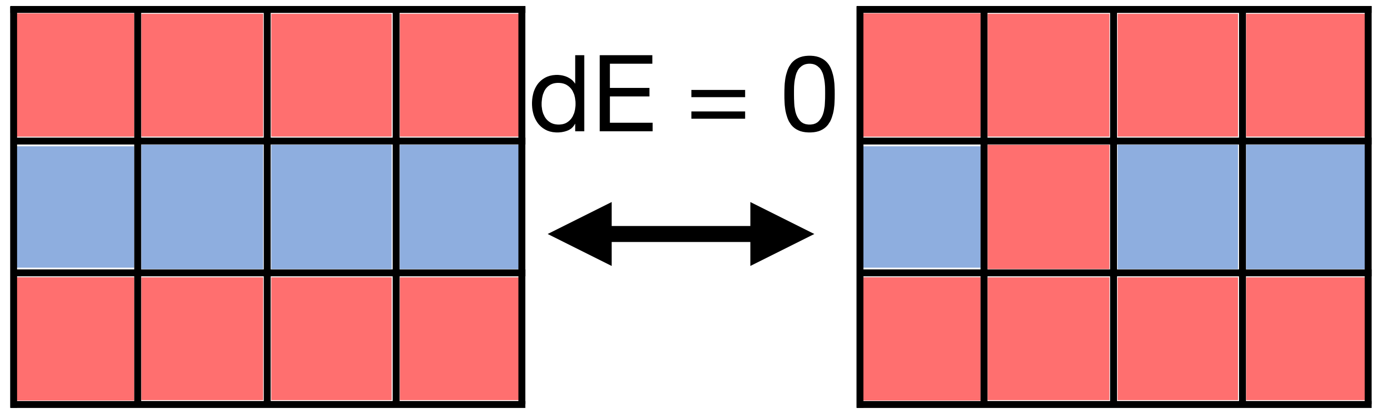
There are **resonant** processes:





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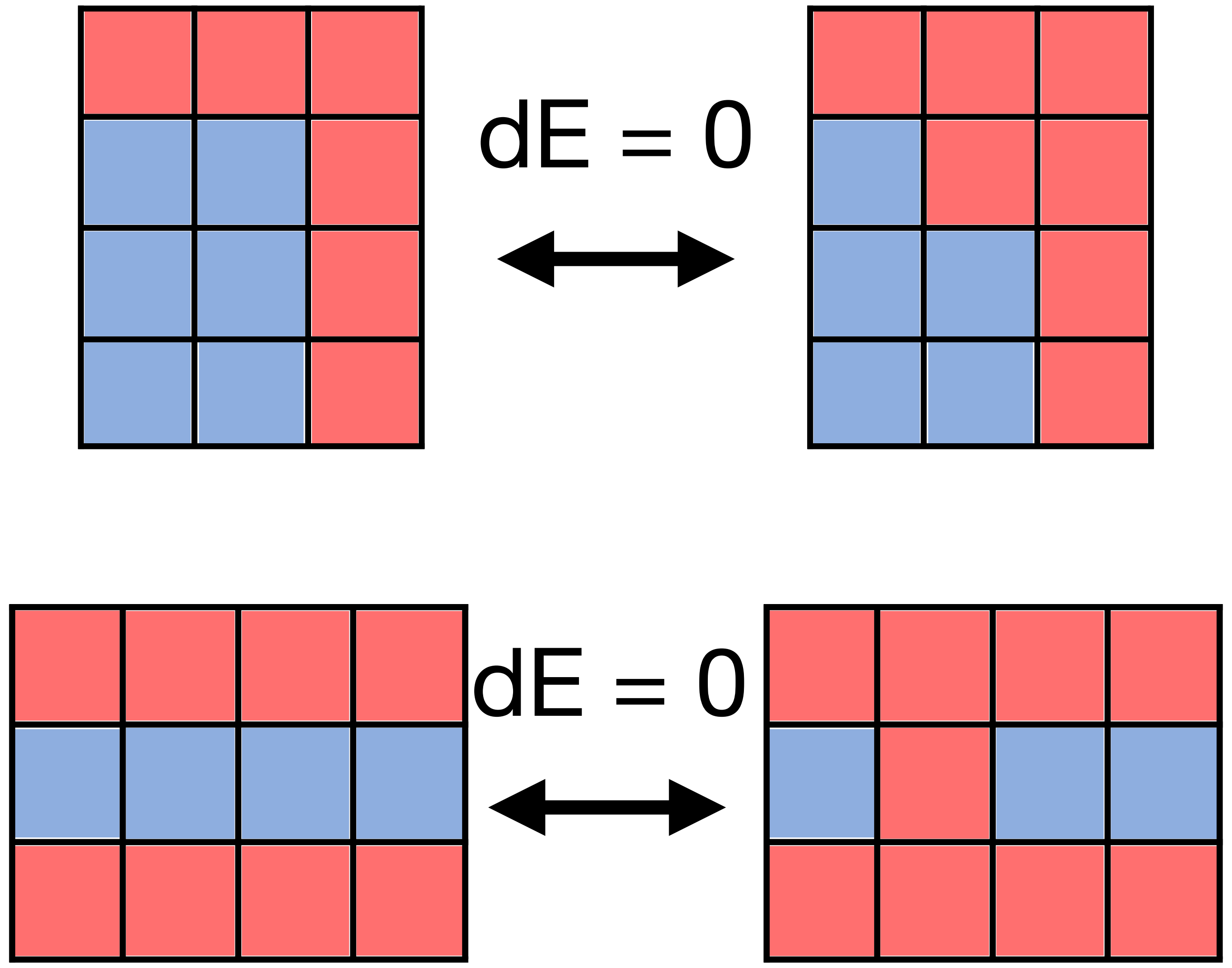
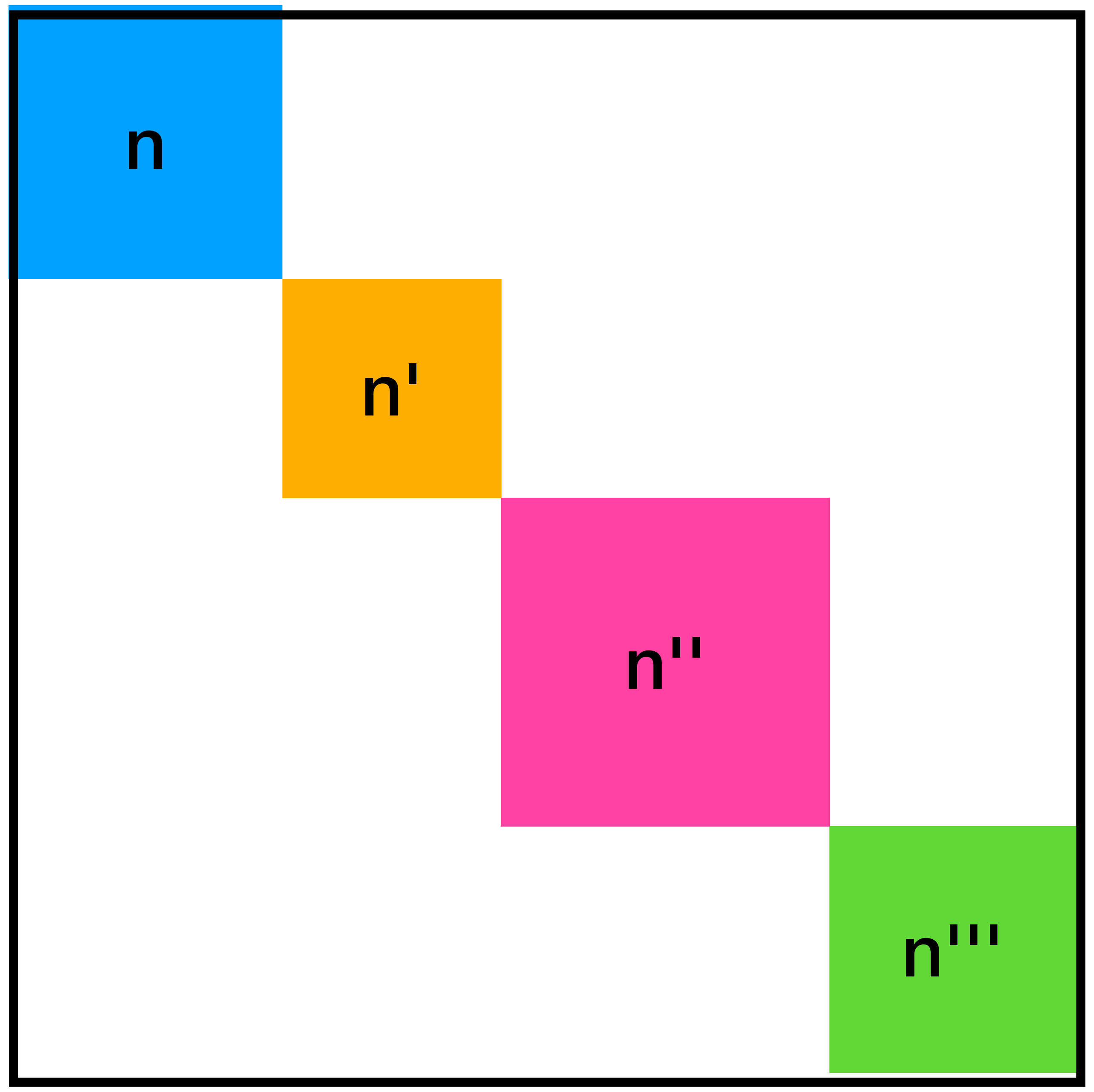


They locally conserve the length of the domain wall!

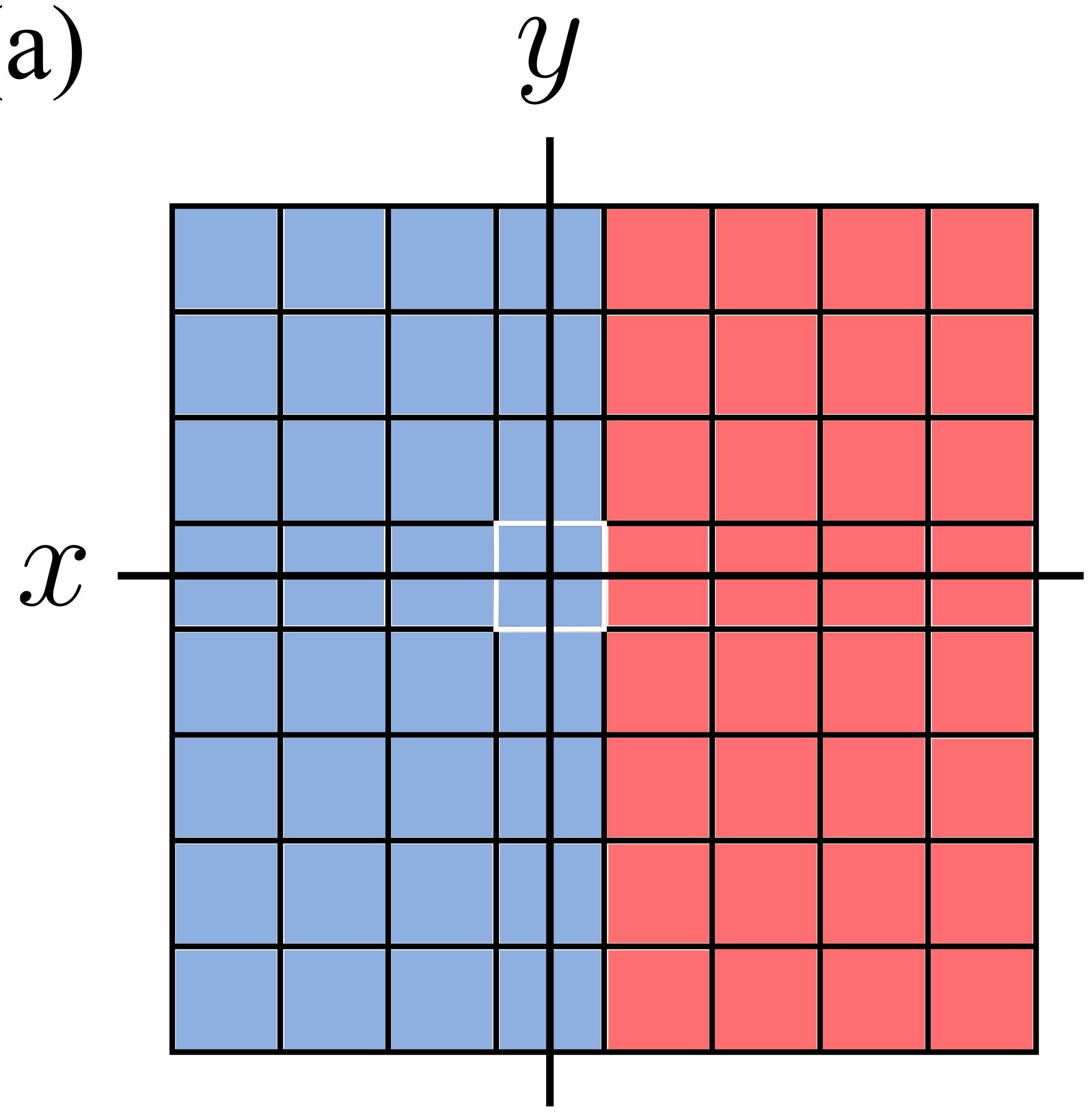
Fragmentation into sectors with same **total domain wall length** *n.*



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

So, dynamics with a domain wall?

(a)



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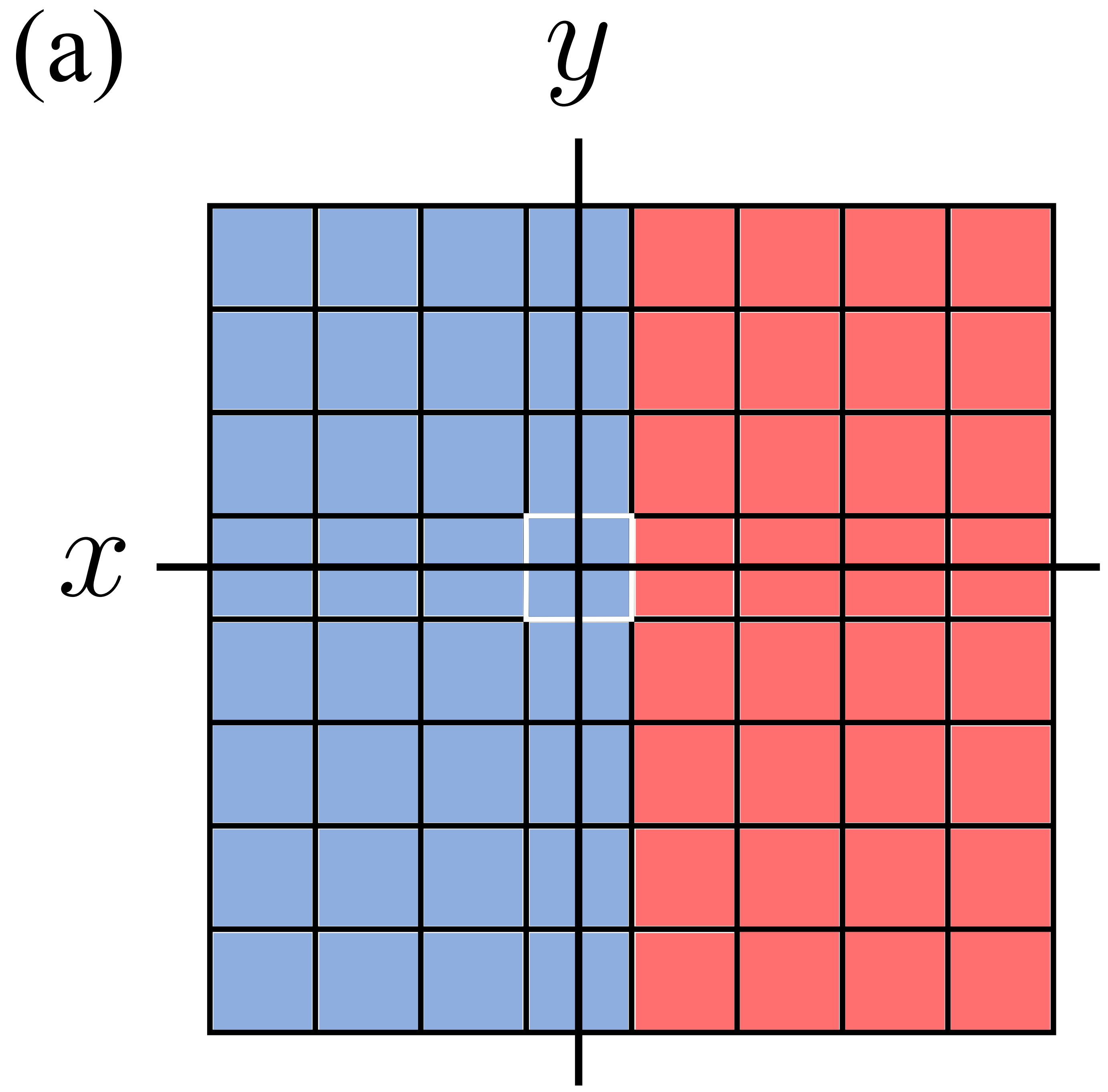
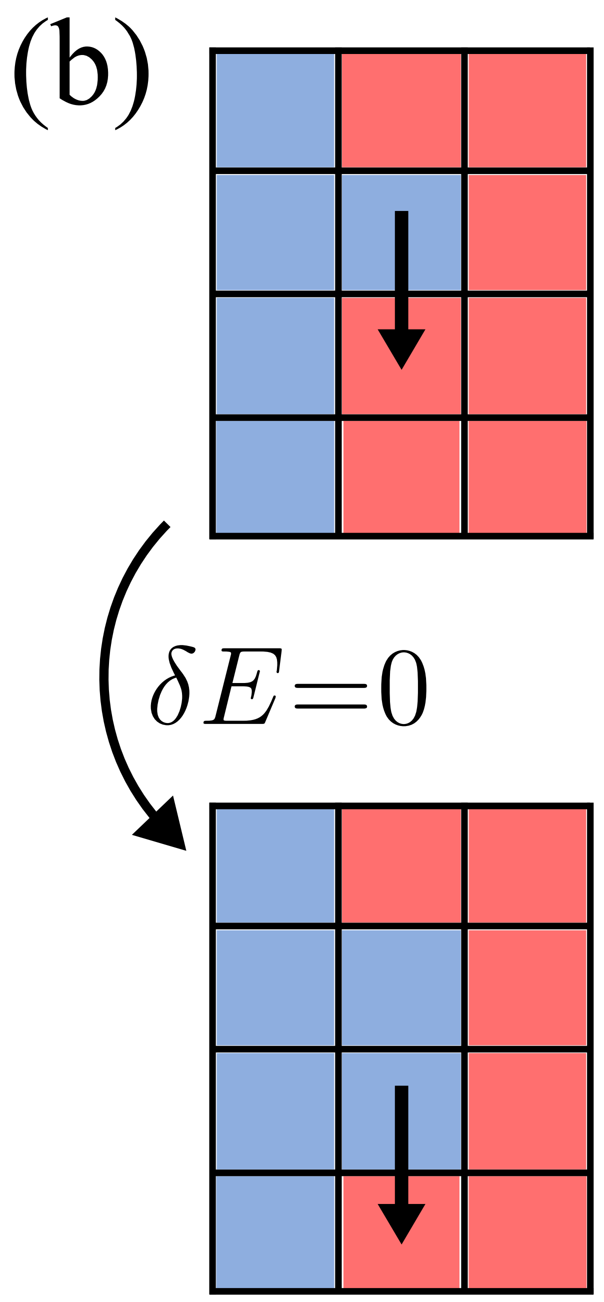


First excitation:



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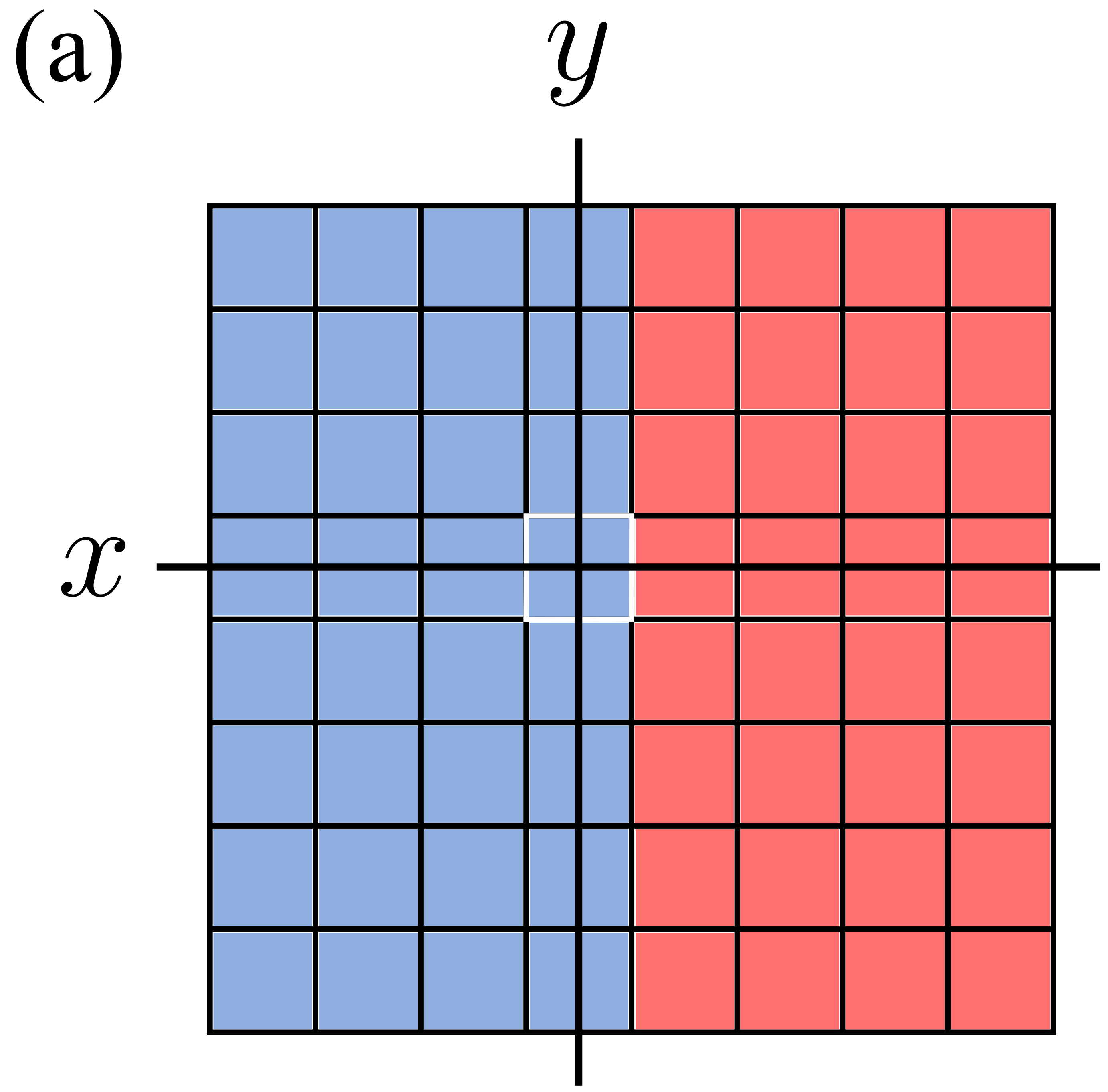

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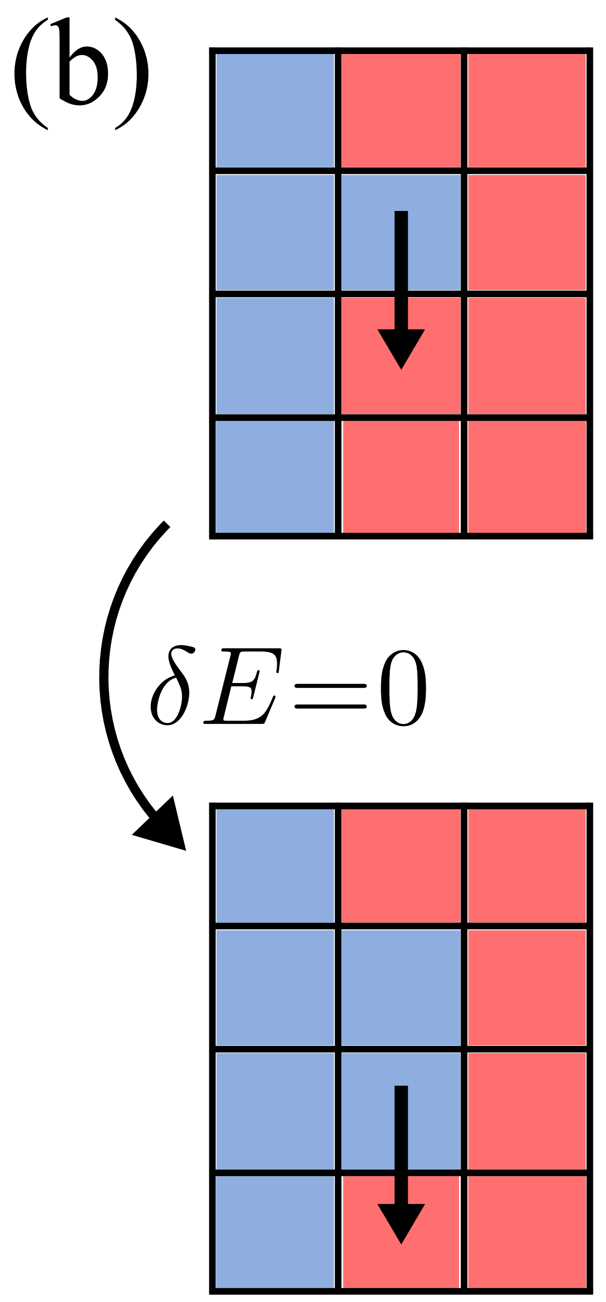


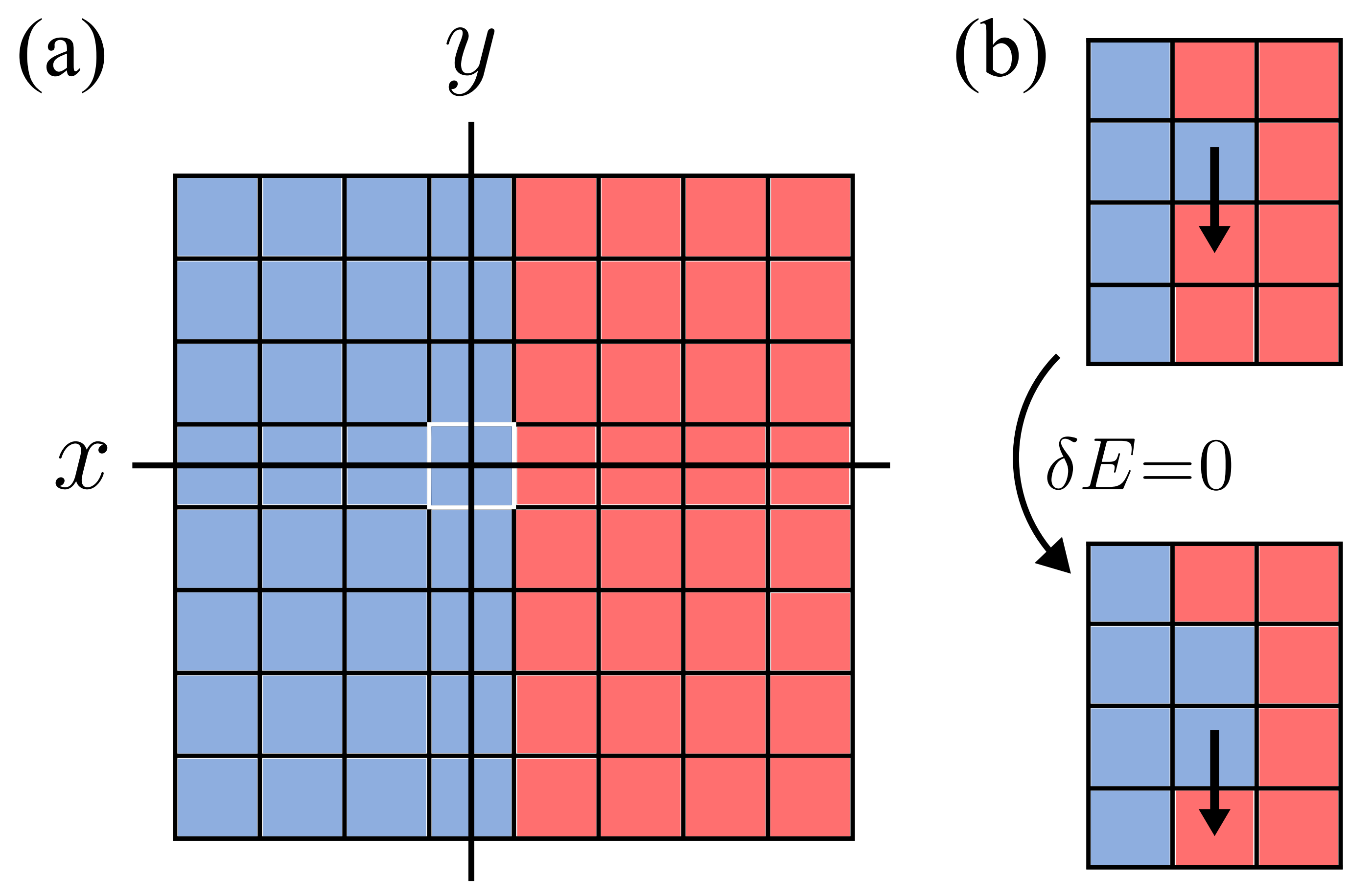
This is effectively a 1D chain.

We know the dispersion! $E(k) = 4J(1 + g\cos(k))$

F. Balducci et al., Interface dynamics in the two-dimensional quantum Ising model, Phys. Rev. B 107, 2022

F. Balducci et al., Localization and Melting of Interfaces in the Two-Dimensional Quantum Ising Model, Phys. Rev. Lett. 129, 2022

So, dynamics with a domain wall?



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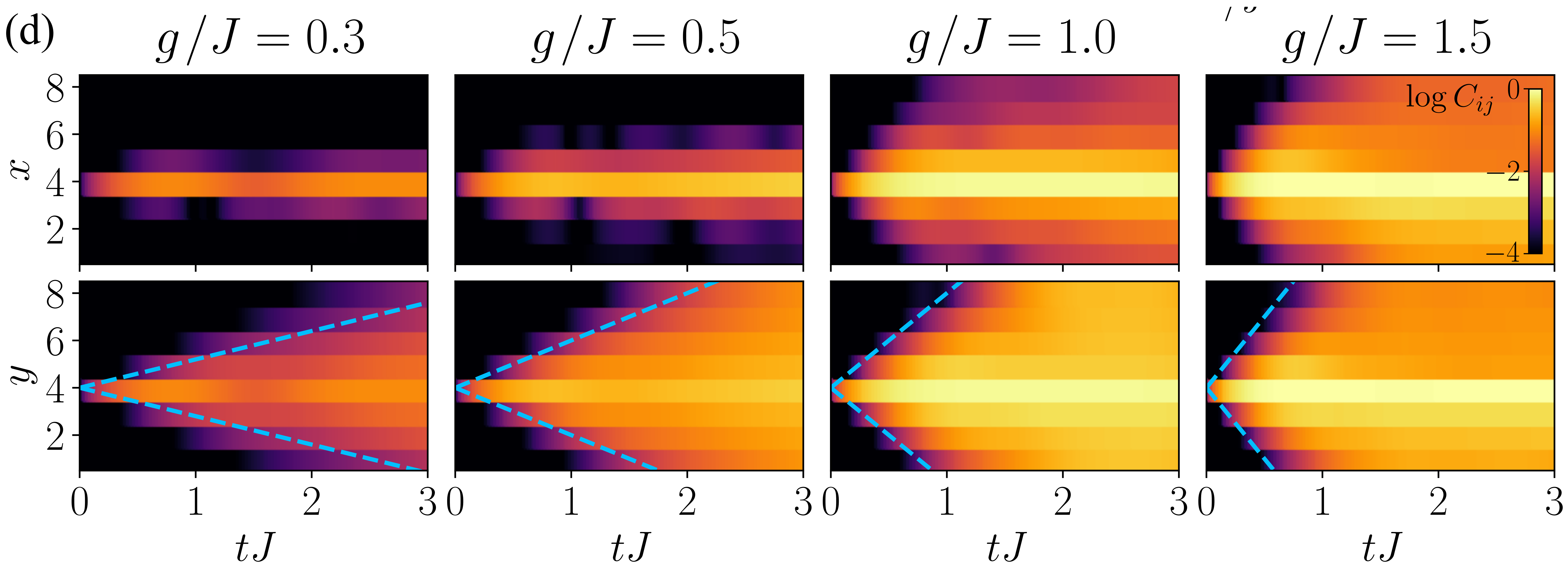

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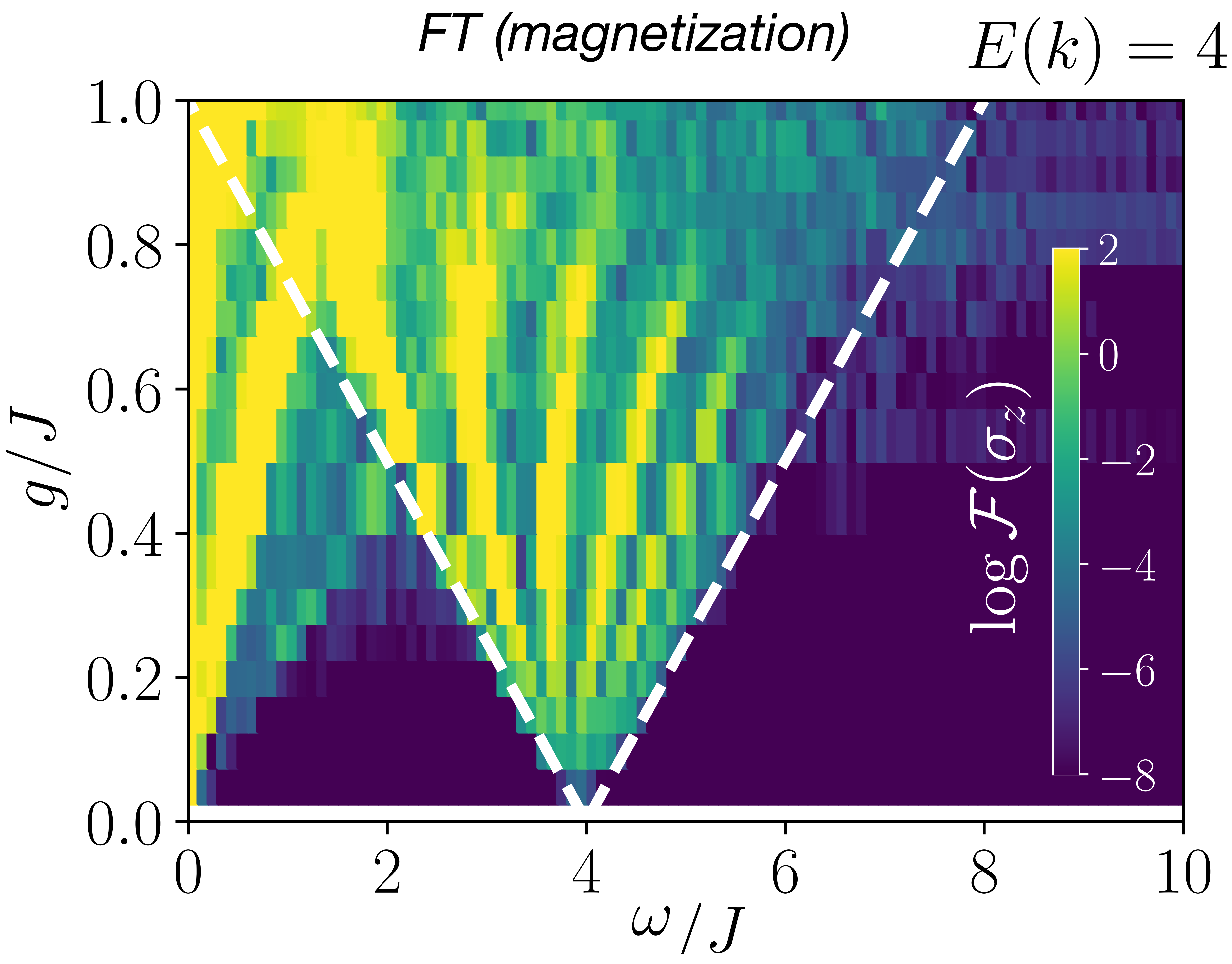
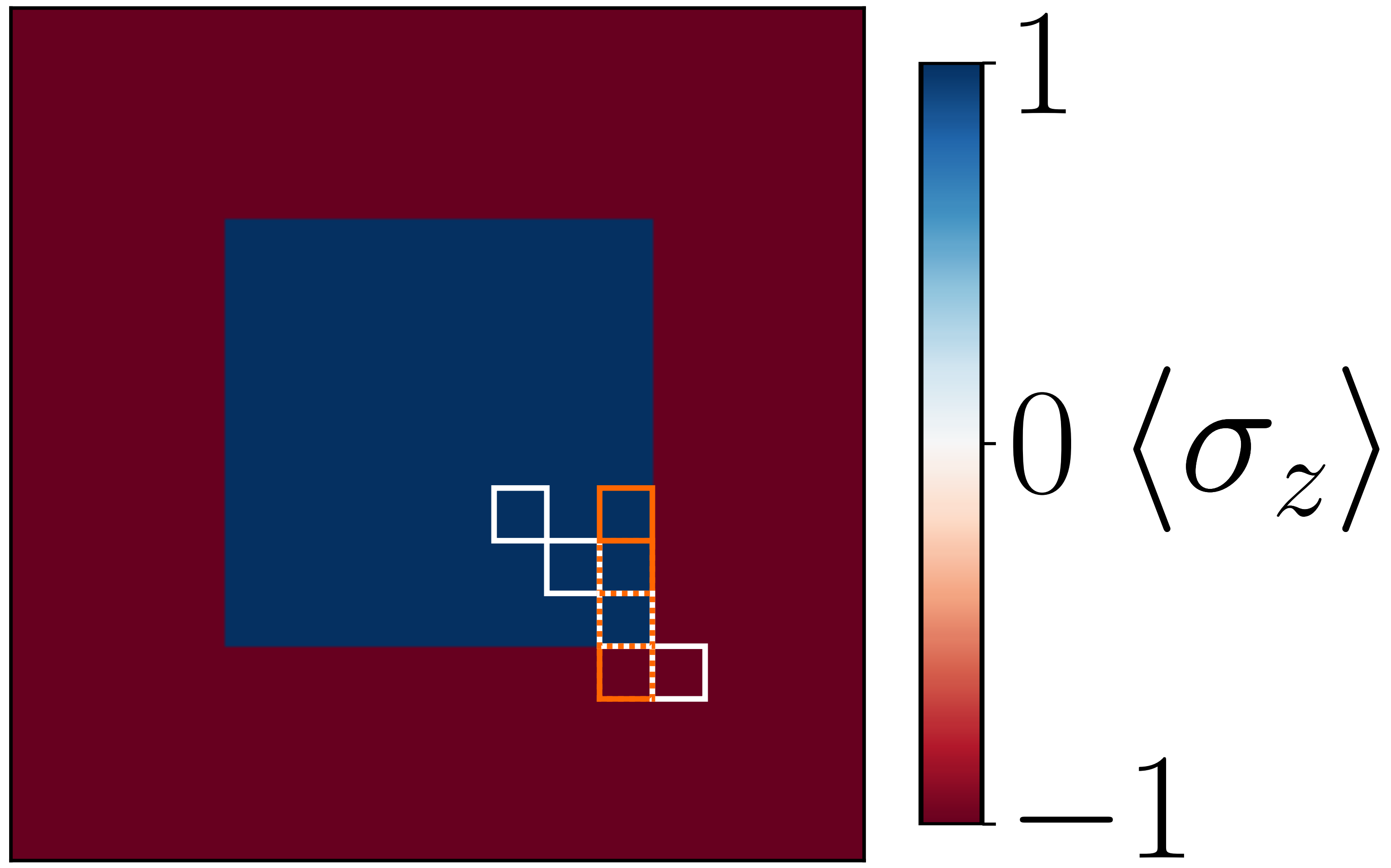


$$E(k) = 4J(1 + g\cos(k))$$

Melting of a square domain?



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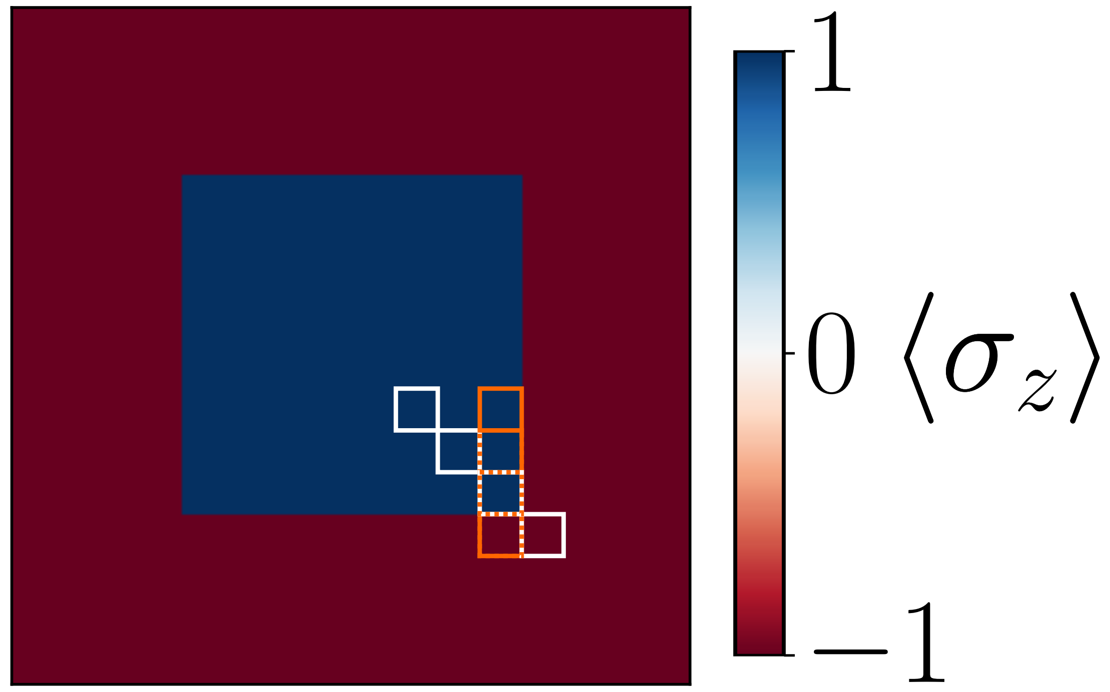
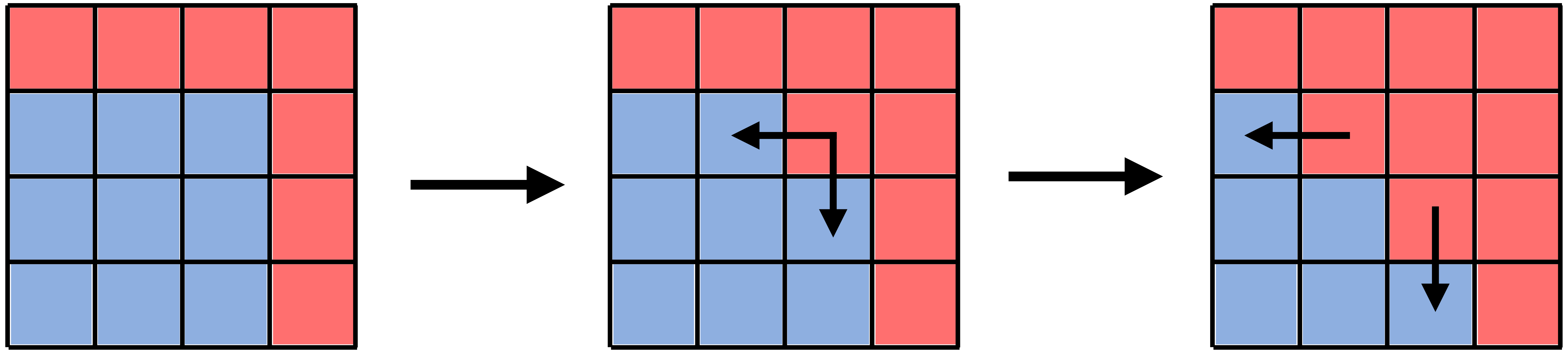


For small g/J, we expect a ***resonant*** melting process, and the **timescale** given by *g*:



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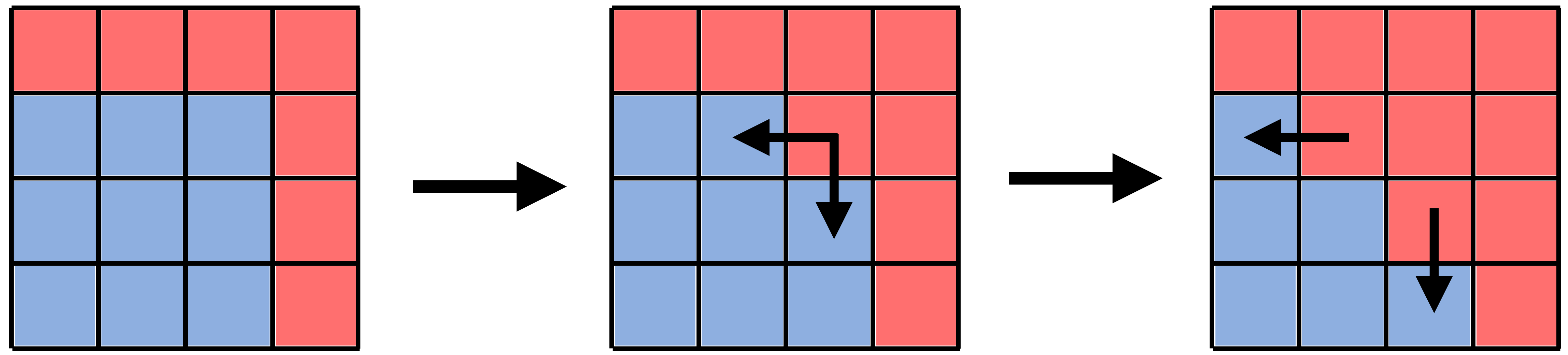
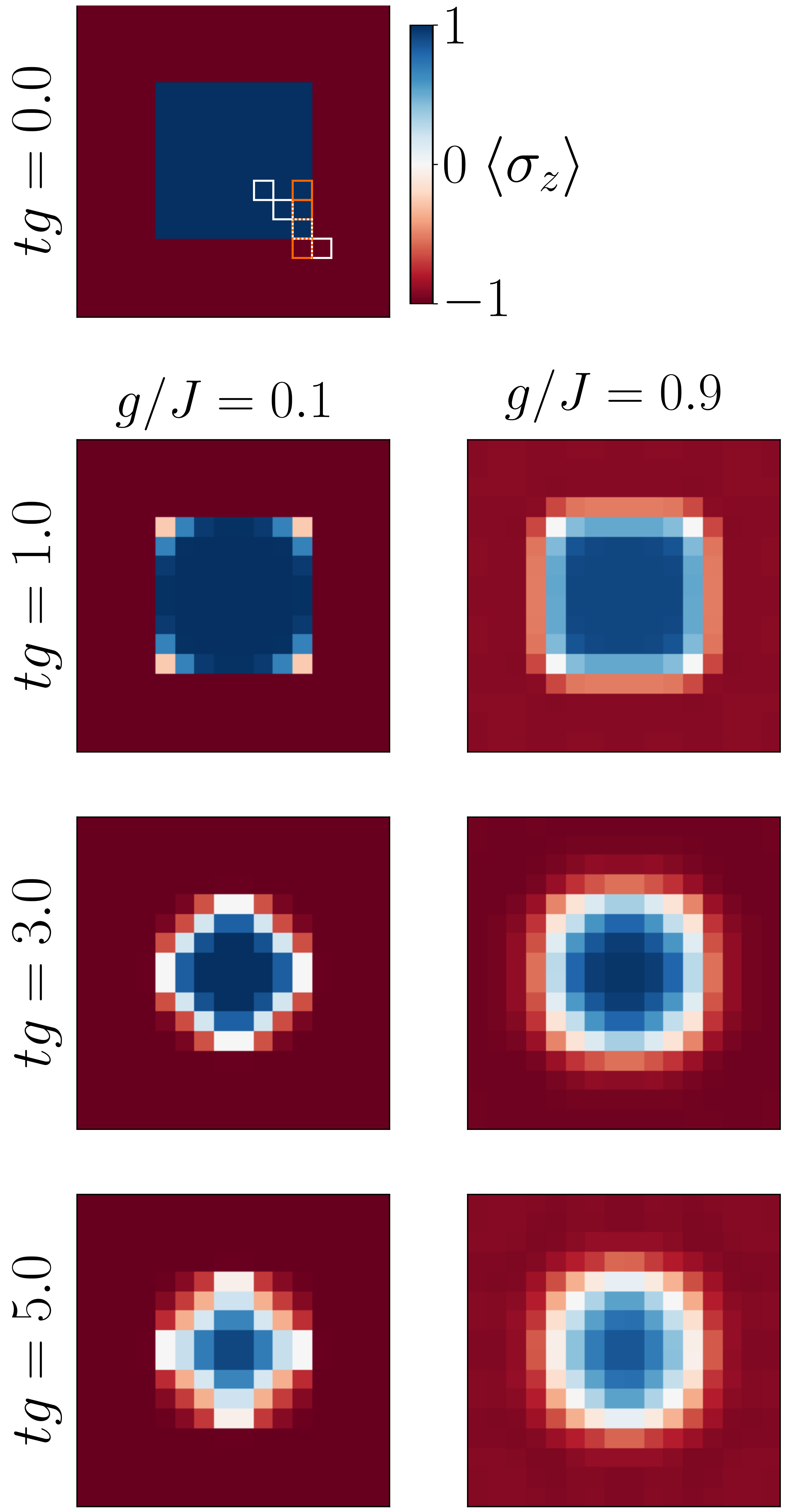


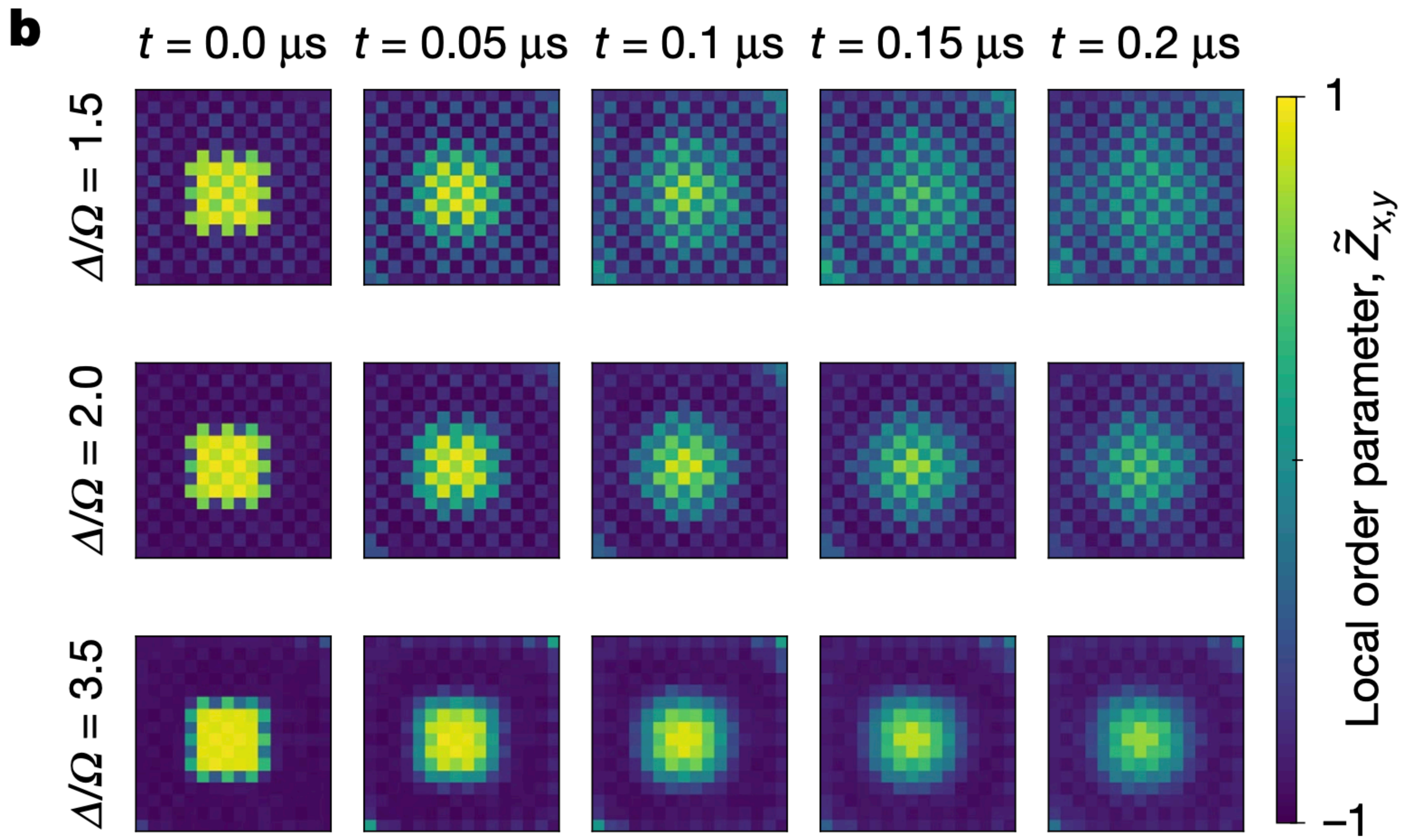


Outlook1: quantum coarsening of interfaces

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

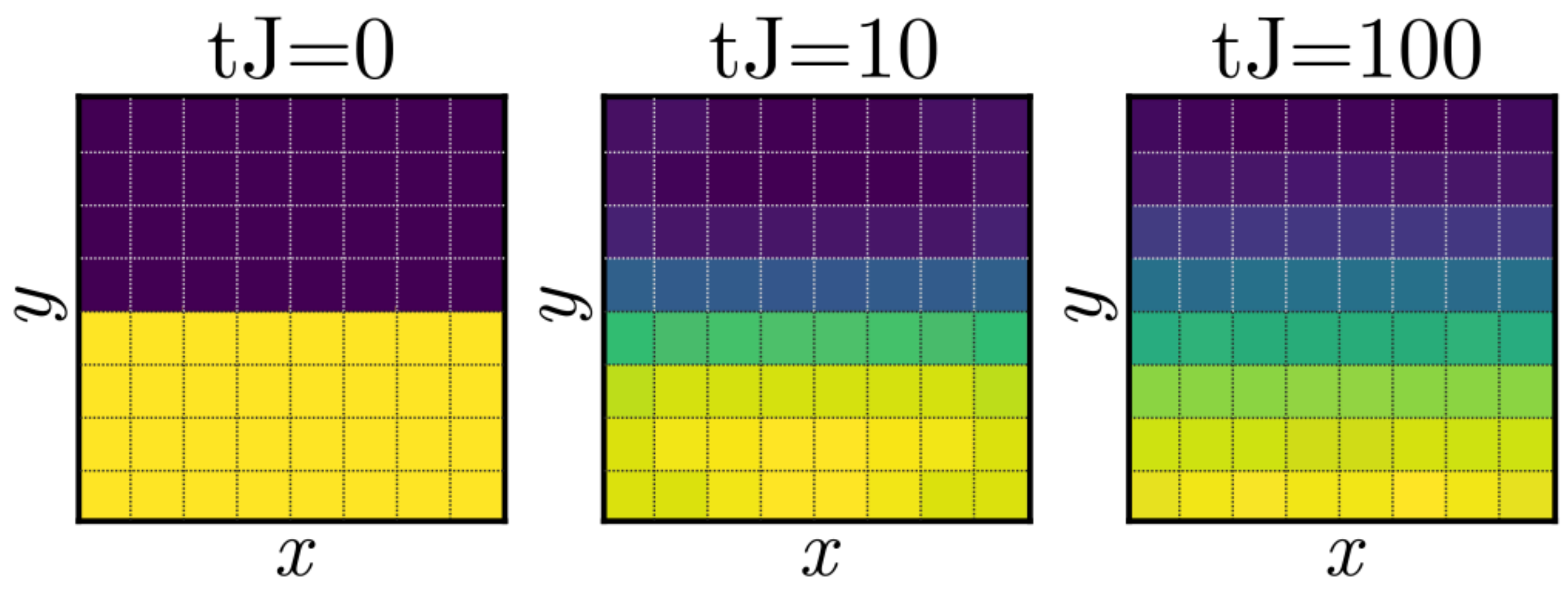
Nature **638**, 86–92 (2025) | Cite this article

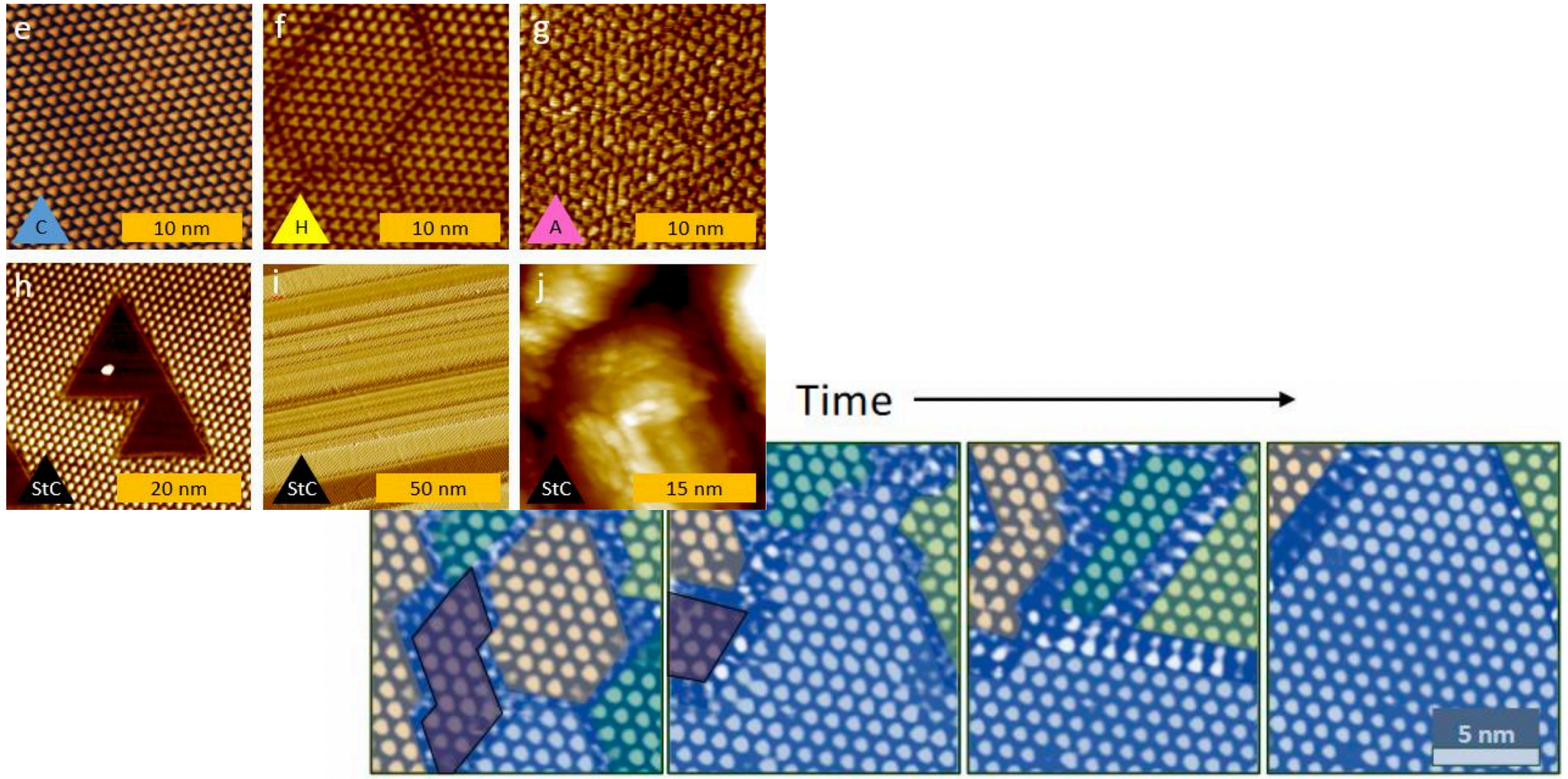


arXiv:2412.10145

Roughening dynamics of interfaces in two-dimensional quantum matter

Wladislaw Krinitsin,[1,2] Niklas Tausendpfund,[1,3] Matteo Rizzi,[1,3] Markus Heyl,[4,5] and Markus Schmitt[1,2]





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

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(Dated: March 6, 2024)

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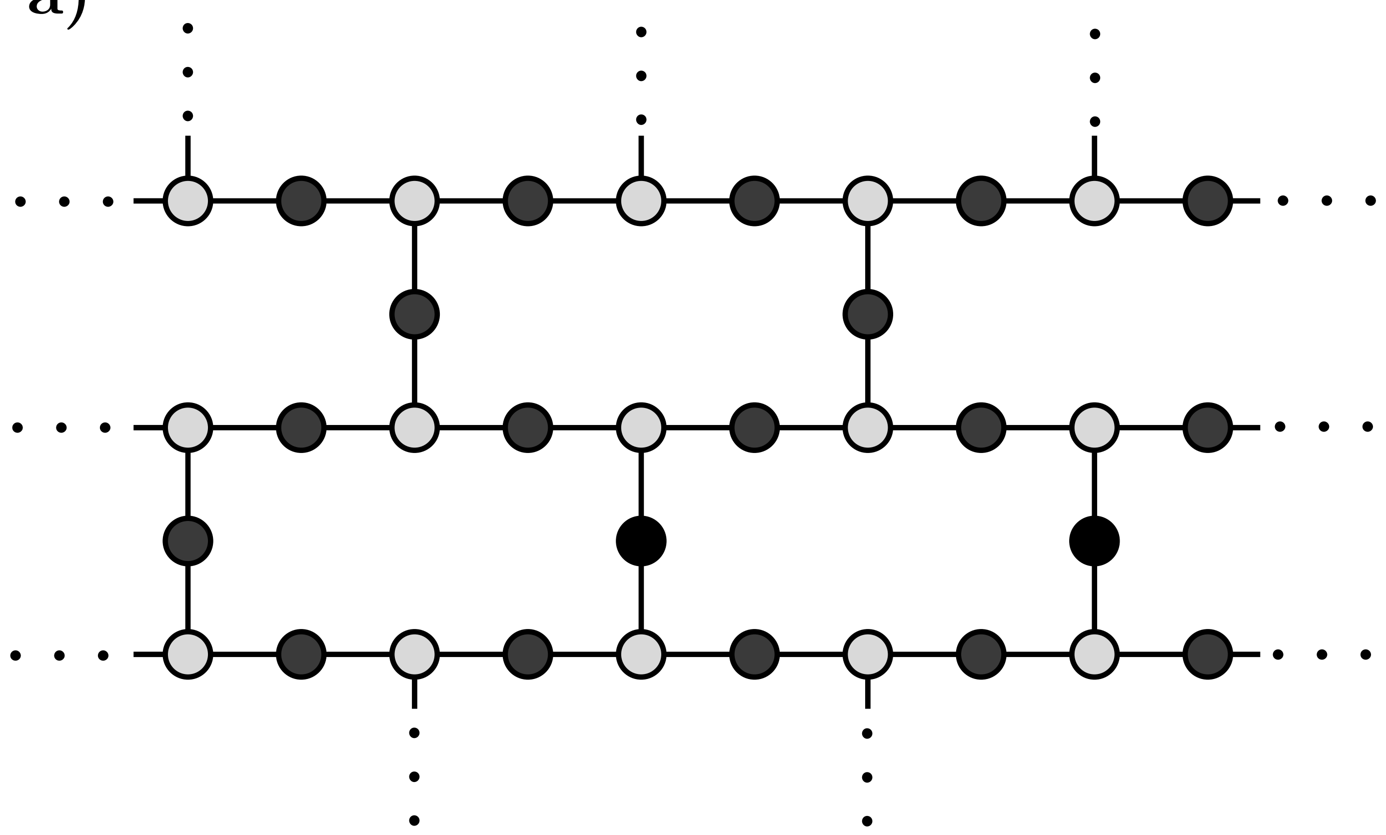
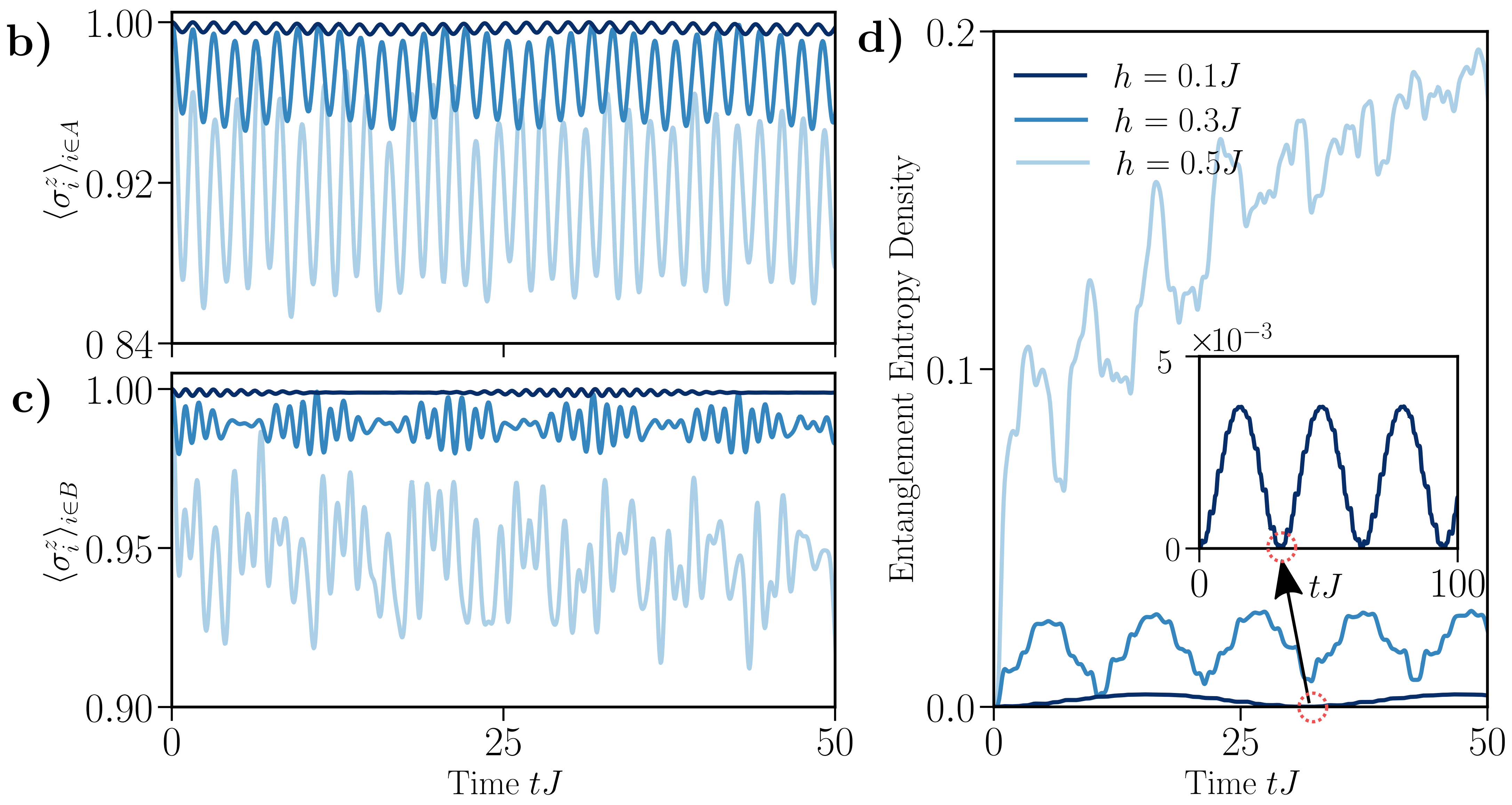
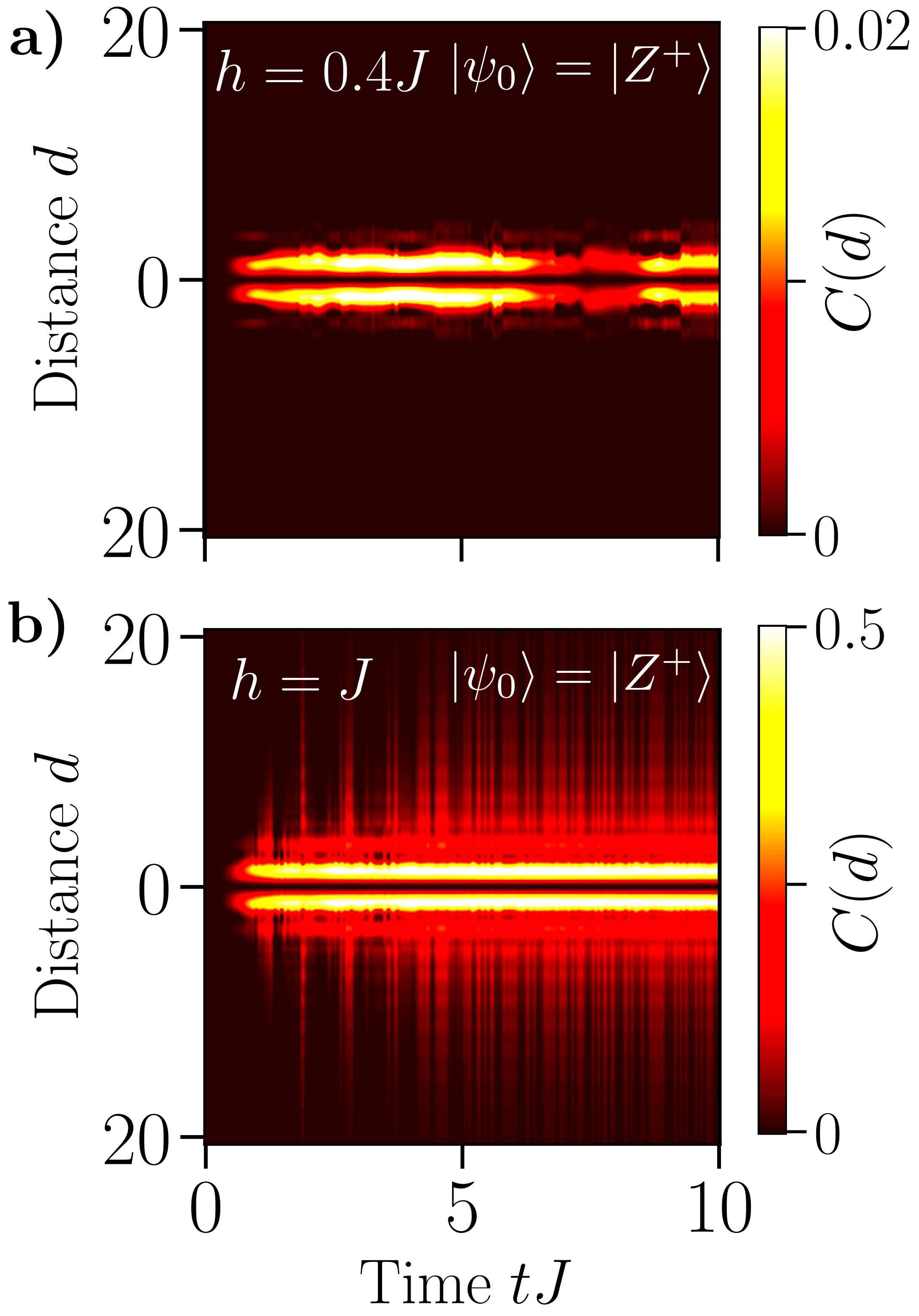
a)

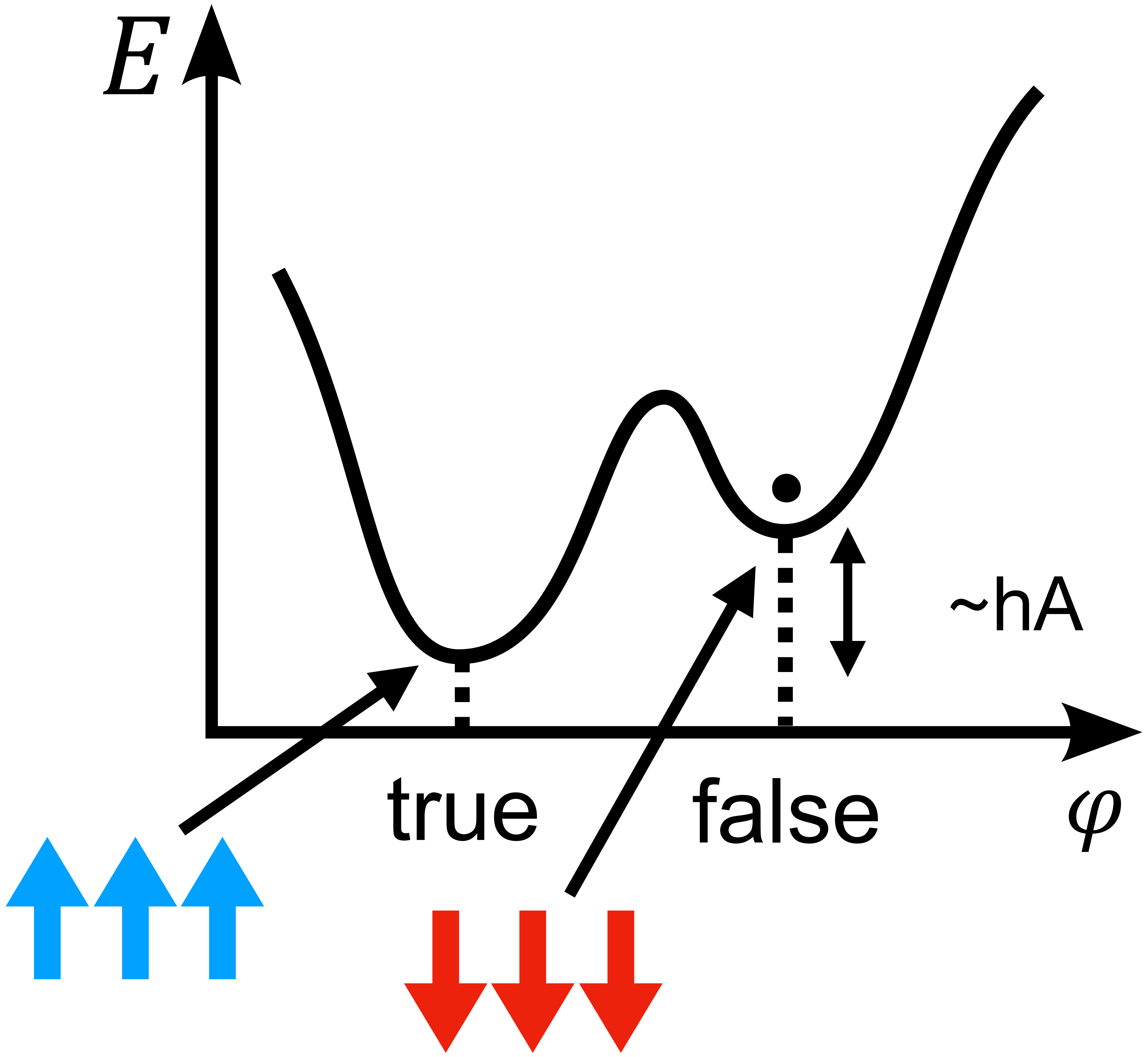


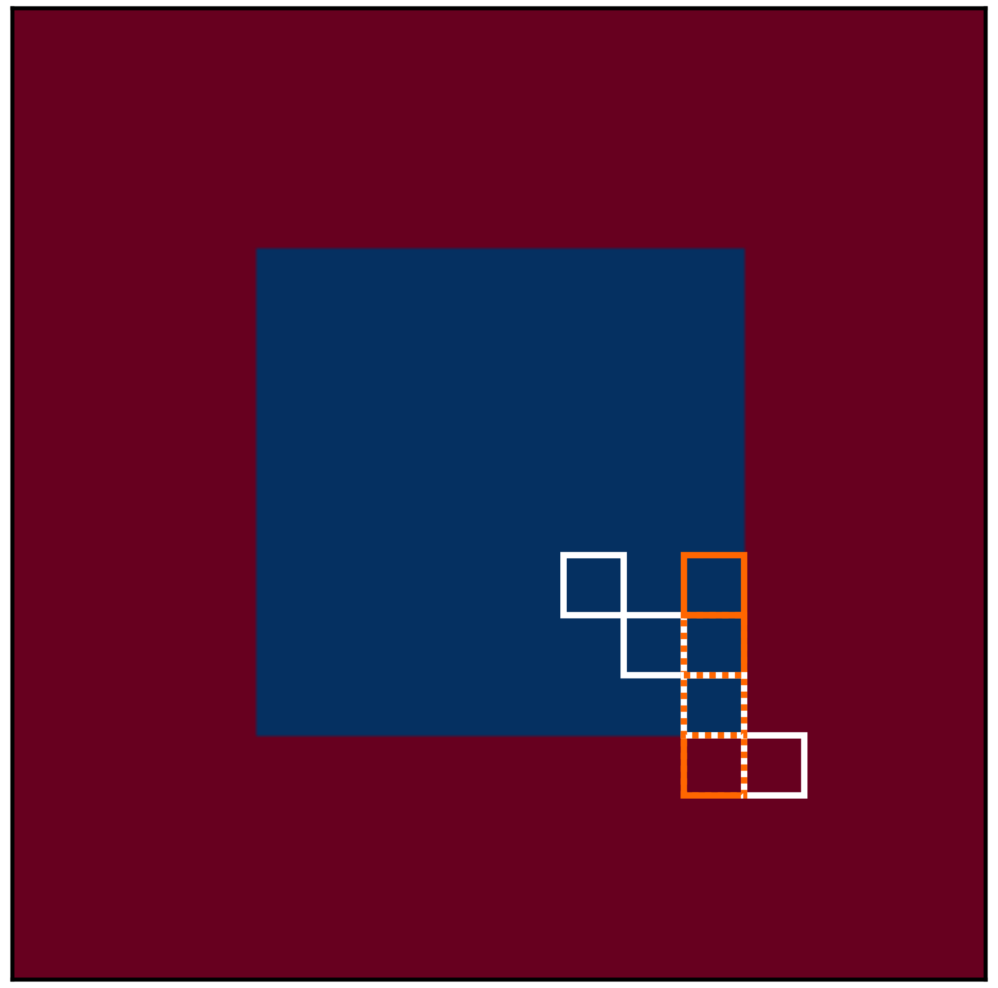




arXiv:2402.01558

Outlook2: false vacuum decay & metastable states





+ longitudinal field

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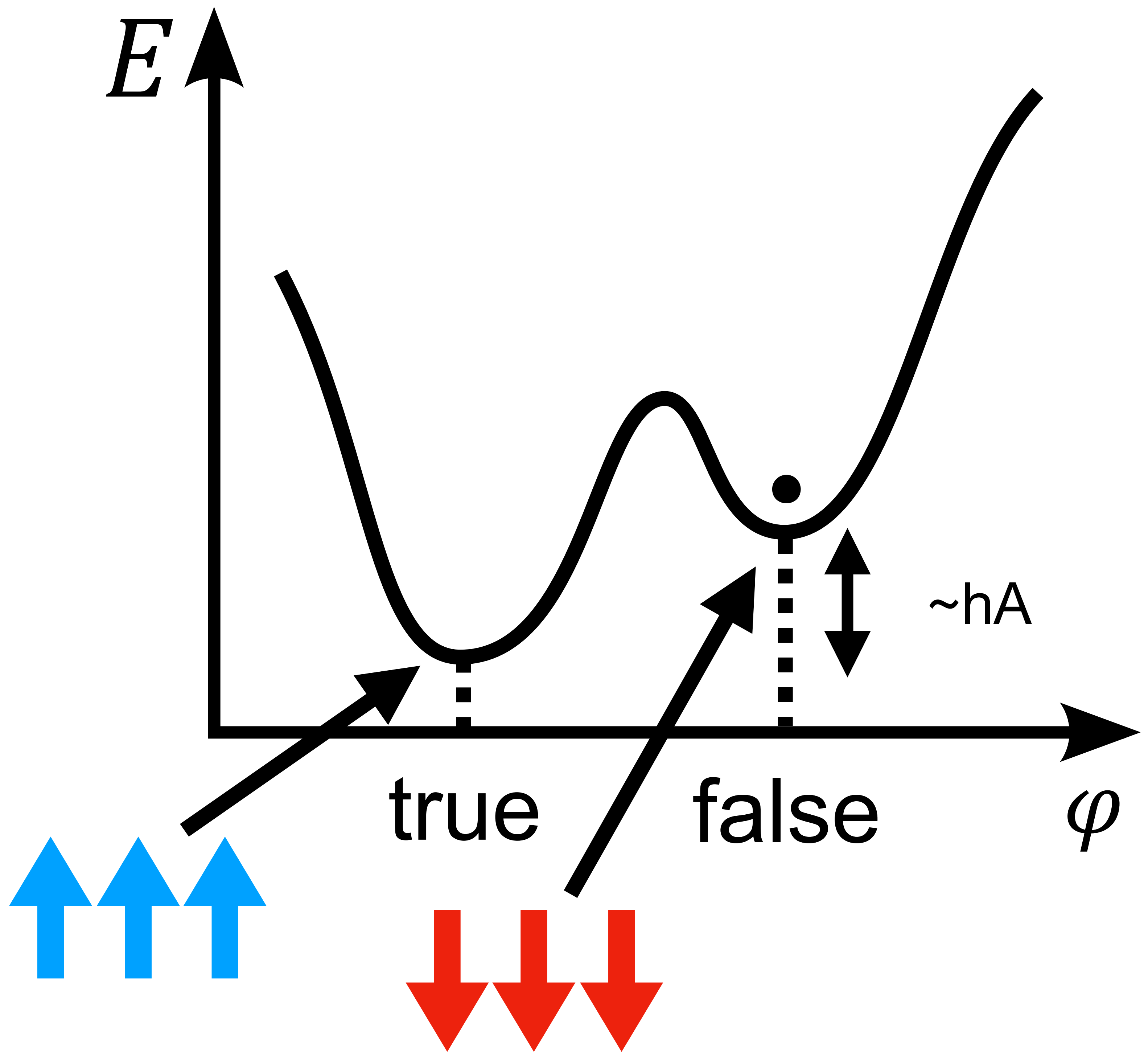
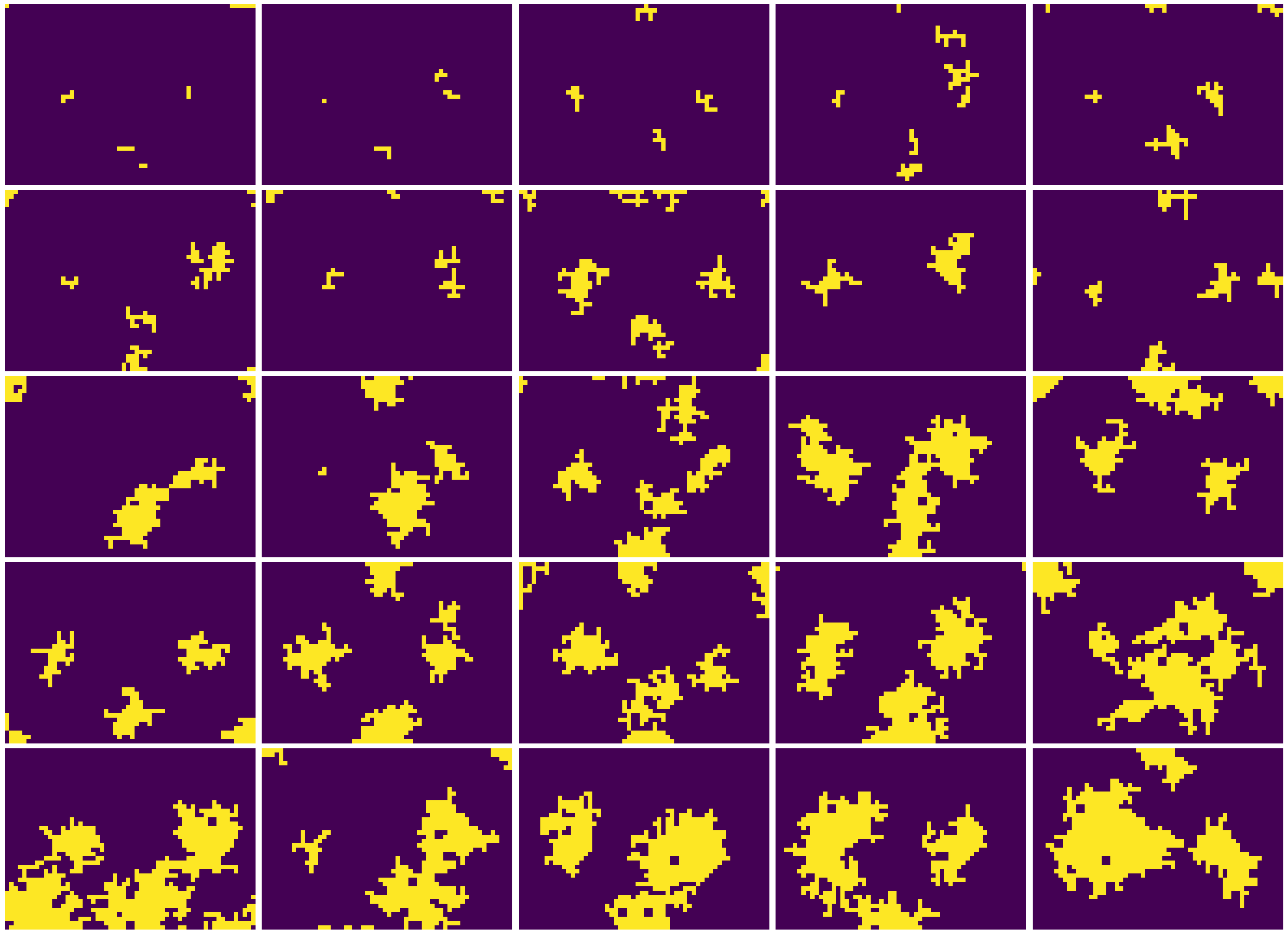
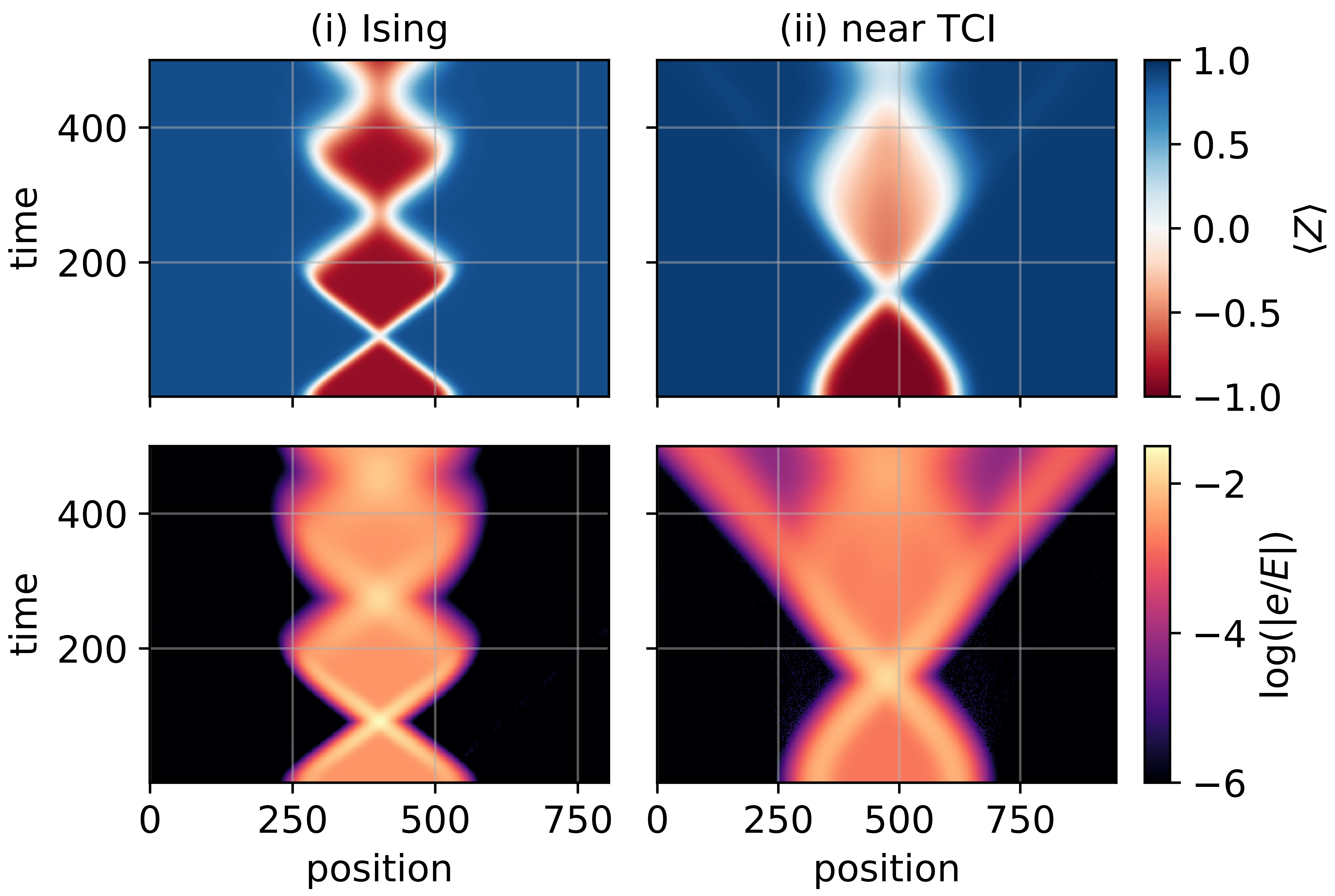


False vacuum decay @dWave? Yes!(?)



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

Outlook3: scattering



Milsted et al., Collisions of False-Vacuum Bubble Walls in a Quantum Spin Chain, PRX Q **3**, 020316, 2022.

Scattering of mesons in quantum simulators, arXiv:2011.10583

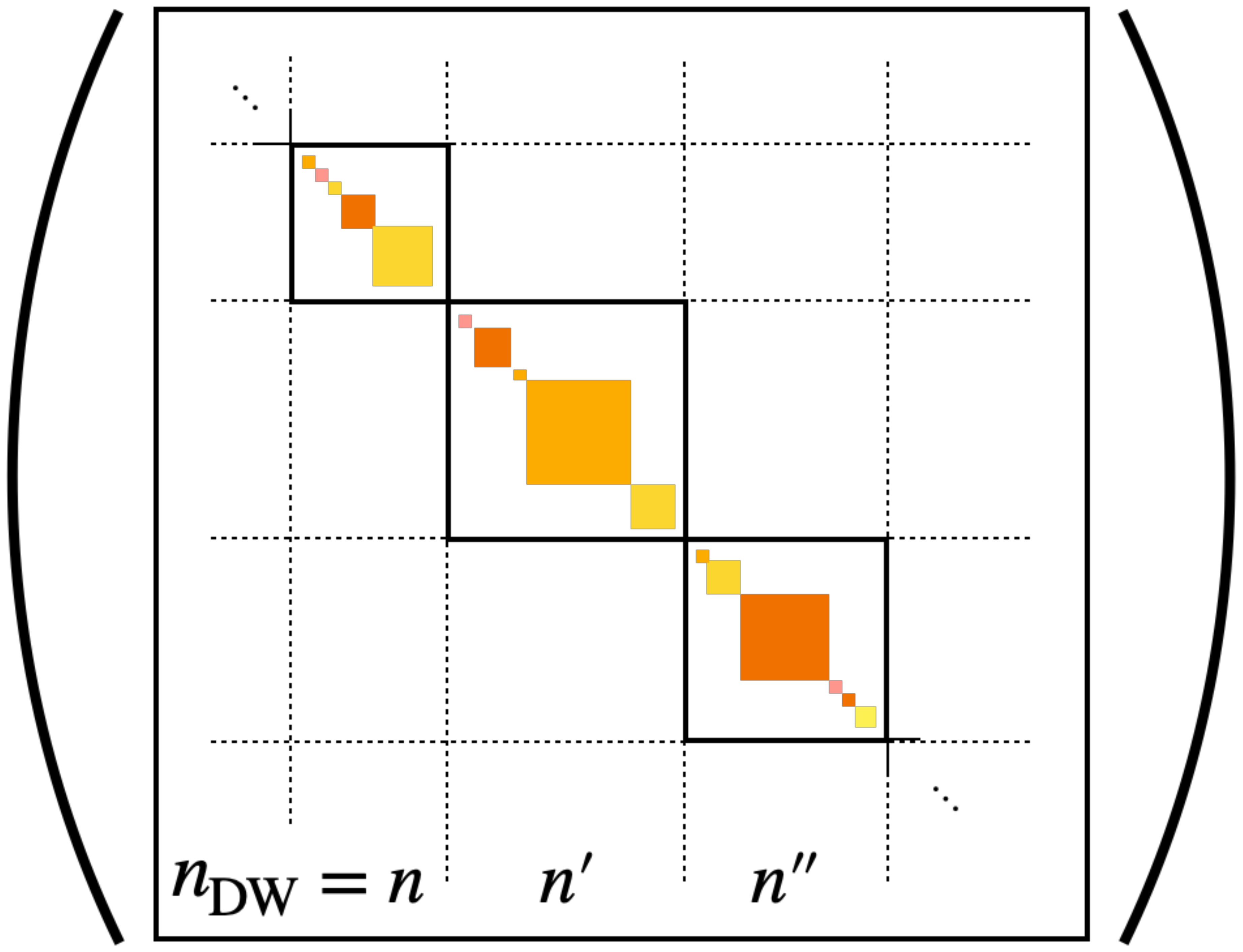
Quantum simulation of scattering in the quantum Ising model, arXiv:1901.05944

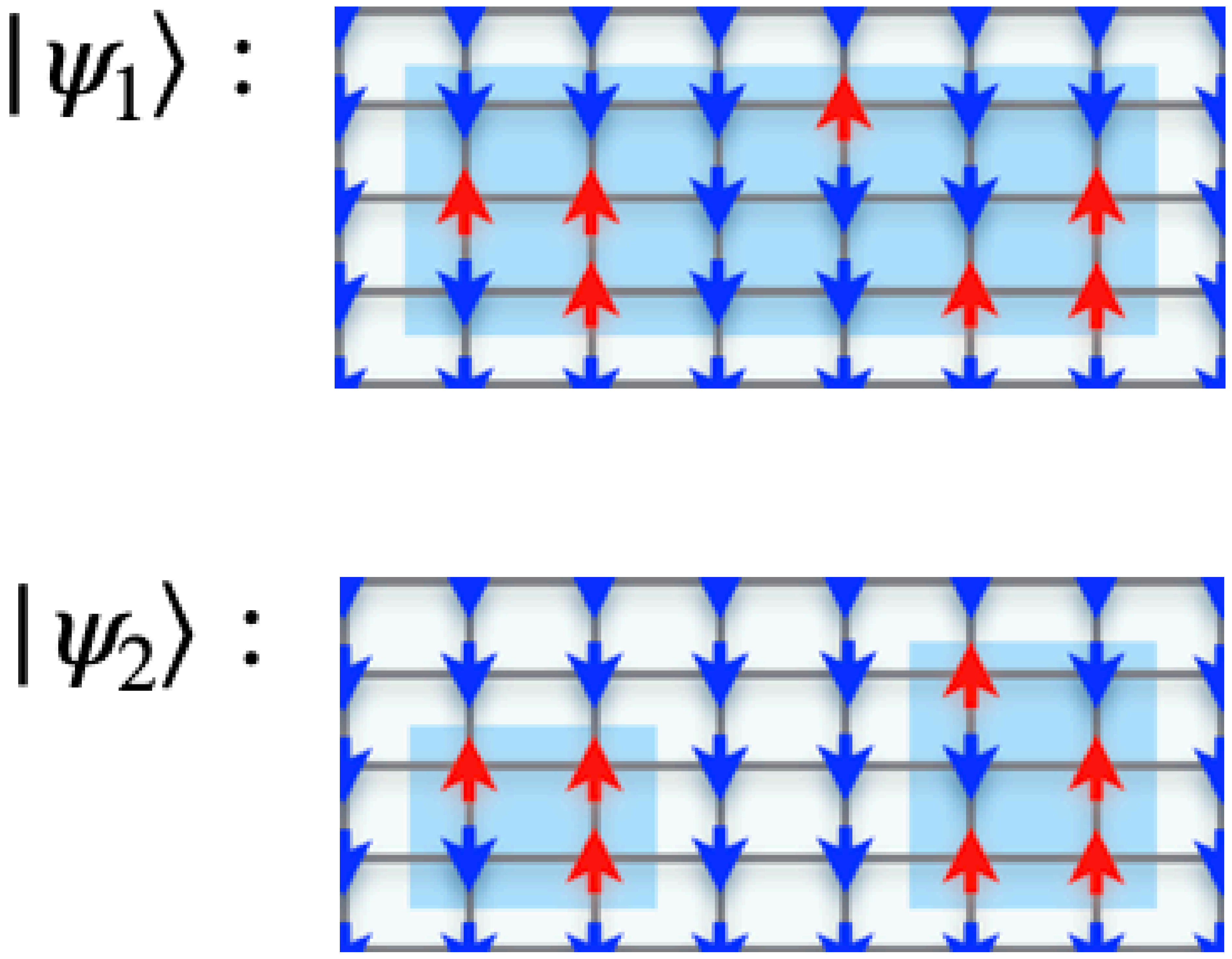
Entanglement generation in (1+1)*D* QED scattering processes, arXiv:2105.03445

and many more...

Outlook3: scattering in 2D!

More fragmentation!





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

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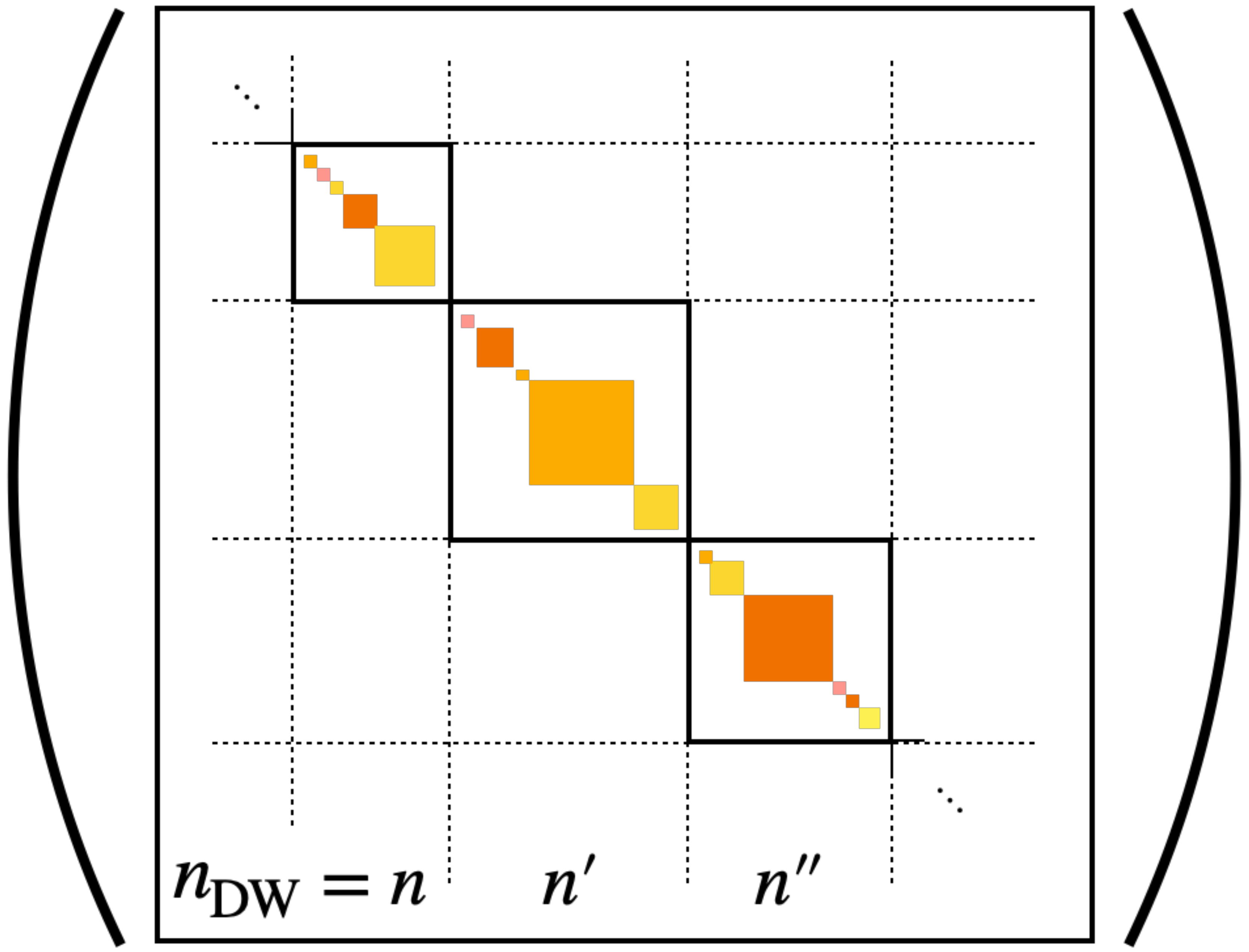

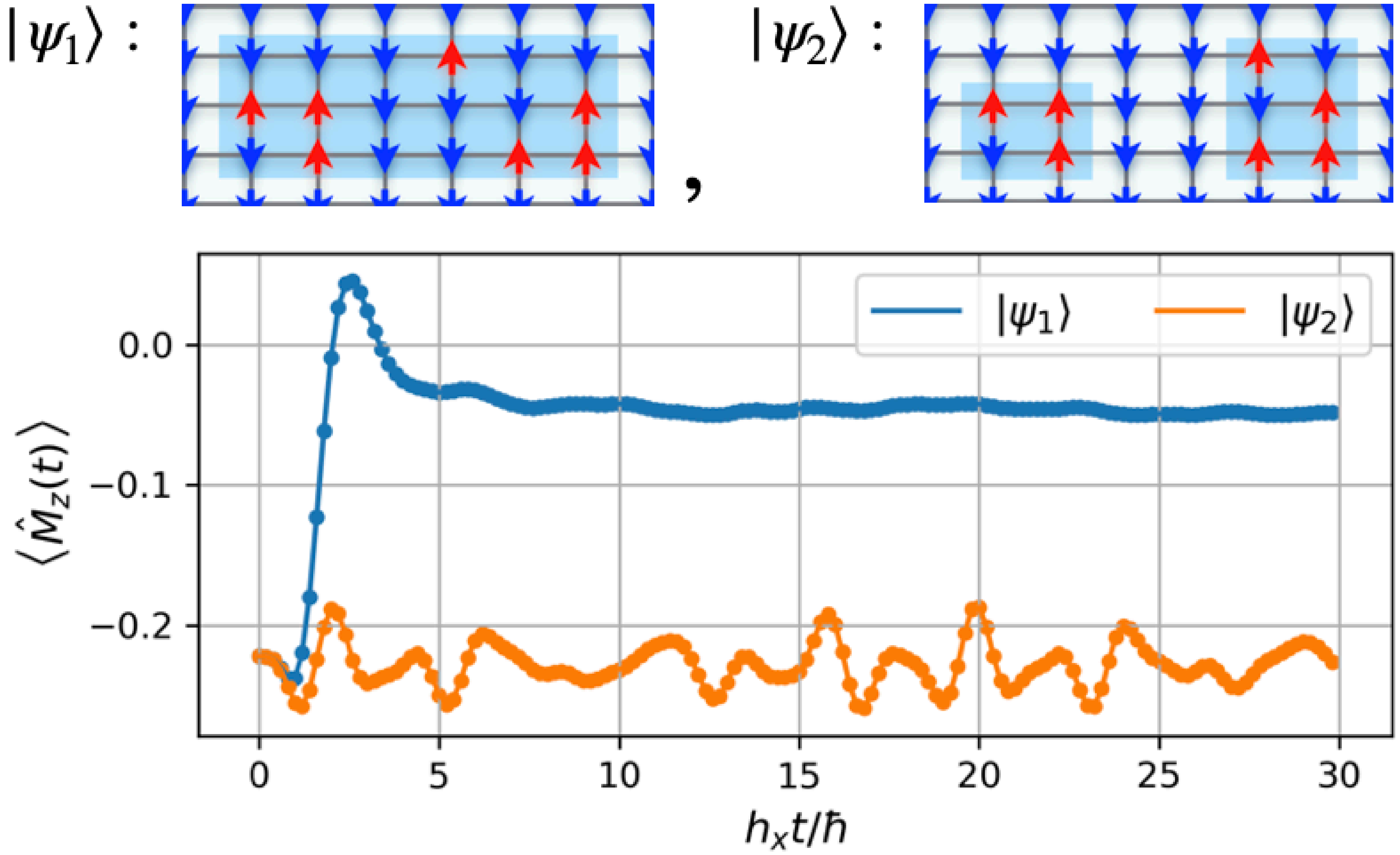

Yoshinaga et al. Emergence of Hilbert Space Fragmentation in Ising Models with a Weak Transverse Field, PRL 129, 090602, 2022

More scattering