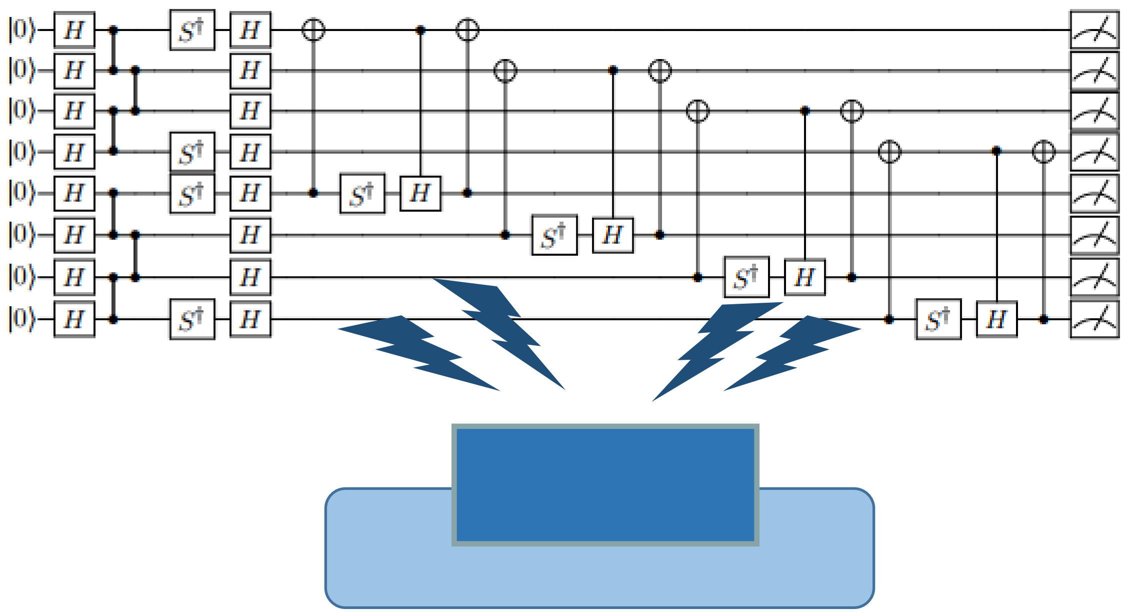
Identification

of symmetry-protected topological states

on noisy quantum computers



Many-body quantum dynamics group

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Inbar Shani

David Dentelski

Yonatan Saadia

Mor Roses

מפא"ת

הקרן הלאומית למדע

ISRAEL SCIENCE FOUNDATION

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Yael Ben-Haim (IBM)

Yehuda Naveh (IBM)

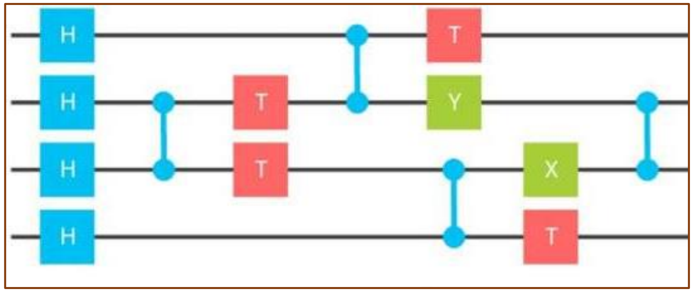
Robert Raussendorf (Vancouver)

Rafael Haenel (Vancouver)

Quantum circuits: the challenge

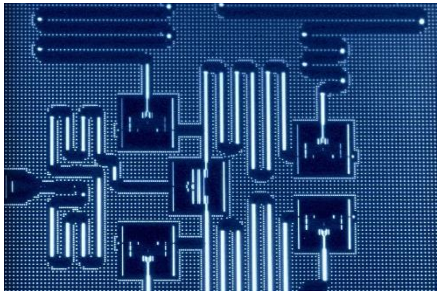
Model : Unitary quantum computer

Reality : Noisy Josephson junctions

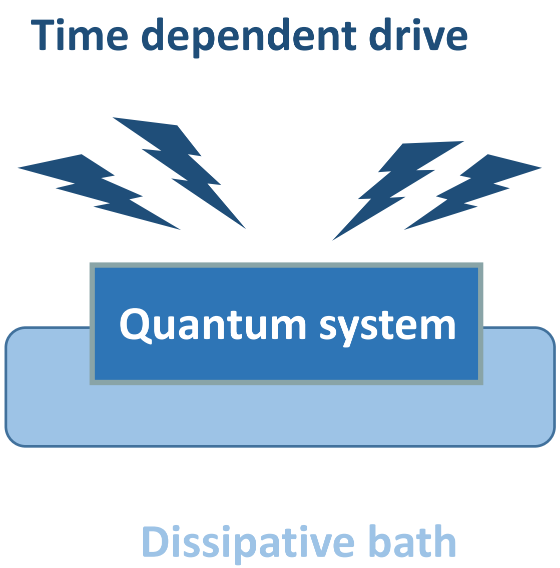


quantum error correction

open quantum systems



Many-body open quantum systems



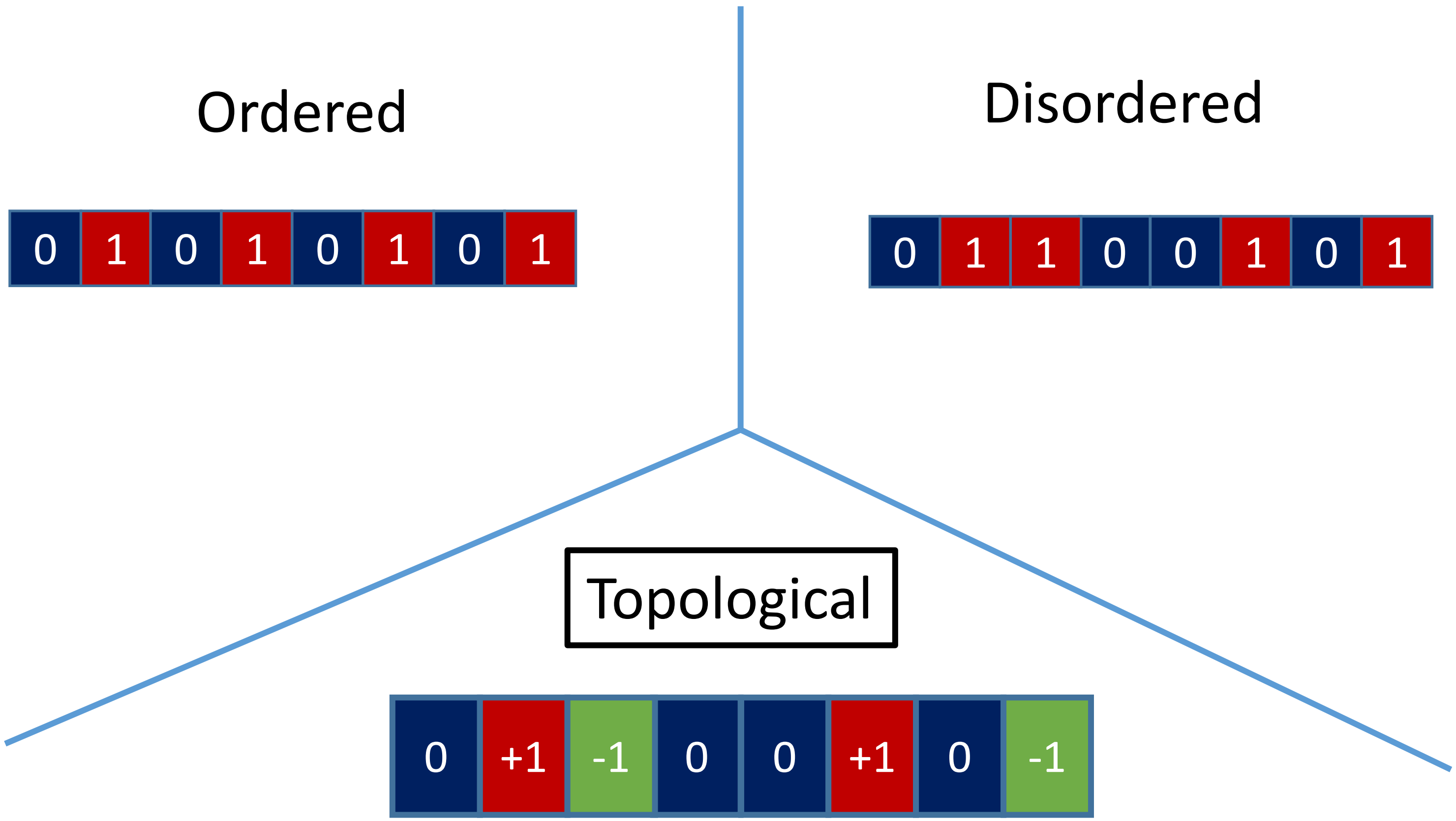
Floquet engineering

Quantum bath engineering

Nonequilibrium universality

Topological phases

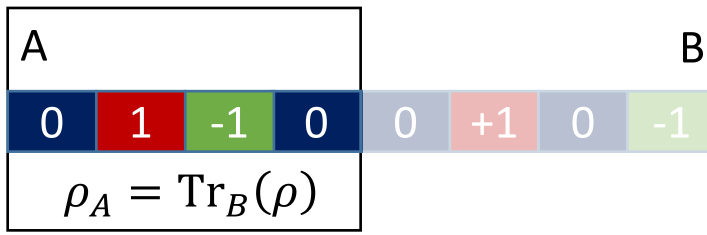
Introduction : phases of matter



Haldane (1982), AKLT (1987), den Nijs&Rommelse (1989), Dalla Torre,Berg&Altman (2006), ….

Symmetry protected topological phases

Subsystem probabilities:



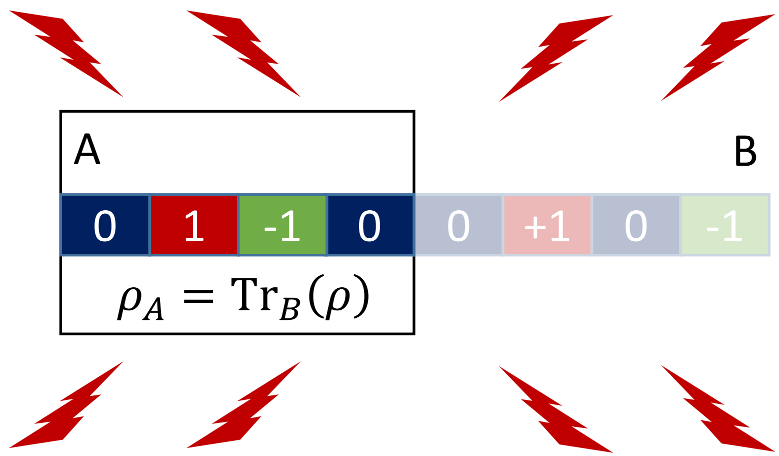
Eigs(ρ_A) = 0.3, 0.3, 0.15, 0.15, 0.05, 0.05, …

Degeneracy is “protected” by a symmetry

Pollmann, Turner, Berg, & Oshikawa (2010) Chen, Gu & Wen (2011)

Noisy symmetry protected topological phase

Extension to open quantum systems ?



Eigs(ρ_A) = 0.25, 0.25, 0.1, 0.1, 0.03, 0.03, … ?

Atzitz, Sela, Dalla Torre (in preparation)

Identification of symmetry-protected topological states on noisy quantum computers

1. **Symmetry resolved entanglement entropy**

2. **Measurement based quantum computing**

Symmetry resolved reduced density matrix

G: Symmetry $\rightarrow G\,|\psi\rangle = g|\psi\rangle$ $\rightarrow [G, \rho_A] = 0$

Trivial

$$\rho_A = \begin{pmatrix} \tilde{\rho}_A(+) & 0 \\ 0 & \tilde{\rho}_A(\text{-}) \end{pmatrix}$$

SPT

$$\rho_A = \begin{pmatrix} \tilde{\rho}_A(+) & 0 \\ 0 & \tilde{\rho}_A(\text{-}) \end{pmatrix}$$

Goldstein & Sela (PRL, 2018)

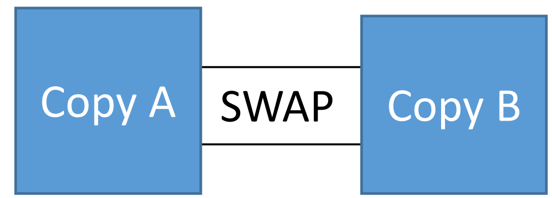
How to measure entanglement?

Renyi entropy: $S_n = Tr[\rho_A^n]$

$$S_n \;=\; 0.3^n + 0.3^n + 0.15^n + 0.15^n + 0.05^n + 0.05^n$$

Replica trick

Daley, Pichler, Schachenmayer, Zoller, PRL (2012)



$n = 2$

PROOF: $\langle SWAP_{AB}\rangle = Tr[\rho^A\rho^B\, SWAP_{AB}] = \sum_{i,j}\langle i_A j_B|\rho^A\rho^B SWAP_{AB}|i_A j_B\rangle$

$$= \sum_{i,j}\langle i_A j_B|\rho^A\rho^B|j_A i_B\rangle = \sum_{i,j}\langle i_A|\rho^A|j_A\rangle\langle j_B|\rho^B|i_B\rangle = Tr[\rho^A\rho^B] = Tr[\rho^2]$$

How to measure **topological** entanglement?

Symmetry resolved reduced density matrix

$$\rho_A^{\pm} = P^{\pm}\rho_A$$

$$\Rightarrow \quad S_n^{\pm} = Tr\left[\left(\rho_A^{\pm}\right)^n\right] = \sum_i \left(\lambda_i^{\pm}\right)^2$$

$$S_n^{+} = 0.3^n + 0.15^n + 0.05^n$$

$$S_n^{-} = 0.3^n + 0.15^n + 0.05^n$$

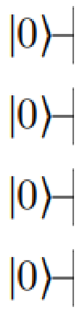
$$S_n^{+} = S_n^{-}\ ?$$

Note: need algorithm to measure SWAP and P at the same time

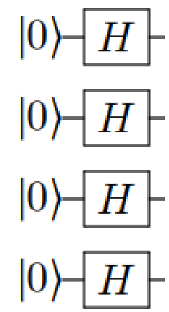
Azses et al, arXiv: 2002.04620

Topological phase with **qubits**

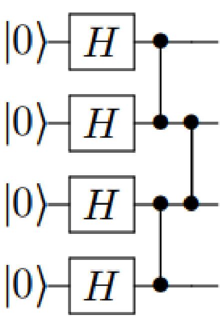
Ordered: Ising coupling



Disordered: Magnetic field



Topological: cluster model

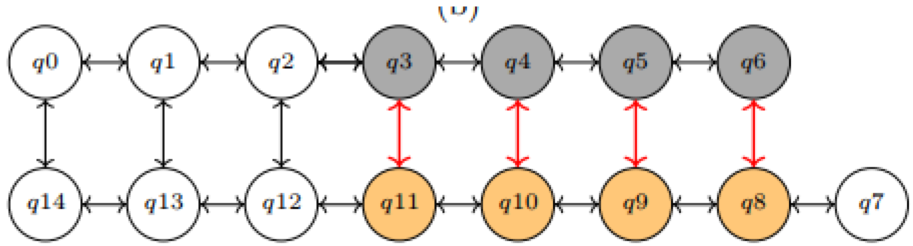


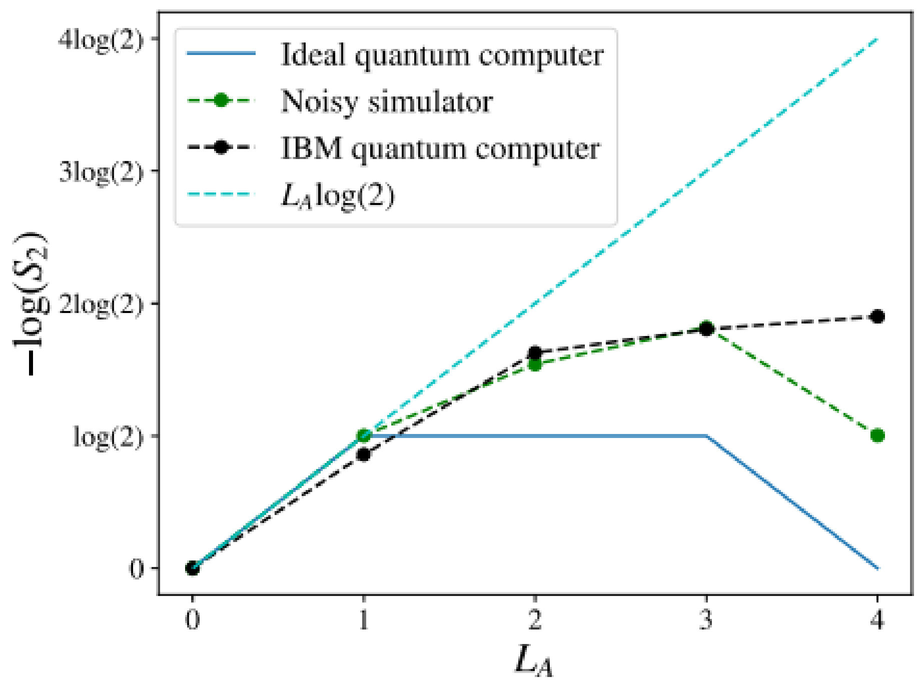
Friedman, Raj

and ref. therein

Cluster state : entanglement

IBM Quantum computer
(publicly available)

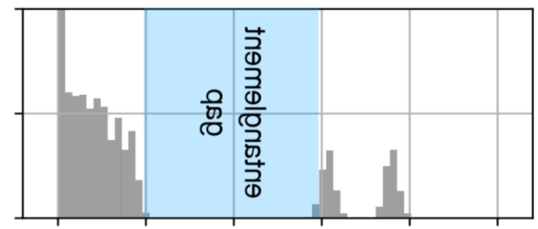




How to detect topology?

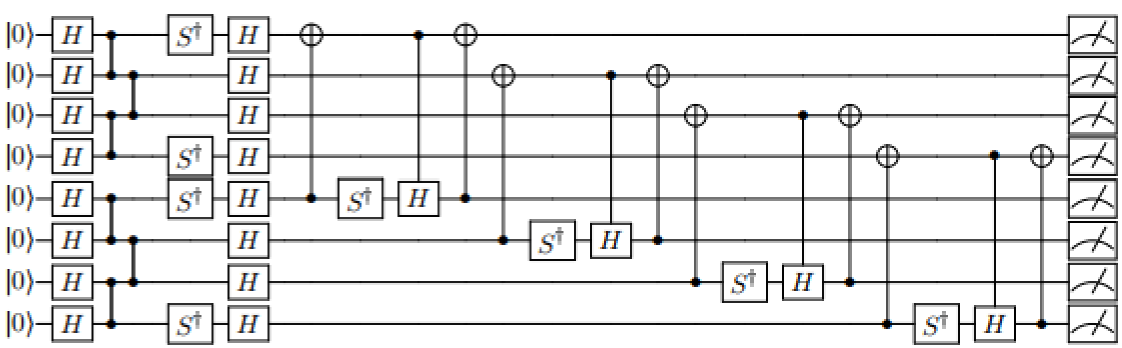
Solution 1

Full tomography of ρ_A

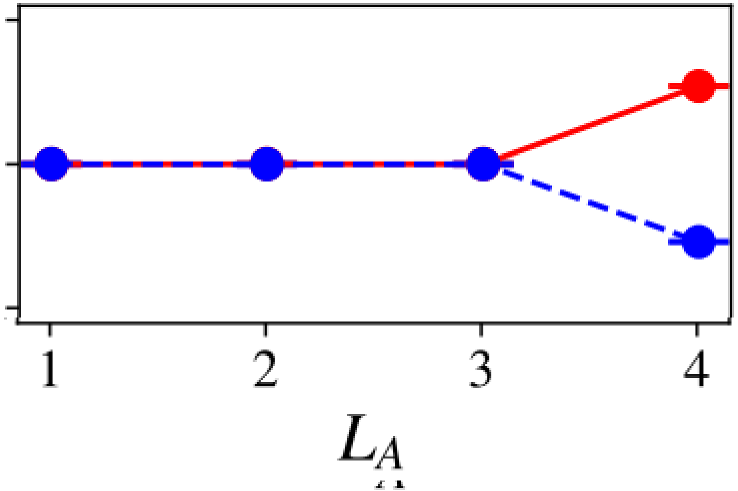


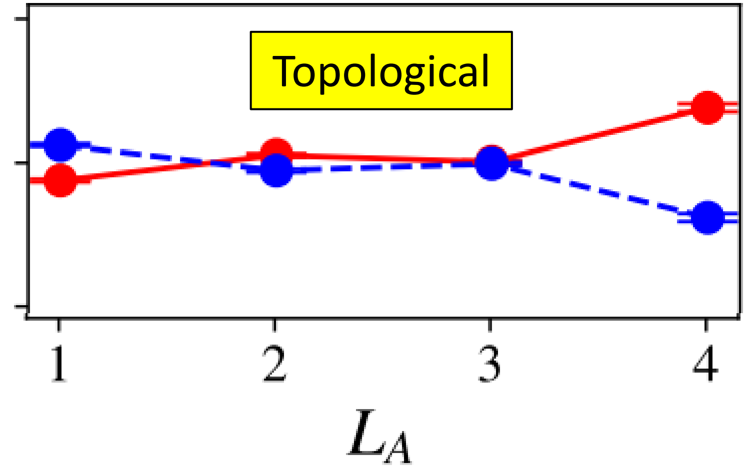
Choo, von Keyserlingk, Regnault & Neupert (PRL, 2018)

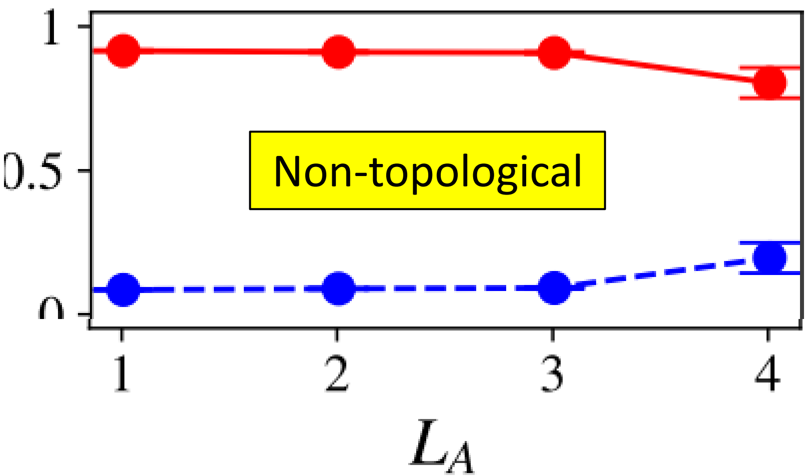
Solution 2



Simulation vs. Experiment

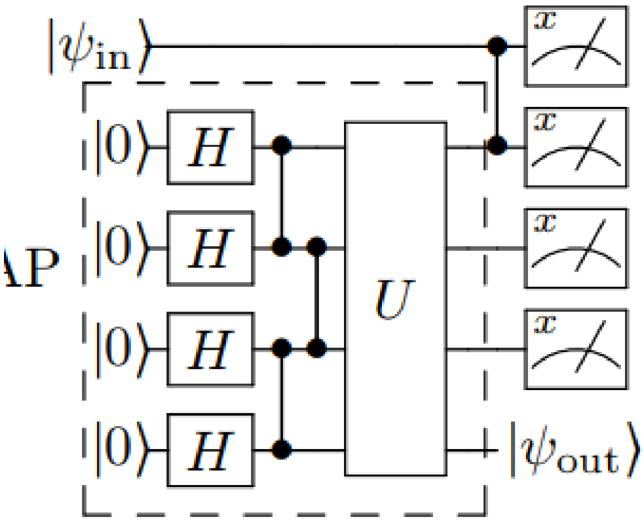




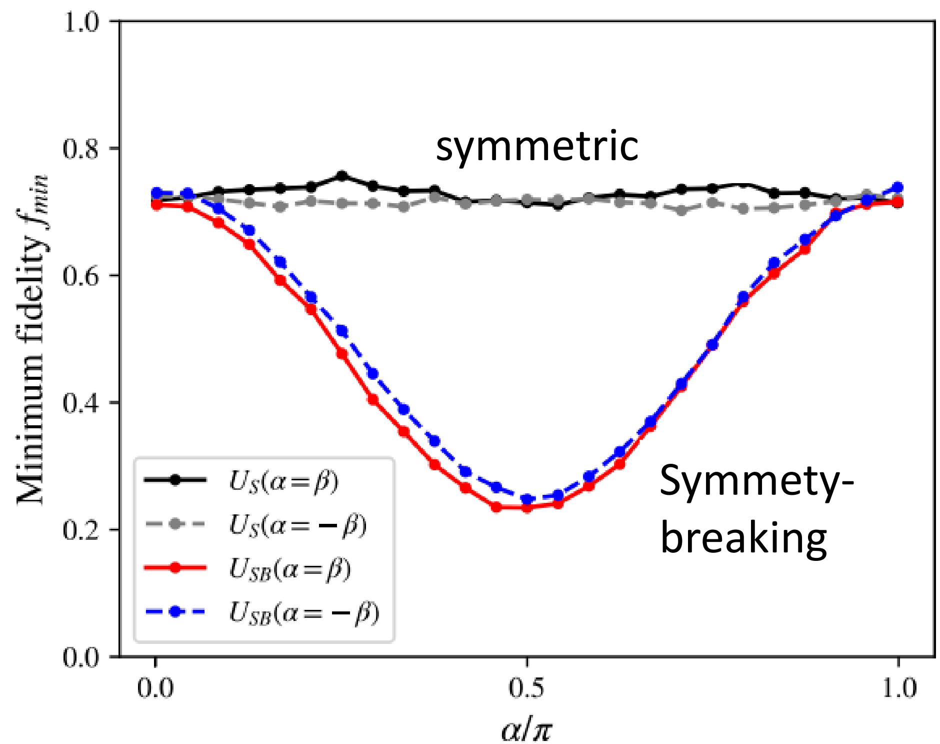


Azses et al, arXiv: 2002.04620

Second method : MBQC



Else et al, PRL (2012)



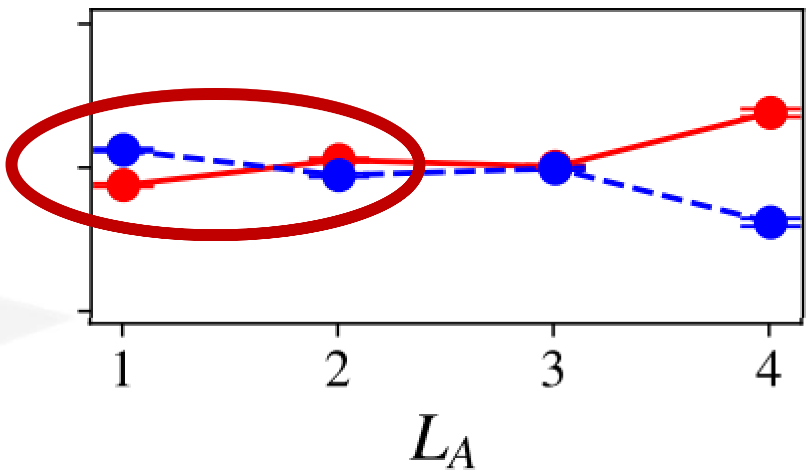
Summary

Many-body physics with superconducting circuits

New phase of matter (?) : Noisy symmetry protected topological states

All I need is … 8 qubits :

Noise characterization:



Azses et al, arXiv: 2002.04620

אוניברסיטת בר־אילן
Bar-Ilan University

Department of Physics - Optics Seminar

mini-series of zoom lectures on

Wednesday, May 27, 12:40 (Israel time) *** note: special time ***

Frank Pollmann – Technical University of Munich

“Efficient simulations of quantum many-body systems on a quantum computer”

Wednesday, June 3rd, 12:00 (Israel time)

Dimitris Angelakis – Centre for Quantum Technologies Singapore & Technical University of Crete

“Spectroscopic signatures of localization with interacting photons in superconducting qubits”

Wednesday, June 10, 12:00 (Israel time)

Prasanta K. Panigrahi - IISER Kolkata

“Simulation of coupled photons and cavity dynamics on IBM quantum computer”

Wednesday, June 17, 12:00 (Israel time)

Titus Neupert- University of Zurich

“Solving a small Hubbard model on IBM’s quantum computer”

Please register at http://tiny.cc/biuoptics

Zoom meeting room: **994 2307 7426**

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New phase of matter (?) : Noisy symmetry protected topological states

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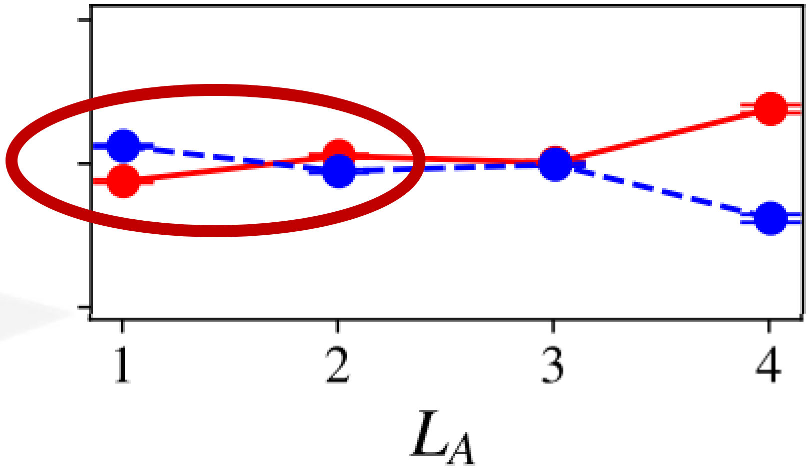

Azses et al, arXiv: 2002.04620