Title: Phase diagram of the honeycomb Floquet code

Speakers: DinhDuy Tran Vu

Series: Quantum Matter

Date: November 23, 2022 - 2:00 PM

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Abstract: The Floquet code implements a periodic sequence of two-qubit measurements to realize the topological order. After each measurement round, the instantaneous stabilizer group can be mapped to a honeycomb toric code, thus explaining the topological feature. However, the code also possesses a time-crystal order distinct from a stationary toric code - an e-m exchange after every cycle. In this work, we construct a continuous path interpolating between the Floquet and toric codes, focusing on the transition between the time-crystal and non-time crystal phases. We show that this transition is characterized by a diverging length scale. We also add single qubit noise to the model and obtain a two-dimensional parametric phase diagram of the Floquet code.

Zoom link: https://pitp.zoom.us/j/95933569447?pwd=UkcrVHdkWERTNVIrcXdCREQ3Y1JUZz09

Phase diagram of the honeycomb Floquet code

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Perimeter Institute, 11/23/2022

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Special thanks to

Matthew Fisher

Ali Lavasani

Jong Yeon Lee

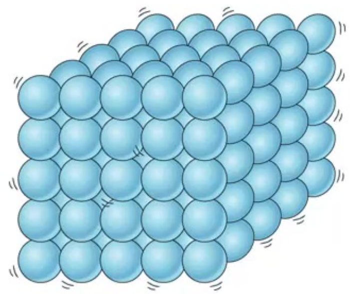
Outline

- Introduction
- Floquet to non-Floquet phase transition
- Floquet - toric phase diagram
- Open question

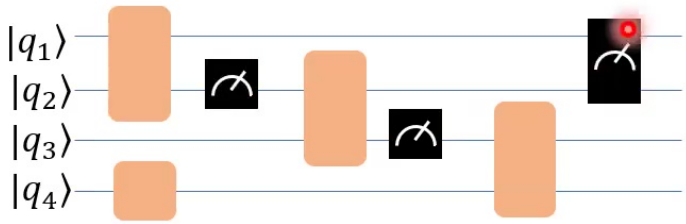
Introduction

Condensed matter phases

Emergent behavior



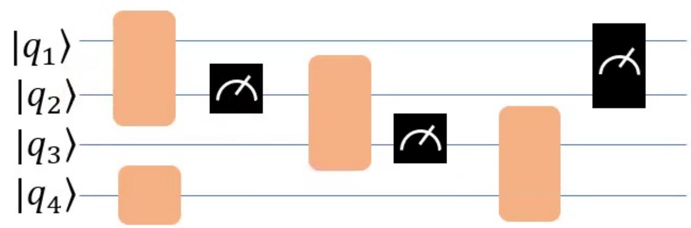
Introduction

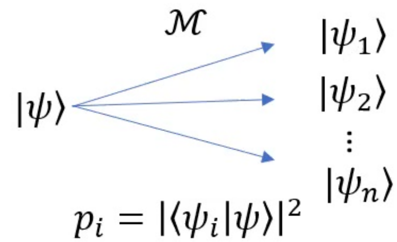


Condensed matter phases

- Metal-insulator
- Gapped (symmetry enriched) topological phases

Introduction





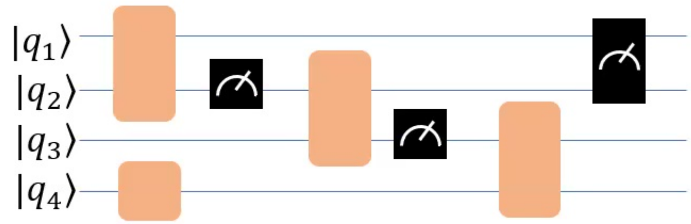
Condensed matter phases

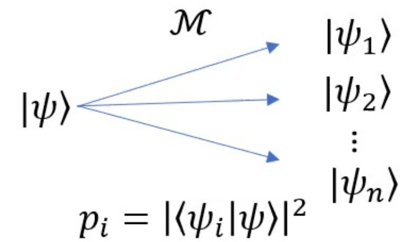
Measurement-induced phases

- Metal-insulator

- Gapped (symmetry enriched) topological phases

Introduction





Condensed matter phases

Measurement-induced phases

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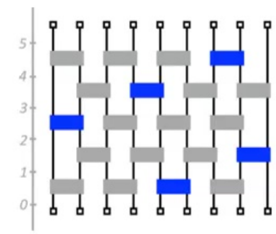
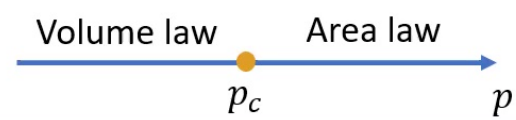
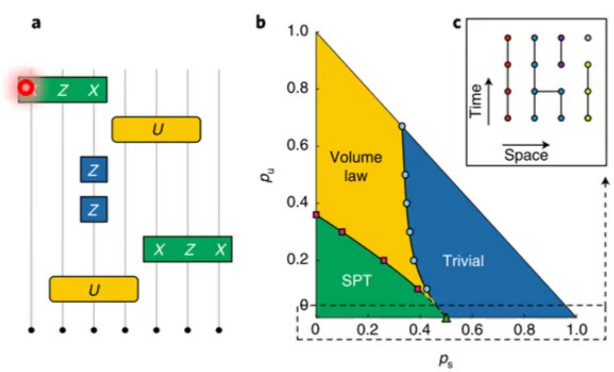


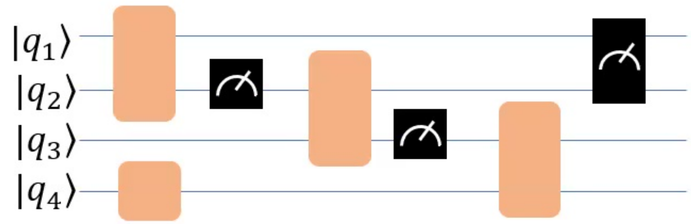


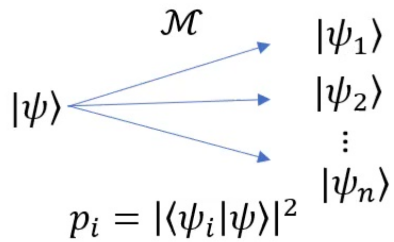
Li, Chen, and Fisher, PRB 2018



Lavasani, Alavirad, and Barkeshli, Nat. Phys. 2021

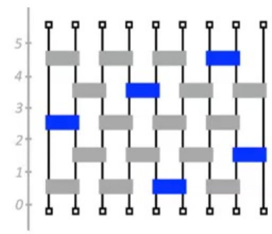
Introduction

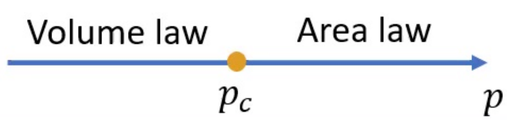




Condensed matter phases

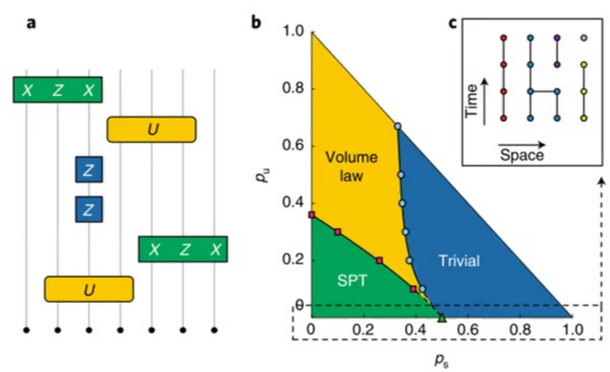
Measurement-induced phases





Li, Chen, and Fisher, PRB 2018

- ❖ Metal-insulator
- ❖ Gapped (symmetry enriched) topological phases



Lavasani, Alavirad, and Barkeshli, Nat. Phys. 2021

π - mode Floquet topological order

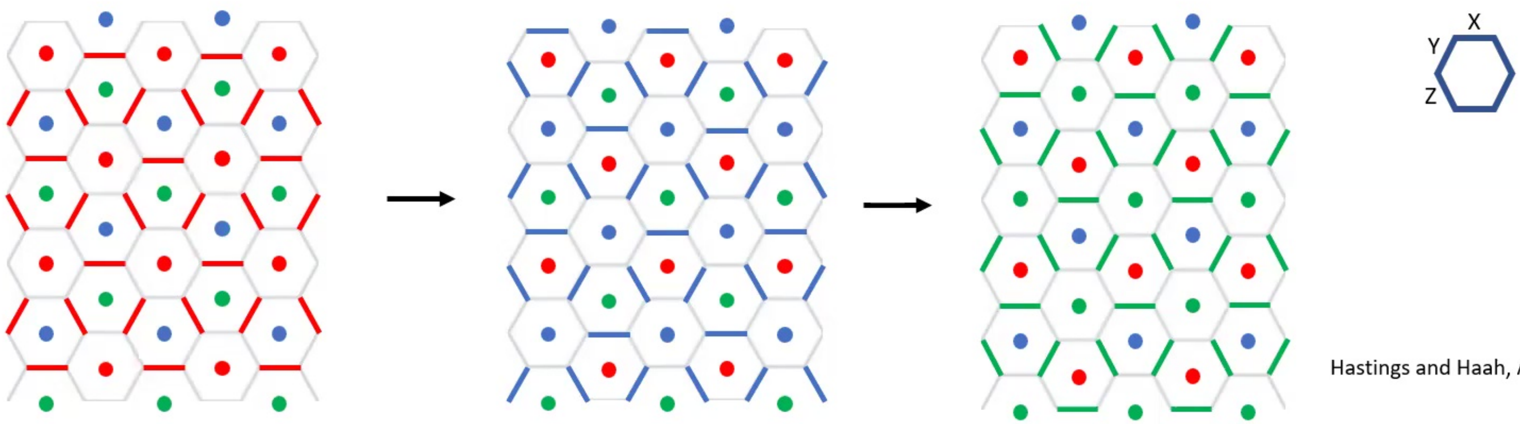
Period doubling

Non-local order parameter

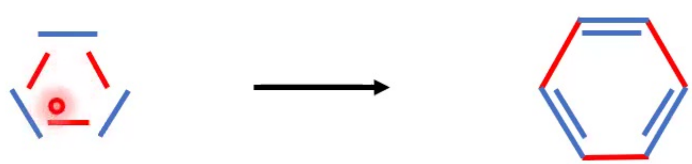
Introduction

N-qubit $|\psi\rangle \leftrightarrow \{S_1, S_2, \ldots, S_N\}$ such that $[S_i, S_j] = 0$ and $S_i|\psi\rangle = |\psi\rangle$

Stabilizer group



Hastings and Haah, ArXiv 2107.02194

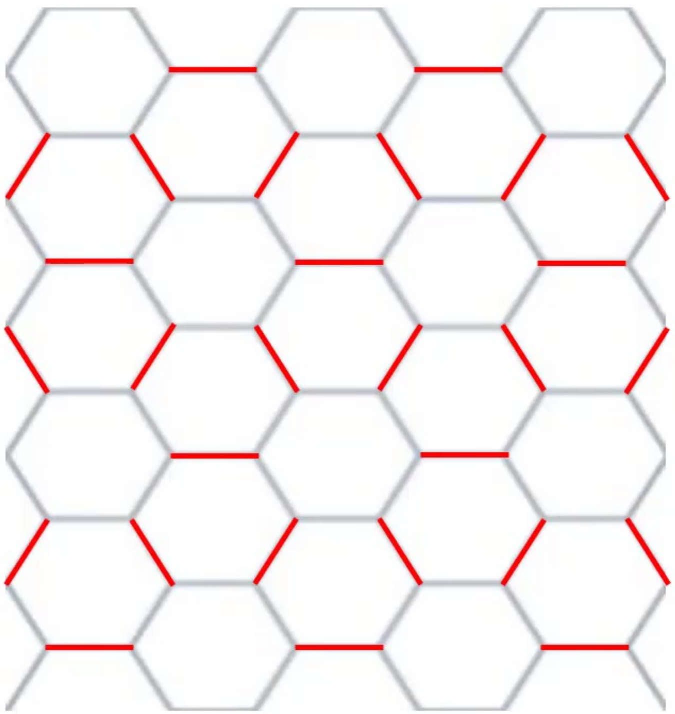


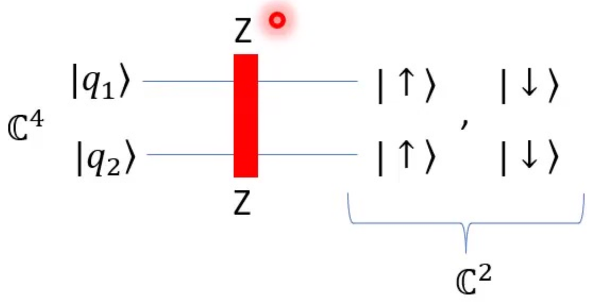
After each round

SG = {  }

Introduction

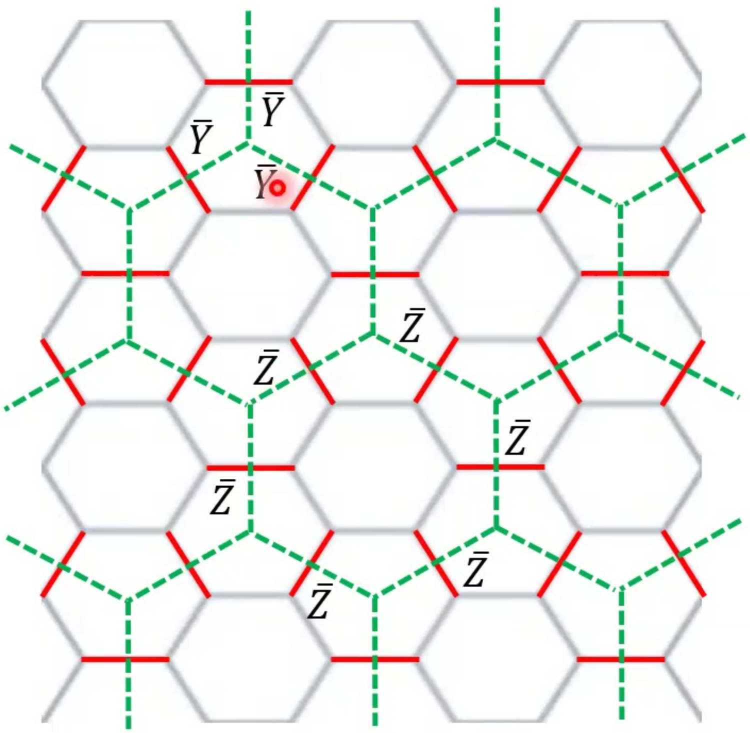
Effective toric code on the superlattice





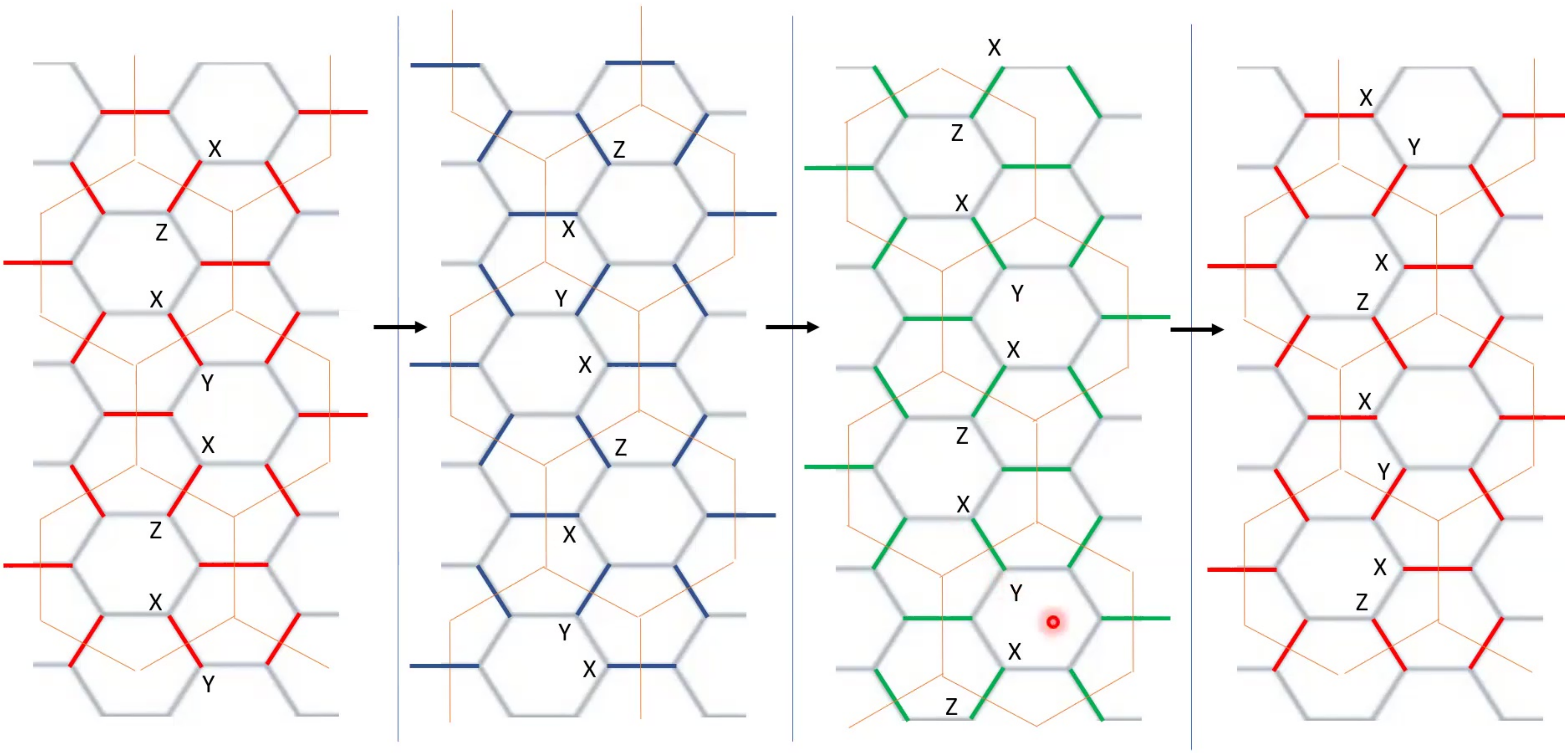
Introduction

Effective toric code on the superlattice



- Toric code without many-body measurement
- Correct errors

[redacted]



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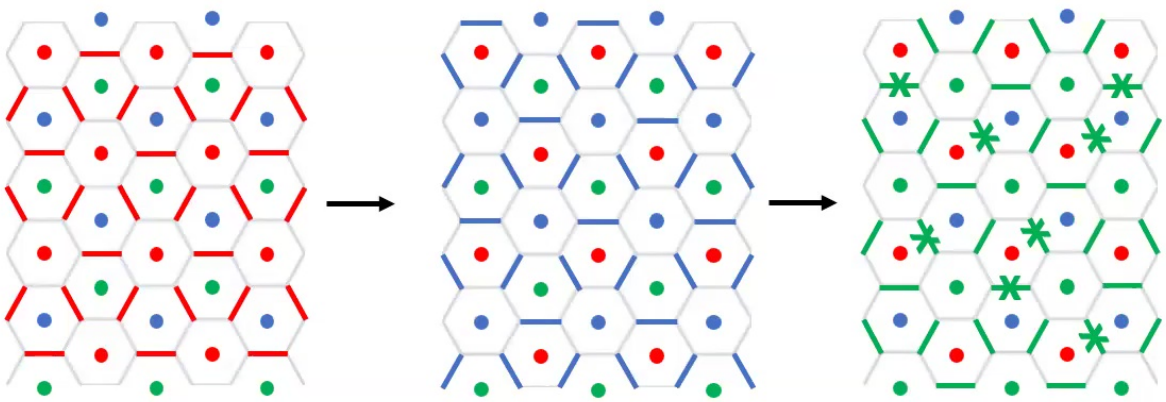
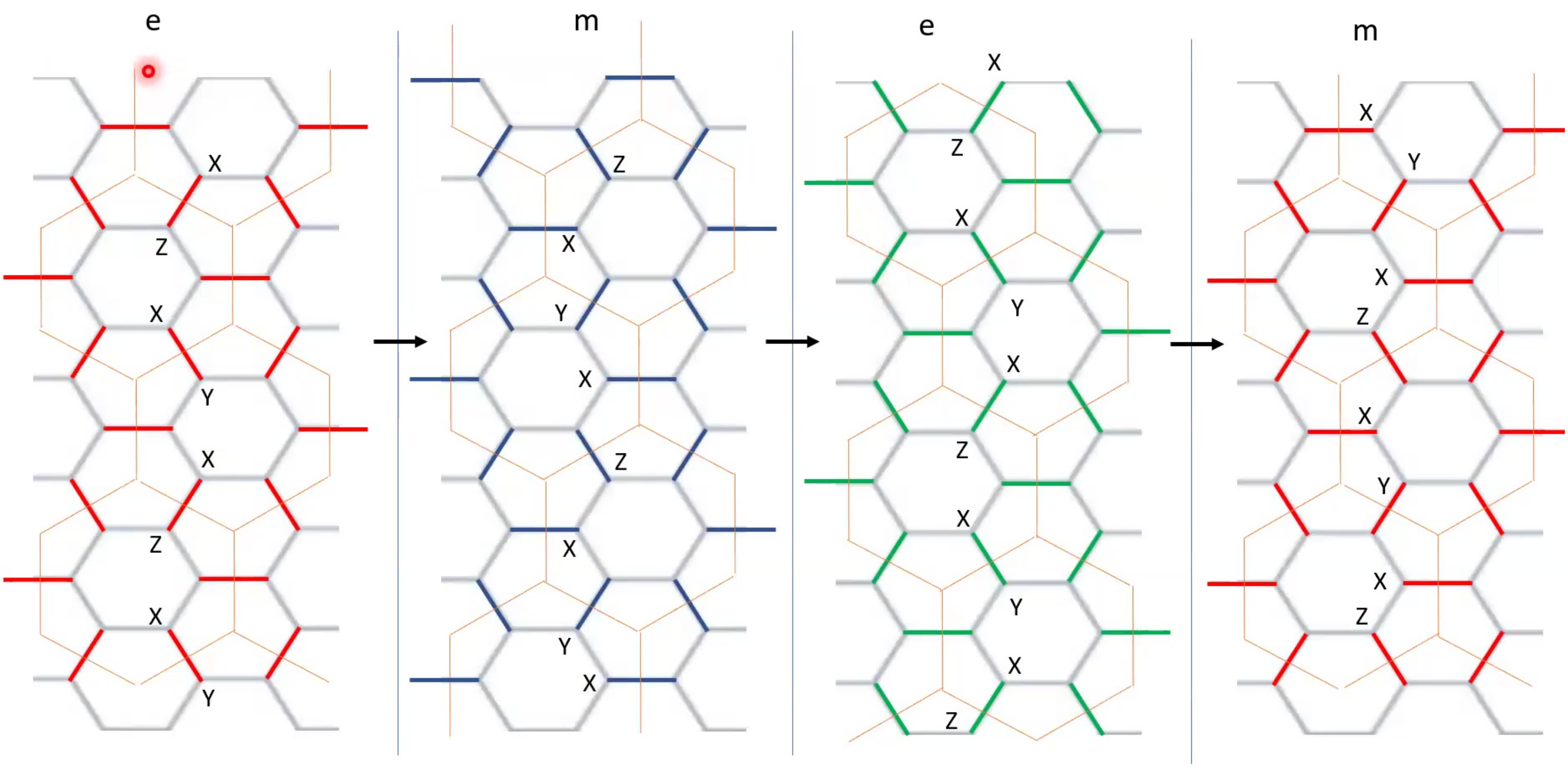
Floquet to non-Floquet phase transition



Green links are randomly missing with p_m

e-m automorphism that breaks the time translational symmetry!



Floquet to non-Floquet phase transition

How to see the e-m exchange?

I. Circuit preparation $t = 0$:

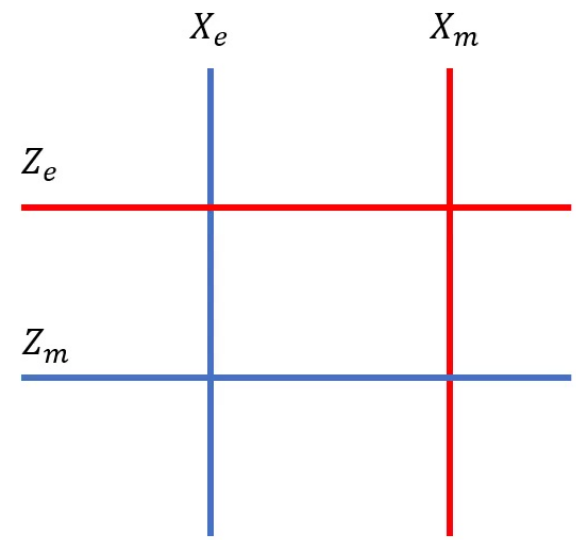
+ measure all the plaquettes
+ measure an **e-type** loop along **x**-direction and an **e-type** loop along **z**-direction

II. Circuit evolution:

+ measure all the red and blue links
+ skip random green links with probability p_m

III. Circuit monitor:

+ measure the original x-direction e-type loop $G(t) = \overline{\langle E(t) \rangle^2}$ after every red round



even t		odd t		even t
$\{X_e, Z_e\}$	$\rightarrow$	$\{X_m, Z_m\}$	$\rightarrow$	$\{X_e, Z_e\}$
$\downarrow$		$\downarrow$		
$\langle X_e \rangle = \pm 1$		$\langle X_e \rangle = 0$		

Floquet side

non-Floquet side

$p_m = 0$

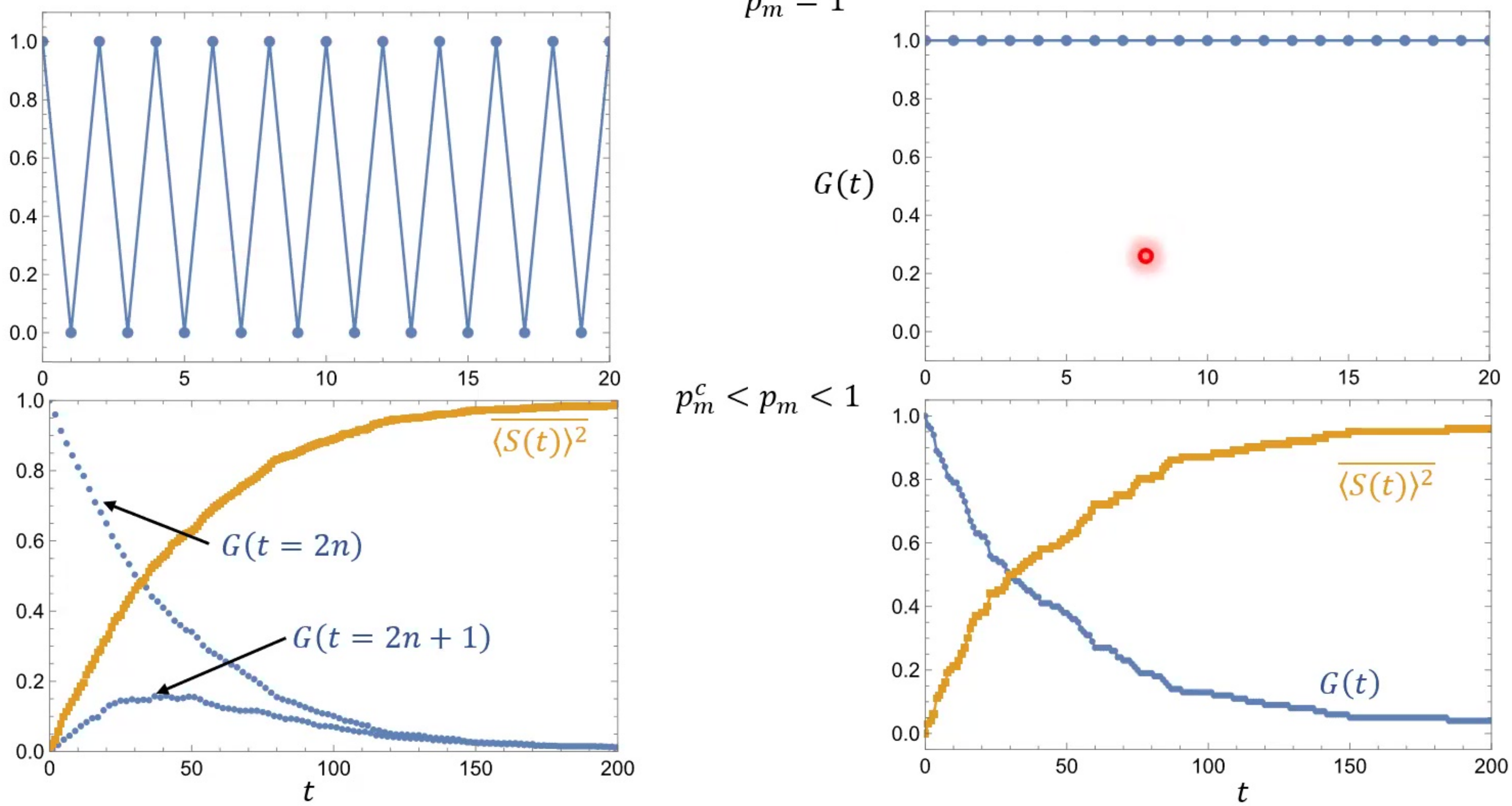
$G(t)$

$p_m = 1$

$G(t)$

$0 < p_m < p_m^c$

$p_m^c < p_m < 1$

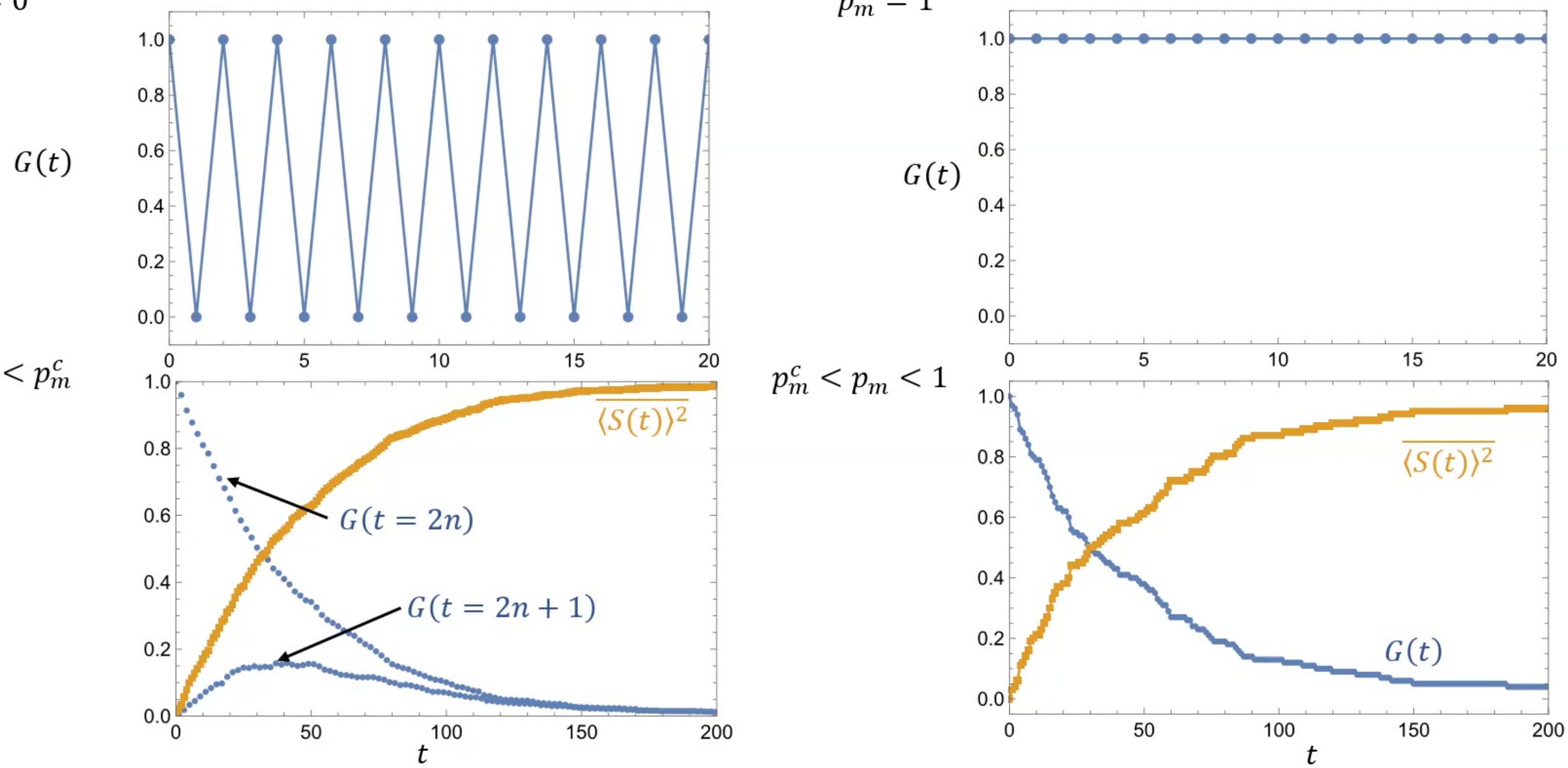


Fixed-point string S

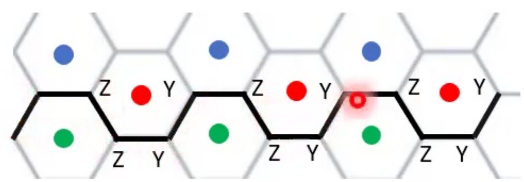
Floquet side | non-Floquet side

$p_m = 0$ | $p_m = 1$

$0 < p_m < p_m^c$ | $p_m^c < p_m < 1$

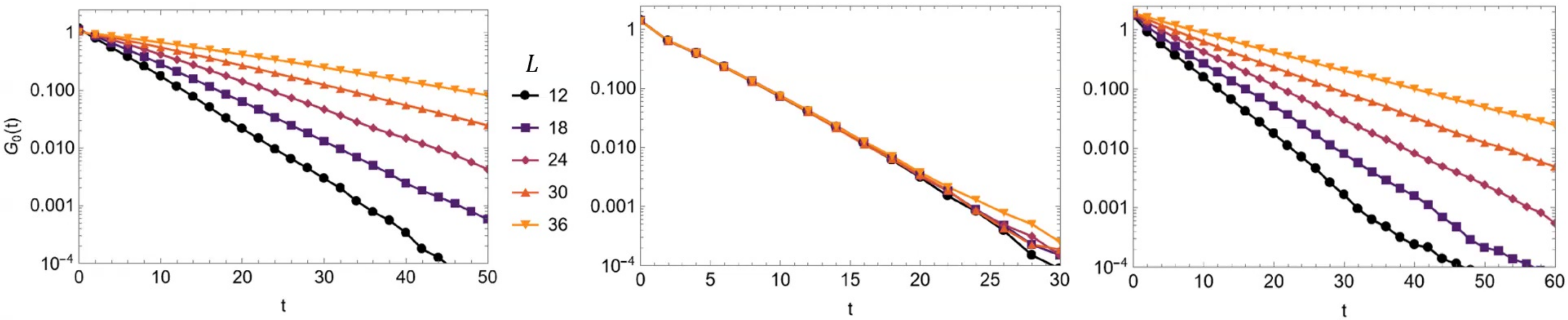


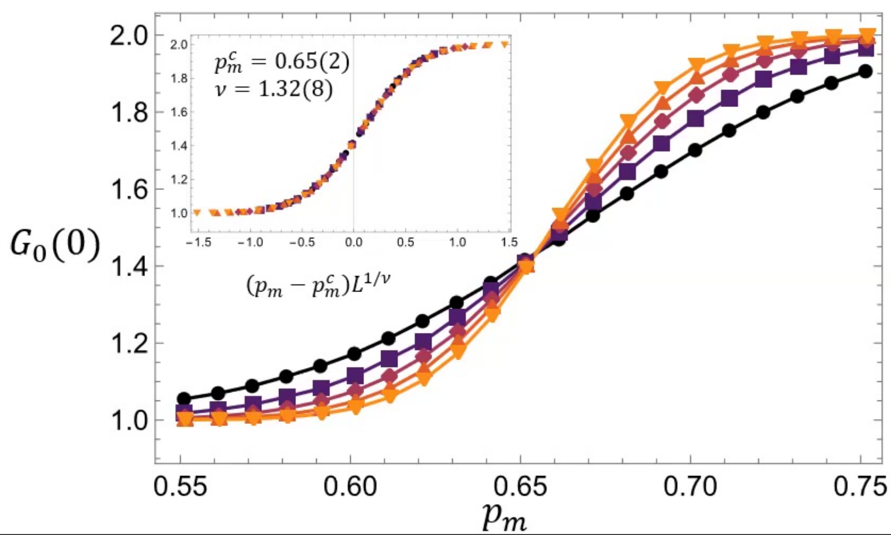
Fixed-point string S

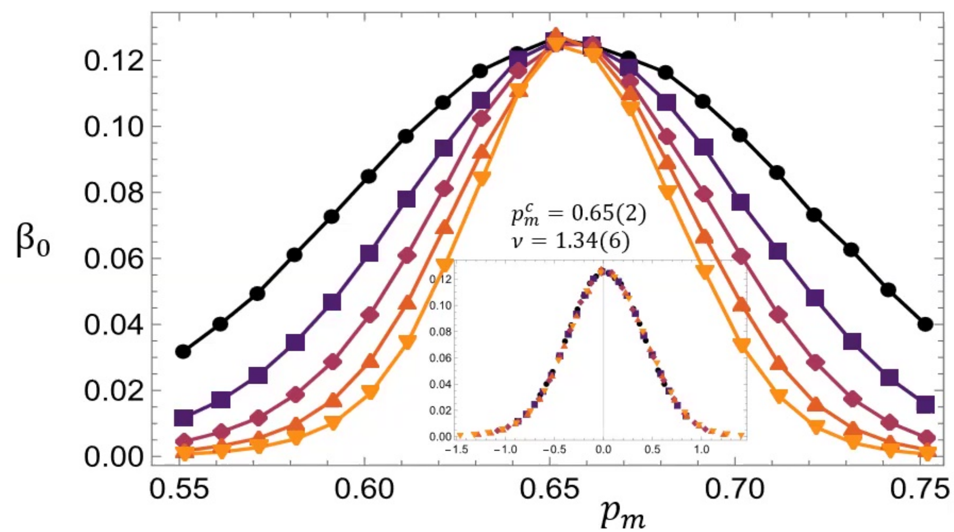


$$G_0(2t) = G(2t) + G(2t+1) \sim A_0 e^{-\beta_0 t}$$

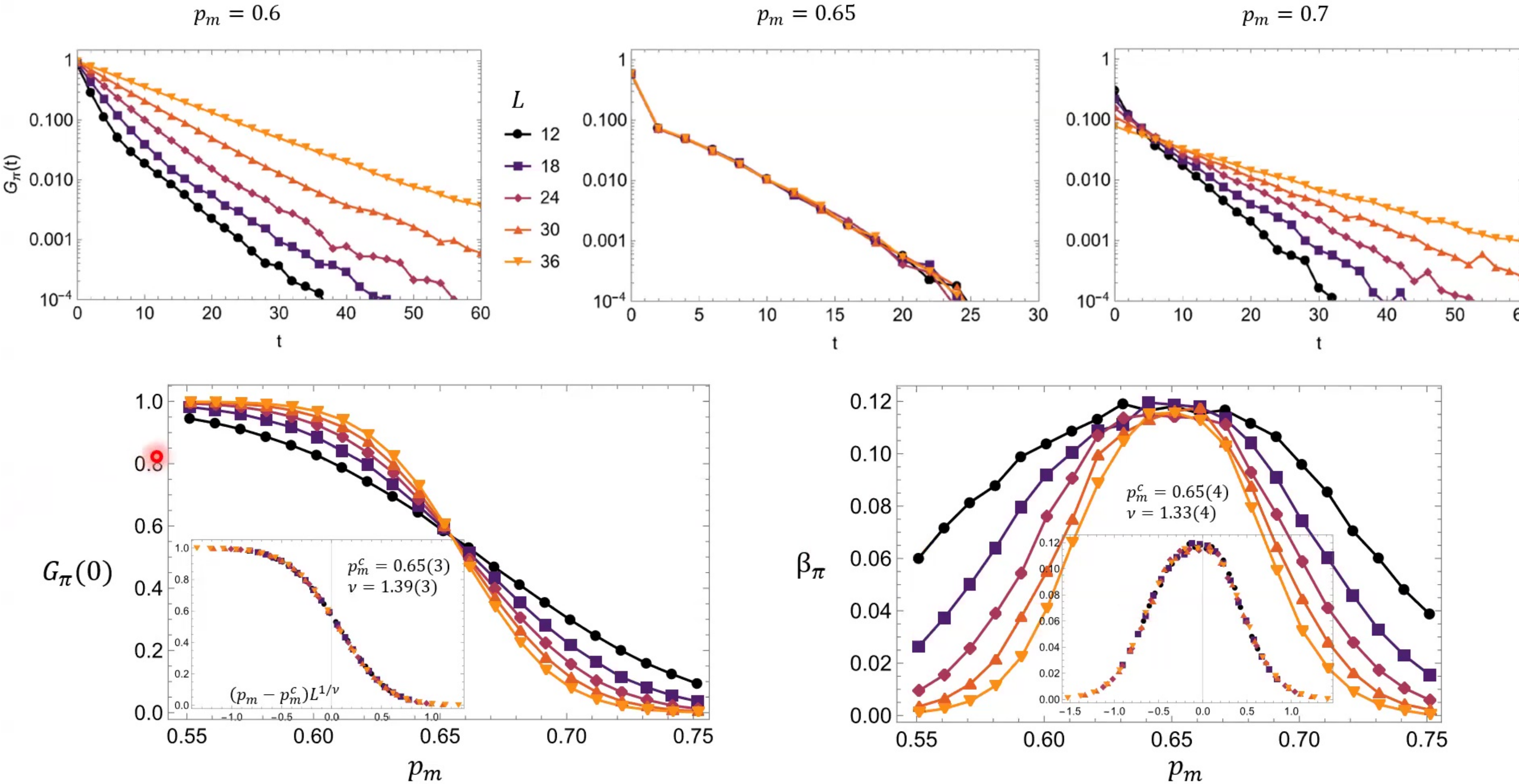
$p_m = 0.6$ $p_m = 0.65$ $p_m = 0.7$



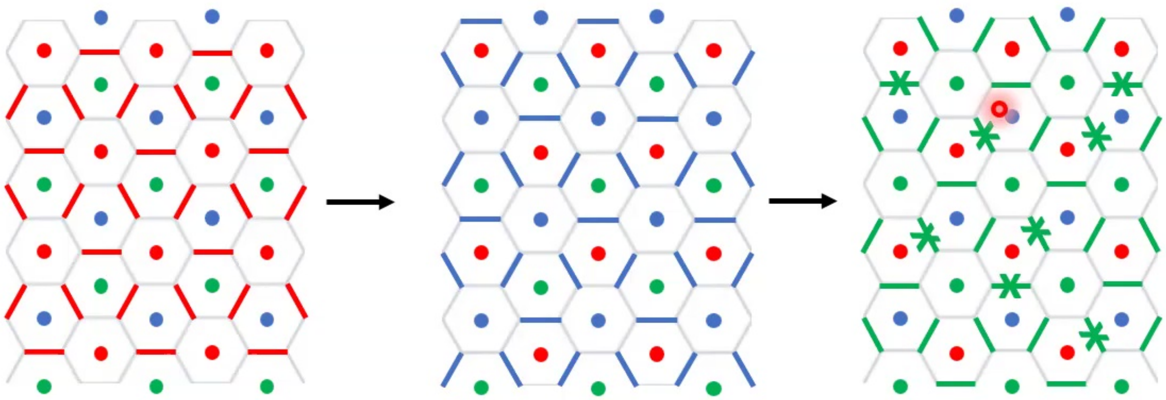




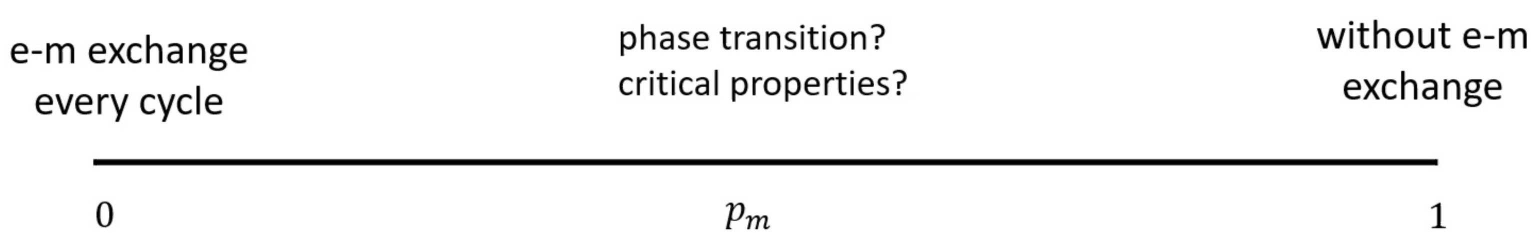
$$G_\pi(2t) = G(2t) - G(2t+1) \sim A_\pi e^{-\beta_\pi t}$$



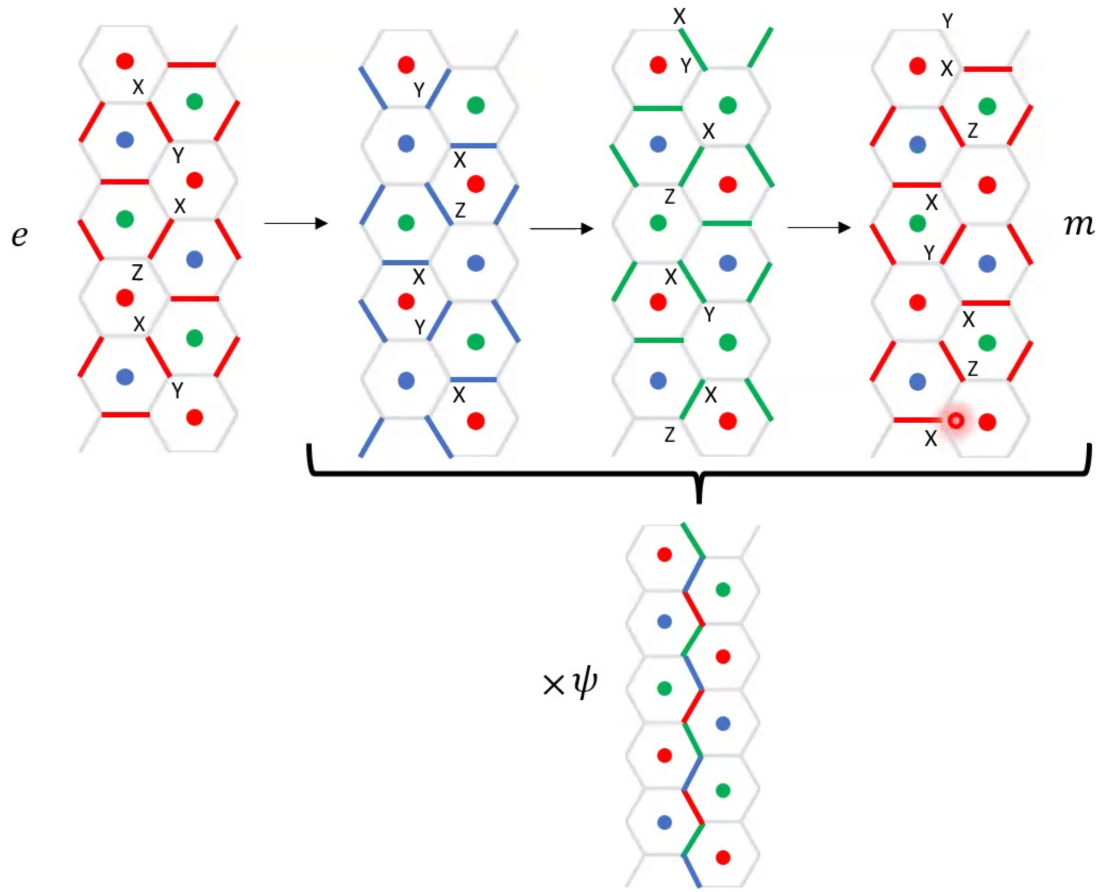
Floquet to non-Floquet phase transition



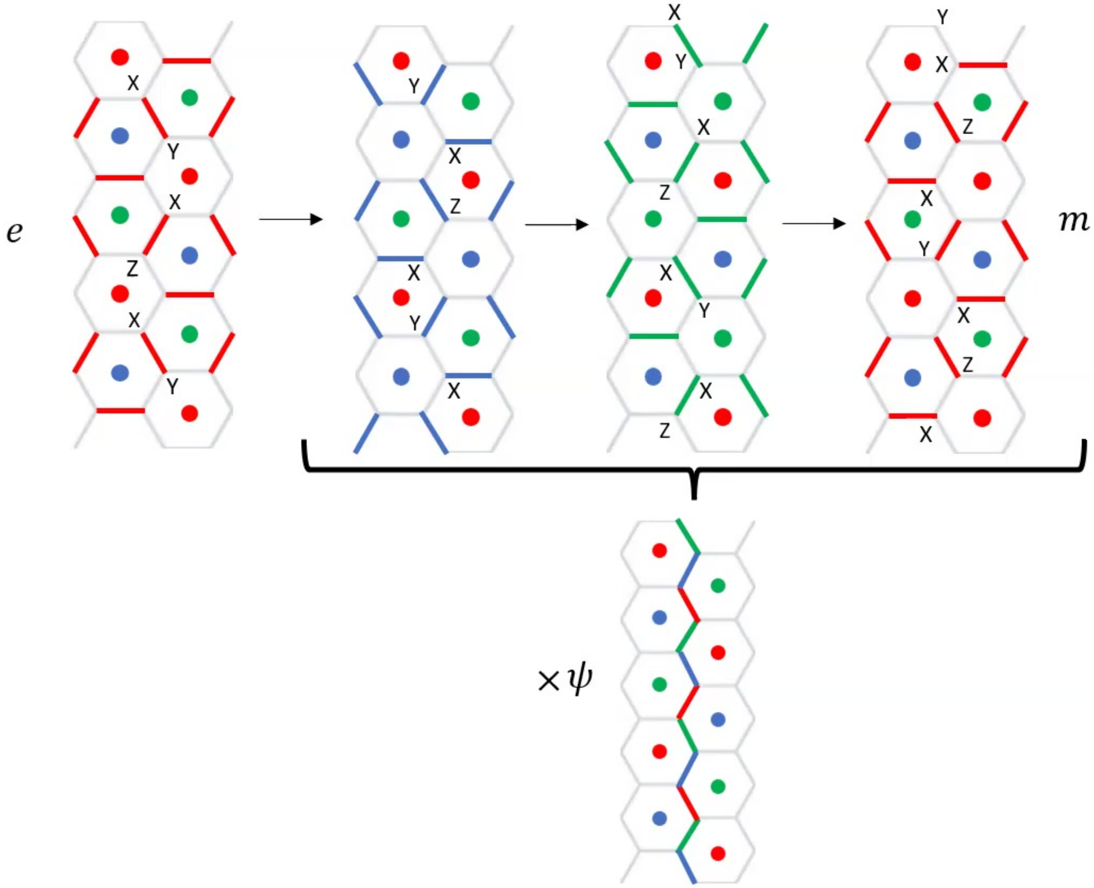
Green links are randomly missing with p_m

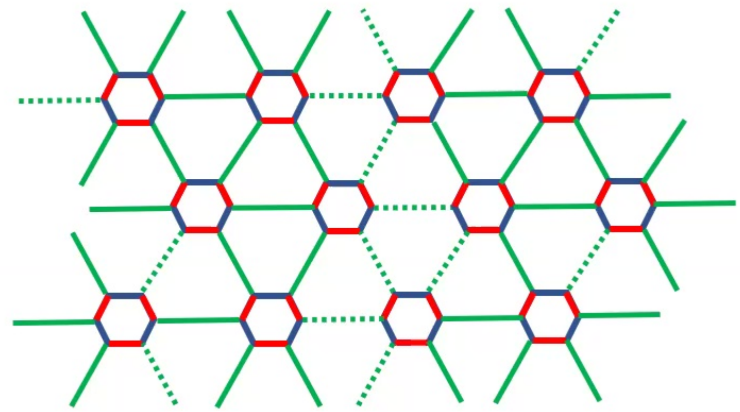


Percolation in triangular lattice



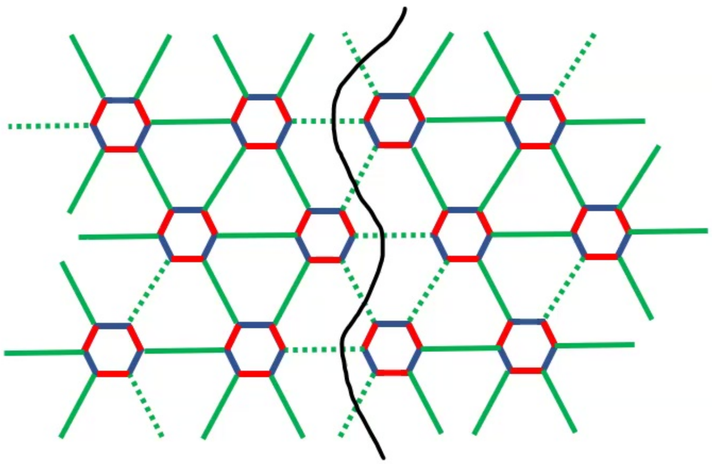
Percolation in triangular lattice

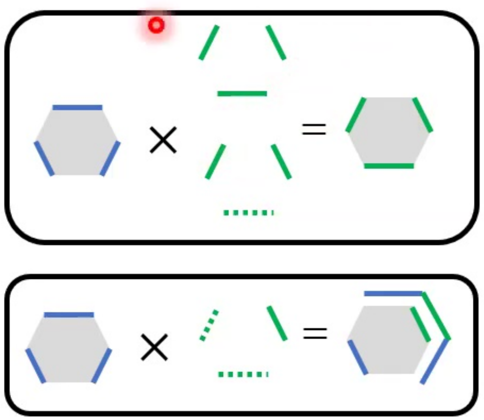


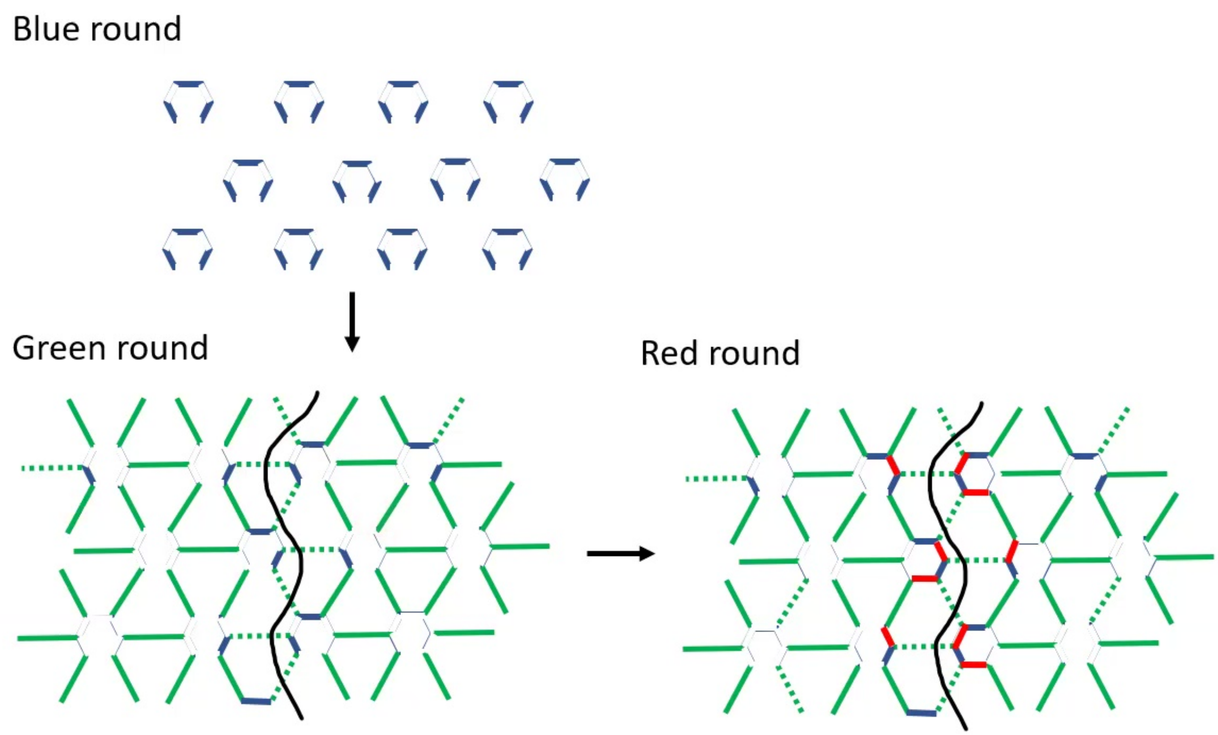


$1 - p_{threshold} \sim 0.653$
$\nu = 4/3 \sim 1.33$

Damping at the critical point







Strings are measured along the domain wall

Floquet to non-Floquet phase transition

What happens at the critical point?

1) Dominant cluster ceases to exist

   -> impossible to find a long ψ-path -> e-m exchange is destroyed

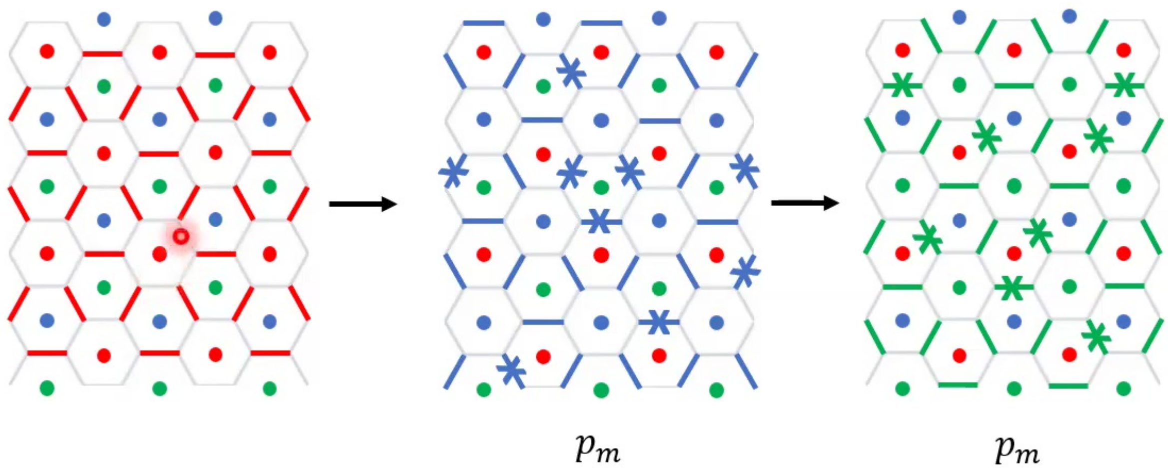
2) Distribution of domain wall length $P(l) \sim e^{-l/\xi}$.

   + Away from the critical point, ξ finite -> $P(L)$ exponentially suppressed

   + At the critical point, $\xi \to \infty$ -> $P(L)$ is size invariant

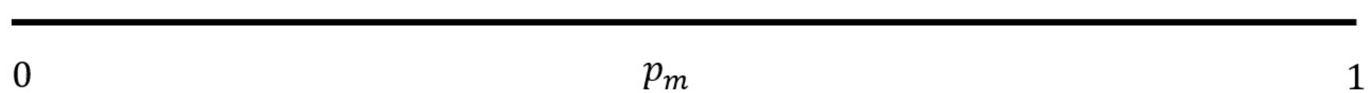
3) Critical properties agree with percolation transition on a triangular lattice

Floquet – toric phase diagram



Floquet code

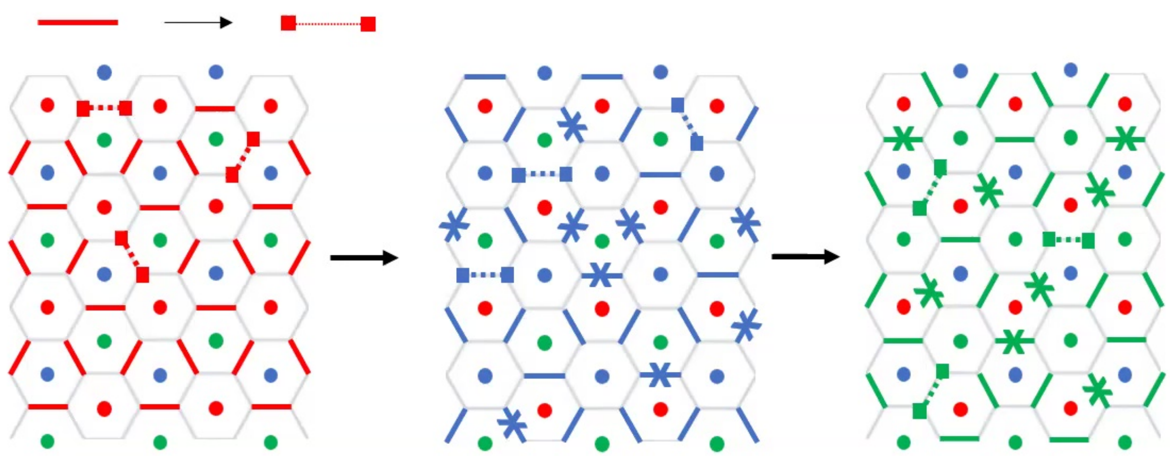
Stationary toric code



Floquet – toric phase diagram

single-qubit error: measurement X_1X_2 -> two measurements X_1 and X_2

anti-commute with plaquettes!



$p_e(1-p_m)$

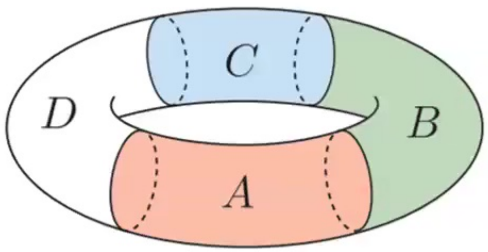
p_m

p_e

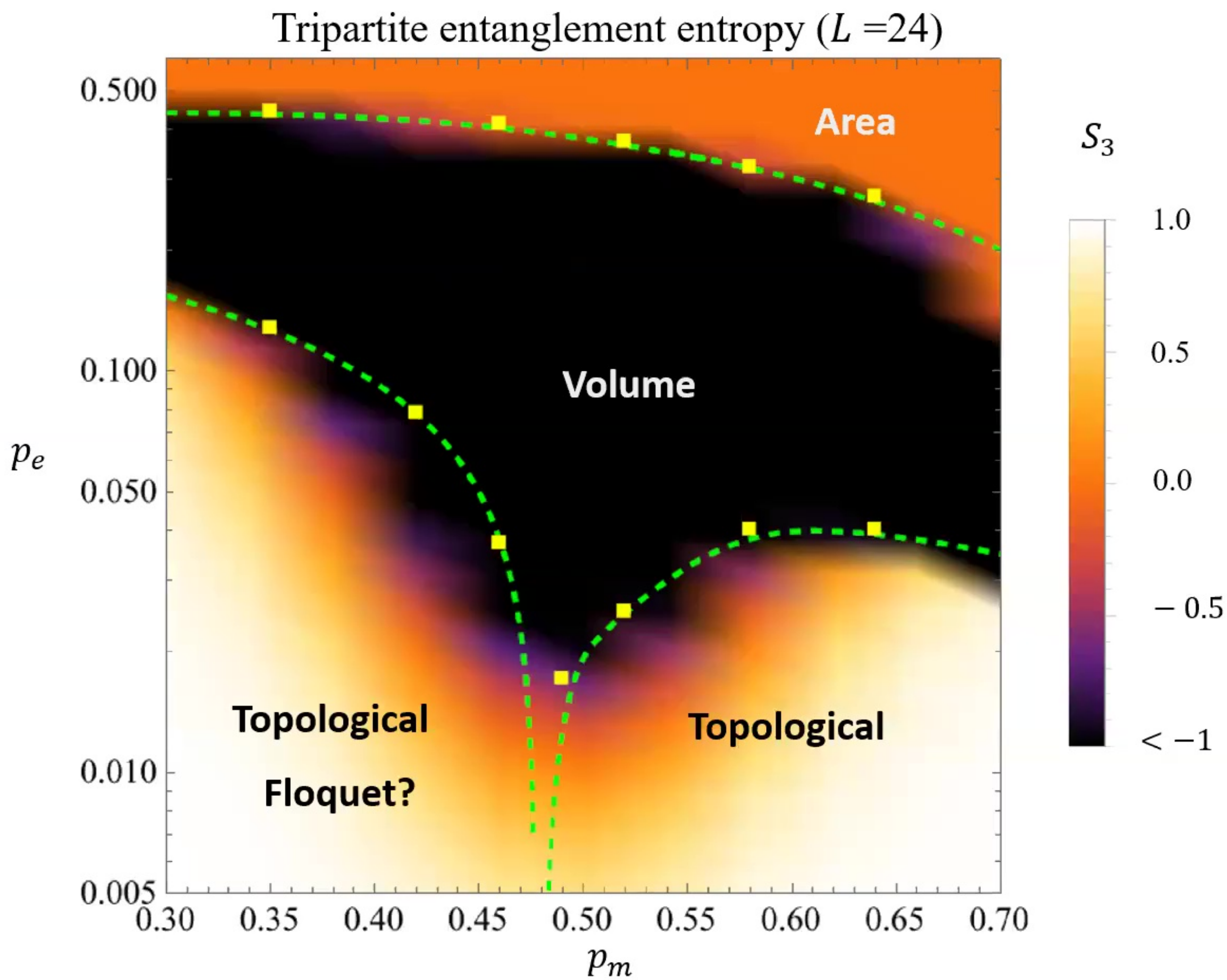
p_m

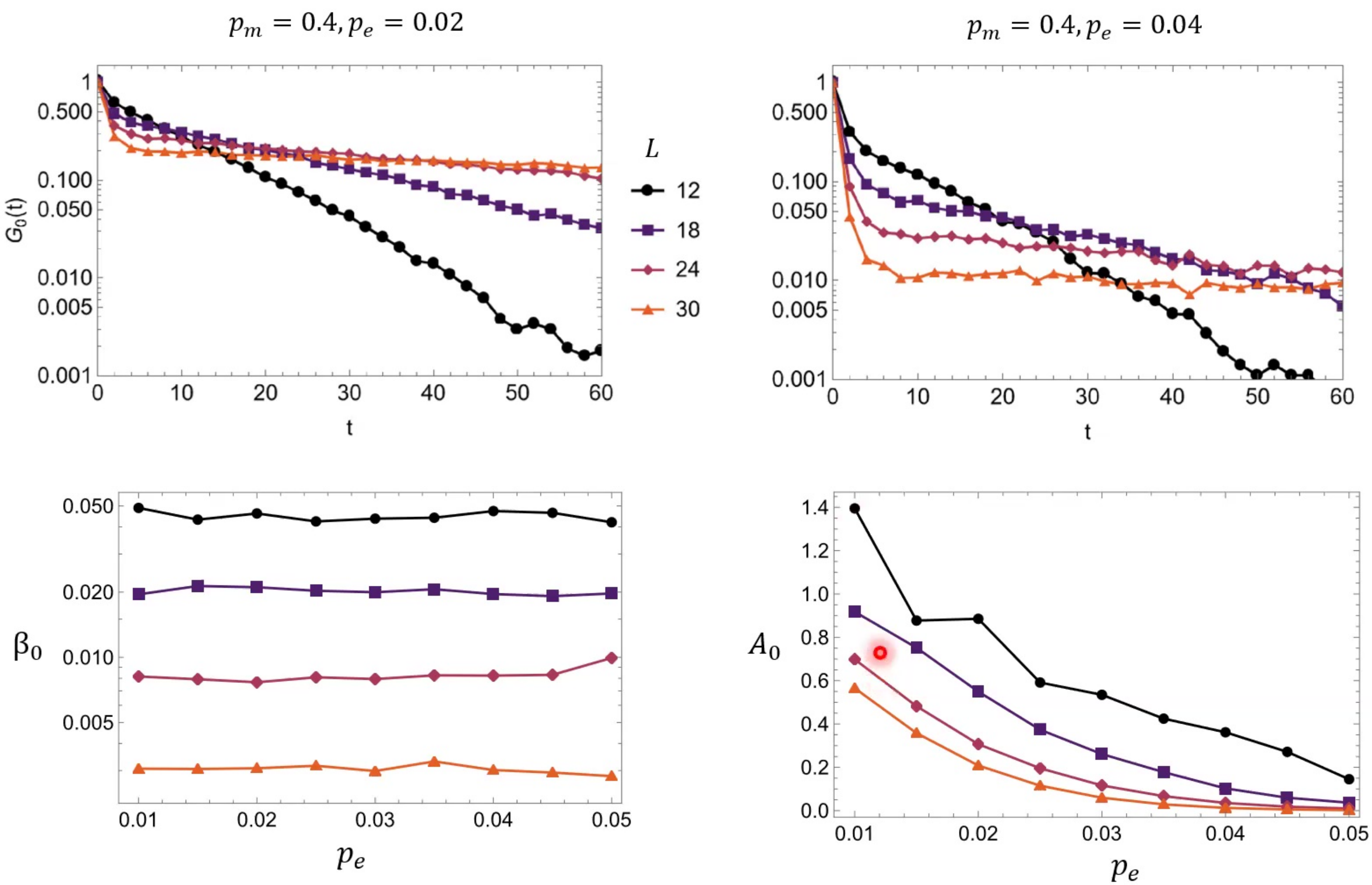
p_e

Floquet – toric phase diagram



$$S_3 = S_A + S_B + S_c$$
$$S_{AB} - S_{AC} - S_{BC} + S_{ABC}$$

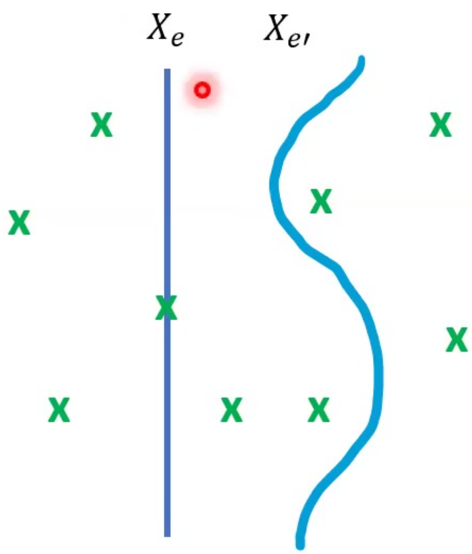


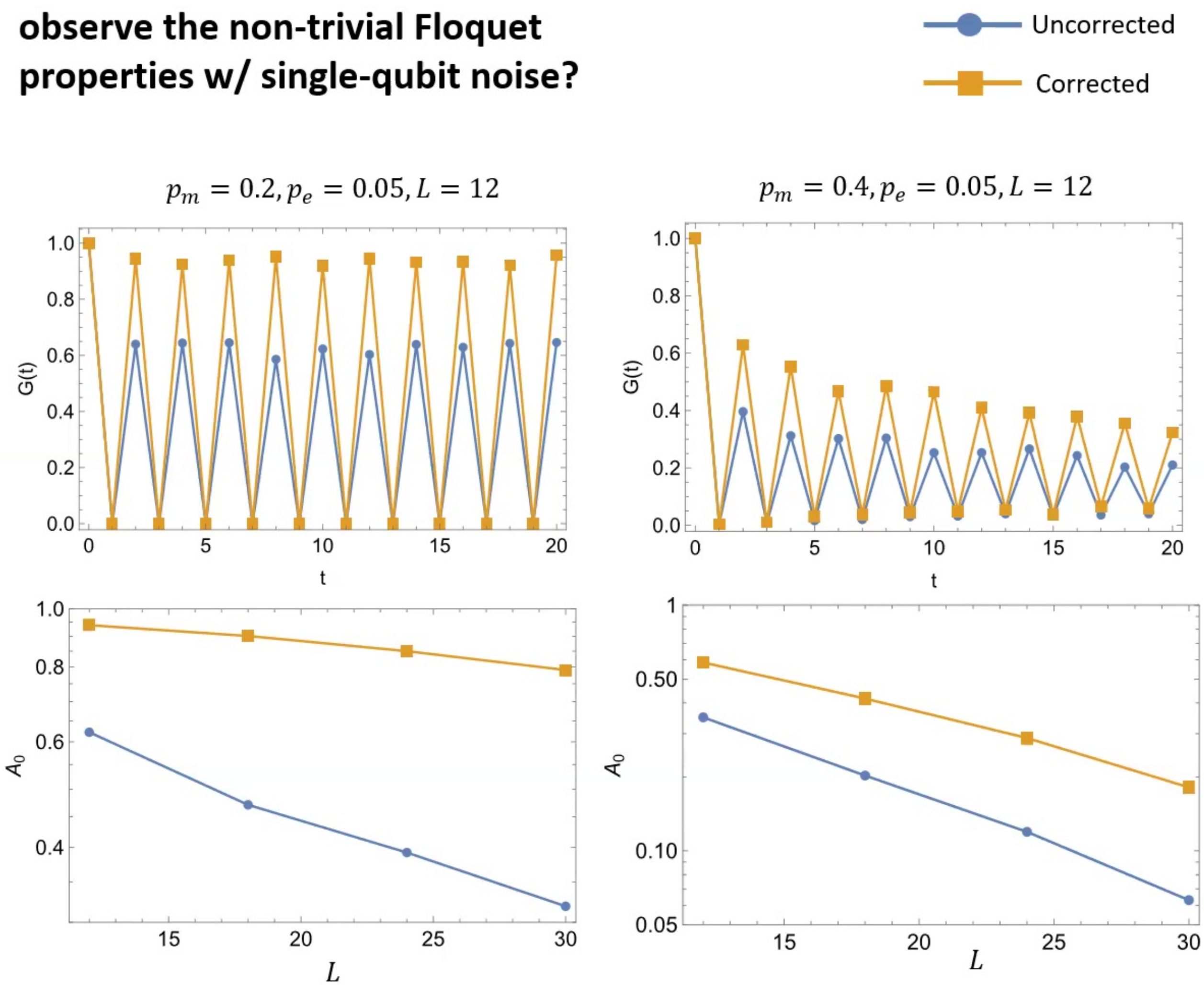


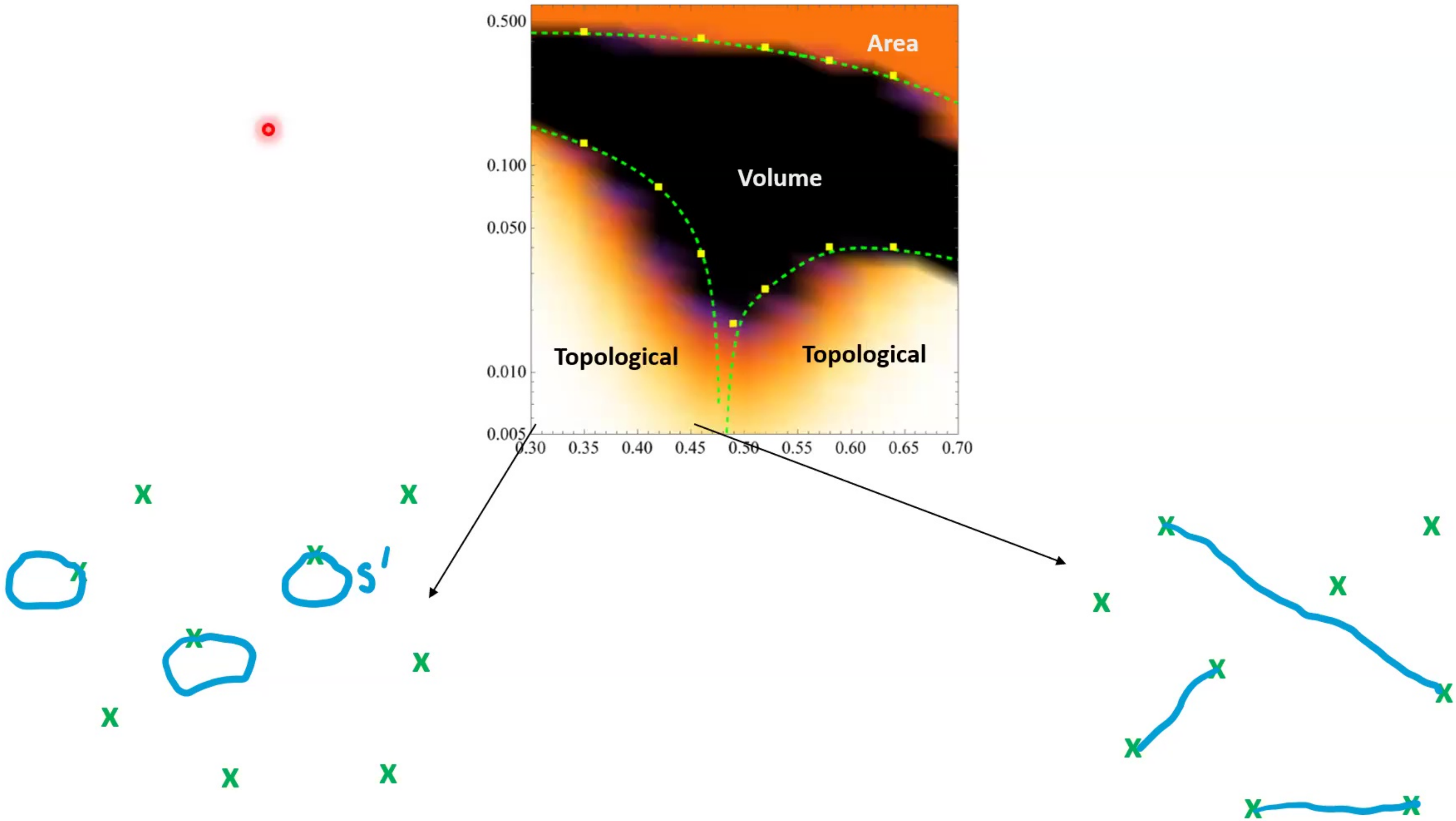
$p_m = 0.4, p_e = 0.02$
$p_m = 0.4, p_e = 0.04$
$G_0(t)$
t
L
12
18
24
30
β_0
A_0
p_e

Open question

observe the non-trivial Floquet properties w/ single-qubit noise?







0.500
0.100
0.050
0.010
0.005
0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70
Area
Volume
Topological
Topological
s'

Better way: Floquet topological invariant

Band topology

Static 2D

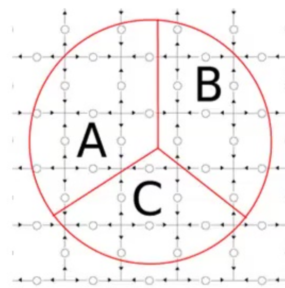
$$C_2 = \int f_{xy}(k) dk_x dk_y$$

Floquet 2D

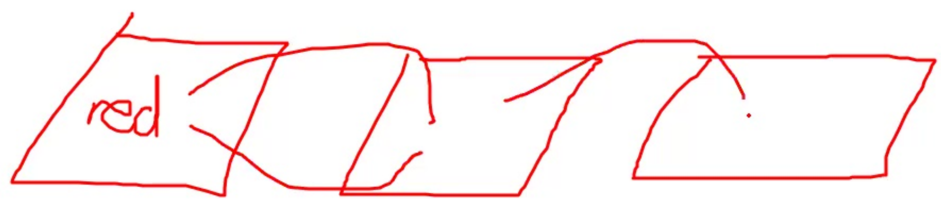
$$C_3 = \int W_3[U(k,t)] dk_x dk_y dt$$

Topological order

Static 2D Topological entanglement entropy



Floquet 2D?



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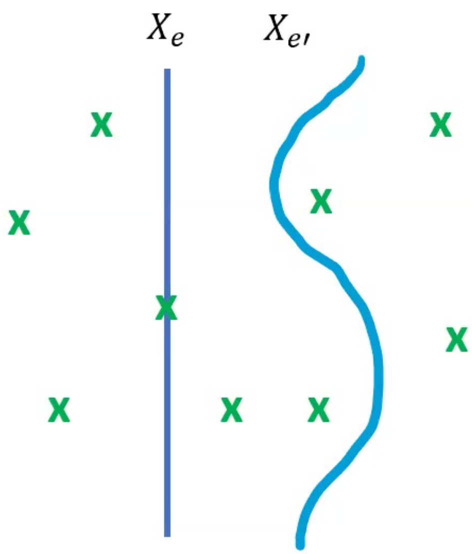

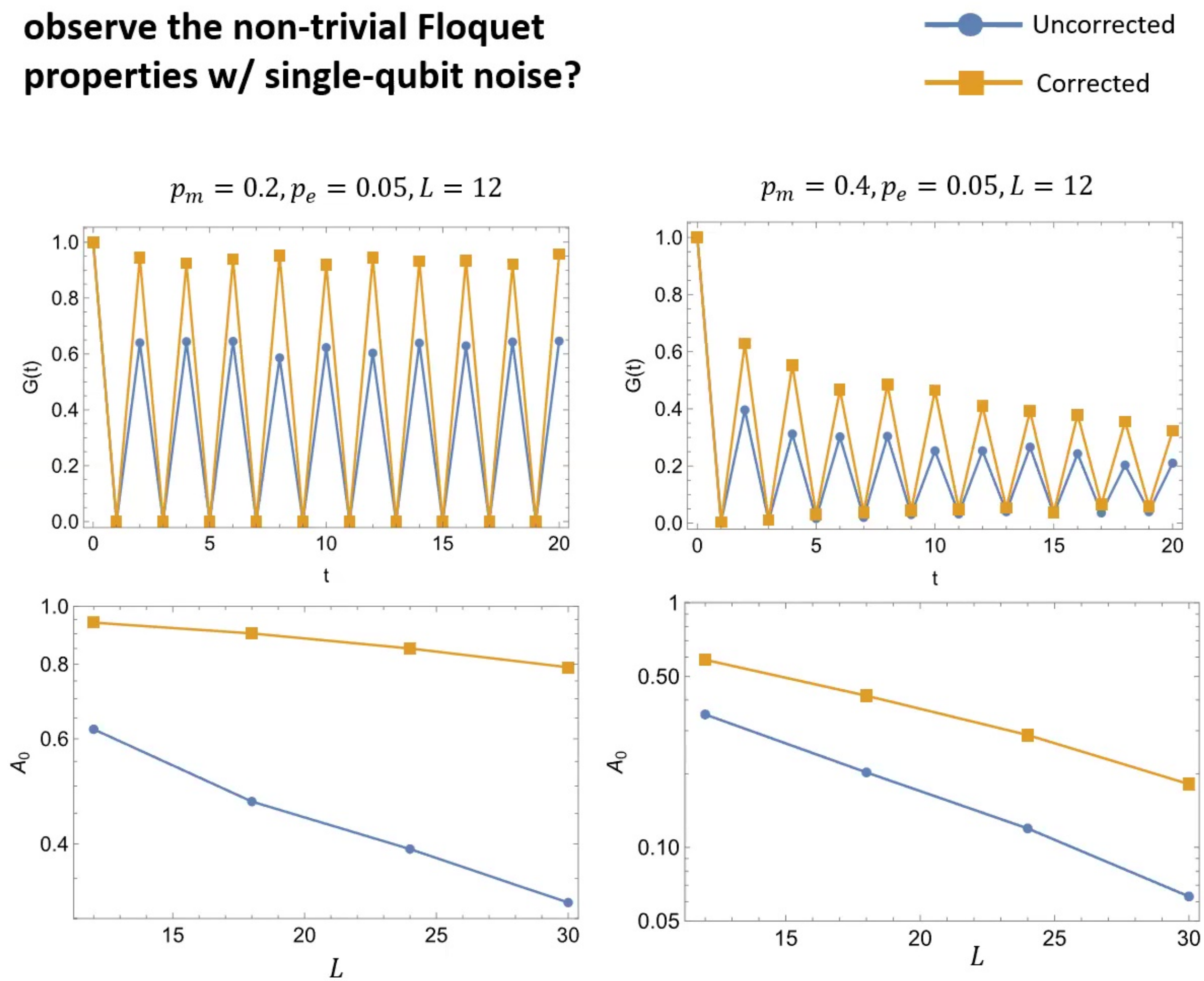

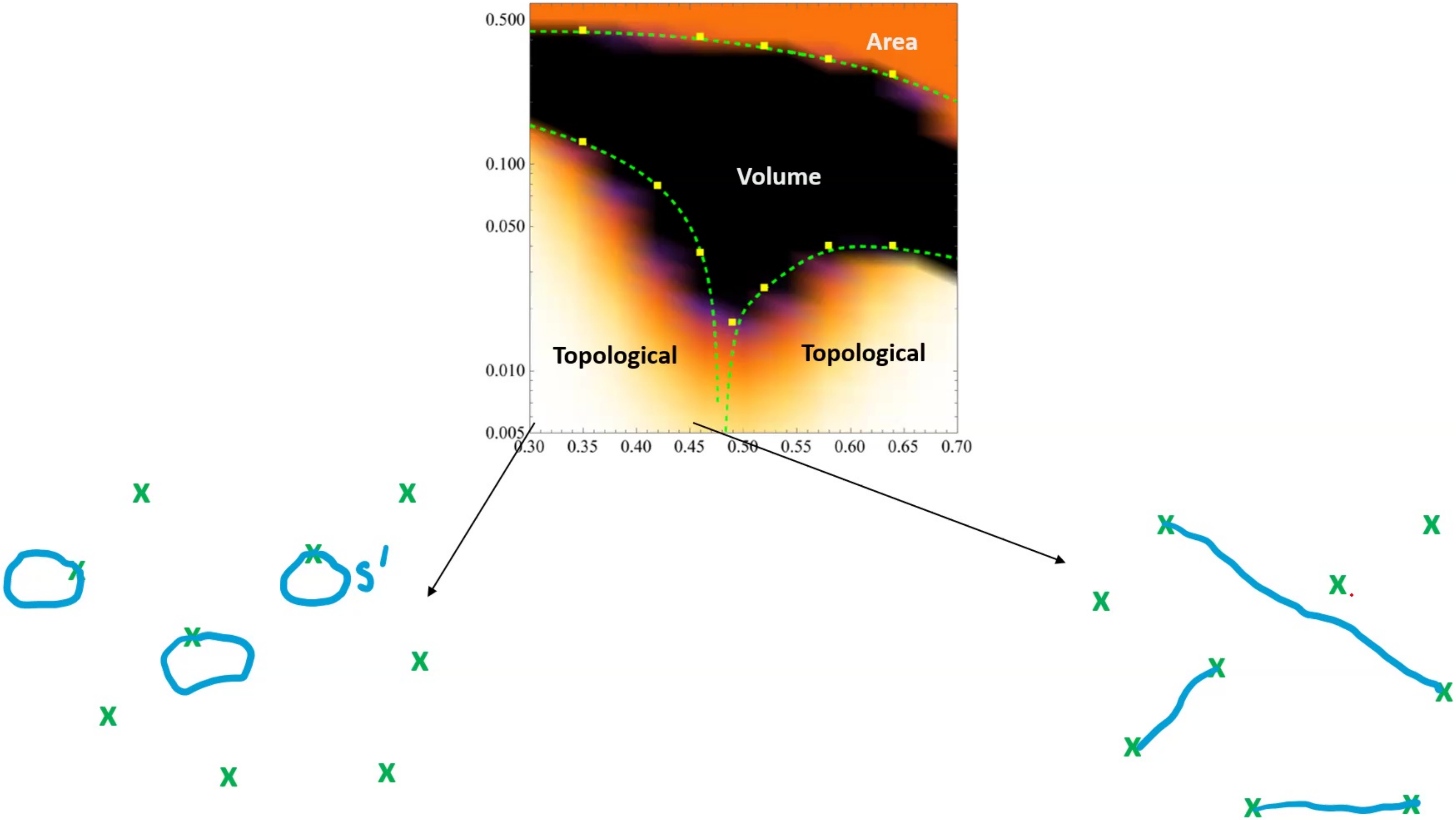
0.500
0.100
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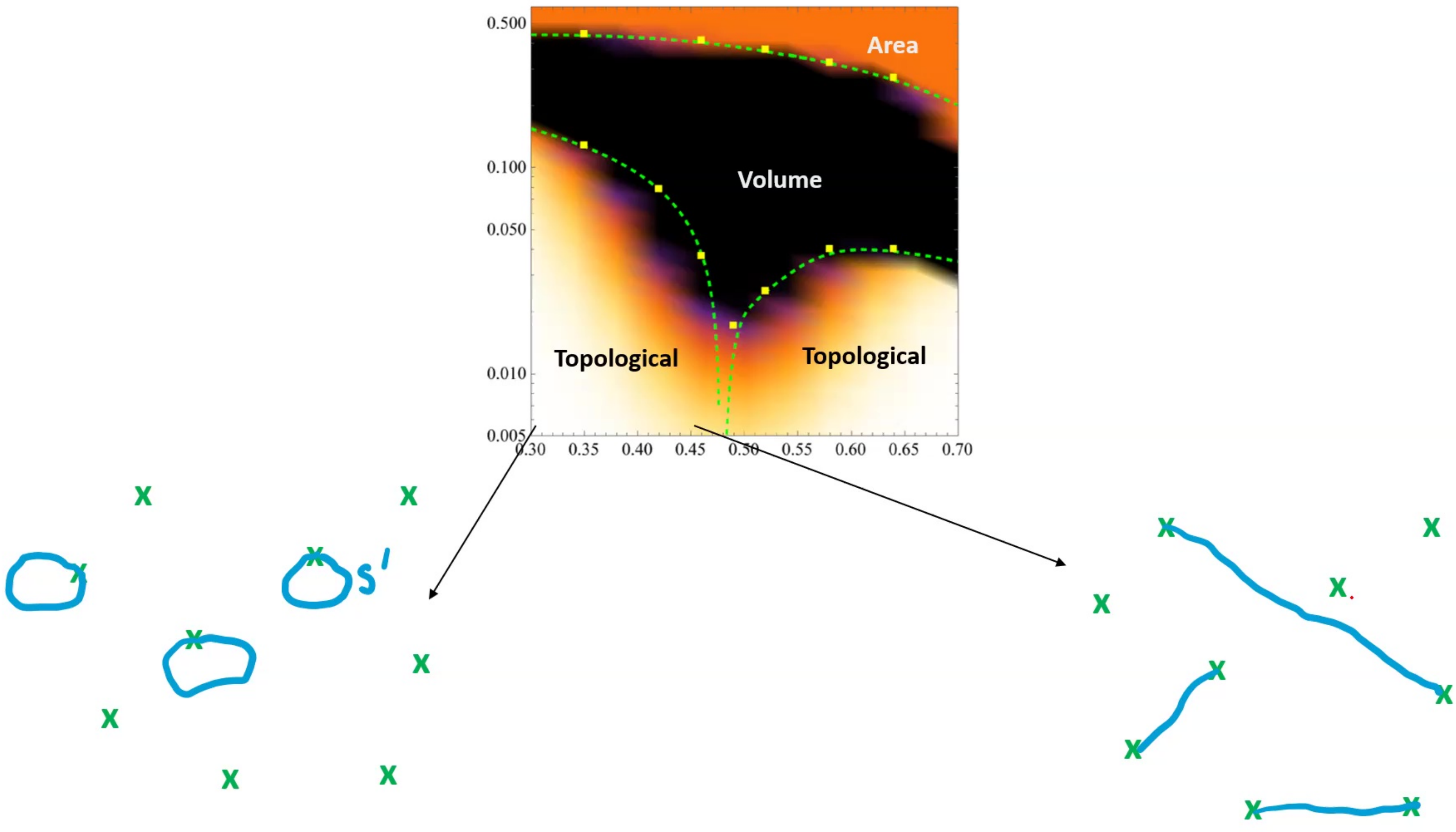
0.45
0.50
0.55
0.60
0.65
0.70
Area
Volume
Topological
Topological
S'


Area
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0.500
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S'

Introduction

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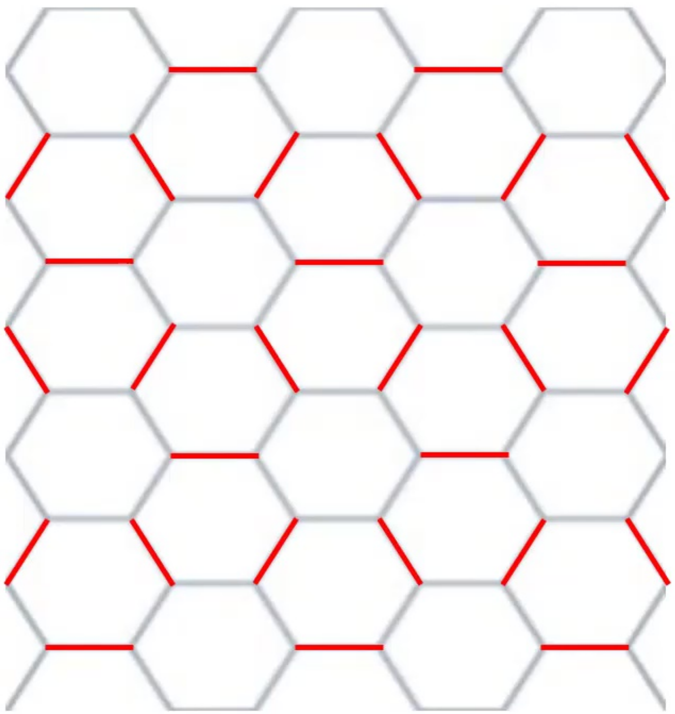
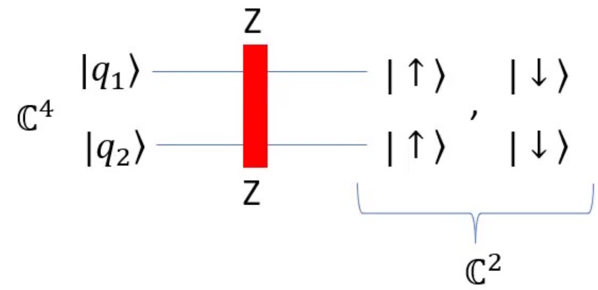
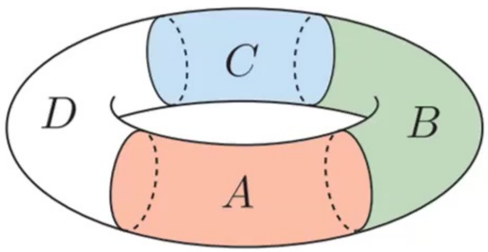




Floquet – toric phase diagram



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