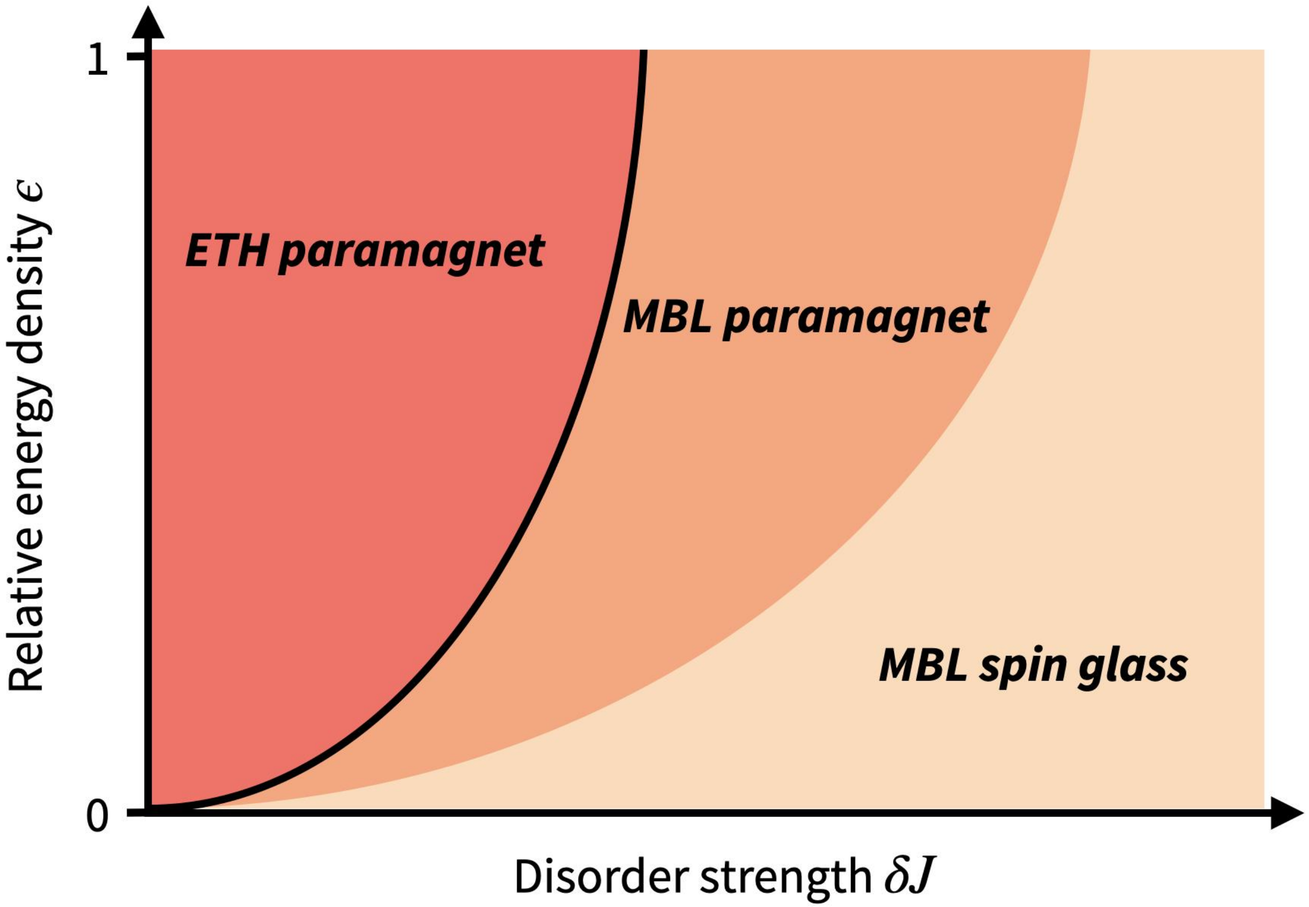
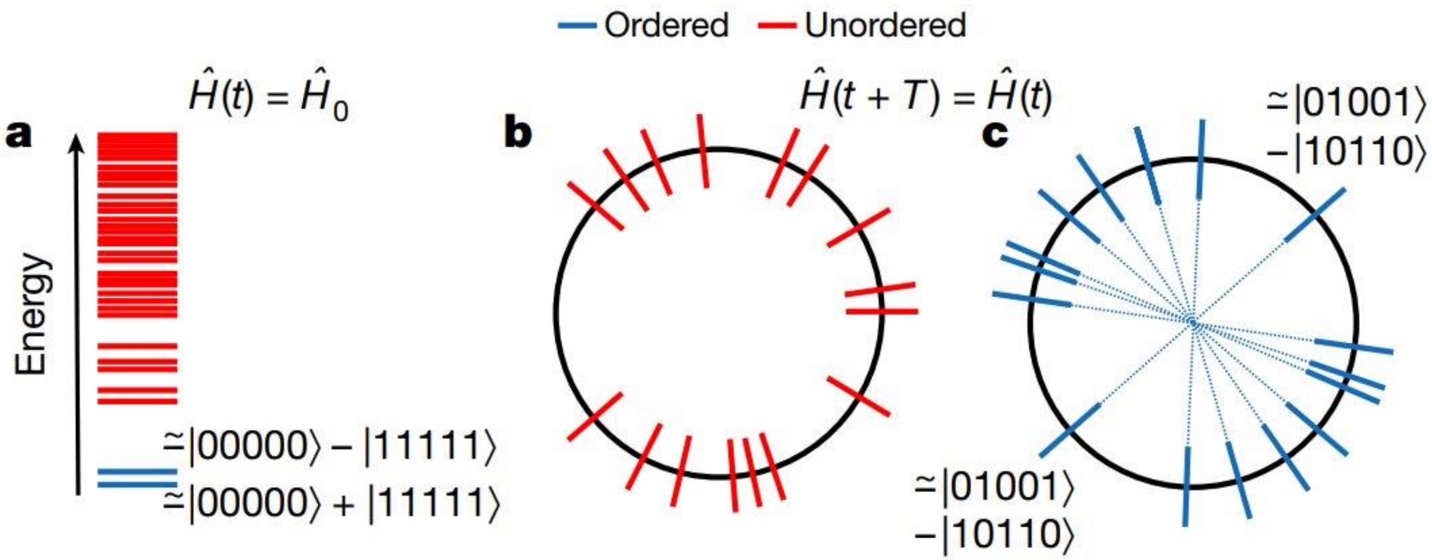
TIME-CRYSTALLINE EIGENSTATE ORDER ON A QUANTUM PROCESSOR

Hristo Tonchev

Faculty of Physics, Sofia University


1
0
Relative energy density ϵ
ETH paramagnet
MBL paramagnet
MBL spin glass
Disorder strength δJ

SOFIA UNIVERSITY
ST. KLIMENT OHRIDSKI
EST. 1888



Benchmarks for experimentally establishing an eigenstate-ordered

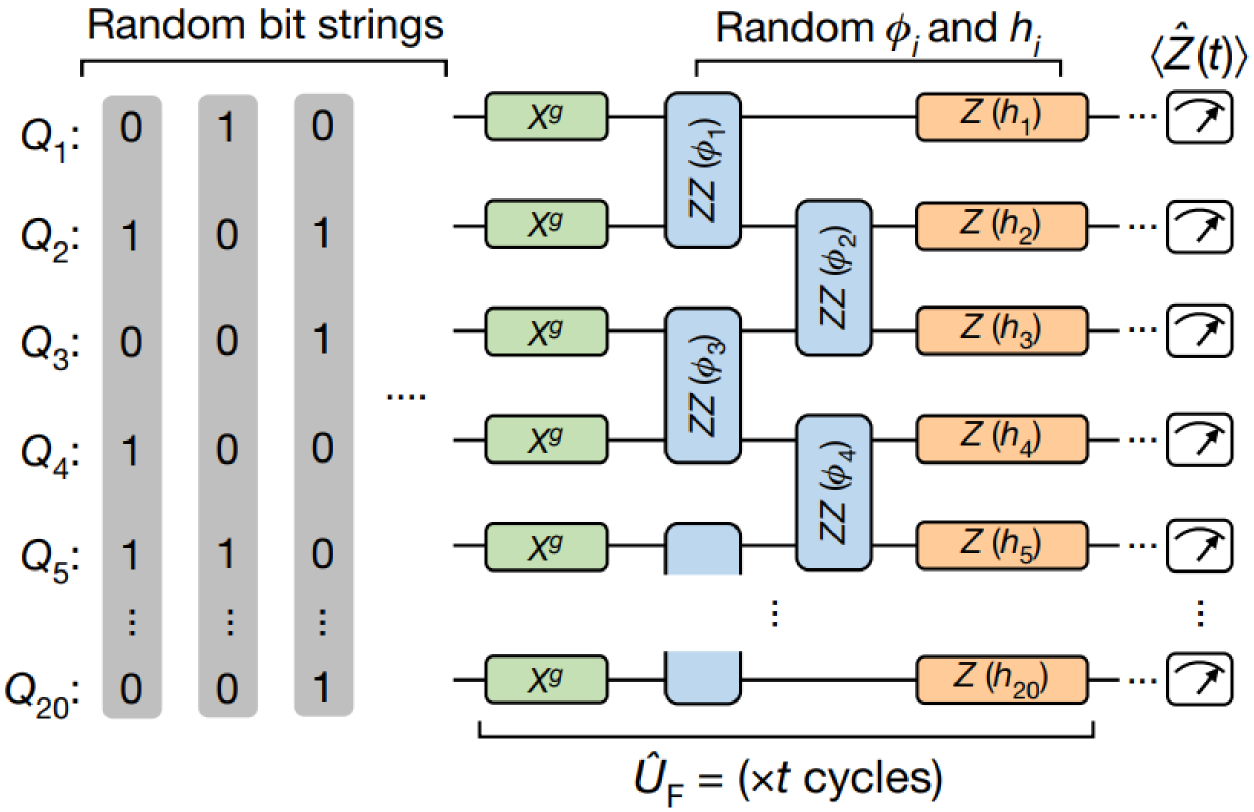
1. Drive parameters are varied to demonstrate stability of the phase in an extended parameter region and across disorder realizations

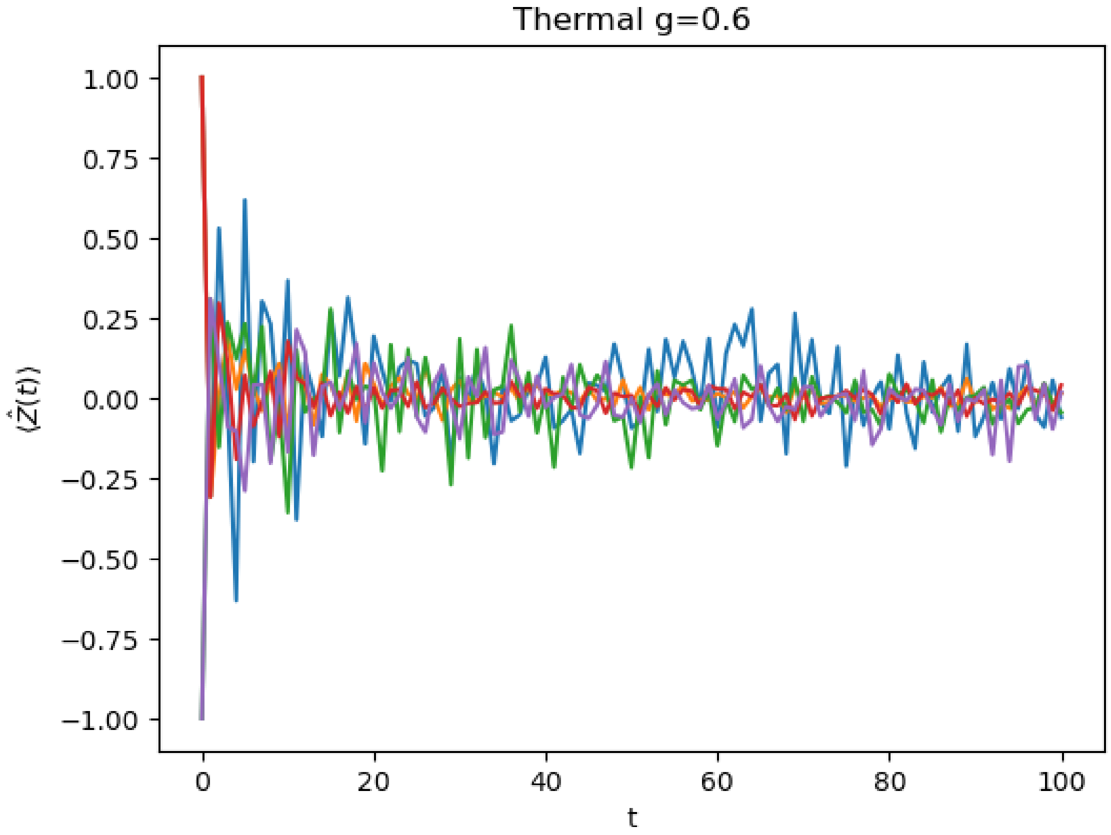
2. The limitations of finite size and finite coherence time are addressed, respectively, by varying system size and verifying that any decay of the subharmonic response is consistent with purely extrinsic decoherence assessed in an independent experiment

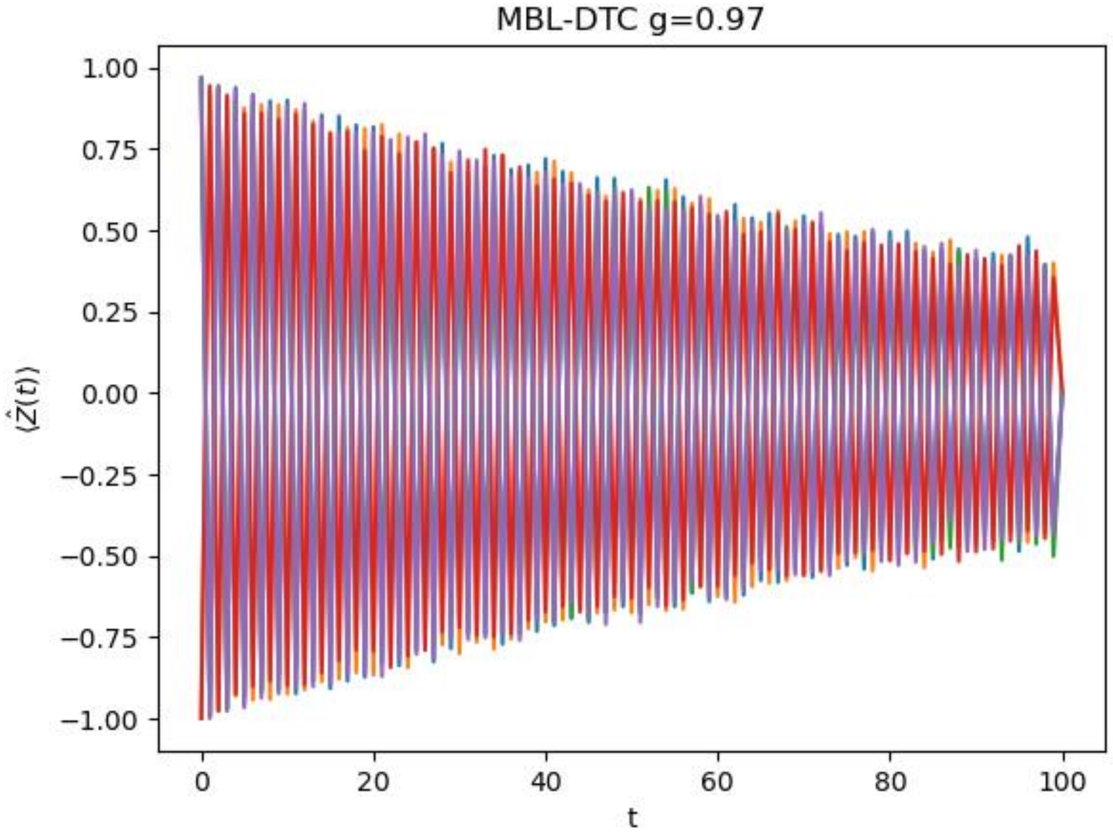
3. Existence of spatiotemporal order across the entire spectrum is established.

Propagator

$$\hat{U}_F = \underbrace{e^{-\frac{i}{2}\sum_i h_i \hat{Z}_i}}_{\text{longitudinal fields}} \; \underbrace{e^{-\frac{i}{4}\sum_i \phi_i \hat{Z}_i \hat{Z}_{i+1}}}_{\text{Ising interaction}} \; \underbrace{e^{-\frac{i}{2}\pi g \sum_i \hat{X}_i}}_{x \text{ rotation by } \pi g}$$

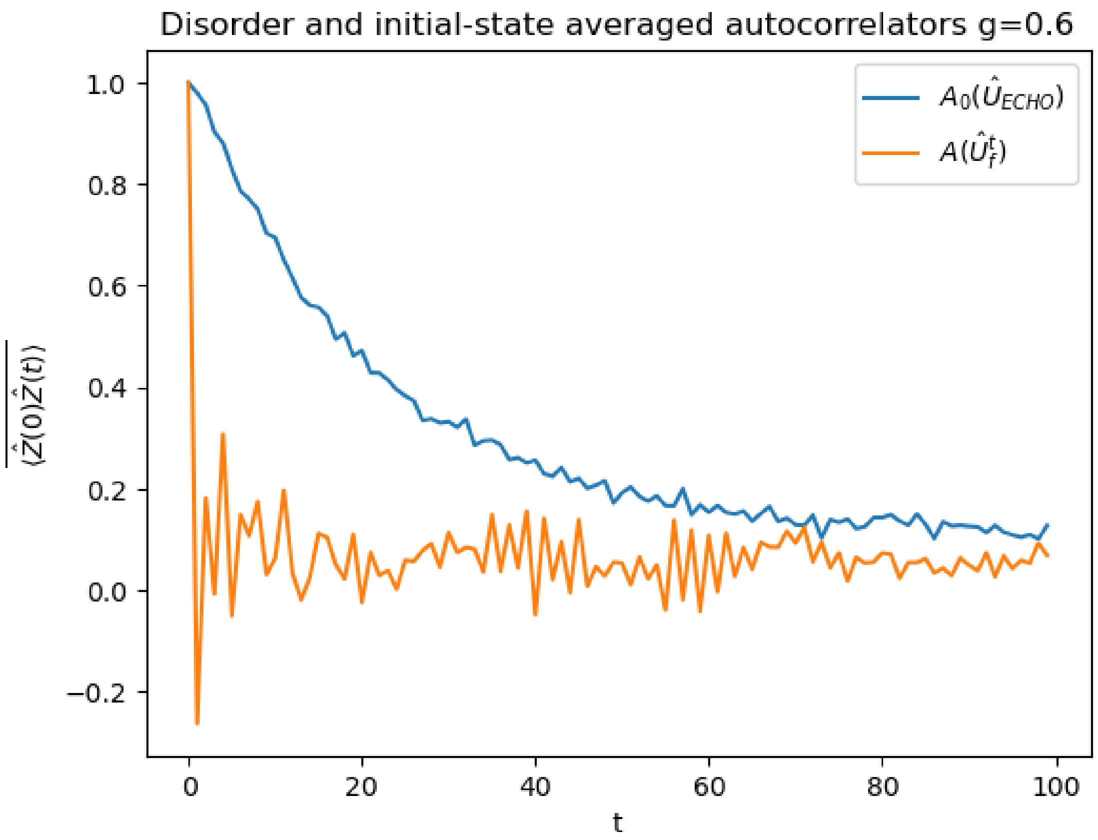


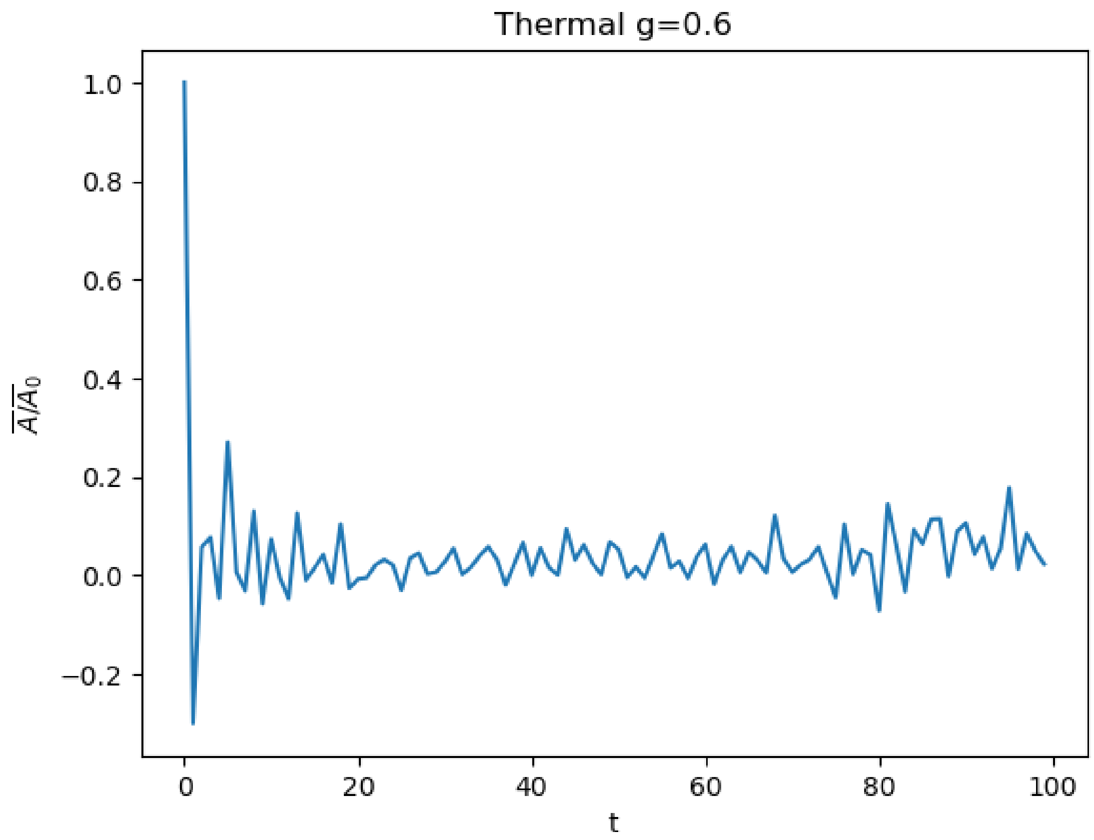

Thermal g=0.6
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
⟨Ẑ(t)⟩
0
20
40
60
80
100
t

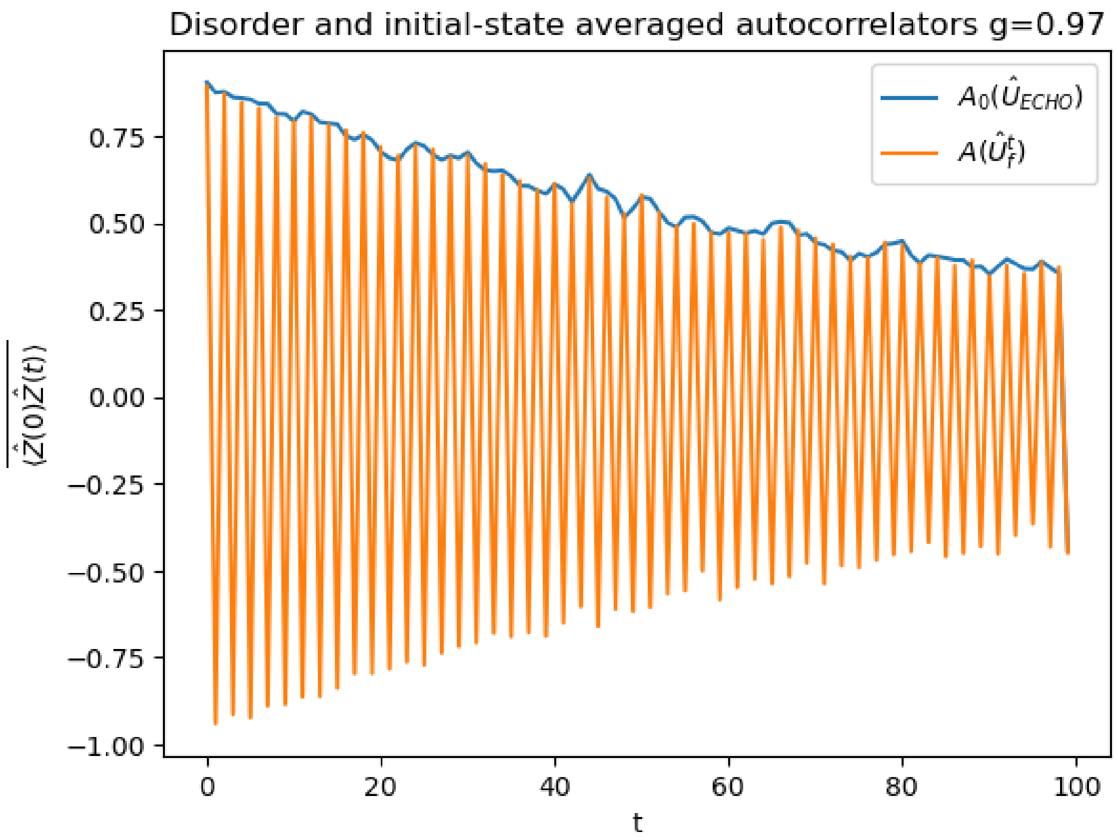

MBL-DTC g=0.97
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
⟨Ẑ(t)⟩
0
20
40
60
80
100
t

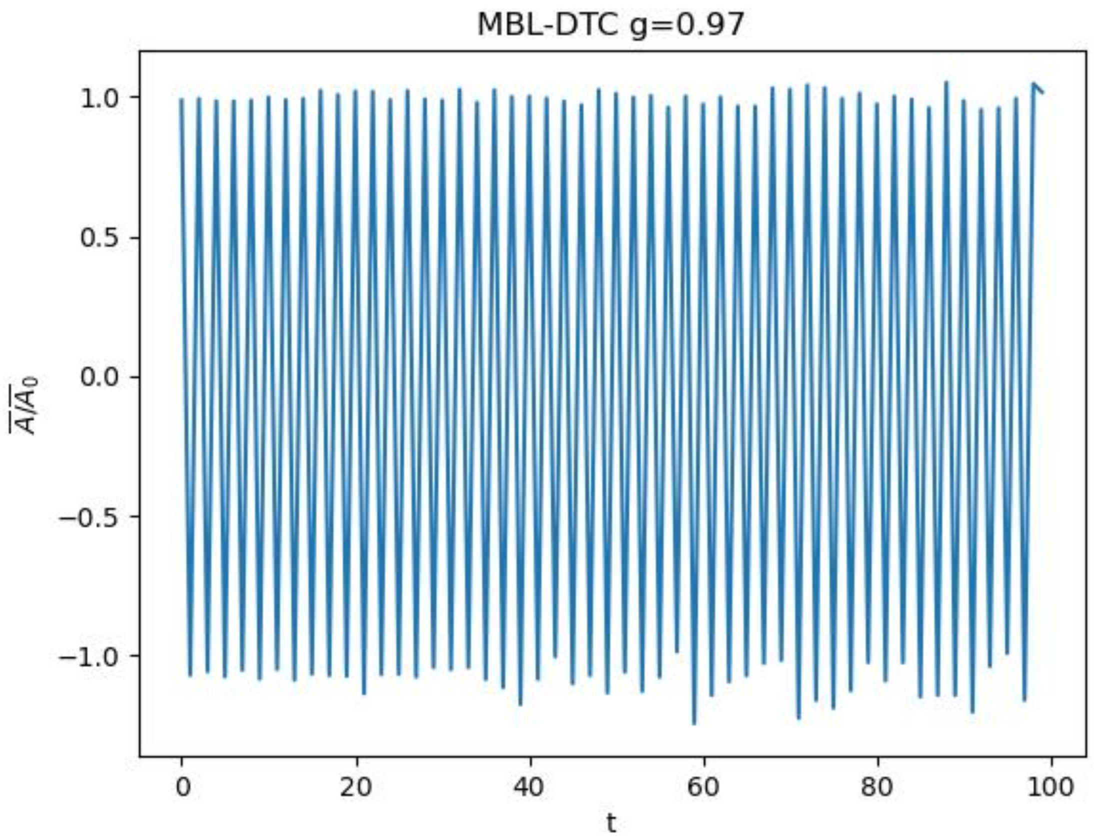
Autocorrelator

$$\hat{U}_{\text{ECHO}} = (\hat{U}_{\text{F}}^{\dagger})^t \hat{U}_{\text{F}}^t$$



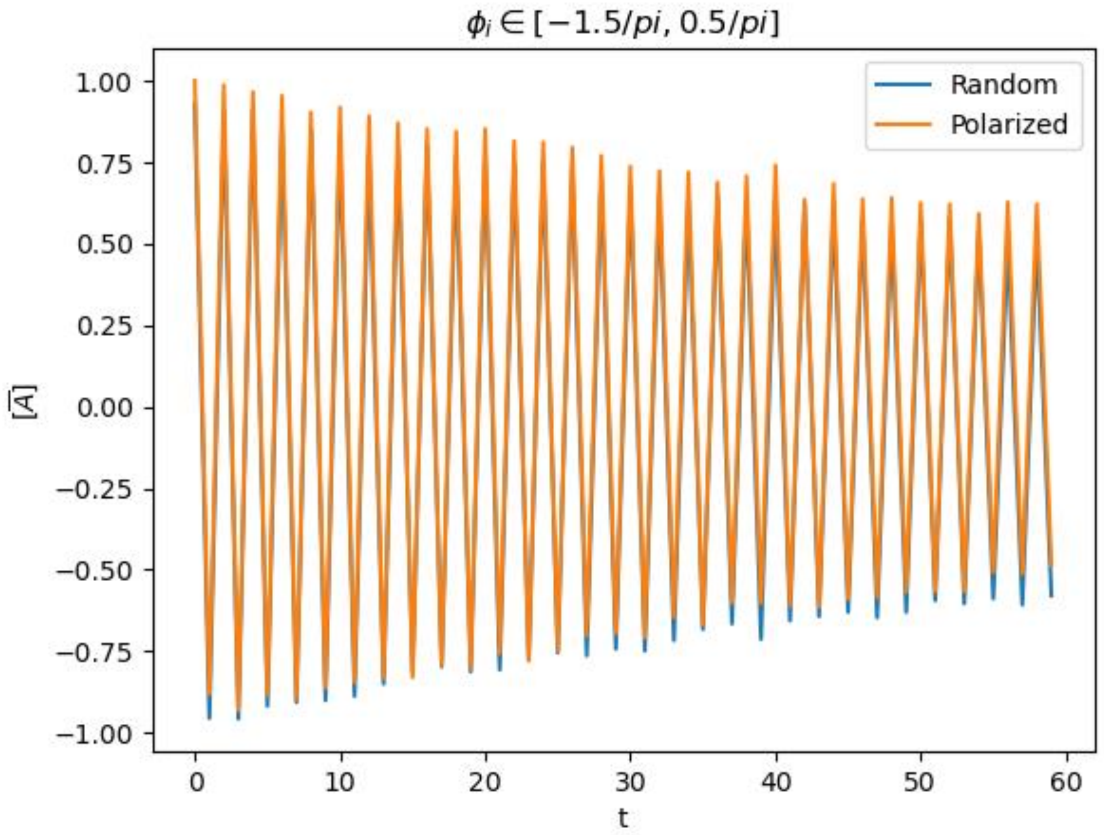


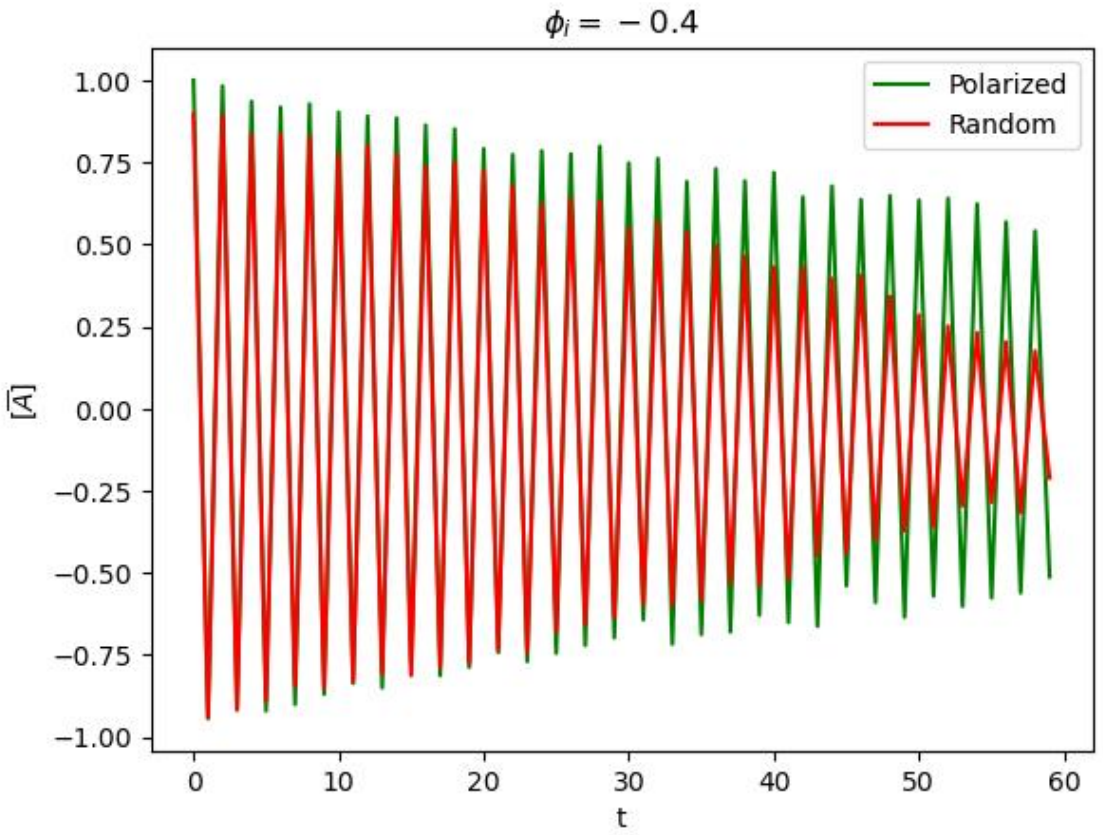

Disorder and initial-state averaged autocorrelators g=0.97
$A_0(\hat{U}_{ECHO})$
$A(\hat{U}_f^t)$
$\overline{\langle \hat{Z}(0)\hat{Z}(t)\rangle}$
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
0
20
40
60
80
100
t

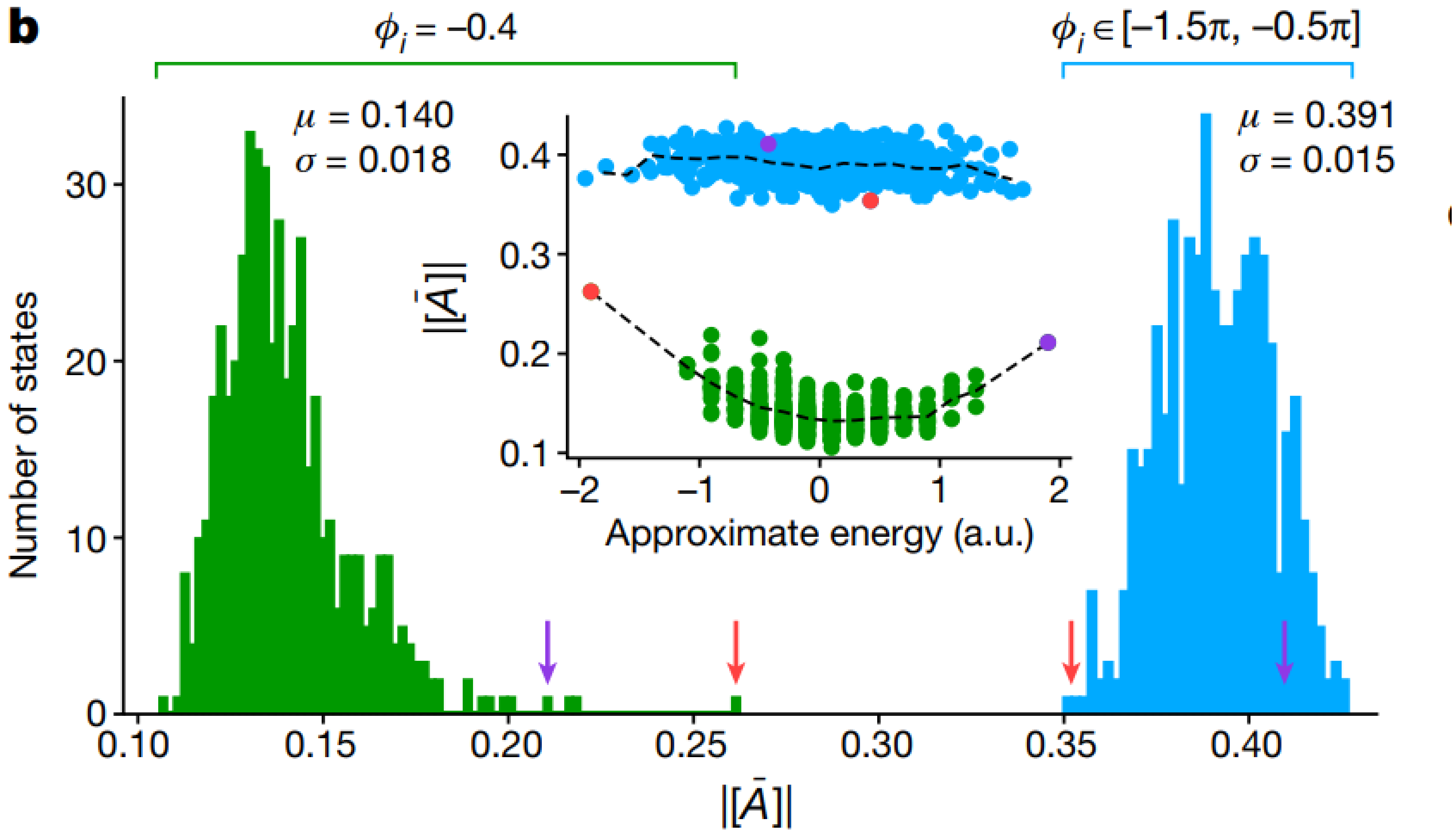

MBL-DTC g=0.97
$\overline{A/A_0}$
1.0
0.5
0.0
−0.5
−1.0
0
20
40
60
80
100
t

How does the choice of an initial state affect the end result?

$[\bar{A}]$ Position and disorder-averaged autocorrelator



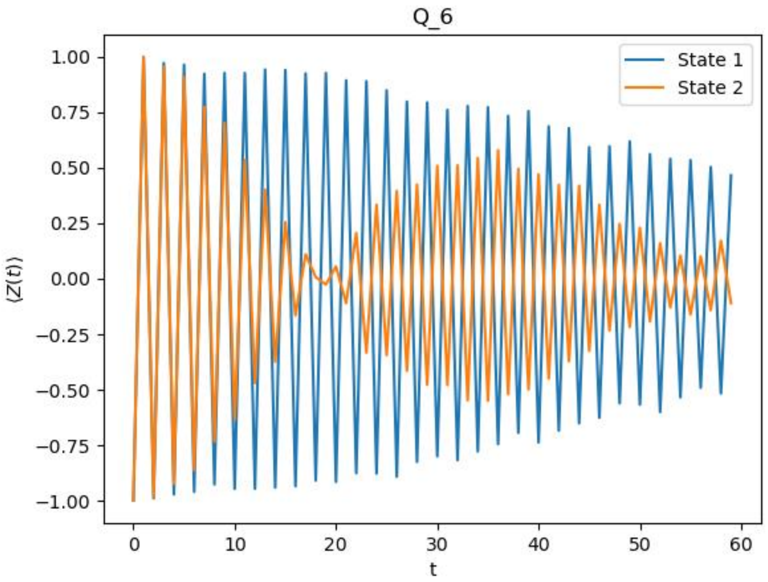


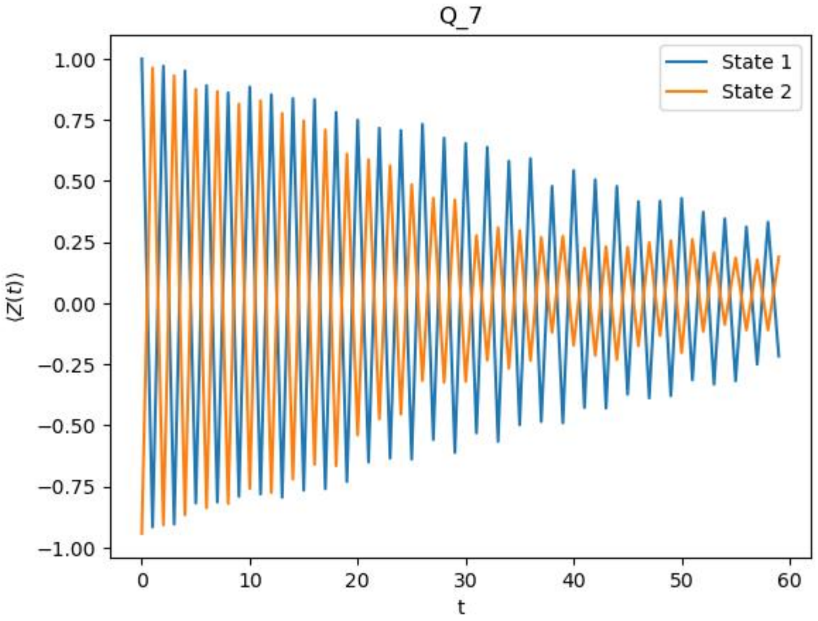

b
$\phi_i = -0.4$
$\phi_i \in [-1.5\pi, -0.5\pi]$
$\mu = 0.140$
$\sigma = 0.018$
$\mu = 0.391$
$\sigma = 0.015$
Number of states
$\|[\bar{A}]\|$
Approximate energy (a.u.)
$\|[\bar{A}]\|$

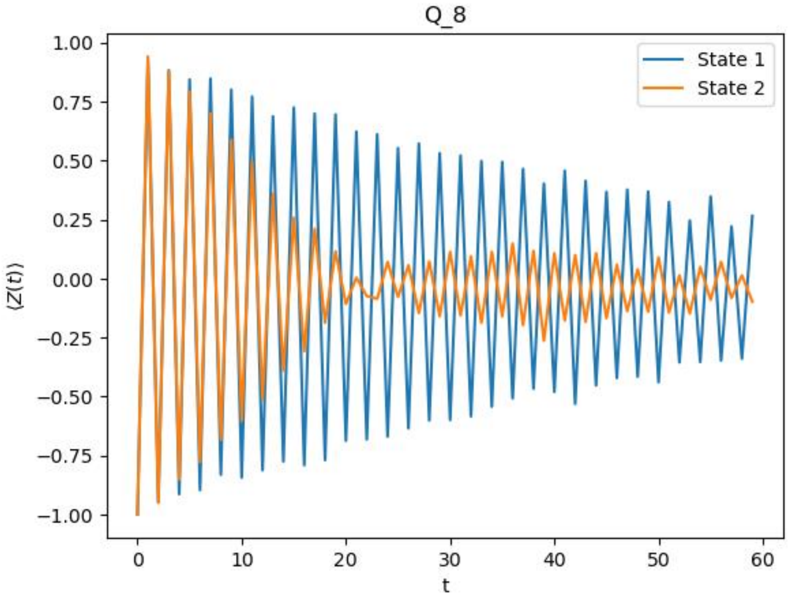
Initial state 1: 00000010000

Initial state 2: 00000000000

$$\phi_i = -0.4$$



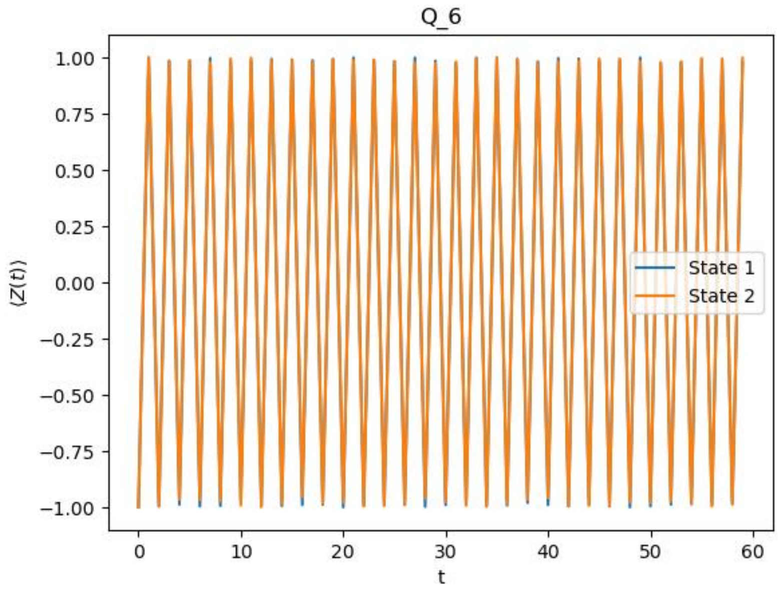


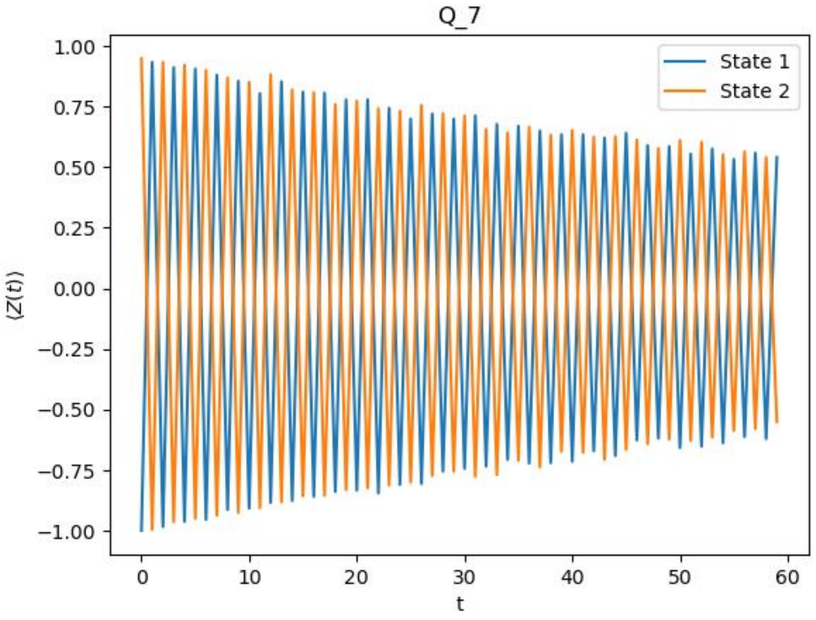


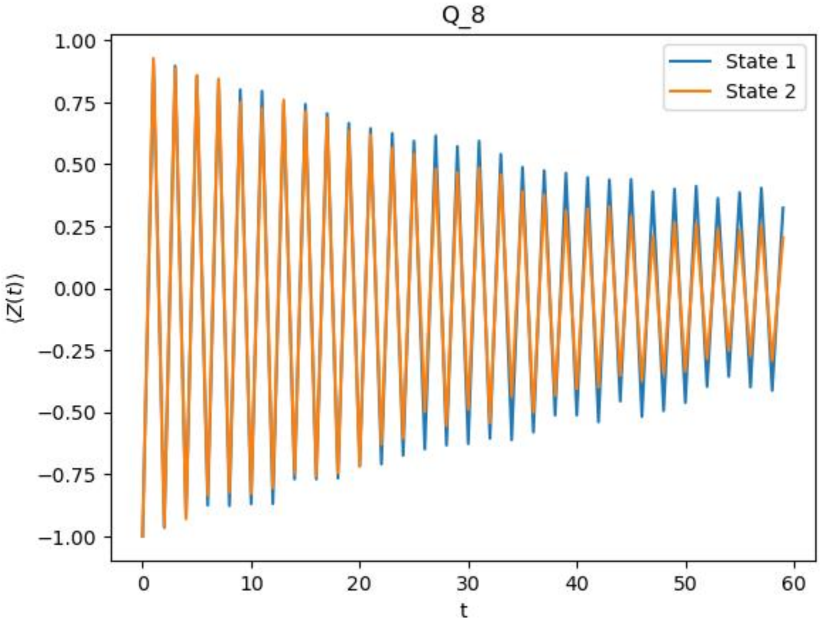
Initial state 1: 0000001000

Initial state 2: 00000000000

$\phi_i \in [-1.5\pi, -0.5\pi]$

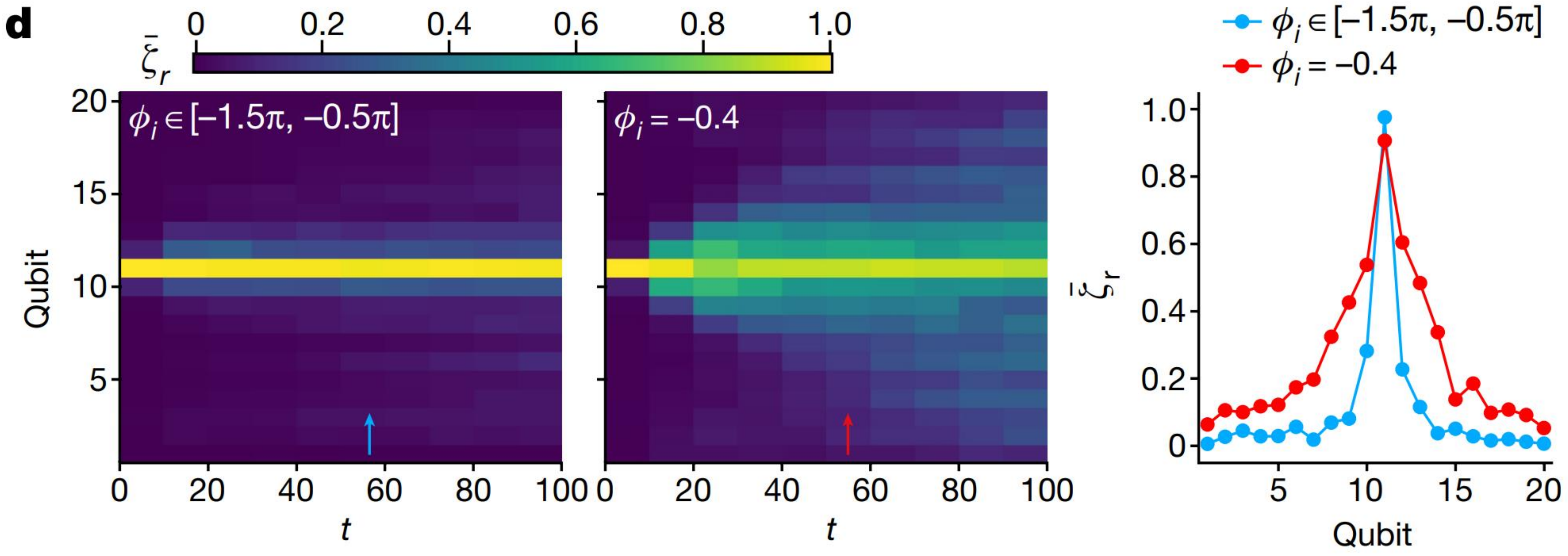


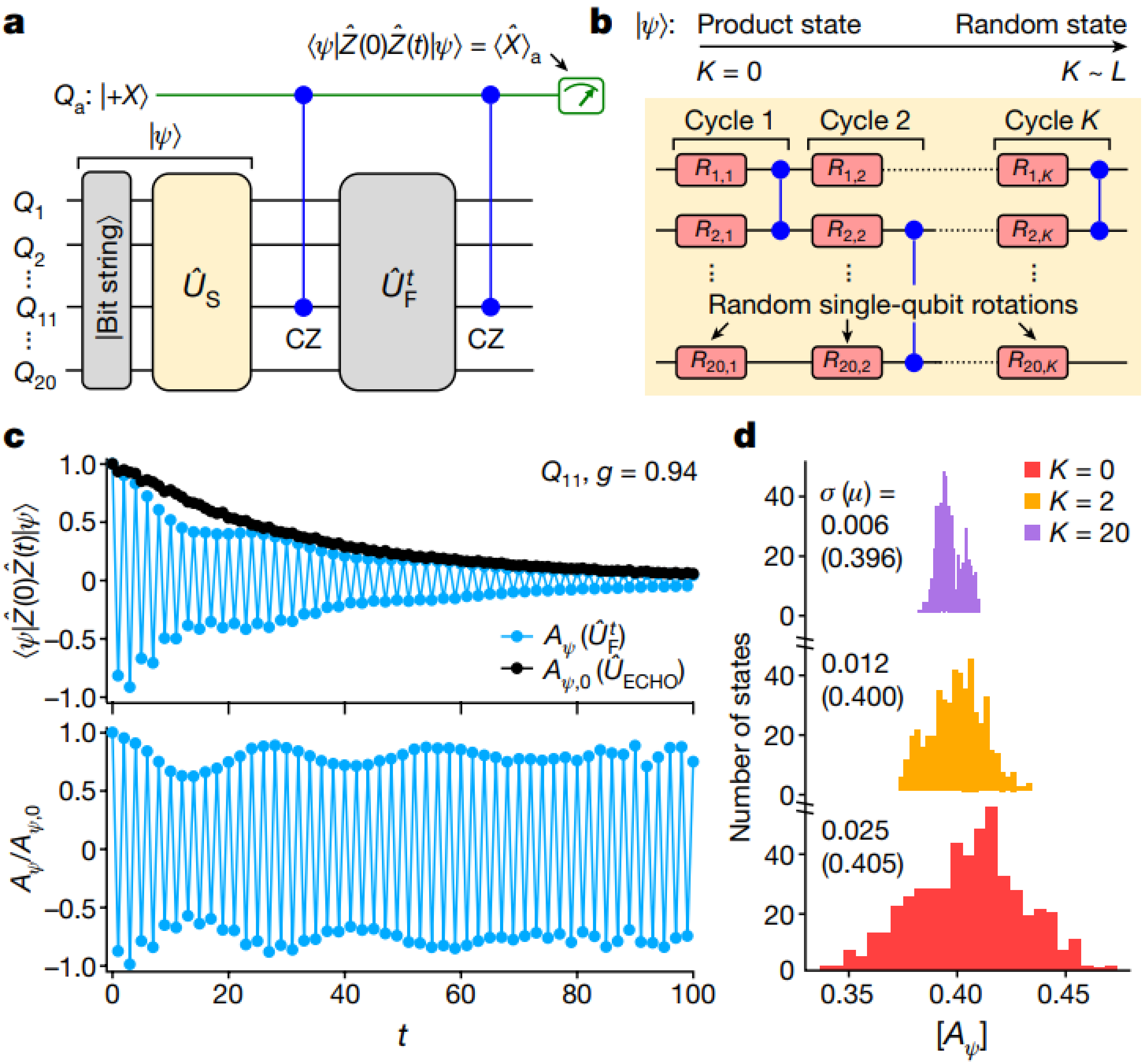




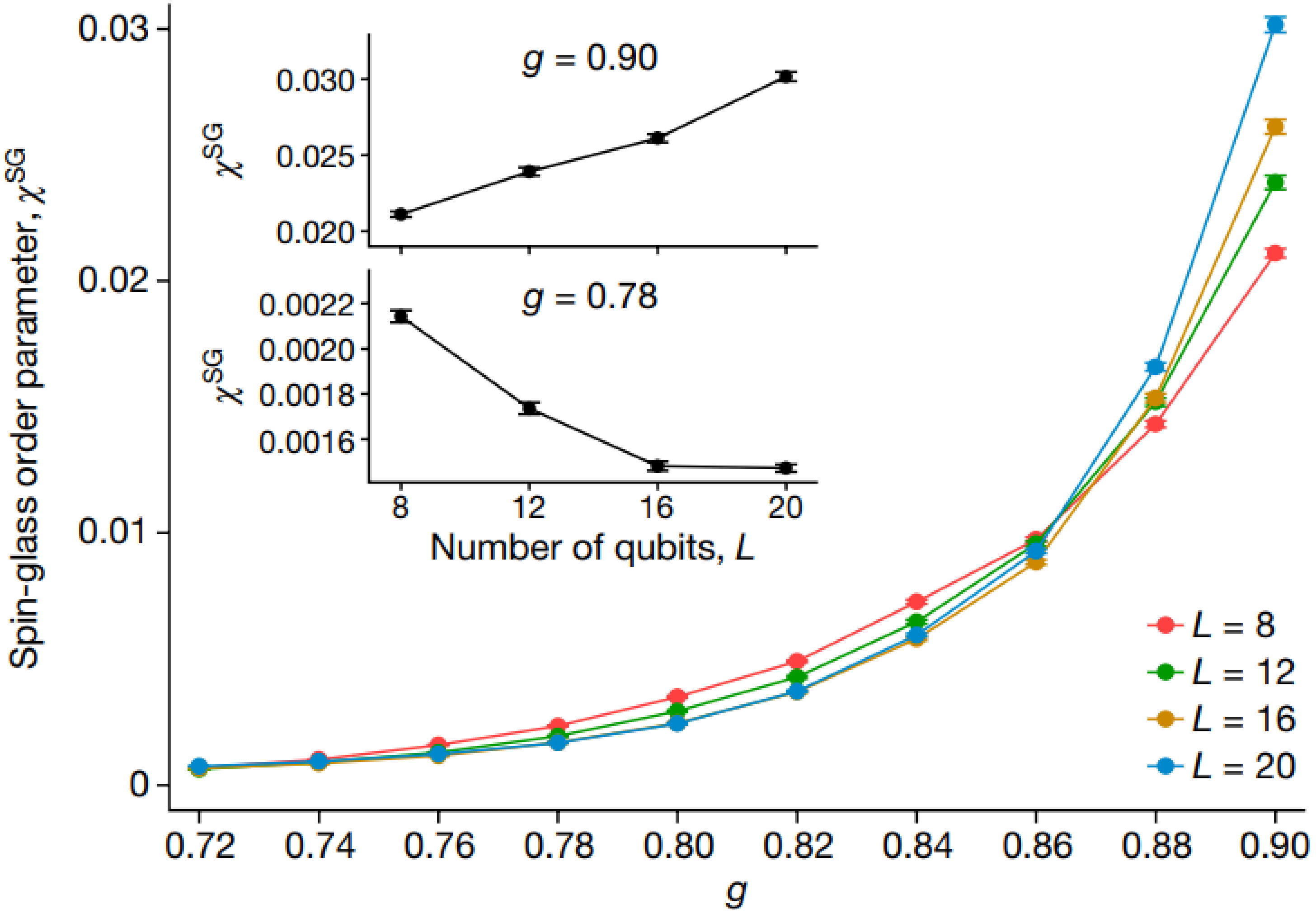
Relative difference between the two signals

$$\zeta_r = |\zeta_1 - \zeta_2| / (|\zeta_1| + |\zeta_2|)$$




a
⟨ψ|Ẑ(0)Ẑ(t)|ψ⟩ = ⟨X̂⟩a
Qa: |+X⟩
|ψ⟩
Q1
Q2
Q11
Q20
|Bit string⟩
ÛS
CZ
ÛF^t
CZ
b
|ψ⟩: Product state
Random state
K = 0
K ~ L
Cycle 1
Cycle 2
Cycle K
R1,1
R1,2
R1,K
R2,1
R2,2
R2,K
Random single-qubit rotations
R20,1
R20,2
R20,K
c
Q11, g = 0.94
⟨ψ|Ẑ(0)Ẑ(t)|ψ⟩
Aψ (ÛF^t)
Aψ,0 (ÛECHO)
Aψ/Aψ,0
1.0
0.5
0
−0.5
−1.0
0
20
40
60
80
100
t
d
σ (μ) =
0.006
(0.396)
0.012
(0.400)
0.025
(0.405)
K = 0
K = 2
K = 20
Number of states
40
20
0
0.35
0.40
0.45
[Aψ]

$$\chi^{SG} = \frac{1}{L-2} \sum_{i \neq j}' \langle \hat{Z}_i \hat{Z}_j \rangle^2$$



Conclusion:

1. The researchers have successfully showcased the ability to engineer and characterize non-equilibrium phases of matter using a quantum processor, presenting experimental evidence of an MBL-DTC.

2. The scalability inherent in their protocols establishes a framework for future investigations into non-equilibrium phases and phase transitions on intricate quantum systems that surpass classical simulability.

3. The streamlined verification of eigenstate order introduced in this study could serve as a broad strategy for determining the presence of specific properties, such as distinct phases, within a quantum processor.