Investigating Computational Phases of Matter on NISQ devices

QCGC Workshop 2023

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January 17, 2023

Motivation - NISQ and Grand Challenges

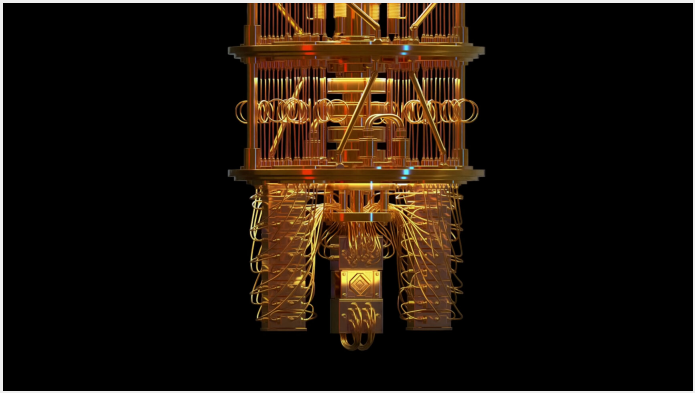

Image Credit: Quanta Magazine

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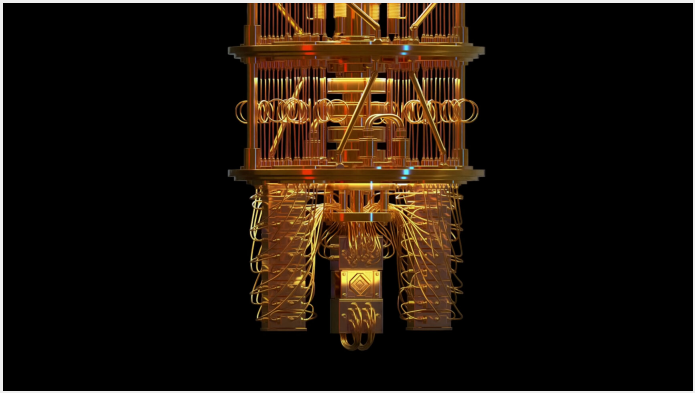

- NISQ era - Shor, large-scale quantum simulation etc. inaccessible.

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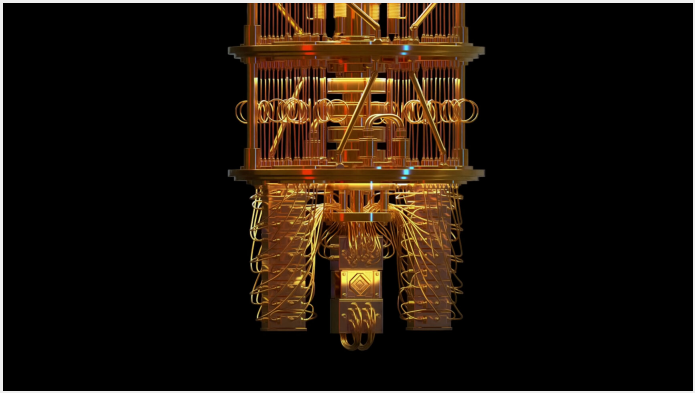

- NISQ era - Shor, large-scale quantum simulation etc. inaccessible.
- What are applications of such devices?

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Motivation - NISQ and Computational Phases of Matter

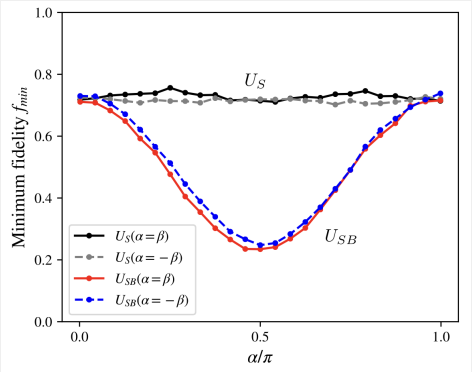

Image Credit: Azses et al.

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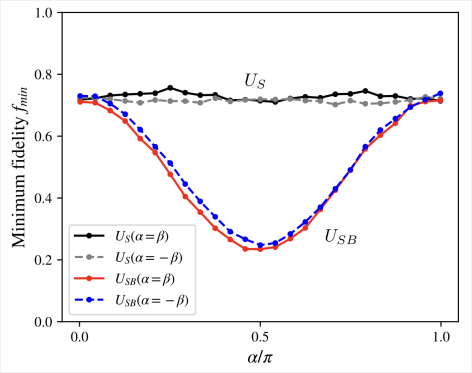

- 2020 - *Identification of Symmetry-Protected Topological States on Noisy Quantum Computers* by Azses et al.

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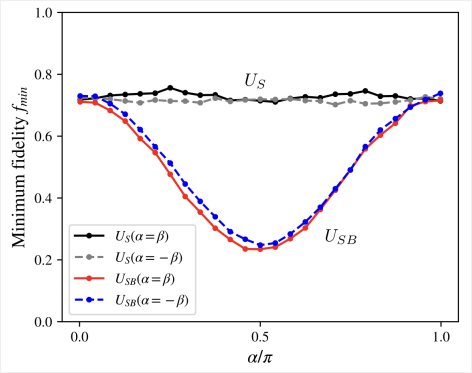

- 2020 - *Identification of Symmetry-Protected Topological States on Noisy Quantum Computers* by Azses et al.
- 2023 - Better understanding of computational phases of matter in finite settings
  - String order parameters
  - Efficient regimes of computation

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States of Interest - The Cluster SPT Phase

Universal Resource: Cluster State $|C\rangle$

Ground state of
$H_{\text{cluster}} = -\sum_i Z_{i-1} X_i Z_{i+1}$

Useless Resource: Product State $|+\rangle^{\otimes N}$

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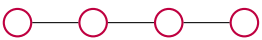

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$$H(\alpha) = -\cos(\alpha)\sum_i Z_{i-1}X_iZ_{i+1} - \sin(\alpha)\sum_i X_i$$

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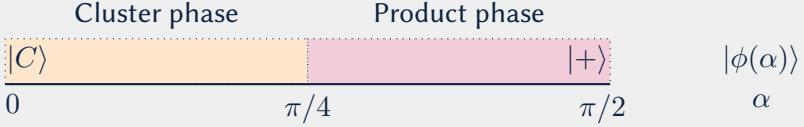
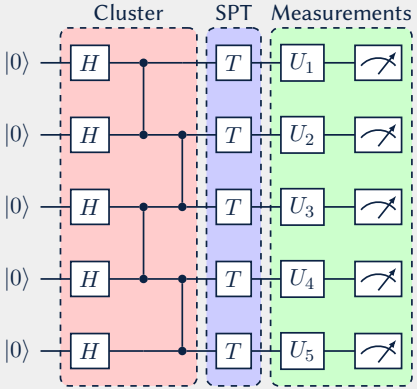


Experiments - Simulating MBQC on IBM Devices



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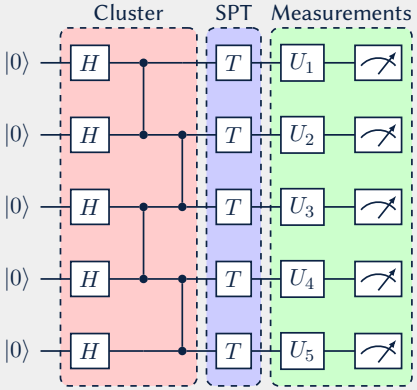

1. Prepare ground states of interest.

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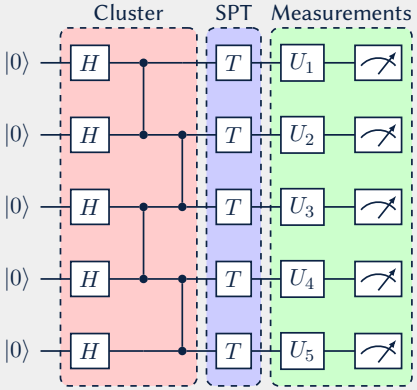

1. Prepare ground states of interest.
2. Measure…

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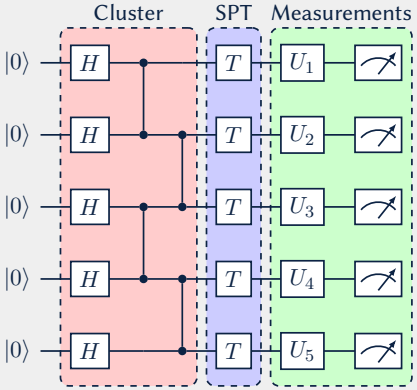

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   - String order parameter & Computational order parameter

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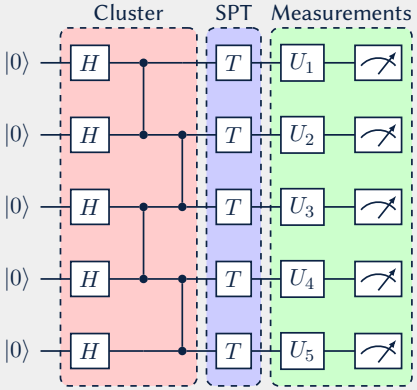

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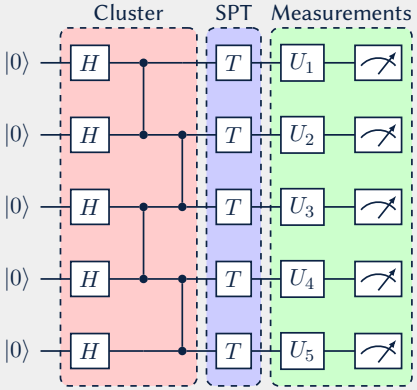
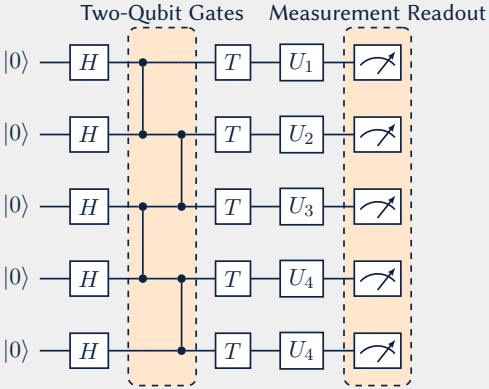
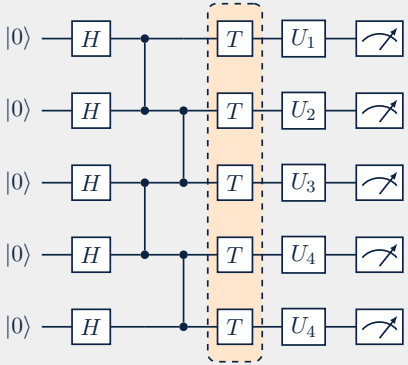


1. Prepare ground states of interest.
2. Measure…
   - String order parameter & Computational order parameter
   - Effect of splitting rotations on logical decoherence
   - Effect of splitting rotations as much as possible on logical decoherence

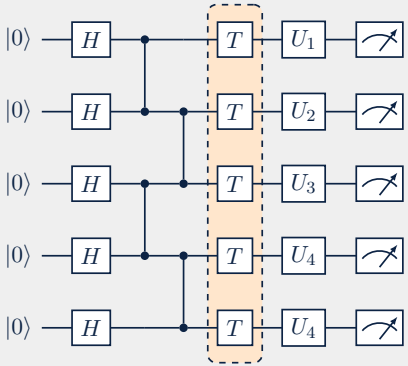
Techniques - Error Mitigation



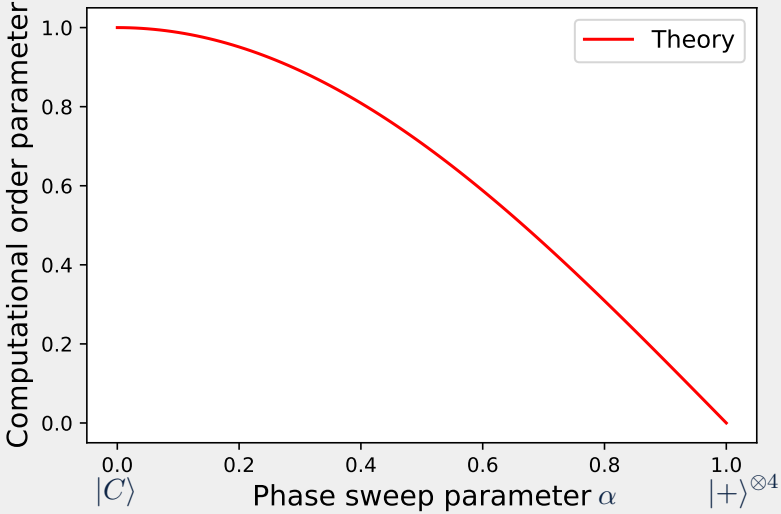
- Zero noise extrapolation to mitigate two-qubit gate errors
- Measurement noise matrix estimation to mitigate readout errors

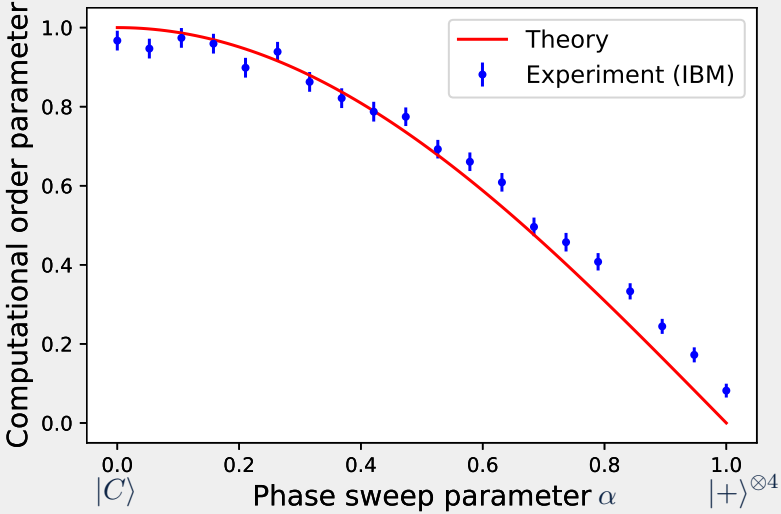

$|0\rangle$
H
T
U_1
U_2
U_3
U_4
U_4

Techniques - Variational State Preparation



- Determine T via variational energy minimization to get desired ground state of $H(\alpha)$:
  1. Prepare local ansatz (from perturbation theory) $|T(\theta)\rangle = \bigotimes_{i=2}^{N-1}(\cos\theta I_i + \sin(\theta)X_i)\,|C\rangle$
  2. Find θ which minimizes $E(\theta) = \langle T(\theta)|\,H(\alpha)\,|T(\theta)\rangle$.
- Remark: T is non-unitary; can be handled via post-processing, or by invoking symmetries to remove probabilistic implementation.


Computational order parameter
1.0
0.8
0.6
0.4
0.2
0.0
Theory
0.0
0.2
0.4
0.6
0.8
1.0
$|C\rangle$
Phase sweep parameter α
$|+\rangle^{\otimes 4}$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