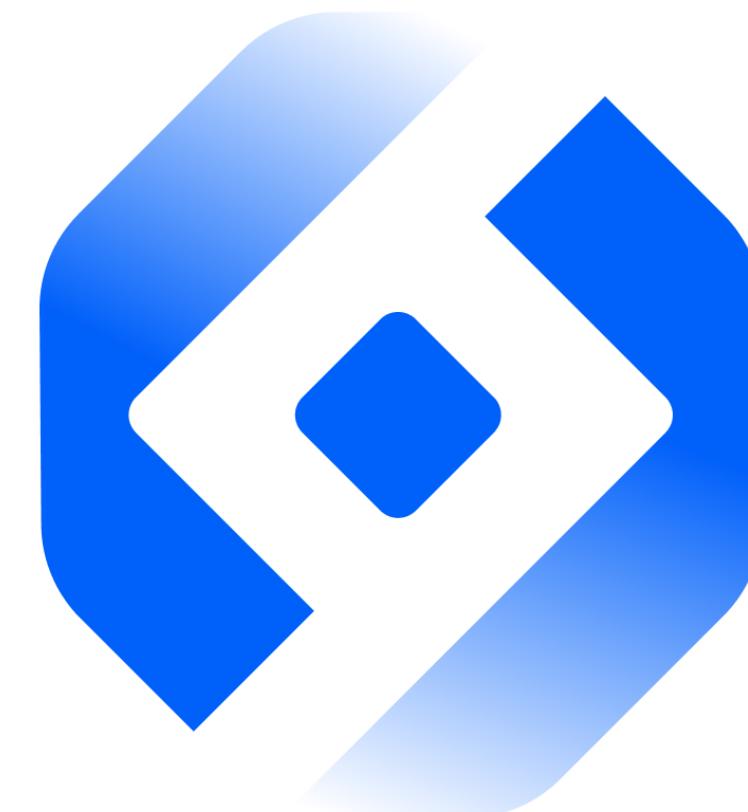


# Peaked Quantum Circuits

**Nick Sherman**

Research Scientist

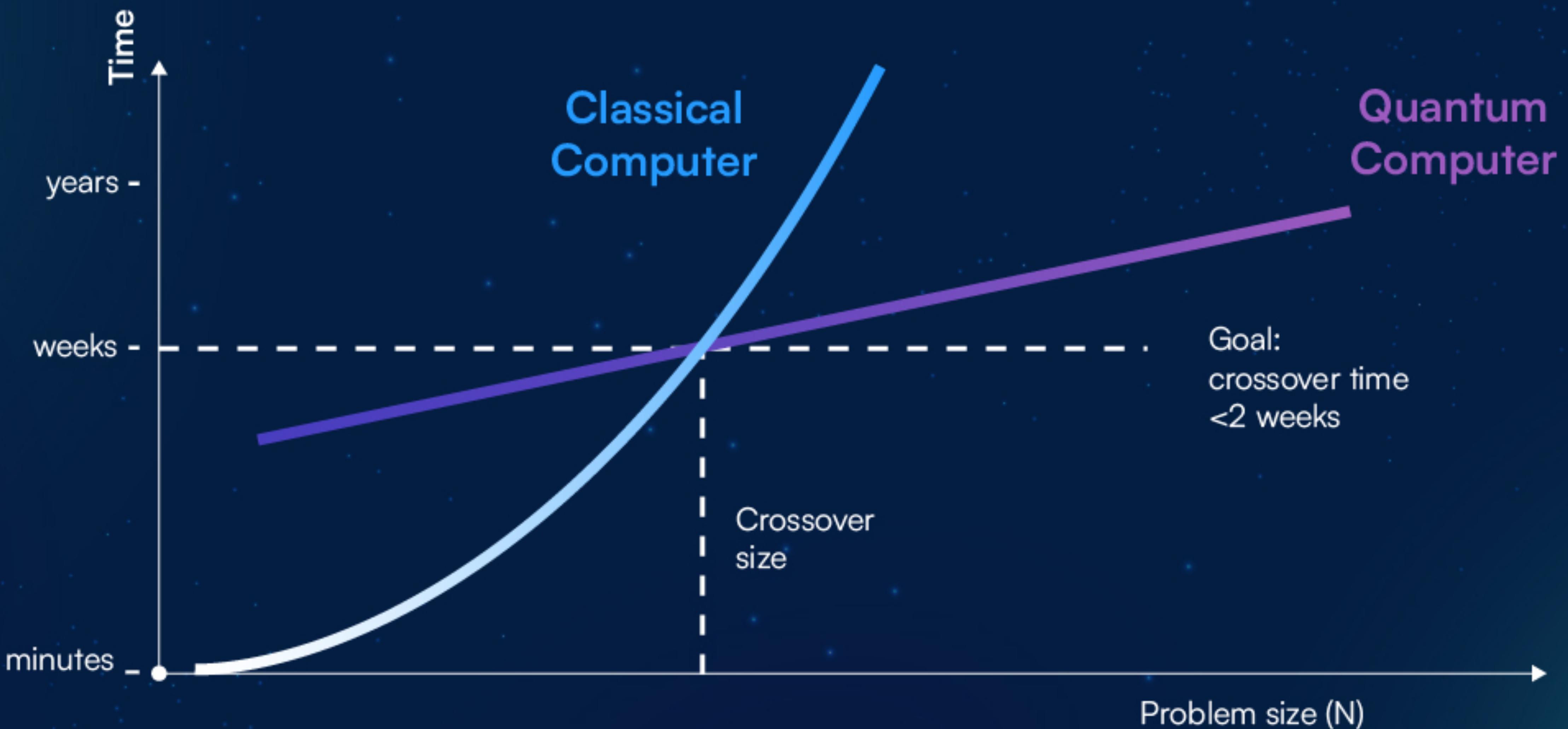


**BlueQubit**

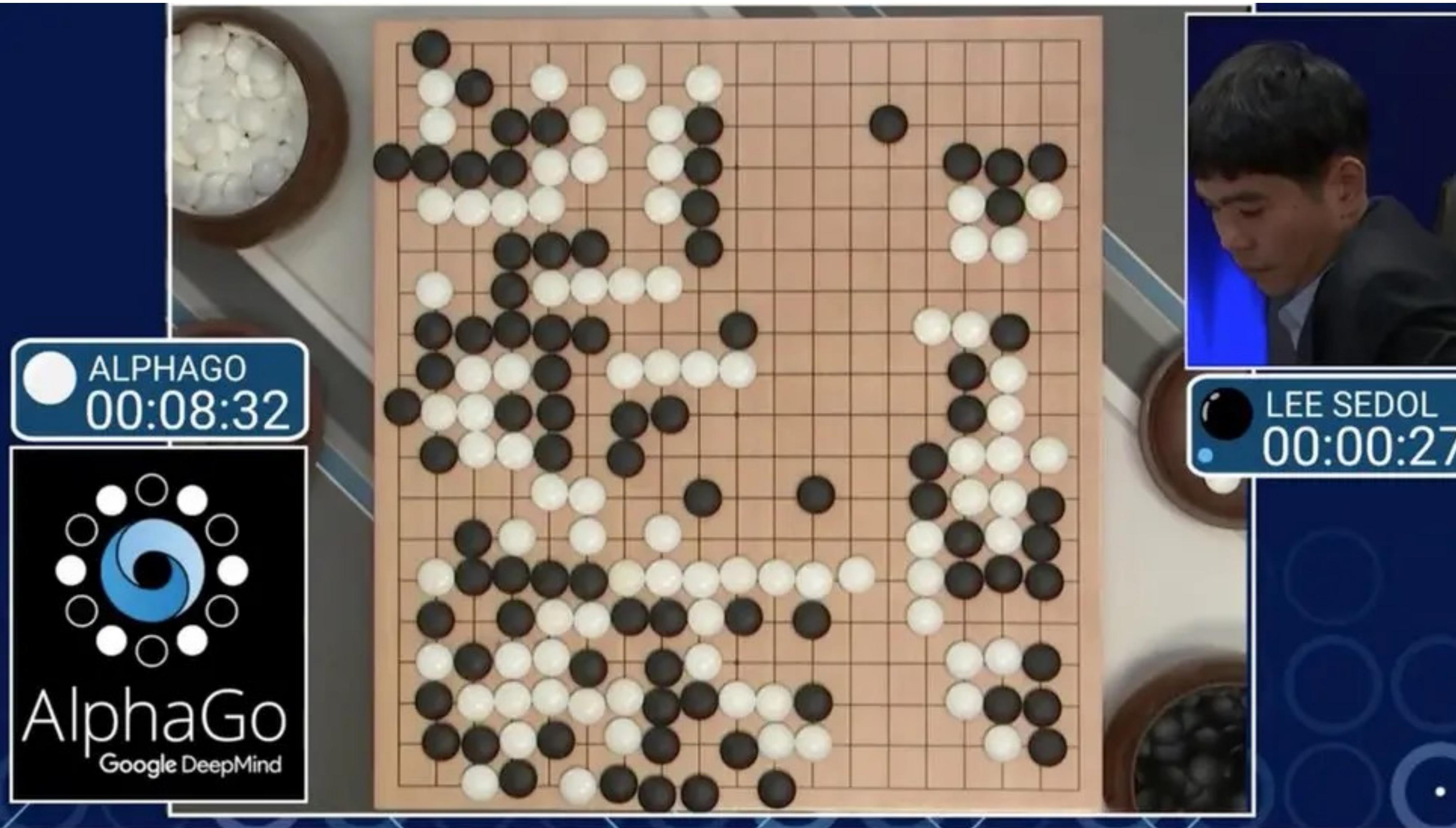
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# Achieving Practical Quantum Advantage



# AI Advantage



“Superhuman performance”

2016

# Random Quantum Circuits

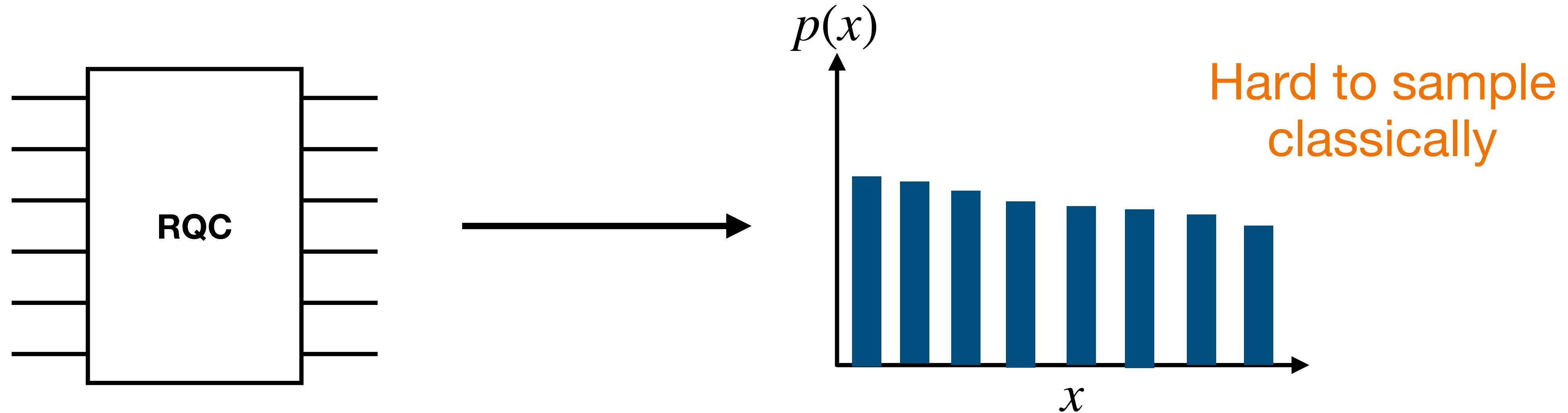
Article | Published: 29 October 2018

## On the complexity and verification of quantum random circuit sampling

[Adam Bouland](#), [Bill Fefferman](#) , [Chinmay Nirkhe](#) & [Umesh Vazirani](#)

[Nature Physics](#) **15**, 159–163 (2019) | [Cite this article](#)

9060 Accesses | 183 Citations | 128 Altmetric | [Metrics](#)



# Quantum Supremacy Experiment

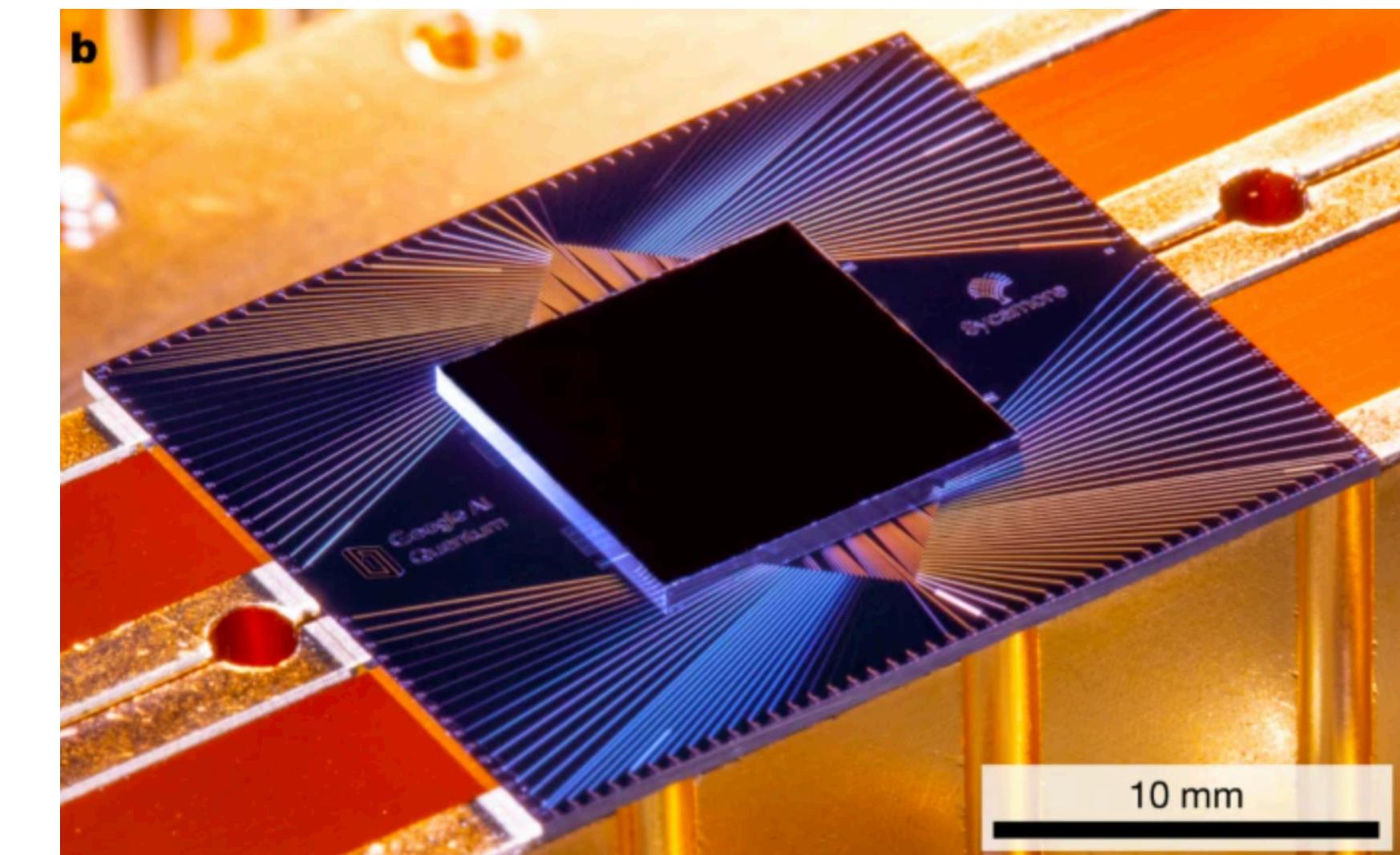
Article | Published: 23 October 2019

## Quantum supremacy using a programmable superconducting processor

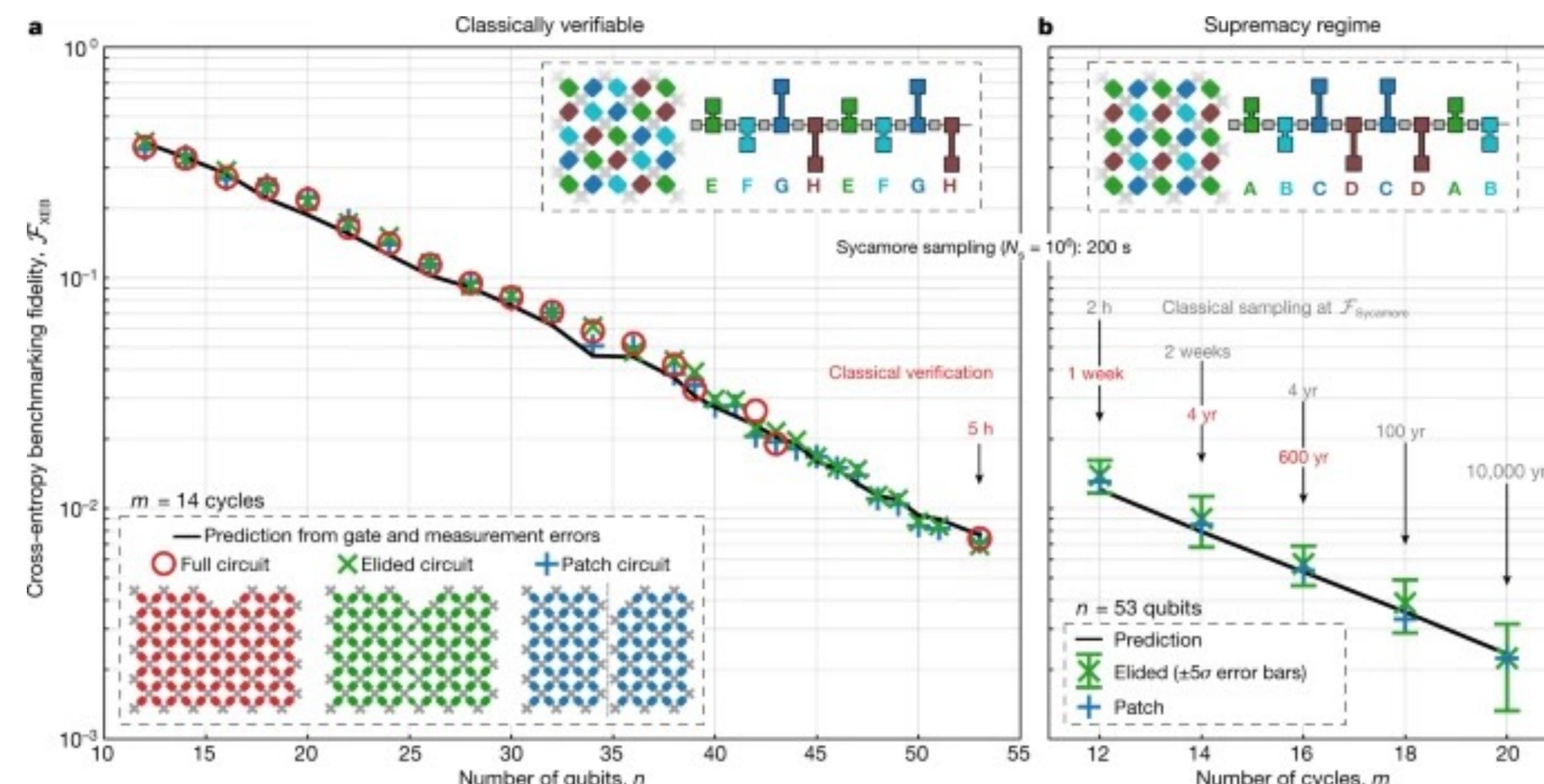
Frank Arute, Kunal Arya, Ryan Babbush, Dave Bacon, Joseph C. Bardin, Rami Barends, Rupak Biswas, Sergio Boixo, Fernando G. S. L. Brandao, David A. Buell, Brian Burkett, Yu Chen, Zijun Chen, Ben Chiaro, Roberto Collins, William Courtney, Andrew Dunsworth, Edward Farhi, Brooks Foxen, Austin Fowler, Craig Gidney, Marissa Giustina, Rob Graff, Keith Guerin, ... John M. Martinis  + Show authors

Nature 574, 505–510 (2019) | [Cite this article](#)

1.16m Accesses | 5097 Citations | 6727 Altmetric | [Metrics](#)



**Time:**  
Quantum: 3 minutes  
Classical: 10,000 years



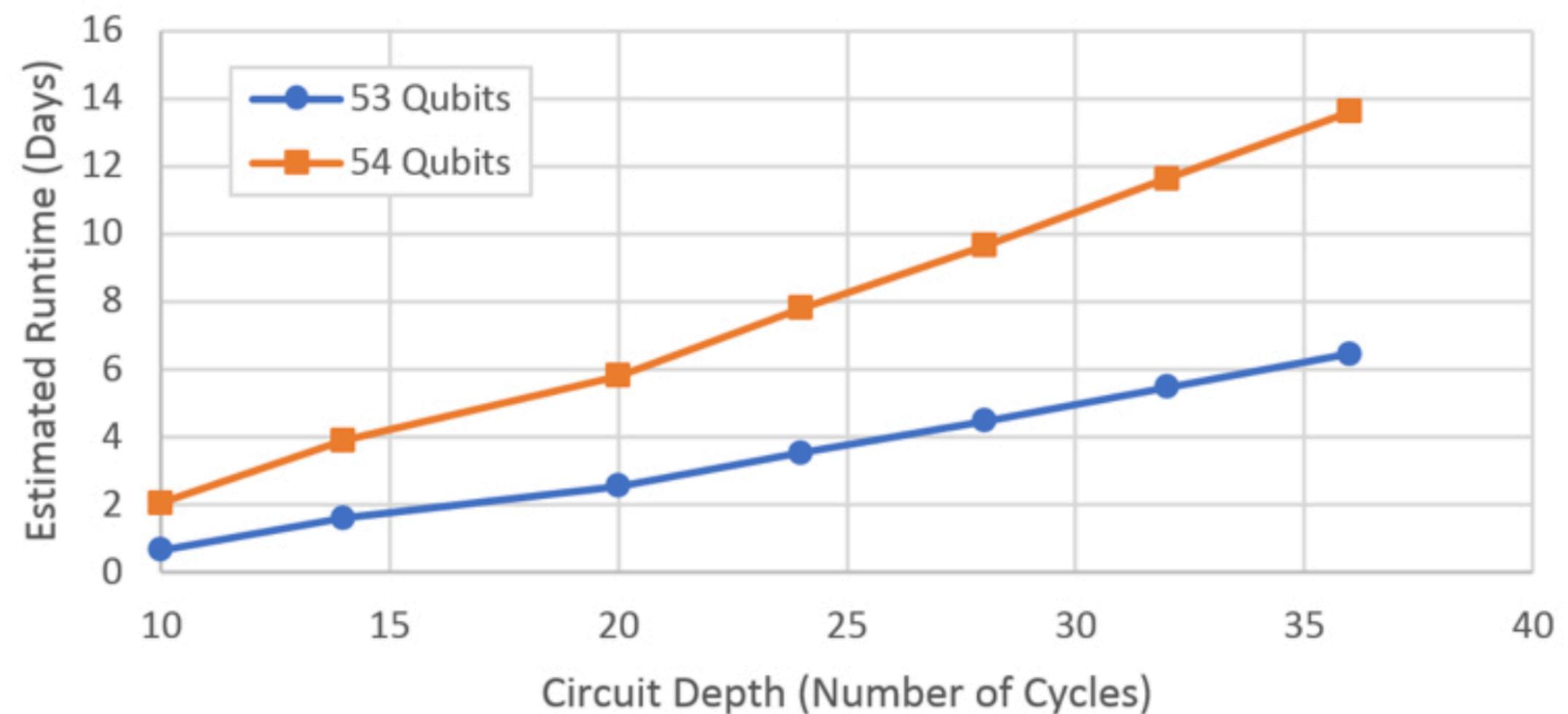
$$F_{XEB} = 2^N \langle P(x_i) \rangle_i - 1$$

$$F_{XEB} = \begin{cases} 0 & \text{Uniform} \\ 1 & \text{Haar} \end{cases}$$

# Quantum Supremacy Skepticism

**IBM**

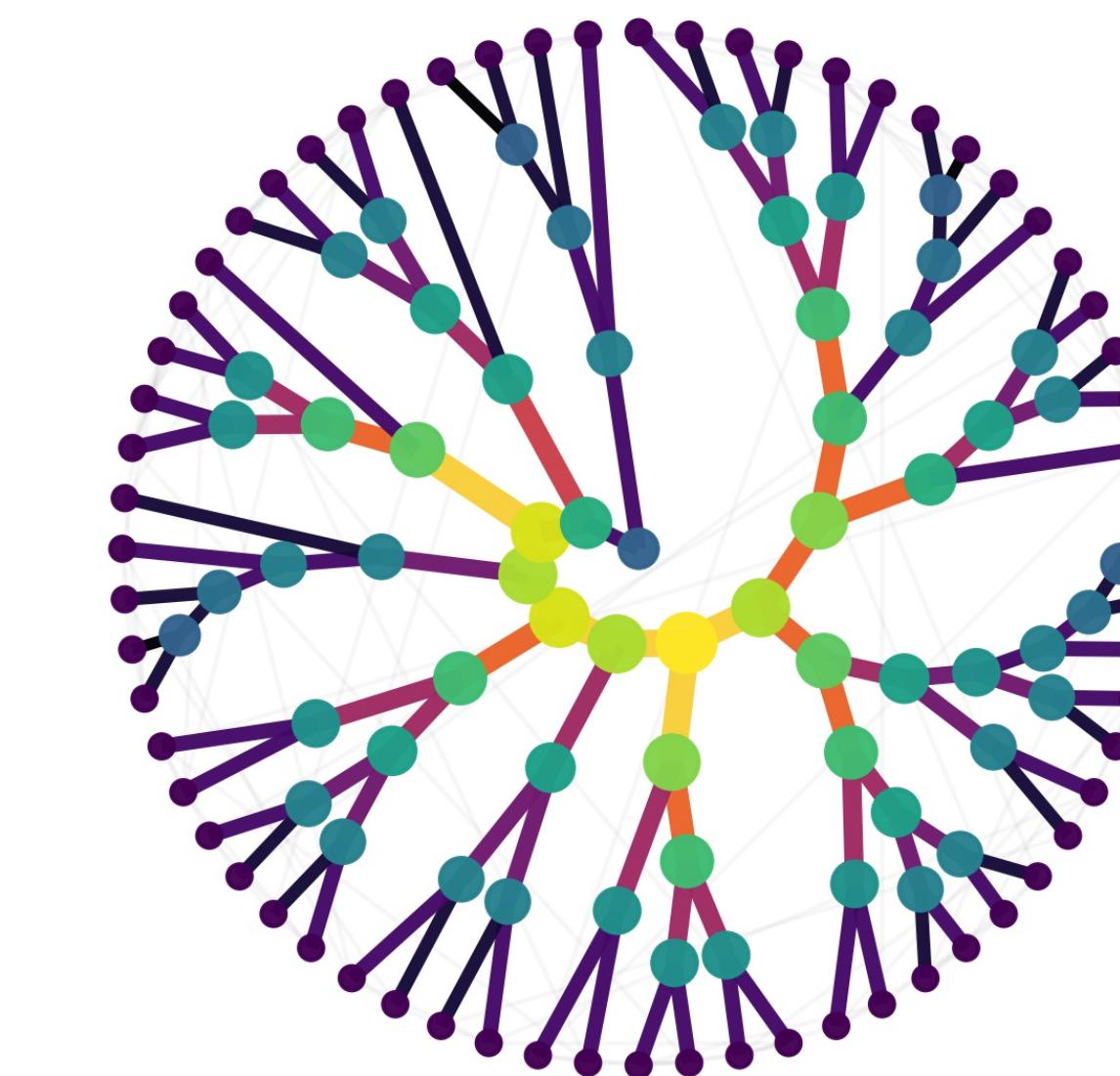
53- and 54-Qubit Sycamore Circuits with Single Precision Storage to Disk (8 bytes per amplitude)



Estimated runtime: 2.5 days

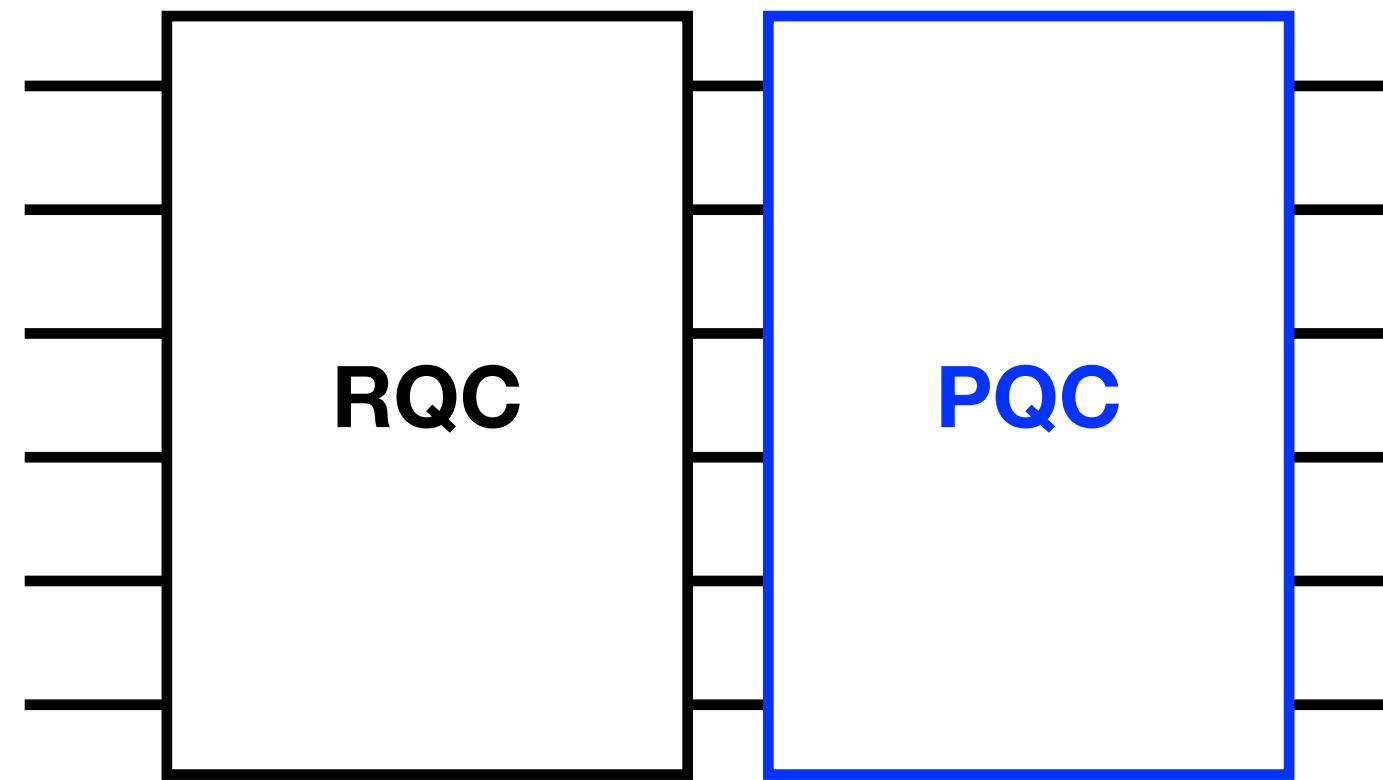
Hyper-optimized tensor network contraction

Johnnie Gray & Stefanos Kourtis (2021)

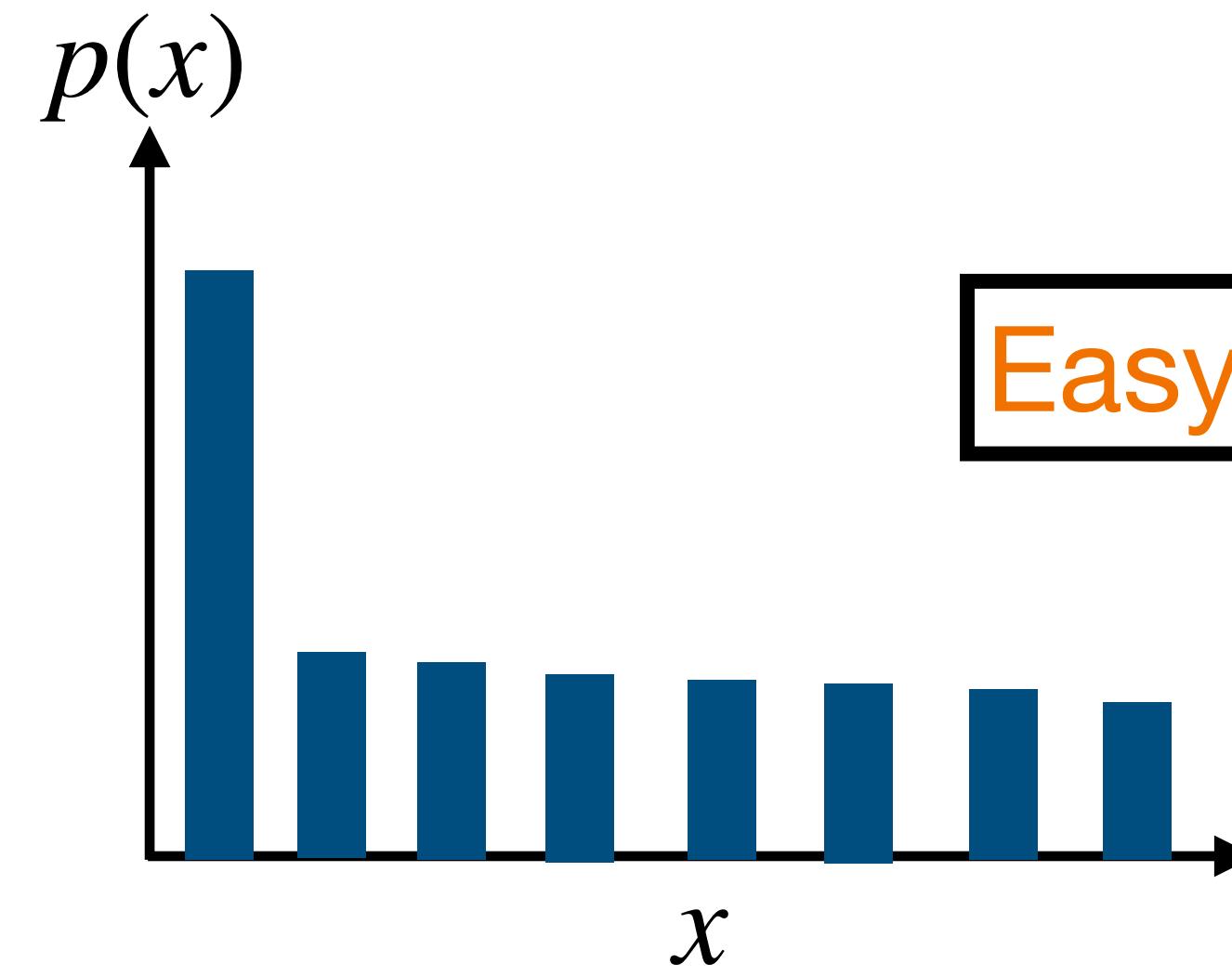
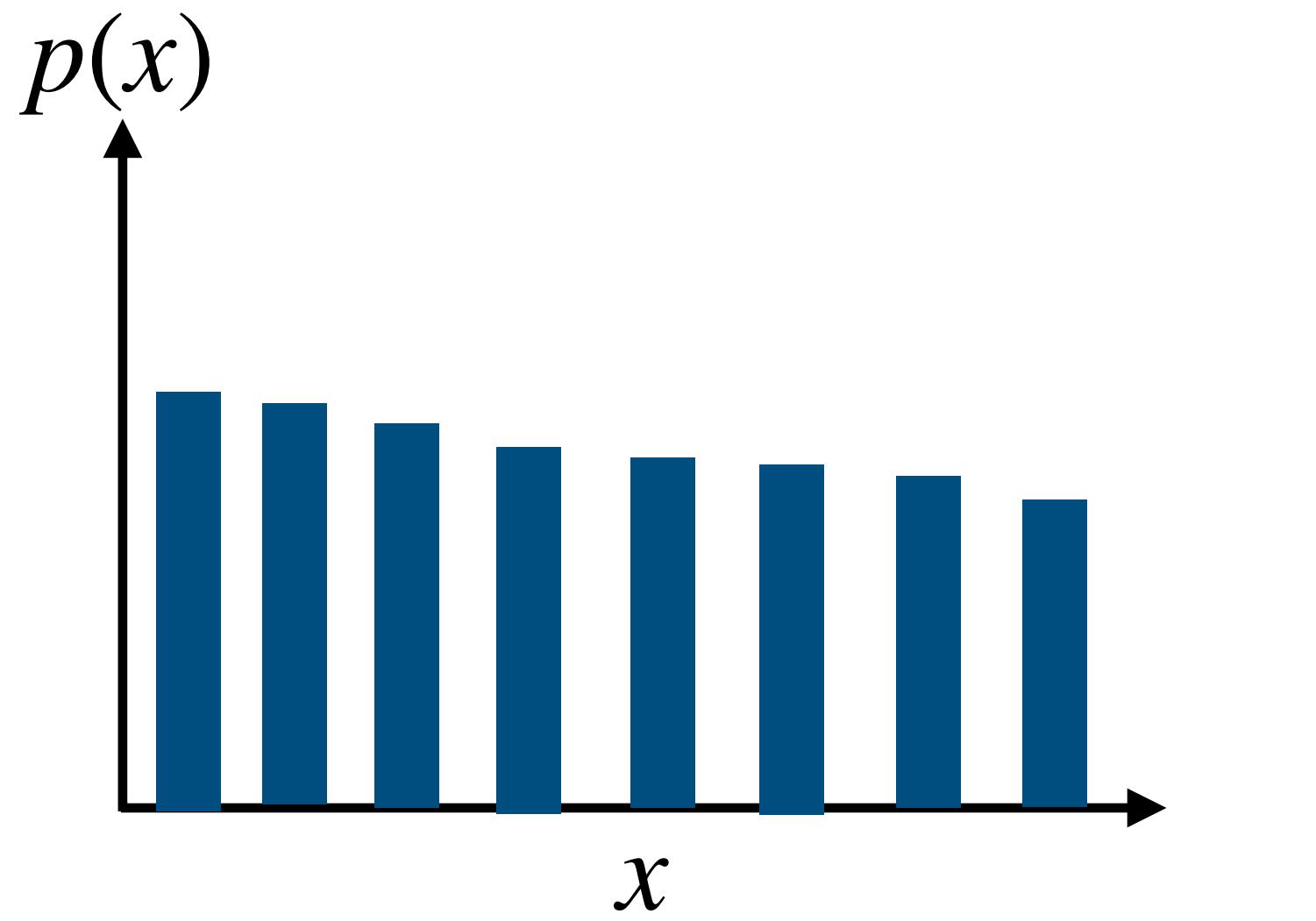


Over 10,000x speedup

# Peaked Quantum Circuits



$$\mathcal{L}(\theta) = - |\langle \mathbf{S} | U_p(\theta) U_R | \mathbf{0} \rangle|^2$$



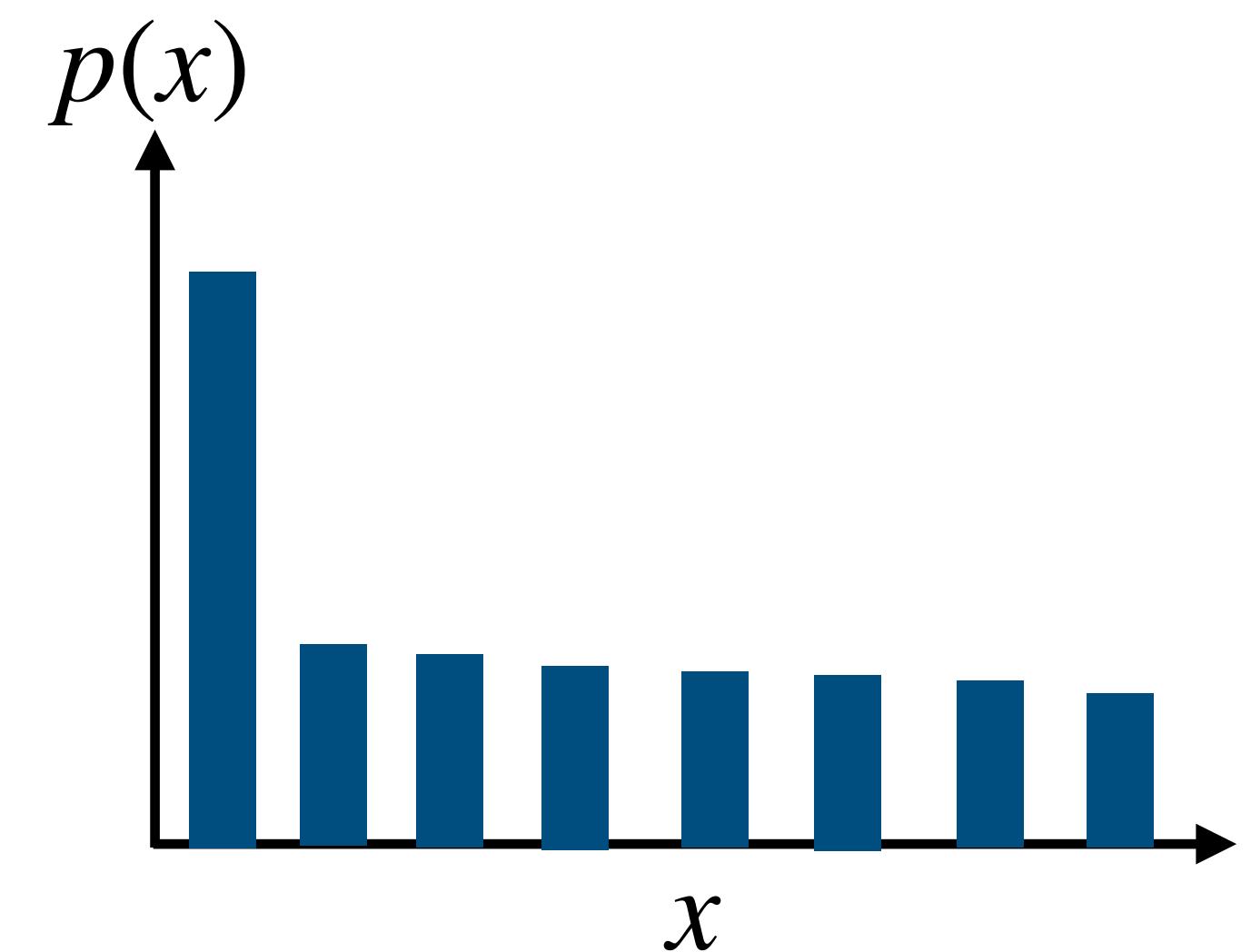
On verifiable quantum advantage with peaked circuit sampling

Scott Aaronson & Yuxuan Zhang (2024)

# Blue Qubit Approach



Hard to train PQC  
For large N.



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# Statevector Simulations

2 qubits:

$$|\psi\rangle = c_{00}|00\rangle + c_{01}|01\rangle + c_{10}|10\rangle + c_{11}|11\rangle$$

N qubits:

$$|\psi\rangle = \sum_{s_0 \dots s_N} C_{s_0 \dots s_N} |s_0 \dots s_N\rangle$$

$$\begin{pmatrix} c_0 \\ c_1 \\ \vdots \\ c_d \end{pmatrix}$$

↑  
 $2^N$  ← Exponential scaling

Gates:

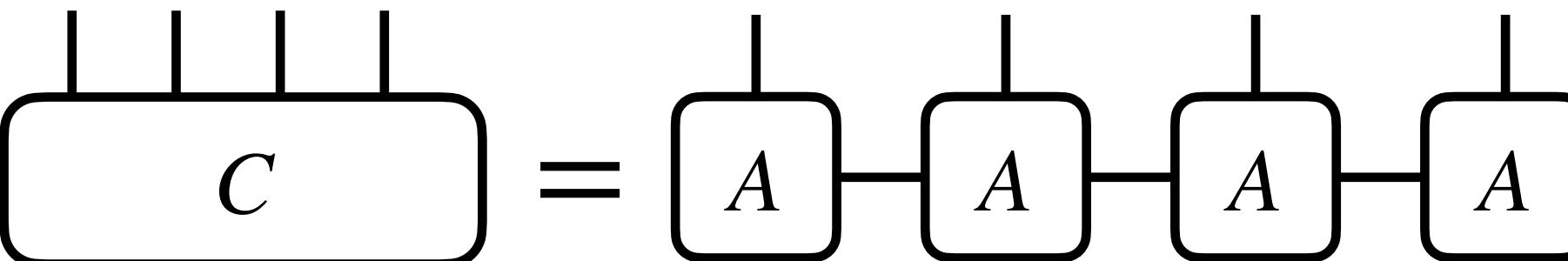
Matrix multiply  
↓  
 $U_G |\psi\rangle$

```
bq = bluequbit.init("<token>")  
bq.run(qc)
```

# Matrix Product State (MPS)

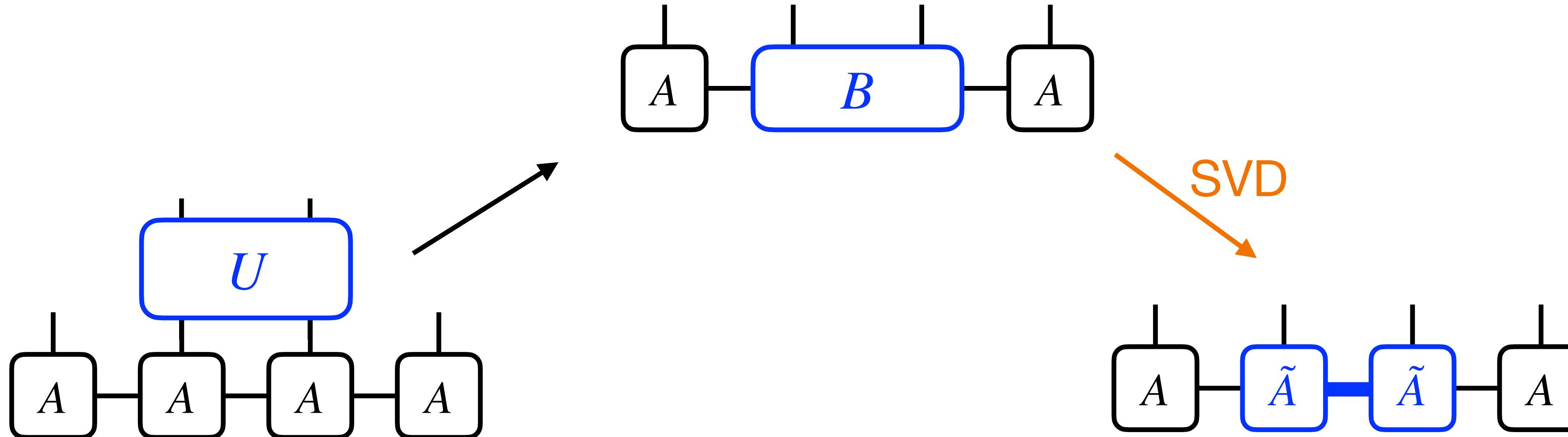
State:

$$|\psi\rangle = \sum_{s_0 \dots s_N} C_{s_0 \dots s_N} |s_0 \dots s_N\rangle$$

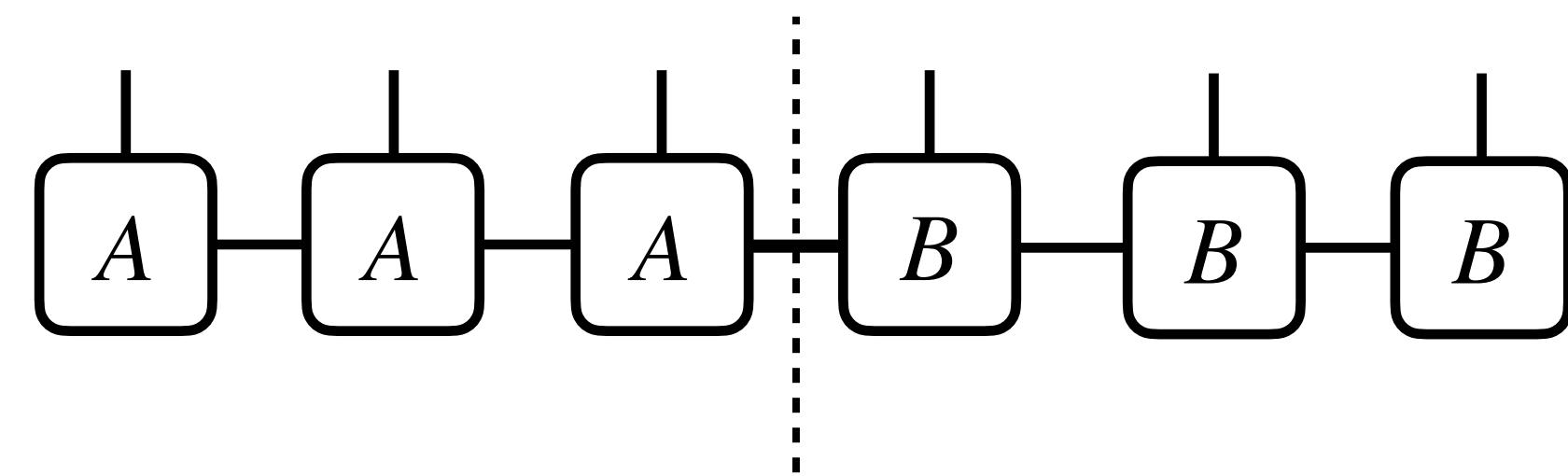
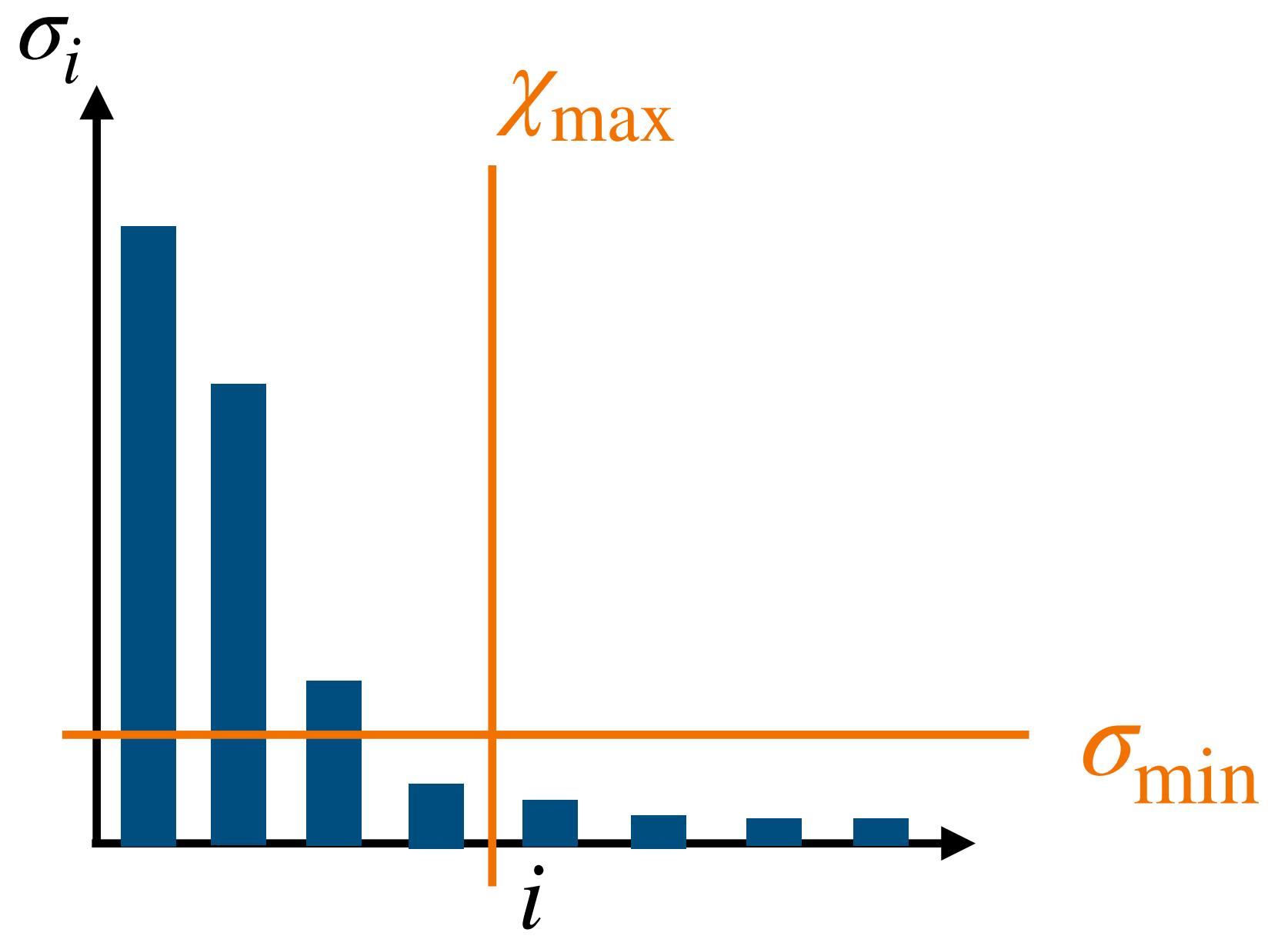


$$C_{s_0 \dots s_N} = A^{(s_0)} A^{(s_1)} \dots A^{(s_N)}$$

Gates:



# Matrix Product State (MPS)



$$\begin{aligned} S_{\text{VN}} &= - \text{Tr} \rho_A \log(\rho_A) \\ &= - \sum_n \sigma_n^2 \log(\sigma_n^2) \end{aligned}$$

Excels with  
low entangled states

```
bq = bluequbit.init("<token>")
options={
    'mps_bond_dimension': 32,
    'mps_truncation_threshold': 1e-16,
}
bq.run(qc, device='mps.cpu', options=options)
```

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