北京大学前沿计算研究中心
Center on Frontiers of Computing Studies, Peking University

Quantum computing and quantum advantage

Xiao Yuan

2025

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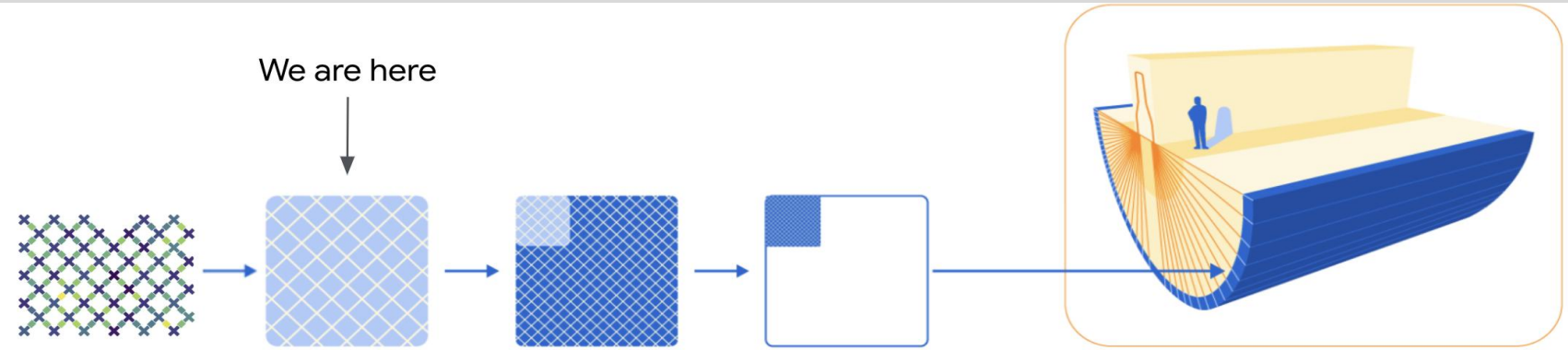
Background: quantum computing



54 — Beyond classical ✔ — **M1** (2019)

10^2 — Logical qubit prototype ✔ — **M2** (2023)

10^3 — 1 long-lived logical qubit — **M3** (2025+)

10^4 — Tileable module (logical gate) — **M4**

10^5 — Engineering scale up — **M5**

10^6 — Error-corrected quantum computer — **M6**

physical qubits

2017 — 2019 — 2020 — 2023 — 2024 — 2030

Google Supremacy
No practical applications

nature

Article | Published: 23 October 2019

Quantum supremacy using a programmable superconducting processor

51 qubit cluster states
MBVQE experiment

nature

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Article | Published: 12 July 2023

Generation of genuine entanglement up to 51 superconducting qubits

48 logical qubits using
280 physical qubits

nature

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Article | Open access | Published: 06 December 2023

Logical quantum processor based on reconfigurable atom arrays

Google realized break-even
for quantum memory

nature

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nature › articles › article

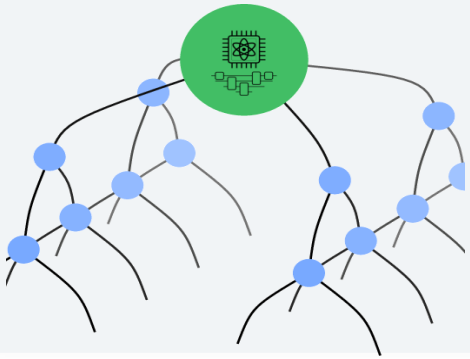
Article | Published: 09 December 2024

Quantum error correction below the surface code threshold

Quantum computing: theory, applications, and experiments

- Open quantum system simulation and non-Hermitian physics
- Framework of variational quantum algorithms
- Classical-quantum computational methods

Quantum Algorithms

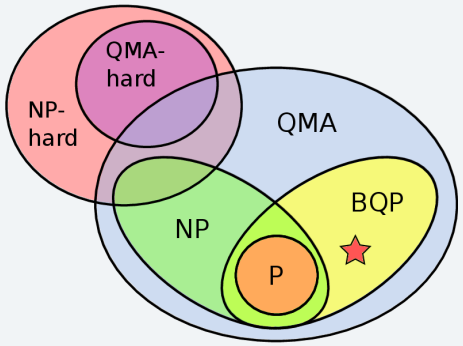


Quantum applications

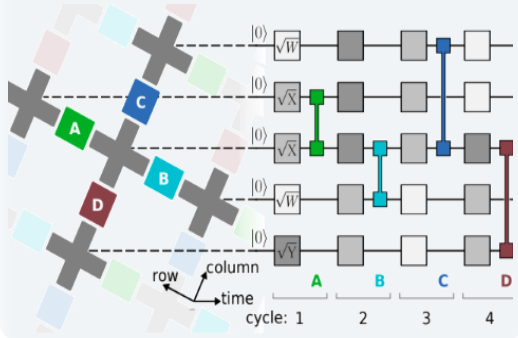
- Quantum computational chemistry: electronic structures
- Molecular docking
- Non-adiabatic dynamics simulation

- Classical simulation of shallow circuits
- Classical dequantization of quantum algorithms

Quantum Advantages



Quantum experiments



- 12-qubit electronic structure experiments
- 53-qubit cluster states and MBVQE
- 95-qubit cluster states and MBQC

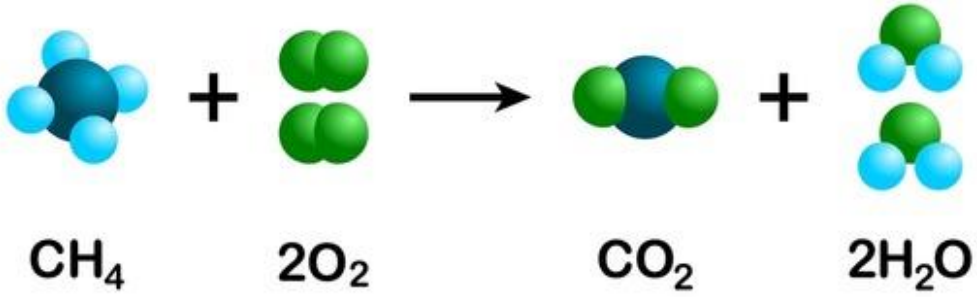
Quantum algorithm design

Quantum dynamics and eigenvalue problems

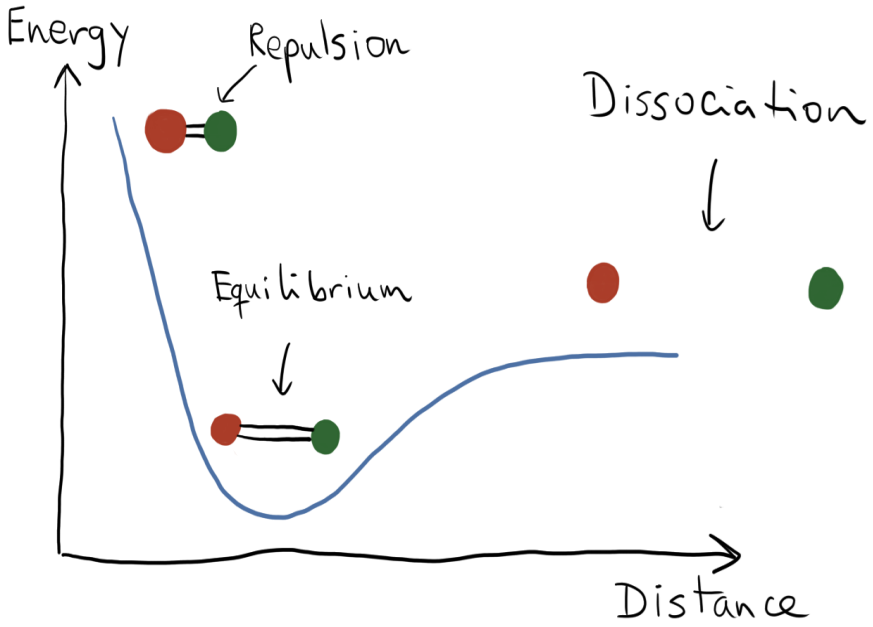
Quantum dynamics

'if you want to make a simulation of Nature, you' d better make it quantum mechanical.'

--- Richard Feynman (1982)



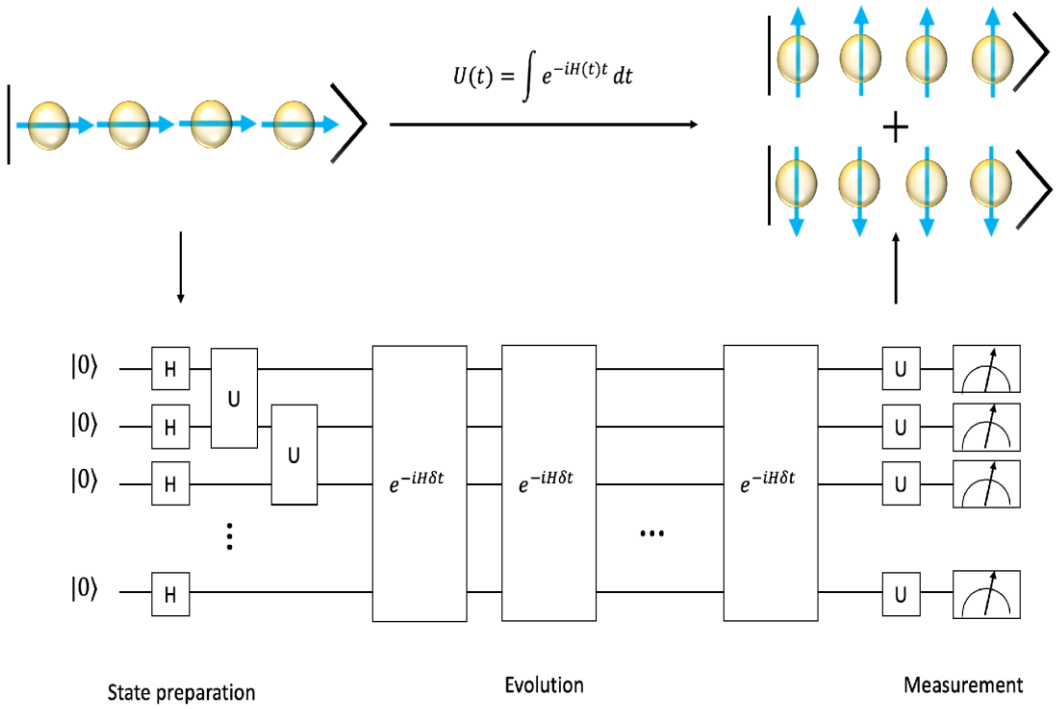
Eigenvalue problems

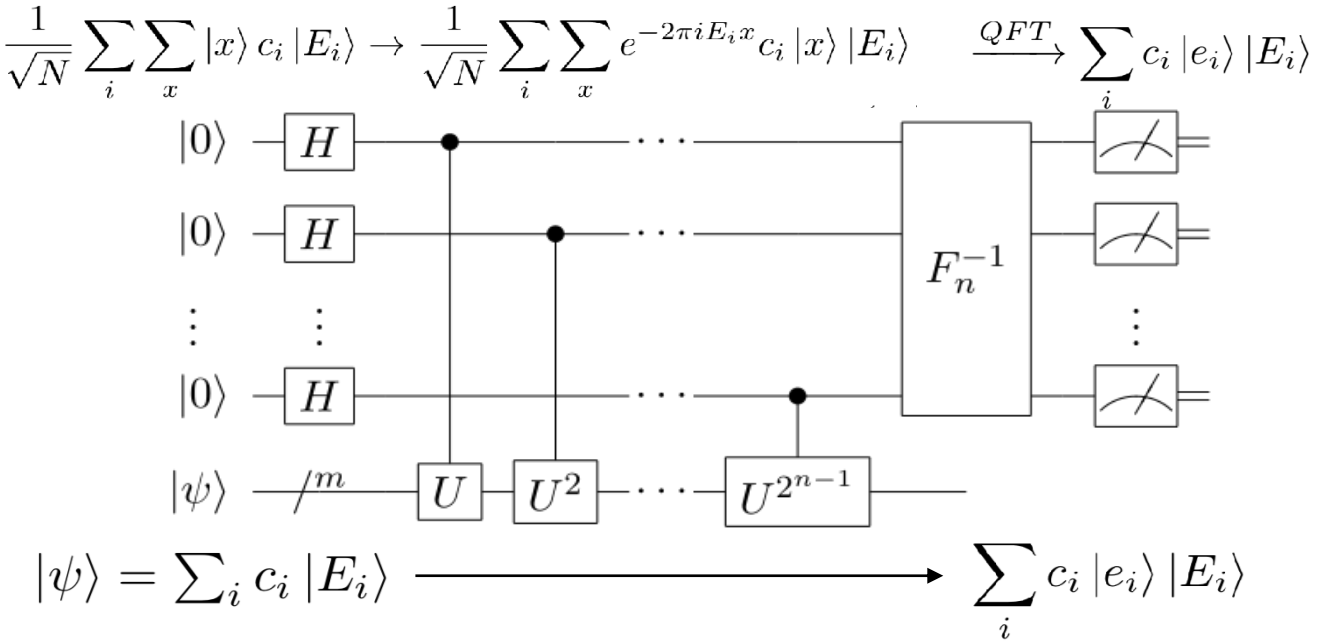


Algorithms designed for universal quantum computers

Dynamic problems: Schrodinger equation $\frac{d|\psi\rangle}{dt} = -iH|\psi\rangle$

Static problem: find the eigenstates of H





Childs, A. M., Maslov, D., Nam, Y., Ross, N. J., & Su, Y. (2018). PNAS, *115*(38), 9456-9461.

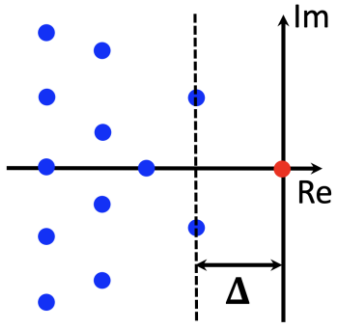
Non-Hermitian Hamiltonians

Non-Hermitian physics naturally emerges in quantum physics and classical processes:

$$H \neq H^{\dagger}$$

The Hamiltonian may have **complex** eigenvalues and **non-orthogonal** eigenvectors

Liouvillian gap



Lindbladian $\dot{\rho} = \mathcal{L}(\rho)$

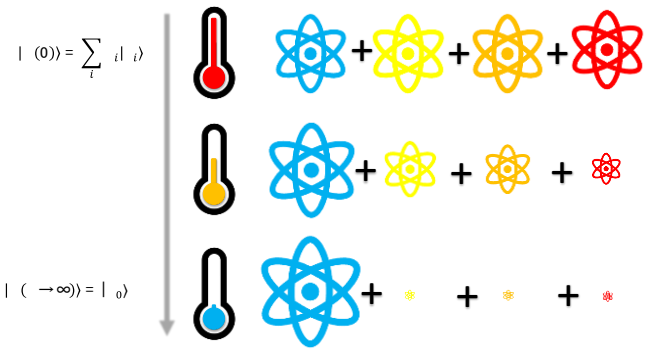
↓

vectorization $\dot{\tilde{\rho}} = \tilde{\mathcal{L}} \cdot \tilde{\rho}$

↓

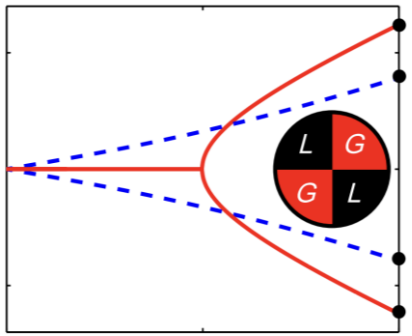
relaxation time $\tau \sim 1/\Delta$

Imaginary time



$$|\psi(\tau)\rangle = \frac{e^{-H\tau}|\psi(0)\rangle}{\sqrt{\langle\psi(0)|e^{-2H\tau}|\psi(0)\rangle}}$$

PT-symmetry breaking



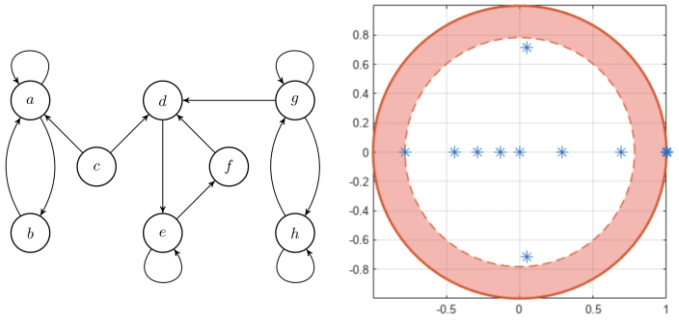
Eigenvalues of non-Hermitian Hamiltonian

↙ ↘

Complex ↔ PT-broken

Real ↔ PT-unbroken

Relaxation time of Markov chain

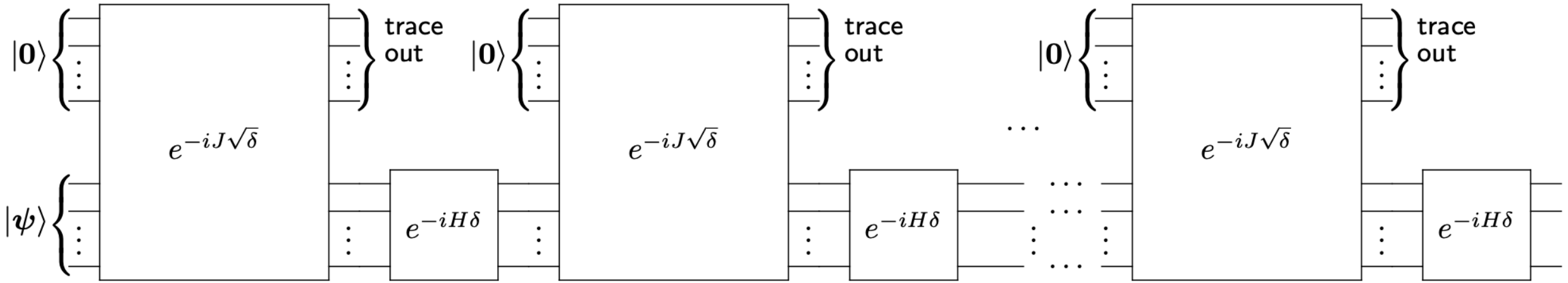


$$g_{\mathrm{mar}} \equiv 1 - \max_{\lambda_j \neq 1} |\lambda_j|$$

$$t_{\mathrm{rel}} \equiv 1/g_{\mathrm{mar}}$$

Lindbladian Simulation with minimal resources

Lindbladian Simulation: $\dot{\rho} = -i[H, \rho] + \sum_{j=1}^{m} \left(L_j \rho L_j^\dagger - \frac{1}{2} L_j^\dagger L_j \rho - \frac{1}{2} \rho L_j^\dagger L_j \right),$



Trotter error accumulates with time and increase with the complex interactions

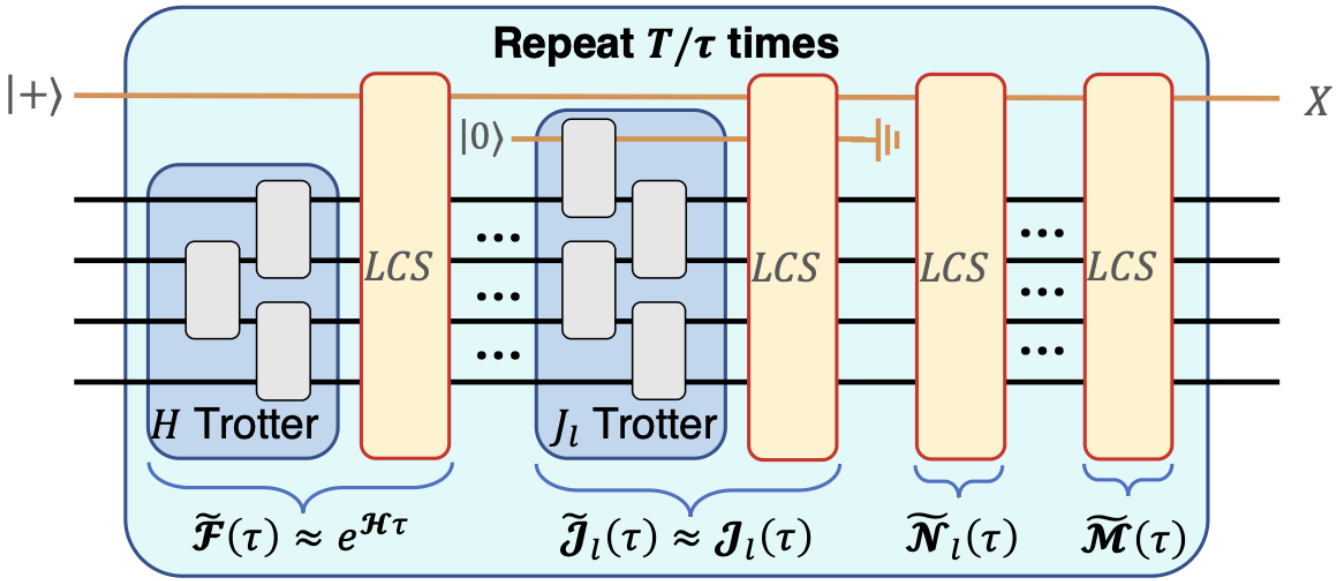
W Yu, X Li, Q Zhao, **X Yuan***, PRL 135 (16), 160602 (2025)

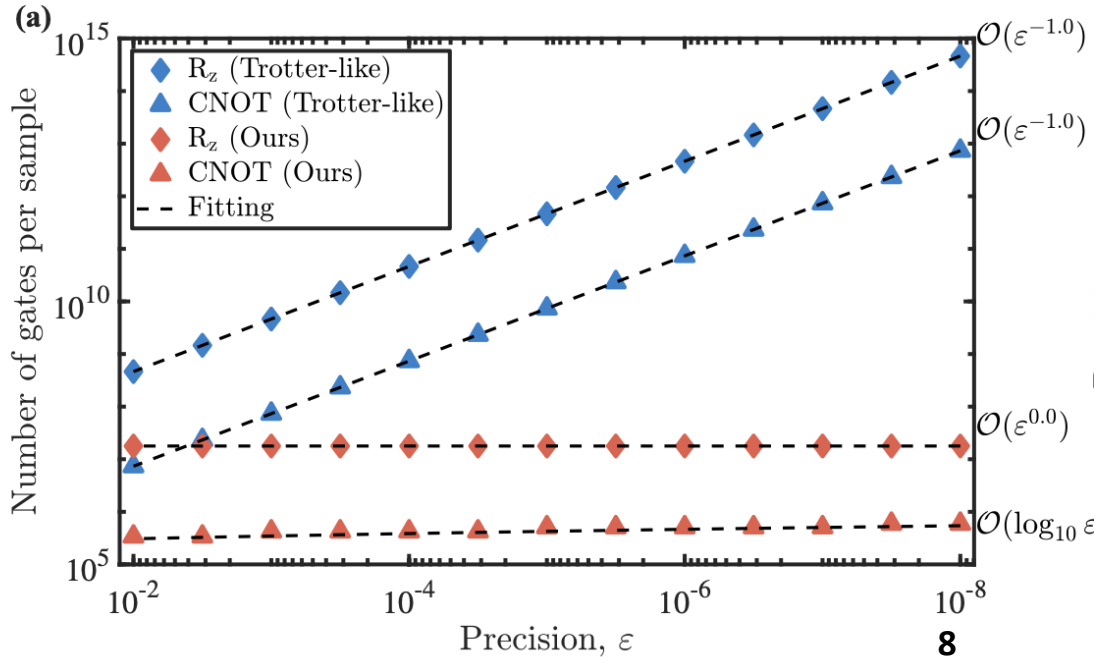
Lindbladian Simulation with minimal resources

A systematic compensation method to suppress Lindbladian Simulation errors

An exponential speedup with minimal ancillary qubits

Methods	Circuit depth	Ancilla
LCU-based [24]	$\mathcal{O}(m^2q^2T\,\mathrm{polylog}(mqT/\varepsilon))$	$\mathrm{polylog}(mqT/\varepsilon)$
Fractional [27]	$\mathcal{O}(mqT\,\mathrm{polylog}(mqT/\varepsilon))$	$\mathrm{polylog}(mqT/\varepsilon)$
p-order DH* [29]	$\mathcal{O}((mq)^pT(T/\varepsilon)^{1/p})$	$\Omega(p\log(m))$
Our result	$\mathcal{O}(mT^2(q+\frac{\log(1/\varepsilon)}{\log T}))$	2





W Yu, X Li, Q Zhao, **X Yuan***, PRL 135 (16), 160602 (2025)

Imaginary time evolution: Fourier transform

Consider the normalized imaginary time evolution

$$|\psi(\tau)\rangle = \frac{e^{-H\tau}|\psi(0)\rangle}{\sqrt{\langle\psi(0)|e^{-2H\tau}|\psi(0)\rangle}}$$

The Fourier transform of $e^{-H\tau}$ (given $H \geq 0$) is

$$e^{-H\tau} = \int_{-\infty}^{\infty} p(x) e^{ix\tau H} \mathrm{d}x$$

where $p(x) = \frac{2}{x^2+1}$ is the Cauchy distribution

The time evolved state becomes

$$|\psi(\tau)\rangle \propto \int_{-\infty}^{\infty} p(x)\mathrm{d}x\, e^{ix\tau H}|\psi(0)\rangle$$

which is a linear combination of real time evolution

The algorithm is applicable to general non-Hermitian Hamiltonians by separating the Hermitian and anti-Hermitian parts

How to implement the linear combination of real time evolution?

- Suppose instead of having the state, we measure some observable O

$$\langle O\rangle_{\psi(\tau)} = \langle\psi(\tau)|O|\psi(\tau)\rangle = \frac{N_\tau(\psi_0, O)}{D_\tau(\psi_0)}$$

$$N_\tau(\psi_0, O) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \mathrm{d}p(x,x')\,\langle\phi(x'\tau)|O|\phi(x\tau)\rangle$$

$$D_\tau(\psi_0) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \mathrm{d}p(x,x')\,\langle\phi(x'\tau)|\phi(x\tau)\rangle$$

- We can measure these terms with a quantum computer
- The integral can be truncated to $O(1/\epsilon)$ for error ϵ

P Zeng, J Sun, **X Yuan*,** arXiv:2109.15304 M. Huo and Y. Li, arXiv:2109.07807.

General non-Hermitian eigensolver

Given a non-Hermitian matrix A, the task is to estimate the **eigenvalue** λ_j, such that

$$A|E_j\rangle = \lambda_j|E_j\rangle$$

The **Jordan normal form** of the matrix is given by

$$A = P\Lambda P^{-1}$$

$$\downarrow$$

$$\Lambda_1 \oplus \Lambda_2 \oplus \cdots \oplus \Lambda_M \xrightarrow{\text{Jordan block}} \Lambda_j = \begin{pmatrix} \lambda_j & 1 & & \\ & \lambda_j & \ddots & \\ & & \ddots & 1 \\ & & & \lambda_j \end{pmatrix}$$

Here P is an invertible matrix, indicating that **the eigenstates are not orthogonal anymore**

X-M Zhang, Y Zhang, W He, and **X Yuan***, PRL 135, 140601 (2025)

General non-Hermitian eigensolver: method 1

Reducing eigenvalue problem to the simpler **singular-value problem**

$$(A-\lambda_j)|E_j\rangle = 0$$

$$\Updownarrow$$

$$A|E_j\rangle = \lambda_j|E_j\rangle$$

$$\Updownarrow$$

Minimum **singular** value of shifted matrix $\sigma_{\min}(A-\lambda_j I)=0$

$$\min|\mu-\lambda_j| \leqslant \varepsilon_{\text{th}} \text{ or } \min|\mu-\lambda_j| \geqslant 2K\varepsilon_{\text{th}}$$

$$\Updownarrow$$

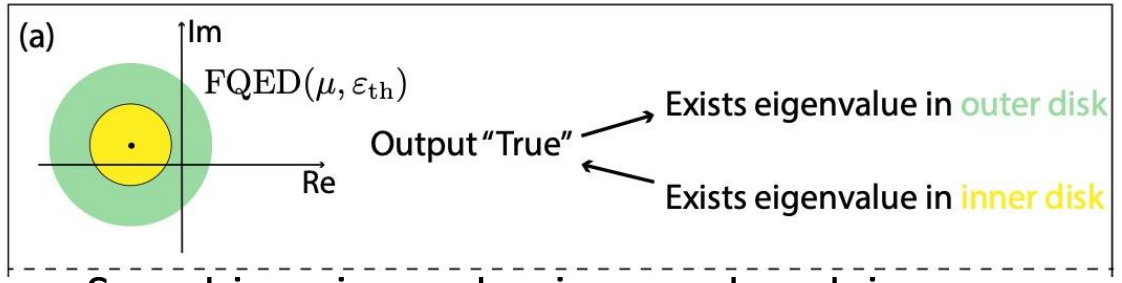
$$\sigma_{\min}(A-\mu I) \leqslant \varepsilon_{\text{th}} \text{ or } \sigma_{\min}(A-\mu I) \geqslant 2\varepsilon_{\text{th}}$$

Solvable with quantum singular value transformation (QSVT) framework

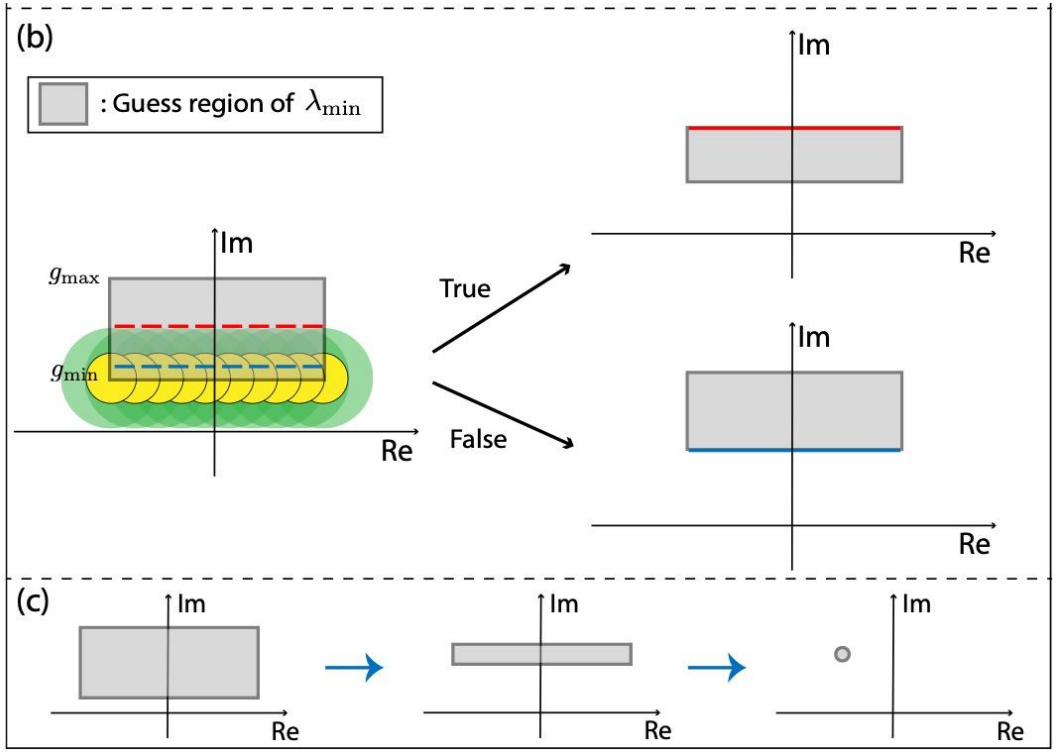
X-M Zhang, Y Zhang, W He, and **X Yuan***, PRL 135, 140601 (2025)

Example: finding eigenvalues closes to a real axis

- Fuzzy quantum eigenvalue detector



- Searching eigenvalue in complex plain



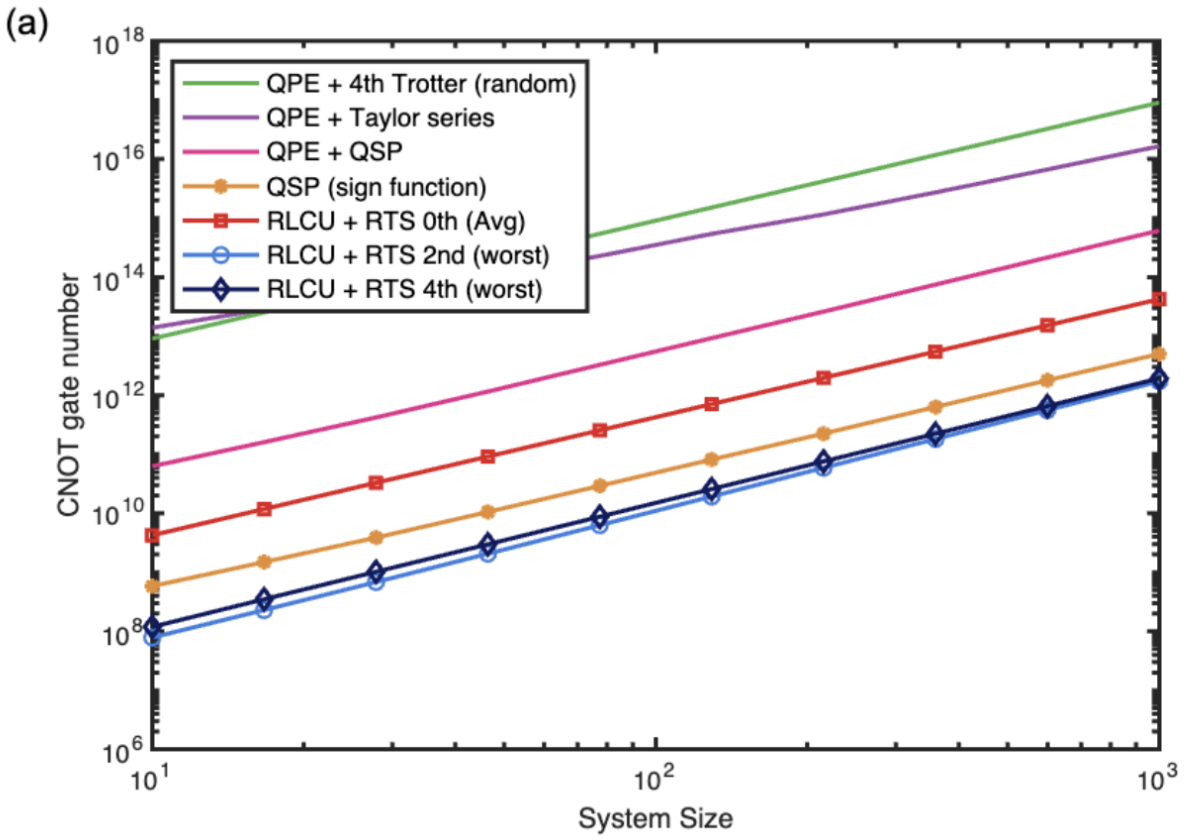
Summary

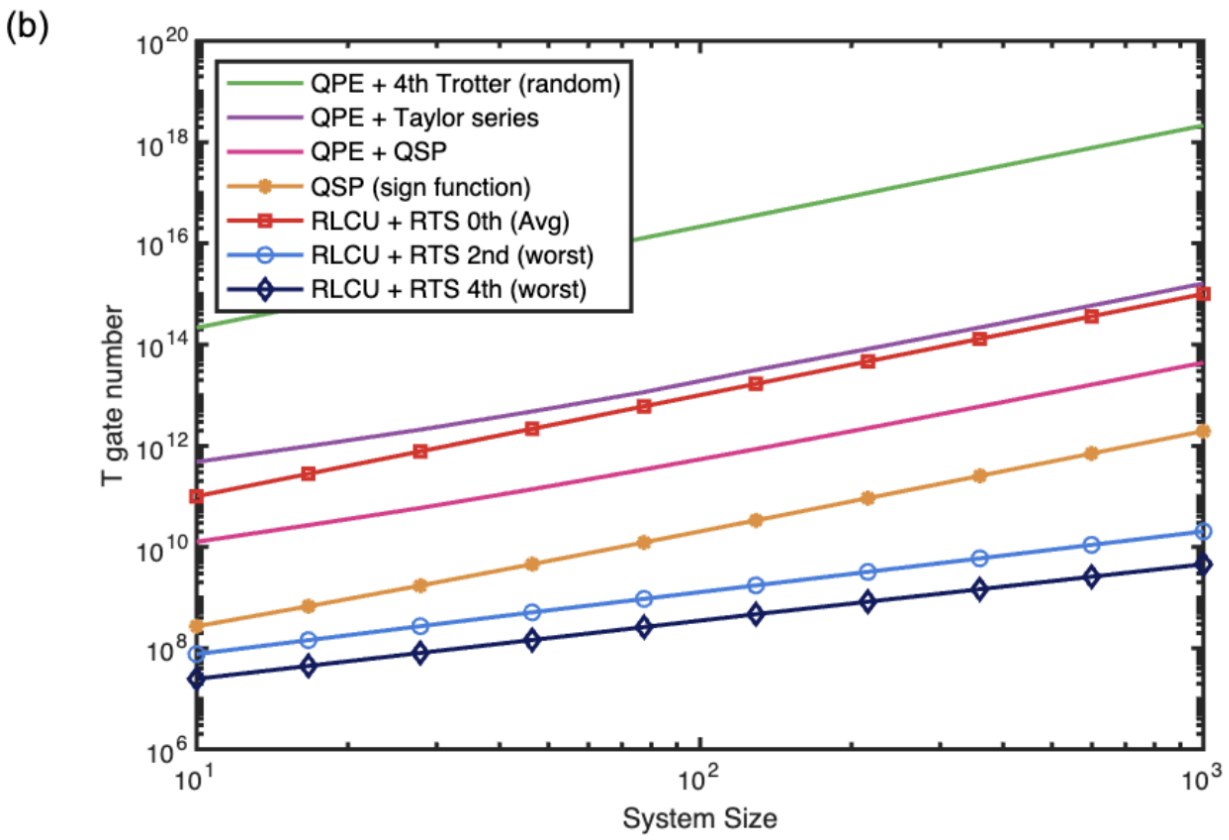
	Hermitian physics	Non-Hermitian physics
Dynamics	Trotterization, LCU, and QSP	**Fourier transform** QEVT [Low, Su FOCS 2024]
Eigenstates	QPE, QSP, QSVT, Filtering, …	**Method 1: convert to QSP** **Method 2: signal processing**

Future directions

- Optimized algorithms with better parameter dependence
- Applications in physics and implementation with quantum computers

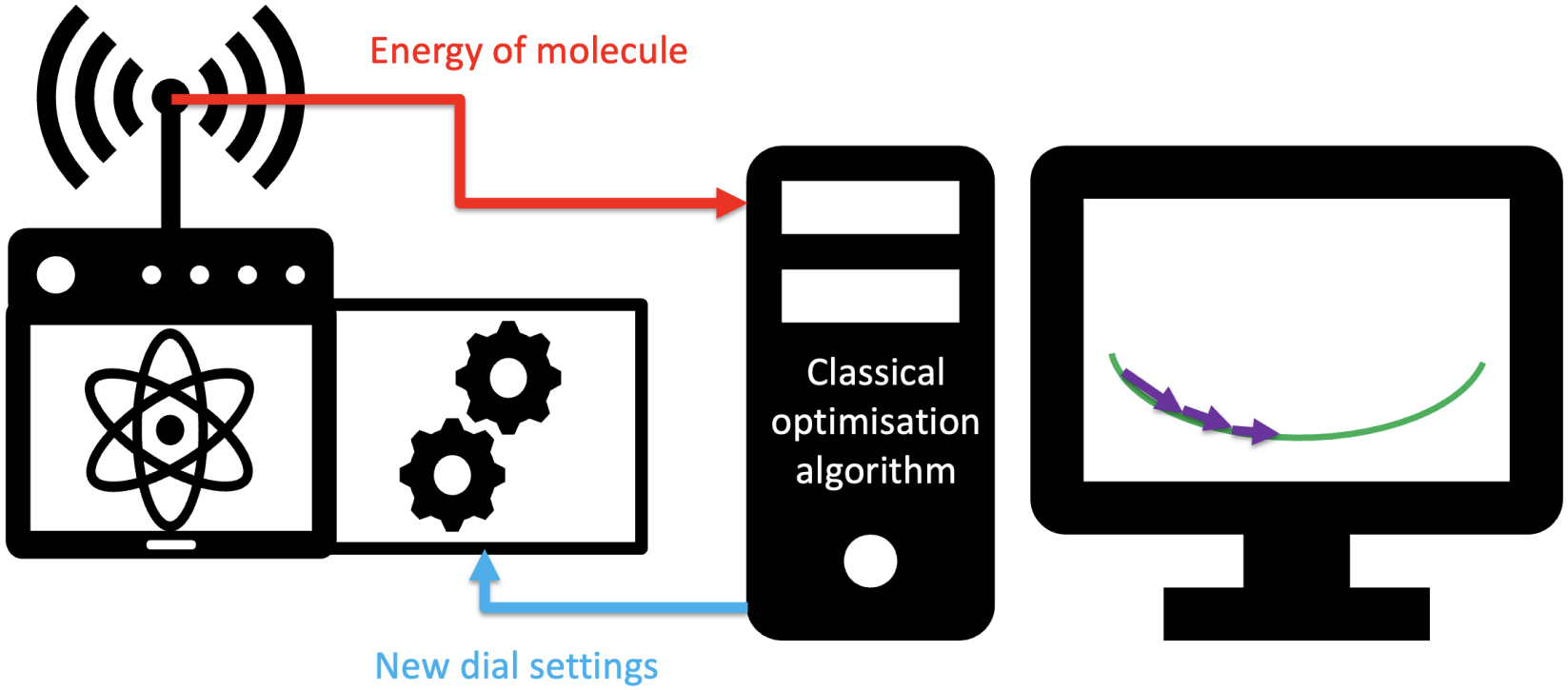
Resource estimation (the number of CNOT gates and T gates) for the ground state property estimation for the 1D Ising Hamiltonian.





J Sun, P Zeng, T Gur, MS Kim, arXiv preprint arXiv:2406.04307

Algorithms designed for near-term quantum computers



Algorithm framework	**X Yuan***, S Endo, Q Zhao, Y Li, SC Benjamin, Quantum 3, 191 (2019)
Imaginary time evolution	S McArdle, T Jones, S Endo, Y Li, SC Benjamin, **X Yuan***, NPJQI 5, 75 (2019)
Open system simulation	S Endo, J Sun, Y Li, SC Benjamin, **X Yuan***, PRL 125, 010501 (2020)
Closed system simulation	ZJ Zhang, J Sun, **X Yuan***, MH Yung, PRL 130, 040601 (2023)

Algorithms designed for near-term quantum computers

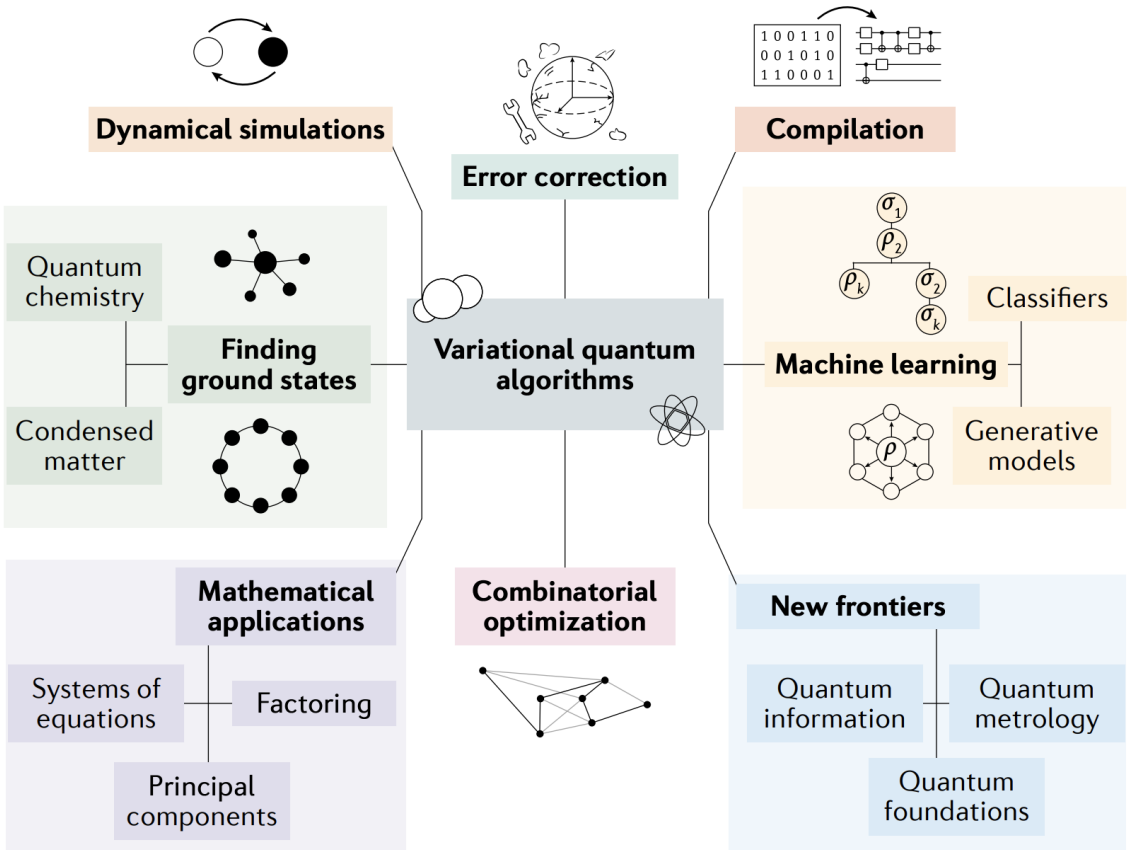


Figure from Nature Reviews Physics 3, 625–644 (2021)

Review for quantum computational chemistry and materials

1. S McArdle, S Endo, A Aspuru-Guzik, SC Benjamin, X Yuan, Quantum computational chemistry, Reviews of Modern Physics 92 (1), 015003
2. Y Cao, et al. Quantum chemistry in the age of quantum computing. Chemical reviews 119.19 (2019): 10856-10915
3. B. Bauer, S. Bravyi, M. Motta, and G. K. Chan, arXiv:2001.03685

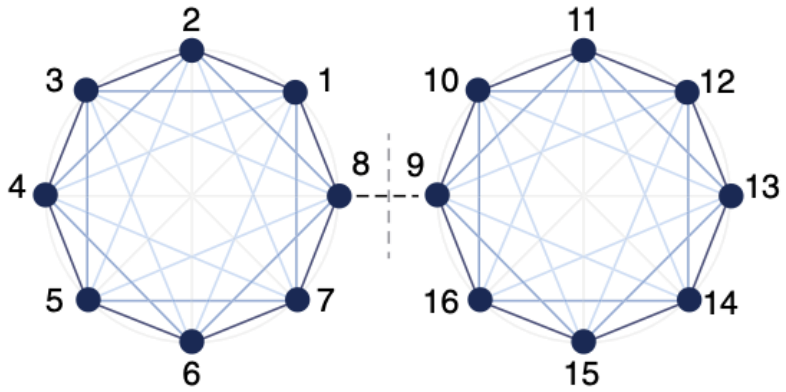
Review for variational quantum algorithms and error mitigation

1. M Cerezo, Andrew Arrasmith, Ryan Babbush, Simon C Benjamin, Suguru Endo, Keisuke Fujii, Jarrod R McClean, Kosuke Mitarai, Xiao Yuan, Lukasz Cincio, Patrick J Coles, Variational quantum algorithms, Nature Reviews Physics 3, 625–644 (2021)
2. S Endo, Z Cai, SC Benjamin, X Yuan, Hybrid quantum-classical algorithms and quantum error mitigation, Journal of the Physical Society of Japan 90 (3), 032001
3. Kishor Bharti et al., Noisy intermediate-scale quantum (NISQ) algorithms, arXiv:2101.08448

Hybrid classical-quantum computing methods

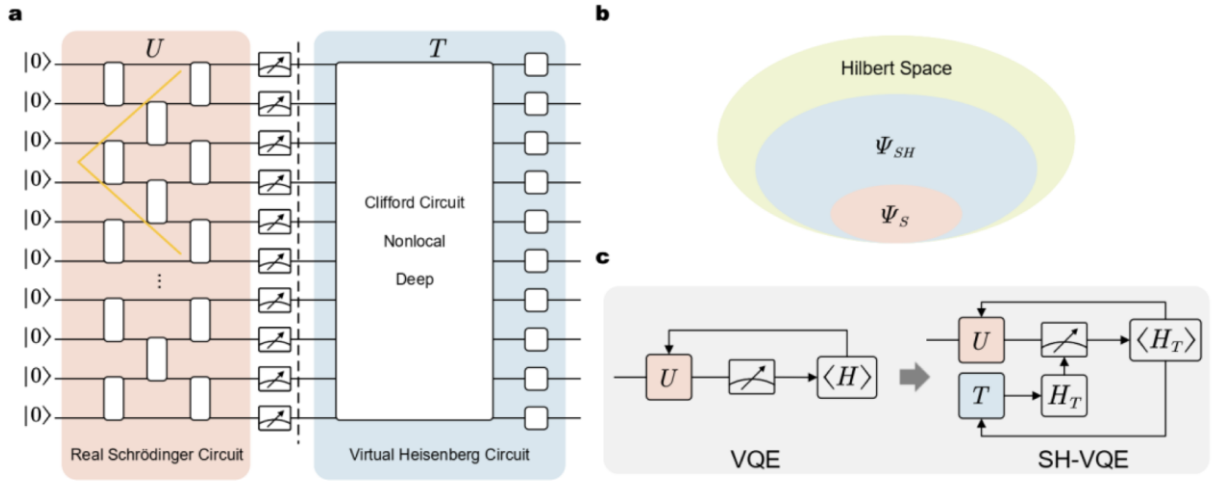
Solve large problems with small QC hardware

- Hybrid tensor network/Embedding methods (eigen-state properties)
- Perturbative quantum simulation (dynamics)



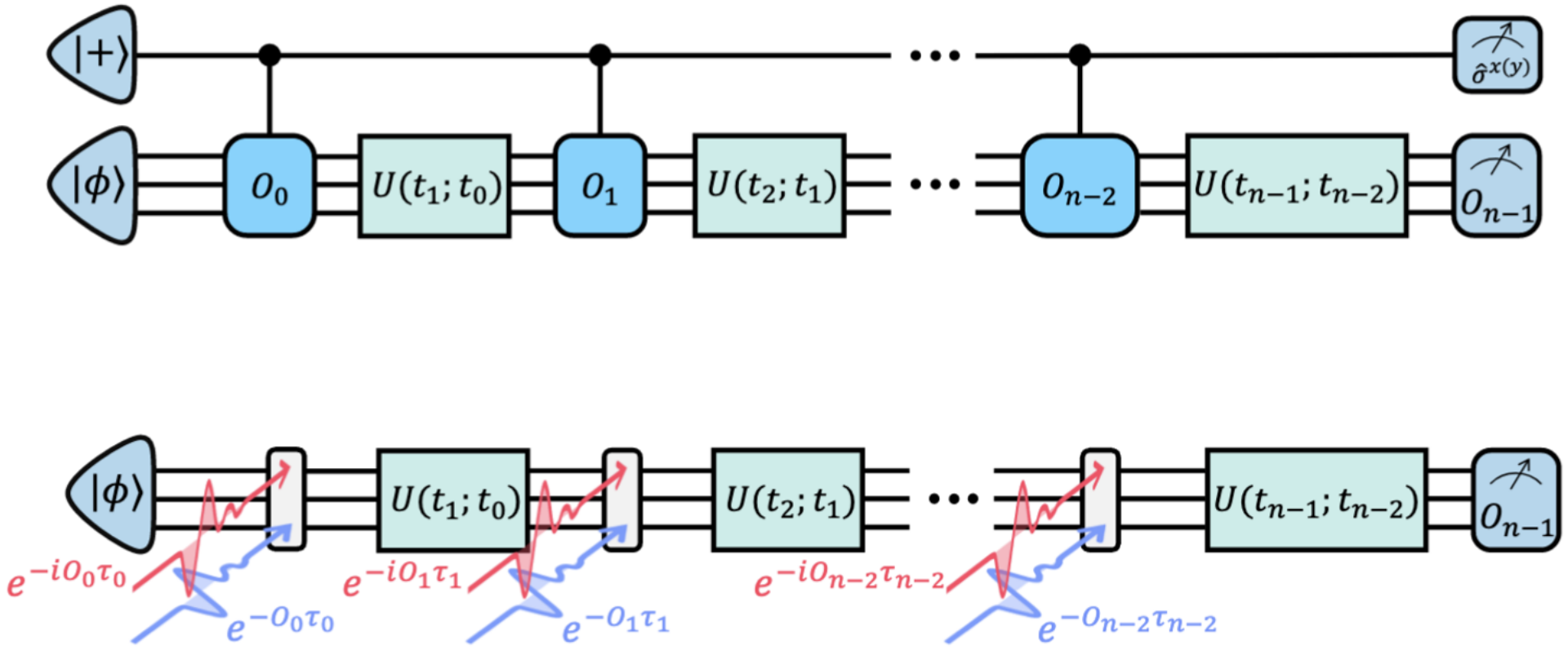
Solve complex problem using a shallower circuit

- Schrodinger-Heisenberg-VQE/MPS-VQE/Neural network-VQE/QC-QMC/SDP-VQE



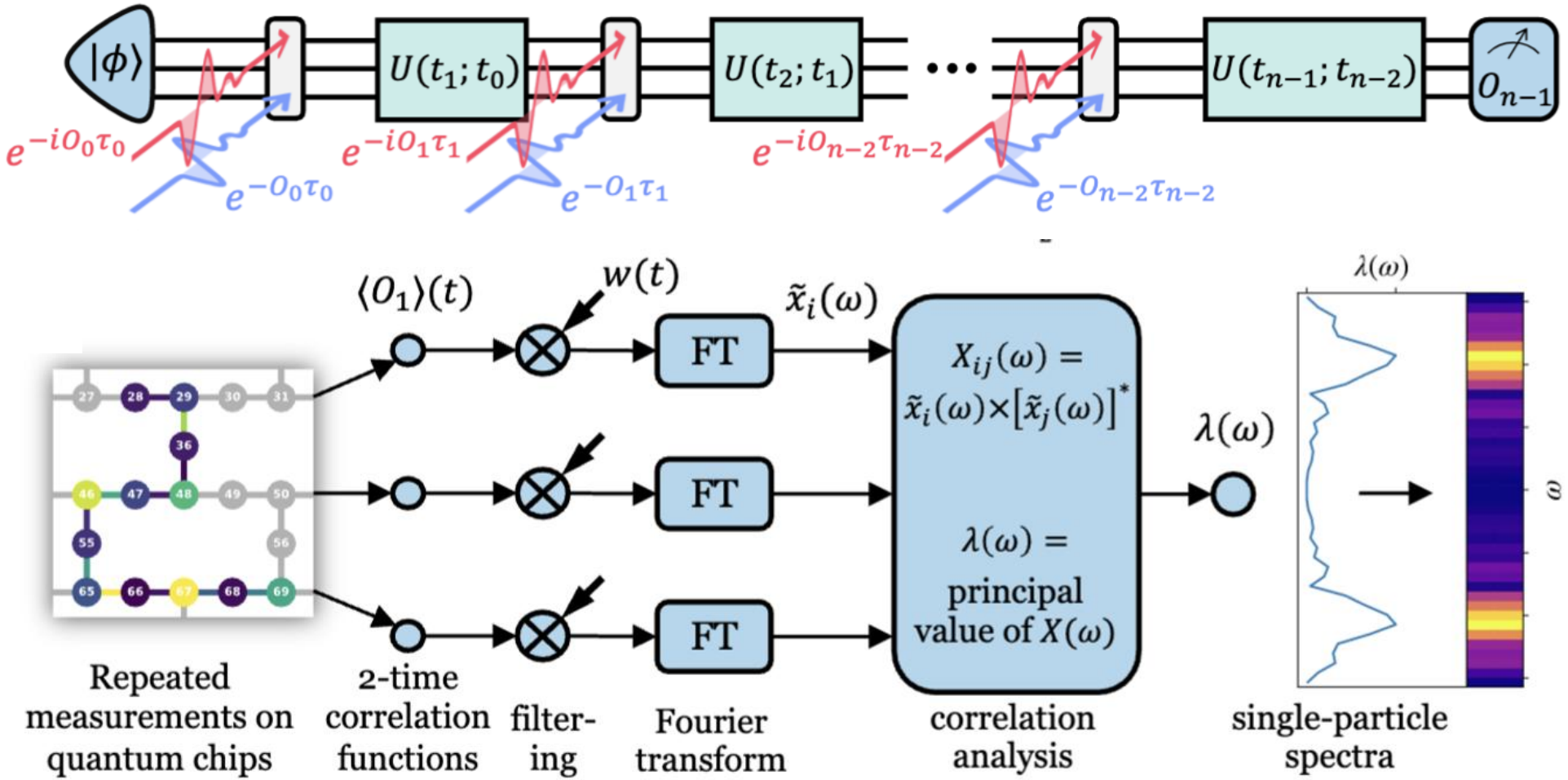
Tensor network	**X Yuan***, J Sun, J Liu, Q Zhao, Y Zhou, PRL 127 (4), 040501 (2021)
Perturbation theory	J Sun, S Endo, H Lin, P Hayden, V Vedral, **X Yuan***, PRL 129 (12), 120505
Virtual circuits	ZX Shang, MC Chen, **X Yuan**, CY Lu, JW Pan, PRL 131, 060406 (2023)

Computing correlation functions with analog hardware



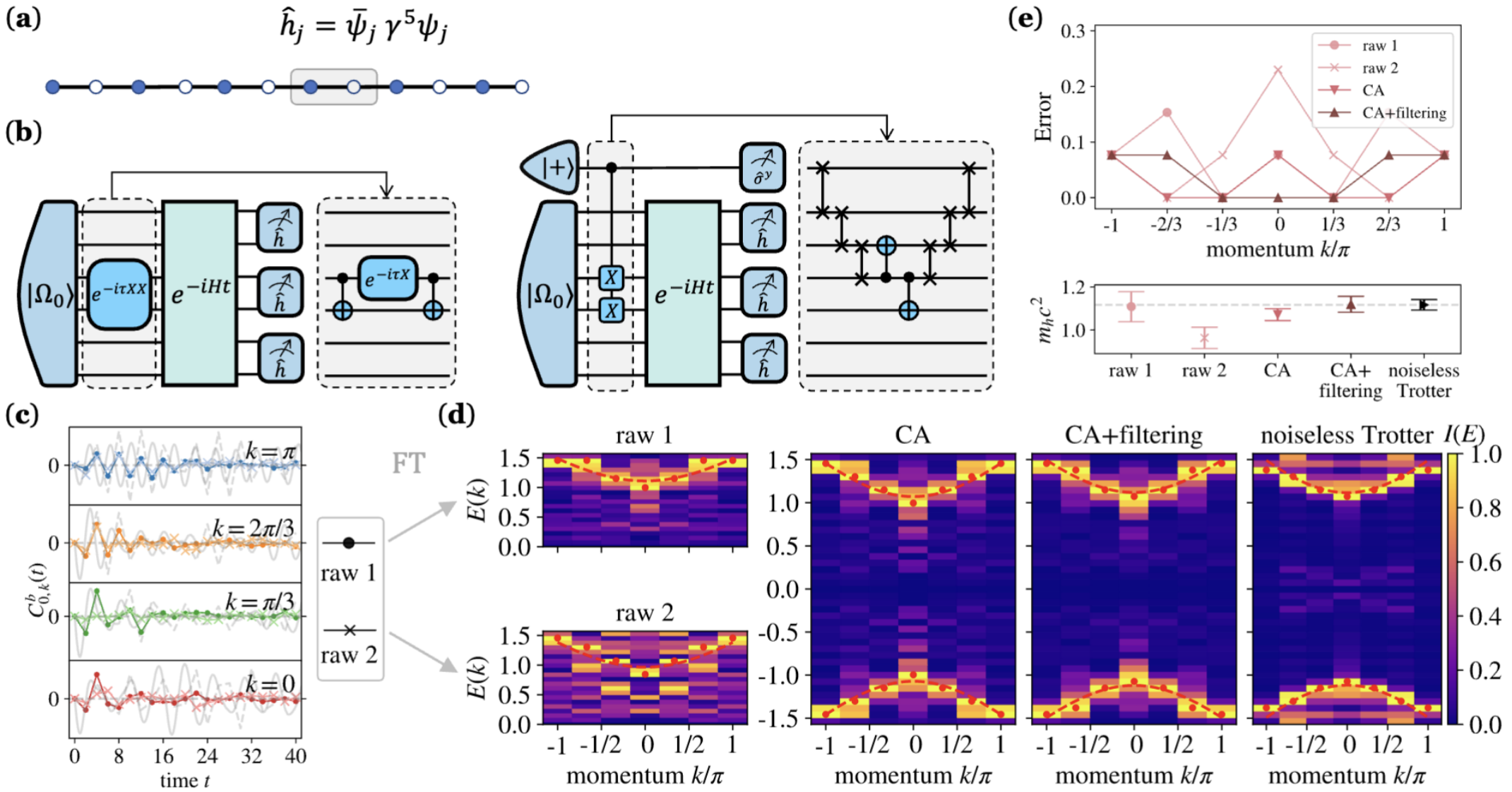
X Wang , L Xiong, X Cai, and **X Yuan***, PRL 135, 230602 (2025)

Computing correlation functions with analog hardware



X Wang , L Xiong, X Cai, and **X Yuan***, PRL 135, 230602 (2025)

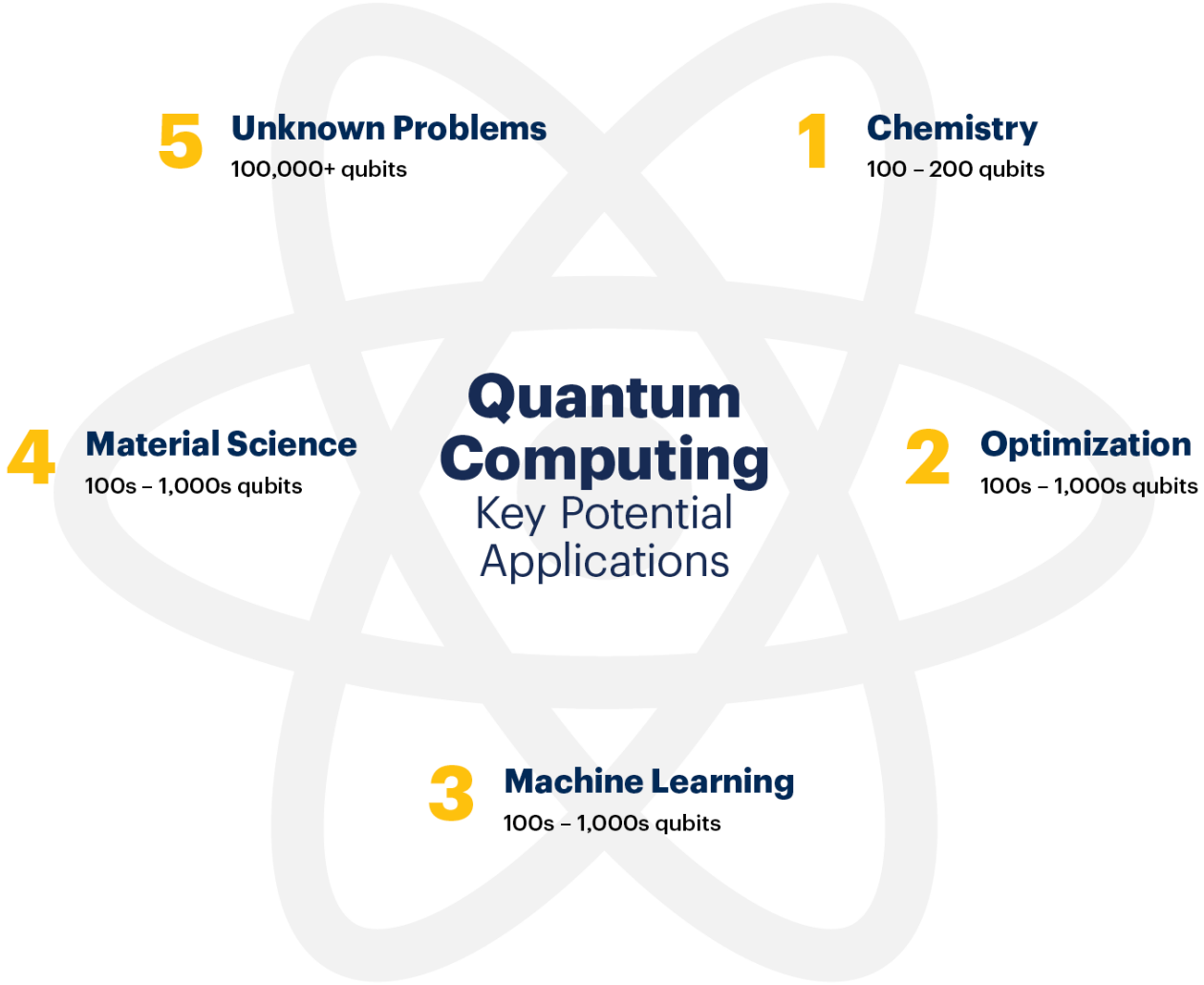
Computing correlation functions with analog hardware



X Wang , L Xiong, X Cai, and **X Yuan***, PRL 135, 230602 (2025)

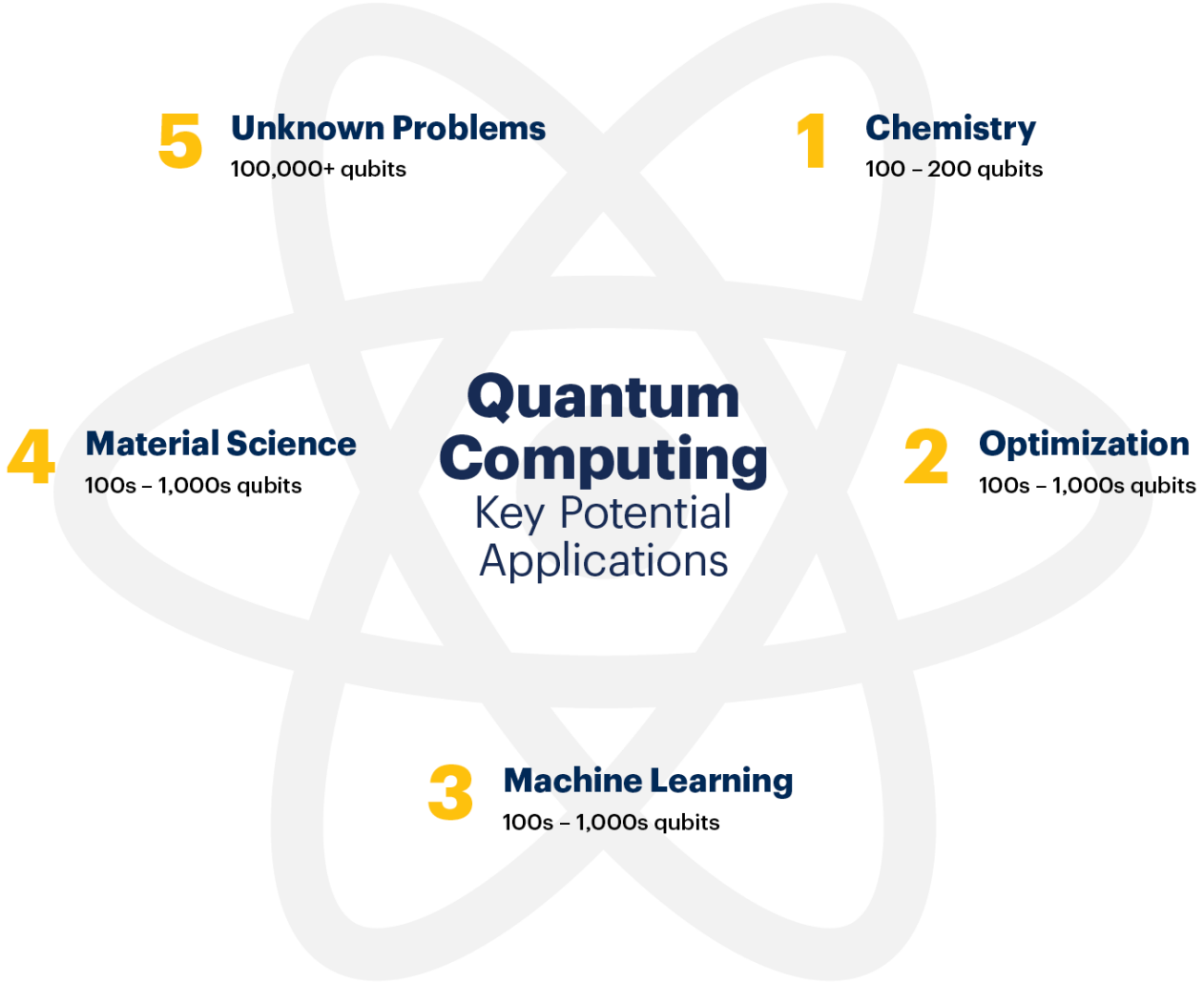
Quantum computing applications

Quantum computing applications



- 具体问题（100-200 qubits）
  - 费米-哈伯德模型 （10*10）
  - 药物小分子（100-200 qubits）
  - 固氮酶（152 qubits）
- 实际应用
  - 化学反应预测
  - 材料性质研究
  - 药物研发

Quantum computing applications



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"Few fields will get value from quantum computing as quickly as chemistry."

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Quantum computational chemistry

Sam McArdle, Suguru Endo, Alán Aspuru-Guzik, Simon C. Benjamin, and Xiao Yuan
Rev. Mod. Phys. **92**, 015003 – Published 30 March 2020

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Hartree–Fock on a superconducting qubit quantum computer

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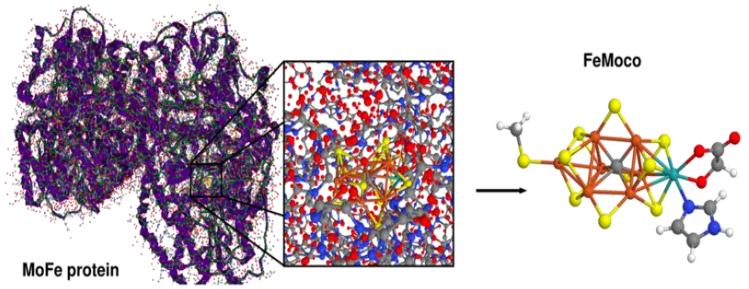

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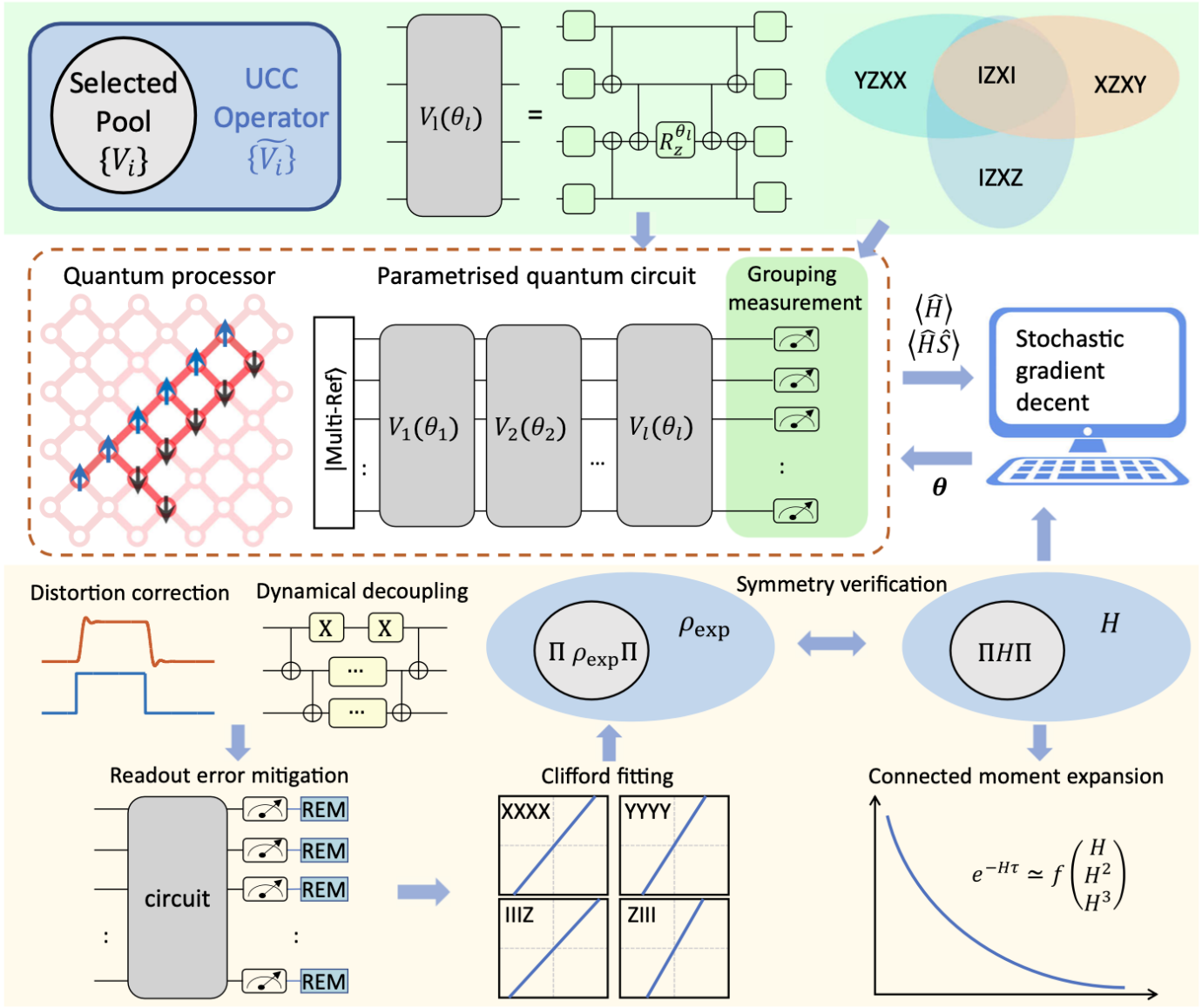
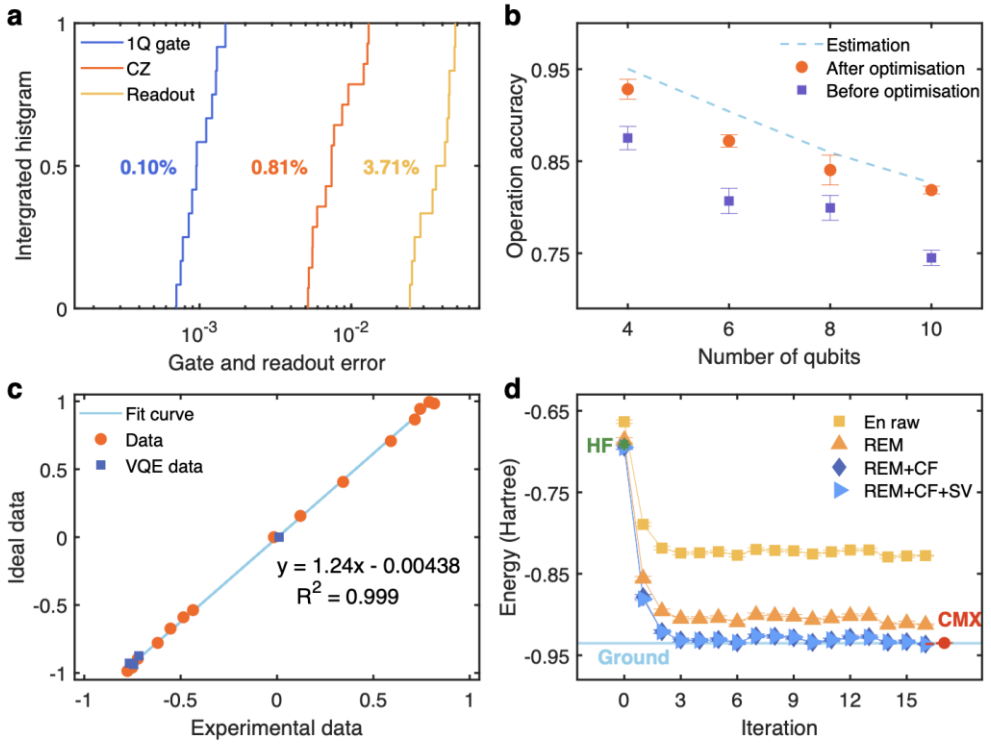
Experimental quantum computational chemistry with optimized unitary coupled cluster ansatz

Quantum computing for electronic structures

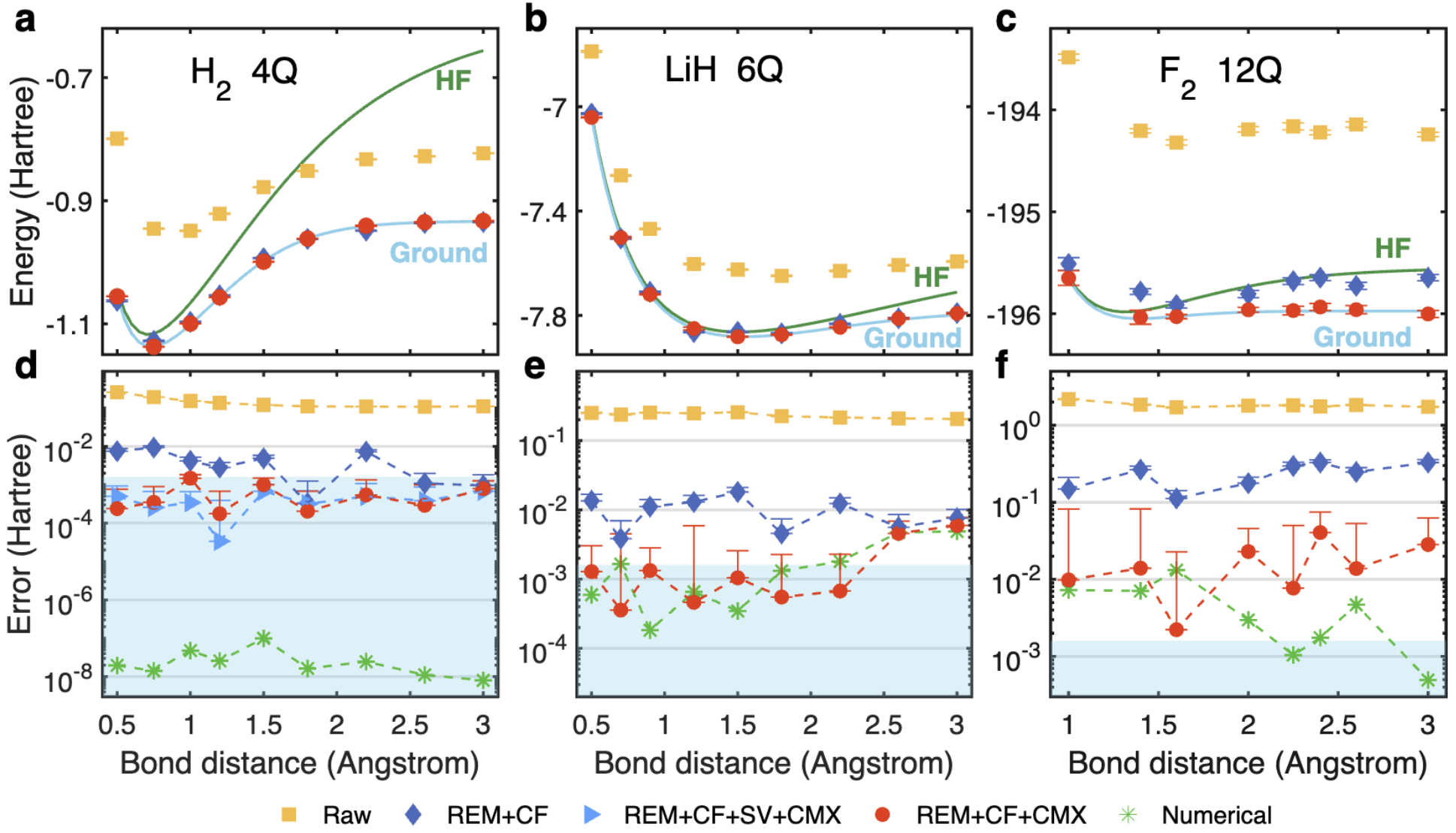


Theory: circuit compiling + measurement reduction
Experiment: device calibration + error mitigation



S Guo, …, **X Yuan***, X Zhu*, and J-W Pan*, Nature Physics, 20, 1240–1246 (2024)

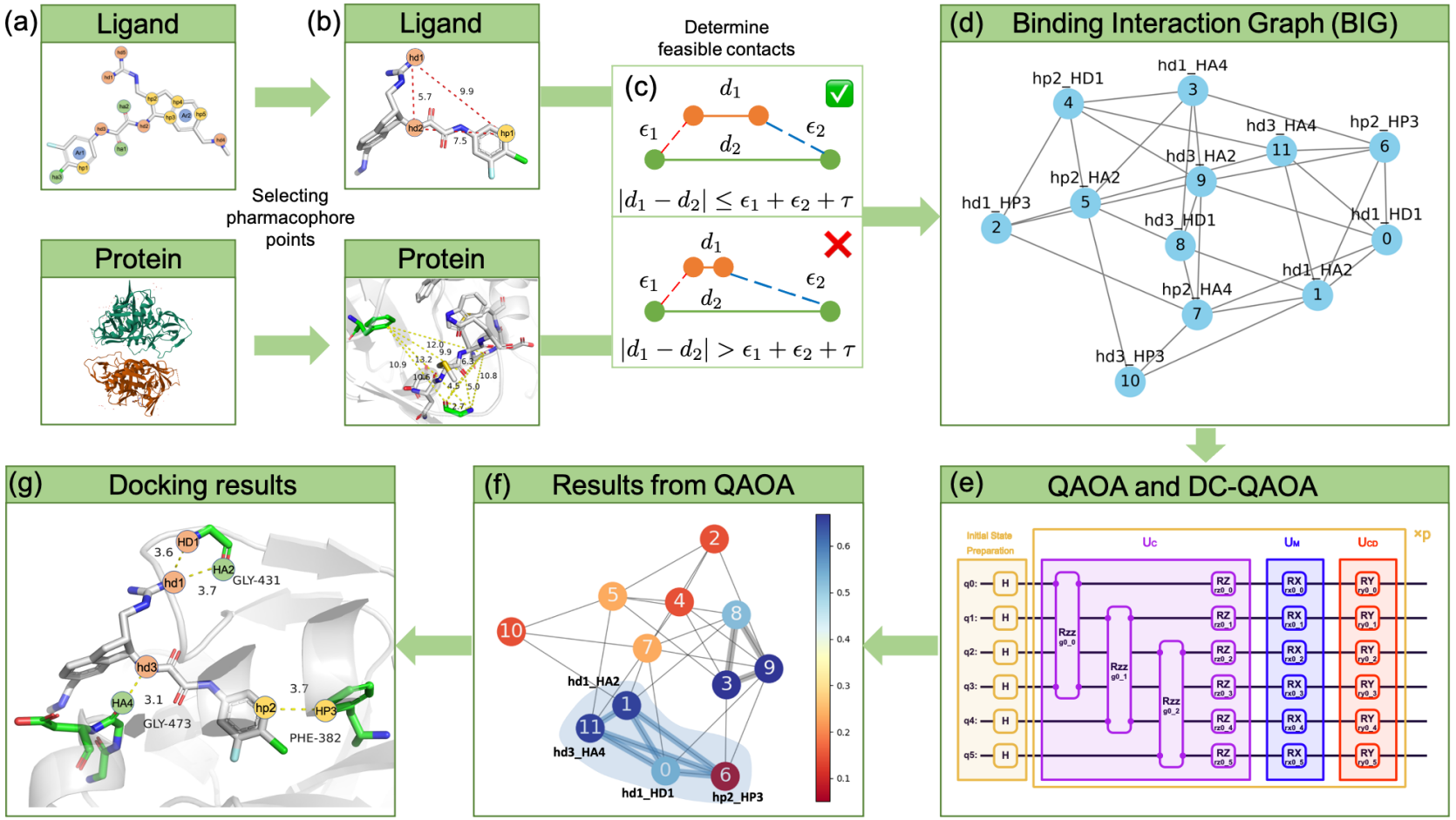
Quantum computing for electronic structures



For F_2
The circuit depth, measurement counts, and accuracy are reduced/improved by two order

S Guo, …, **X Yuan***, X Zhu*, and J-W Pan*, Nature Physics, 20, 1240–1246 (2024)

Molecular docking



被辉瑞制药，再生元制药，英伟达CUDA-Q引用、复现，并应用到实际药物体系发现中

Q Ding,Y Huang, and **X Yuan***, Phys. Rev. Applied 21, 034036 (2024).

Chemical Reviews

Another example demonstrating the capabilities of CUDA-Q are the implementations of the VQE-Quantum approximate optimization algorithm (VQE-QAOA) algorithm for simulations of molecular docking[194] and protein folding.[195] For example, the VQE-QAOA algorithm has been applied to find the optimal configuration of a ligand bound to a protein, implementing the molecular docking simulation as a weighted maximum clique problem.[194] Simulations were performed with up to 12 qubits. The CUDA-Q tutorial[196] reproduces the results using DC-QAOA and compares the CPU and GPU runtimes (Table 1). For 12 qubits, a 16.6× speed up is observed on a single GPU when compared to a single CPU.

Table 1. Execution Time of One "Observe" Call (i.e., Expectation Value) Using DC-QAOA Ansatz[a]

qubits	CPU time (s)	GPU time (s)
6	0.322	0.160
8	1.398	0.390
12	6.863	0.412

[a]Simulations were run with 3, 8, and 13 layers for 6, 8, and 12 qubits, respectively.

Quantum Approximate Optimization Algorithms for Molecular Docking

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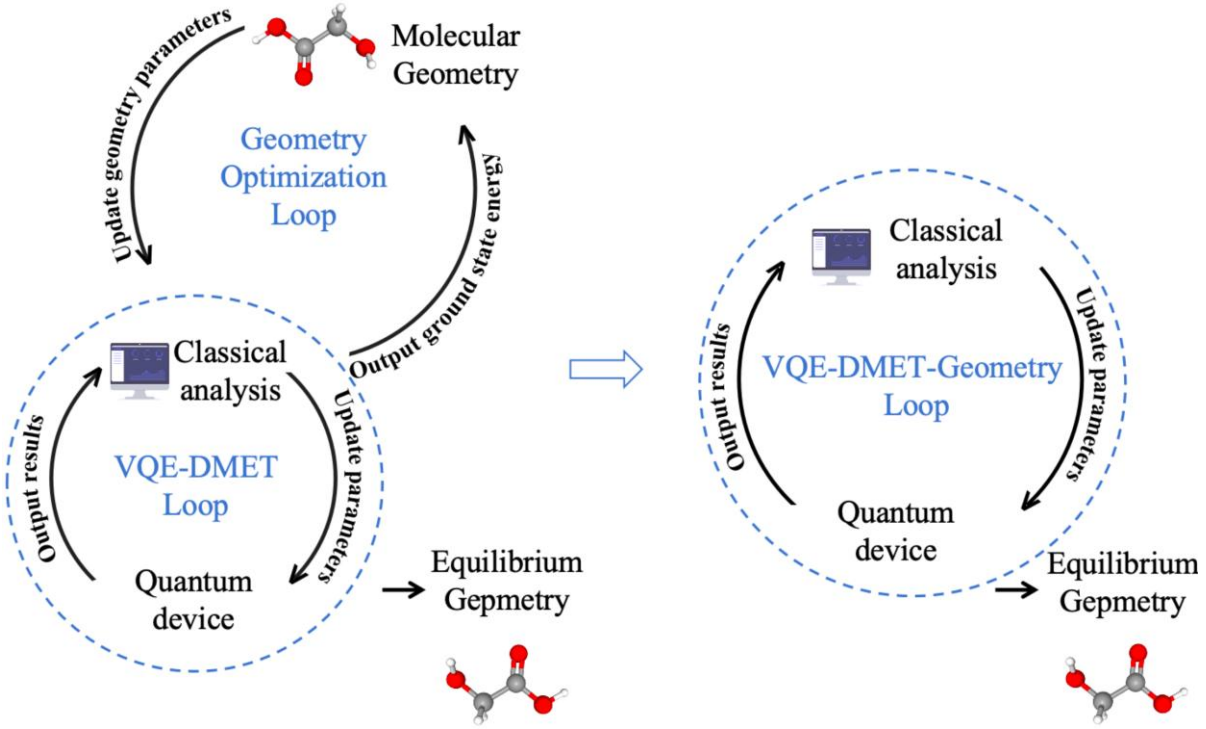
+these authors contributed equally to this work

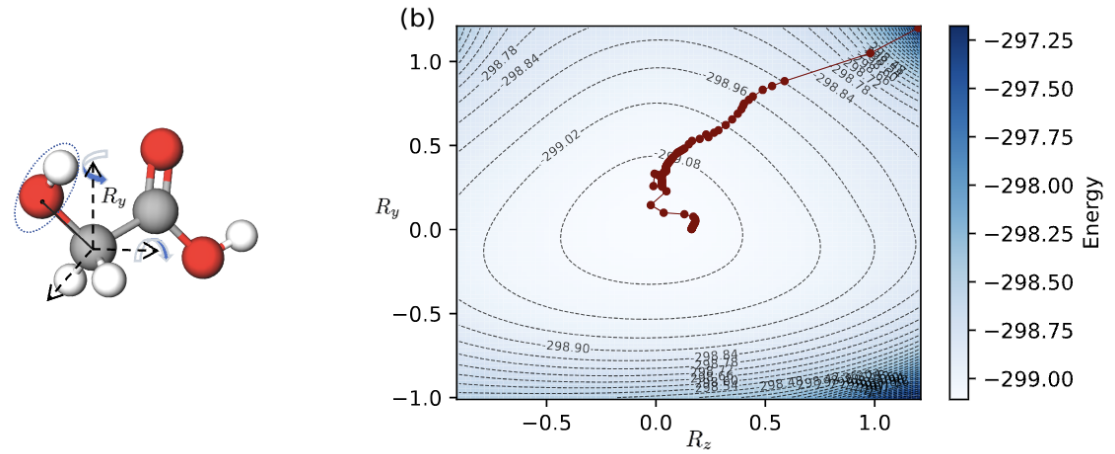
ABSTRACT

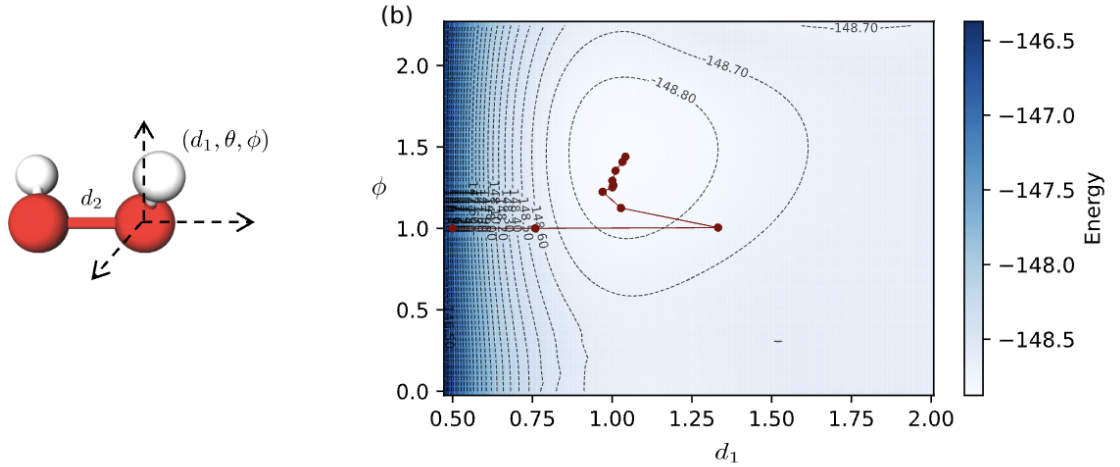
Molecular docking is a critical process for drug discovery and challenging due to the complexity and size of biomolecular systems, where the optimal binding configuration of a drug to a target protein is determined. Hybrid classical-quantum computing techniques offer a novel approach to address these challenges. The Quantum Approximate Optimization Algorithm (QAOA) and its variations are hybrid classical-quantum techniques, and a promising tool for combinatorial optimization challenges. This paper presents a Digitized Counterdiabatic QAOA (DC-QAOA) approach to molecular docking. Simulated quantum runs were conducted on a GPU cluster. We examined 14 and 17 nodes instances - to the best of our knowledge the biggest published instance is 12-node at Ding et al.[1], and we present the results. Based on computational results, we conclude that binding interactions represent the anticipated exact solution. Additionally, as the size of the examined instance increases, the computational times exhibit a significant escalation.

Molecular geometry optimization

A Unified VQE-DMET geometry optimization method



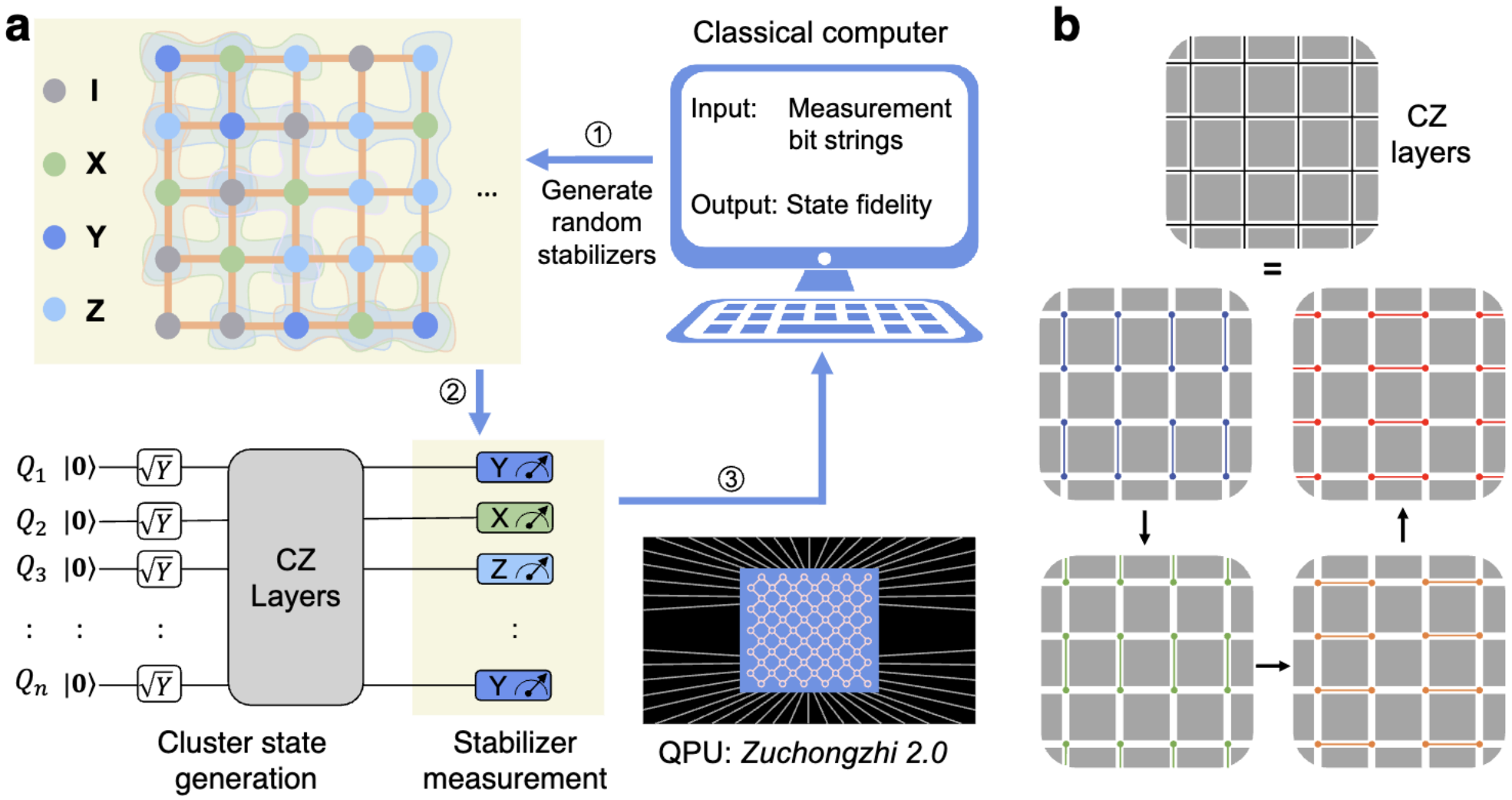




Y Hao, Q Ding, X Wang, **X Yuan*** arXiv:2509.07460

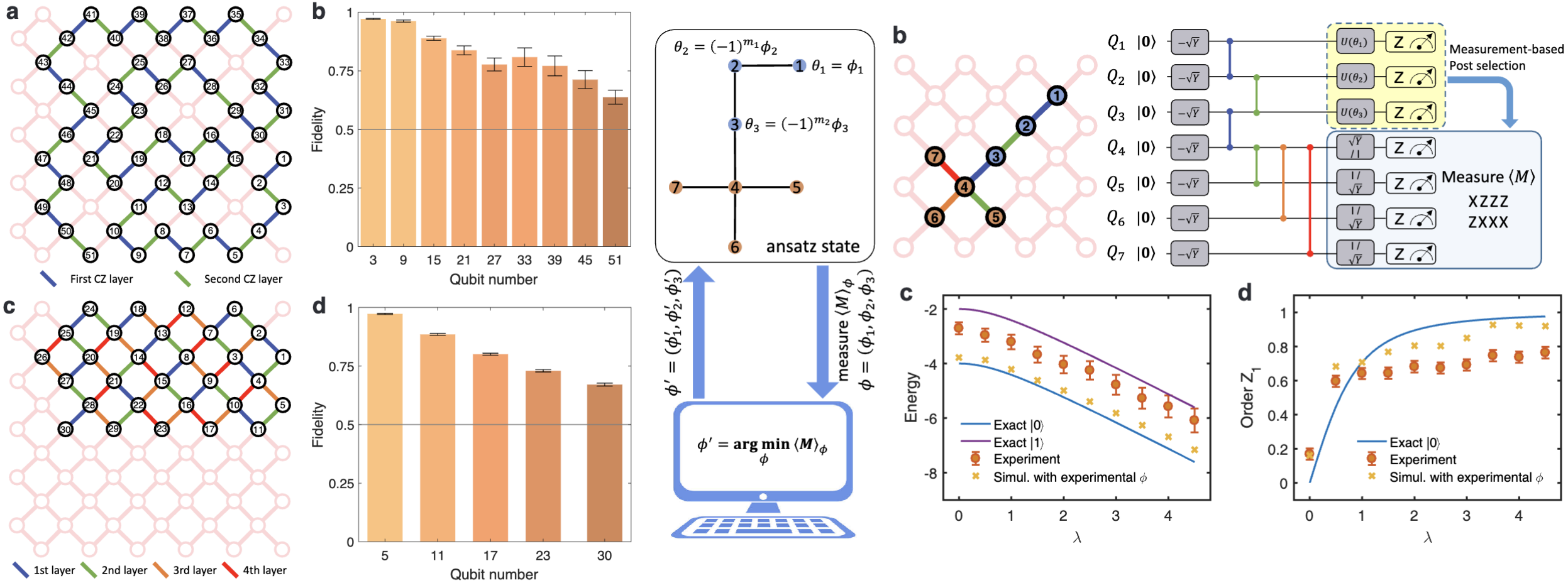
Quantum experiments

Cluster states and MBVQE



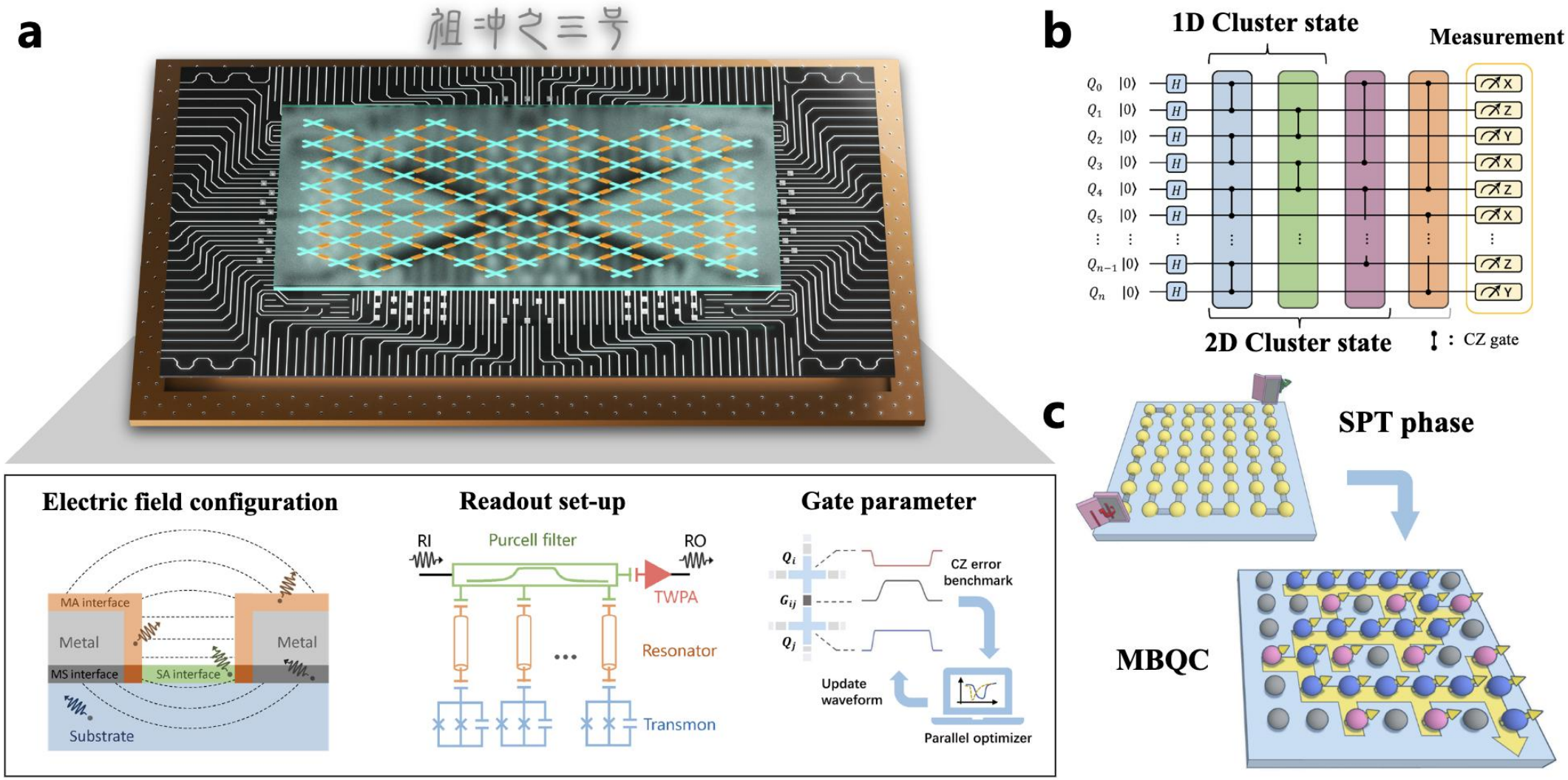
S Cao, ..., **X Yuan***, X Zhu*, J-W Pan*, Nature 619 (7971), 738-742 (2023)

Cluster states and MBVQE



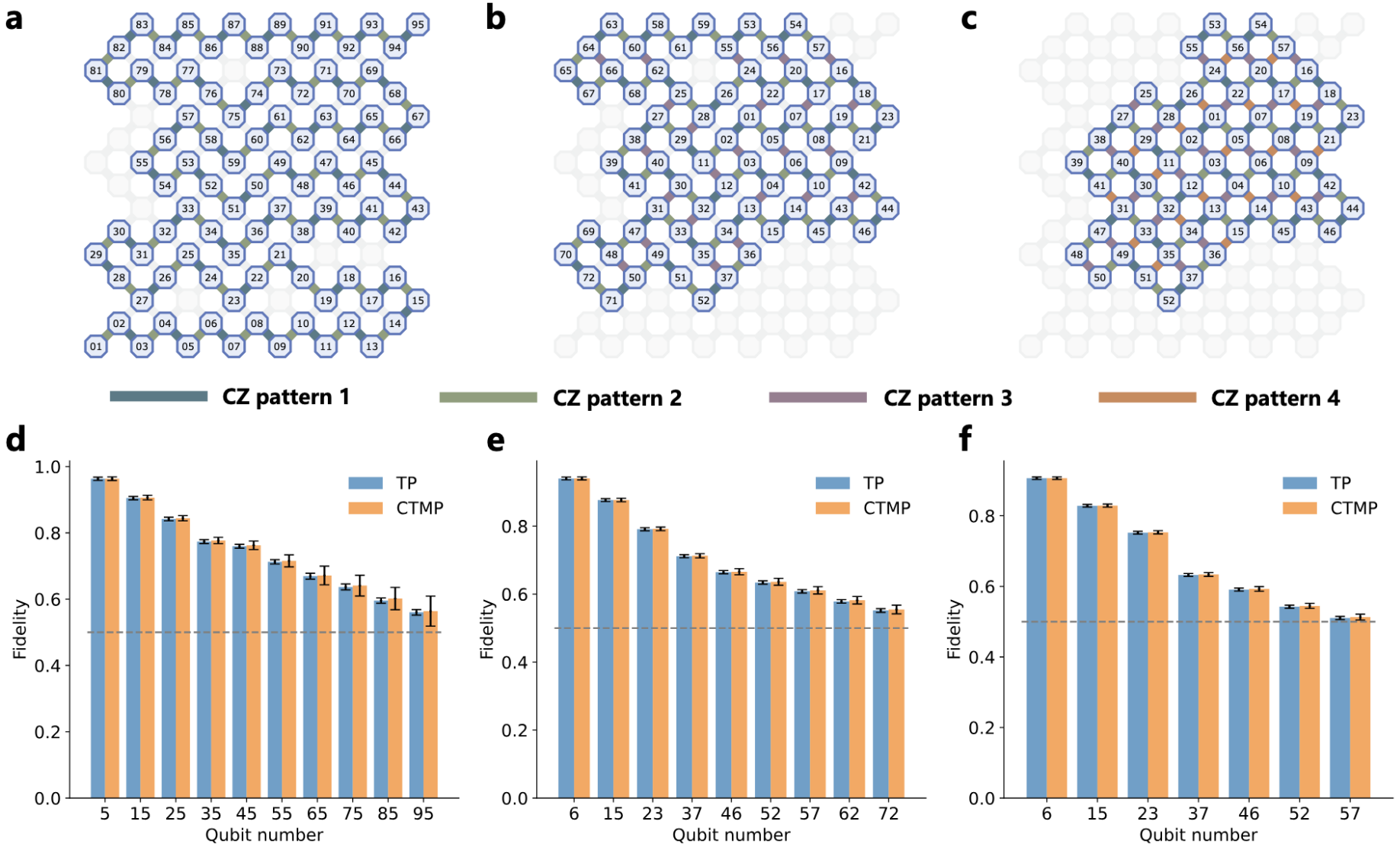
S Cao, ..., **X Yuan***, X Zhu*, J-W Pan*, Nature 619 (7971), 738-742 (2023)

Cluster states and applications



T Jiang …, **X Yuan***, G Ming, X Zhu, J Pan, Accepted by Nature Physics (2026)

Cluster states and applications



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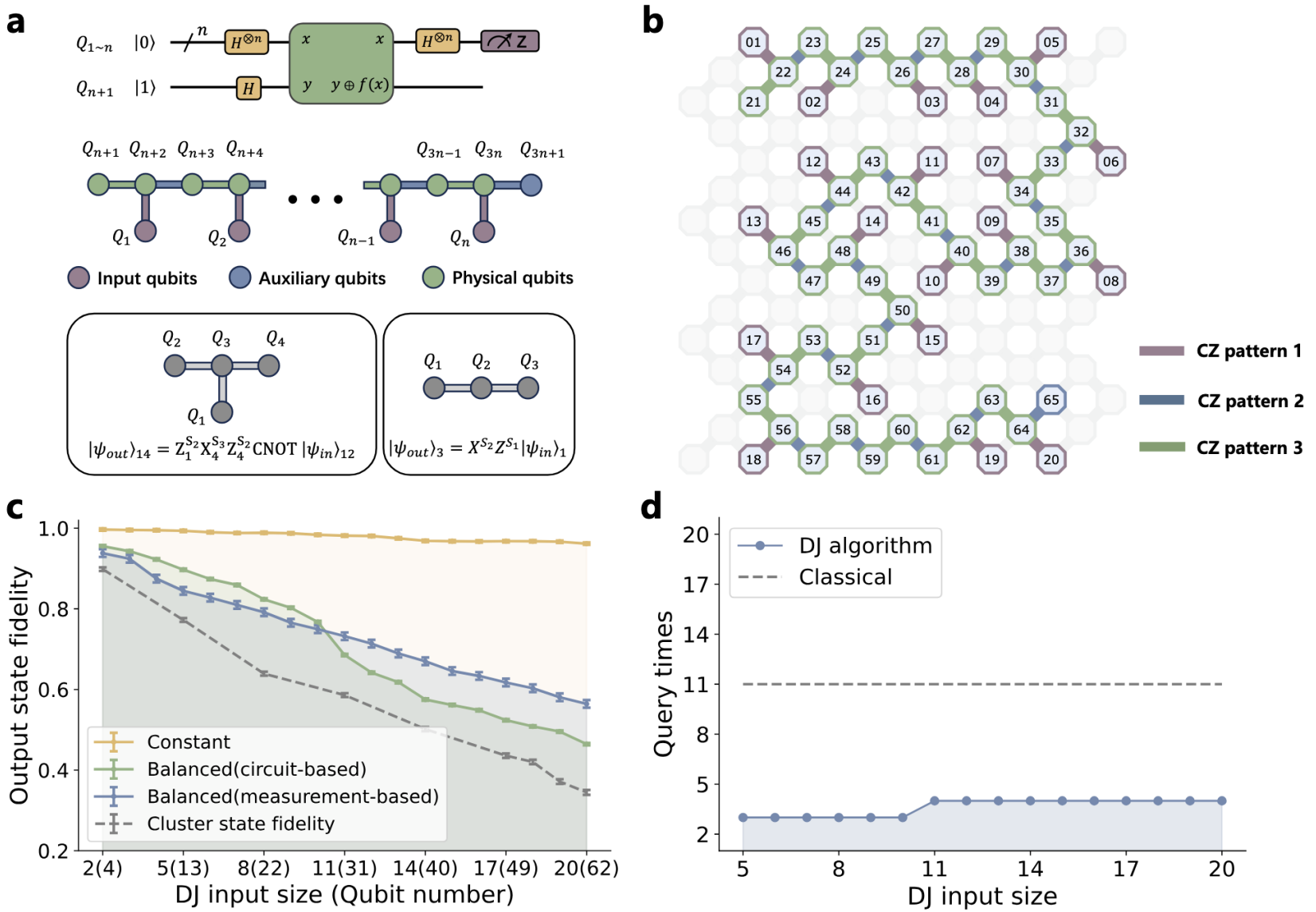
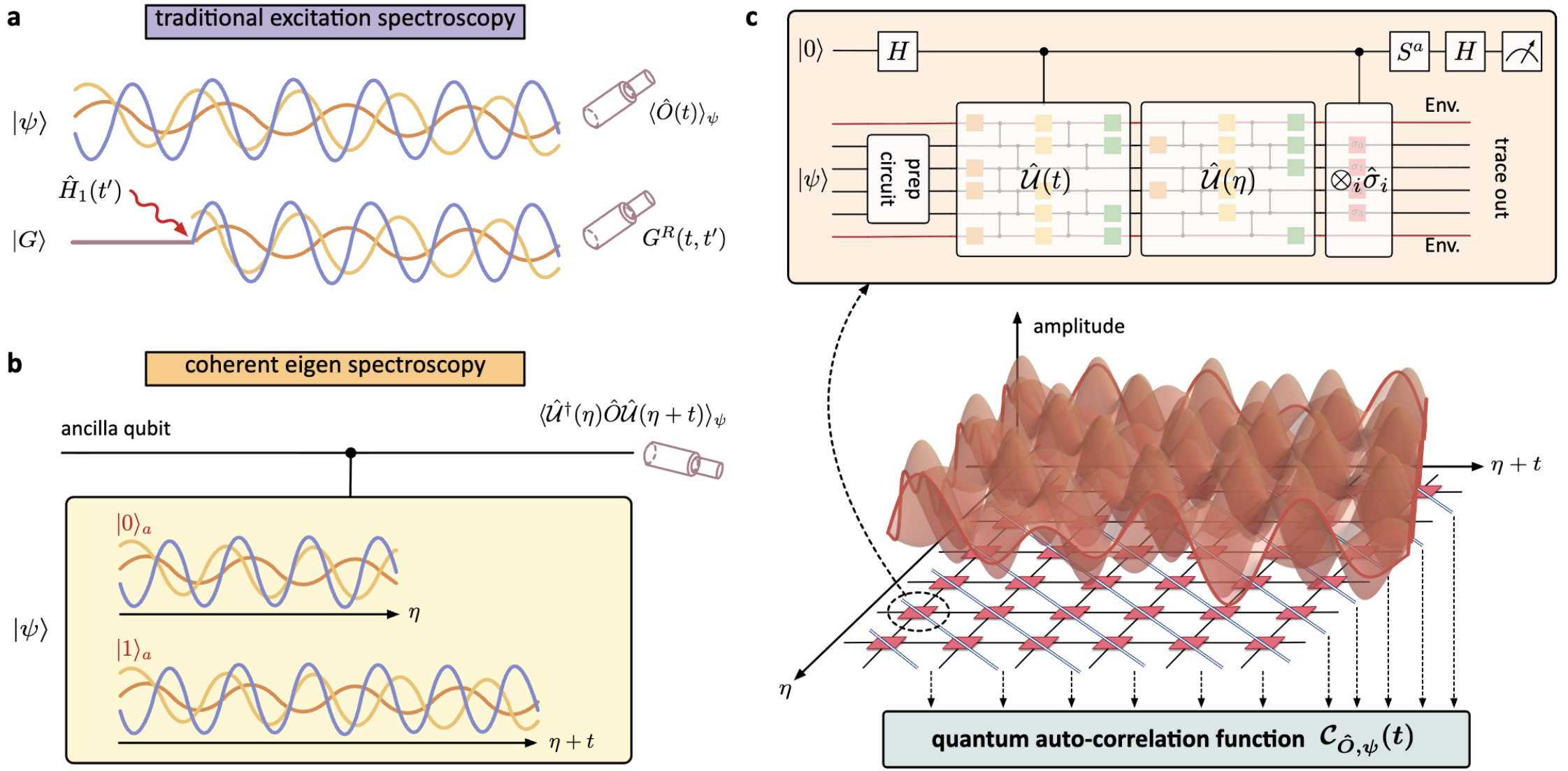
Cluster states and applications



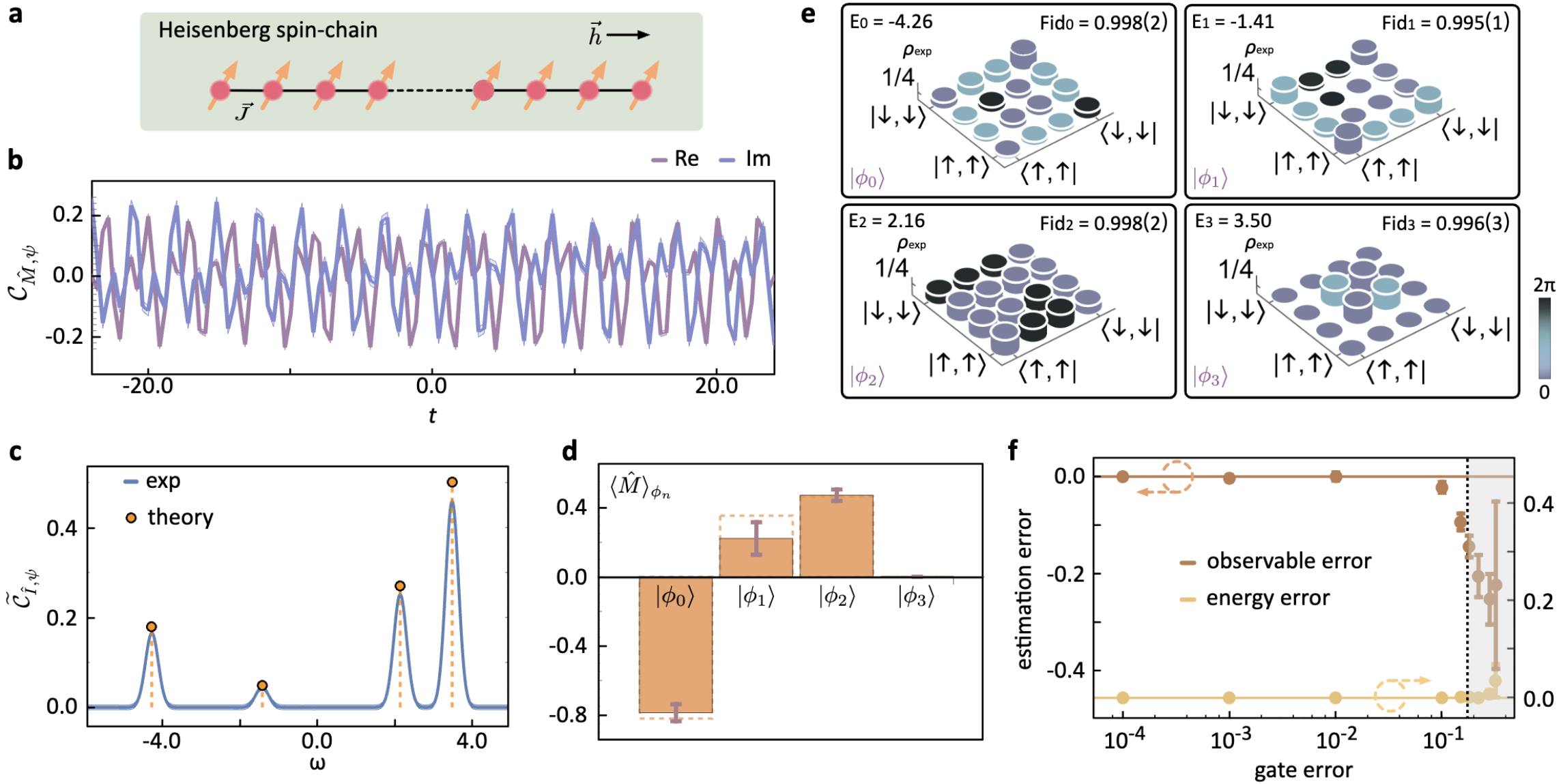
T Jiang …, **X Yuan***, G Ming, X Zhu, J Pan, Accepted by Nature Physics (2026)

Quantum computational spectroscopy



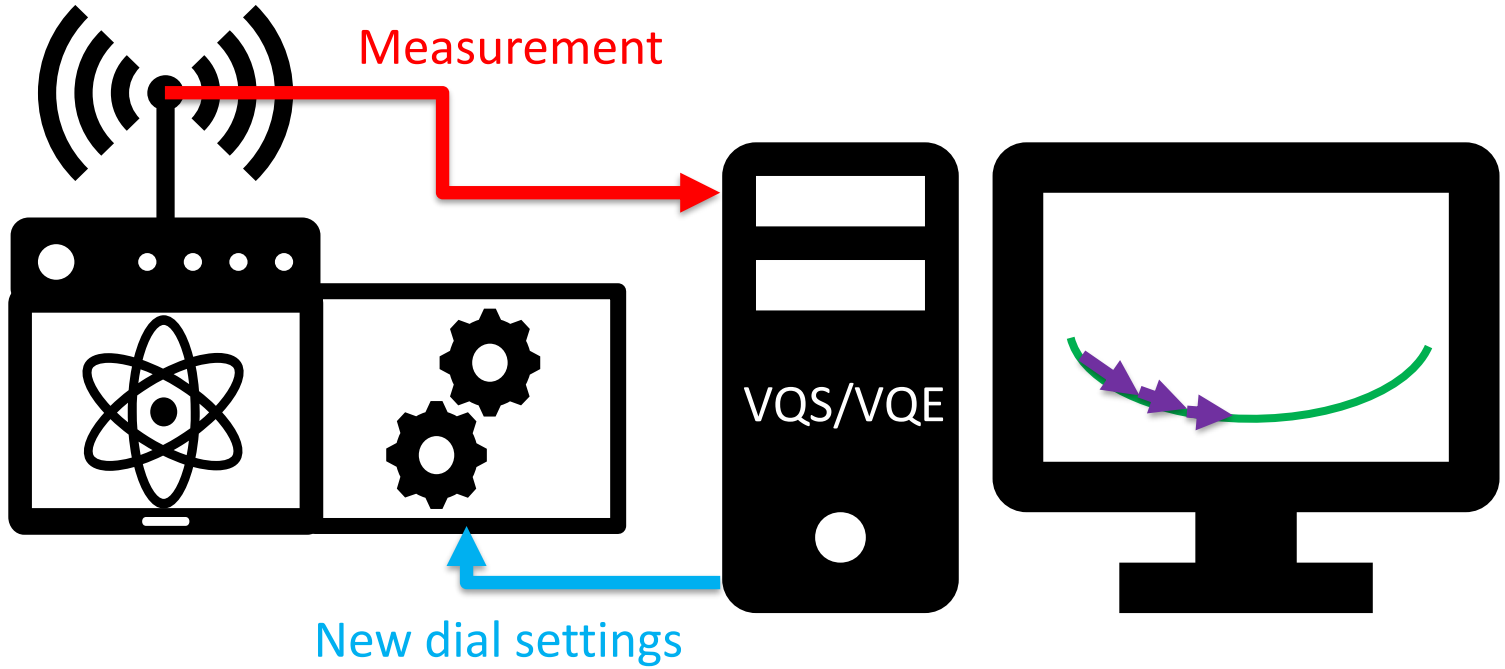
C Zhai, J Sun, J Huang, J Mao, H Bao, S Zhang, Q Gong, V Vedral, **Xiao Yuan***, Jianwei Wang, arXiv:2506.22418 (2025)

Quantum computational spectroscopy



C Zhai, J Sun, J Huang, J Mao, H Bao, S Zhang, Q Gong, V Vedral, **Xiao Yuan***, Jianwei Wang, arXiv:2506.22418 (2025)

Quantum advantage



Major challenges

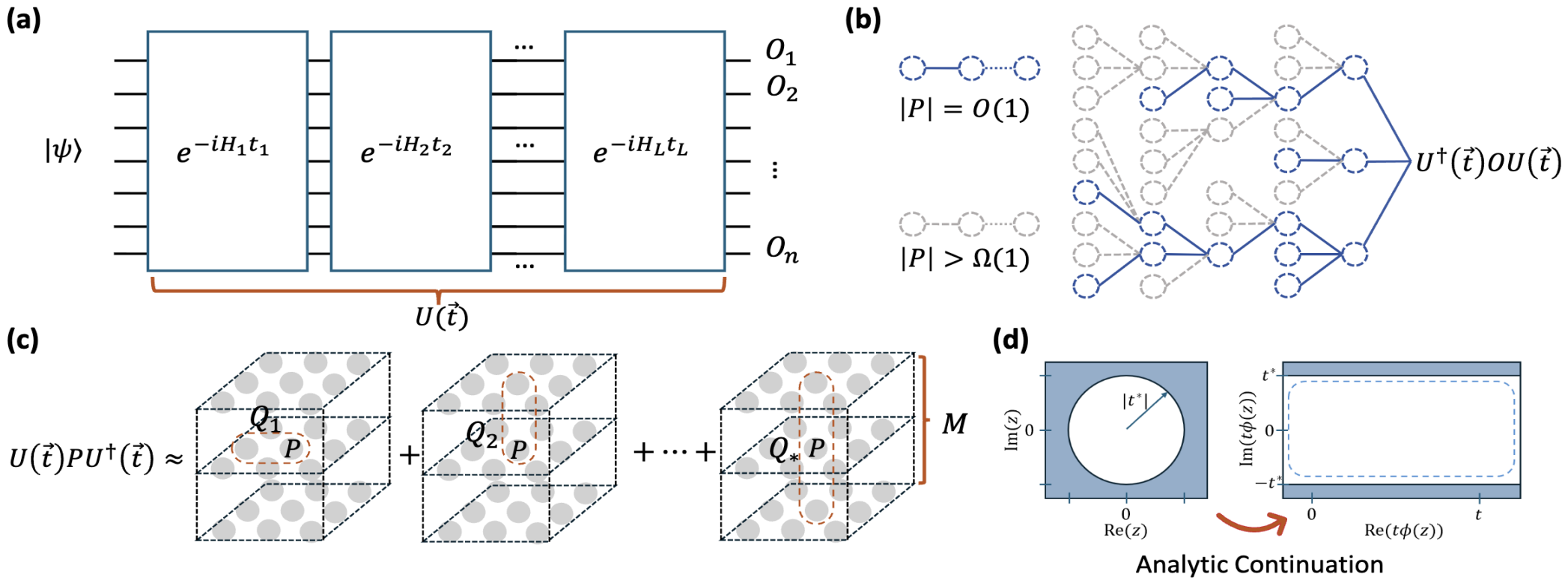
• Ansatz design	Hardware efficient, unitary coupled cluster, Hamiltonian ansatz
• Too many measurements	Measurement reduction via grouping and importance sampling
• Classical optimization (might get trapped in local minima)	Better optimization methods, such as imaginary time evolution
• Barren Plateau	Use problem-specific ansatz and start with a good initial guess
• Noise – error mitigation cost exponentially increase with gate number	Consider a limited number of gates
• Advantage theoretically unclear	Numerically verify

Classical simulation of shallow or noisy quantum circuits

Quantum Circuit	Observables	Task	Run Time
Constant depth, 2D [S. Bravyi, Nat. Phys, 2021]	Any	Mean value	Poly(n)
Constant depth, 3D [S. Bravyi, Nat. Phys, 2021]	Any	Mean value	$O(2^{n^{1/3}})$
Constant depth [S. Bravyi, STOC, 2024]	Positive semidefinite	Probability distribution	$O(n^{\log n})$
Constant depth [R. L. Mann, PRXQuantum 2024]	Close to Identity	Mean value	Poly(n)
Constant time Hamiltonian dynamics [Wu, Zhang, and Yuan, arXiv:2409.04161]	**Any**	**Mean value**	**Poly(n)**

Task	Running Time	Constraints
Sample from a noisy quantum circuit output [D. Aharonov et al., 2023 STOC]	$\mathrm{poly}(n)O(d(1/\epsilon)^{1/q})$	Circuit depth $d \geq \Omega(\log n)$ (Anti-Concentration), Constant-strength (q) local depolarizing channel
Estimate quantum mean values [Y. Shao et al., PRL 2024]	$\mathrm{poly}(n)O(d(\|\|O\|\|_\infty/\epsilon)^{1/q})$	Constant-strength (q) local Pauli channel
Estimate quantum mean values [T. Schuster et al., arXiv: 2407.12768]	$O(dn^{(1/q)\log\left(\frac{\sqrt{d+1}}{\epsilon}\right)-1})$	Constant-strength (q) gate-Based noise

Classical simulation of shallow or noisy quantum circuits



Wu, Zhang, and **Yuan***, arXiv:2409.04161

Guided Local Hamiltonian Problem

The ground-state energy estimation problem is perennial and fundamental problem for both physics and computer science studies.

Definition 1 (Local Hamiltonian problem). *Given as input a k-local Hamiltonian $\hat{H}$ acting on n qudits, specified as a collection of constraints $\left\{\hat{H}_i\right\}_{i=1}^{r} \subseteq \mathcal{H}\left(\mathbb{C}^d\right)^{\otimes k}$ where $k, d \in \Theta(1)$, and threshold parameters $a, b \in \mathbb{R}$, such that $0 \leq a < b$ and $(b-a) \geq 1$, decide, with respect to the complexity measure $\langle H \rangle + \langle a \rangle + \langle b \rangle$:*

1. *If $\lambda_{\min}(\hat{H}) \leq a$, output YES.*
2. *If $\lambda_{\min}(\hat{H}) \geq b$, output NO.*

Yet, the problem is proved to be QMA-complete[1], meaning inefficiency for quantum computing.

Definition 2 (Guided local Hamiltonian problem). *Input: a k-local Hamiltonian $\hat{H}$ acting on n qubits such that $\|\hat{H}\| \leq 1$ query-access to an initial state (density matrix) ρ_I*
Promise: $\|\Pi_0 \rho_I\| \geq \gamma$
Output: an estimate E_0' such that $|E_0' - E_0| \leq \epsilon$

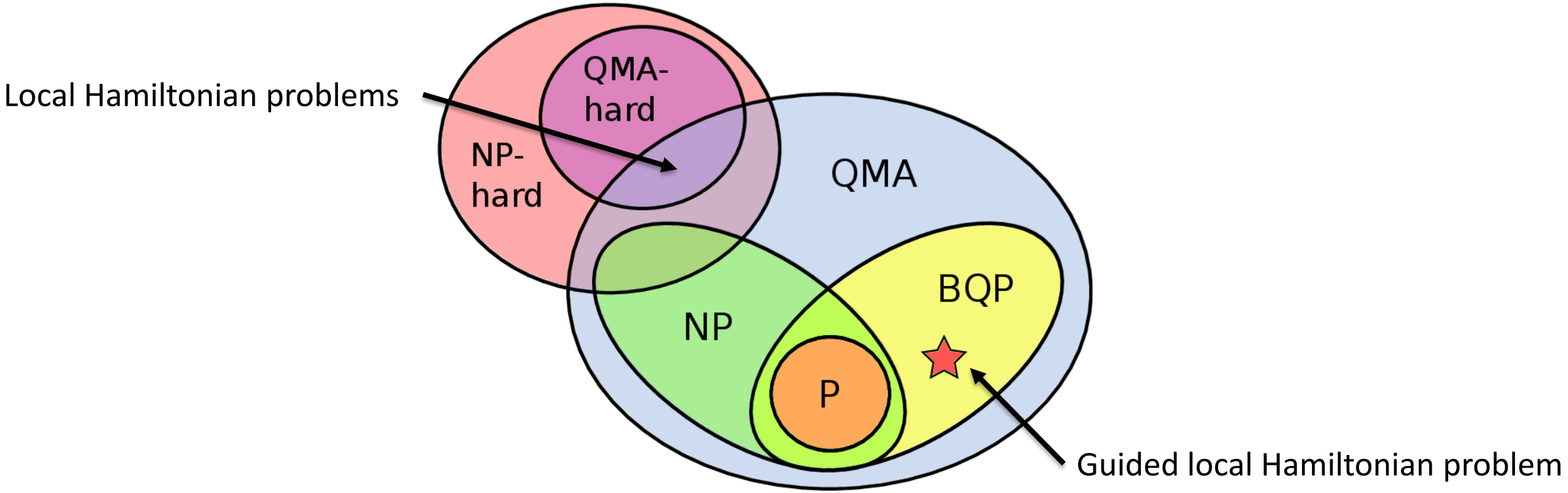
The GLH is proved to be BQP-hard[2], meaning efficiently solvable.

[1] Kiteav et al., (2002) [2]Gharibian, Le Gall STOC (2023)

Dequantization of the GSEE algorithm

The local Hamiltonian problem corresponds to the ground-state problem

The guided local Hamiltonian problem corresponds to the ground-state problem with a nontrivial guiding state



Dequantization of the GSEE algorithm

TABLE I. Comparisons of our results with related previous studies on solving the GLH problem, focusing on accuracy, input constraints, and computational time complexity.

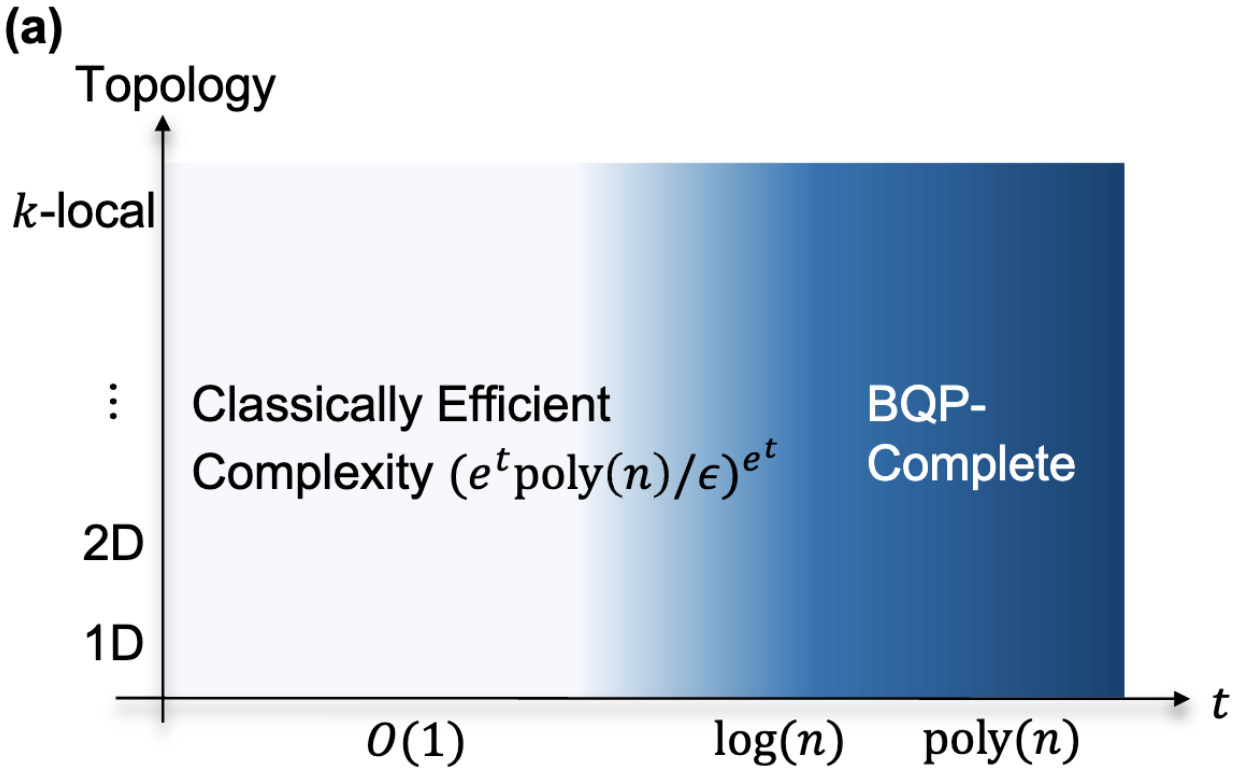
Algorithm	Method	Accuracy	Constraints	Complexity
Refs [24, 25]	—	$\varepsilon = \frac{1}{\text{poly}(n)}$	k-local, $\|H\| \leq 1$, $\gamma \in (\frac{1}{\text{poly}(n)}, 1 - \frac{1}{\text{poly}(n)})$	BQP-complete
Ref [23]	Dequantized QSVT	$\varepsilon = \mathcal{O}(1)$	s-sparse, $\|H\| \leq 1$	$\mathcal{O}\left(\gamma^{-4}(\|S\|\,2^s+1)^{(2+4/\varepsilon)\log(1/\gamma)}\right)$
Ref [26]	Dequantized QSVT	$\varepsilon\|H\| = \mathcal{O}(\|H\|)$	k-local	$(\mathcal{O}(1))^{\log(1/\gamma)/\varepsilon}$
Ref [29]	Dequantized 2D Dynamics	$\varepsilon = \mathcal{O}(1)$	k-local, 2D Symmetry	$\mathcal{O}\left(n^{e^{\log(1/\gamma)/\varepsilon}\log n}\right)$
Theorem 2	Dequantized RQITE	$\varepsilon > \varepsilon^* = \Omega(1)$	k-local	$\varepsilon^{-1}\text{poly}\left[(\|S\|\,\Delta^2\gamma^{-2}\varepsilon^{-1})^{\log(\Delta/(2\varepsilon^*\log(\gamma^{-2}\varepsilon^{-1})))}\right]$
Corollary 1	Dequantized RQITE	$\varepsilon > \varepsilon^*/\|H\|$	k-local, $\tilde{H} = H/\|H\|$	-
Theorem 3	Dequantized RQITE	$\varepsilon = \mathcal{O}(1)$	k-local, $\gamma > 1/\sqrt{2}$, $\mathcal{O}(1)$-dimension	$\mathcal{O}\left((\Delta\varepsilon^{-2}\text{poly}(\|S\|))^{e^{\log(1/(\gamma\varepsilon^2))/\Delta}}\right)$
Corollary 2	Dequantized RQITE	$\varepsilon = \mathcal{O}(1/\|H\|)$	k-local, $\gamma > 1/\sqrt{2}$, $\tilde{H} = H/\|H\|$, $\mathcal{O}(1)$-dimension	-

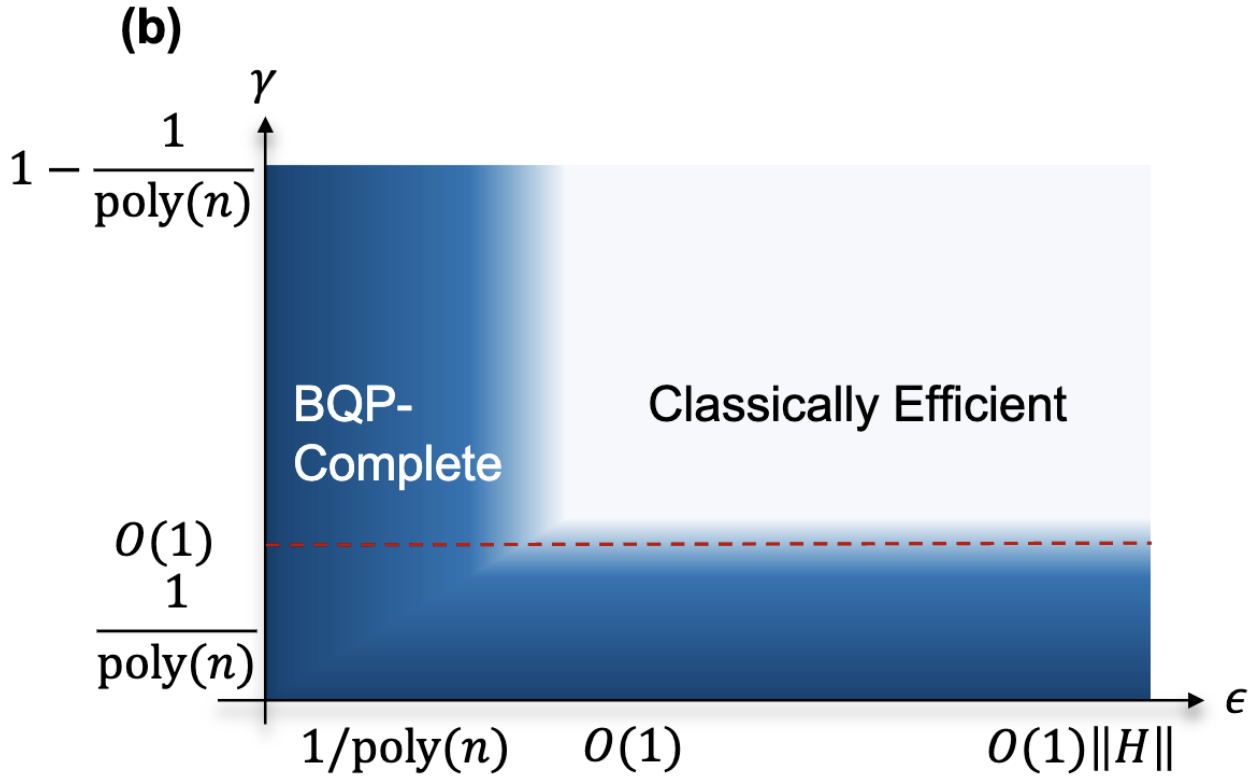
[1]Ghribian and Le Gall, STOC 2022; Zhang, Wu, and **Yuan***, arXiv:2411.16163

Summary for quantum advantages

Dynamic problems: Schrodinger equation $\frac{d|\psi\rangle}{dt} = -iH|\psi\rangle$

Static problem: find the eigenstates of H





Wu, Zhang, and **Yuan***, arXiv:2409.04161; Zhang, Wu, and **Yuan***, arXiv:2411.16163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Center on Frontiers of Computing Studies, Peking University

Thanks!