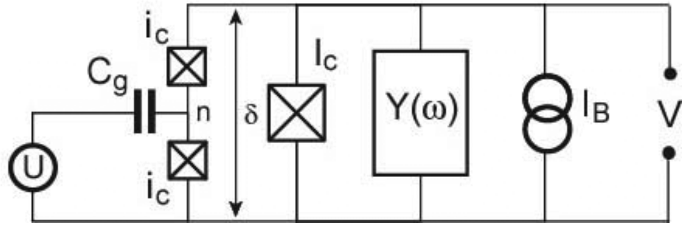
From MQC/MQT 1985
to Qubits 2000
to Nobel Prize 2025
to Quantum Advantage 2045 ?

....

And then what ??

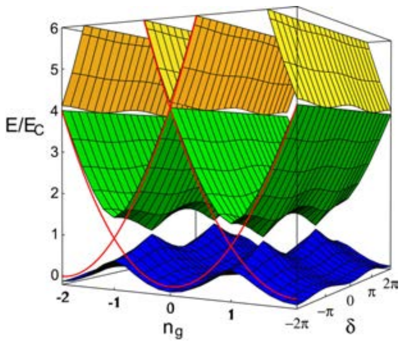
RI.
SE



SQUBIT

Superconducting Qubits:
Quantum Computing with Josephson Junctions

Coordinator:
Göran Wendin, Chalmers



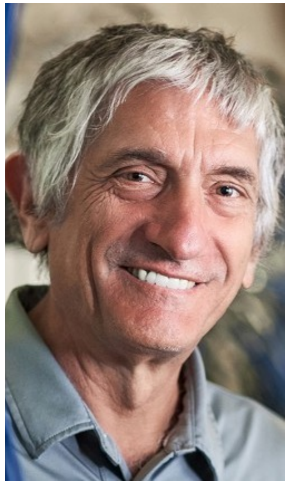
Cooper Pair Box

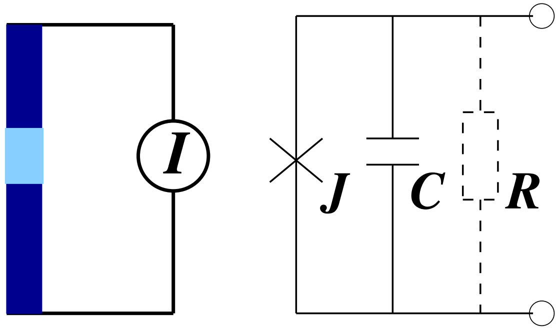
Chalmers	P. Delsing,
	G. Wendin (coord)
Jyväskylä	J. Pekola
KTH	D. Haviland
TU Delft	H. Mooij
Karlsruhe	G. Schön
CEA Saclay	M. Devoret
ISI-Torino/Catania	R. Fazio

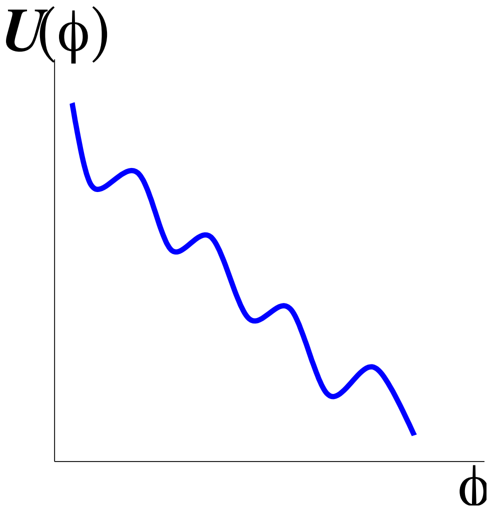
Now Google!

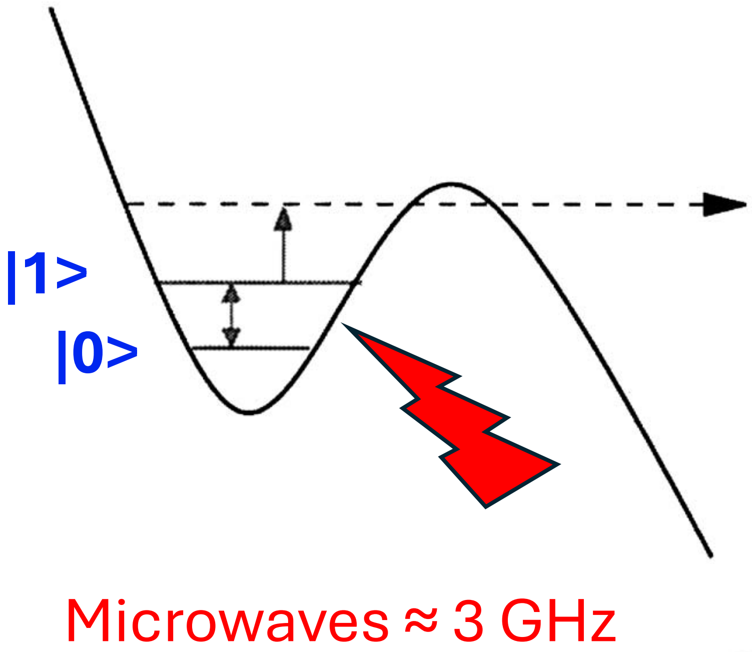
IST-1999-10673 - SQUBIT
Project funded by the Future and Emerging Technologies arm of the IST-FET-QIPC proactive initiative

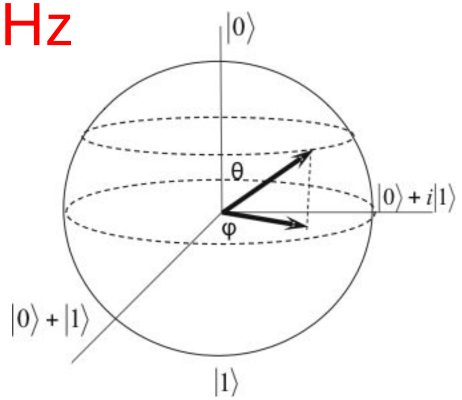
John Martinis' JJ-qubit (2003-2007)











When **T → 0** (thermal energy $k_BT \rightarrow 0$)
the "particle" becomes trapped (MQC)
before tunneling out through the JJ barrier (MQT)
→ Sharp, long-lived qubit levels

2014 – At the threshold for scaling up

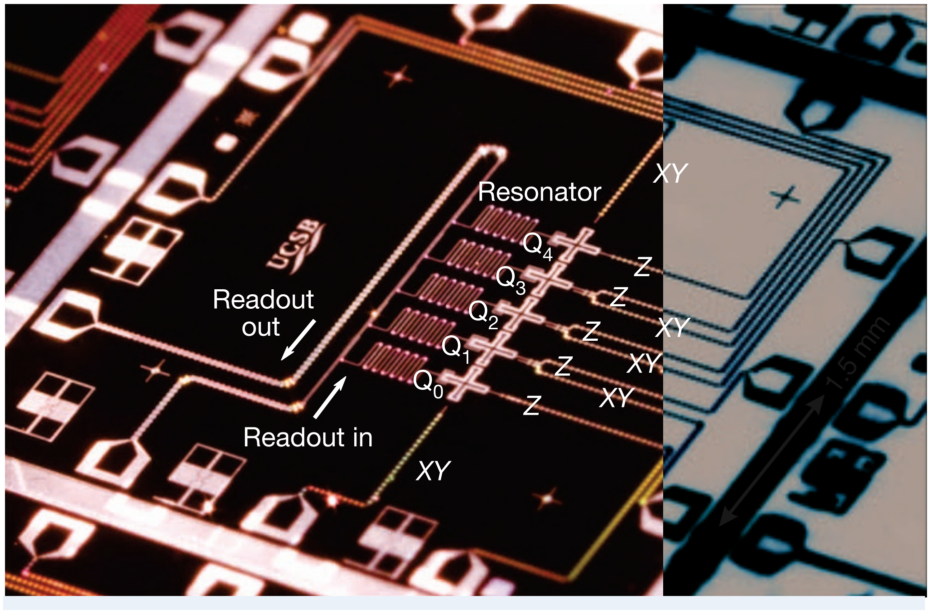
Superconducting quantum circuits at the surface code threshold for fault tolerance

John Martinis UCSB

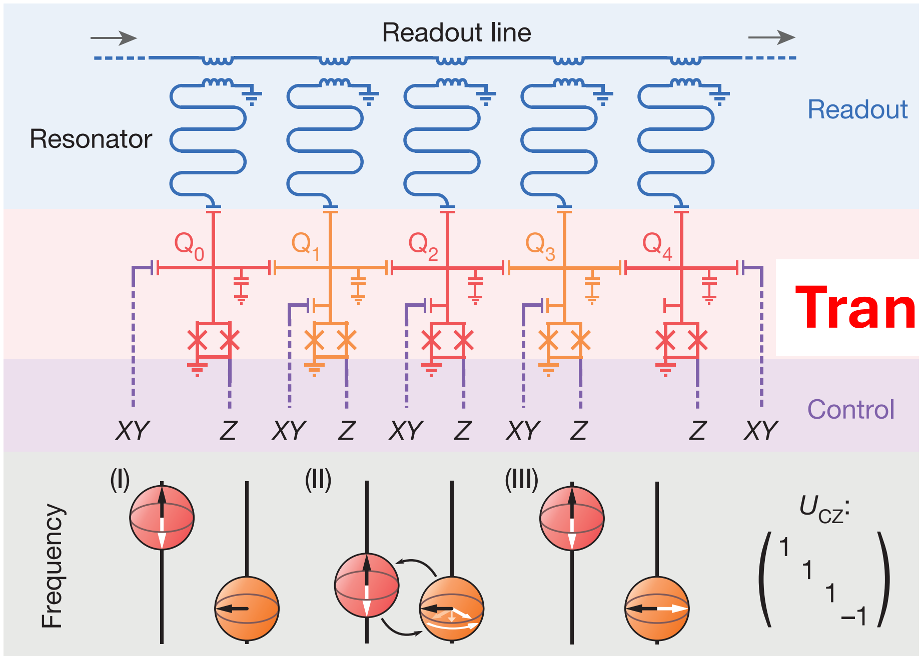
R. Barends[1]*, J. Kelly[1]*, A. Megrant[1], A. Veitia[2], D. Sank[1], E. Jeffrey[1], T. C. White[1], J. Mutus[1], A. G. Fowler[1,3], B. Campbell[1], Y. Chen[1], Z. Chen[1], B. Chiaro[1], A. Dunsworth[1], C. Neill[1], P. O'Malley[1], P. Roushan[1], A. Vainsencher[1], J. Wenner[1], A. N. Korotkov[2], A. N. Cleland[1] & John M. Martinis[1]

500 | NATURE | VOL 508 | 24 APRIL 2014

a



b



c

Transmons

2014 – At the threshold for scaling up

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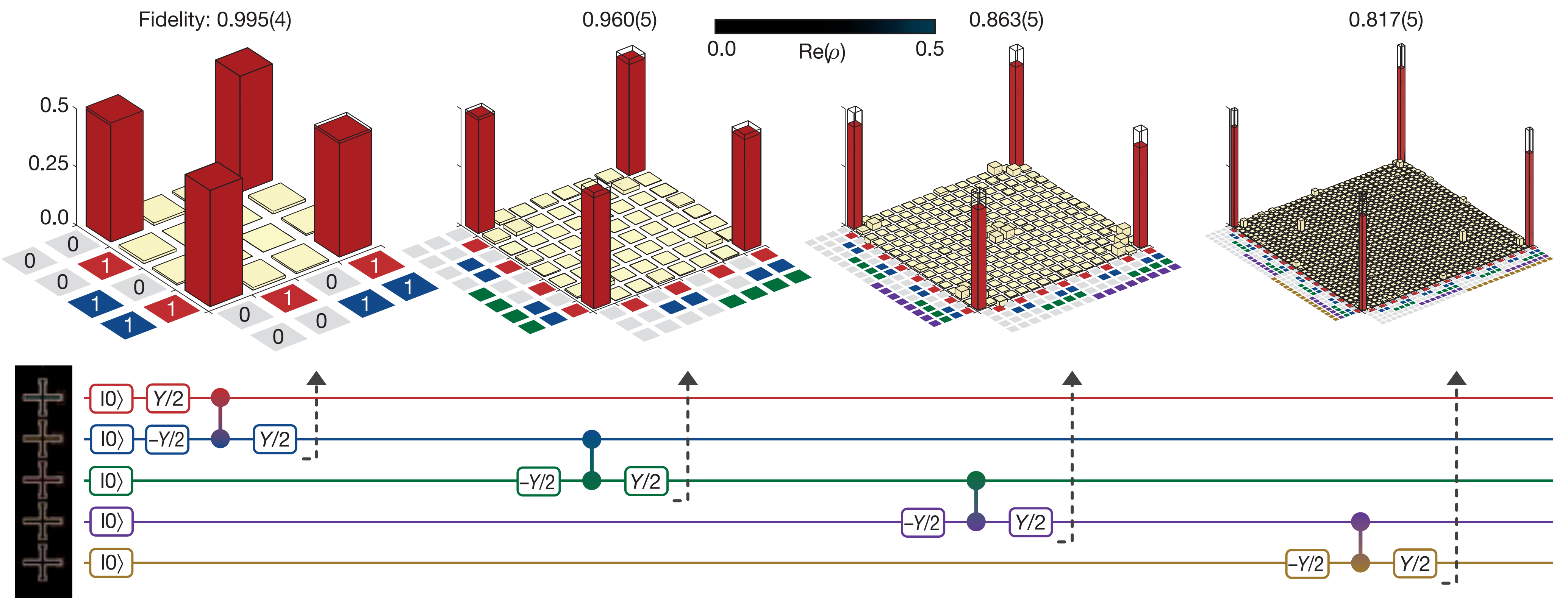
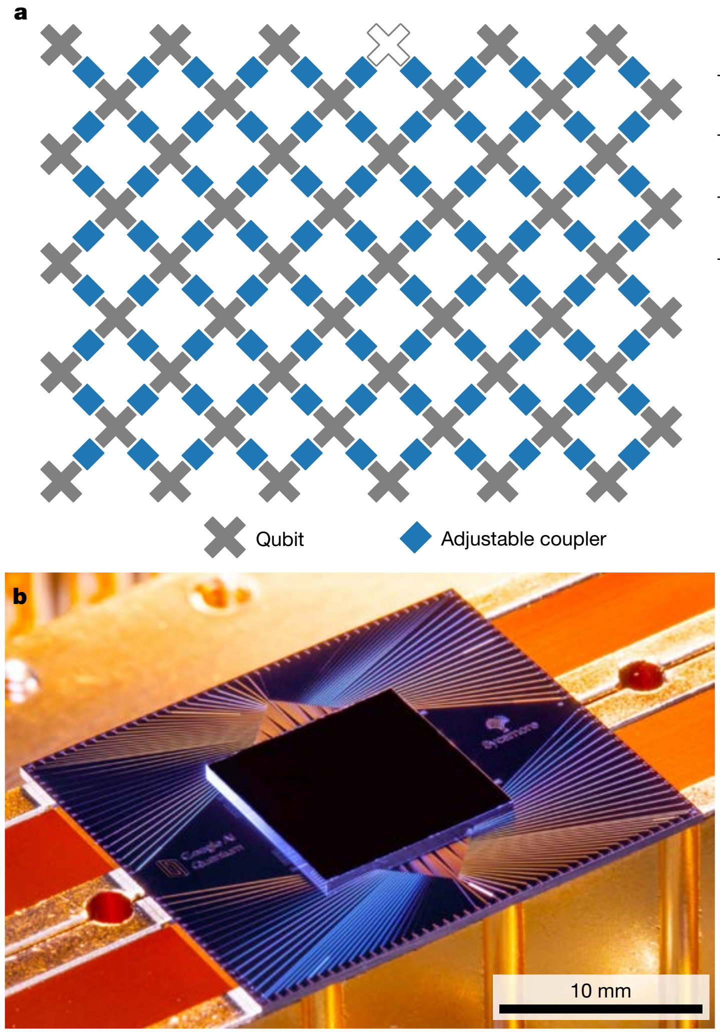


Gate fidelities: **1q, 99.92**; **2q, 99.4**

"5-qubit entanglement"
After millions of tries !!

Quantum supremacy using a programmable superconducting processor

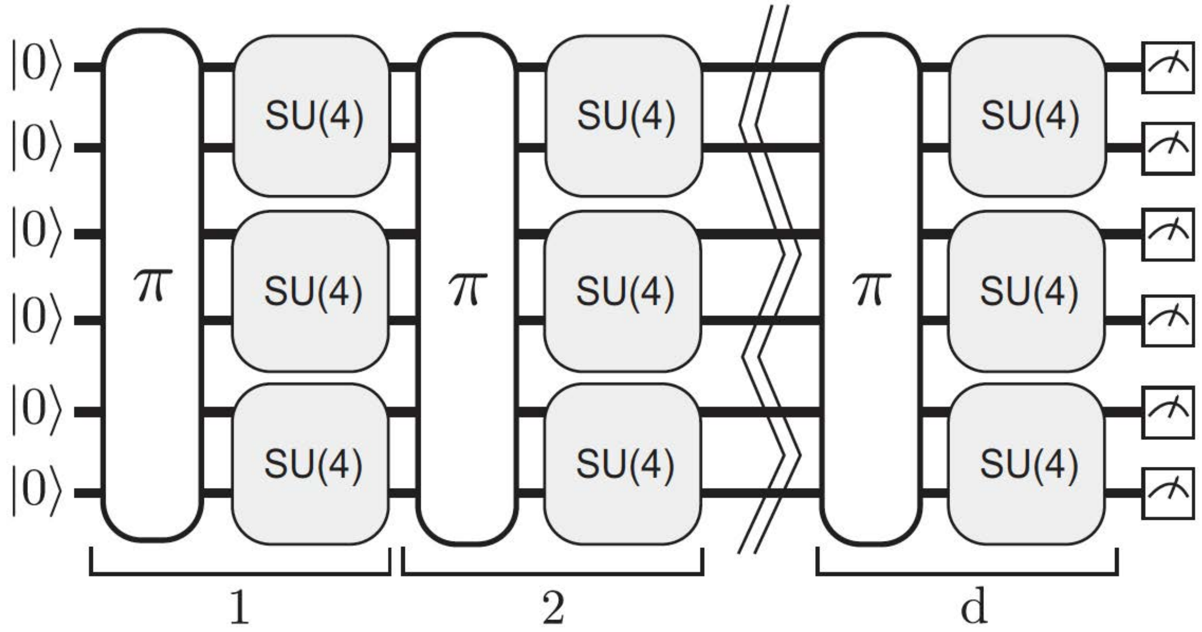


Frank Arute[1], Kunal Arya[1], Ryan Babbush[1], Dave Bacon[1], Joseph C. Bardin[1,2], Rami Barends[1], Rupak Biswas[3], Sergio Boixo[1], Fernando G. S. L. Brandao[1,4], David A. Buell[1], Brian Burkett[1], Yu Chen[1], Zijun Chen[1], Ben Chiaro[5], Roberto Collins[1], William Courtney[1], Andrew Dunsworth[1], Edward Farhi[1], Brooks Foxen[1,5], Austin Fowler[1], Craig Gidney[1], Marissa Giustina[1], Rob Graff[1], Keith Guerin[1], Steve Habegger[1], Matthew P. Harrigan[1], Michael J. Hartmann[1,6], Alan Ho[1], Markus Hoffmann[1], Trent Huang[1], Travis S. Humble[7], Sergei V. Isakov[1], Evan Jeffrey[1], Zhang Jiang[1], Dvir Kafri[1], Kostyantyn Kechedzhi[1], Julian Kelly[1], Paul V. Klimov[1], Sergey Knysh[1], Alexander Korotkov[1,8], Fedor Kostritsa[1], David Landhuis[1], Mike Lindmark[1], Erik Lucero[1], Dmitry Lyakh[9], Salvatore Mandrà[3,10], Jarrod R. McClean[1], Matthew McEwen[5], Anthony Megrant[1], Xiao Mi[1], Kristel Michielsen[11,12], Masoud Mohseni[1], Josh Mutus[1], Ofer Naaman[1], Matthew Neeley[1], Charles Neill[1], Murphy Yuezhen Niu[1], Eric Ostby[1], Andre Petukhov[1], John C. Platt[1], Chris Quintana[1], Eleanor G. Rieffel[3], Pedram Roushan[1], Nicholas C. Rubin[1], Daniel Sank[1], Kevin J. Satzinger[1], Vadim Smelyanskiy[1], Kevin J. Sung[1,13], Matthew D. Trevithick[1], Amit Vainsencher[1], Benjamin Villalonga[1,14], Theodore White[1], Z. Jamie Yao[1], Ping Yeh[1], Adam Zalcman[1], Hartmut Neven[1] & John M. Martinis[1,5]*

Nature | Vol 574 | 24 OCTOBER 2019 | **505**

John M. Martinis, Google

Quantum Volume (QV) (IBM 2019)



IBM, IQM:
N= 8-10

Quantinuum:
N= 25

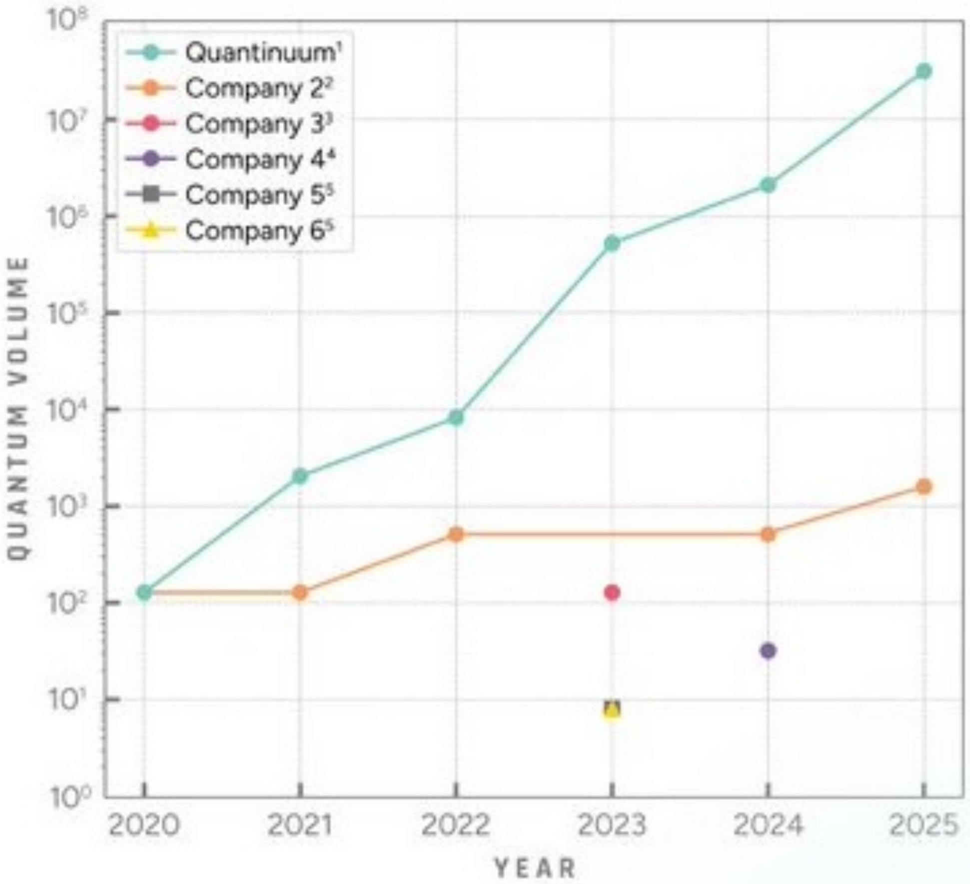
QV = 2^N
Size of the state space!

The definition of QV: $d = N$

Quantinuum Sets New World Record in Quantum Volume

Quantum Volume:

2^{25} = 33,554,432



QUANTINUUM

Simulating physical systems on engineered quantum platforms

Quantum information scrambling:
Quantum scrambling is the
dispersal of local information
into many-body quantum entanglements and correlations distributed throughout an entire system, leading to the
loss of local recoverability of quantum information

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SE

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Quantum information scrambling:

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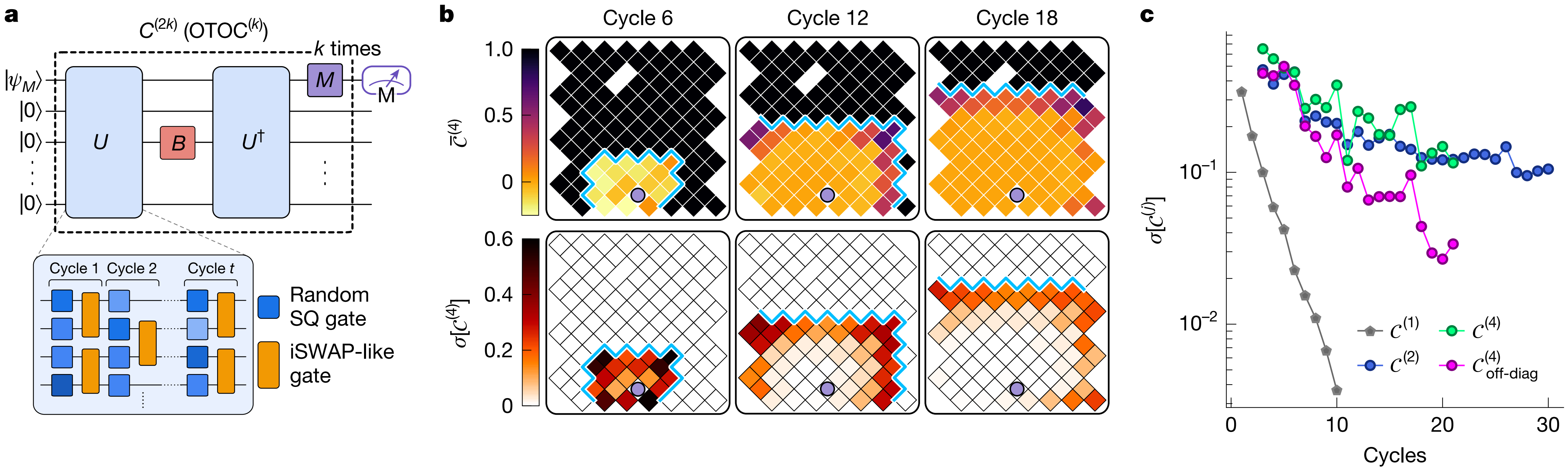
Observation of constructive interference at the edge of quantum ergodicity

Nature | Vol 646 | 23 October 2025 | **829**

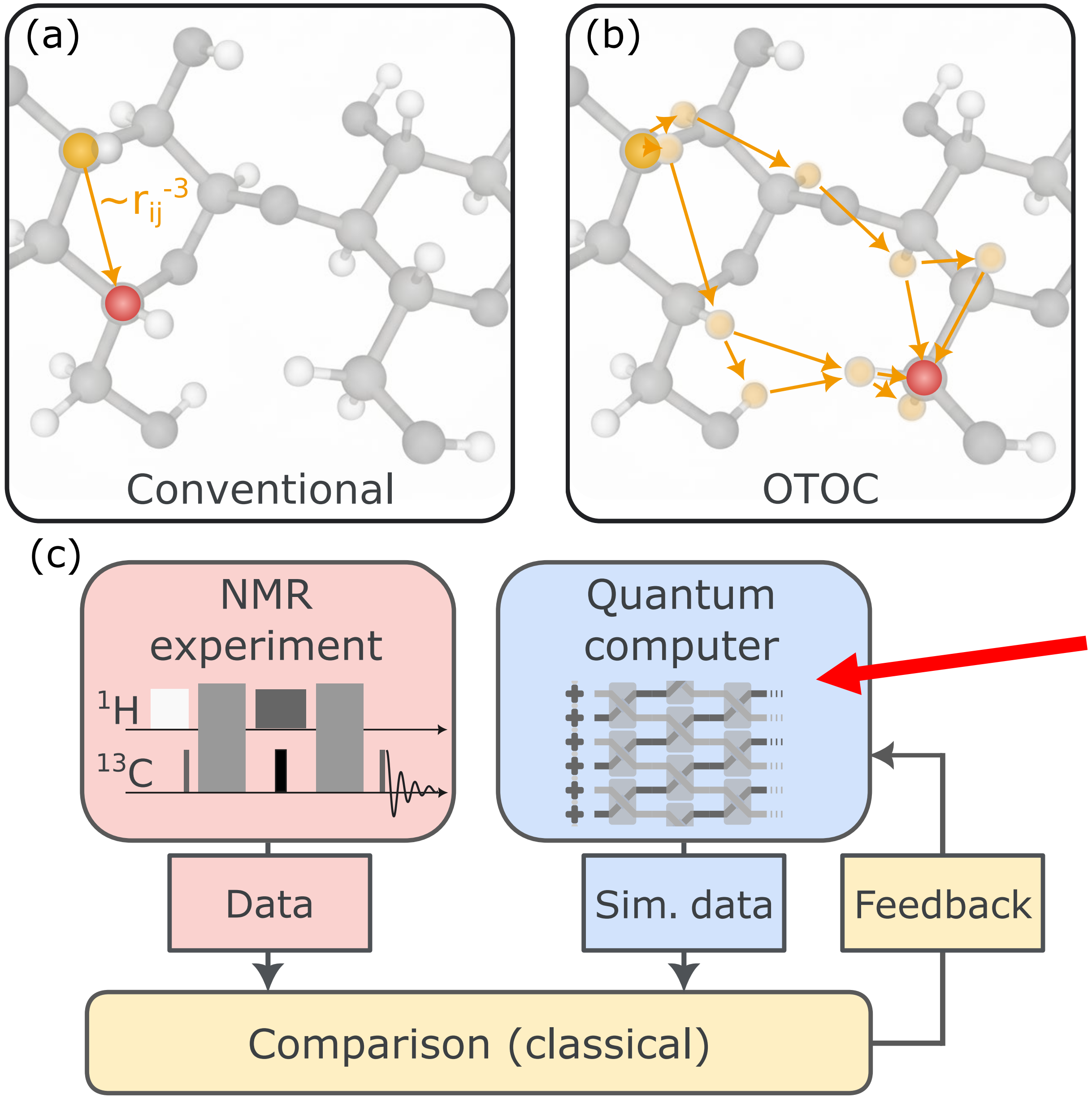
Google



$$C = \langle|\hat{O}^*(t)\hat{M}^*\hat{O}(t)\hat{M}|\rangle$$

Quantum computation of molecular geometry via many-body nuclear spin echoes

Google 2025



$$C = \langle | \hat{O}^*(t) \hat{M}^* \hat{O}(t) \hat{M} | \rangle$$

Quantum Digital Twin !!

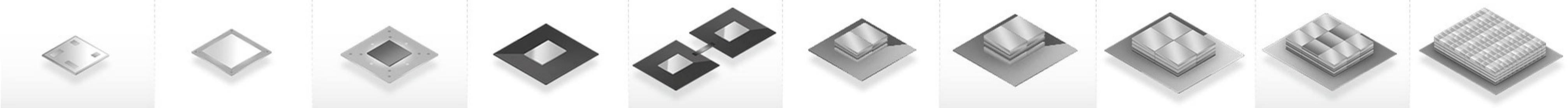
	2022	2023	2024	2025	2026	2027	2028	2030	2031	2033+

	Foundation		Quantum Utility	Quantum Advantage
Simulation $28bn value in 2030	System benchmarking, noise characterisation	Short to medium-sized molecular simulations (e.g., H2O, LiH, BeH2) and simulations of Ising and fermion models Proof of concept: simulation of battery electrolytes	Medium size molecular simulations and new quantum materials for battery optimization and carbon capture	Drug discovery, catalyst and fertilizers design, carbon capture Development of novel quantum materials, battery materials and energy storage
Optimization $18bn value in 2030		Proof of concept: power plant maintenance scheduling, Product portfolio optimization, train scheduling	Medium size problems: portfolio optimization, traveling salesperson and graph coloring problems	Advanced logistics and routing, energy grid optimization, risk management, infrastructure planning, telecom and data center management Global supply chain and transport, global energy systems
Quantum Machine Learning $26bn value in 2030		Proof of concept: predicting chemical reaction behaviour, fraud detection	Anomaly detection, feature selection, quantum data encoding, drug discovery, image generation	Bio data generation for training, drug-discovery, personalized medicine, complex market dynamics modelling, optimizing trading strategies, smart cities and autonomous systems

Software Platform

- Stand-alone algorithm execution
- Loose HPC integration
- Pulse-level access
- HPC integration guidebook
- Tight HPC integration
- Realtime encoding of QLDPC code
- Open architecture and programming framework for developers and partners

Processor Layout



	NISQ					QEC Demonstrators		Fault Tolerance		
	2022	2023	2024	2025	2026	2027	2028	2030	2031	2033+
Performance	99.8%	99.8%	99.9%	99.92%	99.94%	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}
	Two-qubit gate fidelity					Logical error rate				
Qubit count – Crystal Topology	5	20	54	150	300 (150 × 2)	1k	5k	40k	100k	1M
Qubit count – Star Topology			6	24, 46	150					
Logical qubits	Testbeds for 1-2 logical qubits					4-36	60-180	240-720	600-1800	2400-7200

Development roadmap

QUANTINUUM

	2020	2023	2025	2027	2029
SYSTEMS:	SYSTEM MODEL H1	SYSTEM MODEL H2	QUANTINUUM HELIOS	QUANTINUUM SOL	QUANTINUUM APOLLO
PHYSICAL QUBITS:	20	56	96	192	1000's
PHYSICAL 2-QUBIT GATE ERROR:	1×10^{-3}	1×10^{-3}	$< 5 \times 10^{-4}$	$< 2 \times 10^{-4}$	1×10^{-4}
LOGICAL QUBITS:		> 12	~ 50	~ 100	100's
LOGICAL ERROR RATES:		1×10^{-3}	$< 10^{-4}$	$\sim 10^{-5}$	1×10^{-5} to 1×10^{-10}*

*analysis based on recent literature in new, novel error correcting codes predict that error could be as low as 1E-10 in Apollo (ref: arXiv:2403.16054, arXiv:2308.07915)

2025

64-100+ Physical Qubits

99.99% Physical Qubit Fidelity

- All-to-All Connectivity
- Microwave Gate Operations
- 2D Qubit Array
- Mid-Circuit Measurement
- Parallel Operations

2026

100-256+ Physical Qubits

99.99% Physical Qubit Fidelity

12 Logical Qubits

<1.00E-7 Logical Error Rate

- All-to-All Connectivity
- Microwave Gate Operations
- 2D Qubit Array
- Mid-Circuit Measurement
- Parallel Operations

2027

10,000 Physical Qubits

99.99% Physical Qubit Fidelity

800 Logical Qubits

<1.00E-7 Logical Error Rate

- All-to-All Connectivity
- Microwave Gate Operations
- 2D Qubit Array
- Mid-Circuit Measurement
- Parallel Operations

2028

20,000 Physical Qubits

99.99% Physical Qubit Fidelity

1,600 Logical Qubits

<1.00E-7 Logical Error Rate

- All-to-All Connectivity
- Microwave Gate Operations
- 2D Qubit Array
- Mid-Circuit Measurement
- Photonic Interconnect
- Parallel Operations

Quantum Computing Benchmarks: Top Specs by Architecture

	QUANTINUUM QCCD	SUPERCONDUCTING	NEUTRAL ATOM
QUBIT TYPE	Ion (charged atom)	Transmon	Neutral Atom
ARCHITECTURE	Quantum Charge-coupled Device	Fixed 2D grid	Neutral atom tweezer array
IDENTICAL QUBITS	Yes	No	Yes
CONNECTIVITY	All-to-all	Nearest-neighbor	All-to-all
MID-CIRCUIT MEASUREMENT AND RE-USE (DEMONSTRATED)	Yes	Yes	Yes
QUANTUM VOLUME [1] [2]	8,388,608	512	Not published
2 QUBIT GATE ERROR RATE [3] [4] [5]	0.9×10^{-3}	1.4×10^{-3}	4.8×10^{-3}
1 QUBIT GATE ERROR RATE [6] [7] [8]	0.199×10^{-4}	3.5×10^{-4}	2.2×10^{-4}

STATE PREP AND MEASUREMENT (SPAM) ERROR (%) [9] [10] [11]	0.15	0.67	0.6
COHERENCE TIME (μS) [12] [13] [14]	~1,000,000	<100	~1,000,000
LOGICAL ERROR RATE PER ERROR CORRECTION ROUND (%) (DEMONSTRATED) [12] [13] [14]	0.022	0.143	4.9
2 QUBIT GATE TIME (μS), INCLUDING TRANSPORT OVERHEADS [15] [16] [17]	~2000	0.068	~3
CONDITIONAL LOGIC? [18] [19] [20]	Yes	Yes	Yes
PARAMETERIZED ANGLE GATES [20] [21]	Yes	Yes	No
REAL-TIME DECODING [22] [23]	Yes	Yes	No

1. **Quantum Benchmarks: QV versus …. ?**
2. **Are the roadmaps realistic – FTQC around the corner.**
3. **Who is creating all the Q-hype ?**
4. **QA for physical experiments but not for digital computation ?**
5. **Role of AI: AI-4-QC / QC-4-AI (QML) ?**
6. **Q-integration: Q-sensors + QIP + Qcomm + …..**
7. **2045 – where are we ?**
8. **Quantum Evolution or Revolution ?**

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