UNIVERSITÉ DE MONTPELLIER

General introduction to the Quantum Computing landscape

Kenneth MAUSSANG

6 novembre 2024

Ice breaker (Wooclap)

Quantum hype

Buzz word or reality?

PRESENTED BY
TIME 2030
← BACK TO HOME

Quantum Computers Could Solve Countless Problems—And Create a Lot of New Ones

Feb. 2023

https://time.com/6249784/quantum-computing-revolution

IONQ

Products Company Resources Careers Blog Sign In **Get Started**

NEWS IonQ's Most Powerful Quantum System, IonQ Forte, Now Available through the Amazon Braket Direct Program ▶

The future is quantum.

Quantum computing has the potential to change the world, and IonQ is leading the way.

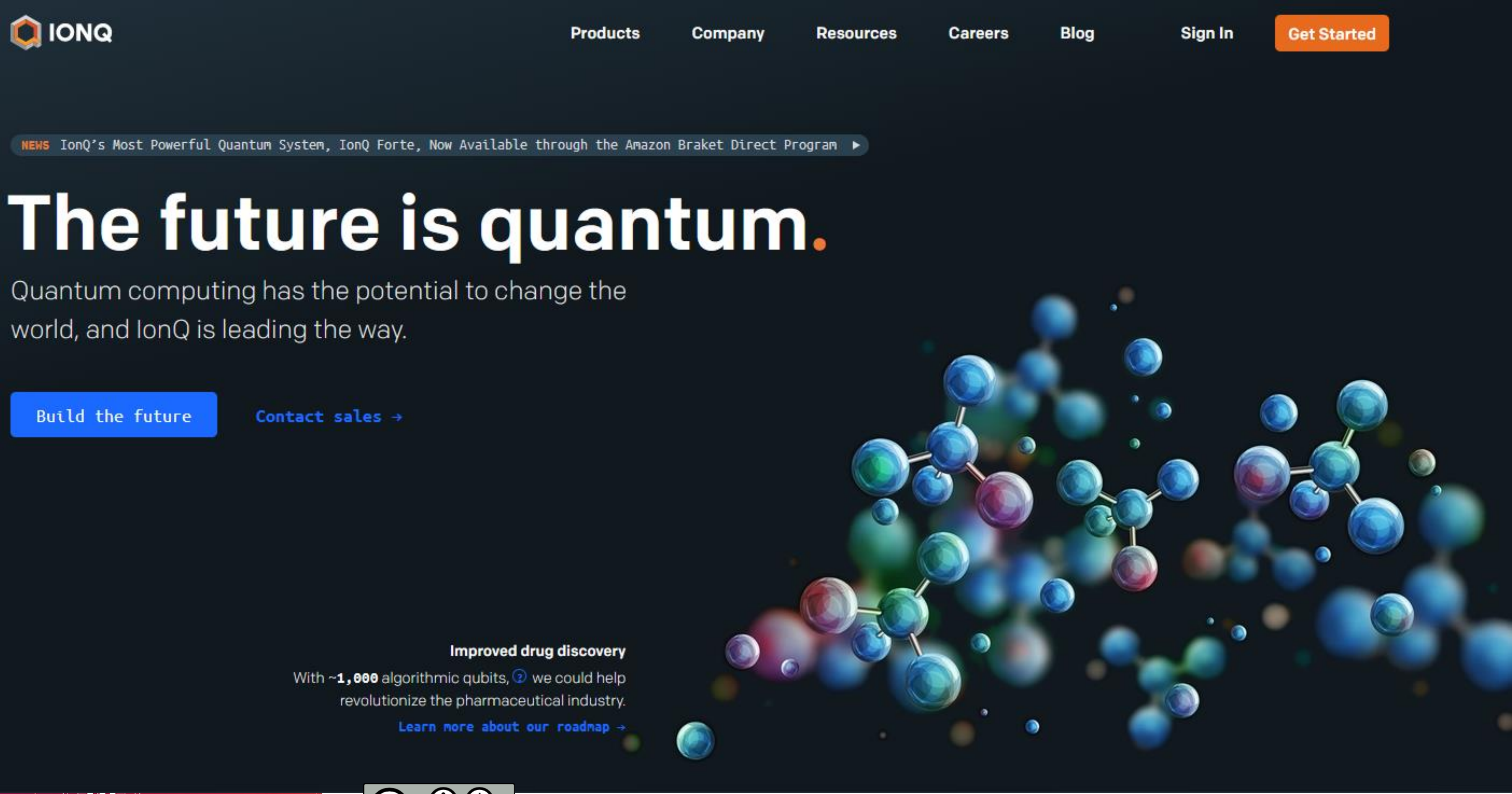
Build the future

Contact sales →

Better battery materials

With ~**250** algorithmic qubits, we could help extend the range and usefulness of electric vehicles.

Learn more about our roadmap →


IONQ
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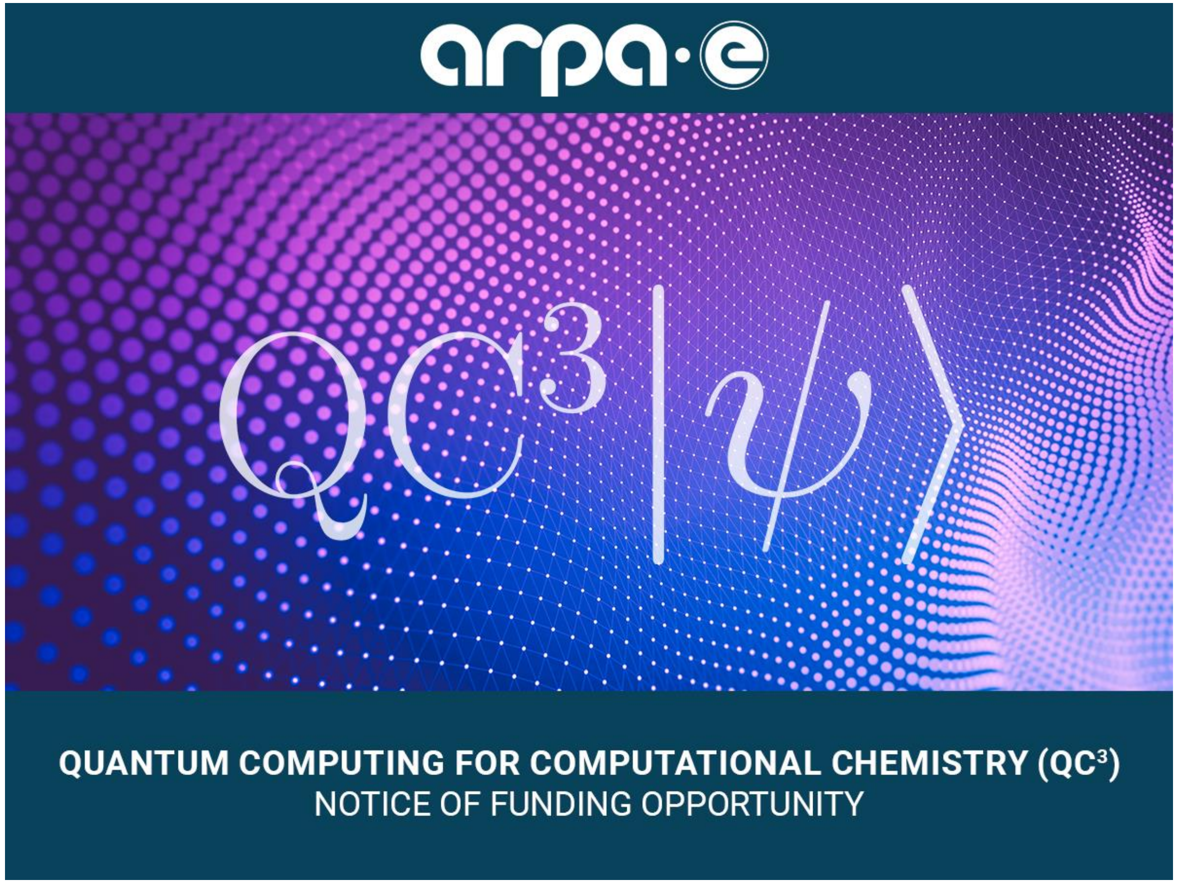
Get Started
NEWS IonQ's Most Powerful Quantum System, IonQ Forte, Now Available through the Amazon Braket Direct Program
The future is quantum.
Quantum computing has the potential to change the world, and IonQ is leading the way.
Build the future
Contact sales →
Improved drug discovery
With ~1,000 algorithmic qubits, we could help revolutionize the pharmaceutical industry.
Learn more about our roadmap →

QC3 program

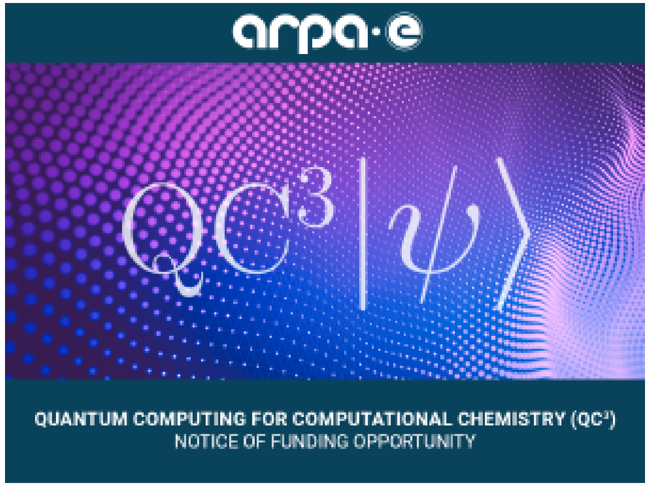


DOE Announces $30M to Use Quantum Computing for Chemistry and Materials Science Simulations

October 24, 2024

WASHINGTON, Oct. 24, 2024 — The U.S. Department of Energy Advanced Research Projects Agency-Energy (ARPA-E) today announced funding to pioneer a new approach to studying chemistry and materials. The Quantum Computing for Computational Chemistry (QC^3) program aims to develop quantum algorithms to advance diverse areas of energy research, such as designing new and sustainable industrial catalysts, discovering new superconductors for more efficient electricity transmission, and developing improved battery chemistries.

“Computer simulations of chemistry and materials drive energy R&D, but classical computing has limits on the complexity it can replicate,” said ARPA-E Director Evelyn N. Wang. “QC^3 projects will harness the power of quantum computing to exceed those limits and provide researchers with the tools to solve high-impact problems in energy.”



https://www.hpcwire.com/off-the-wire/doe-announces-30m-to-use-quantum-computing-for-chemistry-and-materials-science-simulations/

Buzz word or reality?

Here's how Taylor Swift may use cutting-edge quantum technology to plan her concerts.

Taylor Swift Concert goes Quantum

Quantum computers aren't solely intended for tackling Nature's most intricate challenges.

When people hear the words "quantum computer" they imagine some sci-fi tech used by scientists to tackle Nature's most complex mysteries. While that's true, a quantum computer can also be used to solve real-world problems.

(John Shearer / Getty Images for TAS Rights Management)

https://medium.com/@gquinta/taylor-swift-concert-goes-quantum-43ec07438208

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Buzz word or reality?

THÉMA

Les Echos

La feuille de route d'Atos vers le calcul quantique

La... é en 2016, le programme Atos Quantum mise sur les utilisateurs finaux et les applications fu... ures. Le groupe préfère miser sur les logiciels, l'intégration et les applications, plutôt que d'investir dans les qubits et le hardware.

OPINION

Quantum computing has a hype problem

Quantum computing startups are all the rage, but it's unclear if they'll be able to produce anything of use in the near future.

By Sankar Das Sarma — March 28, 2022

hype-problem/

Microsoft Quantum Computer

Atos Quantum Learning Machine

Quantum Solutions Lab

Collaborate with experts to accelerate the development of quantum solutions

IBM Quantum

Science

NEWS | PHYSICS

Ordinary computers can beat Google's quantum computer after all

Superfast algorithm put crimp in 2019 claim that Google's machine had achieved "quantum supremacy"

2 AUG 2022 · 5:05 PM · BY ADRIAN CHO

Georges-Olivier Reymond, PDG de Pasqal, start-up spécialisée dans l'informatique quantique.

Buzz w

La feuille de

Lancé en 2016, le programme
futures. Le groupe préfère m
d'i

What is the
should we b

By Frank Gardner
BBC security correspondent

27 January https://www.b

Informatiqu
termine les
l'épreuve de

Sécurité : *Les tentatives*
communications résistant
ont débuté en mars 2021.
période cruciale.

https://www.zdnet.fr/actualites/
reseau-a-l-epreuve-des-quanta-3

CHRONIQUE

Ordinateur quantique, Godot de la Tech ?

Alors que le personnage de Samuel Beckett reste un héros fantomatique, le « quantum » commence à se matérialiser, souligne Sylvain Duranton.

Ajouter à mes articles | Commenter | Partager | Allemagne | Hedge Funds

https://www.lesechos.fr/idees-debats/editos-analyses/ordinateur-quantique-godot-de-la-tech-2101791

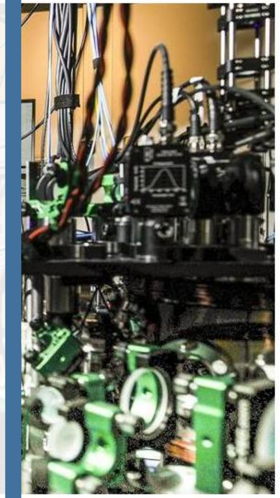
Les Echos - Sylvain Duranton (directeur monde de BCG X) - Publié le 16 juin 2024

Quantum
Learning Machine

Quantum

Quantum AI

d'euros pour
quantique



quantique.

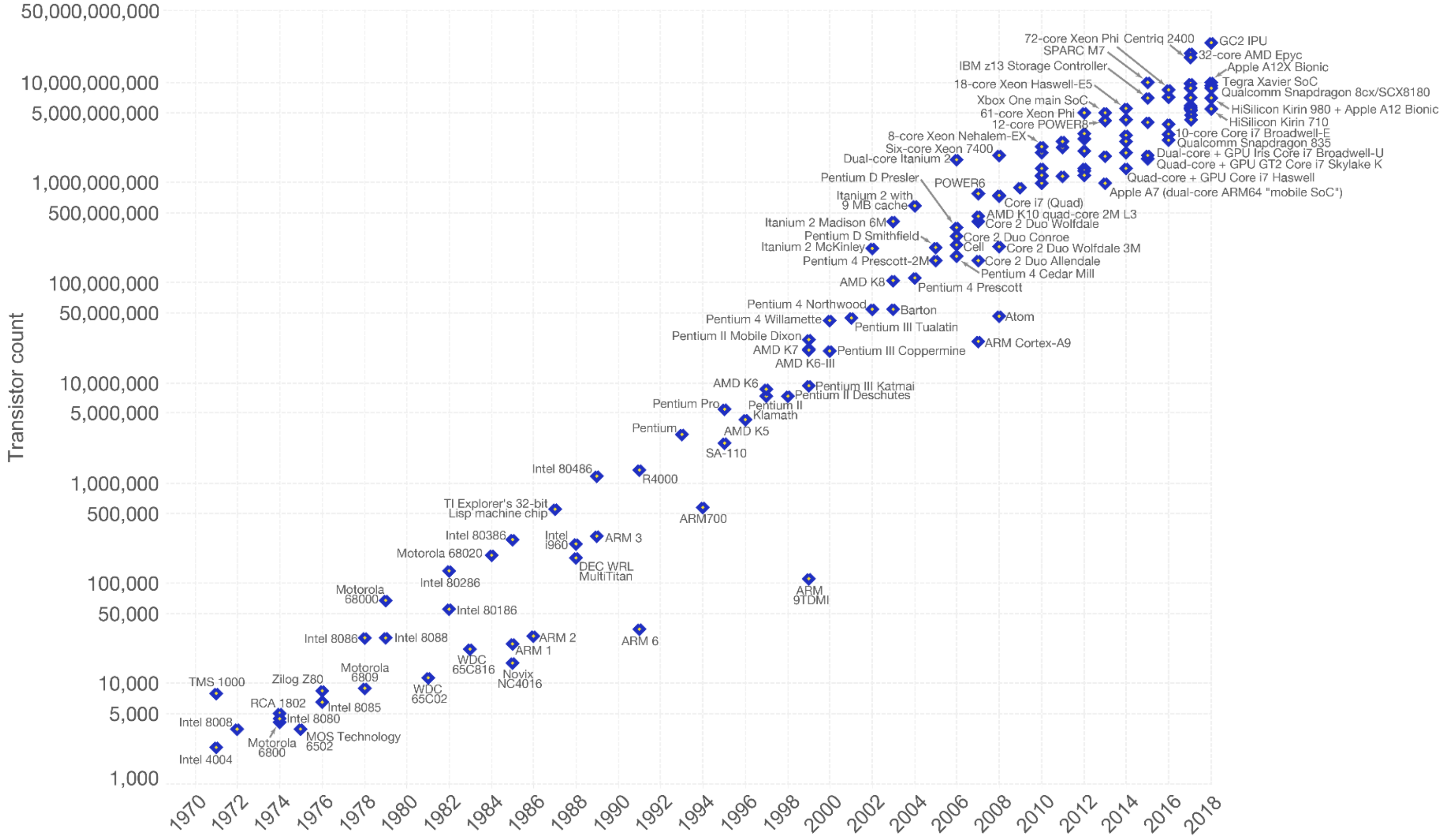
Why such an interest?

End of Moore’s law

Moore’s Law – The number of transistors on integrated circuit chips (1971-2018)

Our World in Data

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important as other aspects of technological progress – such as processing speed or the price of electronic products – are linked to Moore's law.



Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)
The data visualization is available at OurWorldinData.org. There you find more visualizations and research on this topic.

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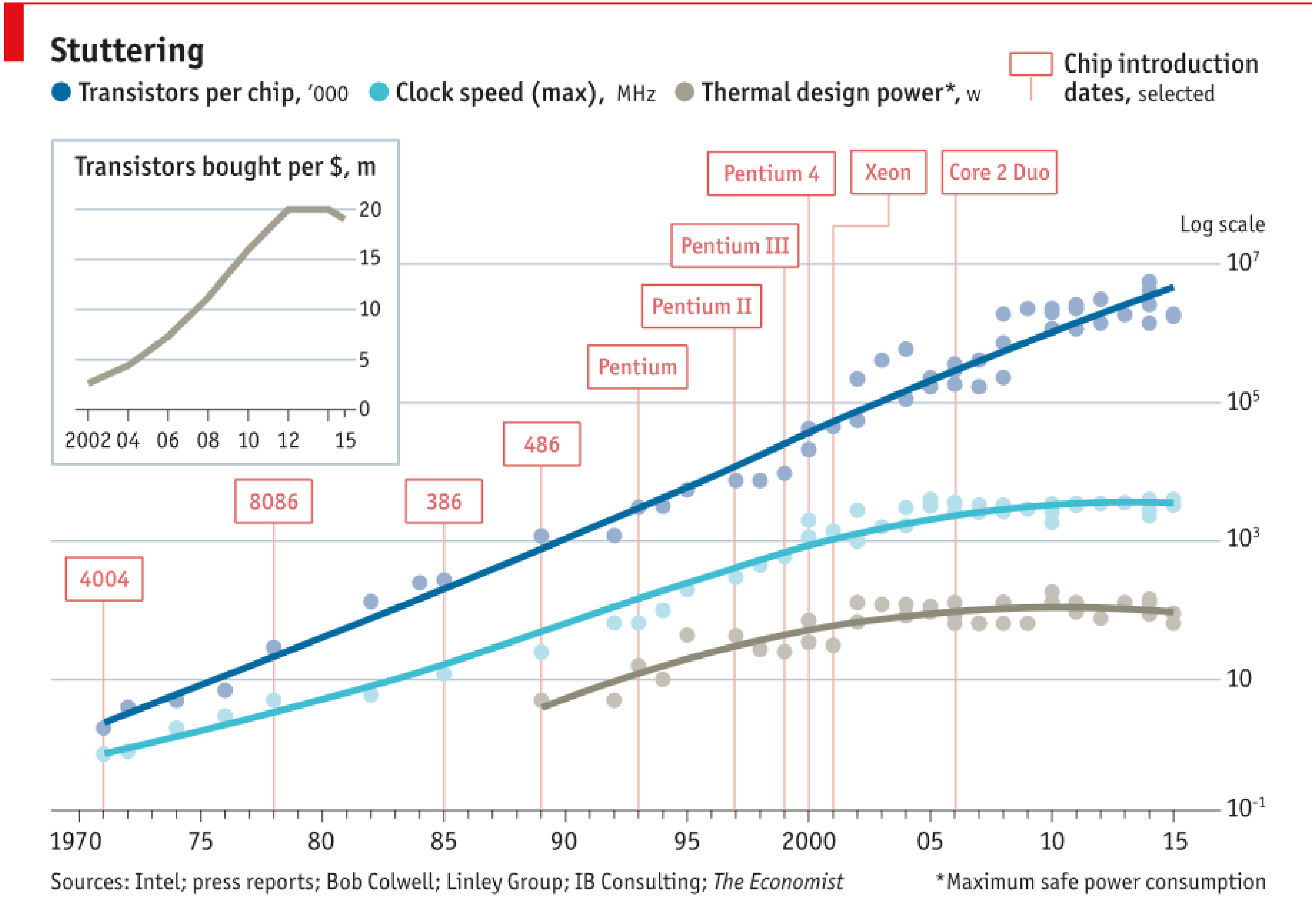
End of Moore's law



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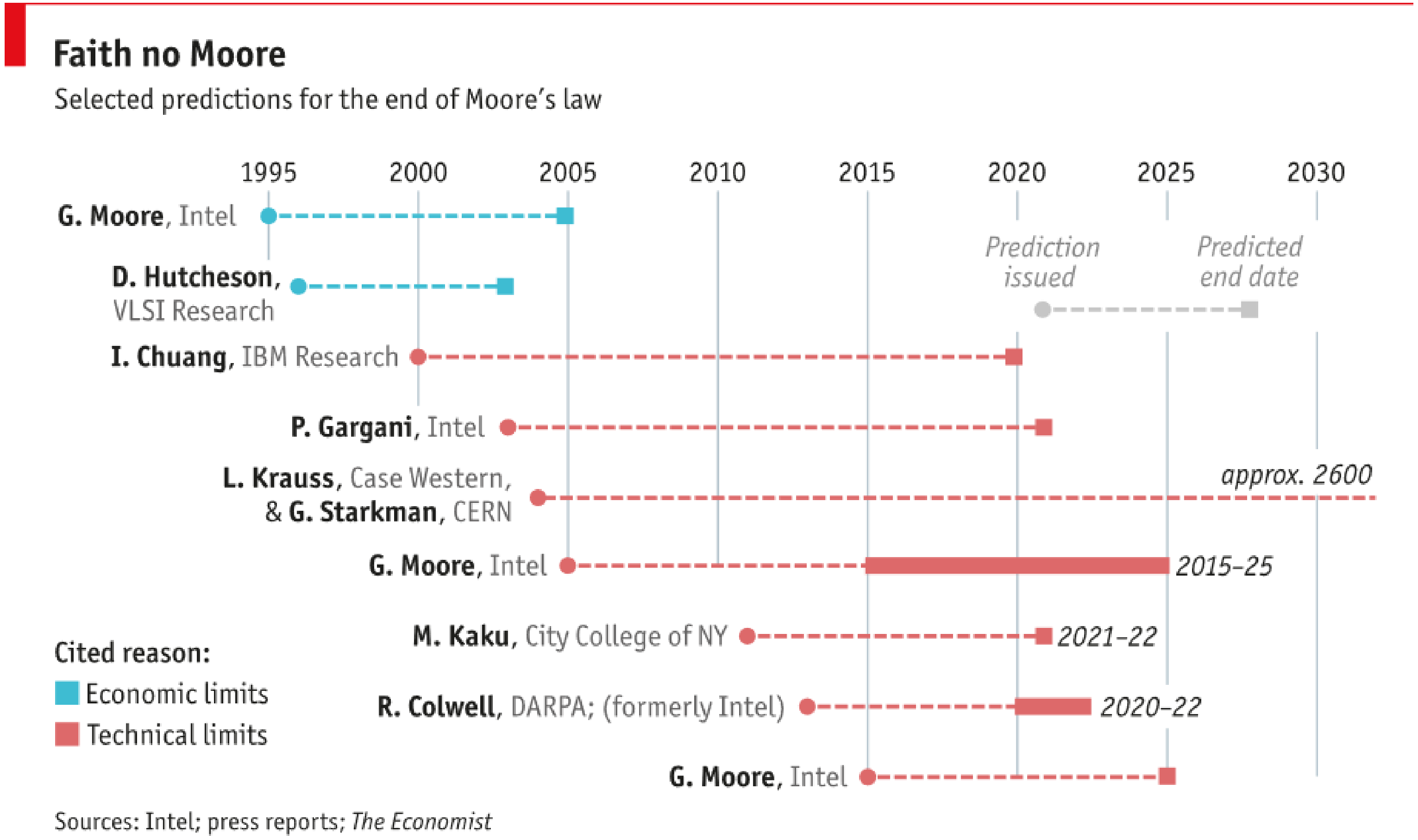
End of Moore's law



Post-silicon area ?

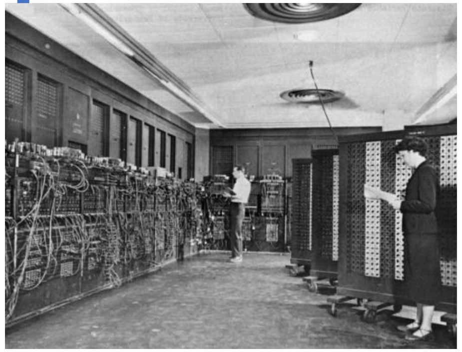
- neuromorphic;
- new materials (carbon based,…);
- biotech (data storage, computing);
- **quantum ????**

Toward a quantum market?

Knowing where we come from to know where we are going…

La Pascaline (1652)

1945



ENIAC
(Electronic Numerical
Integrator And Computer)
Ballistic Research Laboratory

5,000 cycles/s for operations
on 10 digits numbers.

1 cycle:
- W register,
- R register,
- add/substract numbers.

30 tons
72m² ground surface
140 kW
$500,000 ($6,300,000 in todays' dollars)

Knowing where we come from to know where we are going…

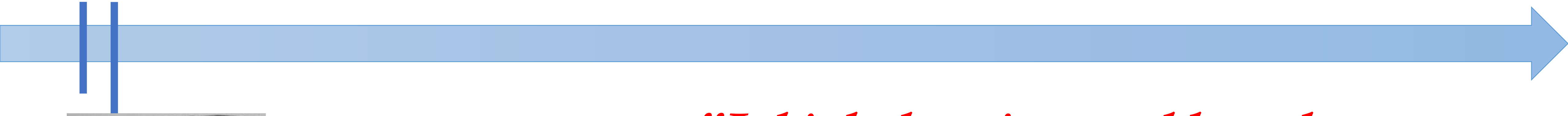
La Pascaline (1652)

1945 1947

First transistor !

Knowing where we come from to know where we are going…

La Pascaline (1652)



First transistor !

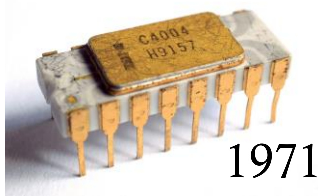
"I think there is a world market for about five computers."

Thomas J. Watson, IBM's president (early 1940s)

https://www.theguardian.com/technology/2008/feb/21/computing.supercomputers

Knowing where we come from to know where we are going…

La Pascaline (1652)

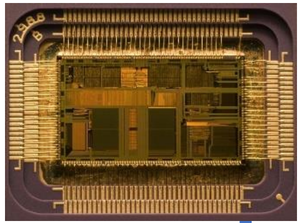


Intel 4004

1971

1.2M-1.6M transistors (100 MHz)

Intel i486



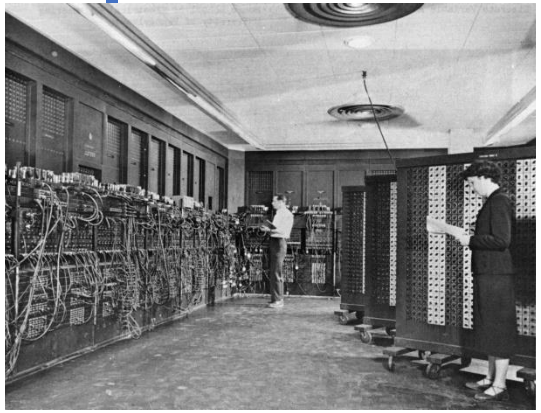
1989

Qualcomm QSD8250 1GHz

2018

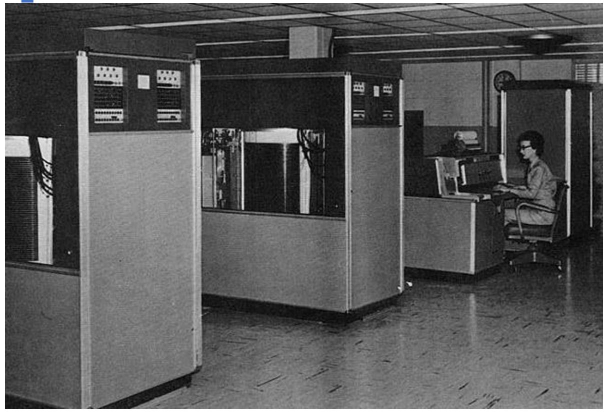
SCX8180
Transistors de 7nm
 # 8,500,000,000
112m²

1945 1947 1956 1966



ENIAC

Transistor



IBM 305 RAMAC

Magnetic memories

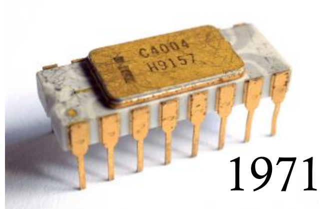
Apollo Guidance Computer and its DSKEY

Integrated circuits

Knowing where we come from to know where we are going…

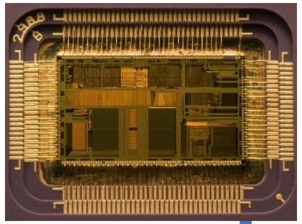
La Pascaline (1652)

Intel 4004



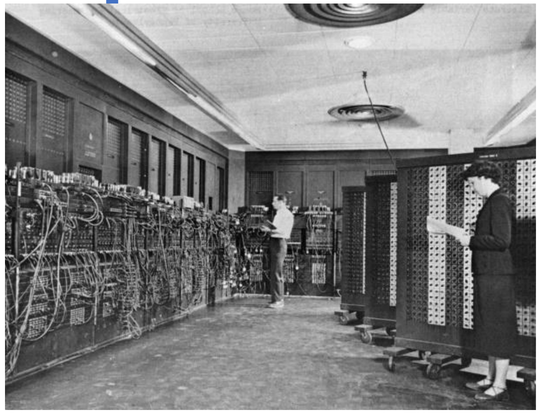
1971

Intel i486



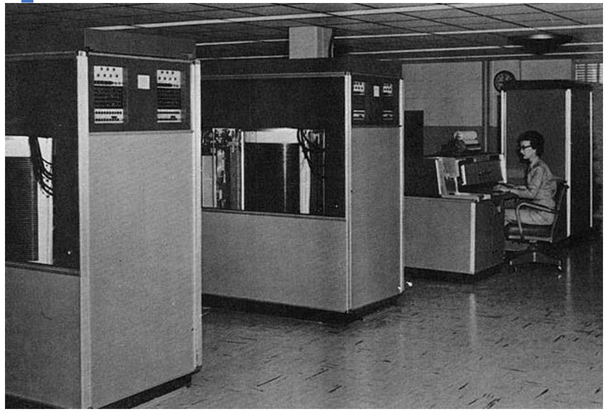
1989

1945 1947 1956 1966 2018



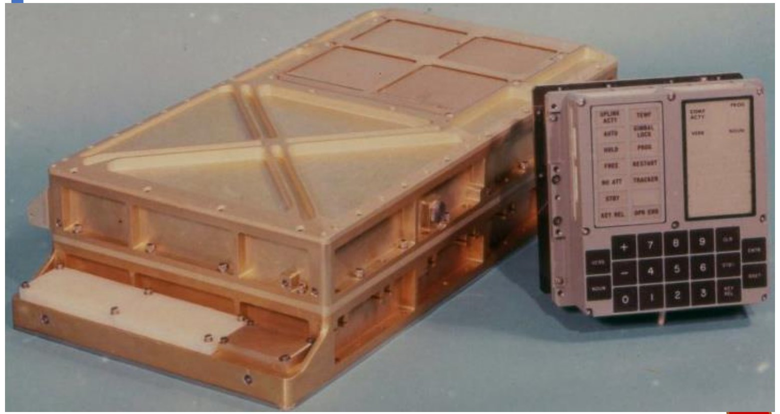
ENIAC

Transistor



IBM 305 RAMAC

Magnetic memories



Apollo Guidance Computer and its DSKEY

Integrated circuits

50 years

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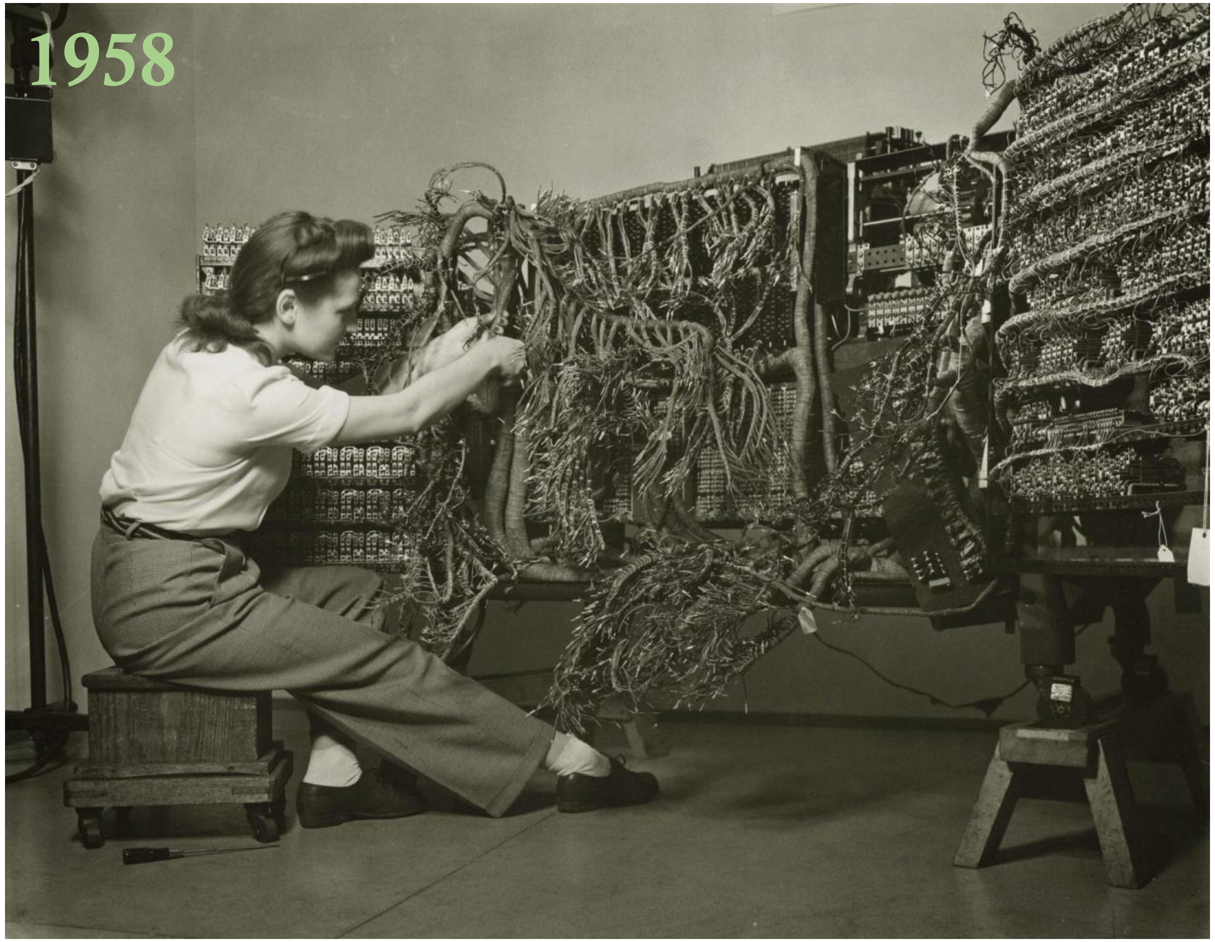
Knowing where we come from to know where we are going…

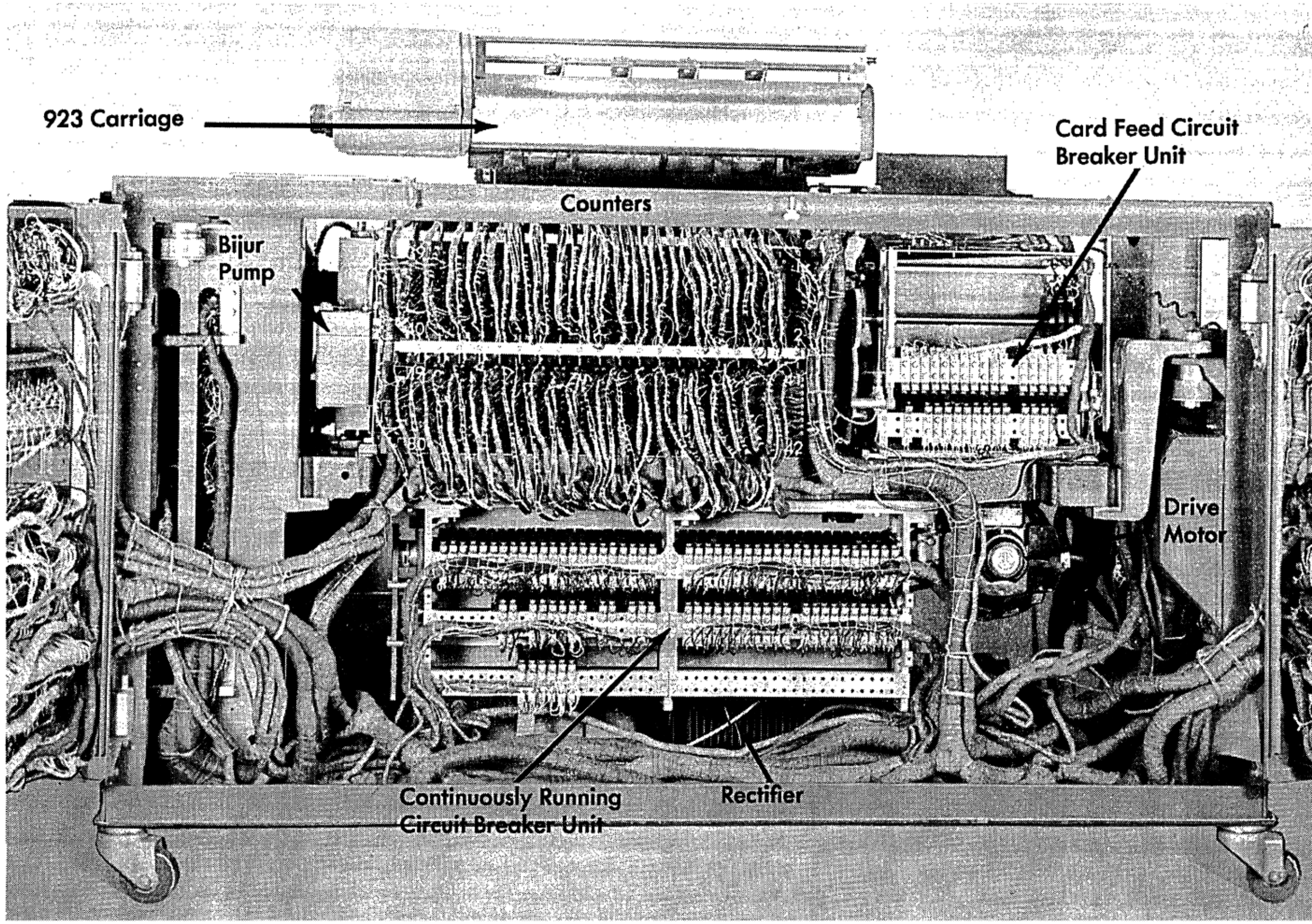
Classical computer
48 years ago…
(almost 50 years)

Steve Wozniak's Apple I (1976).

https://x.com/historyinmemes/status/1851933885971497081

Knowing where we come from to know where we are going…

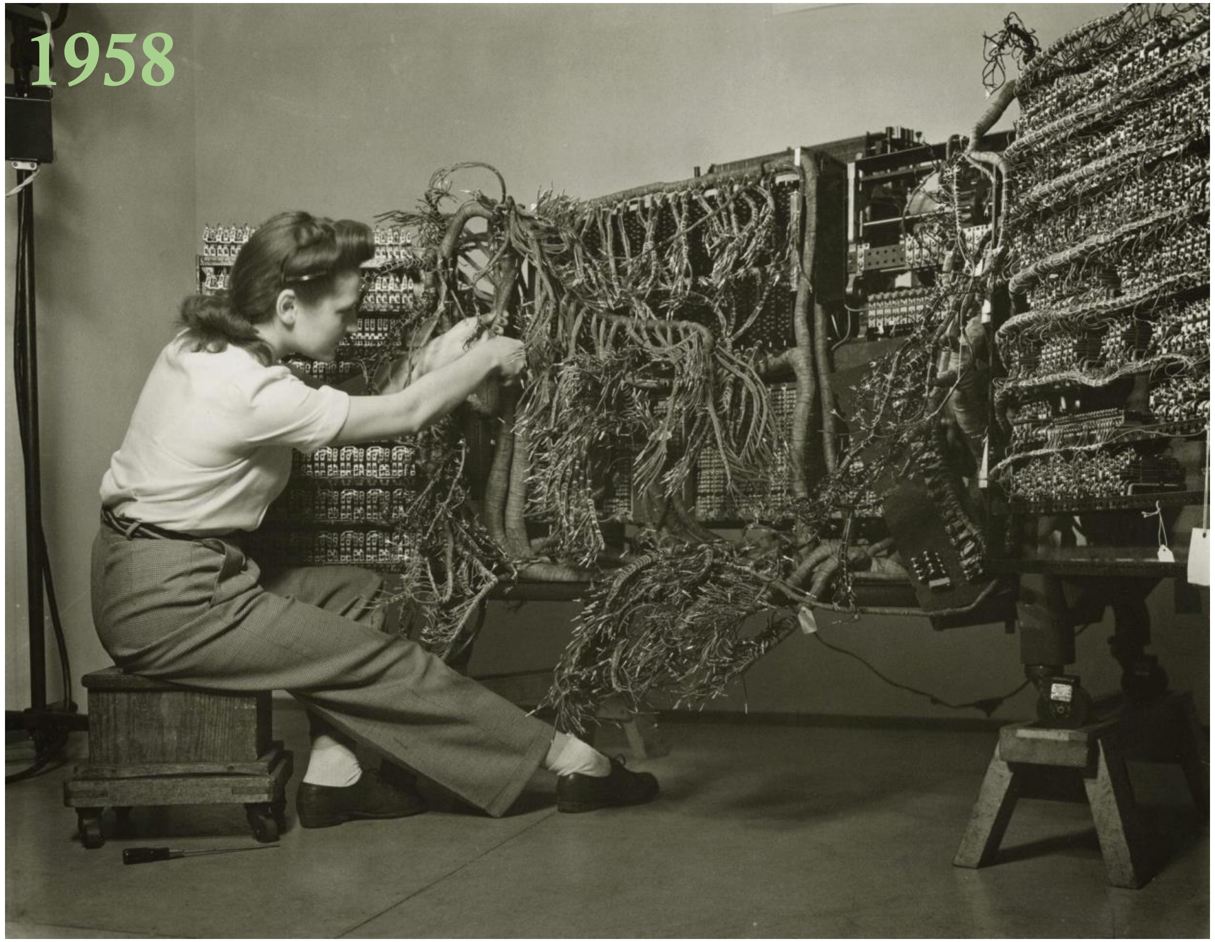




IBM 405

http://www.righto.com/2017/11/identifying-early-ibm-computer-in.html

Knowing where we come from to know where we are going...



IBM 405

Maika Takita, a Japanese IBMer and Research Staff Member based in Yorktown Heights, New York

http://www.righto.com/2017/11/identifying-early-ibm-computer-in.html
https://twitter.com/IBM/status/1526195925449842689

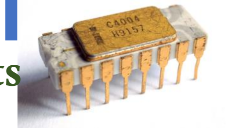
Knowing where we come from to know where we are going…

1945 — Transistor (1947)

1956 — Magnetic memories

1966 — Integrated circuits

CPU 1971



1995

2018

Quantum timeline

1980 — First idea of a quantum computer (Feynman, Deutsch)

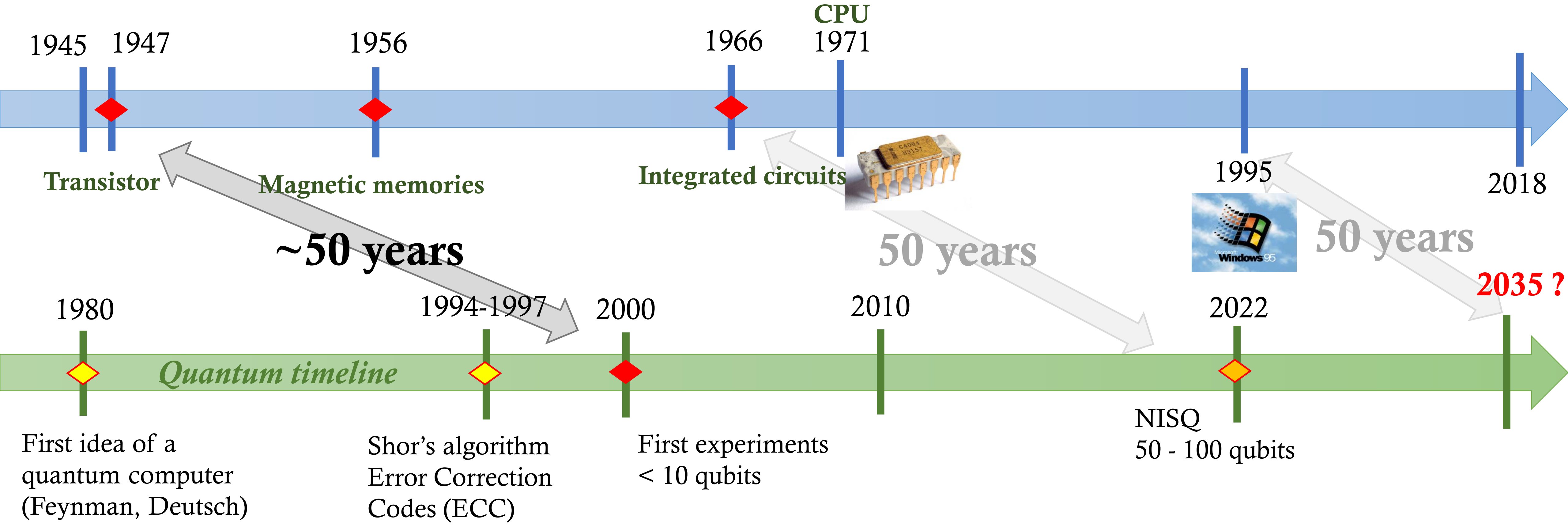
1994-1997 — Shor's algorithm
Error Correction Codes (ECC)

2000 — First experiments
< 10 qubits

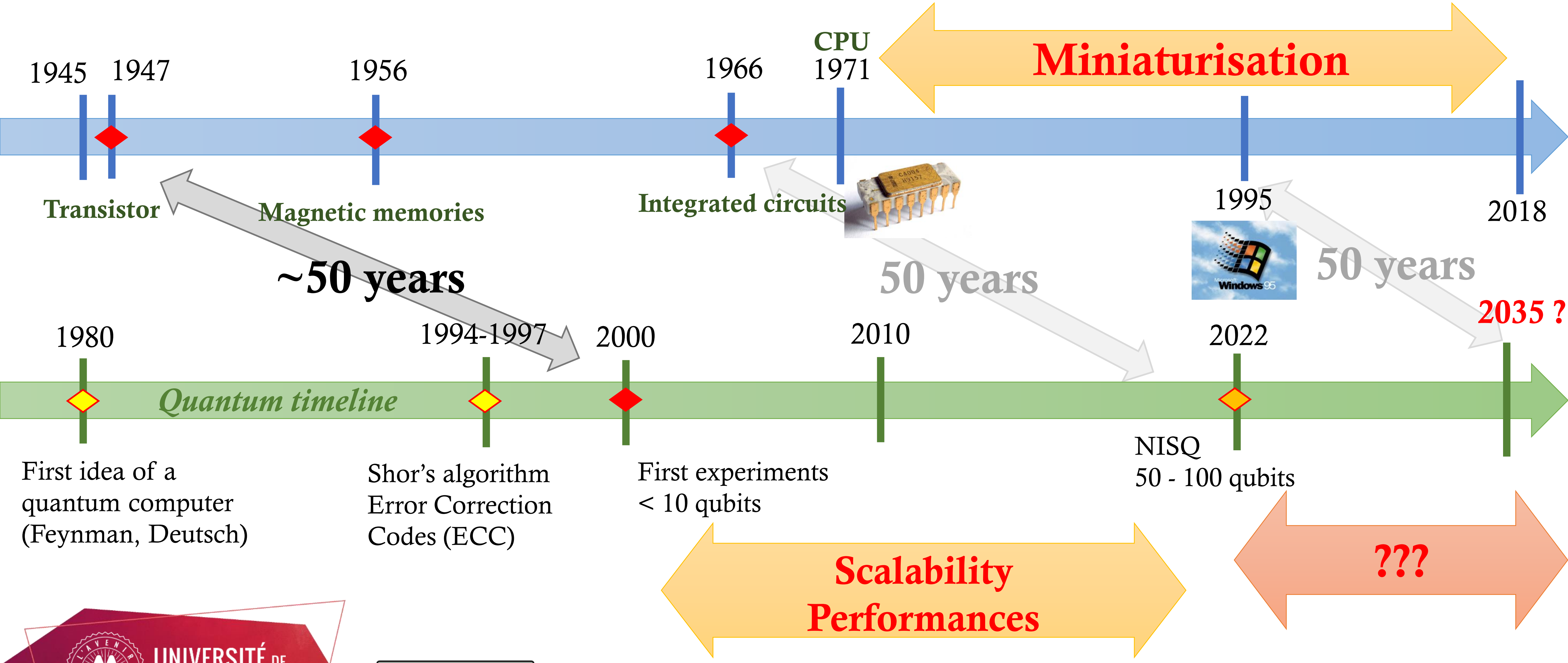
2010

2022 — NISQ
50 - 100 qubits

Knowing where we come from to know where we are going…



Knowing where we come from to know where we are going...



Always Look on the Bright Side of Life

BCG

QUANTUM COMPUTING / ARTICLE

The Long-Term Forecast for Quantum Computing Still Looks Bright

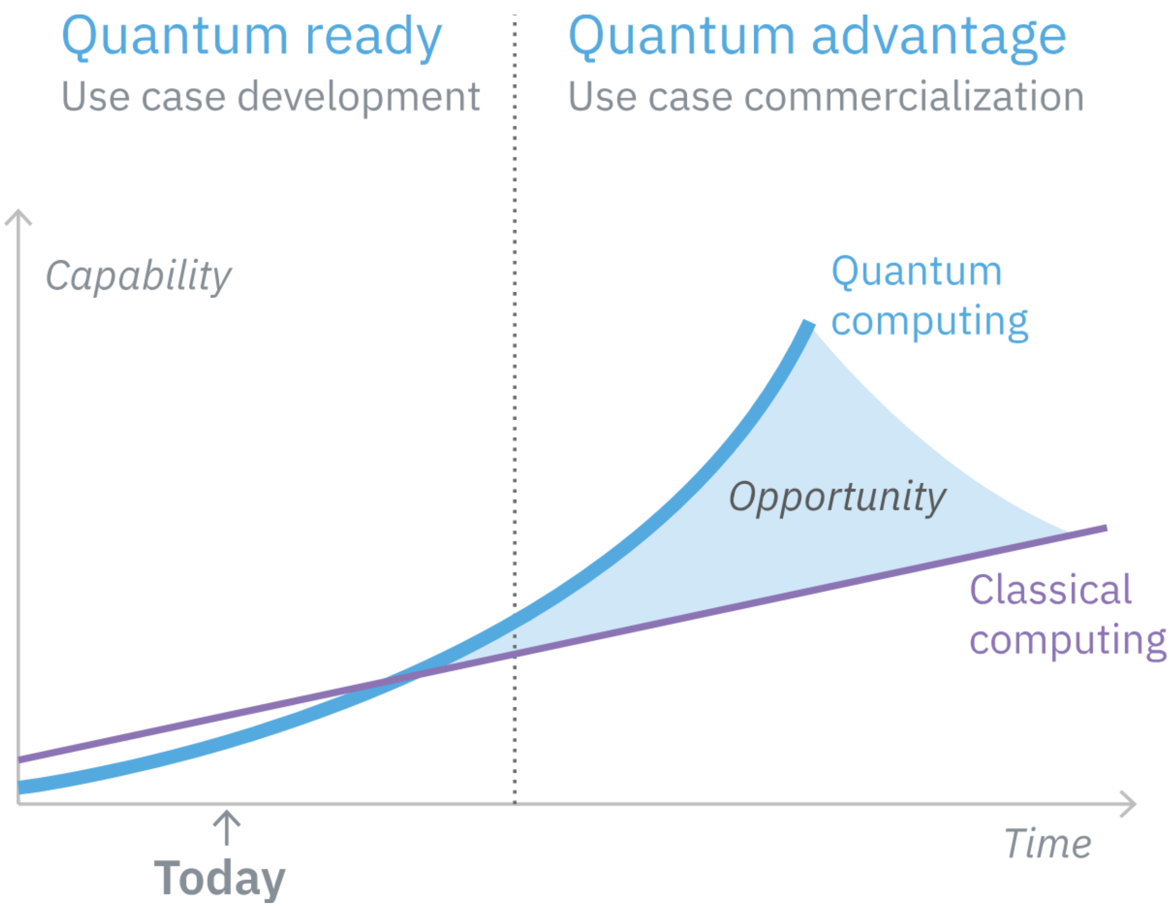
JULY 18, 2024

By Jean-François Bobier, Matt Langione, Cassia Naudet-Baulieu, Zheng Cui, and Eitoku Watanabe

READING TIME: 15 MIN

https://www.bcg.com/publications/2024/long-term-forecast-for-quantum-computing-still-looks-bright

Always Look on the Bright Side of Life



https://www.ibm.com/thought-leadership/institute-business-value/public/static/images/Quantum-Report/Figure3.svg

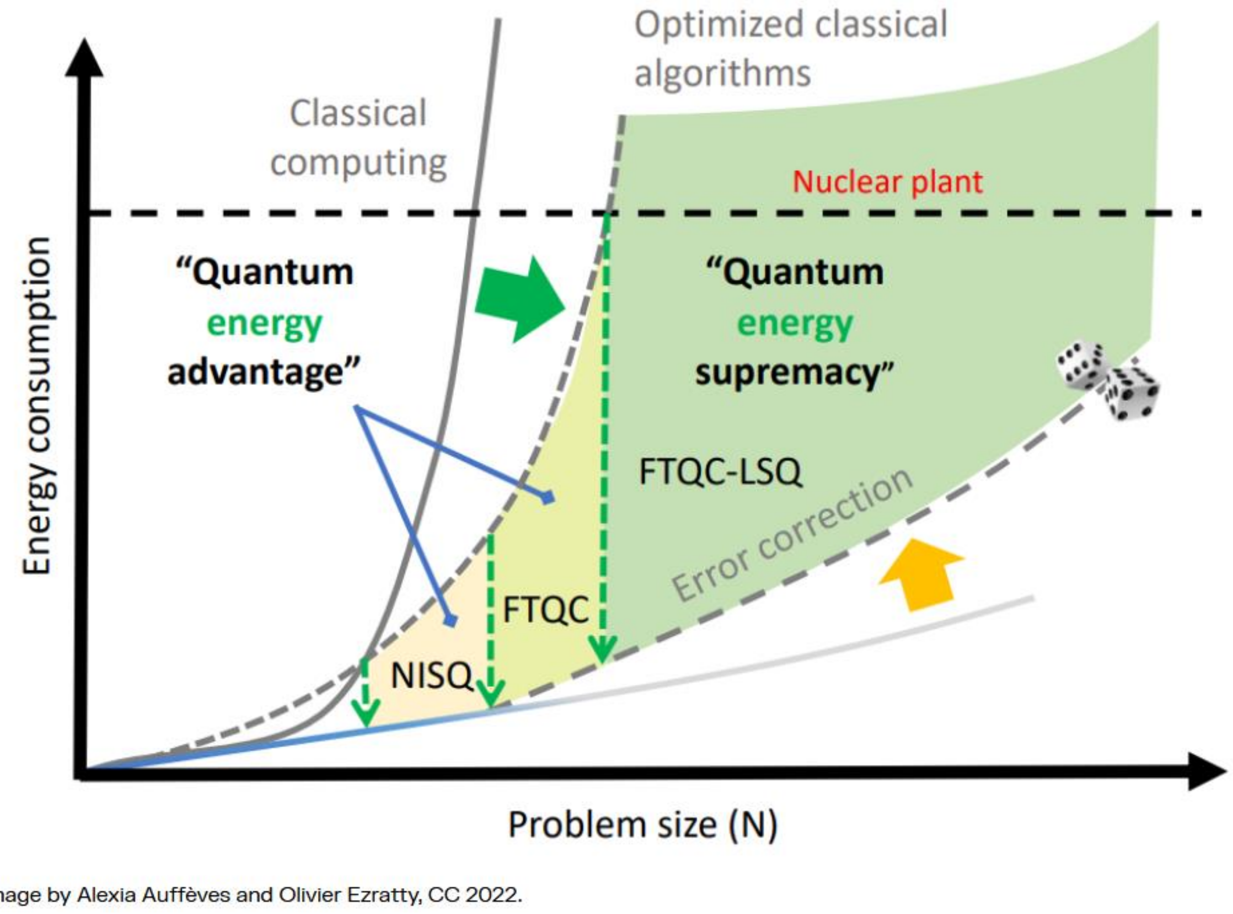
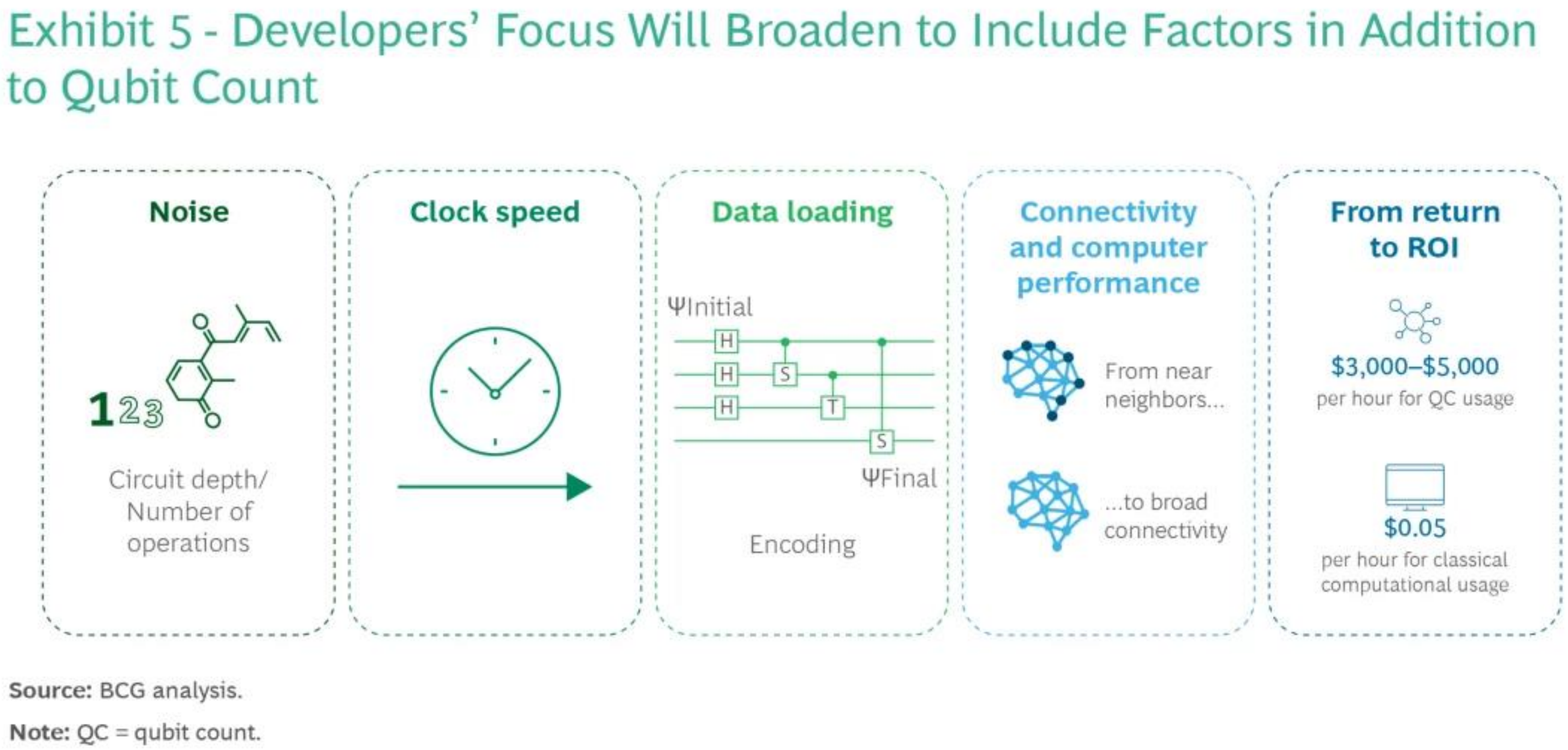


Image by Alexia Auffèves and Olivier Ezratty, CC 2022.

https://www.pasqal.com/news/quantum-computing-rethinking-energy-consumption/

Always Look on the Bright Side of Life



https://www.bcg.com/publications/2024/long-term-forecast-for-quantum-computing-still-looks-bright

What promises? Which end-users?

What promises? Which end-users?

Pharmaceutical industry

Finance

Chemistry

Quantum computing

Cryptography

Energy

Tech

Manufacturing industry

Los Alamos National Laboratory

Potential Applications of Quantum Computing at Los Alamos National Laboratory

v0.1.0

Andreas Bärtschi, Francesco Caravelli, Carleton Coffrin[1], Jonhas Colina, Stephan Eidenbenz, Abhijith Jayakumar, Scott Lawrence, Minseong Lee, Andrey Y. Lokhov, Avanish Mishra, Sidhant Misra, Zachary Morrell, Zain Mughal, Duff Neill, Andrei Piryatinski, Allen Scheie, Marc Vuffray, Yu Zhang

LA-UR-24-24966
May 2024

E.g.: Computational catalysis for artificial photosynthesis

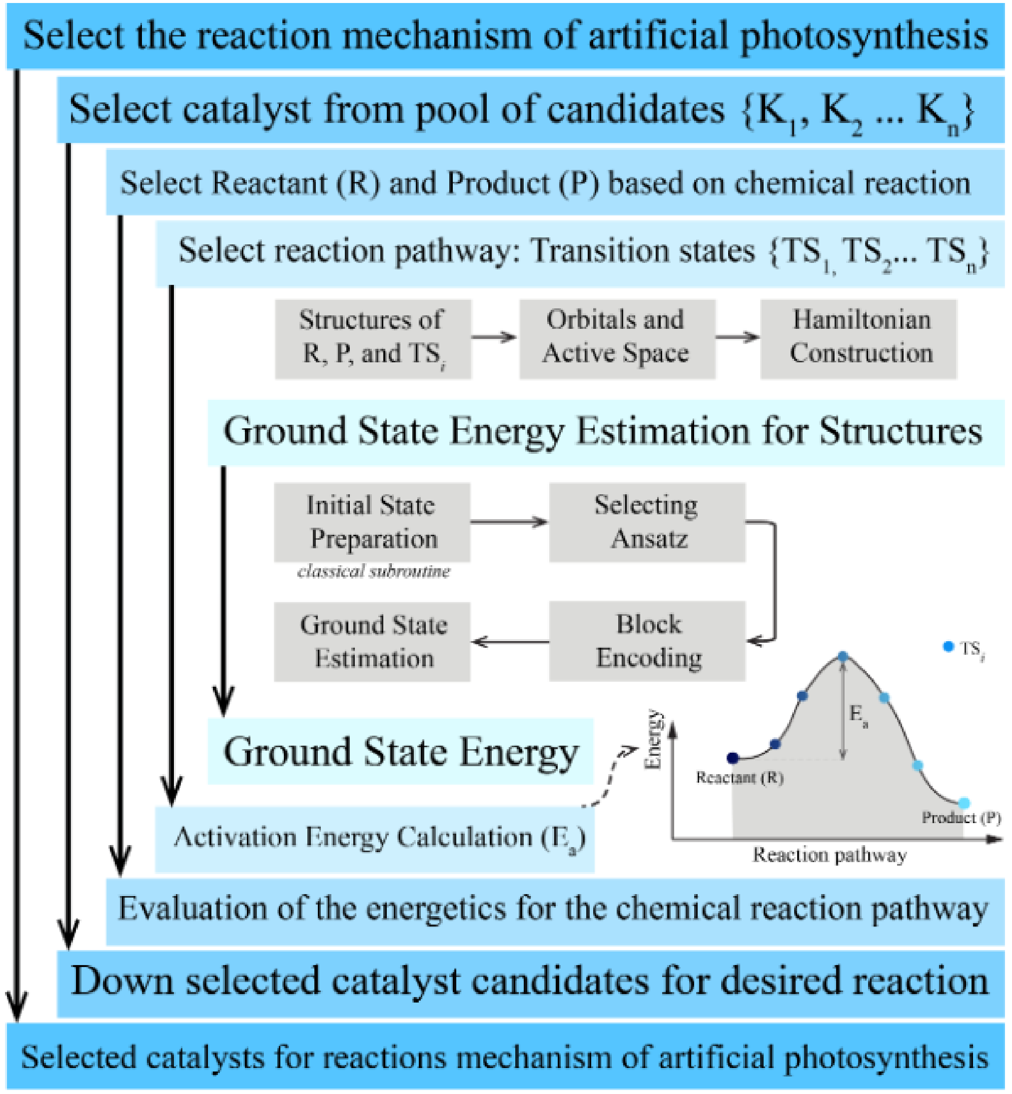
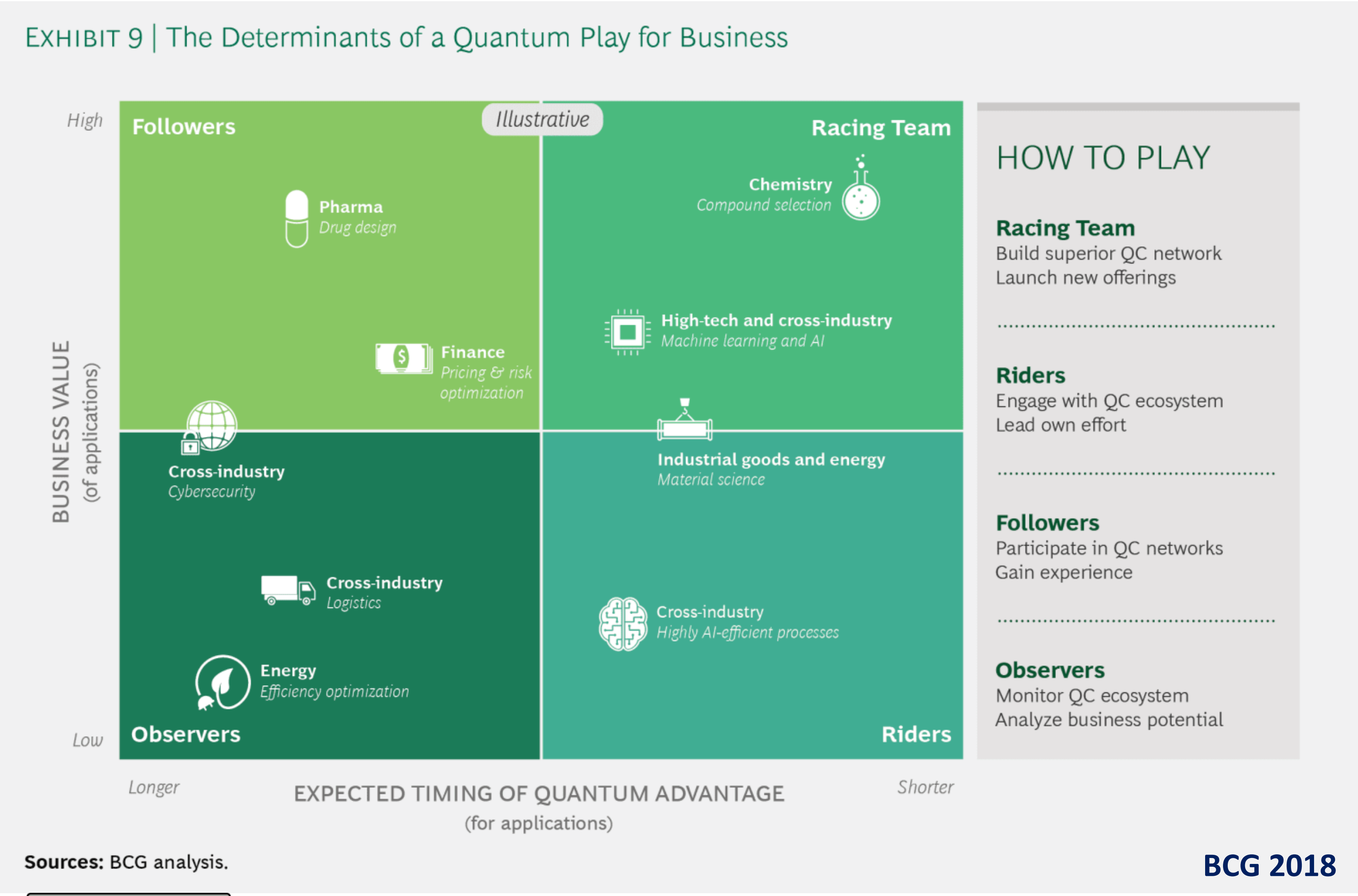


Figure 6-1: Flowchart of selecting catalysts for different reaction mechanisms of artificial photosynthesis using computational modeling.

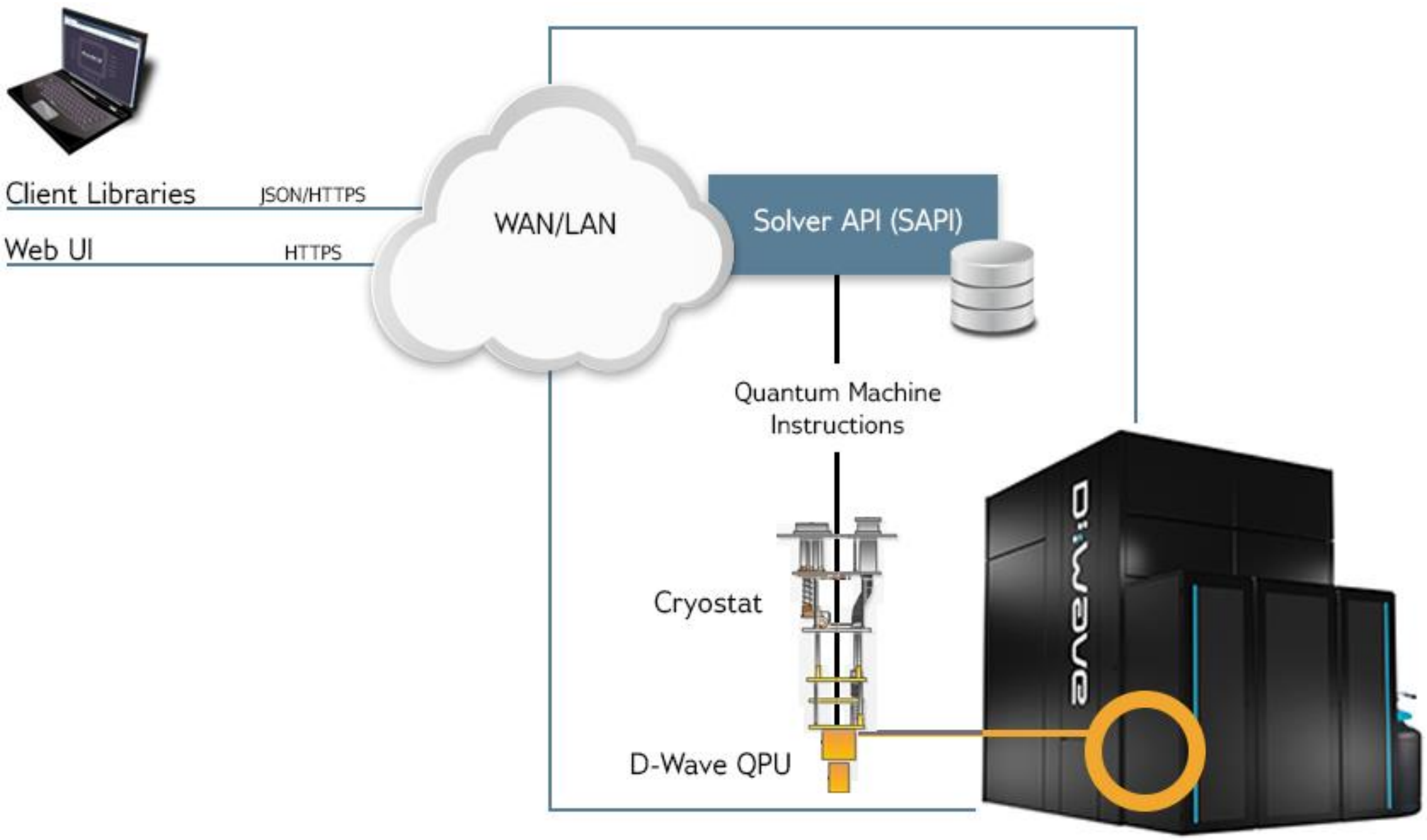
ArXiv:2406.06625

What promises? Which end-users?



BCG 2018

Quantum computing **is not** a quantum version of a computer



- **Hybrid approach** CPU/QPU
- SaaS economic model
- No quantum OS
- Algorithms: **everything has to be constructed (by « quantum thinking »)**

https://www.dwavesys.com/

Hybrid computing

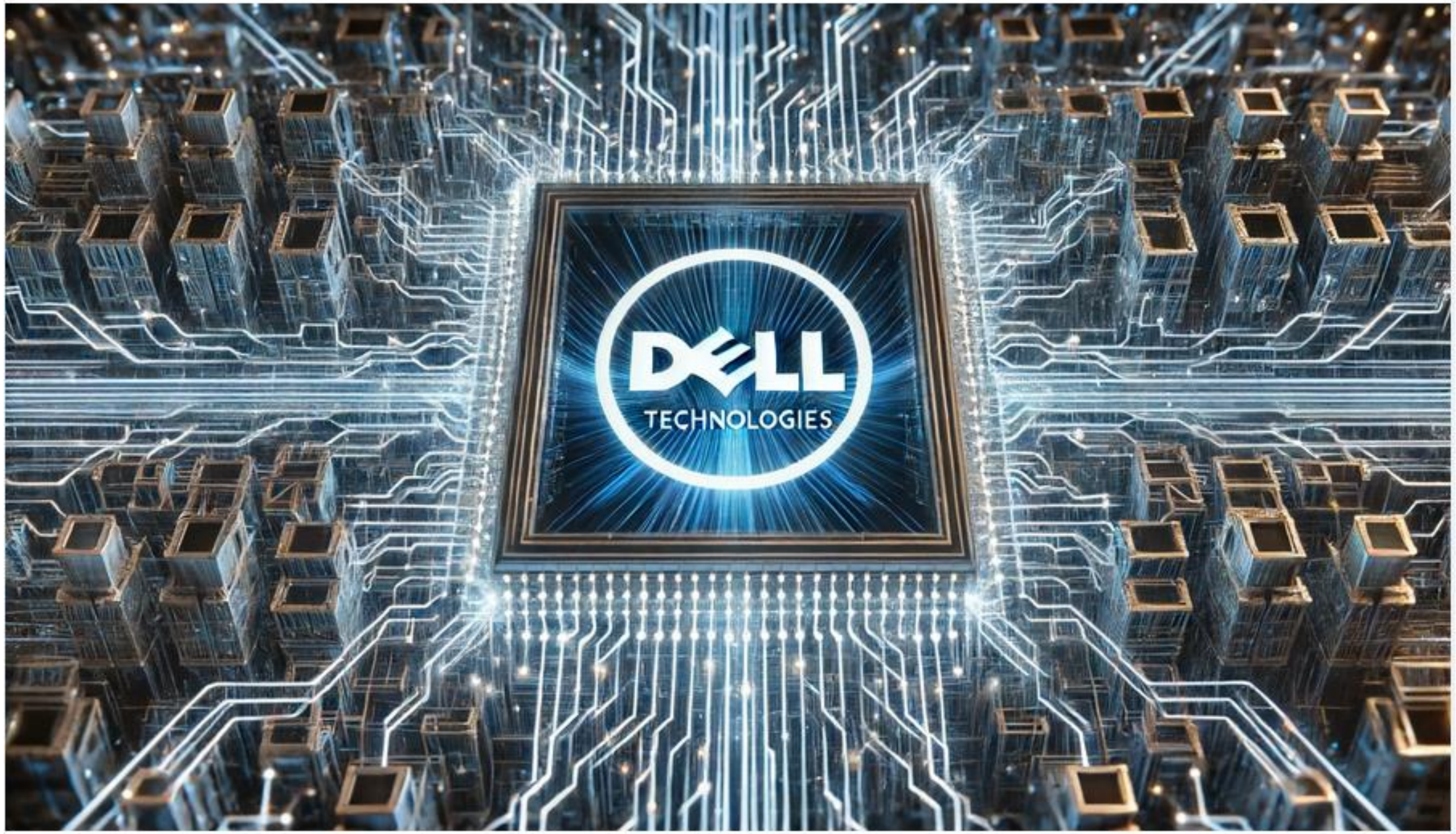
- Dell Technologies has recently announced initiatives that involved quantum computing.

- The company has developed a **strategic collaboration with Aramco** to explore the use of advanced computing in the energy sector.

- **Dell also released information about its hybrid classical/quantum platform with IonQ.**

Dell Technologies Continues To Make Progress With Quantum Computing Initiatives

Quantum Computing Business · Matt Swayne • June 17, 2024



https://thequantuminsider.com/2024/06/17/dell-technologies-continues-to-make-progress-with-quantum-computing-initiatives/

Hybrid computing

•A 20-qubit quantum computer has been integrated into a supercomputer, SuperMUC-NG in Germany.

•The installation was part of a collaboration with the Leibniz Supercomputing Centre (LRZ) of the Bavarian Academy of Sciences and Humanities, the Q-Exa consortium, led by IQM Quantum Computers (IQM).

•The IQM quantum processor unit, based on superconducting circuits, has been combined with conventional computer technology to create the new system.

Germany Launches First Hybrid Quantum Computer At Leibniz Supercomputing Centre

Quantum Computing Business Matt Swayne • June 19, 2024

https://thequantuminsider.com/2024/06/19/germany-launches-first-hybrid-quantum-computer-at-leibniz-supercomputing-centre/

How many qubits?

Qubit(s)

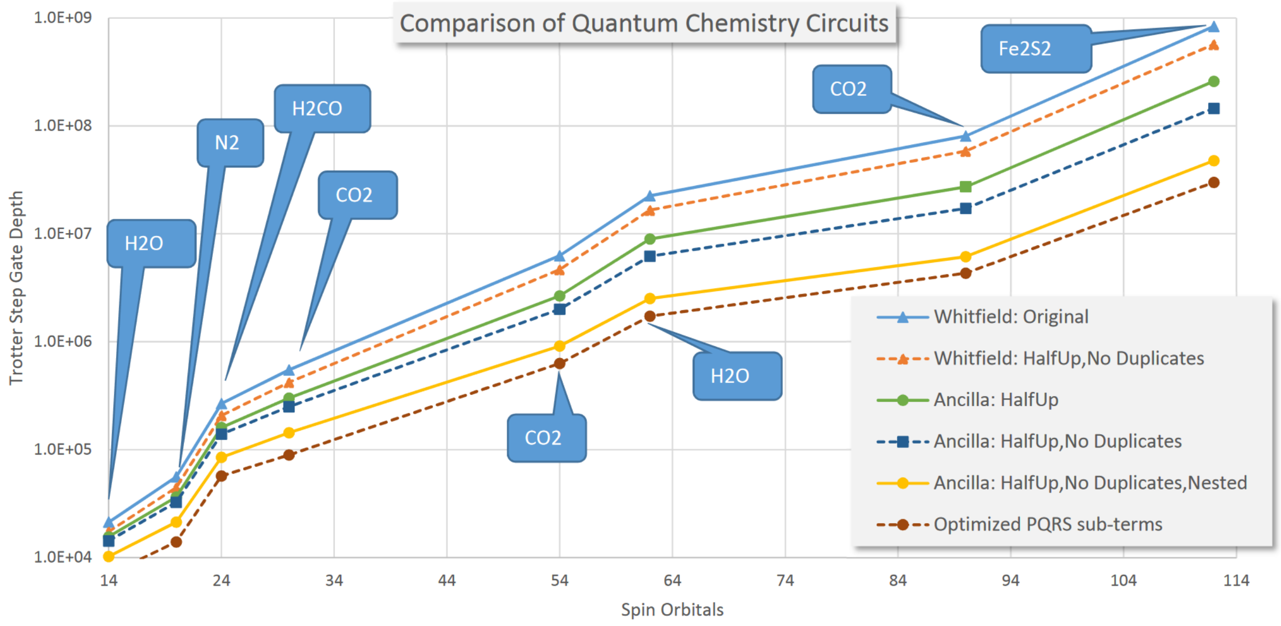
Is a single qubit useful?

How many qubits are required?

Qubit(s)

Is a single qubit useful?

How many qubits are required?



ArXiv:1403.1539

Molecule	Formula	Bits needed	Qubits needed
Water	H_20	10^4	14
Ethanol	C_2H_6O	10^{12}	42
Caffeine	$C_8H_{10}N_4O_2$	10^{48}	160
Sucrose	$C_{12}H_{22}O_{11}$	10^{82}	274
Penicillin	$C_{16}H_{18}N_2NaO_4S$	10^{86}	286

Number of classical bits and qubits in order to represent energy states of molecules.

Typ. few hundreds of qubits

→Number of qubits

→« Depth » of quantum circuit

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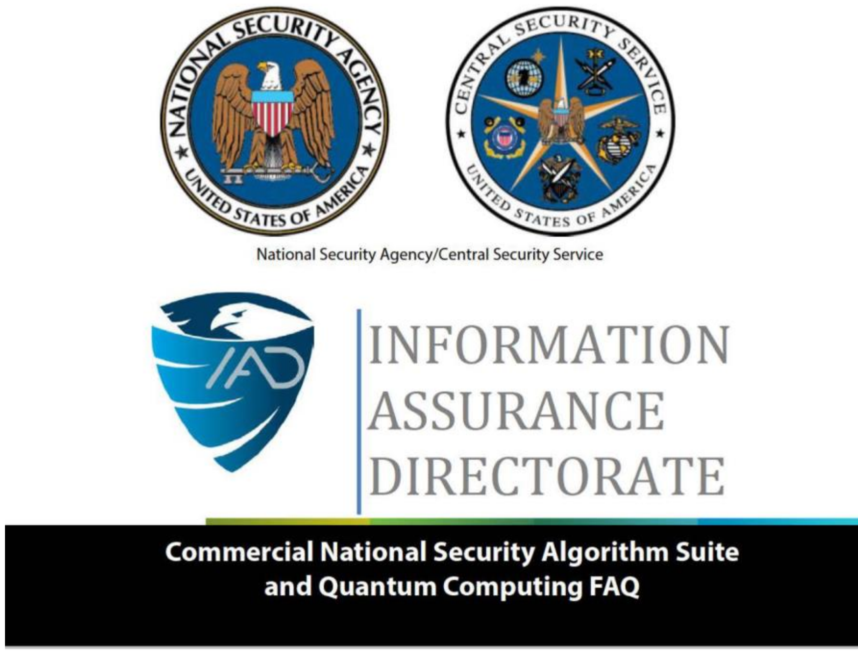
Qubit(s)

Is a single qubit useful?

How many qubits are required?



NSA (2016)

RSA encryption algorithm – 2048 bits key.

- Better known algorithm: 1 billions of years.
- Shor’s algorithm (**<u>4096 perfect qubits</u>**) :

  <1 second (QC @ 1 GHz)
  120 seconds (QC @ 1 MHz)
  15 days (QC @ 1 kHz)
  10 years (QC @1 Hz)

A compare between Shor’s quantum factoring algorithm and general Number Field Sieve, Hamdi *et al.* (2014)

Qubit(s)

Is a single qubit useful?

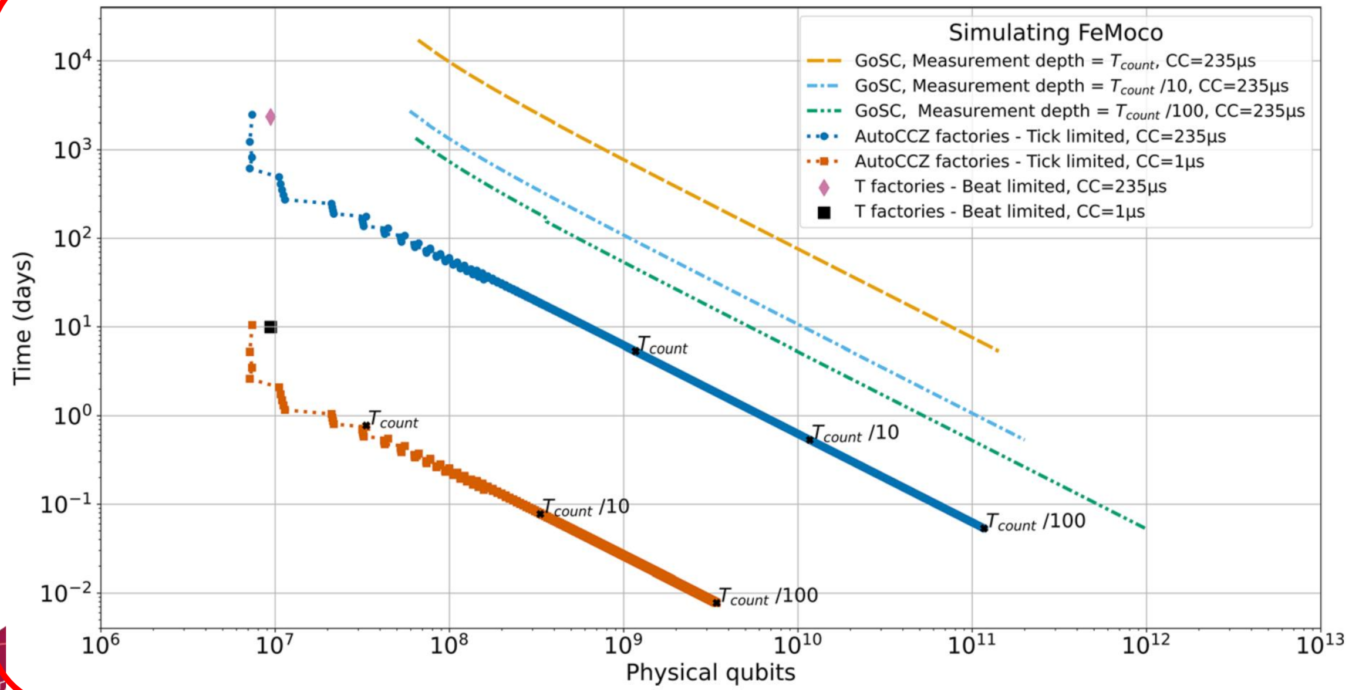
How many qubits are required?

How to factor 2048 bit RSA integers in 8 hours using 20 million noisy qubits

Craig Gidney[1] and Martin Ekerå[2]

[1]Google Inc., Santa Barbara, California 93117, USA
[2]KTH Royal Institute of Technology, SE-100 44 Stockholm, Sweden
Swedish NCSA, Swedish Armed Forces, SE-107 85 Stockholm, Sweden

https://arxiv.org/abs/1905.09749



B. Breaking Bitcoin's EC encryption

Breaking encryption has received a lot of attention in the quantum computing community since Shor's breakthrough algorithm,[74] which provides a near exponential speedup for prime factoring that has direct implications for breaking RSA encryption. Gidney and Ekerå provide algorithmic improvements in addition to the surface code strategies for breaking RSA encryption, and they estimate that 20×10^6 qubits running for 8 h could break it with a code cycle time of 1 μs.[31] In a blueprint for a shuttling-based trapped ion device, which

The impact of hardware specifications on reaching quantum advantage in the fault tolerant regime

Cite as: AVS Quantum Sci. 4, 013801 (2022); doi: 10.1116/5.0073075
Submitted: 27 September 2021 · Accepted: 7 December 2021 ·
Published Online: 25 January 2022

Mark Webber,[1,2,a)] Vincent Elfving,[3] Sebastian Weidt,[1,2] and Winfried K. Hensinger[1,2]

What is a « good » qubit?

Quantum state preservation (coherence)

→ *weak coupling with environment, cryogenic temperatures*

Individual qubit manipulation

Individual qubit detection

Quantum gates

→ *coupling strength controlable with other qubits*

The number of qubits is not, intrinsically, a relevant metric !

Noisy Intermediate-Scale Quantum - NISQ (John Preskill)

→ physical qubit / logical qubit

characterized by T_1, T_2, T_2, C-not error rate, single gate error rate,…*

T_1, T_2 ????

Density matrix: $$\hat{\rho} \in \left\{ \frac{\mathbb{I} + \vec{n}\cdot\hat{\vec{\sigma}}}{2} \; , \; \|\vec{n}\| \leq 1 \right\}$$

pure state vs thermal state $$\hat{\rho} = |\psi\rangle\langle\psi| \qquad \hat{\rho} = \frac{e^{-\beta\hat{H}}}{\mathrm{Tr}\left(e^{-\beta\hat{H}}\right)}$$

Basic model of decoherence

$$\frac{\partial\hat{\rho}}{\partial t} = -\frac{i}{\hbar}\left[\hat{H},\hat{\rho}\right] - \frac{1}{T_1}\left(\hat{\rho} - \hat{\rho}_{\mathrm{thermal}}\right) - \frac{1}{T_2}\begin{pmatrix} 0 & \rho_{10} \\ \rho_{01} & 0 \end{pmatrix}$$

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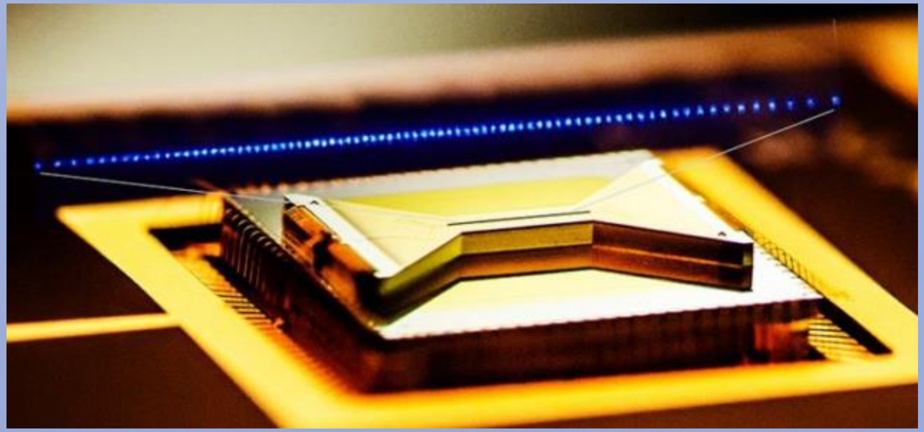
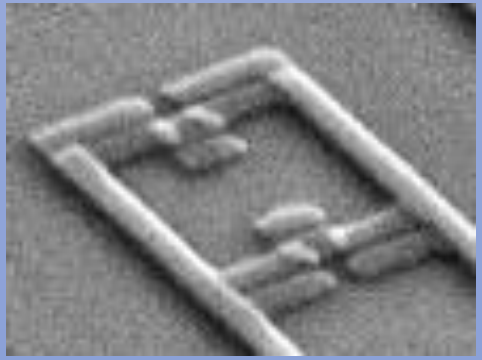
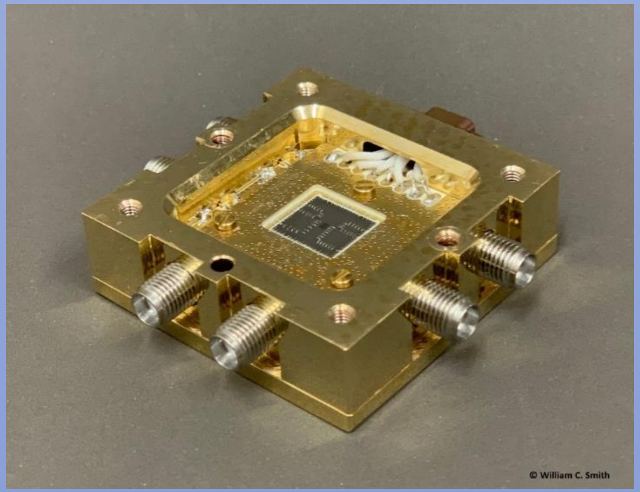
Qubits and QPU experimental achievment

Qubit VS transistor

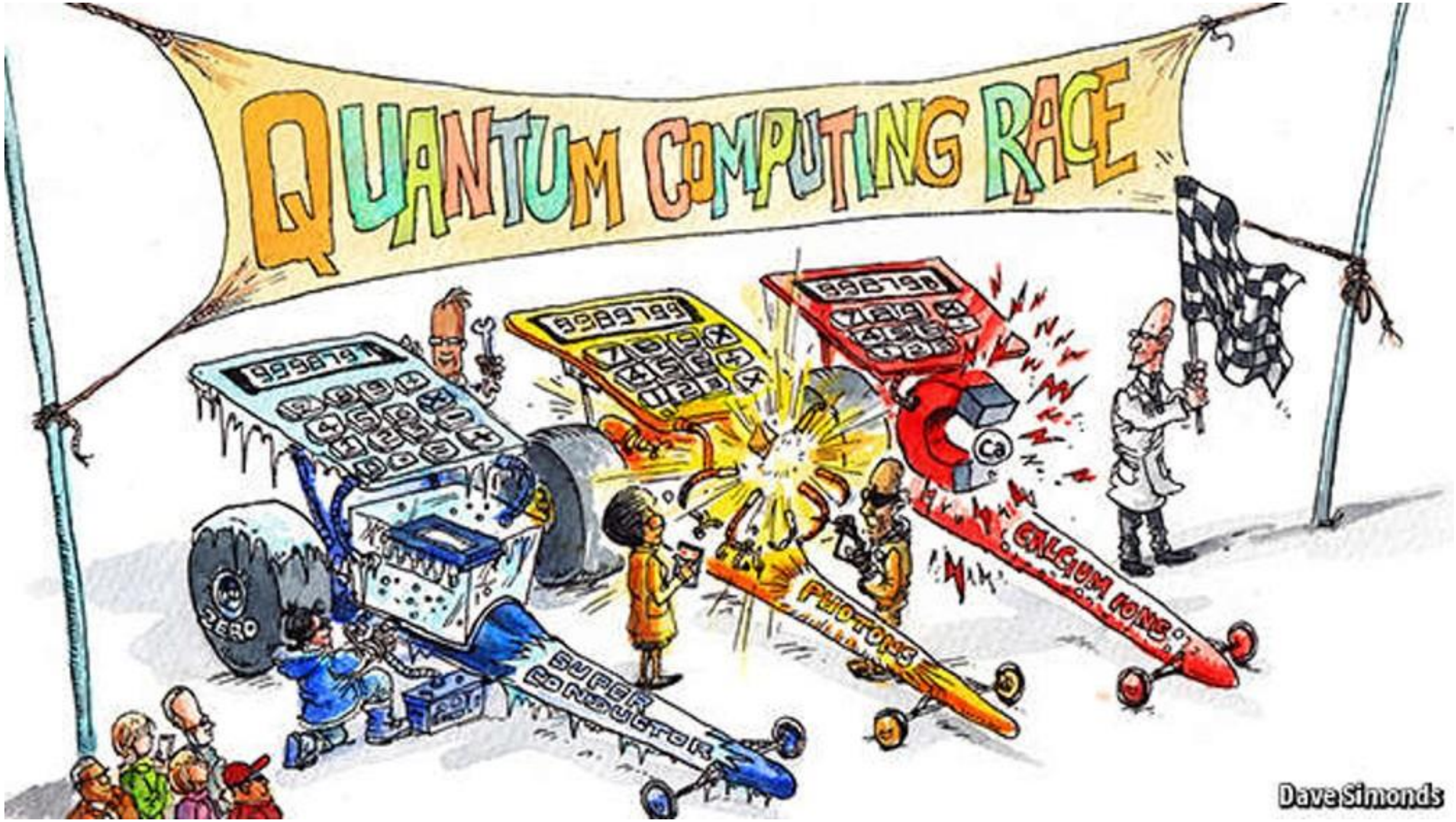
A qubit is a single atom or a single meta-atom (individual quantum system)







The quantum race



https://www.economist.com/science-and-technology/2015/06/20/a-little-bit-better

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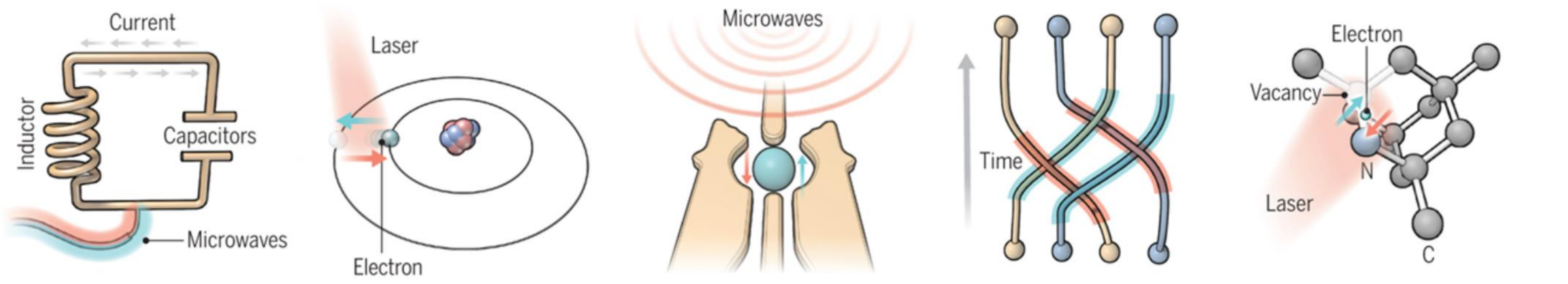
The quantum race

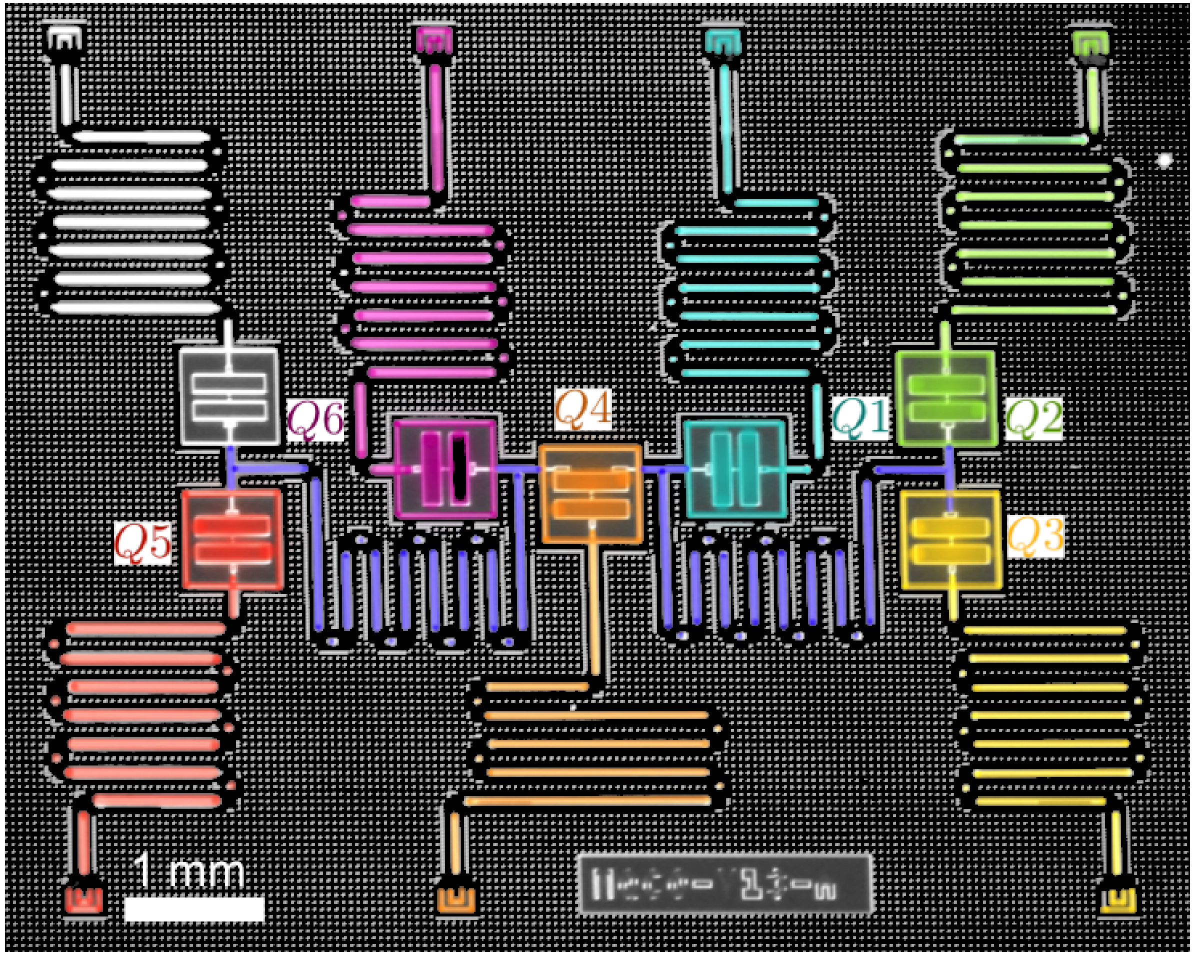


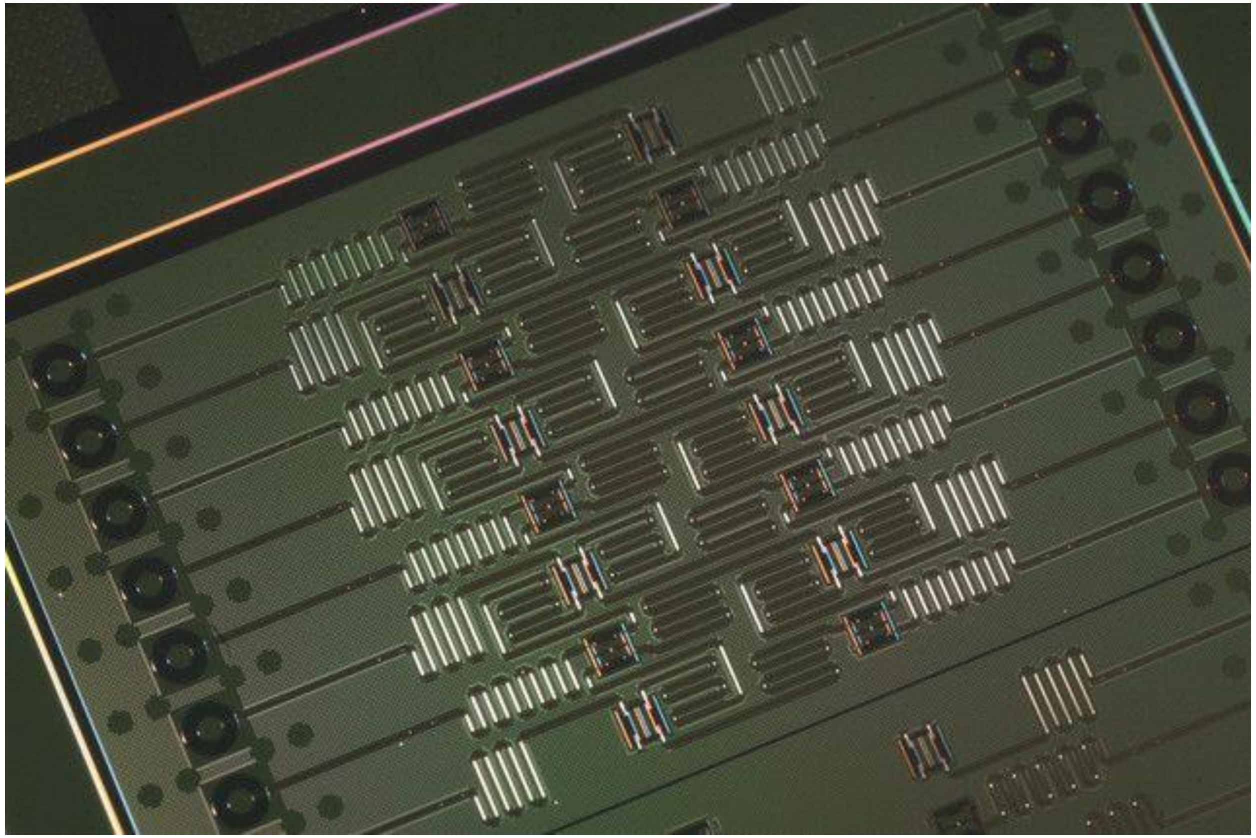
Superconducting loops	Trapped ions	Silicon quantum dots	Topological qubits	Diamond vacancies
A resistance-free current oscillates back and forth around a circuit loop. An injected microwave signal excites the current into super-position states.	Electrically charged atoms, or ions, have quantum energies that depend on the location of electrons. Tuned lasers cool and trap the ions, and put them in superposition states.	These "artificial atoms" are made by adding an electron to a small piece of pure silicon. Microwaves control the electron's quantum state.	Quasiparticles can be seen in the behavior of electrons channeled through semi-conductor structures. Their braided paths can encode quantum information.	A nitrogen atom and a vacancy add an electron to a diamond lattice. Its quantum spin state, along with those of nearby carbon nuclei, can be controlled with light.
Longevity (seconds) 0.00005	>1000	0.03	N/A	10

Science (2012)

1 – Supraconductor qubits

Supraconductor qubits

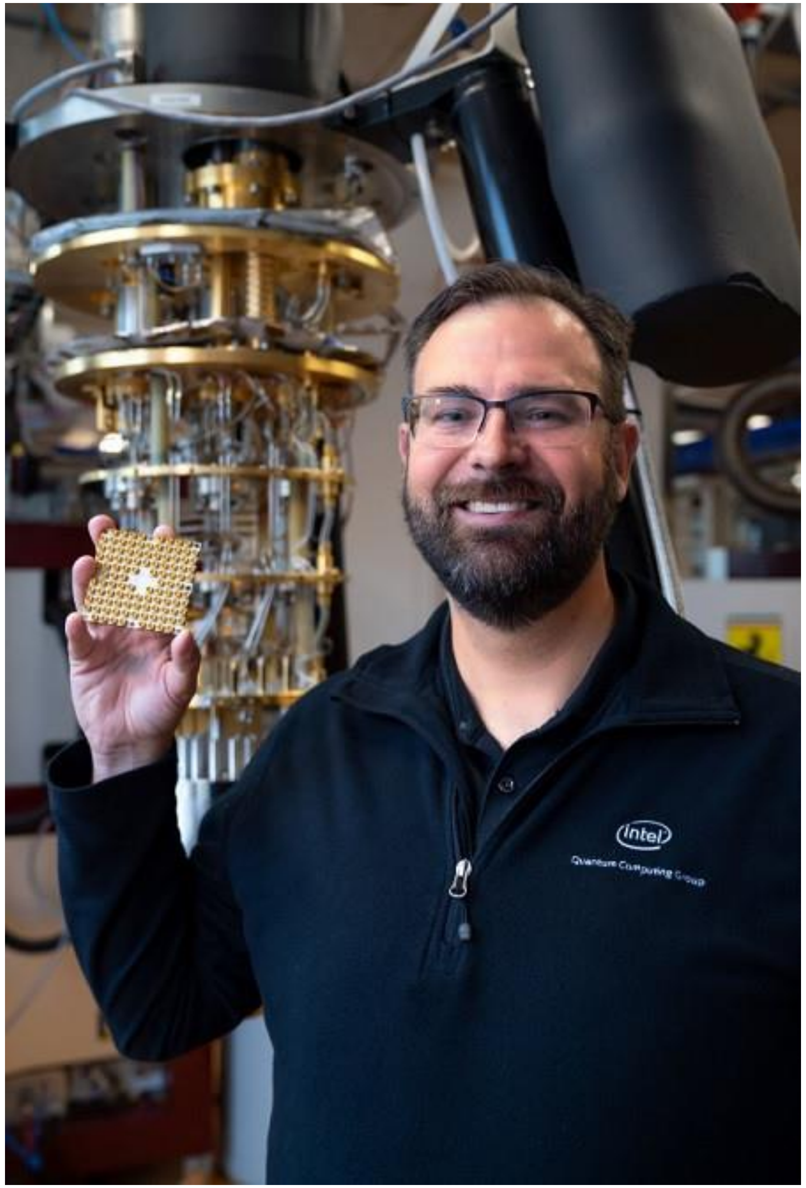


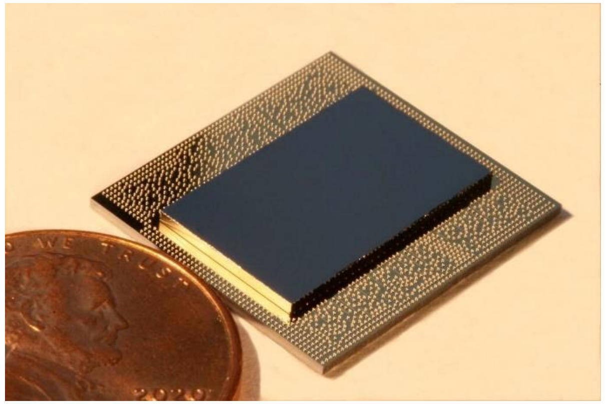


IBM

Supraconductor qubits

Google





Intel

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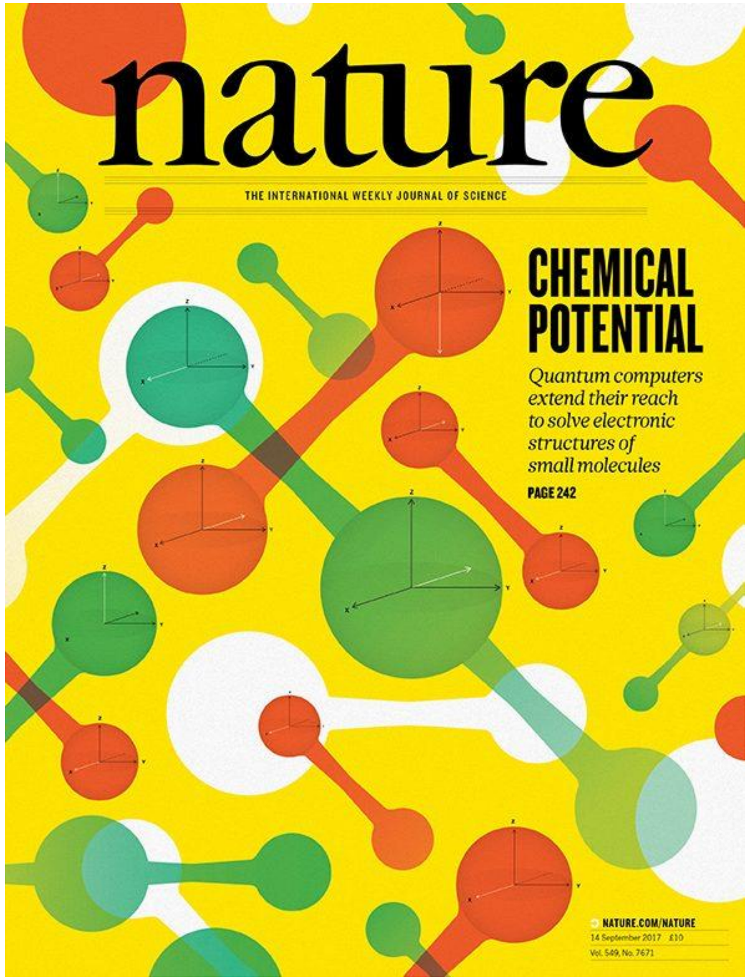
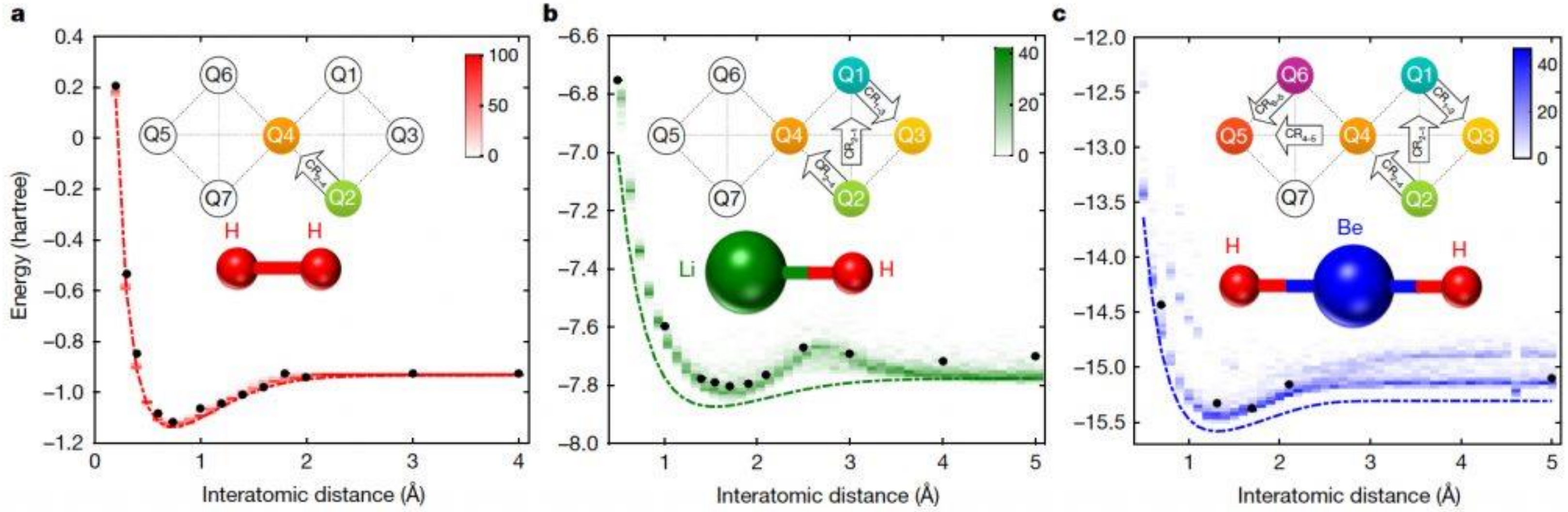
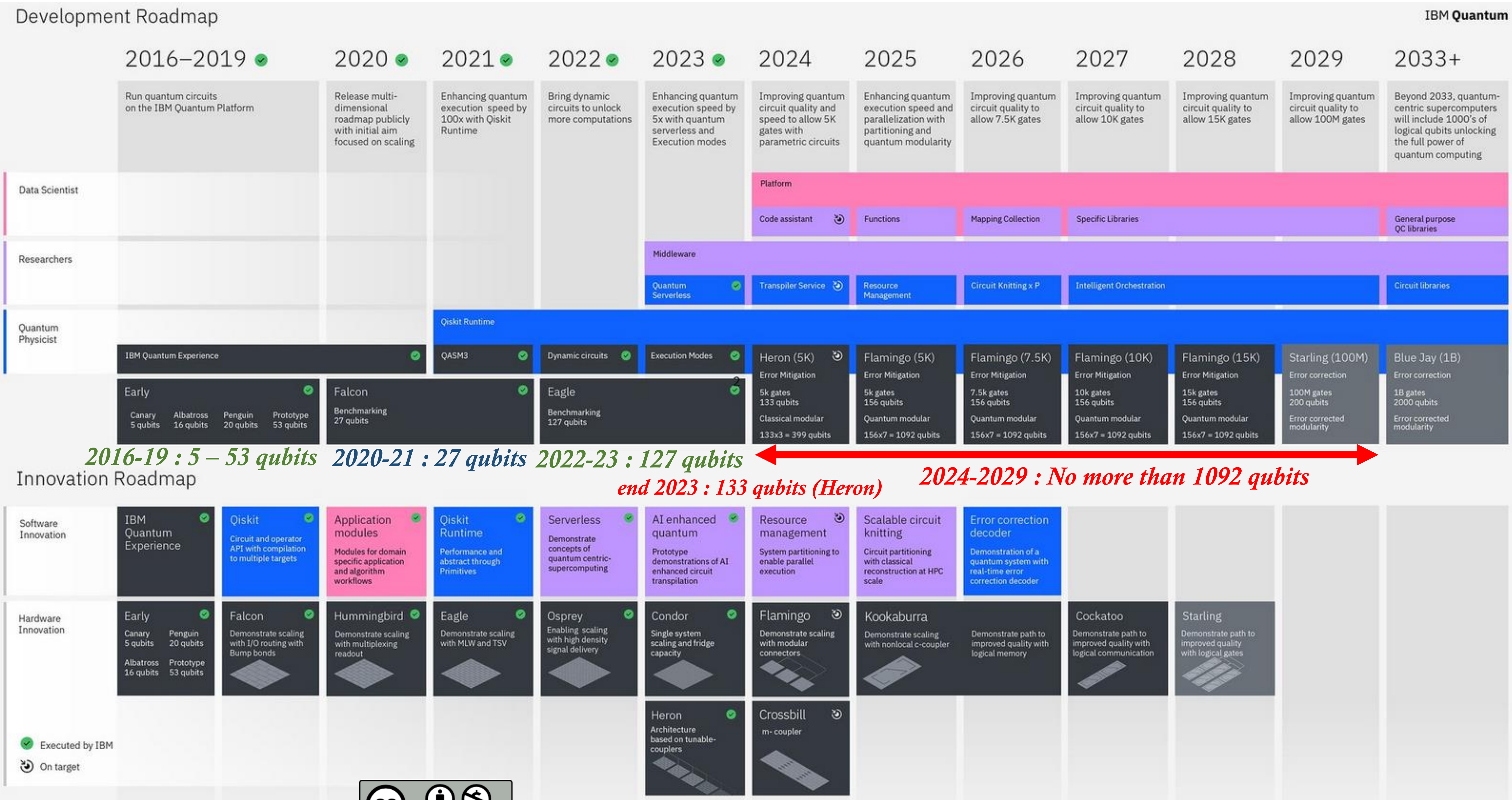
Supraconductor qubits

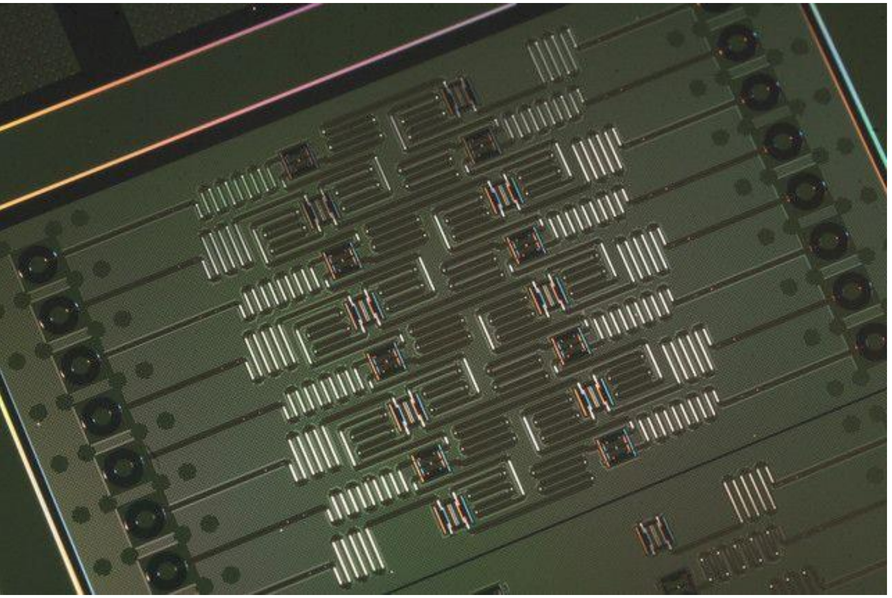




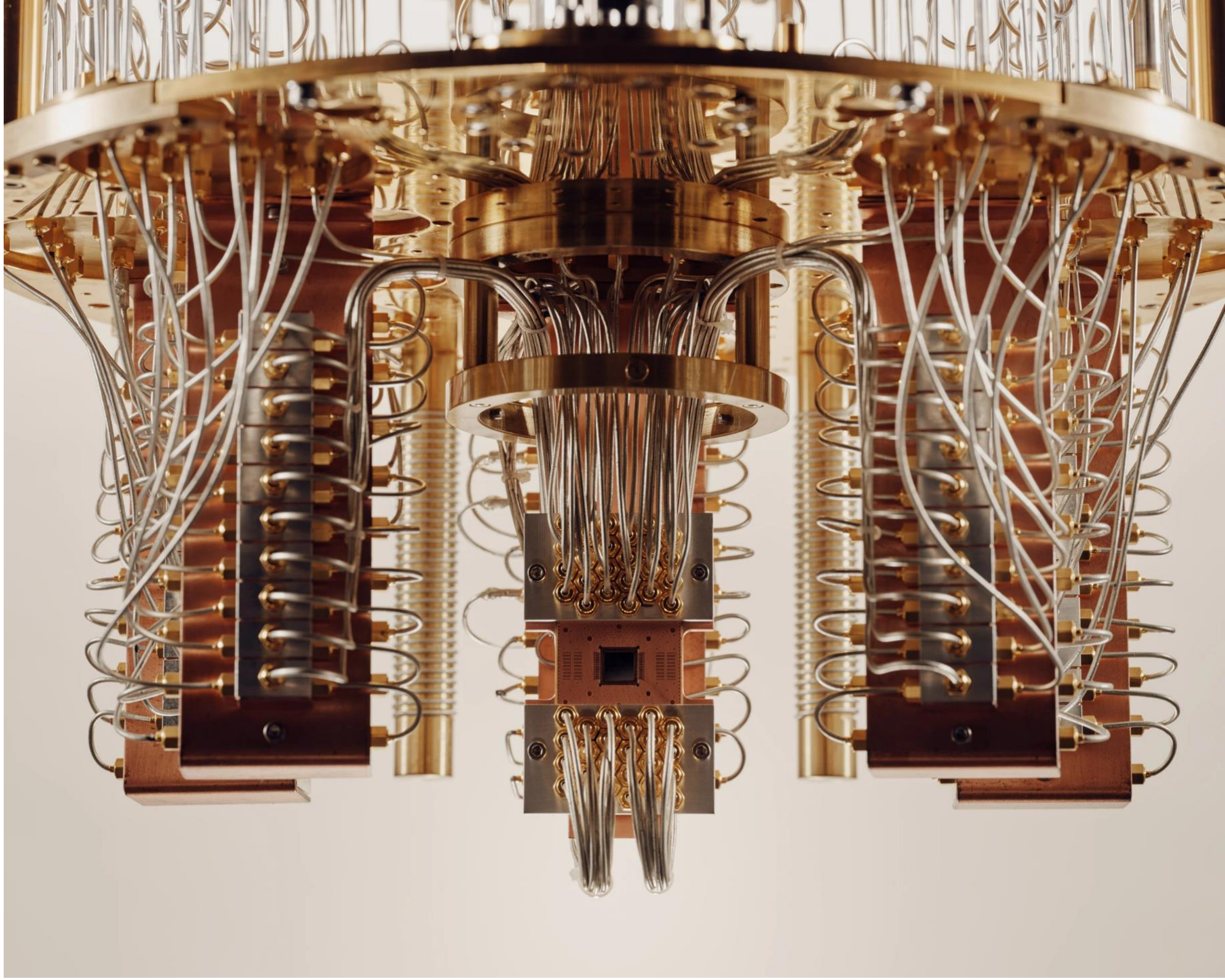


https://research.ibm.com/blog/quantum-roadmap-2033

Reality

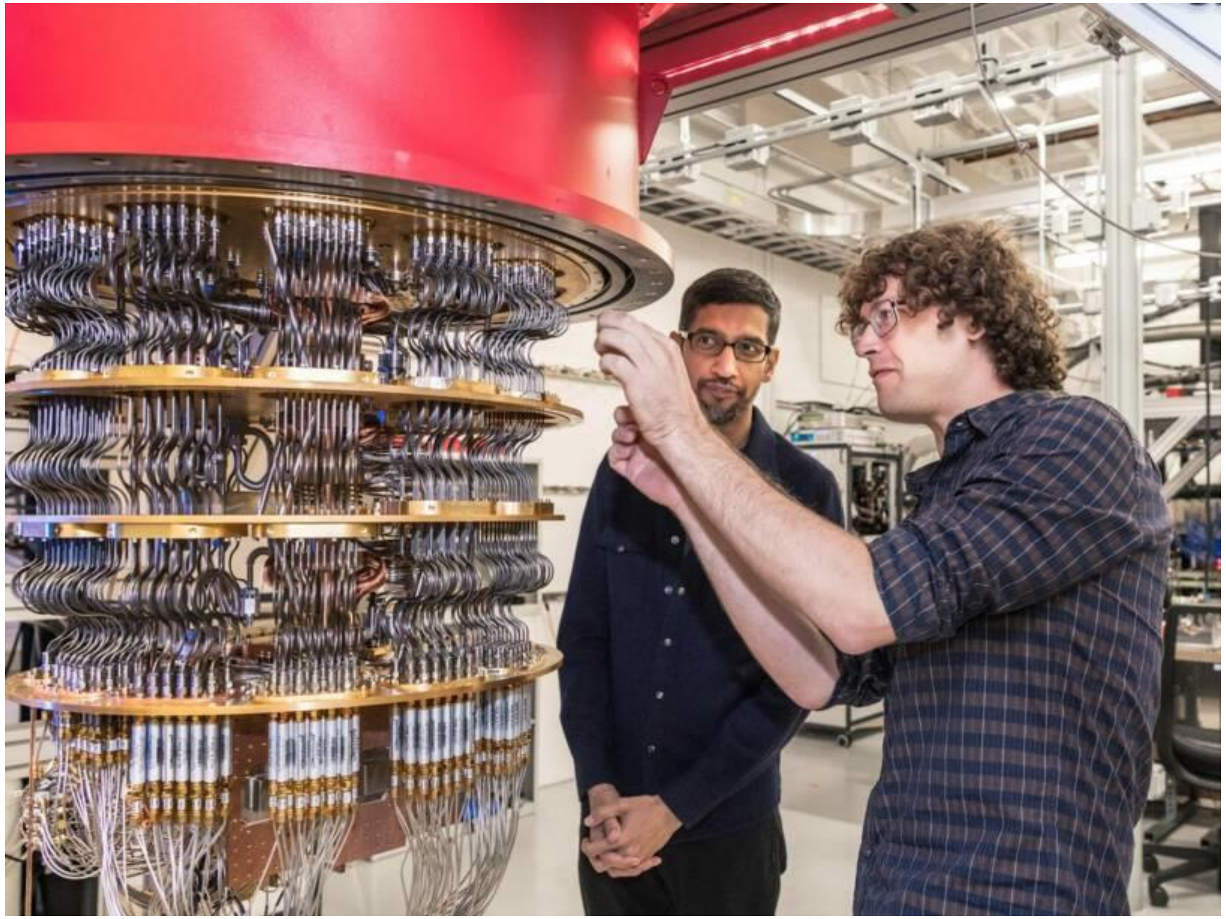


IBM research



https://time.com/6249784/quantum-computing-revolution

Reality



2 – Photonic qubits

Photonic qubits

Encoding a qubit on single photons

Quantum light

- **Particule of light: single photons**
- **Continuous variables and squeezed light.**

Encoding in: polarisation, spatial modes, wavelength, temporal modes (« time-bin », suited for propagation over long distances).

Technological challenge: single photon sources

Ideal source

- **High purity (~~multi-photon~~)**
- **High emission rate**
- **Telecom wavelength**
- **Deterministic**

Photonic qubits

Basic elements for quantum calculation with photons : beam splitter and phase-shifter.

Article | Open access | Published: 23 July 2014

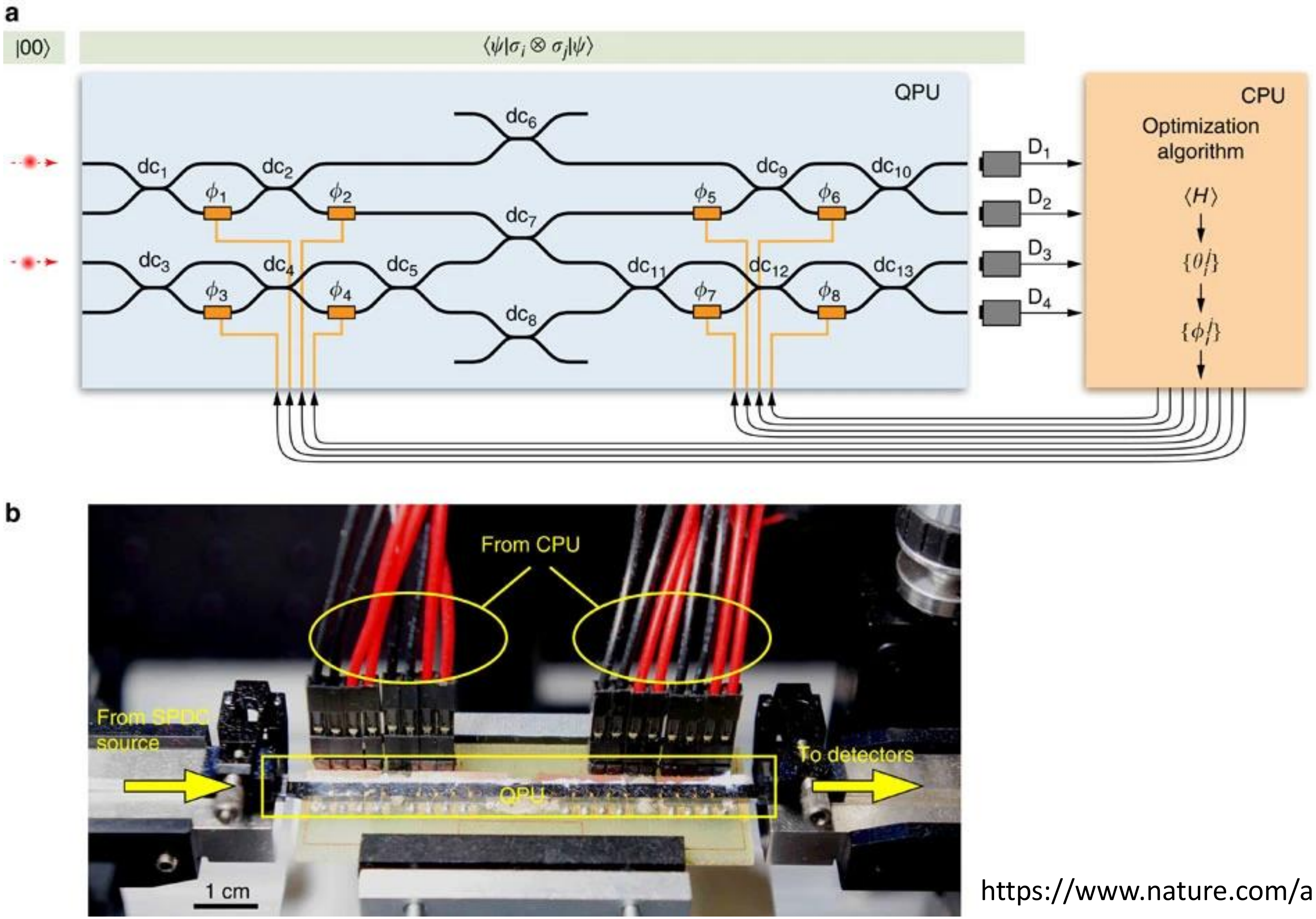
A variational eigenvalue solver on a photonic quantum processor

Alberto Peruzzo, Jarrod McClean, Peter Shadbolt, Man-Hong Yung, Xiao-Qi Zhou, Peter J. Love, Alán Aspuru-Guzik & Jeremy L. O'Brien

Nature Communications **5**, Article number: 4213 (2014) | Cite this article

https://www.nature.com/articles/ncomms5213

Photonic qubits



https://www.nature.com/articles/ncomms5213

Photonic qubits

XANADU

HARDWARE SOFTWARE ABOUT

BUILDING A SUPER
COMPUTER ON A SINGLE CHIP

Quantum computing with light can solve in hours or days what would otherwise take billions of years with existing chips.

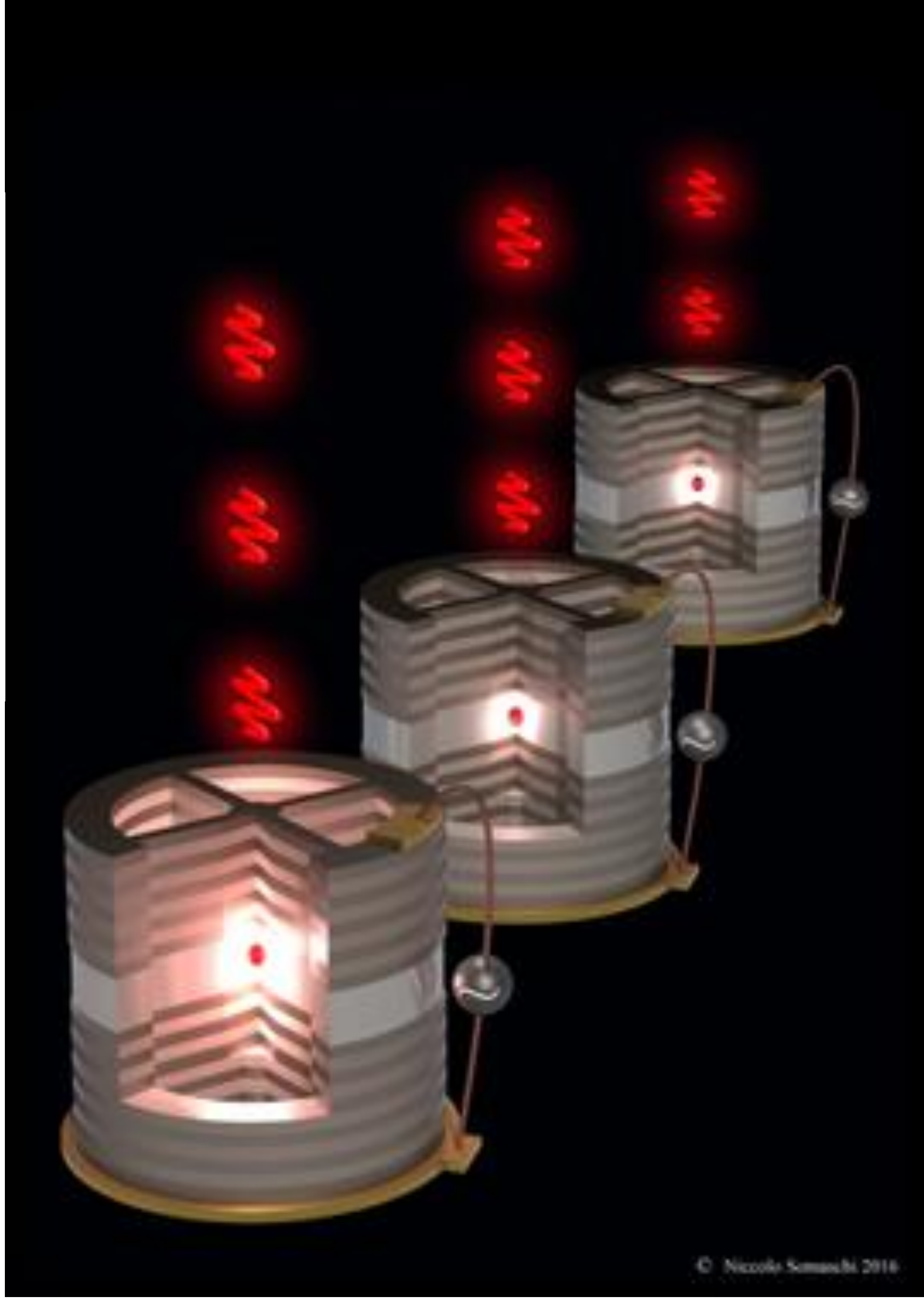
Photonic qubits

La start-up française Quandela lève 50 millions d’euros pour fabriquer des ordinateurs quantiques

Ce financement, qui a lieu moins d’un an après les 100 millions levés par son concurrent Pasqal, illustre les avancées de cette technologie.

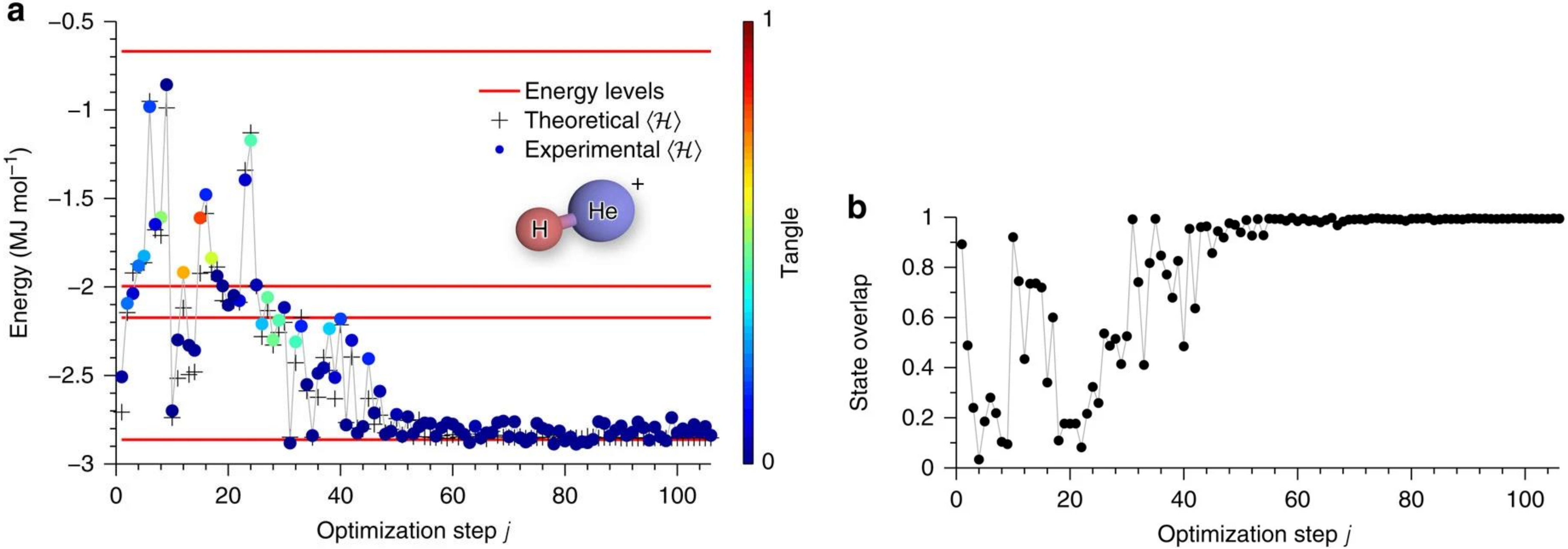
Par Olivier Pinaud

Publié le 07 novembre 2023 à 09h05, modifié le 07 novembre 2023 à 10h31 · Lecture 3 min. · Read in English



Photonic qubits

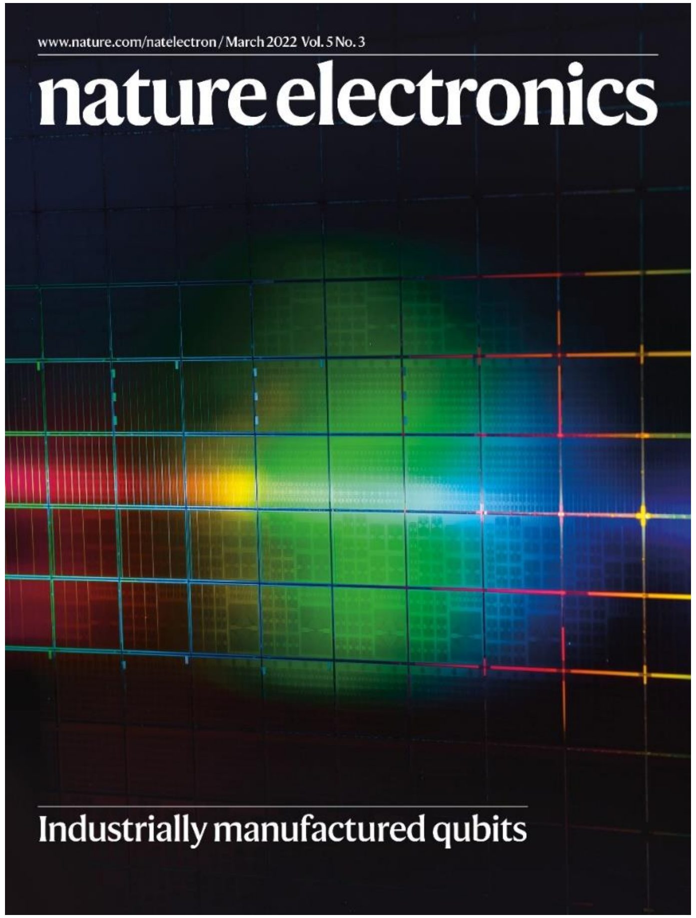
Exemple: computation of the fundamental state of a He-H^+ molecule.



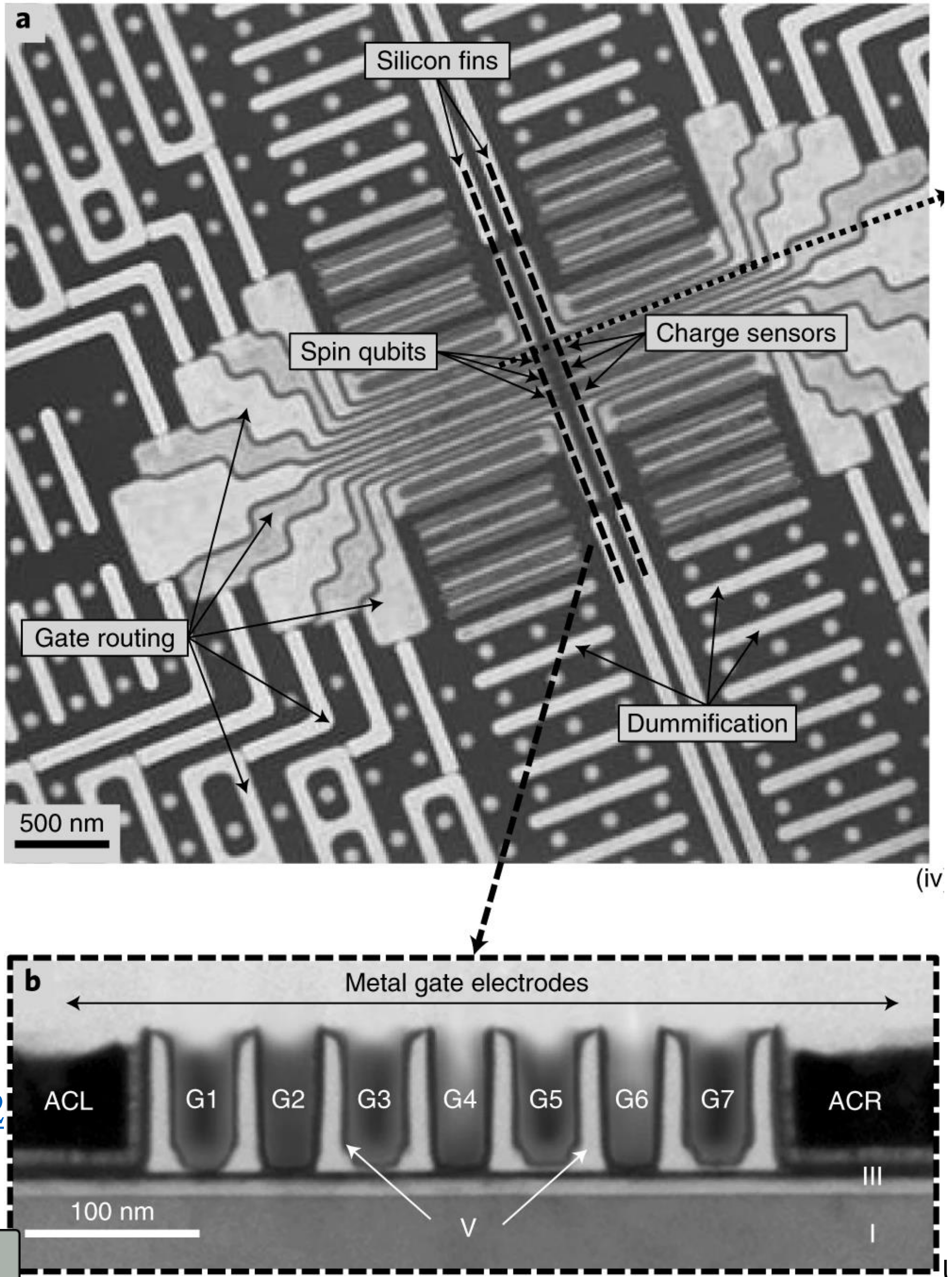
https://www.nature.com/articles/ncomms5213

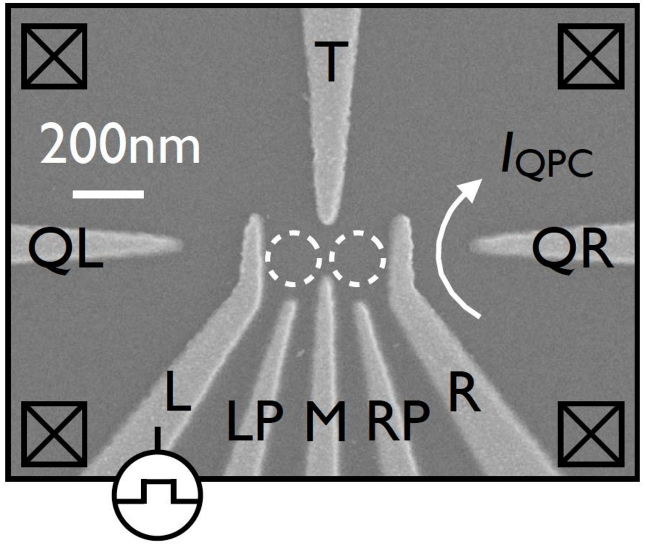
3 – Spin qubits

Spin qubits



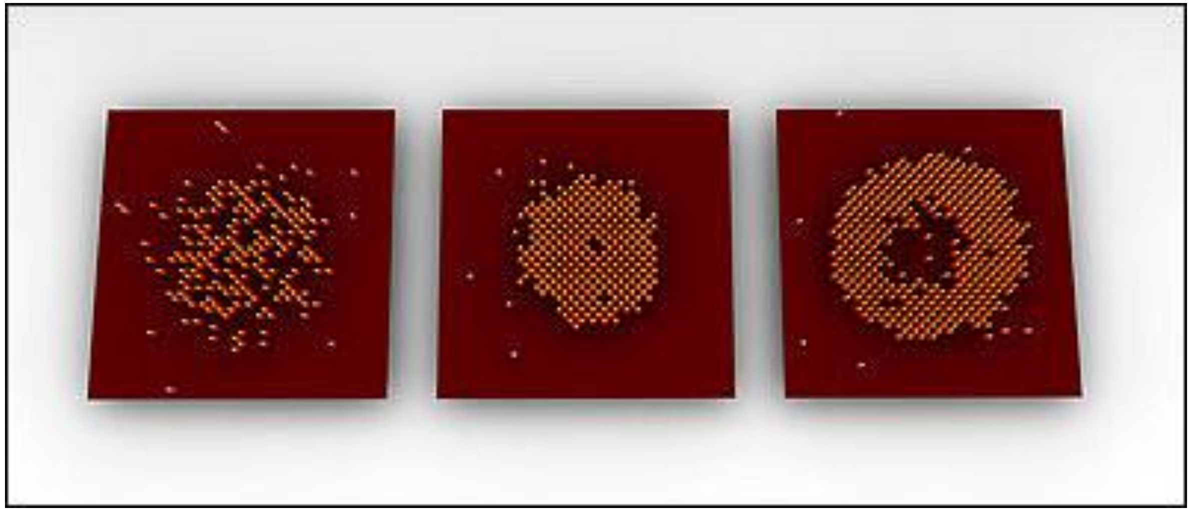
https://www.nature.com/articles/s4192

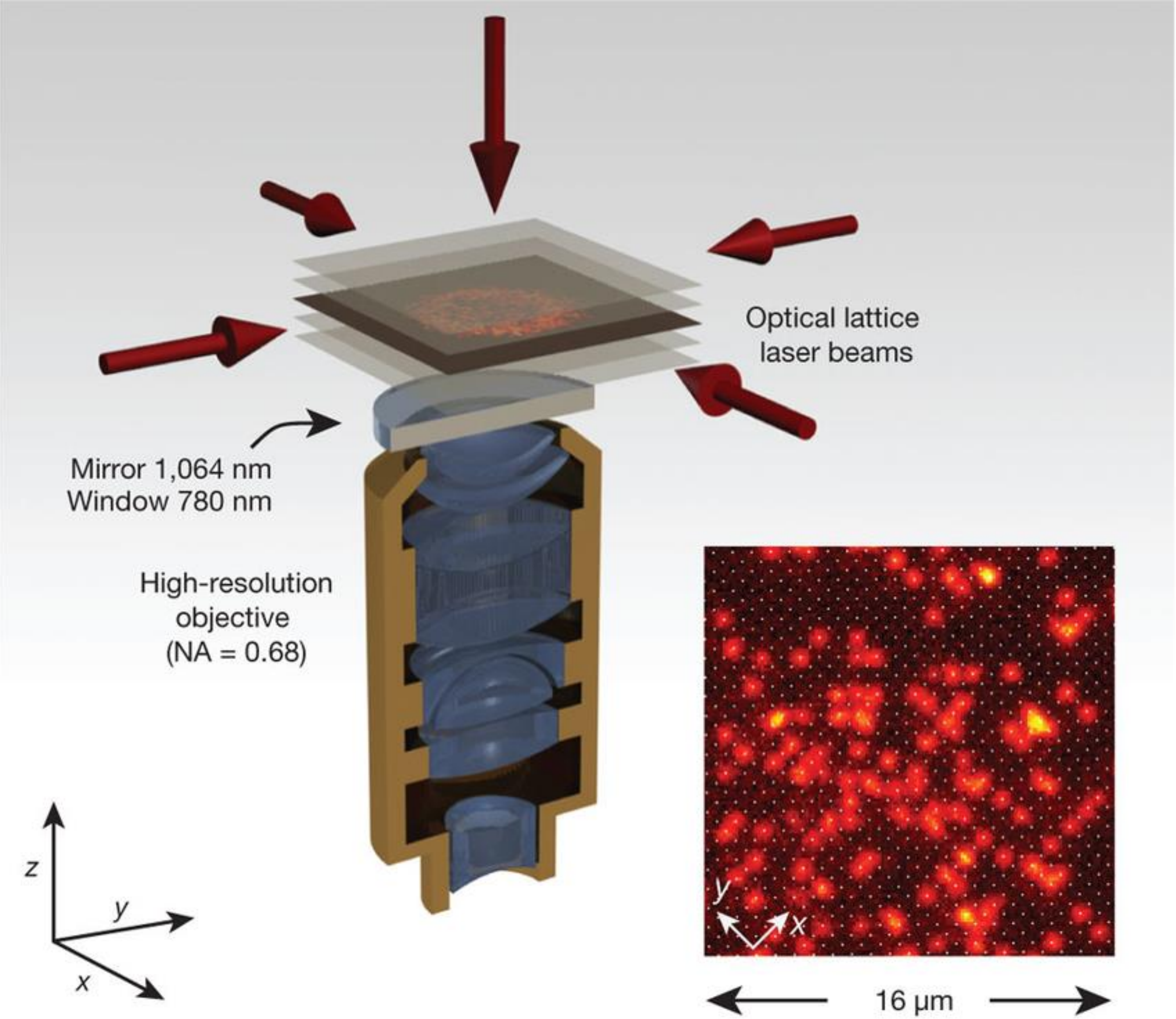




4 – Ultracold (neutral) atoms qubits

Ultracold (neutral) atoms qubits

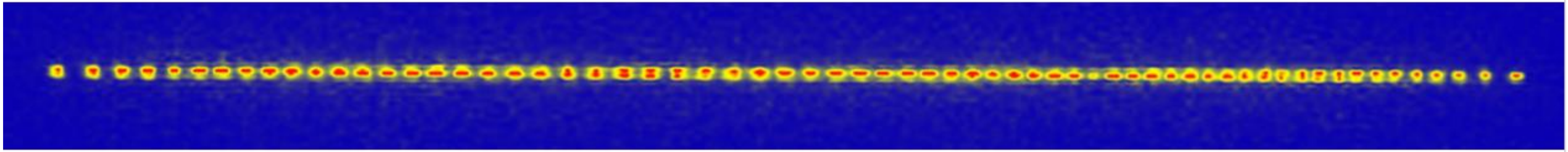




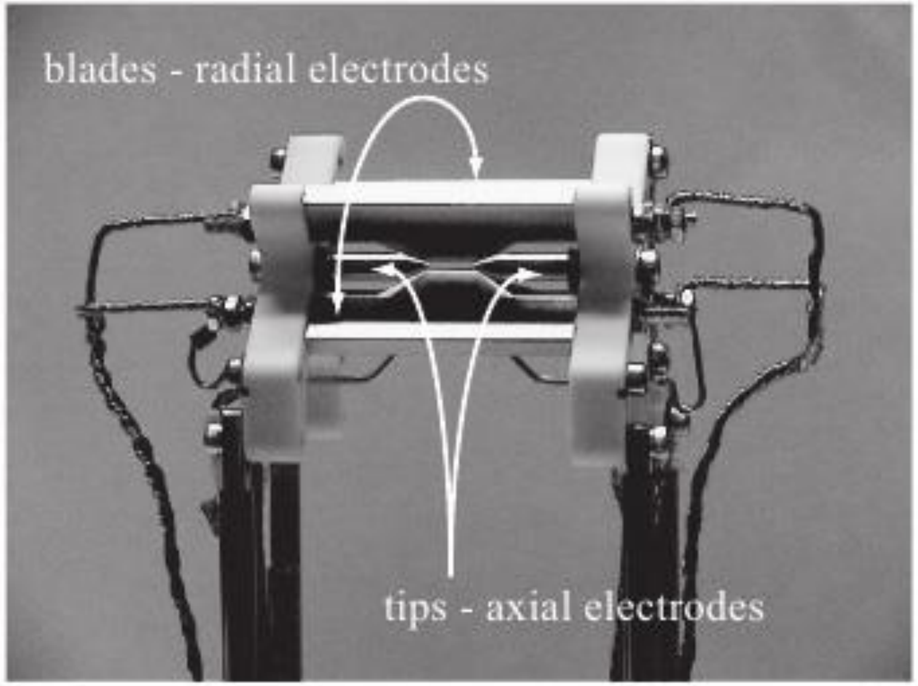
Ultracold (neutral) atoms qubits

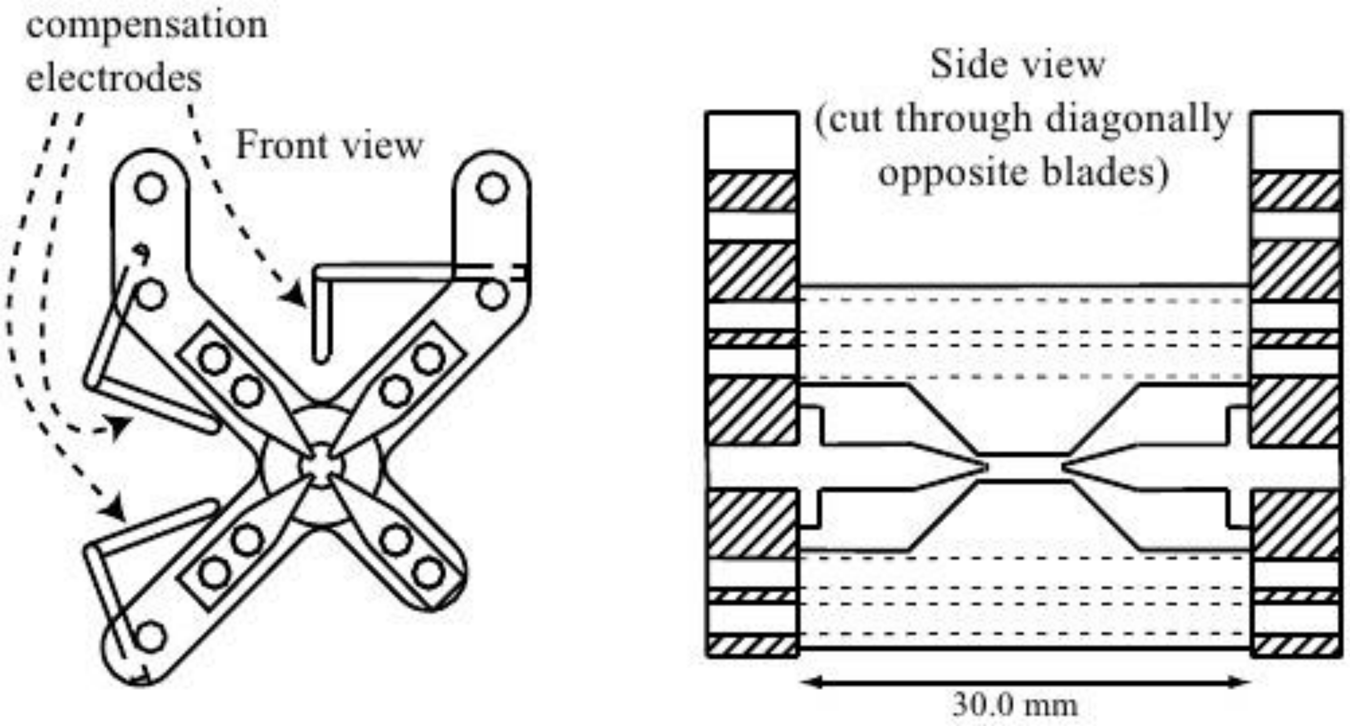
5 – Trapped ions qubits

Trapped ions qubits



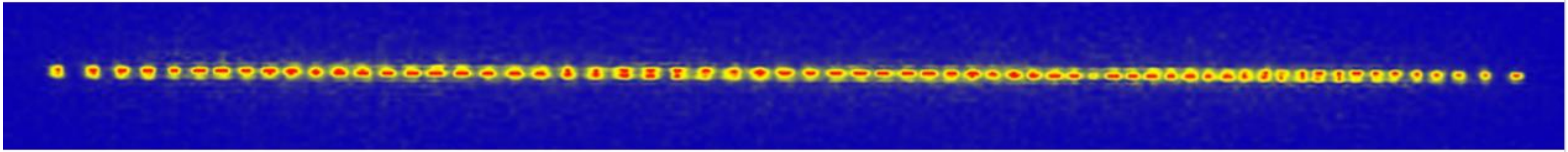
Chain of individual ions (R. Blatt, Innsbruck)



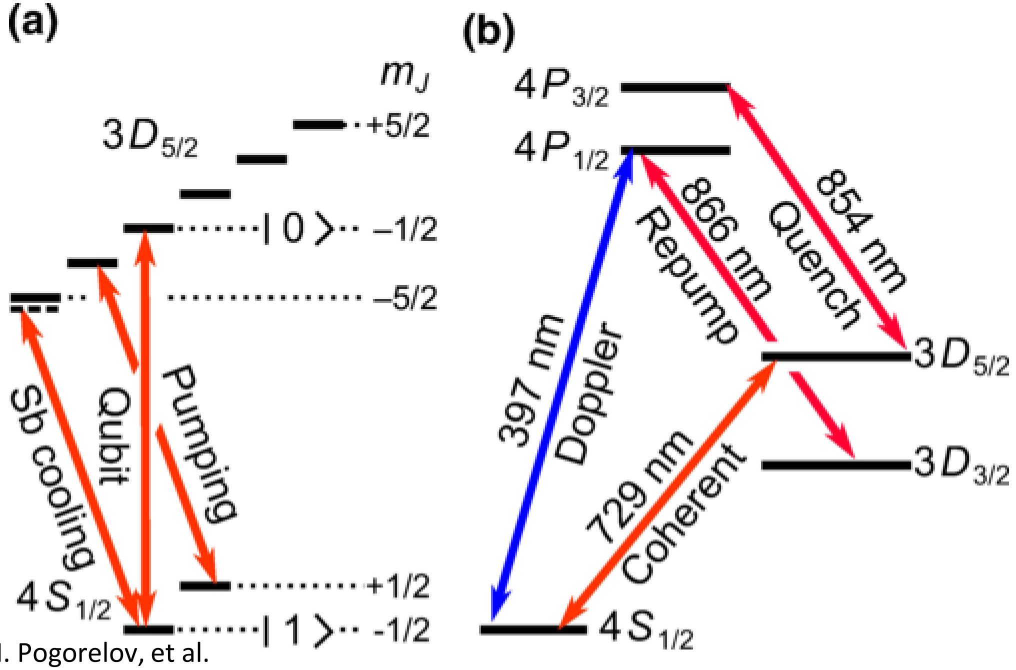


https://en.wikipedia.org/wiki/Trapped-ion_quantum_computer

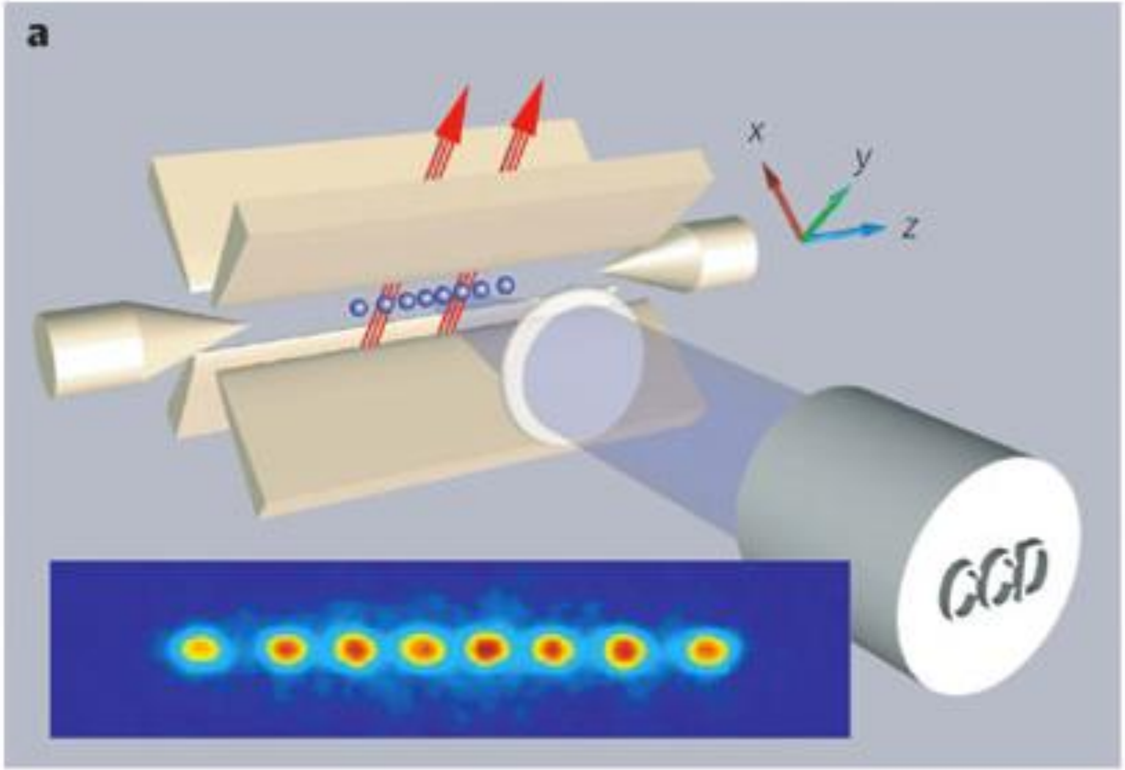
Trapped ions qubits



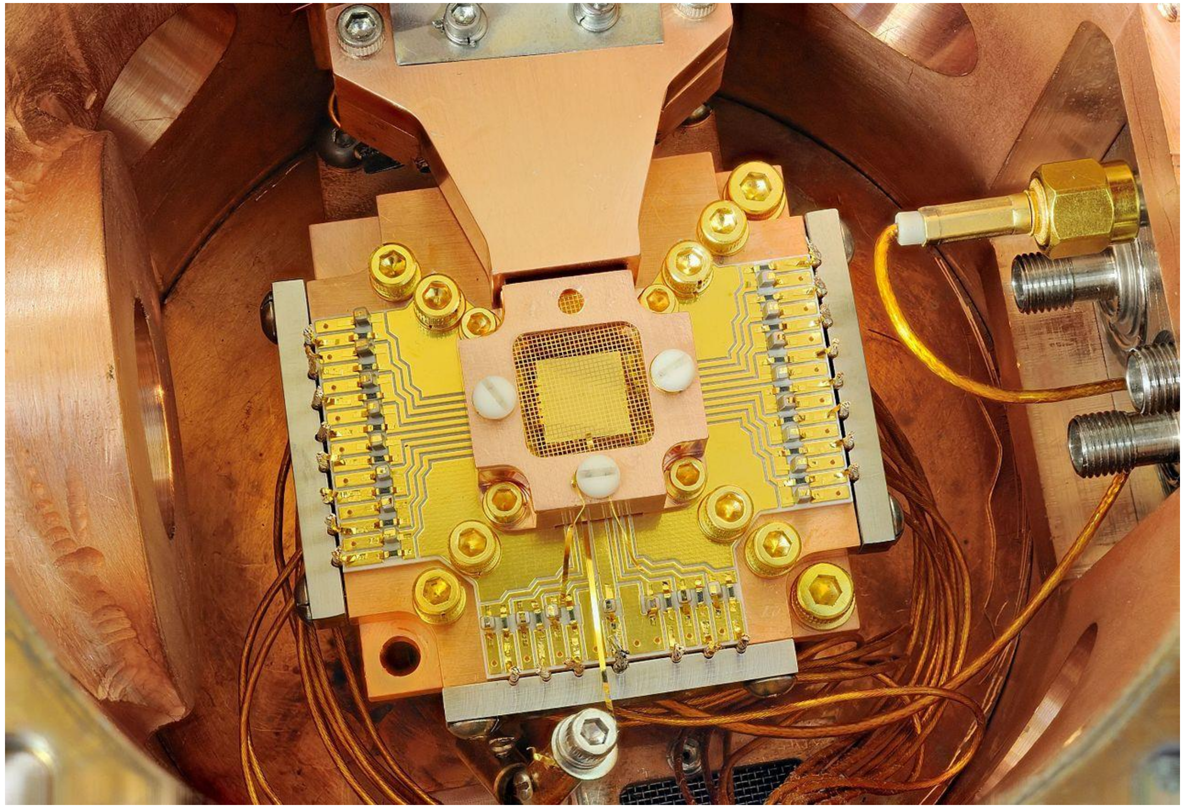
Chain of individual ions (R. Blatt, Innsbruck)

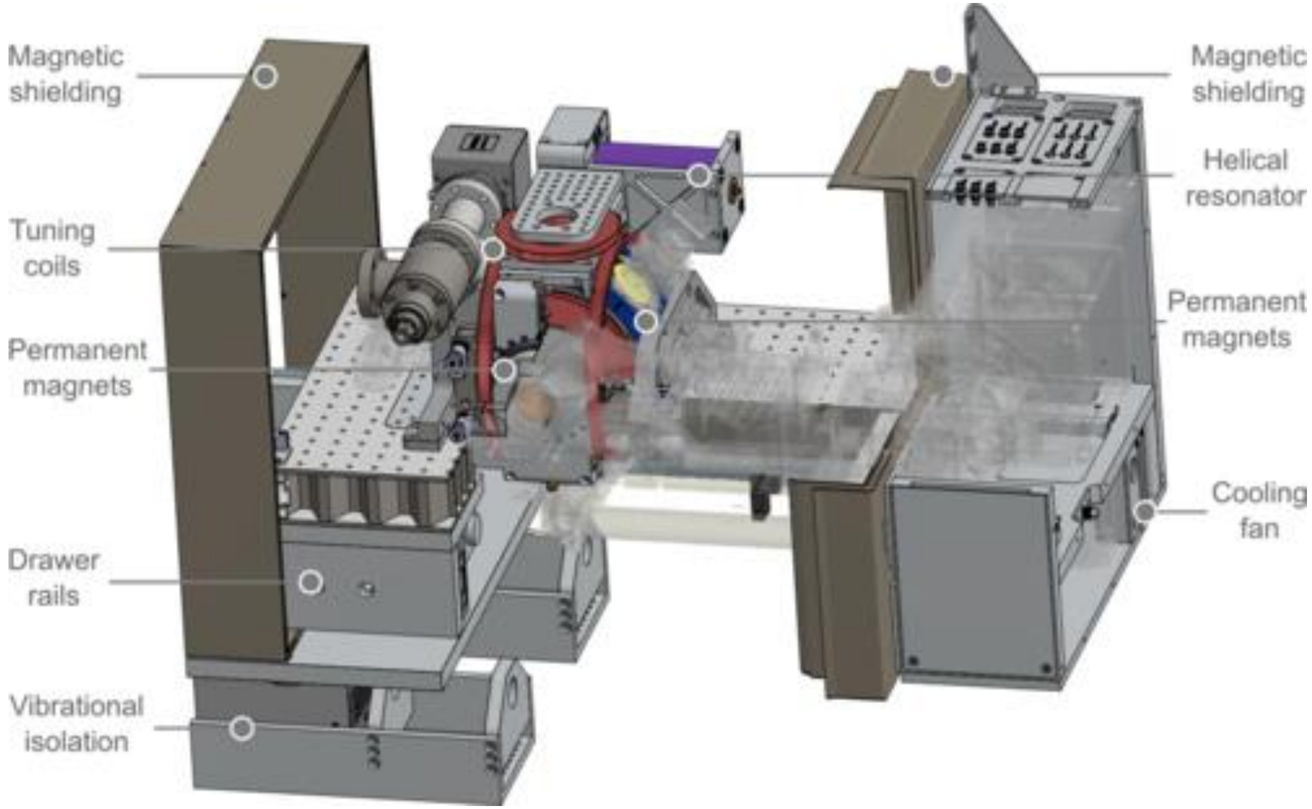


I. Pogorelov, et al.
https://journals.aps.org/prxquantum/abstract/10.1103/PRXQuantum.2.020343



Trapped ions qubits





https://en.wikipedia.org/wiki/Trapped-ion_quantum_computer

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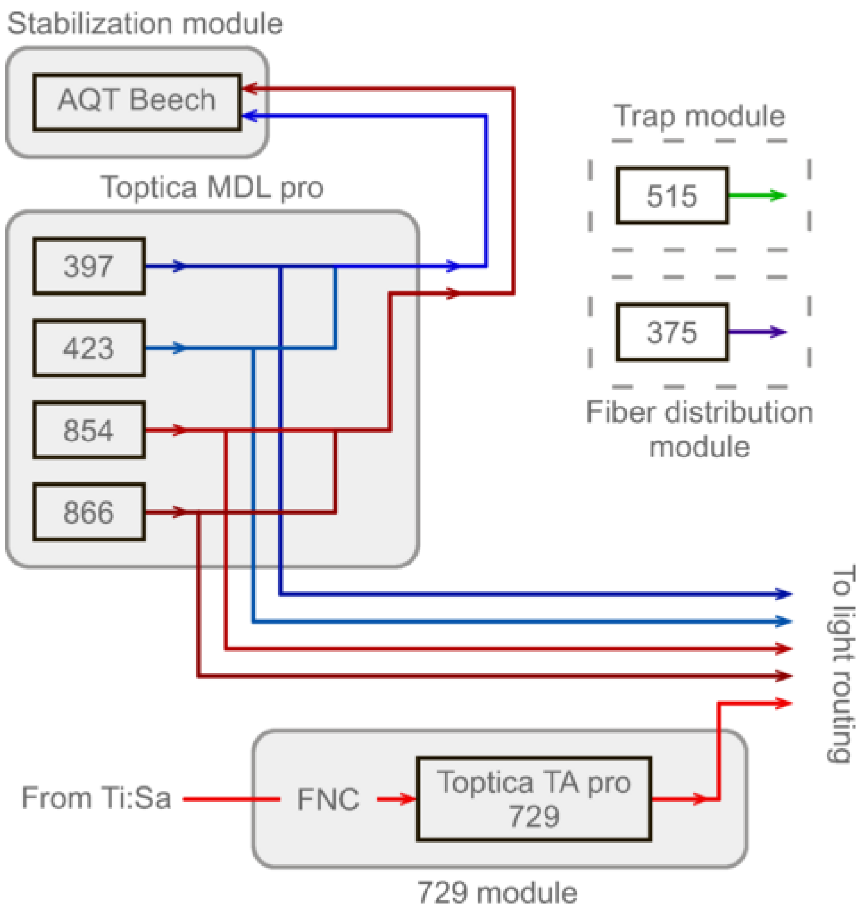
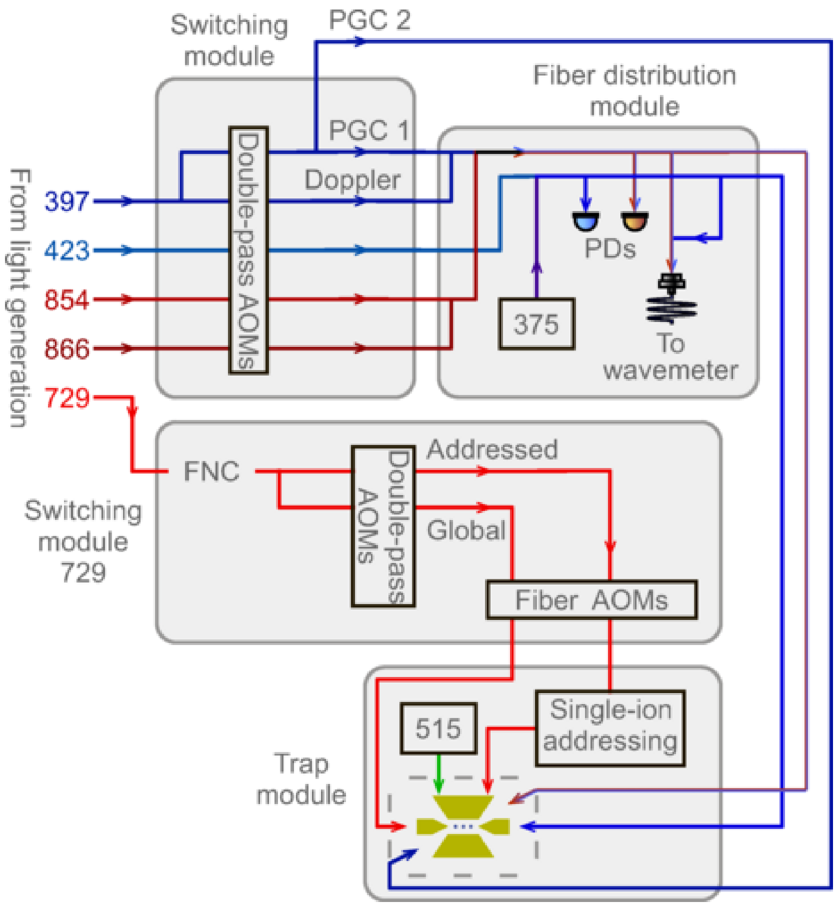
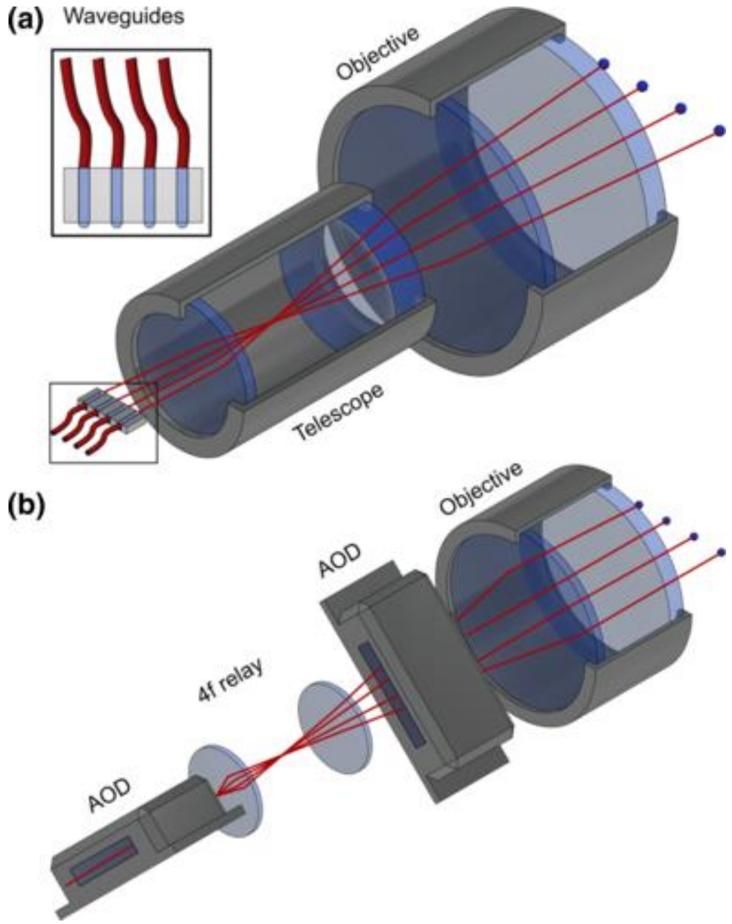
Trapped ions qubits

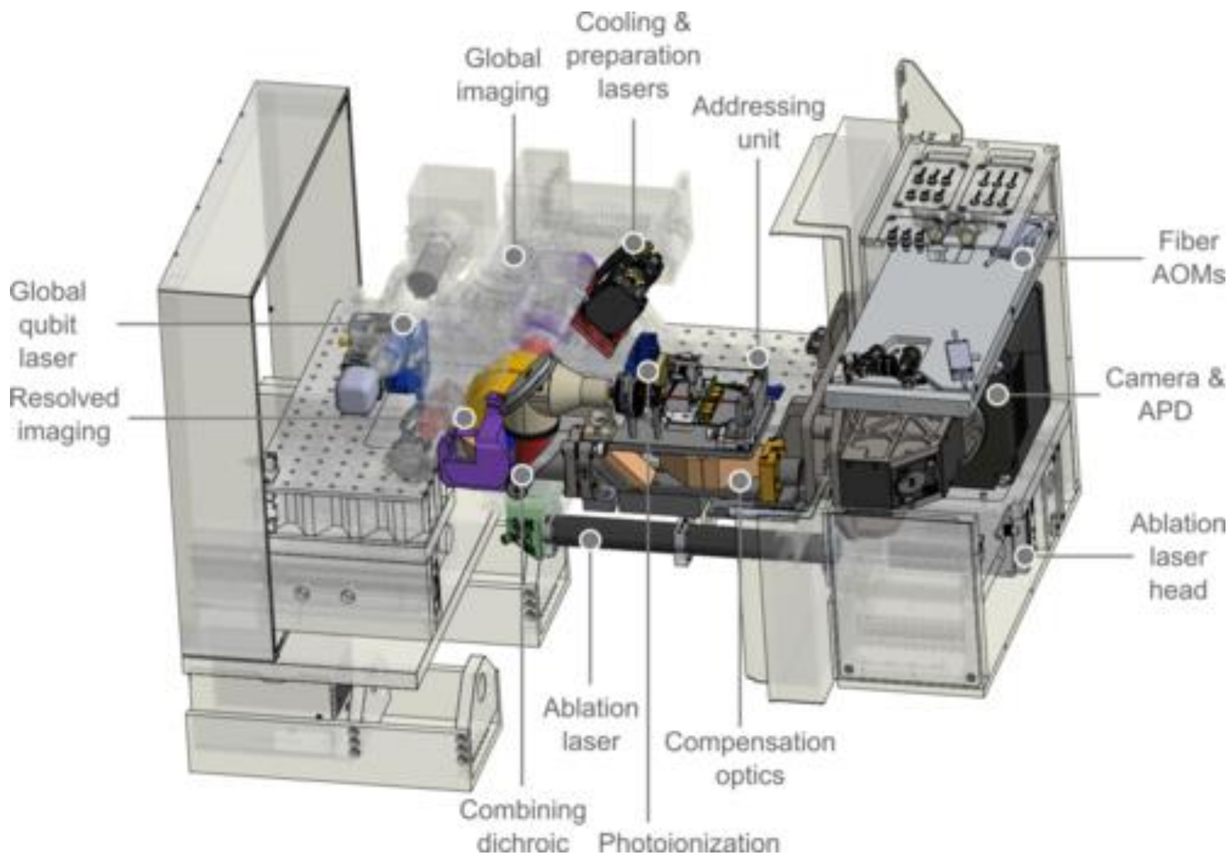




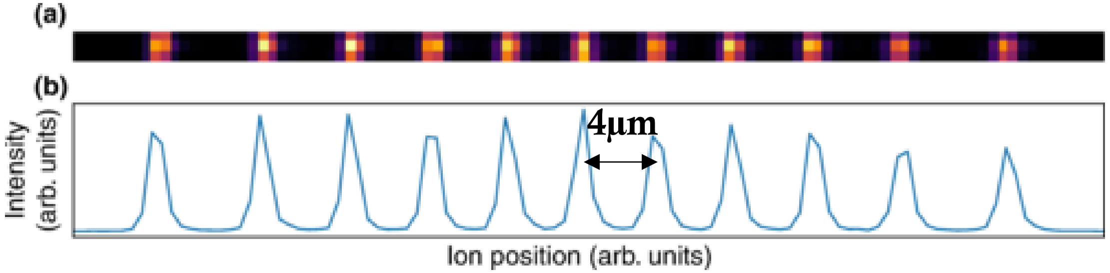


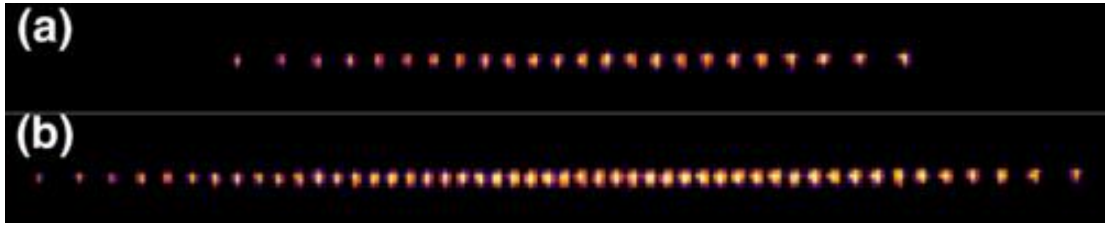
I. Pogorelov, et al.
https://journals.aps.org/prxquantum/abstract/10.1103/PRXQuantum.2.020343

Trapped ions qubits



I. Pogorelov, et al.
https://journals.aps.org/prxquantum/abstract/10.1103/PRXQuantum.2.020343





https://ionq.com/

5 – Topological qubits

Topological qubits

PHYSICAL REVIEW B **107**, 245423 (2023)

Editors' Suggestion

InAs-Al hybrid devices passing the topological gap protocol

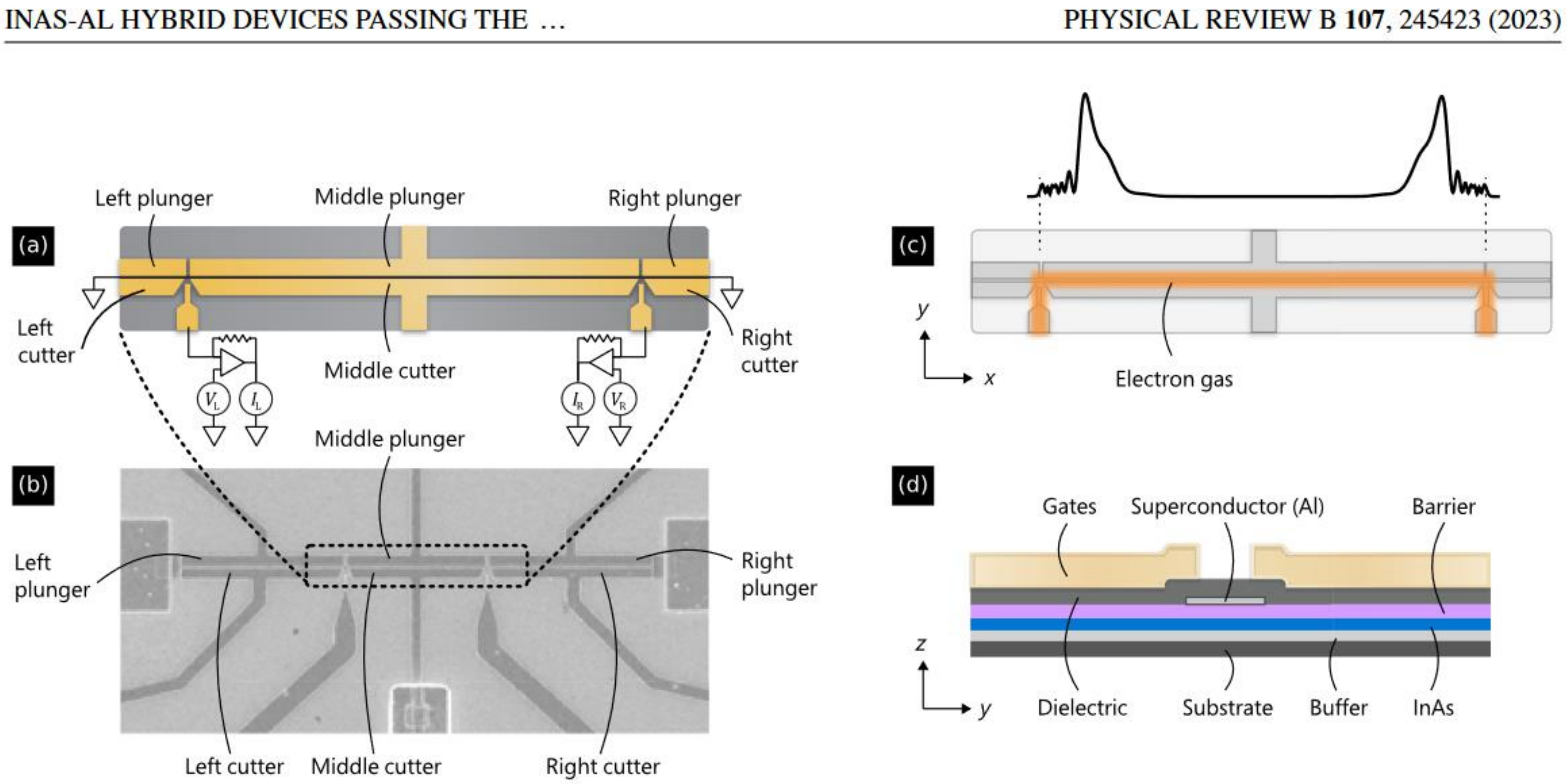
Morteza Aghaee *et al.**
(Microsoft Quantum)

(Received 12 October 2022; revised 9 March 2023; accepted 10 May 2023; published 21 June 2023)

We present measurements and simulations of semiconductor-superconductor heterostructure devices that are consistent with the observation of topological superconductivity and Majorana zero modes. The devices are fabricated from high-mobility two-dimensional electron gases in which quasi-one-dimensional wires are defined by electrostatic gates. These devices enable measurements of local and nonlocal transport properties and have been optimized via extensive simulations to ensure robustness against nonuniformity and disorder. Our main result is that several devices, fabricated according to the design's engineering specifications, have passed the topological gap protocol defined in Pikulin *et al.* (arXiv:2103.12217). This protocol is a stringent test composed of a sequence of three-terminal local and nonlocal transport measurements performed while varying the magnetic field, semiconductor electron density, and junction transparencies. Passing the protocol indicates a high probability of detection of a topological phase hosting Majorana zero modes as determined by large-scale disorder simulations. Our experimental results are consistent with a quantum phase transition into a topological superconducting phase that extends over several hundred millitesla in magnetic field and several millivolts in gate voltage, corresponding to approximately one hundred microelectronvolts in Zeeman energy and chemical potential in the semiconducting wire. These regions feature a closing and reopening of the bulk gap, with simultaneous zero-bias conductance peaks at *both* ends of the devices that withstand changes in the junction transparencies. The extracted maximum topological gaps in our devices are 20–60 μeV. This demonstration is a prerequisite for experiments involving fusion and braiding of Majorana zero modes.

DOI: 10.1103/PhysRevB.107.245423

Topological qubits



Quantum race

Technology	Pros	Cons	Entreprises
Supraconductors	# qubits ~100, T_1~100µs, gate fidelity >99%, Gate operation time ~10-50ns, TRL5, silicon technology	Requires sub-K temperatures	IBM, Google, Rigetti, D-waves, Alice et Bob, Intel,…
Trapped ions	T_1~50s, gate fidelity >99%, room temperature, TRL4, # qubits ~32	1D geometry, Gate operation time ~3-50µs,	IonQ
Ultracold atoms	Room temperature	Quantum simulators	Pasqal
Electronic spin	Electrical read-out of qubit state	# qubits ~2, TRL 2-3	C12
Topological insulators	Topological protection	Relies on Majorana zero mode, not observed yet… Initially expected in 2018	Microsoft
Photons	Flying qubit, room temperature, fast gating, modular design, quantum internet compatible	Connectivity	Quandela, QuiX quantum, Xanadu,…