Welcome to the NISQ era

(Noisy Intermediate Scale Quantum)

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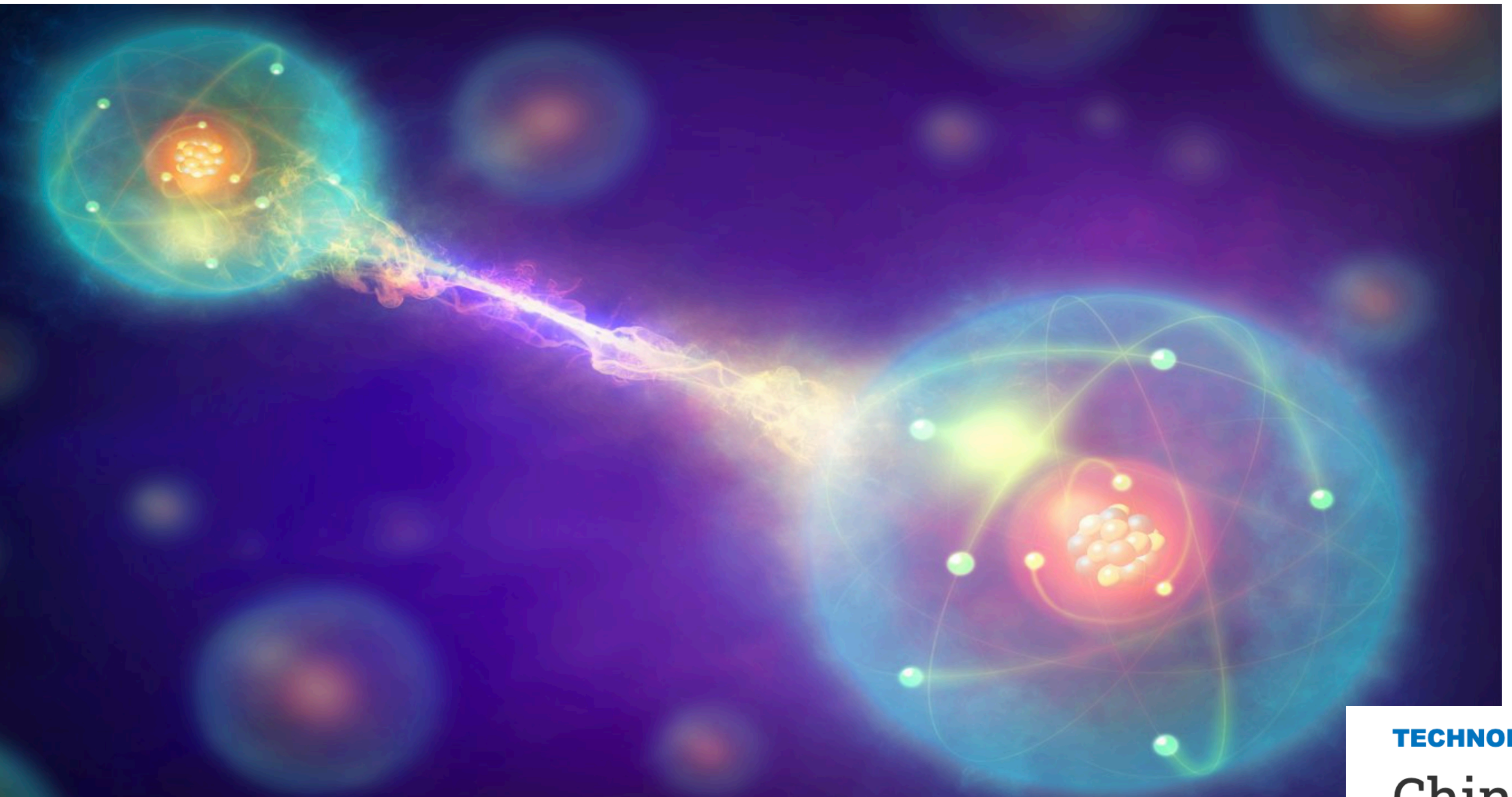
NEWSWEEK MAGAZINE

As China Leads Quantum Computing Race, U.S. Spies Plan for a World with Fewer Secrets

BY FRED GUTERL ON 12/14/20 AT 5:00 AM EST



QUANTUM FRONTIERS

REPORT ON COMMUNITY INPUT TO THE NATION'S STRATEGY FOR QUANTUM INFORMATION SCIENCE

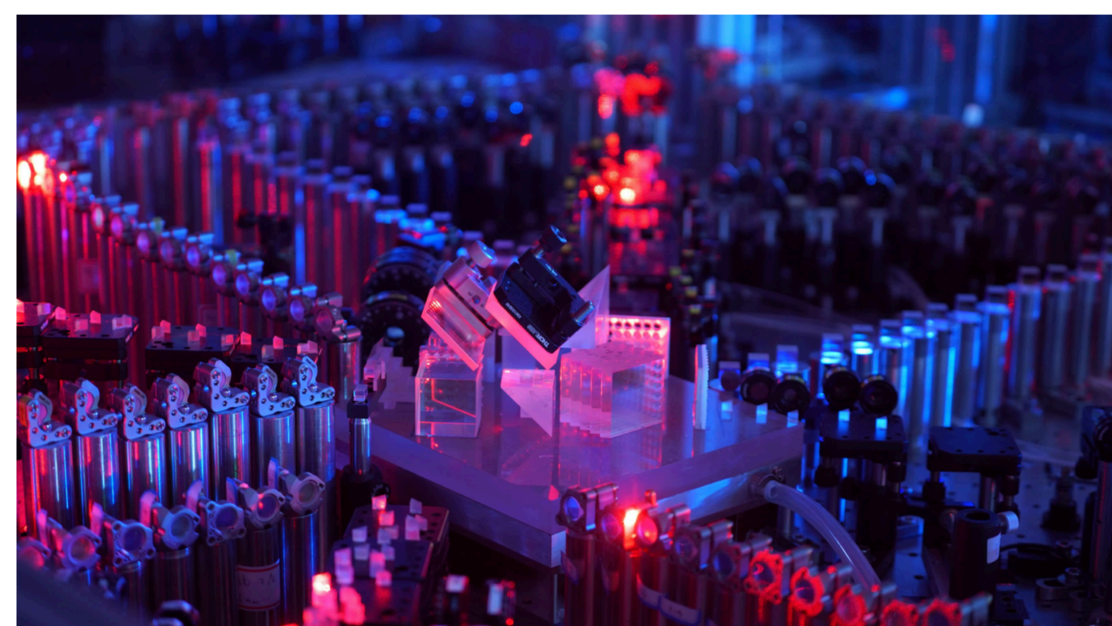
Product of

THE WHITE HOUSE

TECHNOLOGY

China claims milestone in quest for 'quantum supremacy'

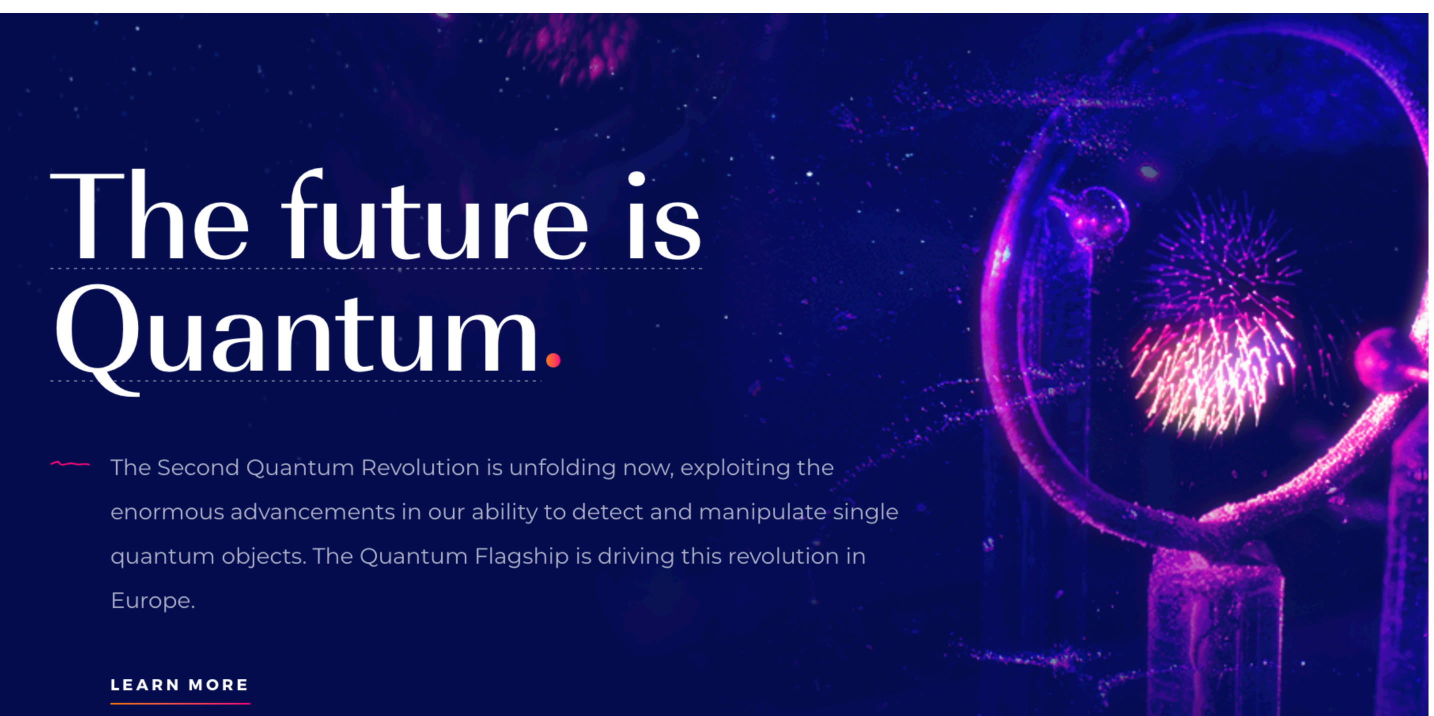
Google only other researcher that says it has achieved computing goal



An optical quantum computer developed by a team of Chinese researchers including those from the University of Science and Technology of China. (courtesy of Han-Sen Zhong of the research group)

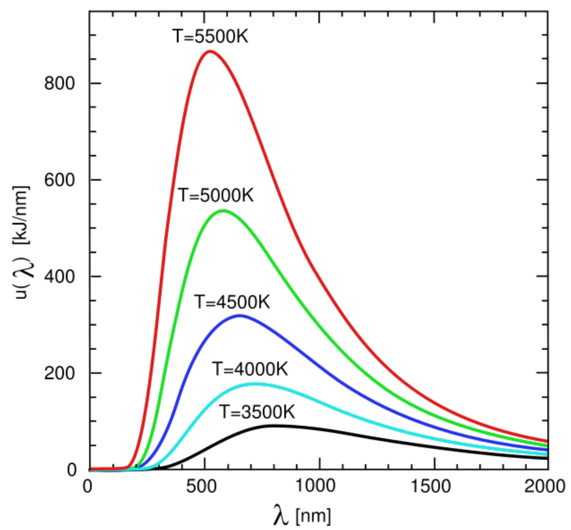
AKIRA OIKAWA, Nikkei staff writer

December 13, 2020 23:29 JST

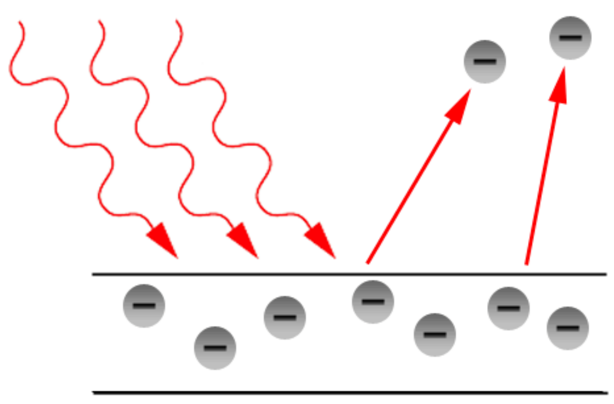


The Quantum World

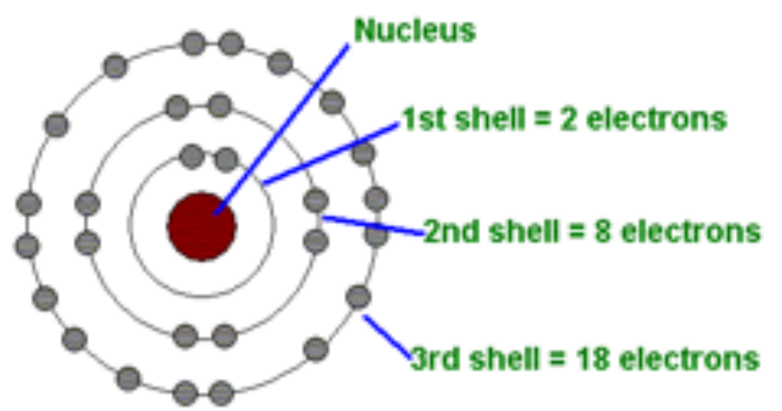
The first quantum revolution explained the microscale



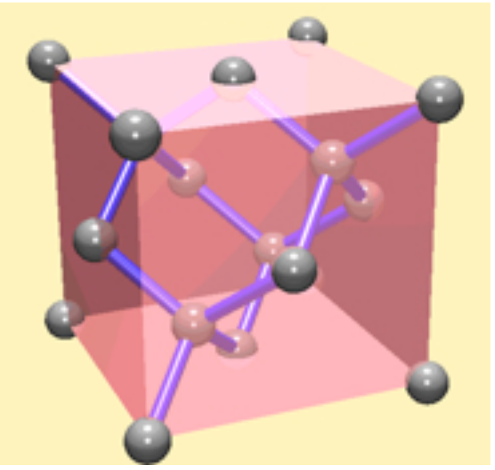
Blackbody radiation

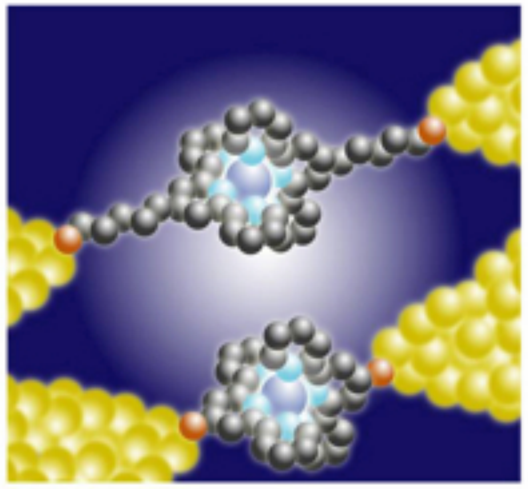


Photoelectric effect



Atomic structure

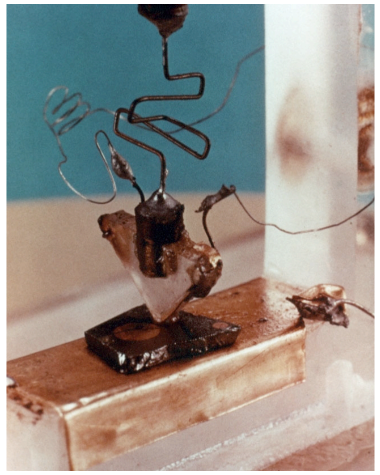




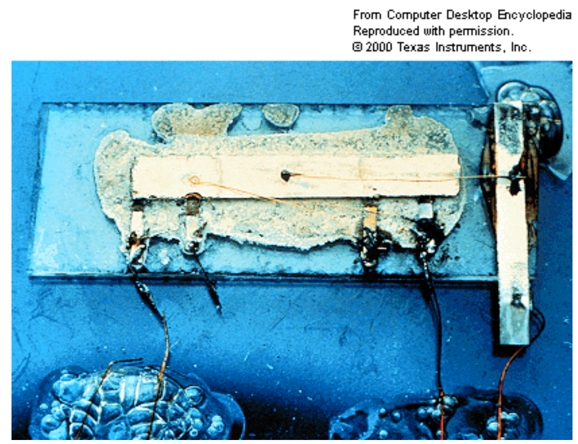
and how the particles, atoms and molecules interact to give us the world as we experience it.

Classical Computing

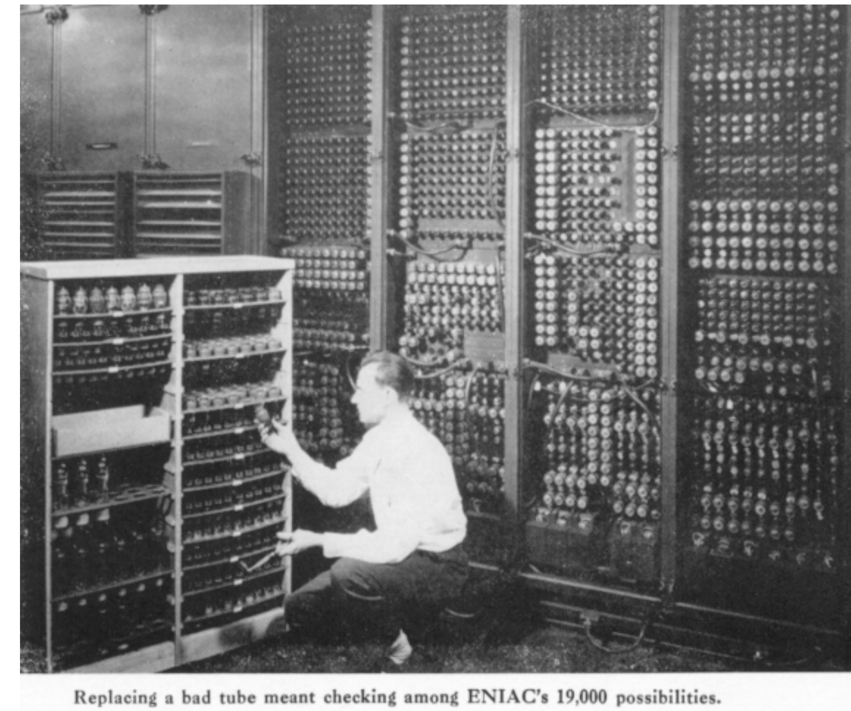
1800 – 1940's



1947: solid-state

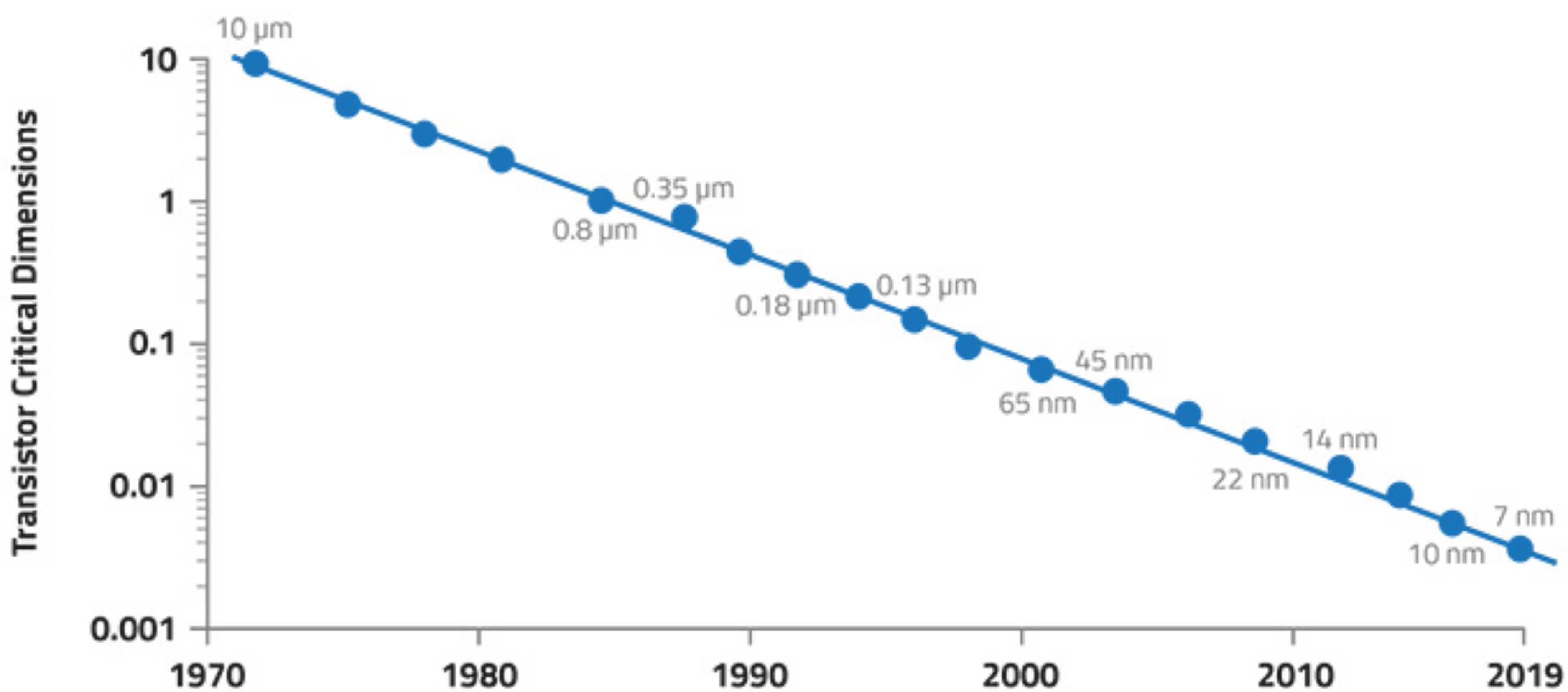


1958: Integrated circuit
(semi-conductor)



The ENIAC contained 17,468 vacuum tubes

large slow switches → small fast switches



Moore's Law

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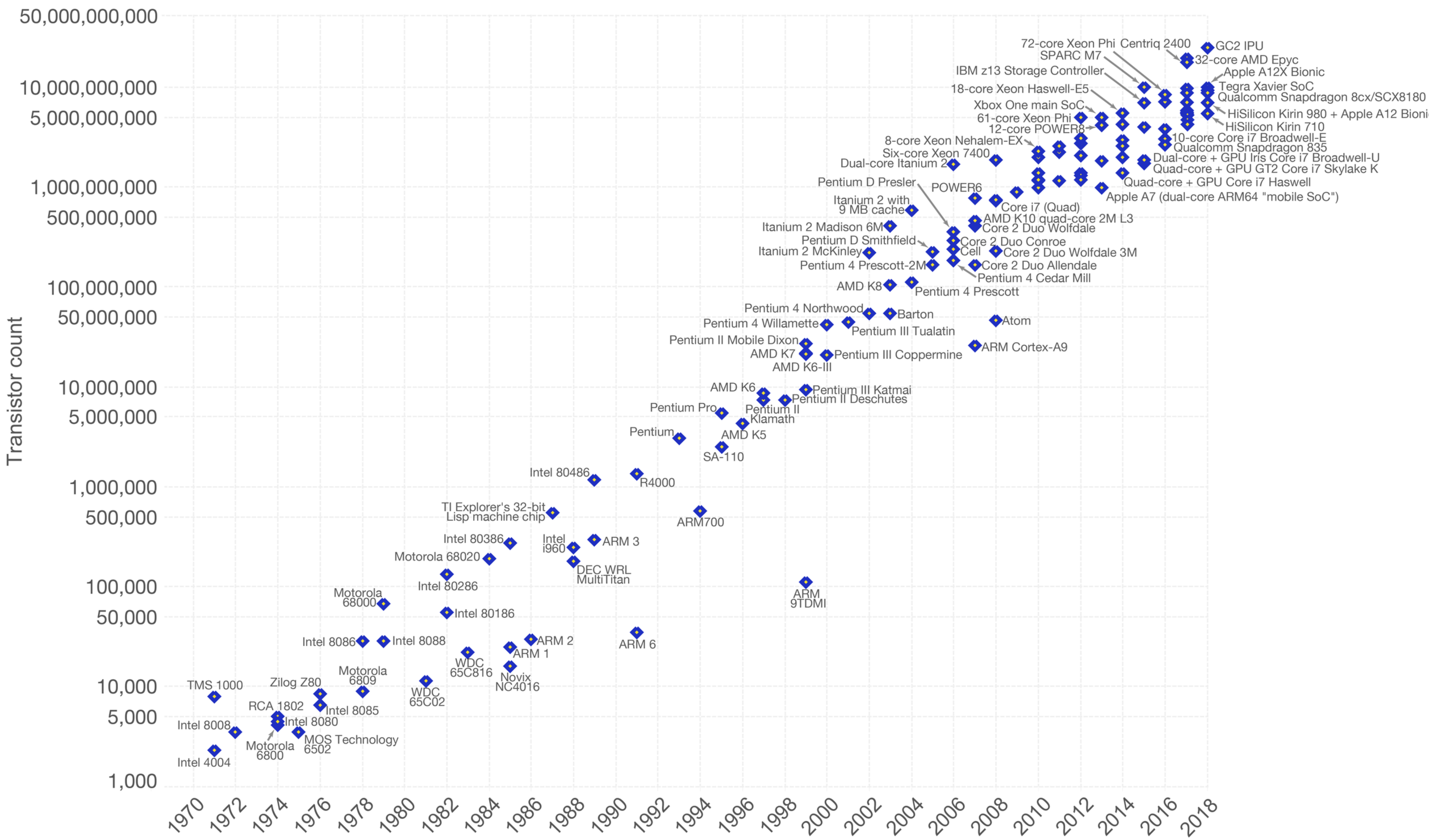
Moore's Law – The number of transistors on integrated circuit chips (1971-2018)

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.

Our World in Data



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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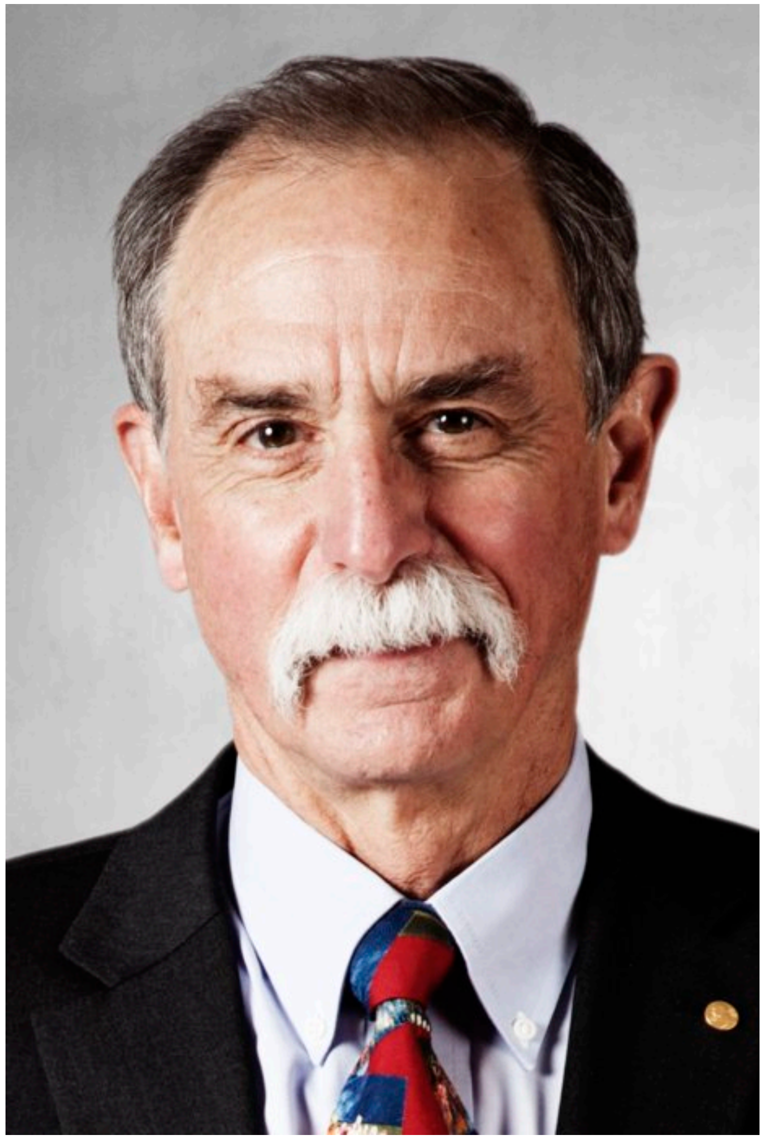
Second Quantum Revolution

The Nobel Prize in Physics 2012 was awarded jointly to Serge Haroche and David J. Wineland "for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems



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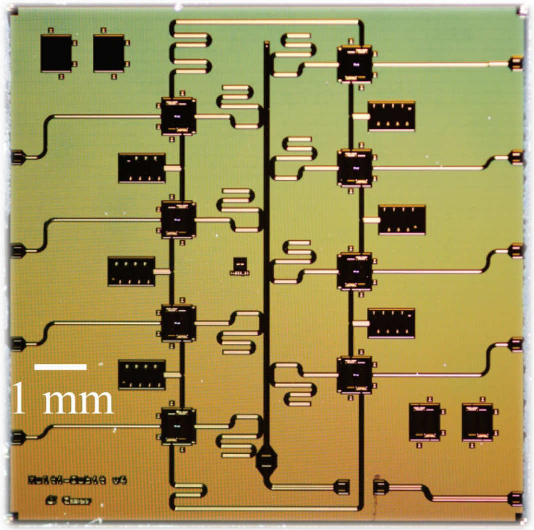
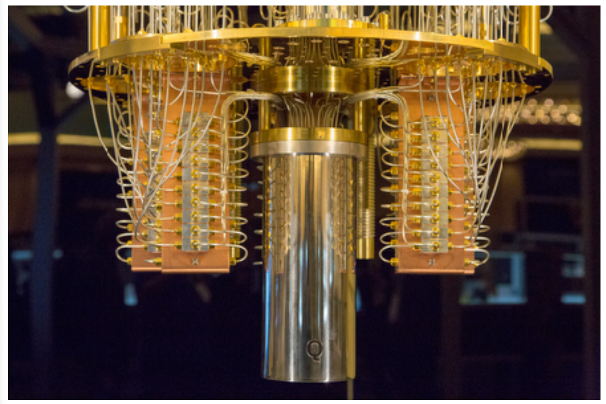
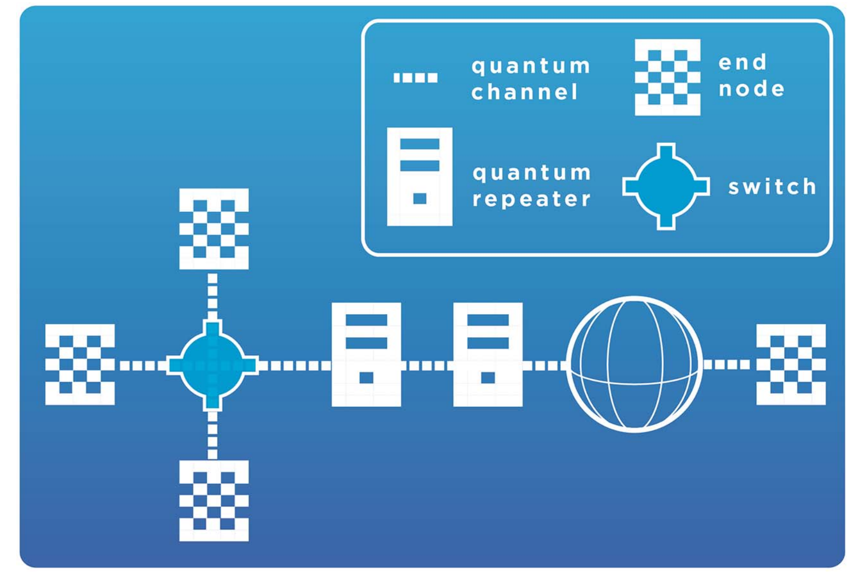
Quantum Applications

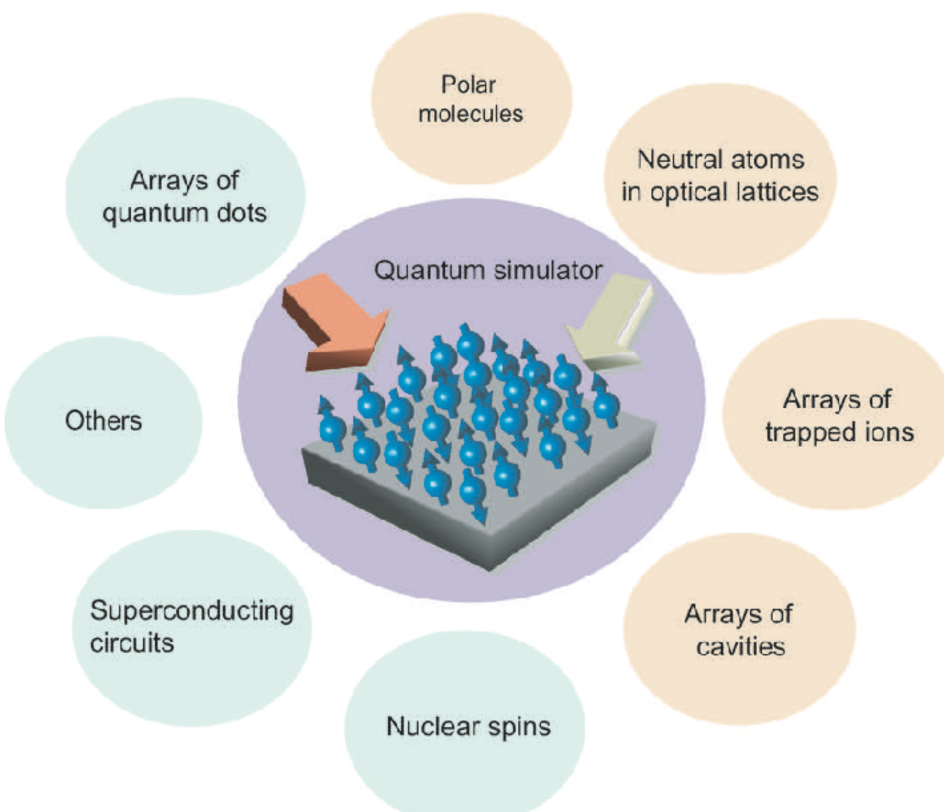
Computing



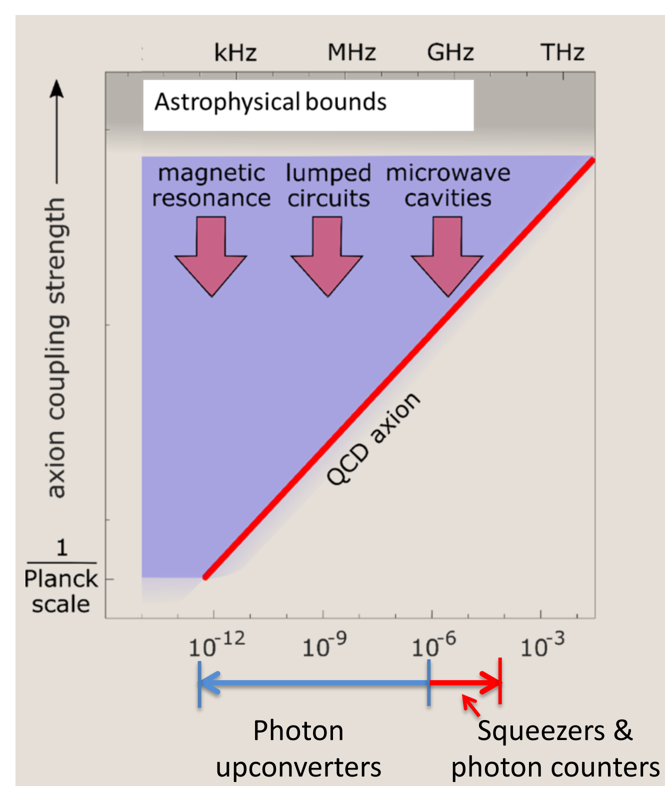


Communications

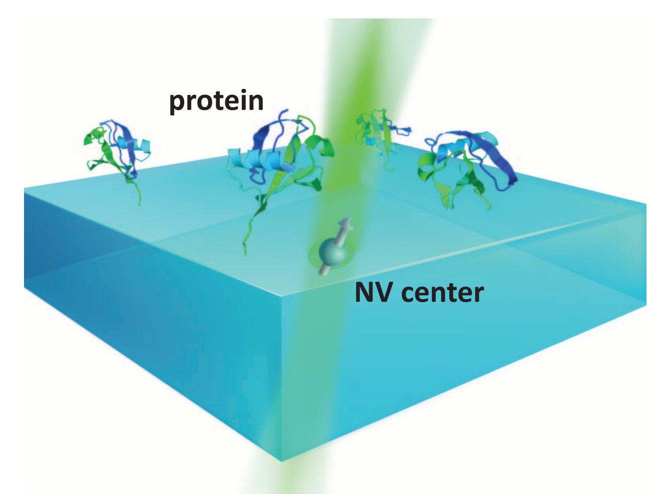




Simulation



Sensing



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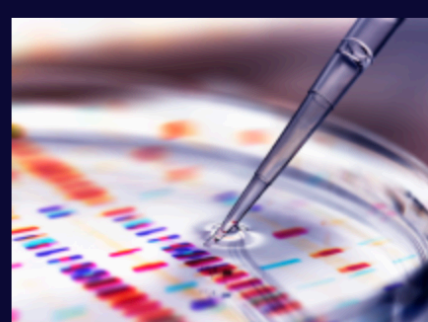
Why quantum computing - Rigetti

Industry Use Cases

The true value of quantum computing will be unlocked through practical applications. With new tools and new ways of thinking, quantum computing will forever change the way we solve problems across industries.

Materials Discovery

Design and optimize new druglike molecules for known targets.

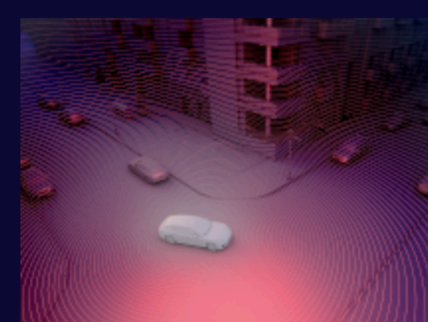


Aid drug discovery for ‘undruggables’ e.g. neurodegenerative diseases

Develop synthetic enzymes and catalysts for food and energy production

Large-Scale Optimization

Optimize returns and risks for large financial portfolios



Train better AI with less computational overhead

Reduce fuel costs by optimizing vehicle routing

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Quantum Scaling

spin qubit

$|\downarrow\rangle$ $\qquad |\psi\rangle = \alpha|\uparrow\rangle + \beta|\downarrow\rangle$

$|\uparrow\rangle$ $\qquad \left(|\alpha|^2 + |\beta|^2 = 1\right)$

Evolution $\qquad |\phi\rangle = U|\psi\rangle$

2×1 vector	2×2 matrix	2×1 vector	One qubit
$2^n \times 1$ vector	$2^n \times 2^n$ matrix	$2^n \times 1$ vector	n qubits
4096×1 vector	4096×4096 matrix	4096×1 vector	n =12

more than16 million elements !

Quantum Bits or Qubits

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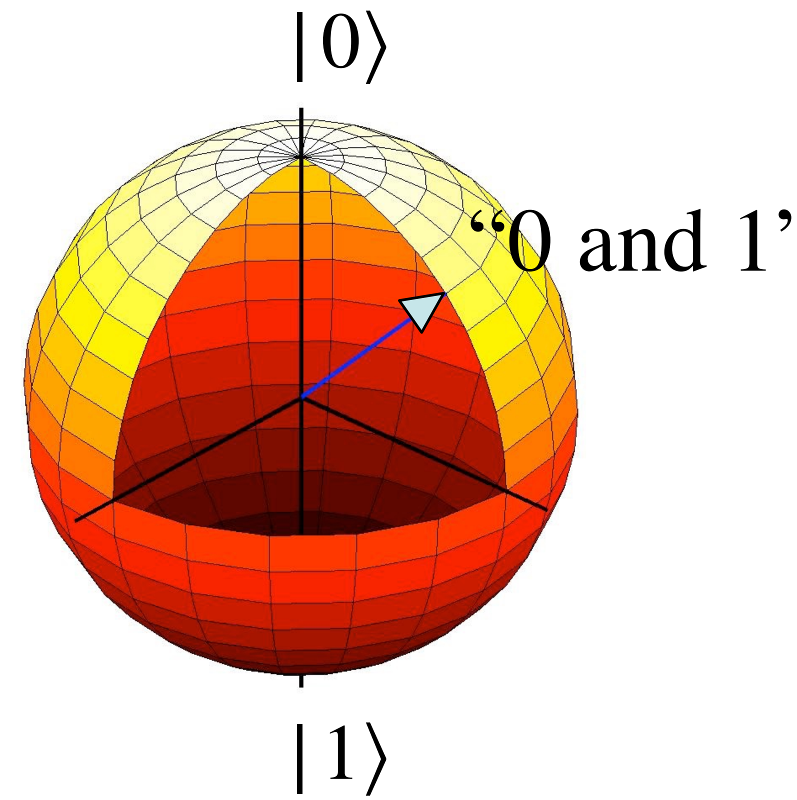
qubit	spin
$\vert 1\rangle$	$\vert \uparrow \rangle$
$\Delta E = \hbar\omega$	$\Delta E = \hbar\omega$
$\vert 0\rangle$	$\vert \downarrow \rangle$

$$\underbrace{\mathscr{H}_{\text{int}} = \omega_I S_z}_{\text{interaction with B field}}$$

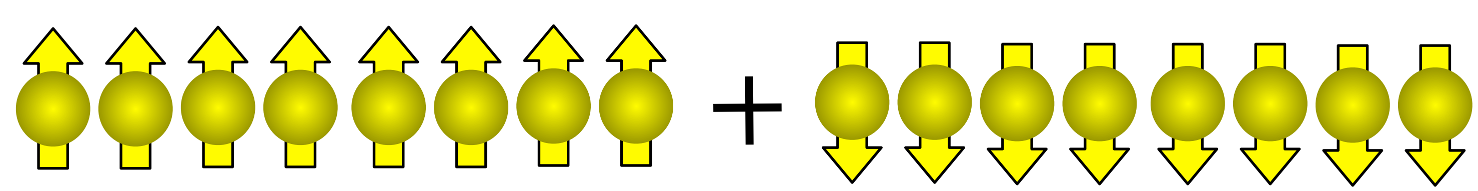


$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

Qubit can be in a continuum of states

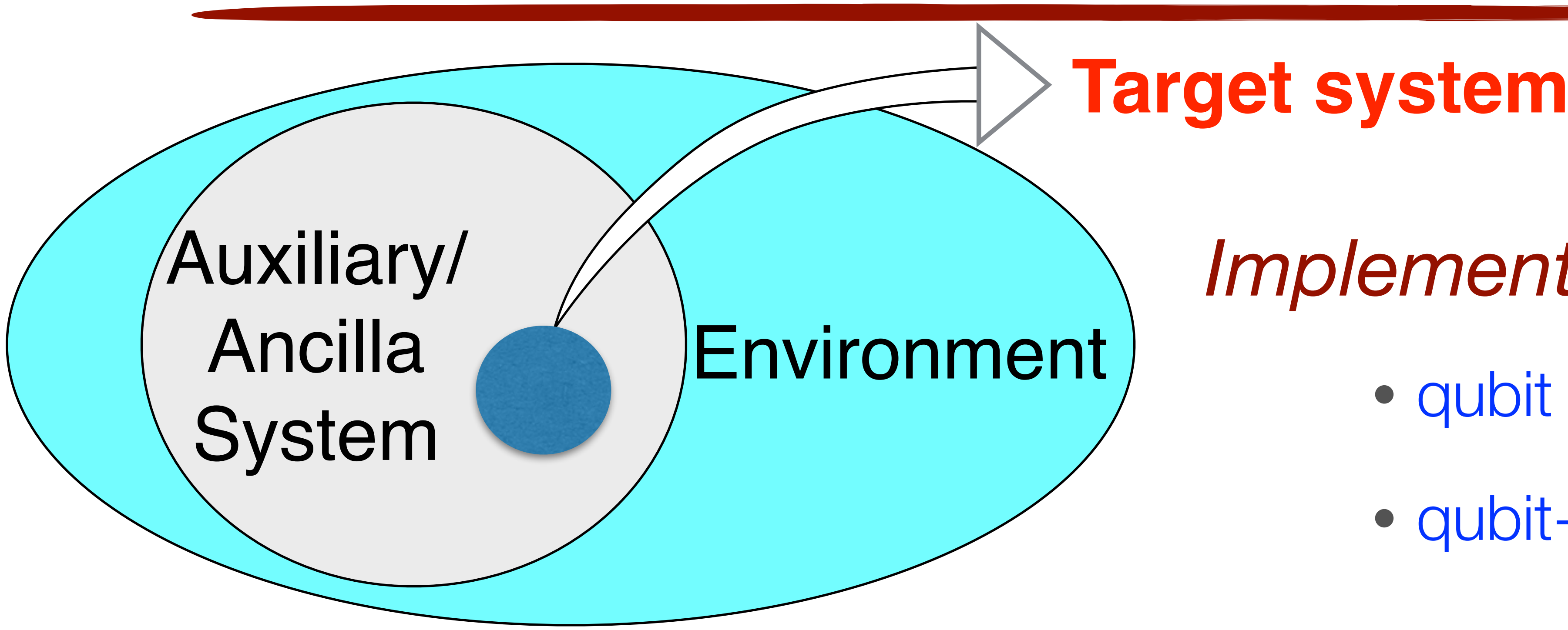
Quantum states are fragile - and can't be copied

Consider an entangled state:



If any are disturbed, they all collapse

Control an isolated system?



Implement quantum protocols

- qubit rotations
- qubit-qubit interactions

- Implement a specific unitary or potentially non-unitary gate operation on the target-system with high fidelity
- Decouple the target-system from the rest of the system
- Decouple the target-system and the system from interactions with the environment

Drive carefully in Hilbert space

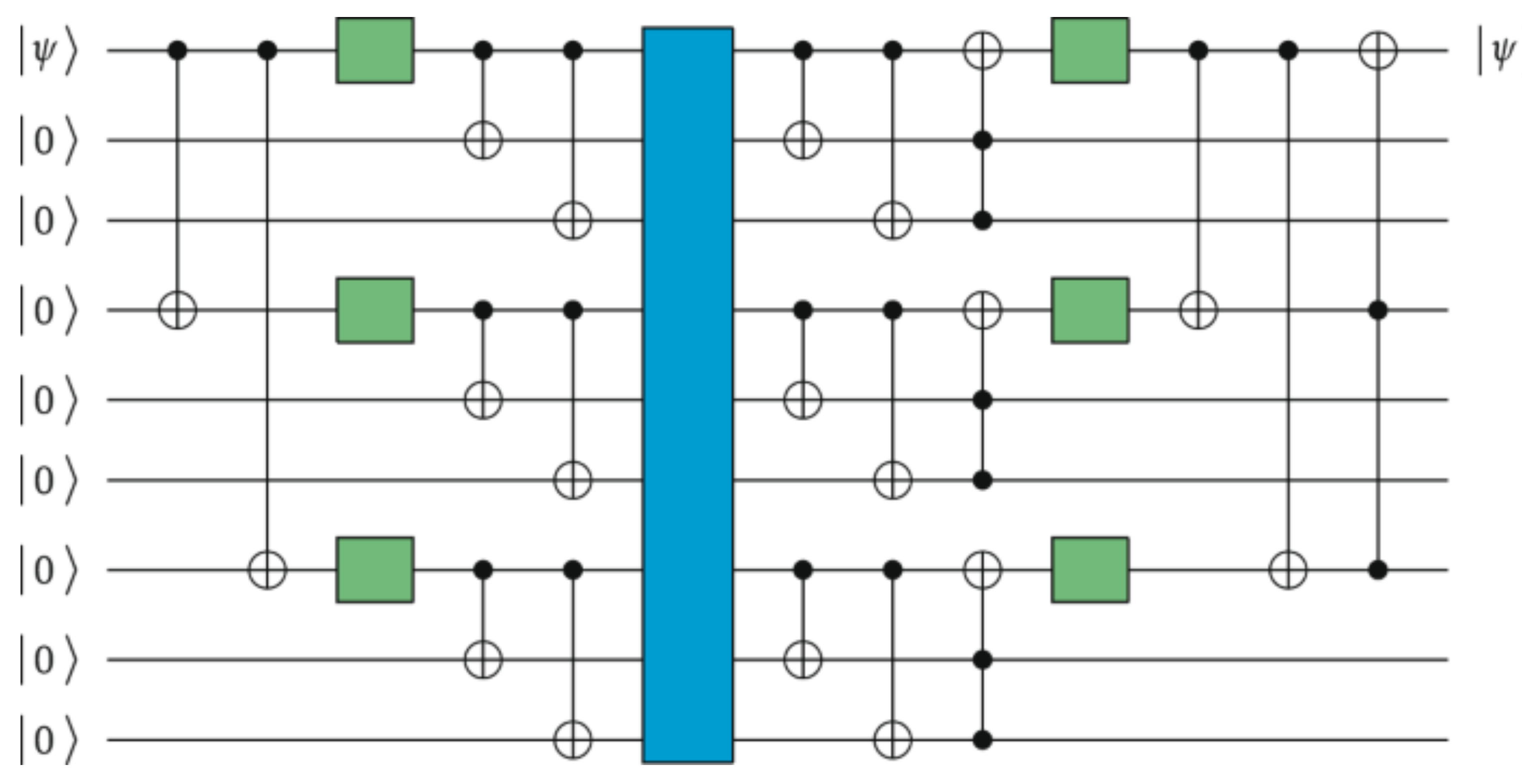
Fault tolerance

Can we survive errors?   Yes, if they are low enough….

Quantum Error Correction

- encode one qubit into many

Shor's 9 qubit code



Comes at the cost of scaling

Quantum Threshold Theorems

- how low do the errors need to be?

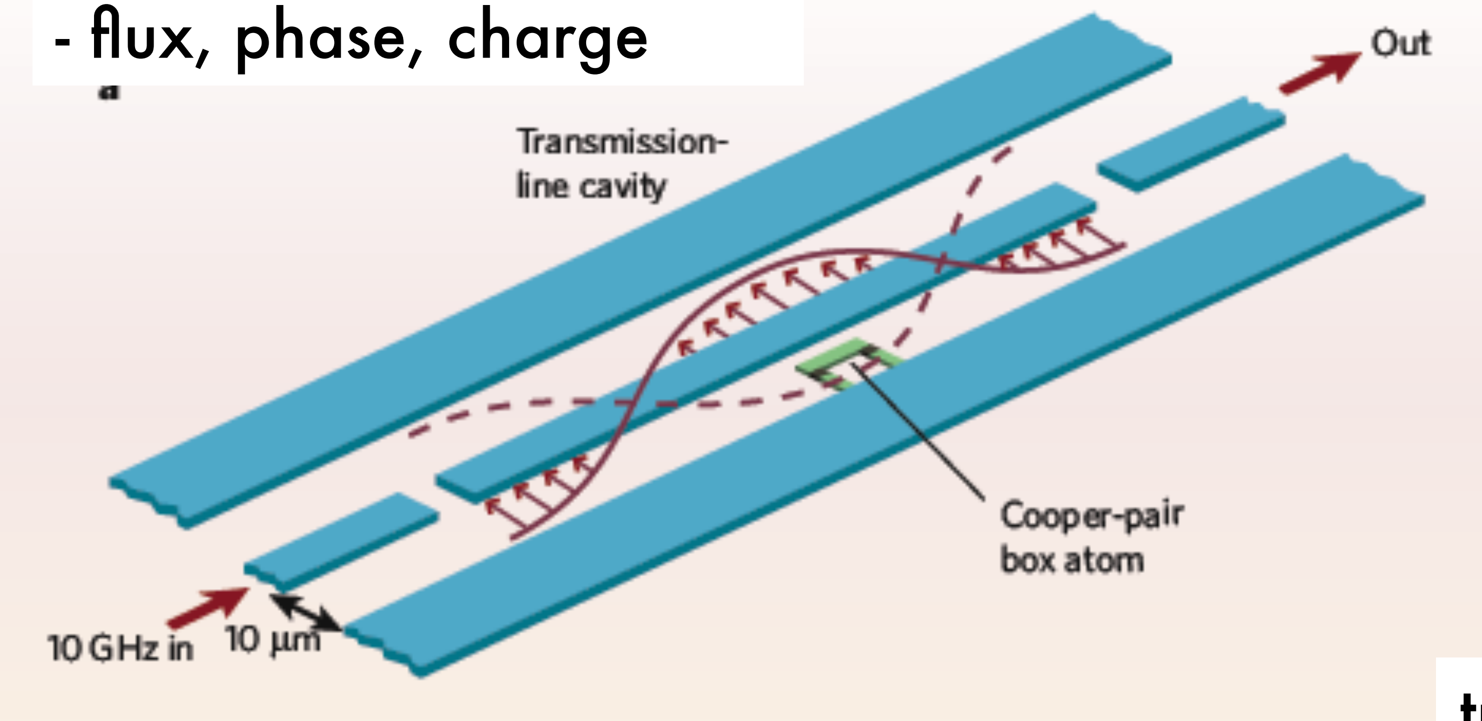
DiVincenzo Criteria

- Array of well-characterized qubits
- Ability to initialize the qubits to a known state
- Long decoherence times - longer than the gate operation time
- Universal set of quantum gates
- Ability to measure the state of the qubit - either identical or complementary to the initial state

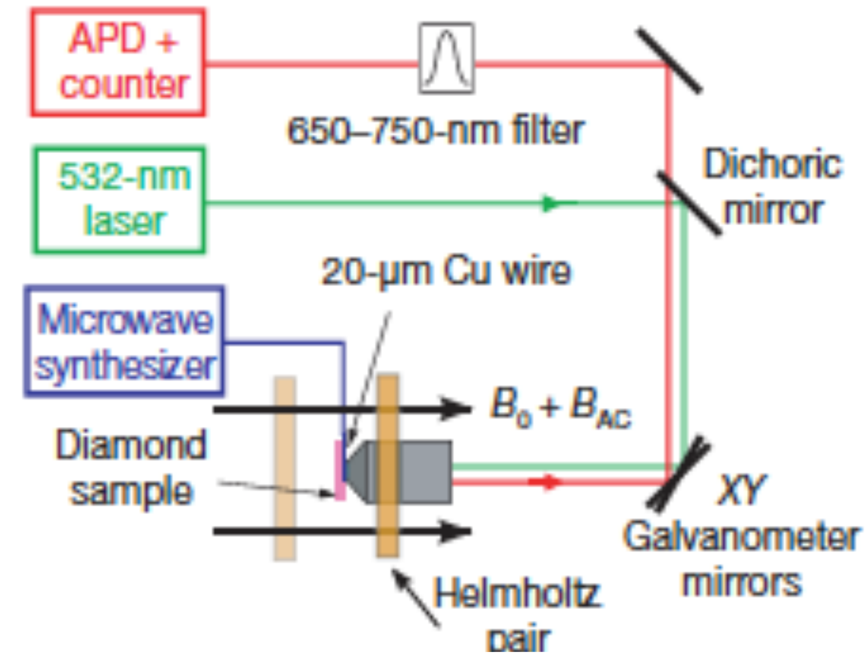
We need to do this fault tolerantly

Implementations

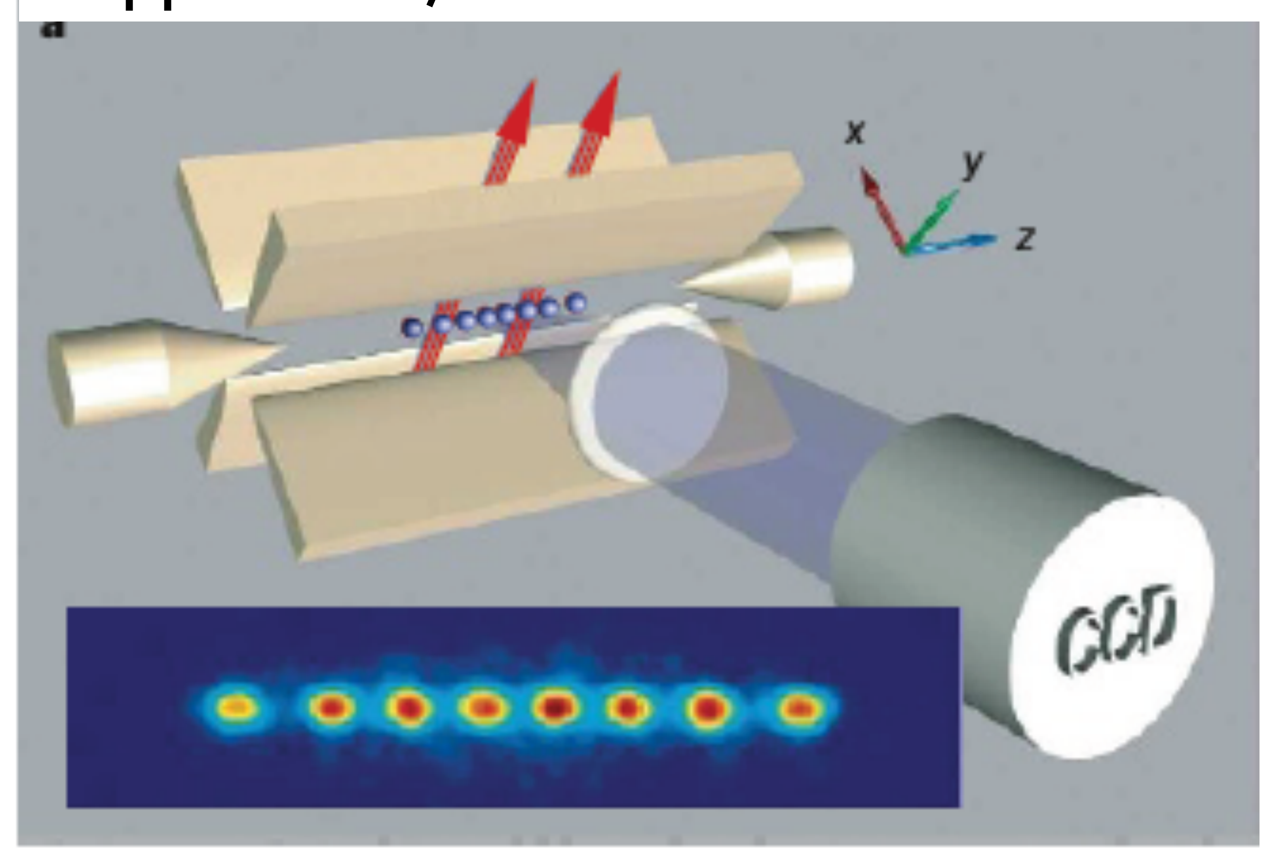
superconducting qubits
- flux, phase, charge

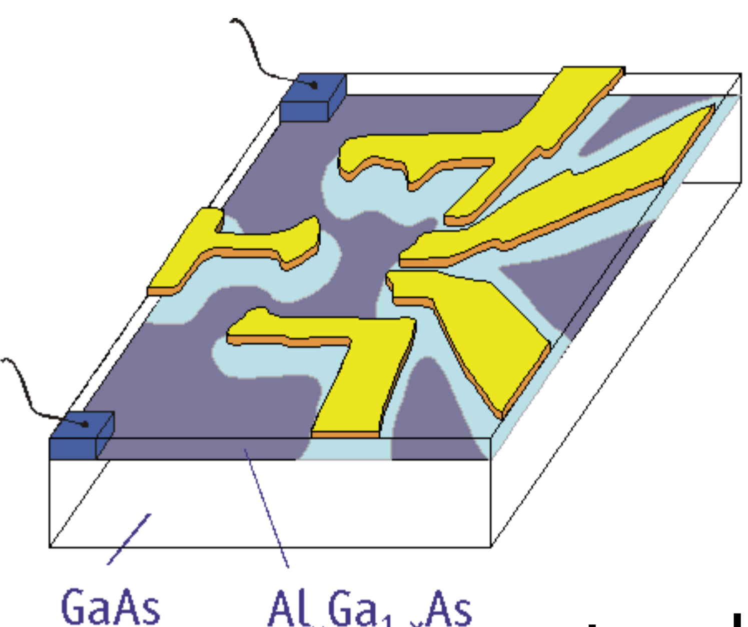


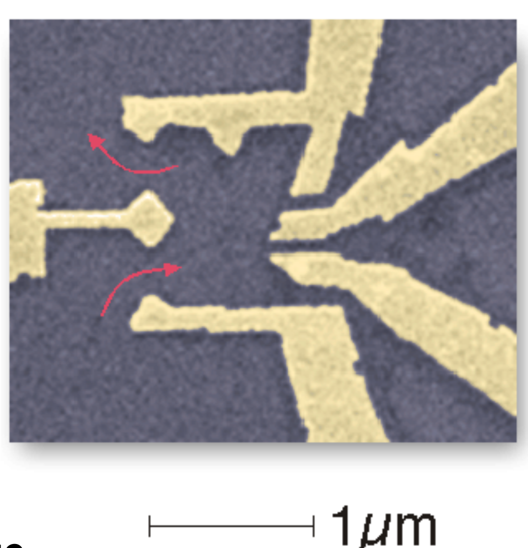
molecular systems / diamonds / etc.



trapped ions / neutral atoms

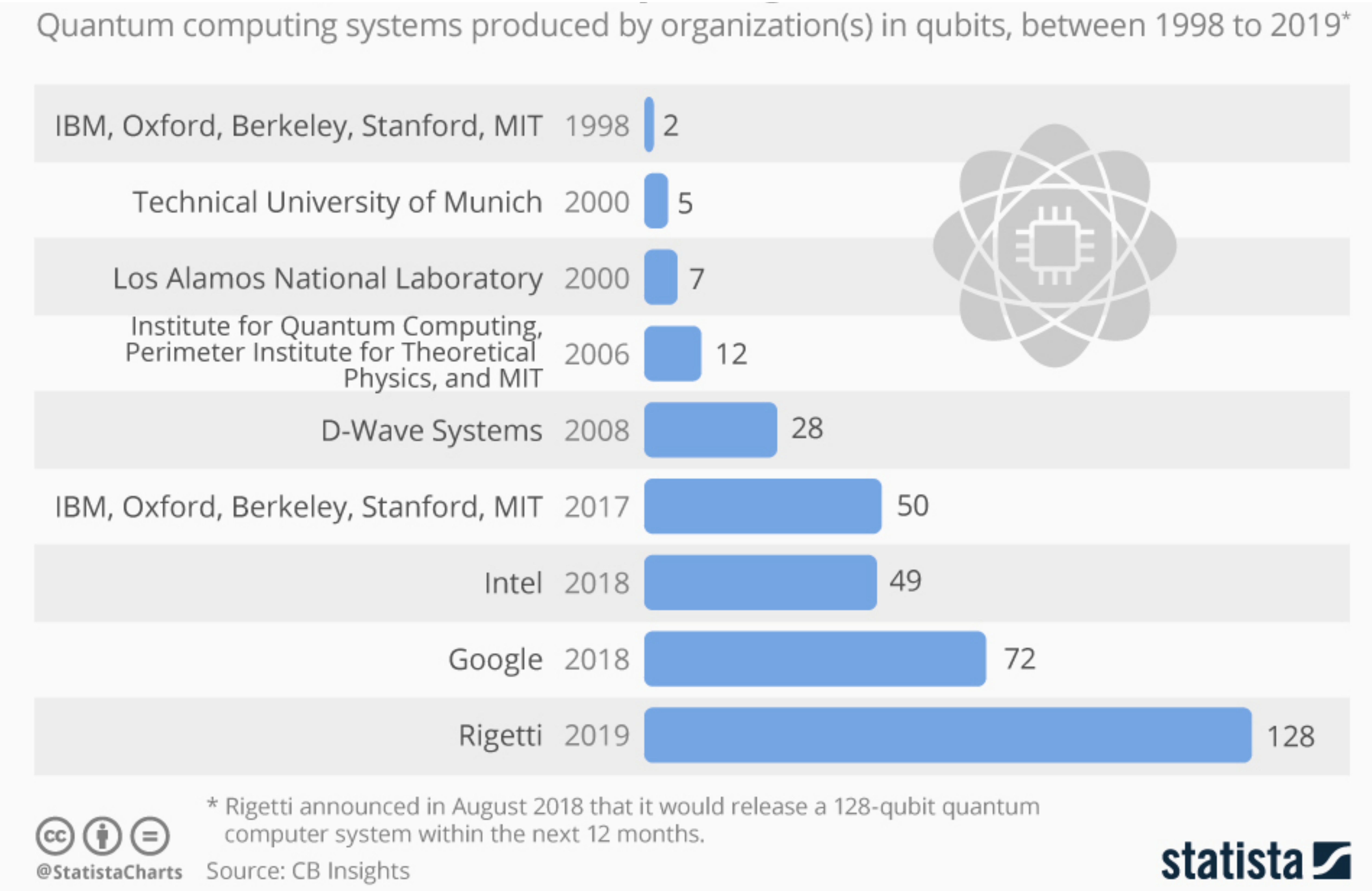






quantum dots

Growth in Qubits



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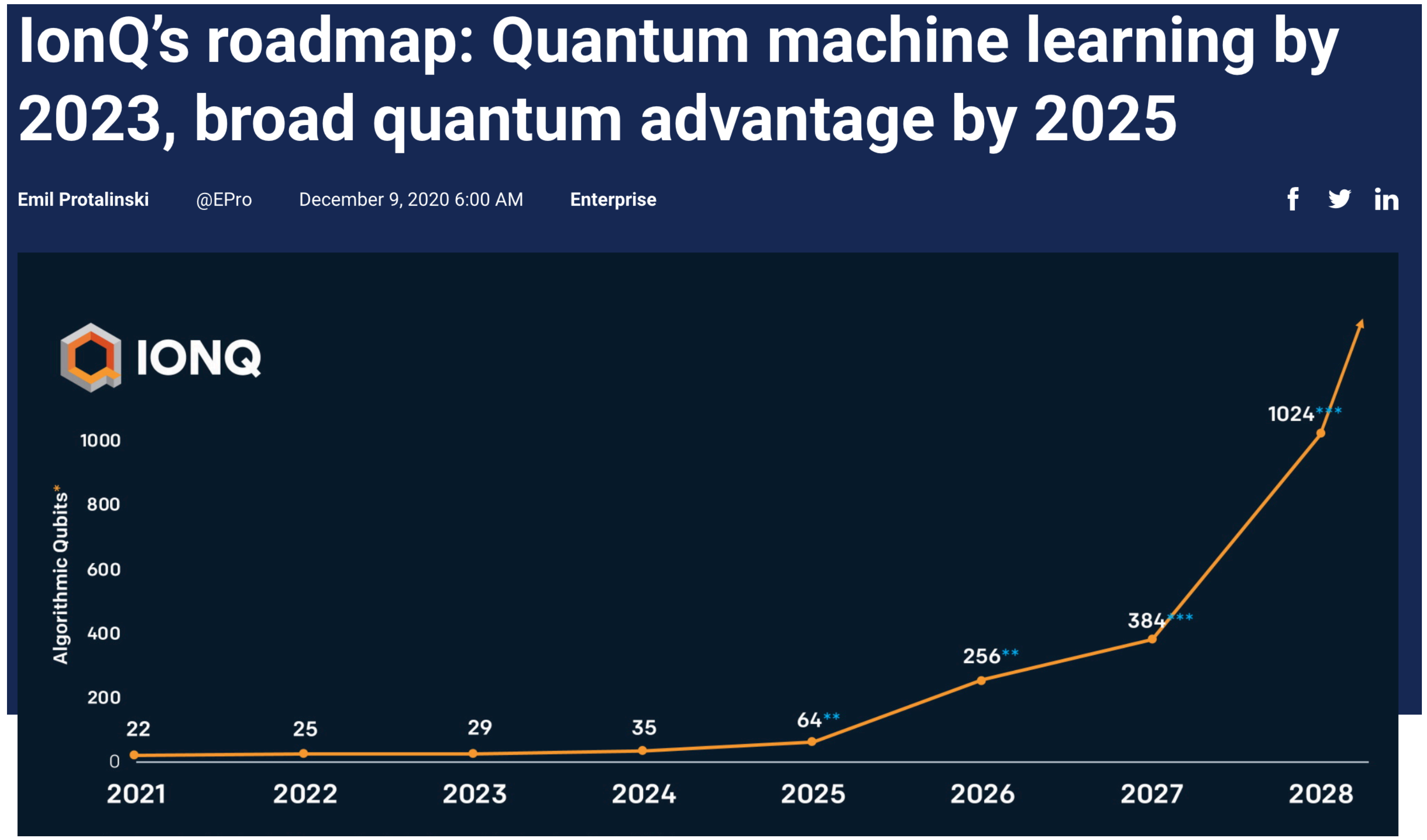
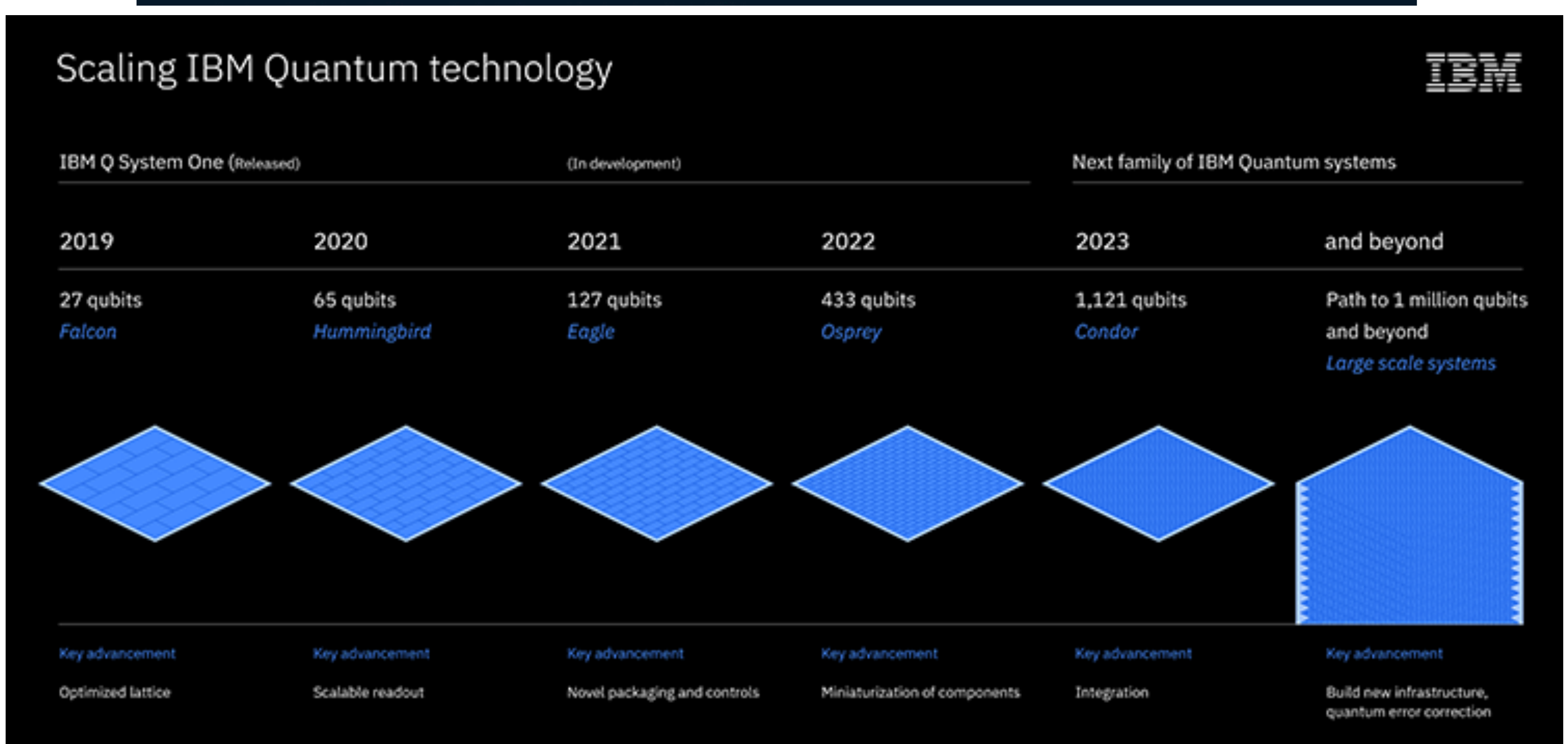
Projecting Forward





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Challenges

- Hardware Architecture Engineering
- Cryogenics
- Microwave and Optical Engineering
- Material Science
- Quantum Control
- Quantum Error Correction
- Algorithms
- Integration and full-stack design
- Applications