

Un'iniziativa di



LAKE COMO SCHOOL
OF ADVANCED STUDIES

Con il sostegno di



Regione
Lombardia



Fondazione Provinciale
della Comunità Comasca
ONLUS



ICC
DA CENT'ANNI
NEL FUTURO
CONFINDUSTRIA COMO

Le serate della **Lake Como School of Advanced Studies**

DALLA SABBIA AL COMPUTER: LE TECNOLOGIE QUANTISTICHE DOVE MENO TE LE ASPETTI

Fabio Pezzoli

Università di Milano-Bicocca



International School on Mid-infrared Technologies for Quantum Sensing



Dalla sabbia al computer: le tecnologie quantistiche dove meno te le aspetti

Fabio Pezzoli

Bicocca Quantum Technologies
The National Quantum Science and Technology Institute

Departmento di Scienza dei Materiali, Università di Milano-Bicocca



@FabioPezzoli



@fabiopezzoli.bsky.social



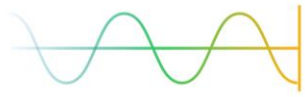
nature.com/commsphys



100 YEARS OF QUANTUM IS JUST THE BEGINNING

The 2025 International Year of Quantum Science and Technology (IYQ) recognizes 100 years since the initial development of quantum mechanics. Join us in engaging with quantum science and technology and celebrating throughout the year!

[Search All Events →](#)



100 Years of Quantum Progress



Health & Wellbeing

Quantum photonics is advancing medical imaging and diagnosis.

Quantum chemistry is supporting the development of new vaccines and drugs.



Reduced Inequalities

Open science and gender equity in education and research will ensure that **quantum solutions** are accessible to all.



Industry & Infrastructure

Quantum science is essential for developing new materials that drive technological innovation.



Economic Growth

Quantum science and technologies are integral to many industries; future economic and financial infrastructures will be secured by **quantum information**.



Climate Action

Quantum physics will inform next-generation sensors for environmental monitoring; quantum computers will improve the accuracy of long-term climate models.



Clean Energy

Quantum engineering is leading to more energy efficient and affordable solar cells and low emission LED light sources.

TECNOLOGIE QUANTISTICHE



Computing

Un nuovo paradigma informatico per la risoluzione di problemi difficili da trattare.



Communications

Trasferimento di informazioni che garantisce la sicurezza nelle comunicazioni.

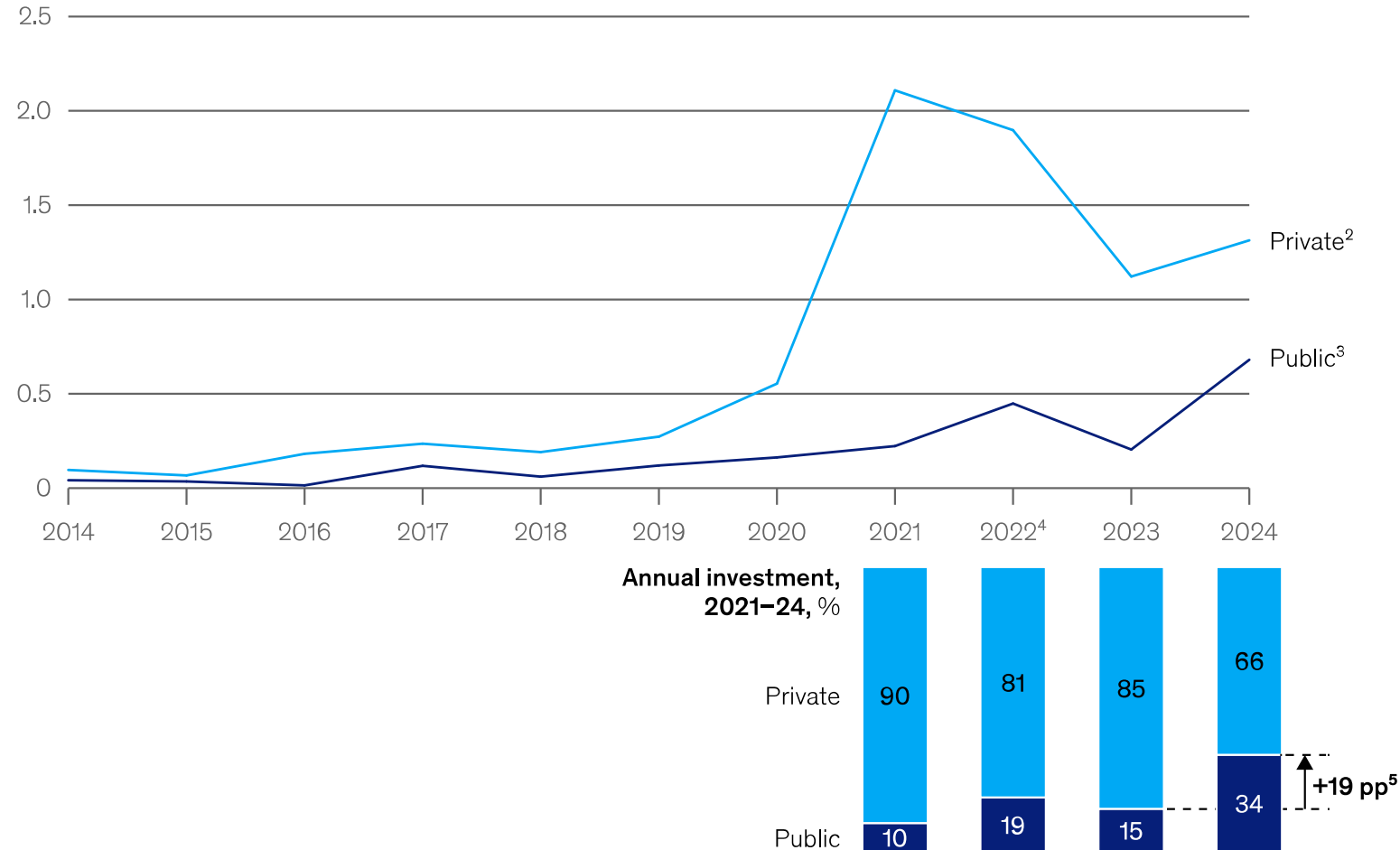


Sensing

Sensori in grado di fornire misurazioni accurate (campi elettromagnetici, gravità,..)

Public investment in quantum technology start-ups increased 19 percentage points from 2023 to 2024.

Quantum technology (QT) investments by funding type, 2014–24,¹ \$ billion

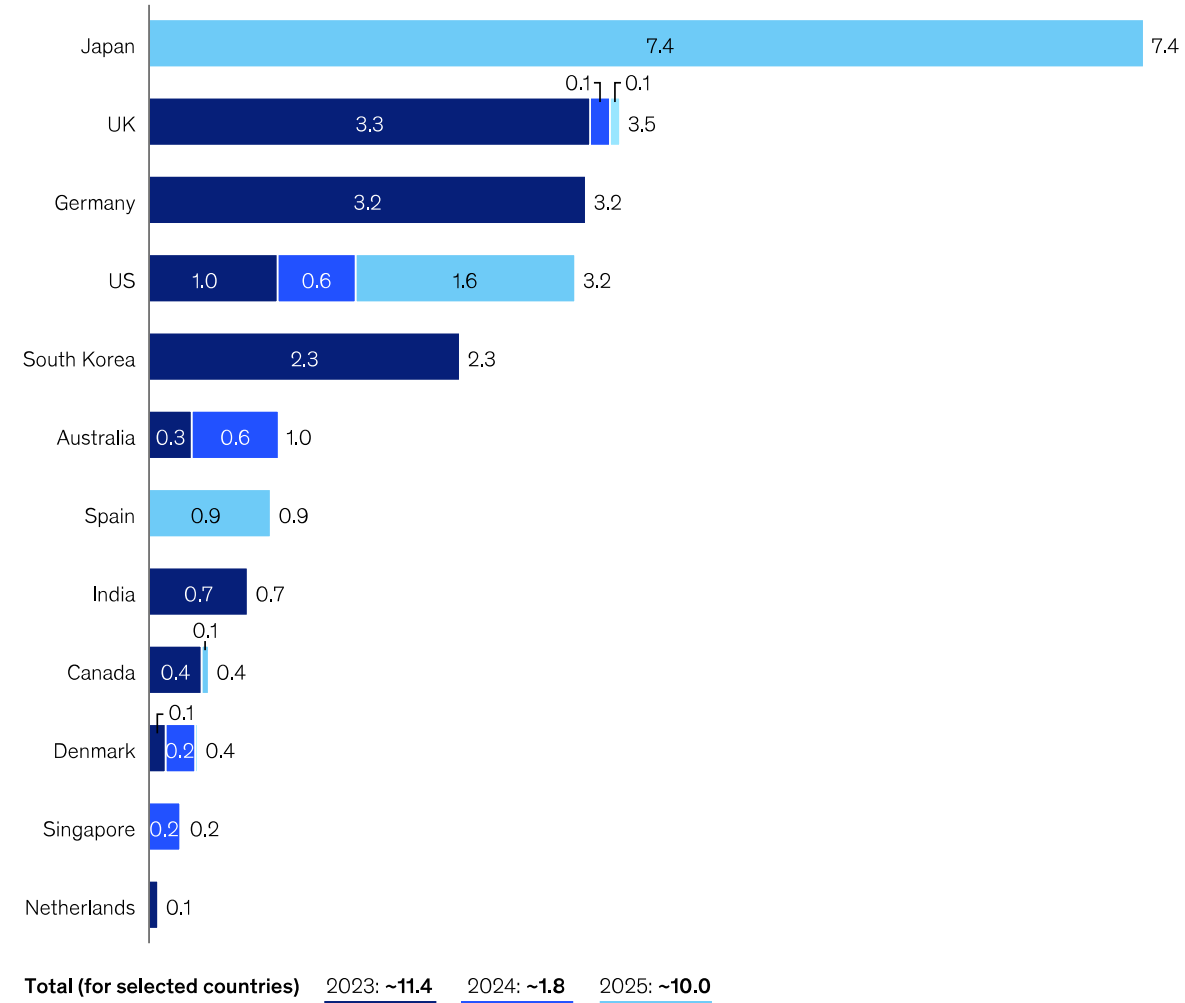


¹Based on investment data recorded in PitchBook; actual investment likely higher (excluding investments with missing details on investment types); data availability on start-up investment in China is limited. ²Including investments from venture capital funds, hedge funds, corporations, angel investors, and accelerators. ³Including investments from governments, sovereign wealth funds, and universities. ⁴Excluding other uncategorized funding data. ⁵Percentage points.
Source: PitchBook

Announcements of public investments in quantum technology reached \$10 billion in early 2025, with Japan accounting for nearly 75 percent.

Announced government investments in quantum technology (QT), Jan 2023–Apr 2025, \$ billion

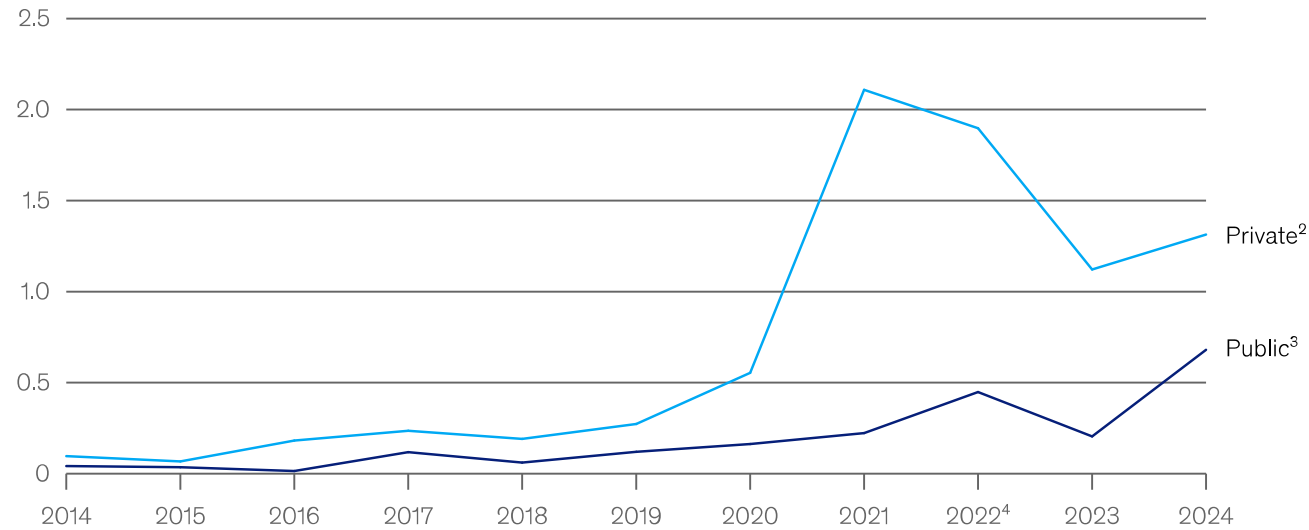
Year announced:
■ 2023 ■ 2024 ■ 2025 (Jan–Apr)



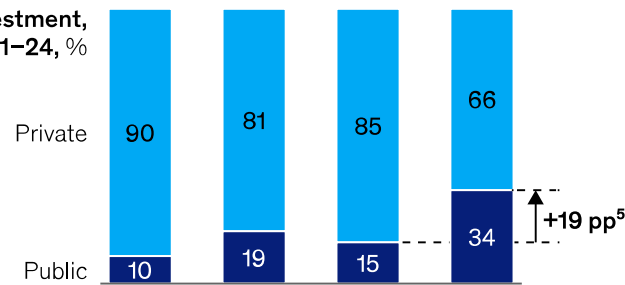
Note: Figures may not sum, because of rounding. Limited transparency on commercial activity in China; numbers excluding the \$136 billion announced investment toward emerging technologies due to unclarity of relevance for QT; the ~\$15 billion investment is not shown here because it was announced before 2023. Numbers also excluding \$680 million in Swedish investments toward research and innovation, and US–Swedish investment of \$40 million toward next-generation networks, AI, quantum technology, and educational science within STEM areas. Also excluding Saudi Arabia’s \$6.4 billion investment in 2022 toward future tech because no breakdown for quantum technology is present; excluding Qatar’s (QIA) and Bpifrance’s investment in Alice & Bob in 2025 due to missing breakdown of investment, Japan’s investment is not exclusively directed toward quantum technology (includes next-generation chip design as well). Source: Press search

Public investment in quantum technology start-ups increased 19 percentage points from 2023 to 2024.

Quantum technology (QT) investments by funding type, 2014–24,¹ \$ billion



Annual investment, 2021–24, %



¹Based on investment data recorded in PitchBook; actual investment likely higher (excluding investments with missing details on investment types); data availability on start-up investment in China is limited. ²Including investments from venture capital funds, hedge funds, corporations, angel investors, and accelerators. ³Including investments from governments, sovereign wealth funds, and universities. ⁴Excluding other uncategorized funding data. ⁵Percentage points. Source: PitchBook

Strategic Pillars of the EU Quantum Ecosystems



Bring quantum technologies from the **lab** to the **market** and consolidate European scientific leadership in quantum research

Fundamental R&D
Technology Supply

Advanced Digital Skills

Develop short term **training courses** and **Master's programmes** in key capacity areas

RESEARCH BASED
HORIZON EUROPE



2021-2027

INFRASTRUCTURES

Funded by



European Chips Act

Bolster Europe's competitiveness & resilience in semiconductors & **quantum chips** including production facilities & Quantum Fund

From Lab to Market



Pilot Lines & Testing Facilities

Q Sensing Deployment

Build and **deploy** Quantum sensing devices

Quantum Gravimeters

Quantum MRIs

EuroQCI

Build and **deploy** in the next decade a certified secure pan-European end-to-end QCI for **cybersecurity services**

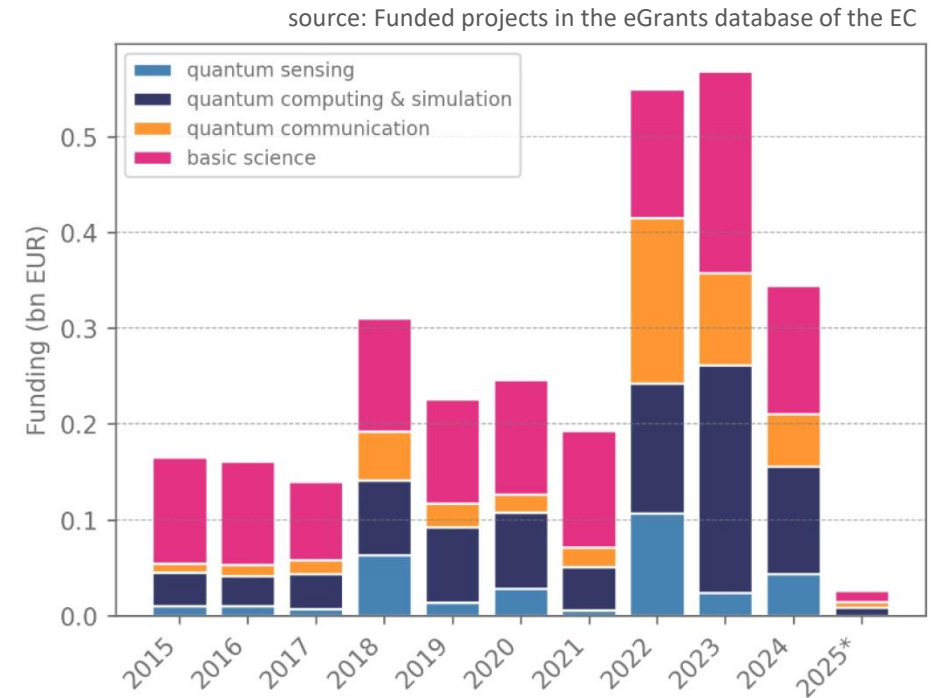
QKD Infrastructure

EuroHPC-QCS

Build and **deploy** an infrastructure for high performance computing and **quantum computing**

HPC with Accelerators

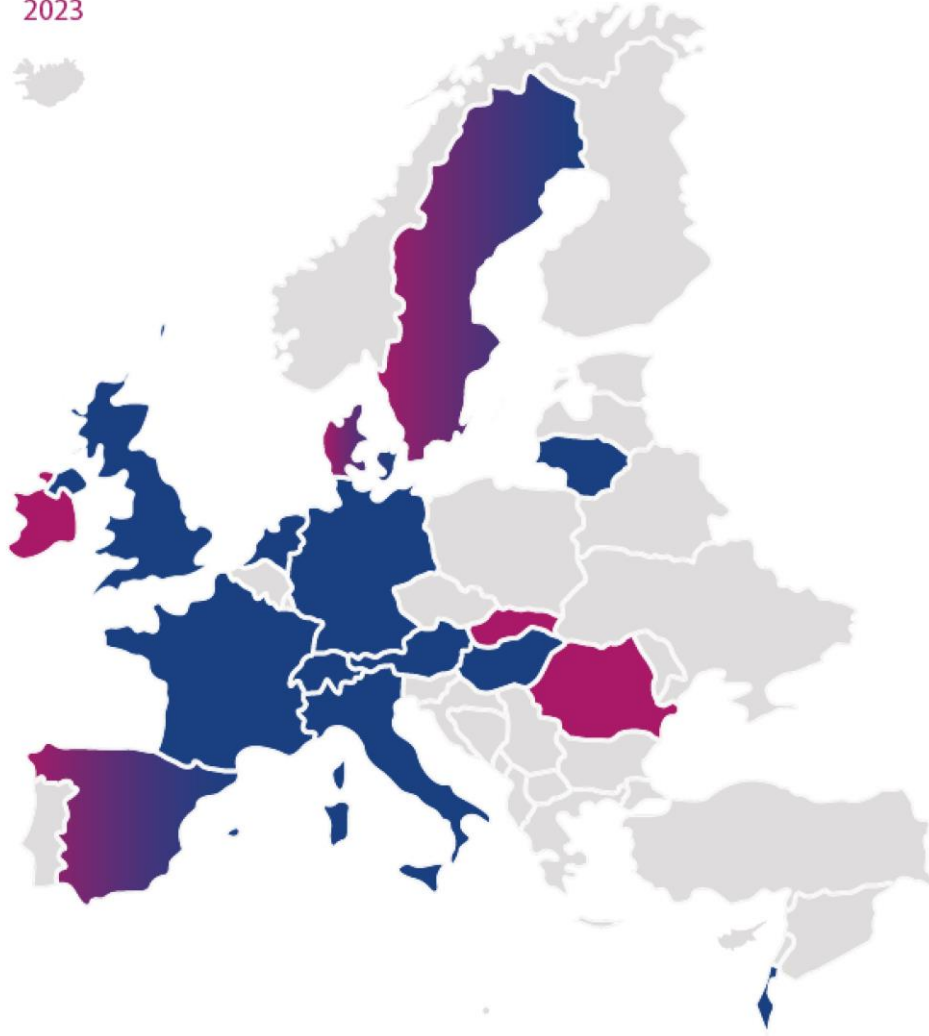
Stand-alone Q Computers



Last update: 2025-02-04

Quantum landscape in Europe

2023



- Countries with developed national quantum strategy and/or significant government contribution
- Countries with national quantum strategy in
- Countries with significant government contribution and national quantum strategy in progress

Strategic Pillars of the EU Quantum Ecosystems





NQSTI

National Quantum Science
and Technology Institute

The consortium NQSTI at a glance

116 M€

funding

3+

years lifespan

332+

Researchers and engineers
across Italy

20

Institutions (research
centres, universities and
enterprises)

Clima



Illuminazione



Computazione

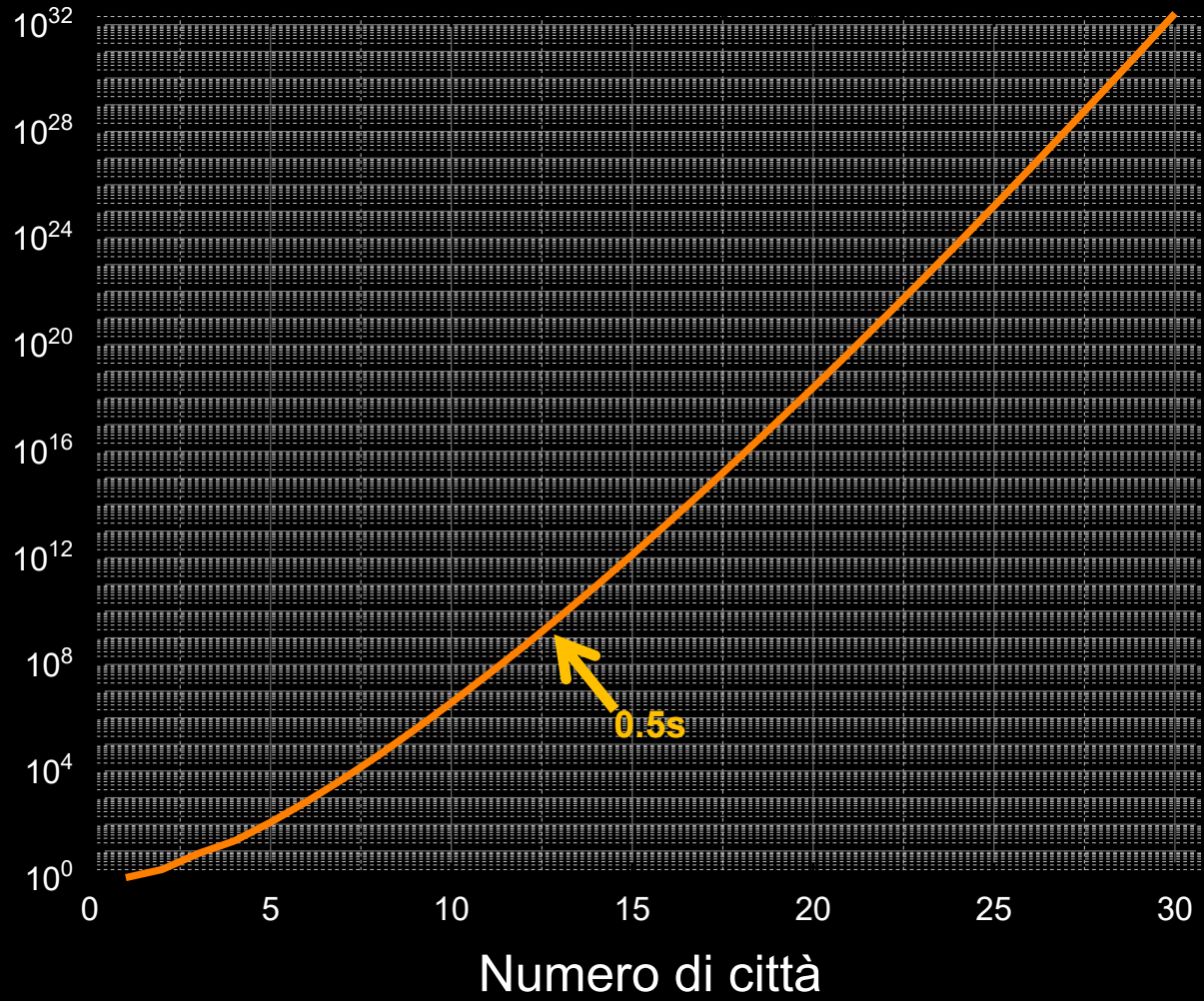


Esplorazione



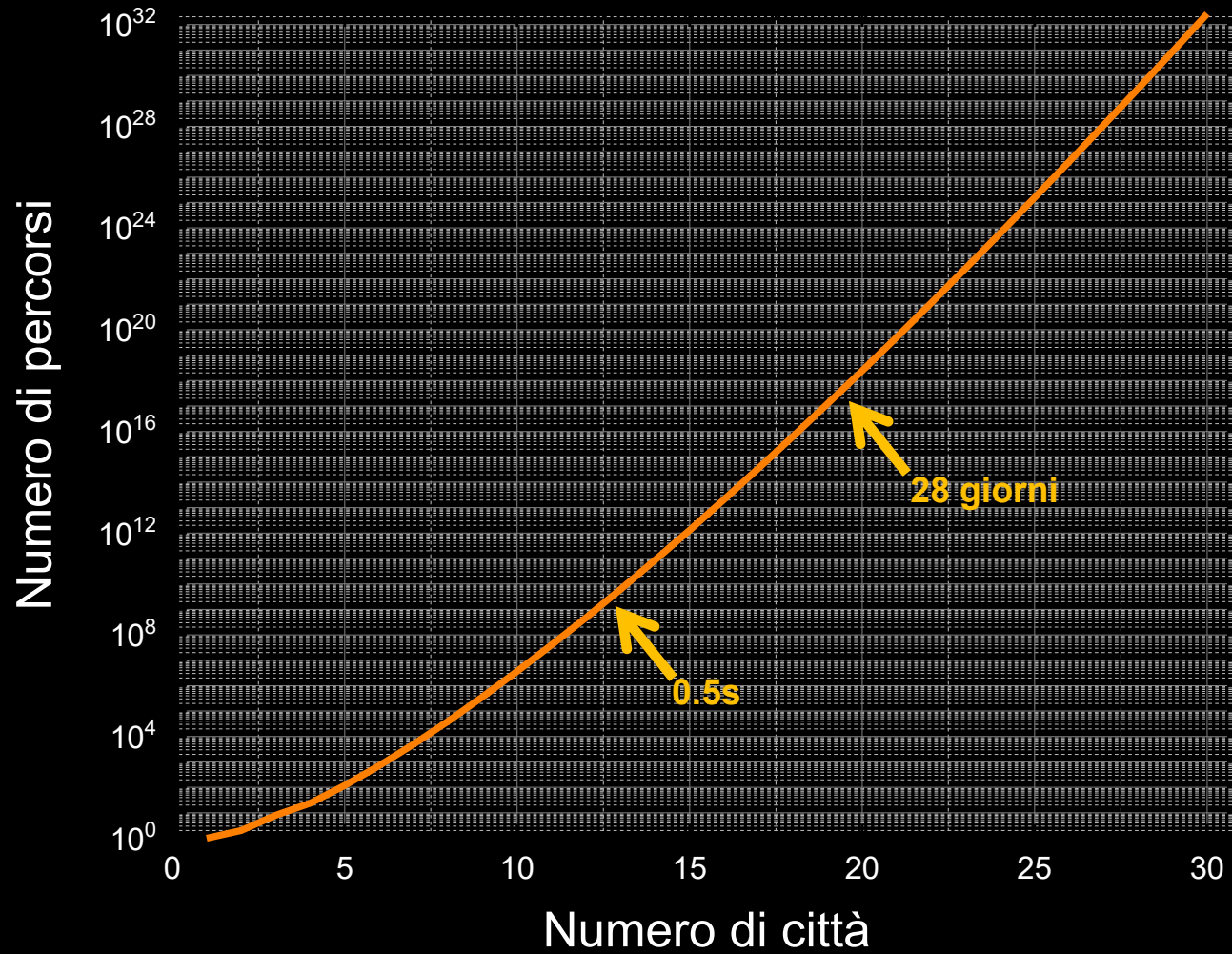


Numero di percorsi

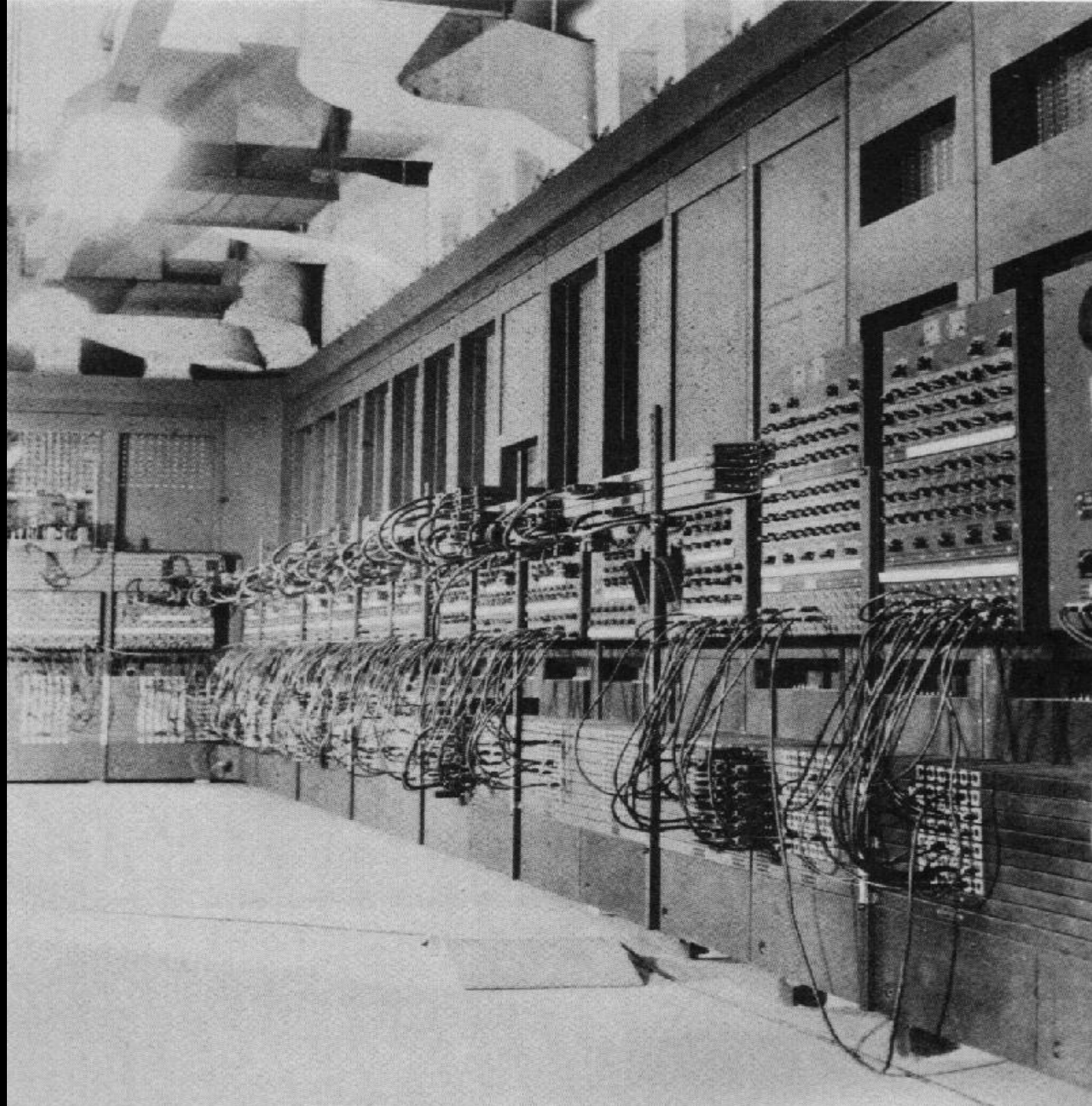


12 città → ~ 500 milioni di possibili percorsi
1 GHz → 10⁹ computazioni/s









1946 - ENIAC

Electronic Numerical Integrator and Calculator

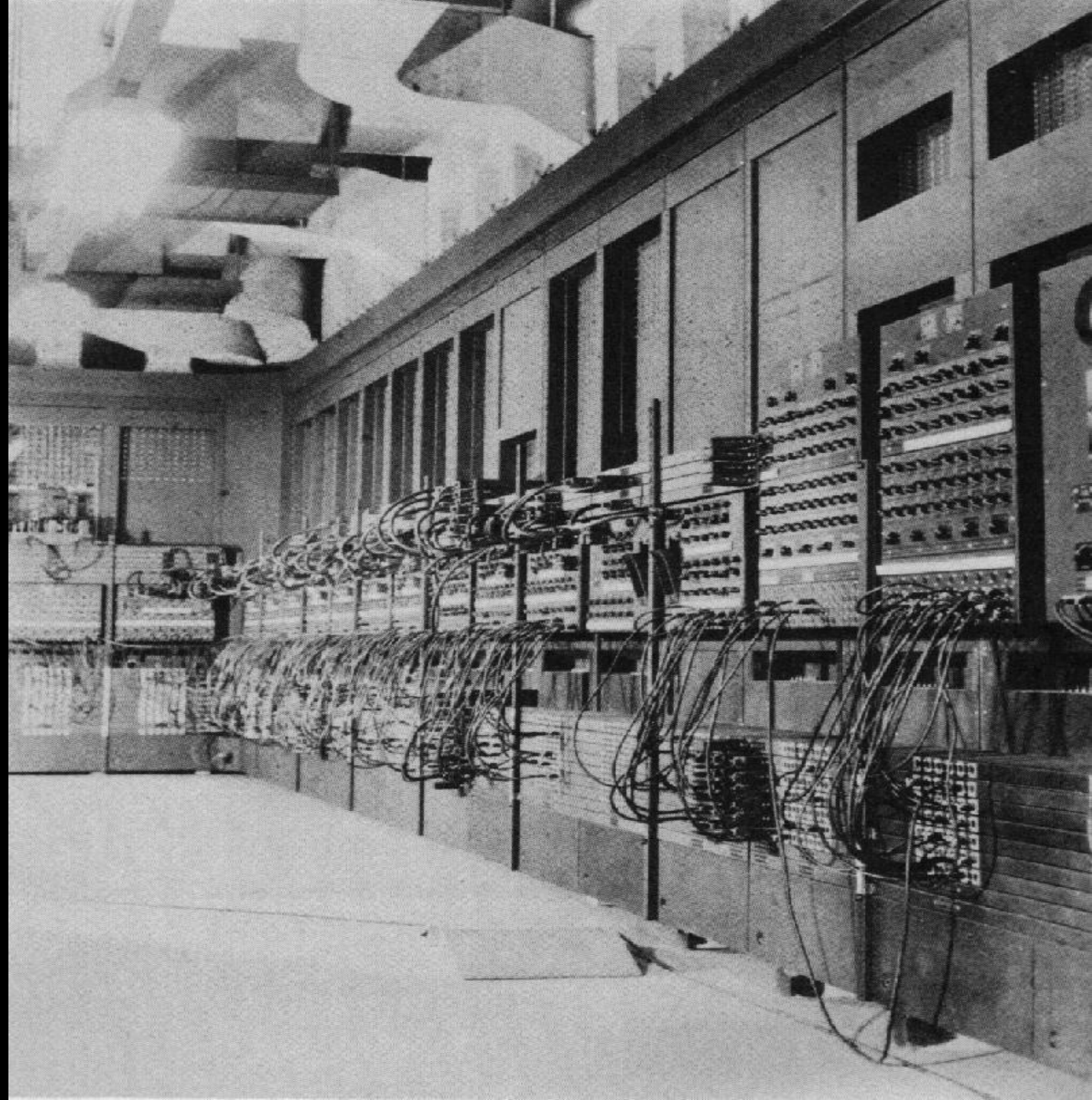
17000 valvole

70000 resistori

10000 capacitori

peso: 30000 kg

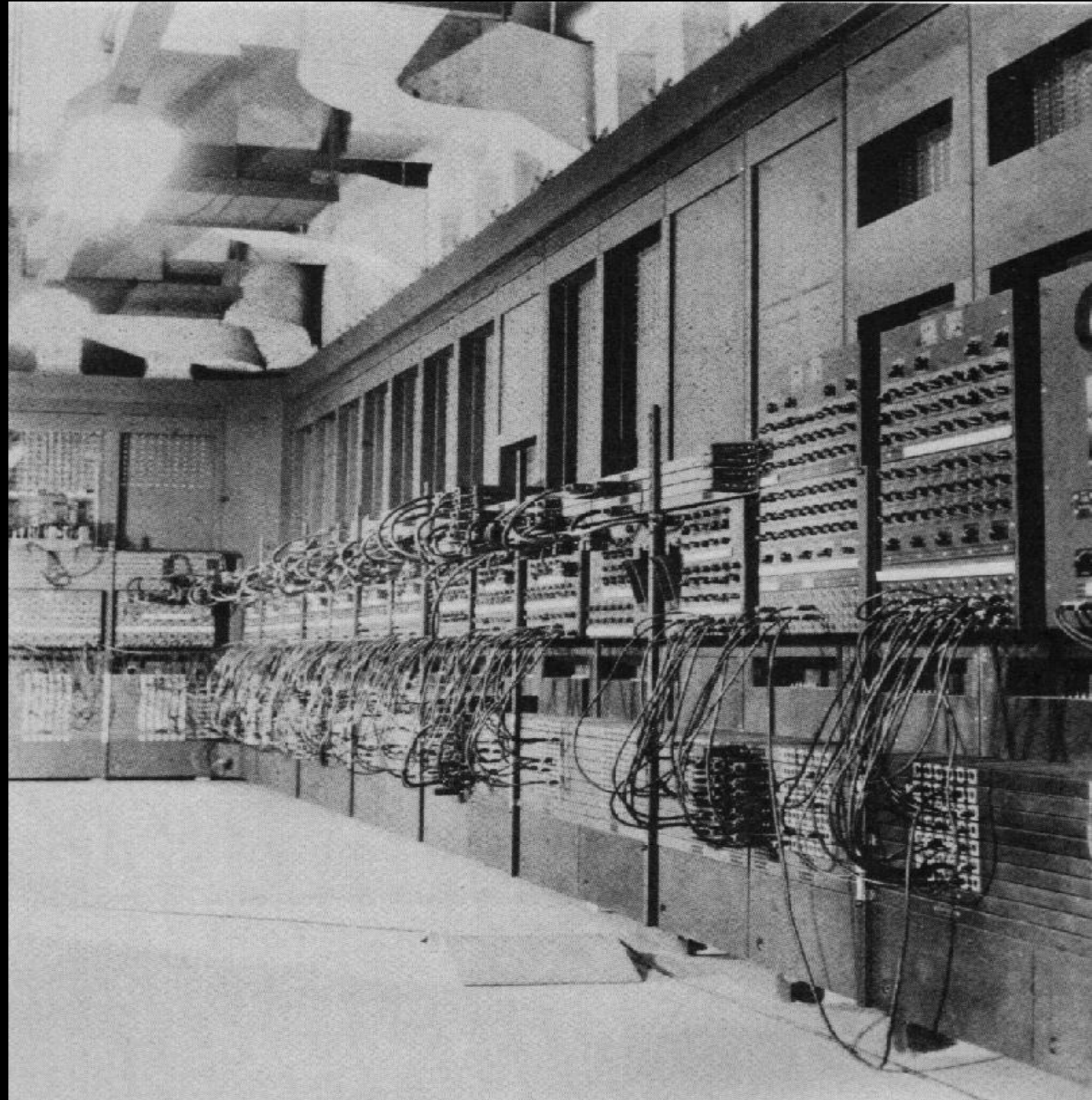
**300 moltiplicazioni o 5000
somme in un secondo**

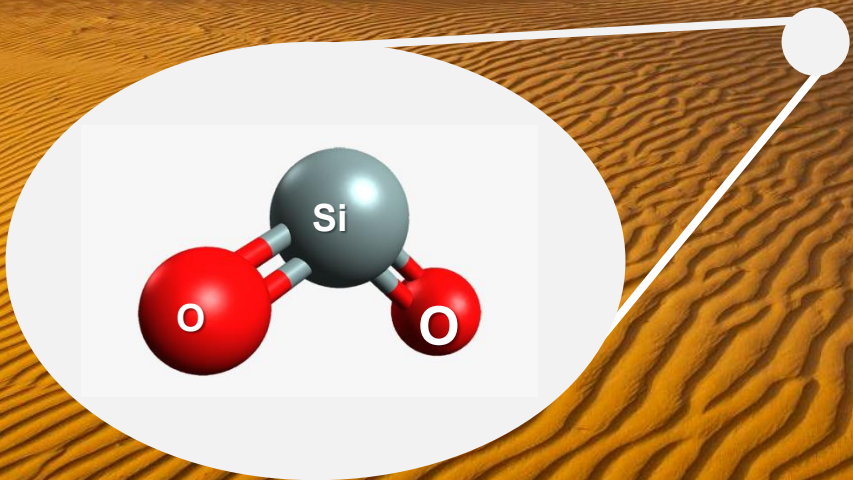


1946 - ENIAC

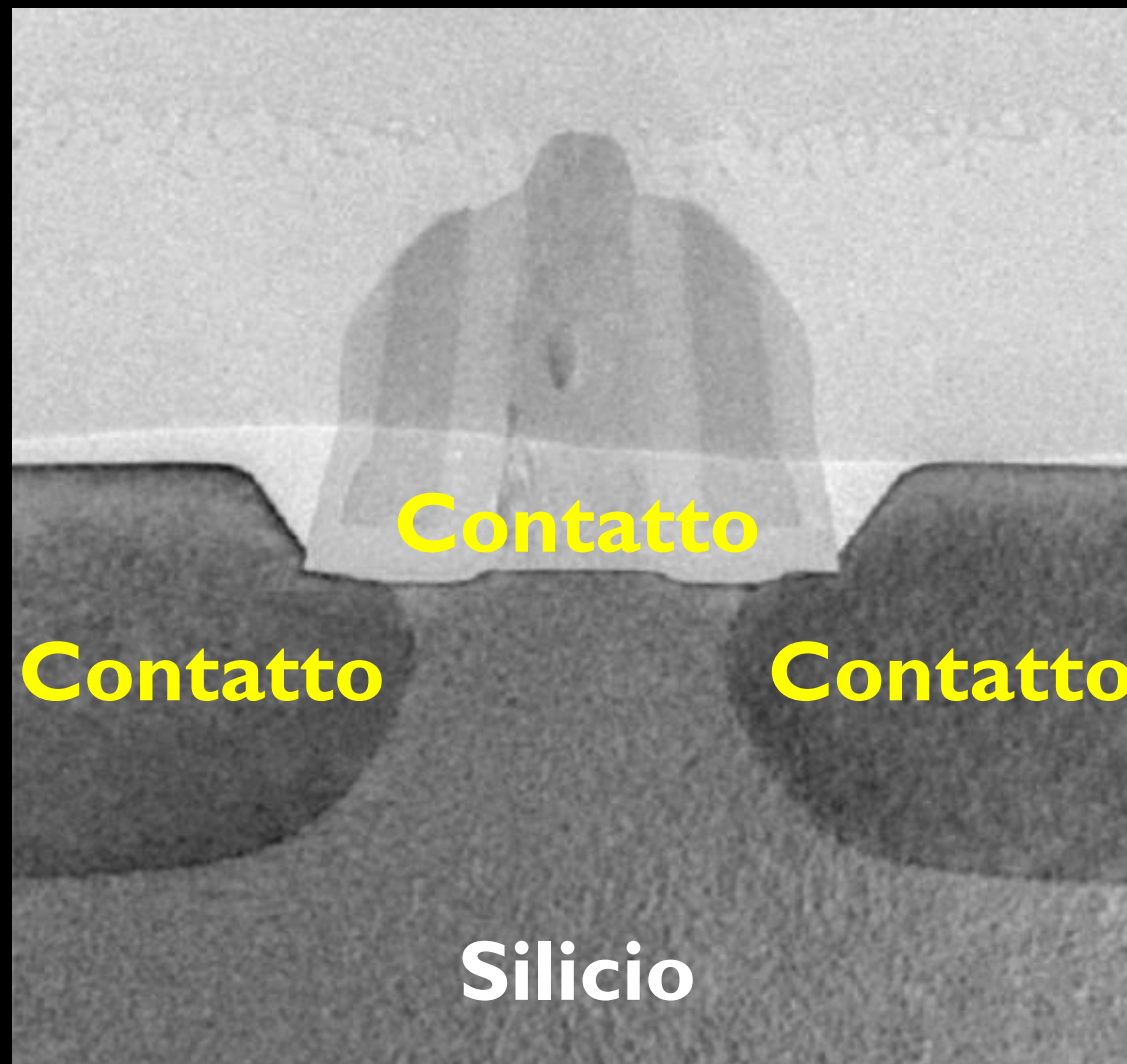
Electronic Numerical Integrator and Calculator

Patsy Simmers, Gail Taylor, Milly Beck, Norma Stec.

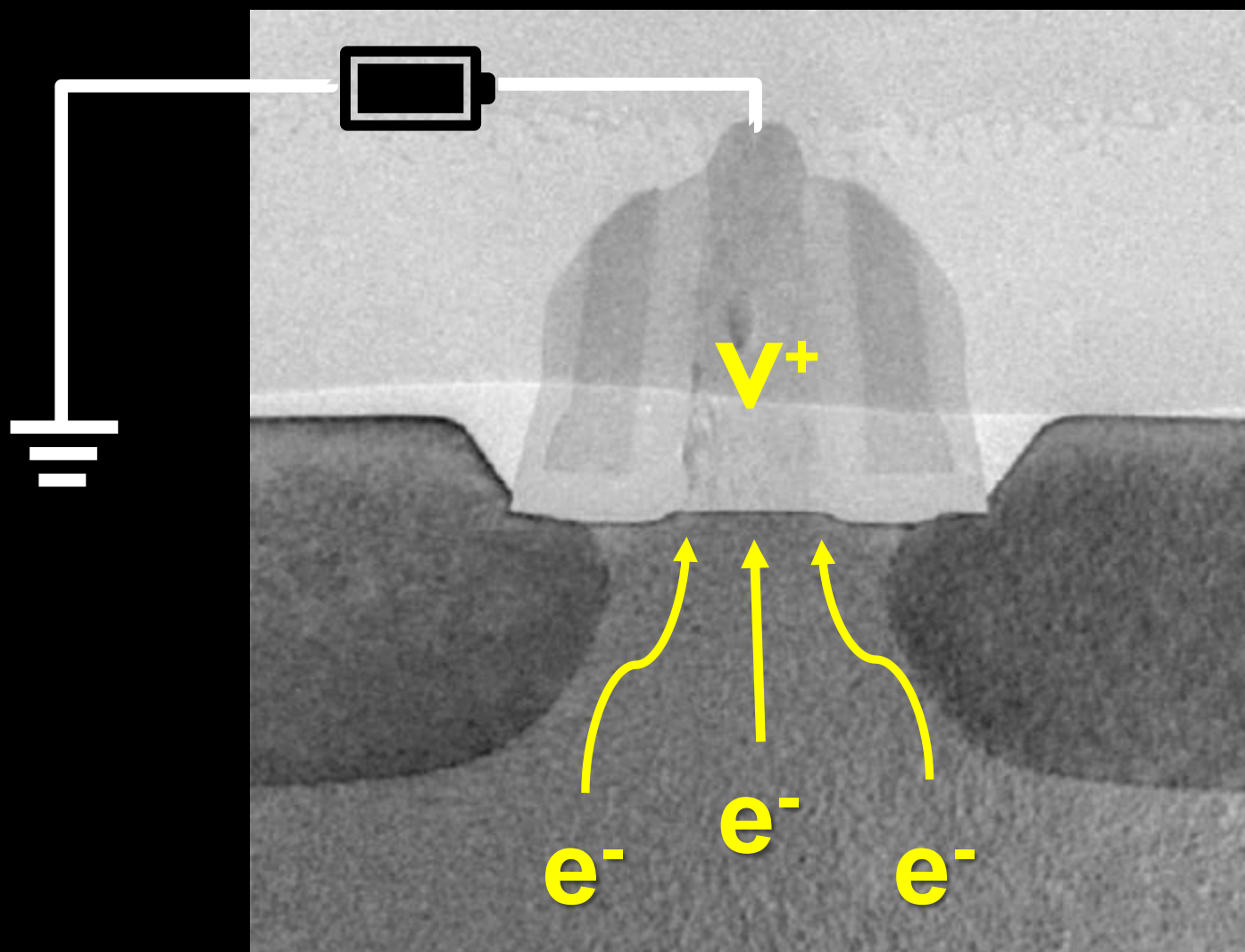




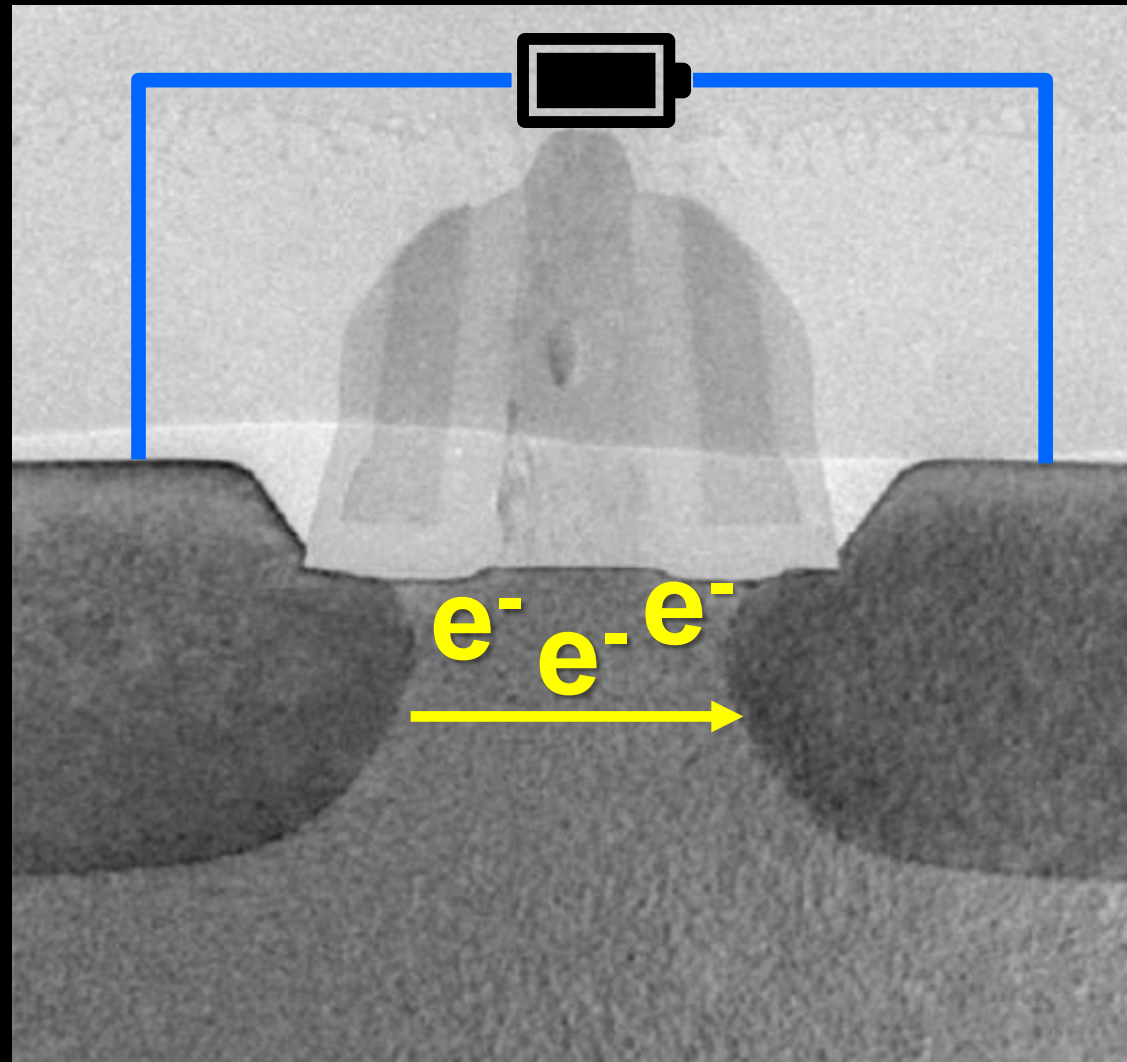
Transistor



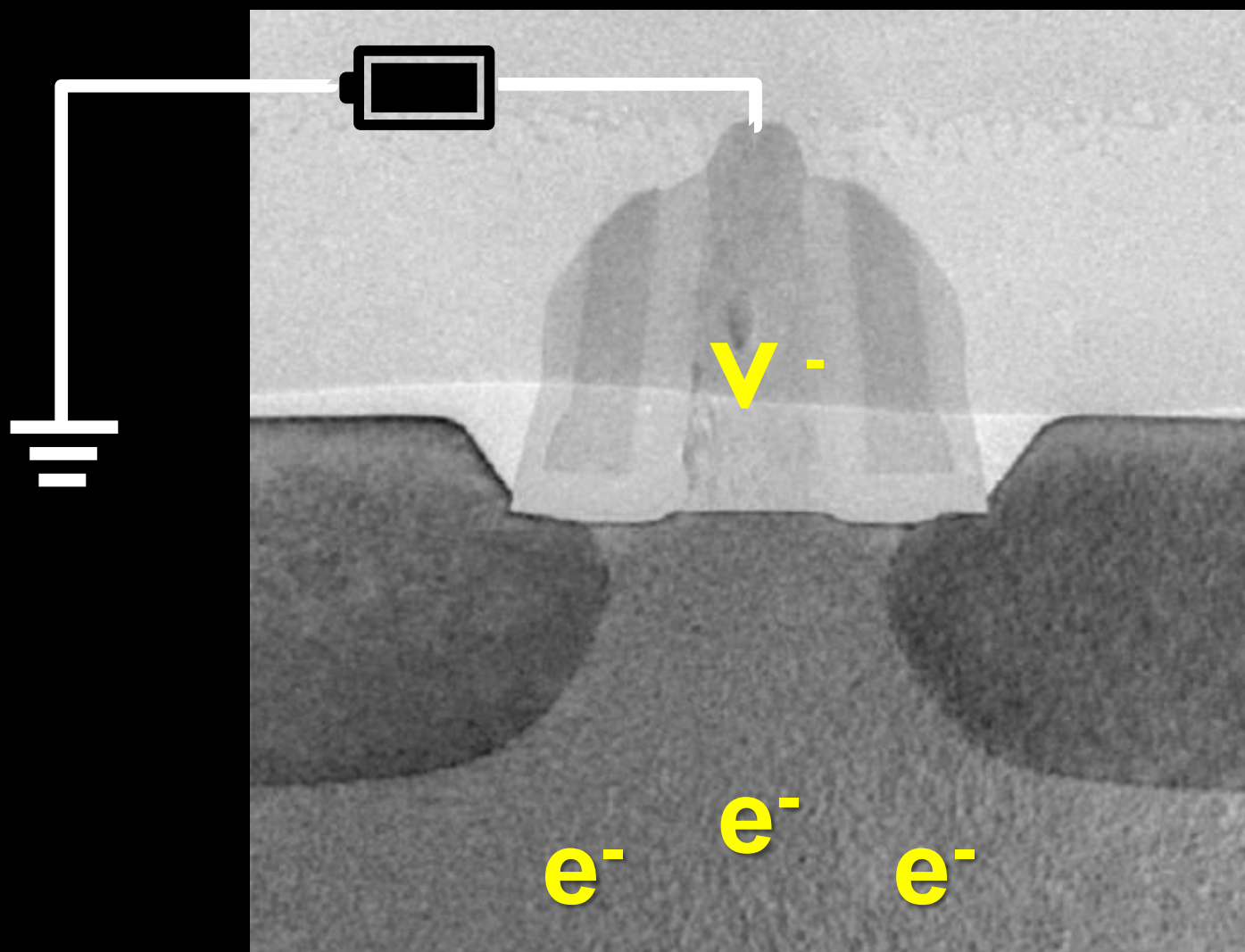
Transistor



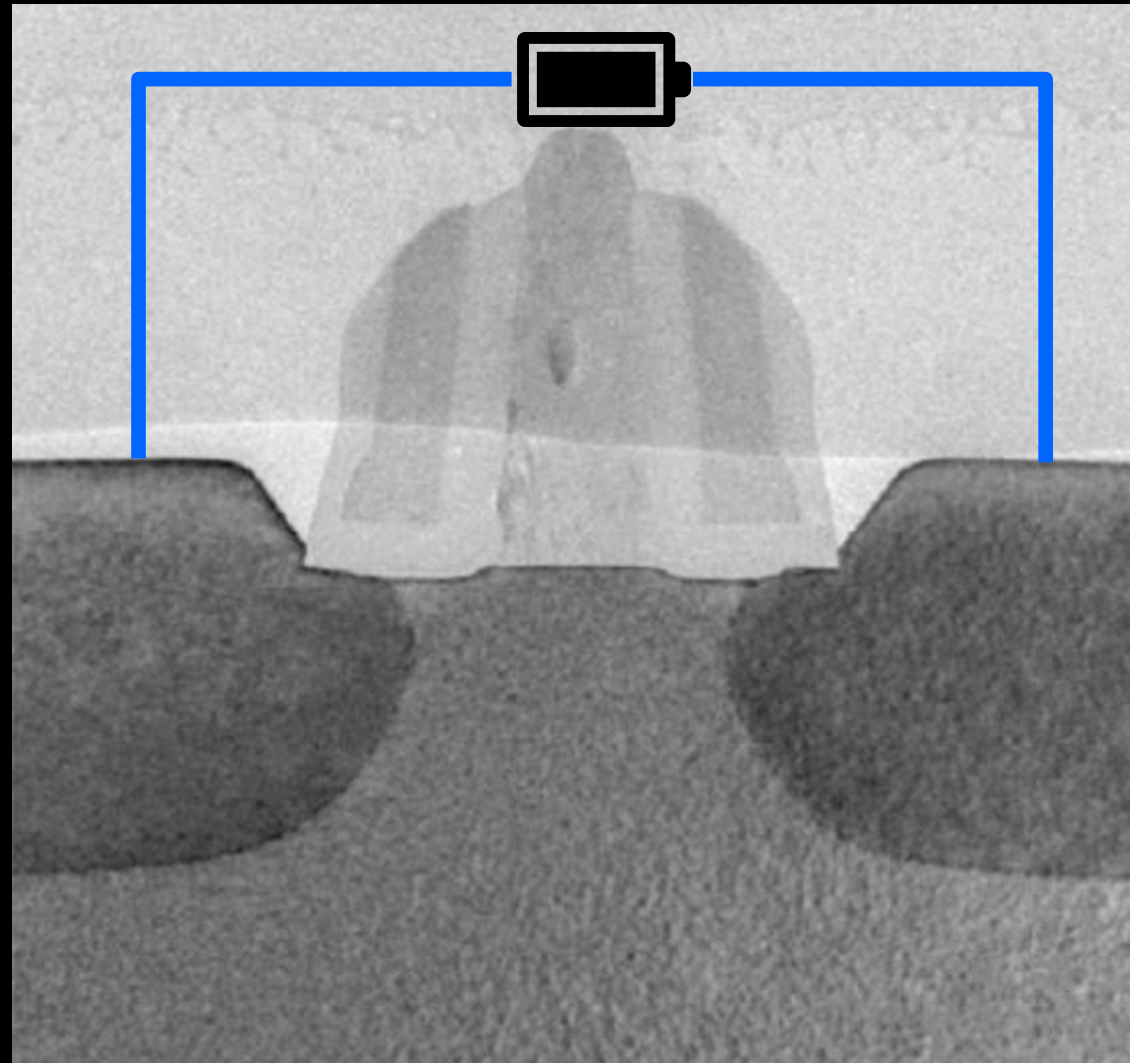
Transistor



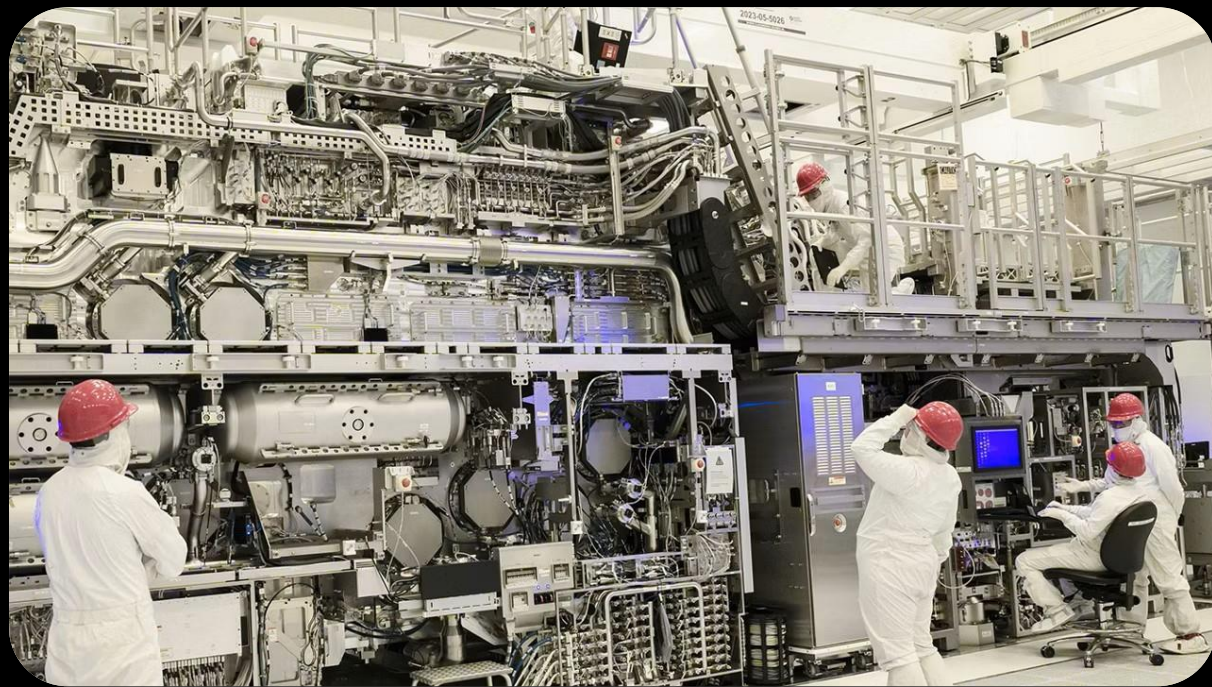
Transistor

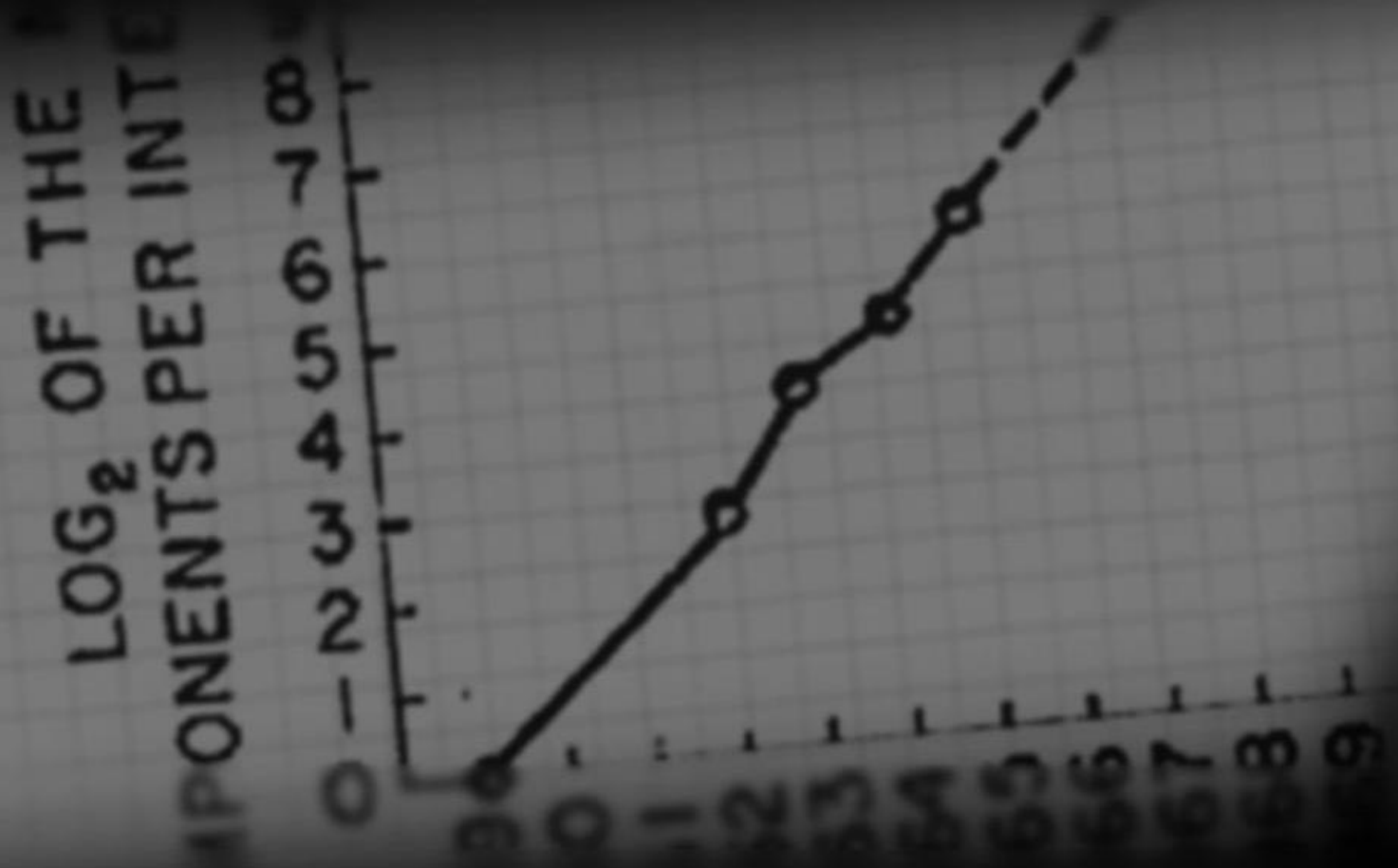


Transistor



Per i wafer di silicio sono richiesti livelli di purezza pari o superiori al 99,9999999%, il che significa che è tollerabile **meno di 1 atomo estraneo su un miliardo**.





G. Moore, Intel.com

'...Il numero di transistor incorporati in un chip raddoppia quasi ogni 24 mesi ...'

THE RELATIVE SIZE OF PARTICLES

From the COVID-19 pandemic to the U.S. West Coast wildfires, some of the biggest threats now are also the most microscopic.

A particle needs to be 10 microns (μm) or less before it can be inhaled into your respiratory tract. But just how small are these specks?

Here's a look at the relative sizes of some familiar particles \blacktriangleright

HUMAN HAIR 50-180 μm \blacktriangleright
FOR SCALE

FINE BEACH SAND 90 μm \blacktriangleright

GRAIN OF SALT 60 μm \blacktriangleright

WHITE BLOOD CELL 25 μm \blacktriangleright

GRAIN OF POLLEN 15 μm \blacktriangleright

DUST PARTICLE (PM₁₀) <10 μm \blacktriangleright

RED BLOOD CELL 7-8 μm \blacktriangleright

RESPIRATORY DROPLETS 5-10 μm \blacktriangleright

DUST PARTICLE (PM_{2.5}) 2.5 μm \blacktriangleright

BACTERIUM 1-3 μm \blacktriangleright

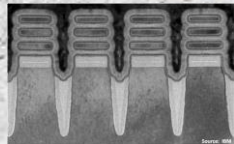
WILDFIRE SMOKE 0.4-0.7 μm \blacktriangleright

CORONAVIRUS 0.1-0.5 μm \blacktriangleright

T4 BACTERIOPHAGE 0.225 μm \blacktriangleright

ZIKA VIRUS 0.045 μm \blacktriangleright

Transistor
0.0018 μm



Pollen can trigger allergic reactions and hay fever—which 1 in 5 Americans experience every year.

Source: Harvard Health

The visibility limits for what the naked eye can see hovers around 10-40 μm .



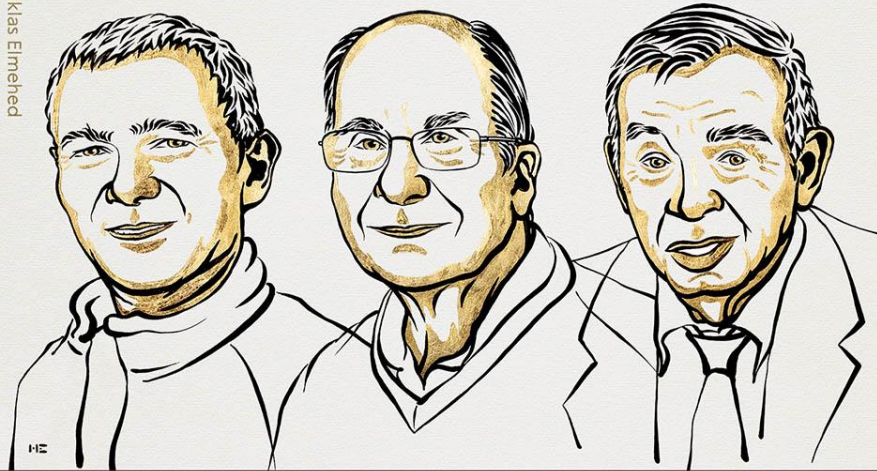
Respiratory droplets have the potential to carry smaller particles within them, such as dust or coronavirus.



Wildfire smoke can persist in the air for several days, and even months.

THE NOBEL PRIZE
IN CHEMISTRY 2023

Illustrations: Niklas Elmehed



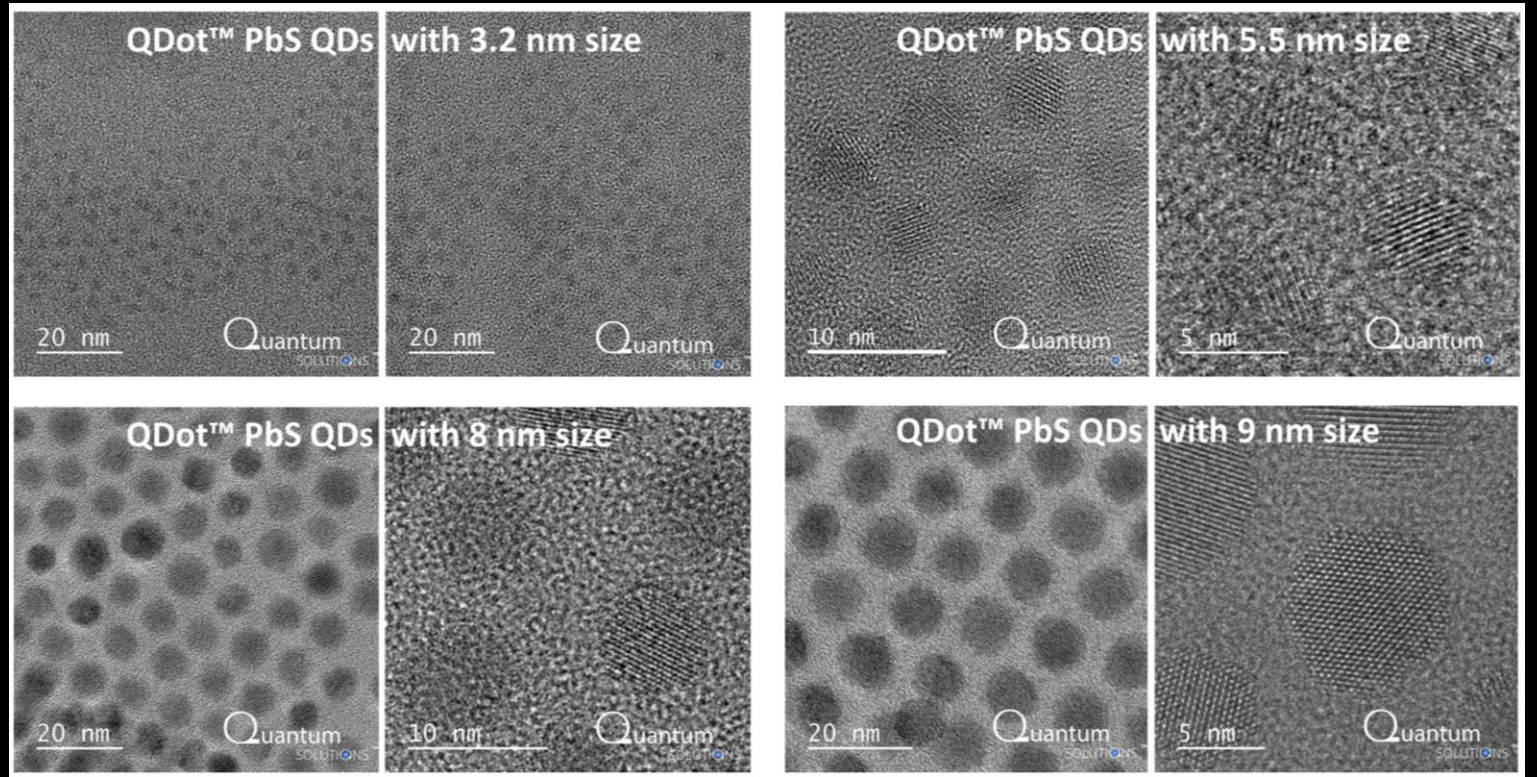
Mounqi G.
Bawendi

Louis E.
Brus

Alexei I.
Ekimov

"for the discovery and synthesis of quantum dots"

THE ROYAL SWEDISH ACADEMY OF SCIENCES



Dalla Qualità dell'immagine al Colore e alla Sicurezza

 CHECK 01



Quantum Dot Content

Sono necessari almeno 3000 ppm di quantum dot per un miglioramento significativo nella qualità dell'immagine.

 CHECK 02



Quantum Dot Film

Un fattore chiave per determinare la resa cromatica e la durata nel tempo è la capacità di riprodurre colori vividi.

 CHECK 03



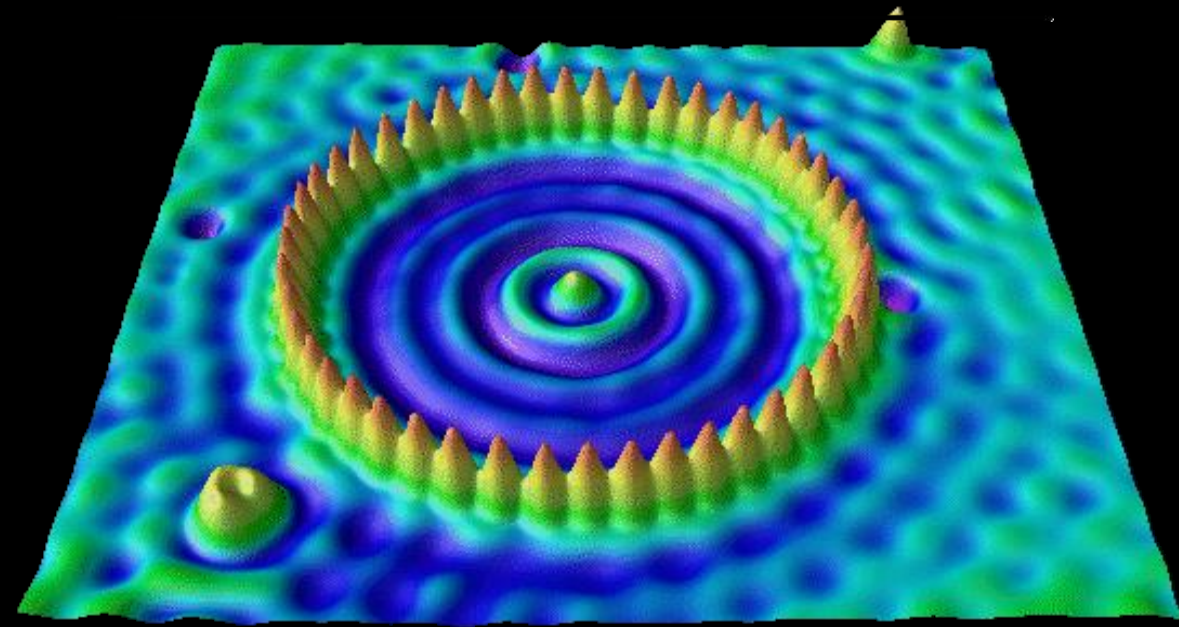
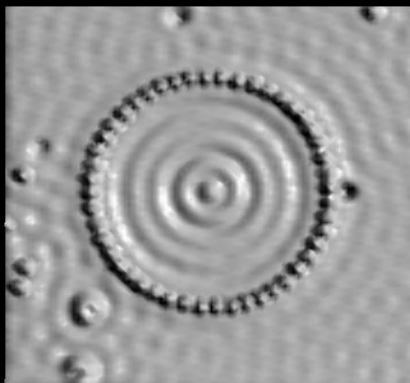
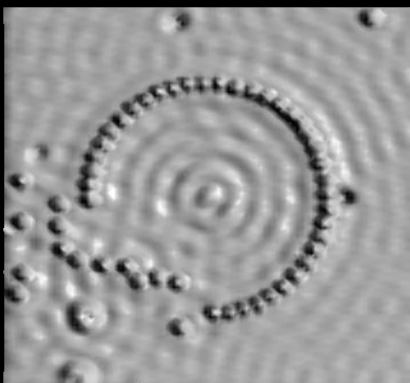
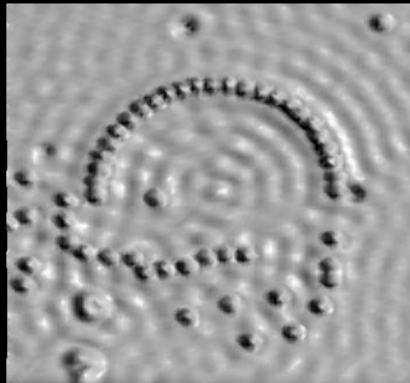
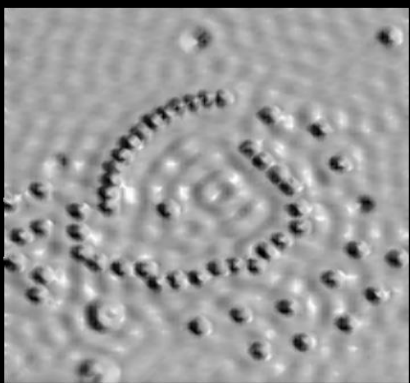
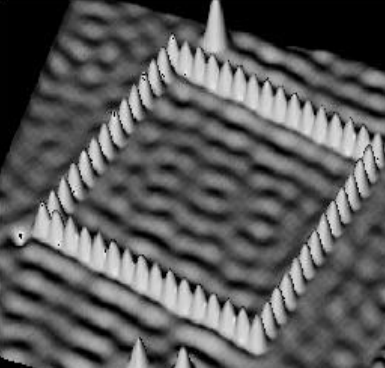
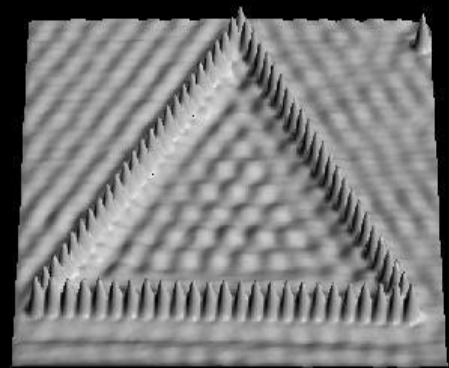
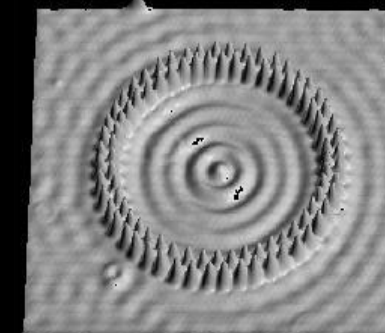
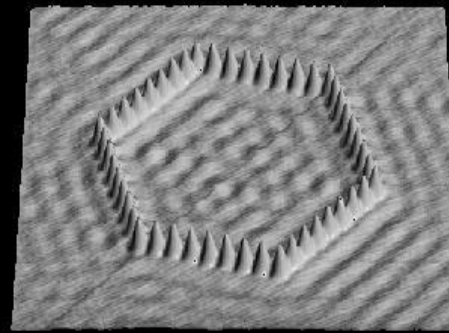
No-Cadmium

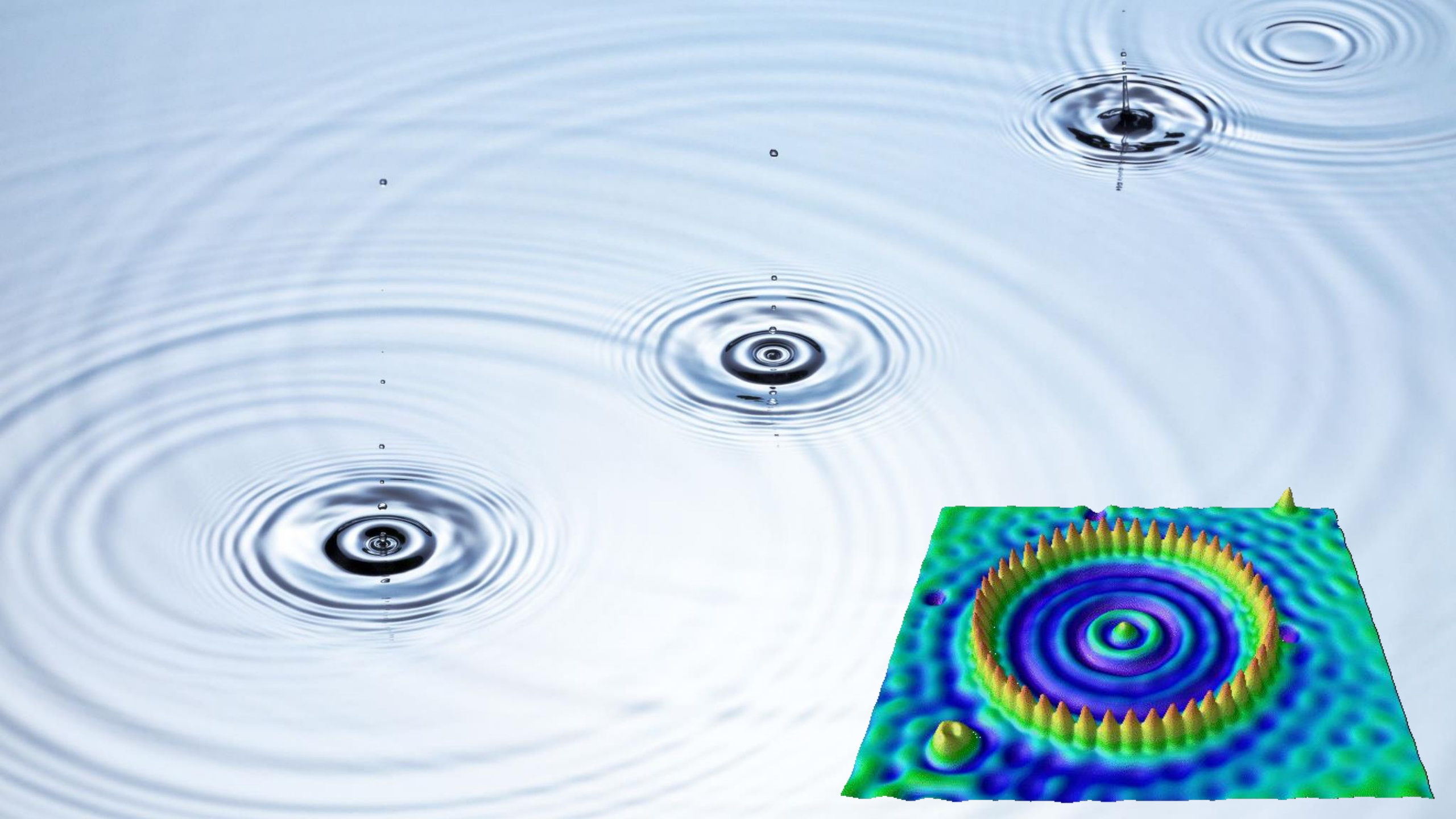
Materiali sicuri e privi di sostanze nocive.

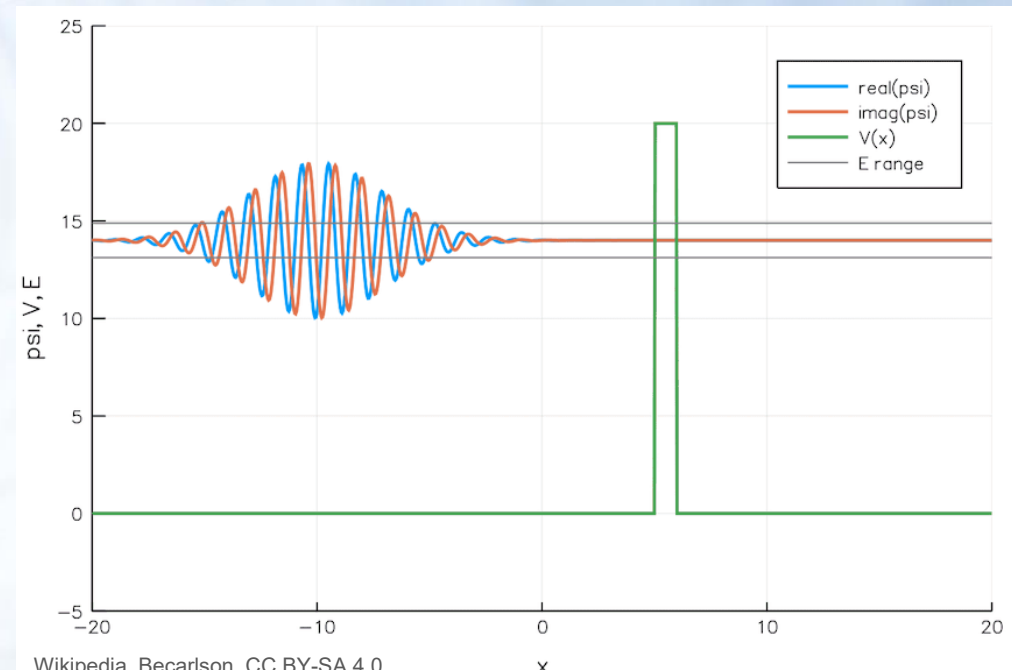


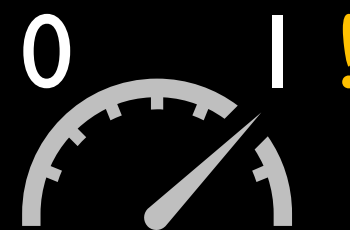
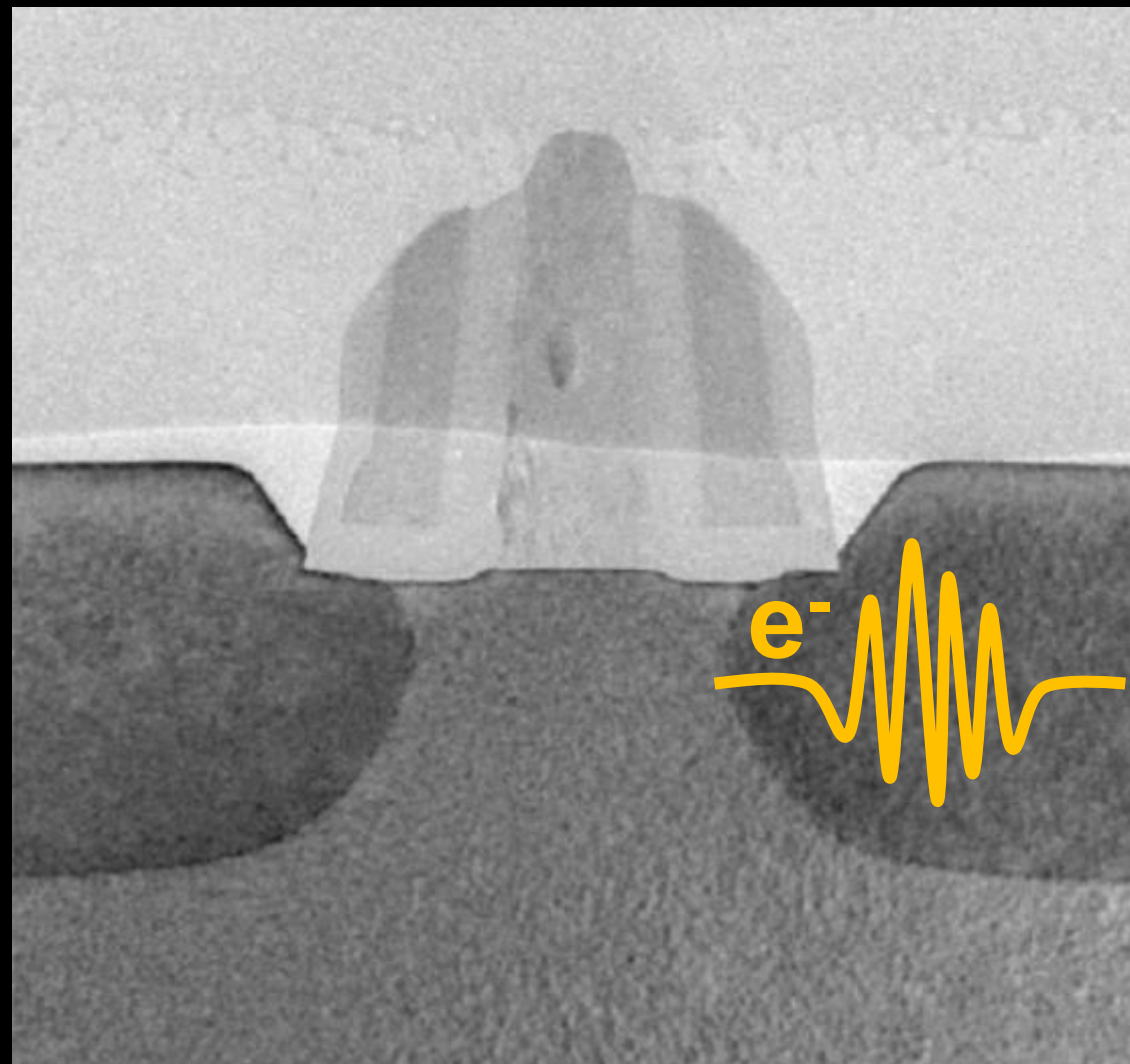
Neo QLED

Binnig e Rohrer, 1986



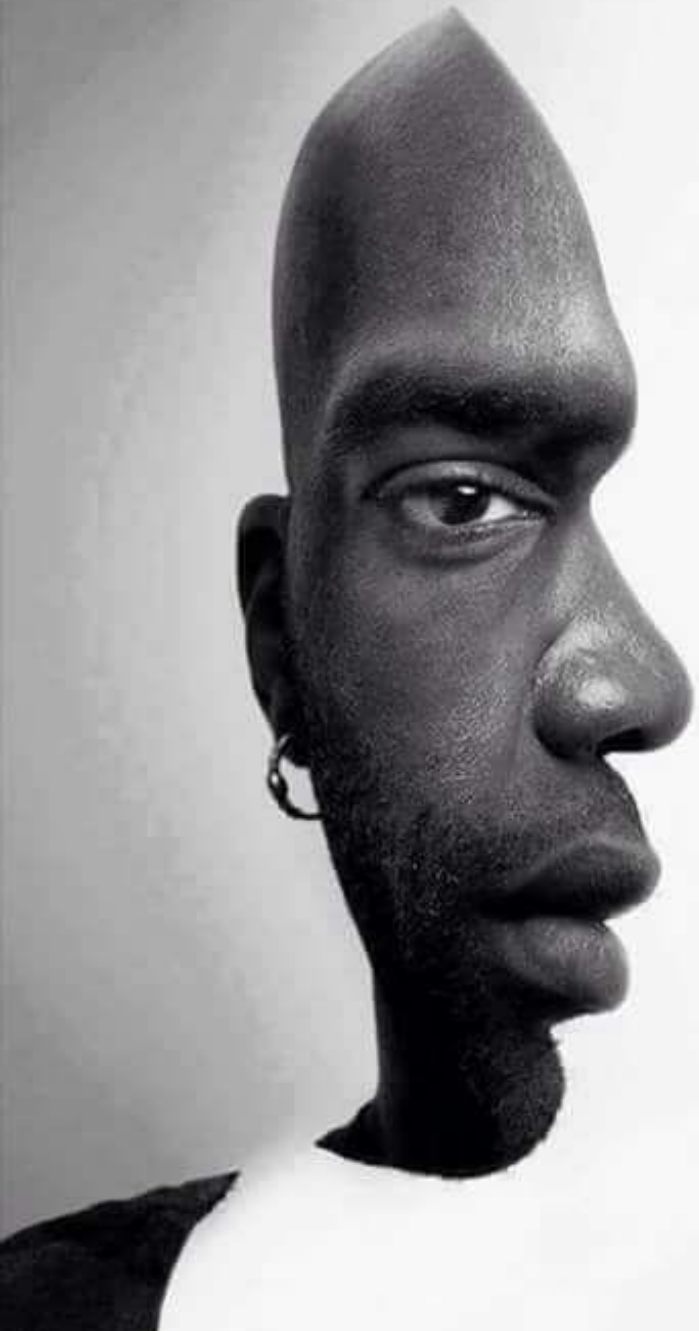






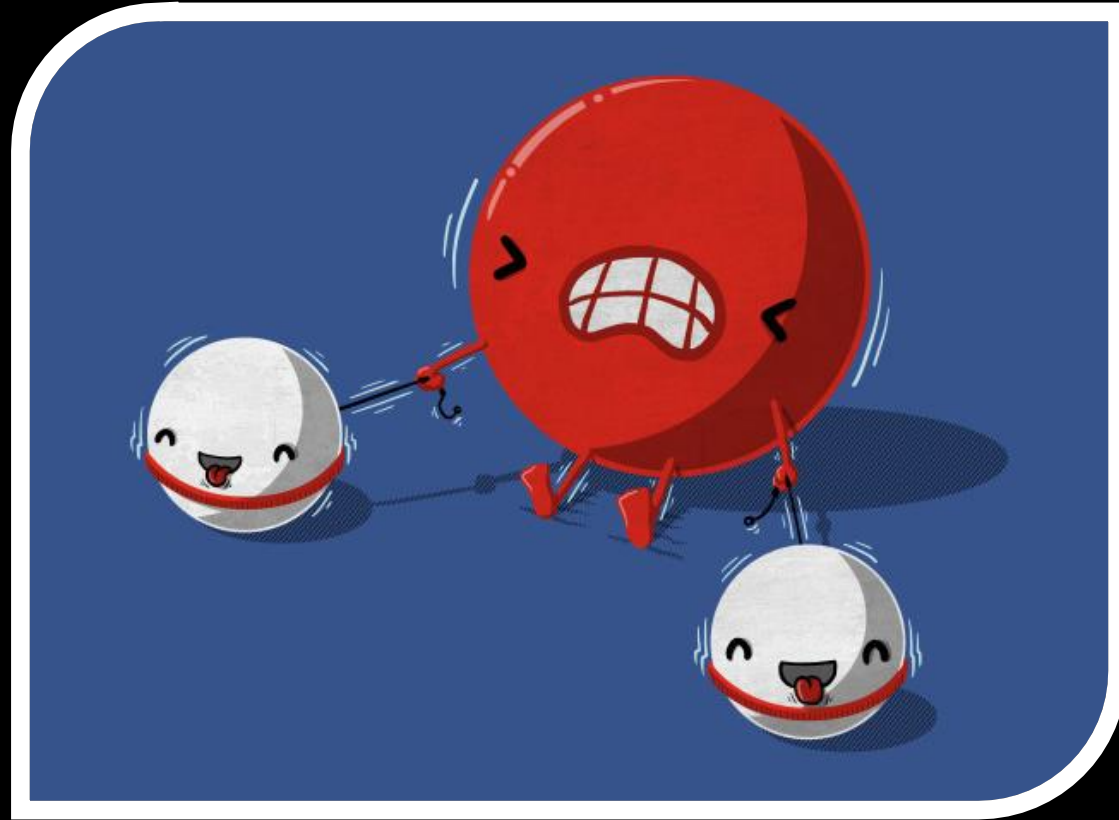


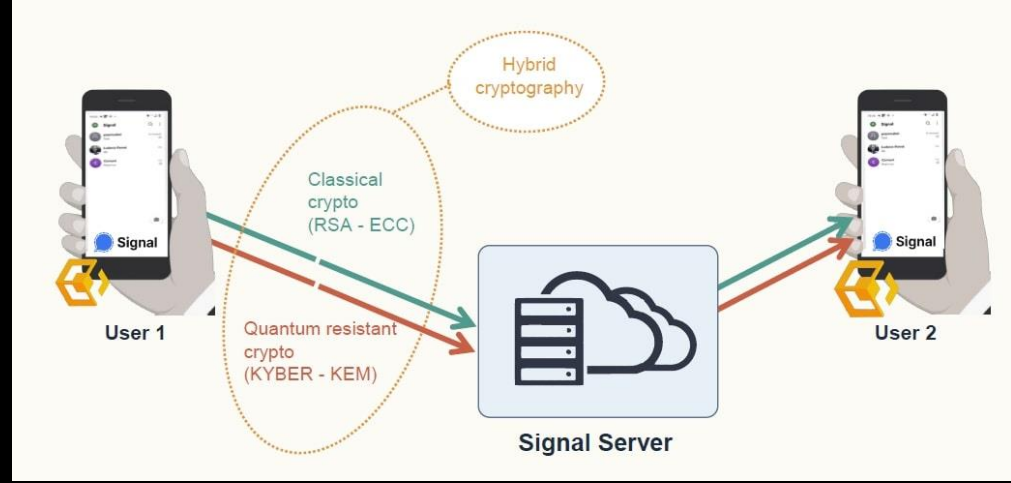
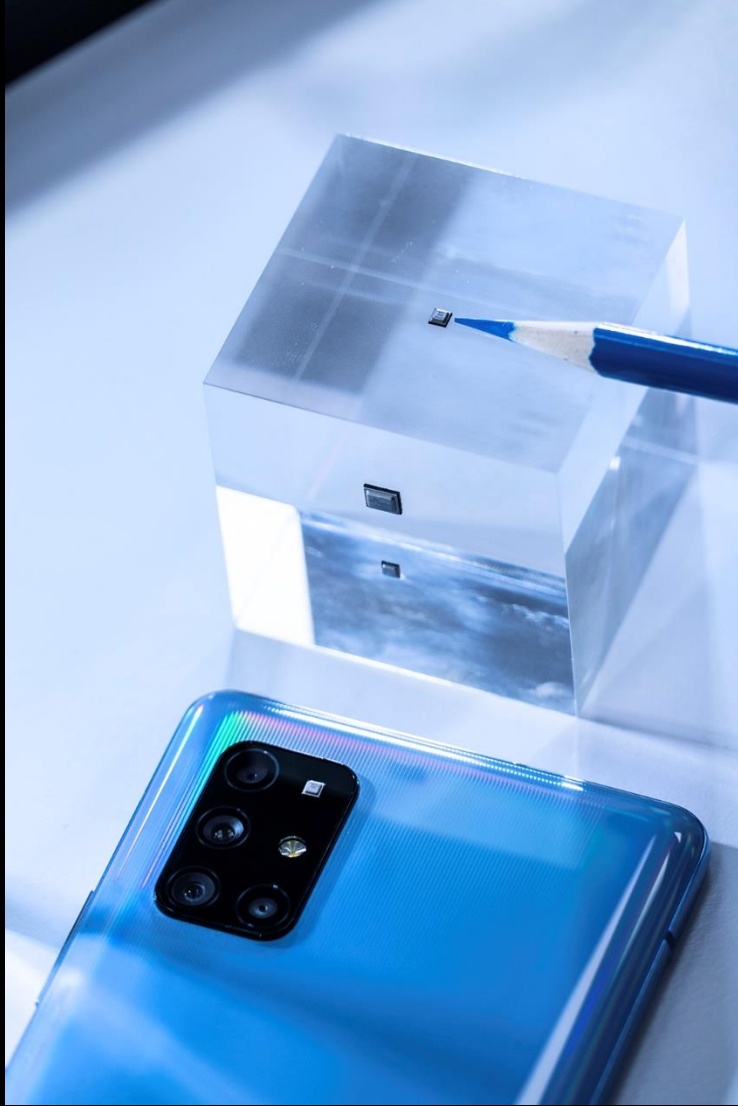
Tunneling quantistico



Principio di sovrapposizione

Molecola d'acqua: H₂O

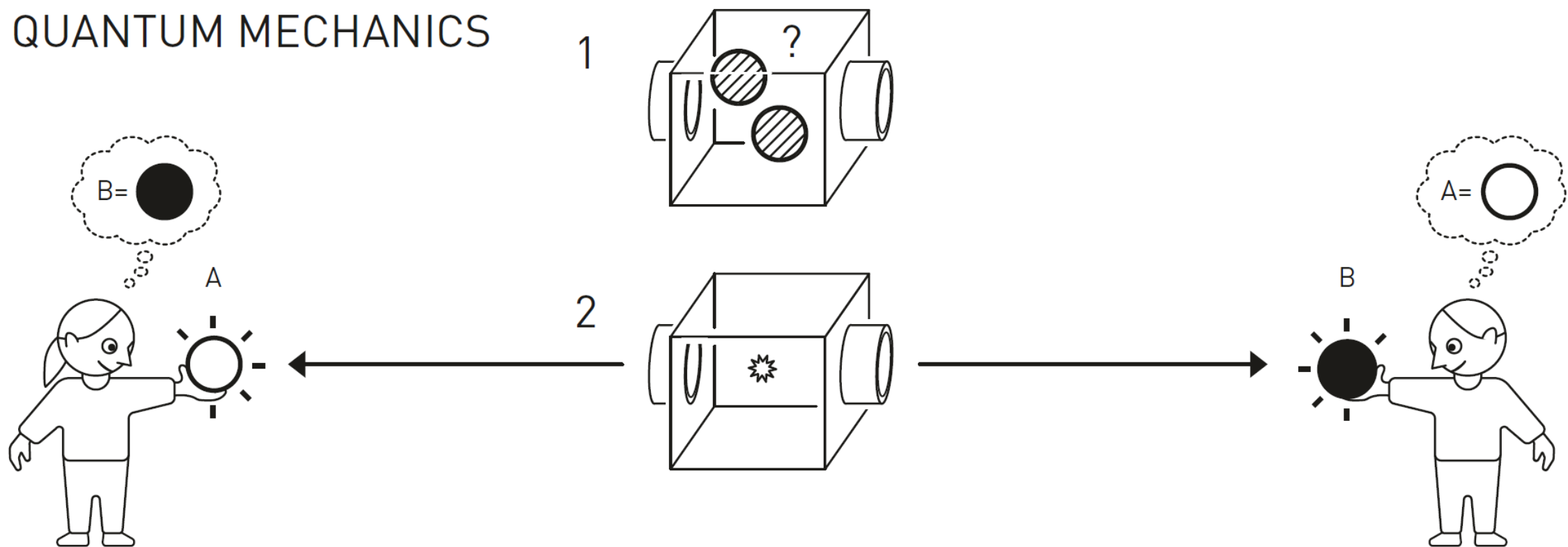




Galaxy Quantum4



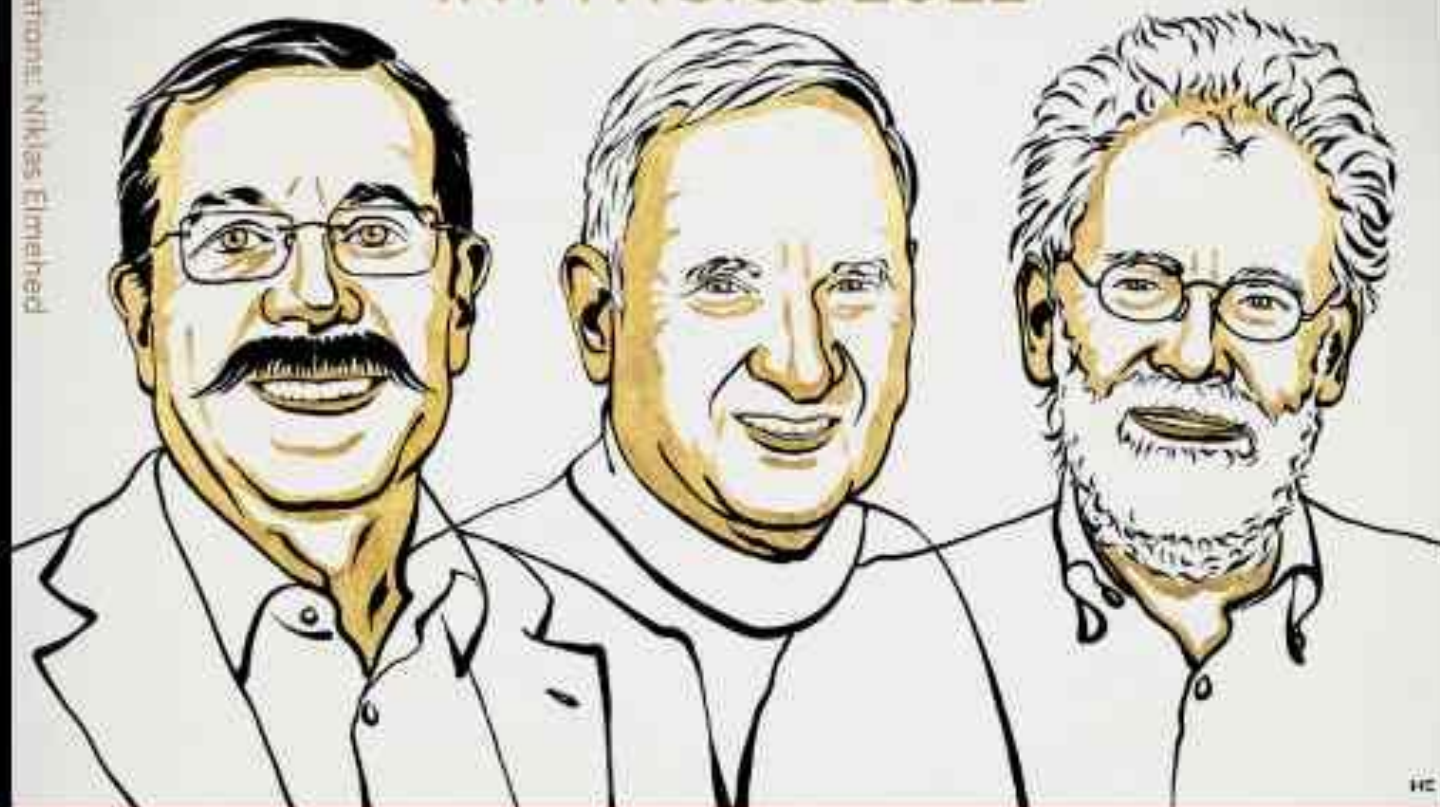
QUANTUM MECHANICS



©Johan Jarnestad/The Royal Swedish Academy of Sciences

THE NOBEL PRIZE IN PHYSICS 2022

Illustrations: Niklas Elmehed



Alain
Aspect

John F.
Clauser

Anton
Zeilinger

"for experiments with entangled photons,
establishing the violation of Bell inequalities
and pioneering quantum information science"

THE ROYAL SWEDISH ACADEMY OF SCIENCES

Entanglement-based secure quantum cryptography over 1,120 kilometres

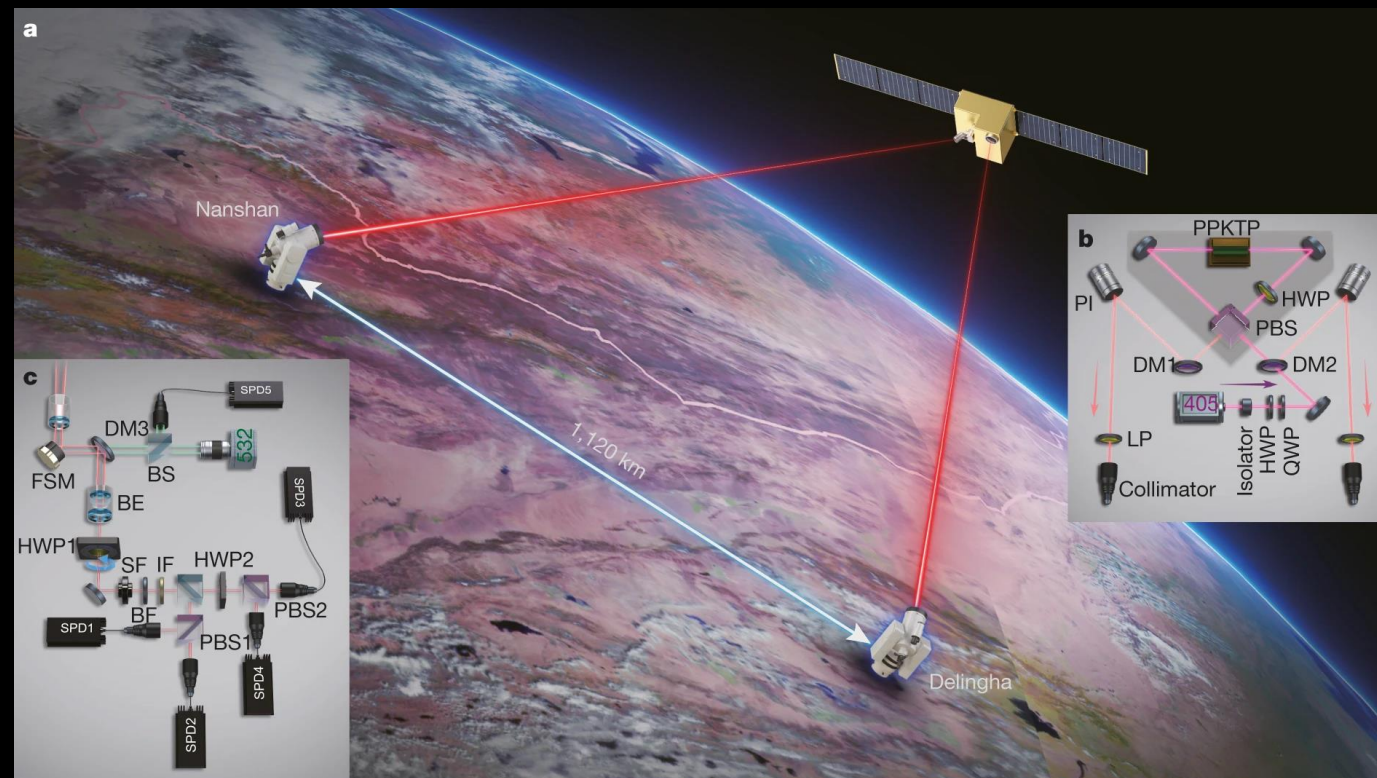
<https://doi.org/10.1038/s41586-020-2401-y>

Received: 15 July 2019

Accepted: 13 May 2020

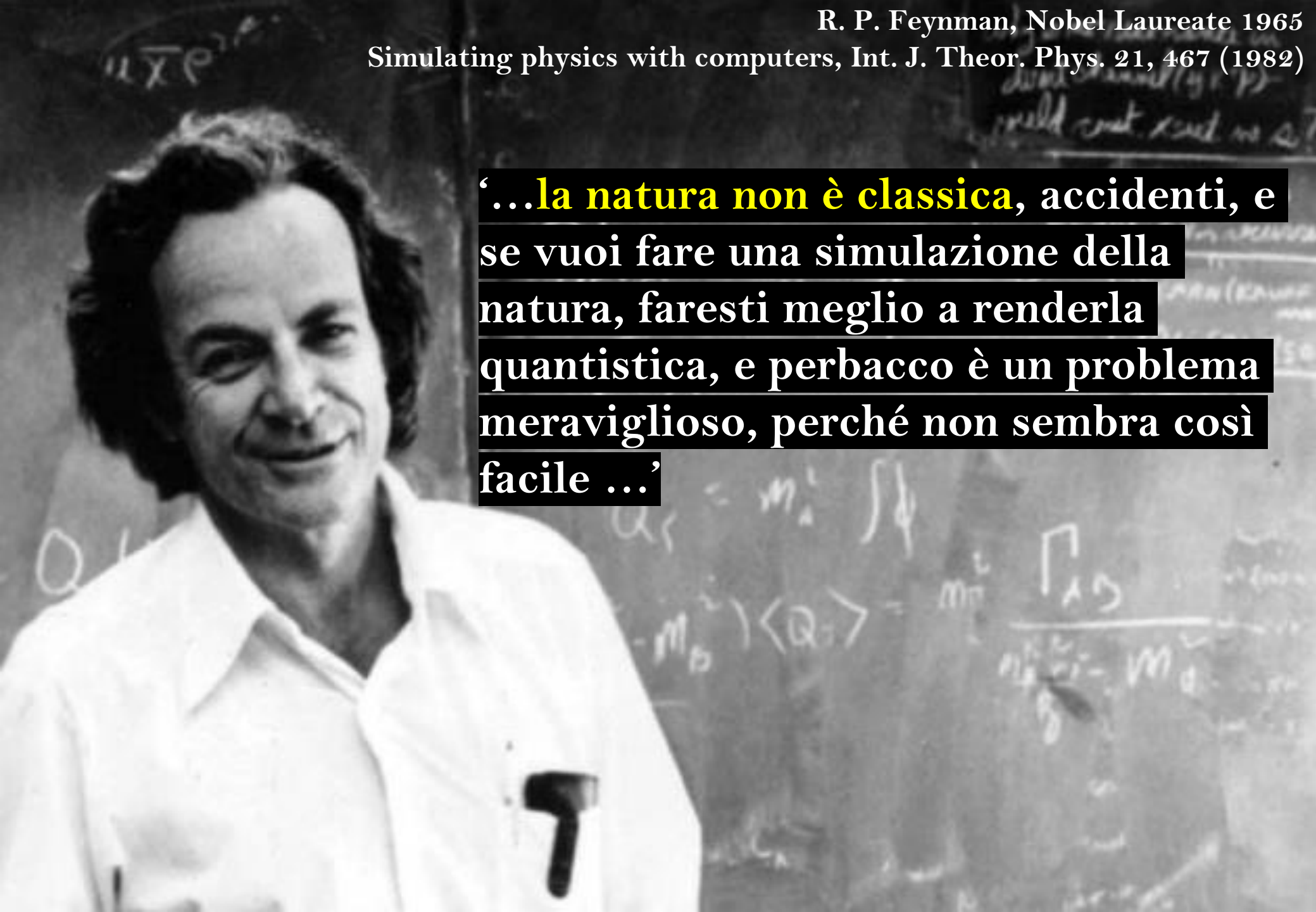
Published online: 15 June 2020

Juan Yin^{1,2,3}, Yu-Huai Li^{1,2,3}, Sheng-Kai Liao^{1,2,3}, Meng Yang^{1,2,3}, Yuan Cao^{1,2,3}, Liang Zhang^{2,3,4}, Ji-Gang Ren^{1,2,3}, Wen-Qi Cai^{1,2,3}, Wei-Yue Liu^{1,2,3}, Shuang-Lin Li^{1,2,3}, Rong Shu^{2,3,4}, Yong-Mei Huang⁵, Lei Deng⁶, Li Li^{1,2,3}, Qiang Zhang^{1,2,3}, Nai-Le Liu^{1,2,3}, Yu-Ao Chen^{1,2,3}, Chao-Yang Lu^{1,2,3}, Xiang-Bin Wang², Feihu Xu^{1,2,3}, Jian-Yu Wang^{2,3,4}, Cheng-Zhi Peng^{1,2,3}✉, Artur K. Ekert^{7,8} & Jian-Wei Pan^{1,2,3}✉

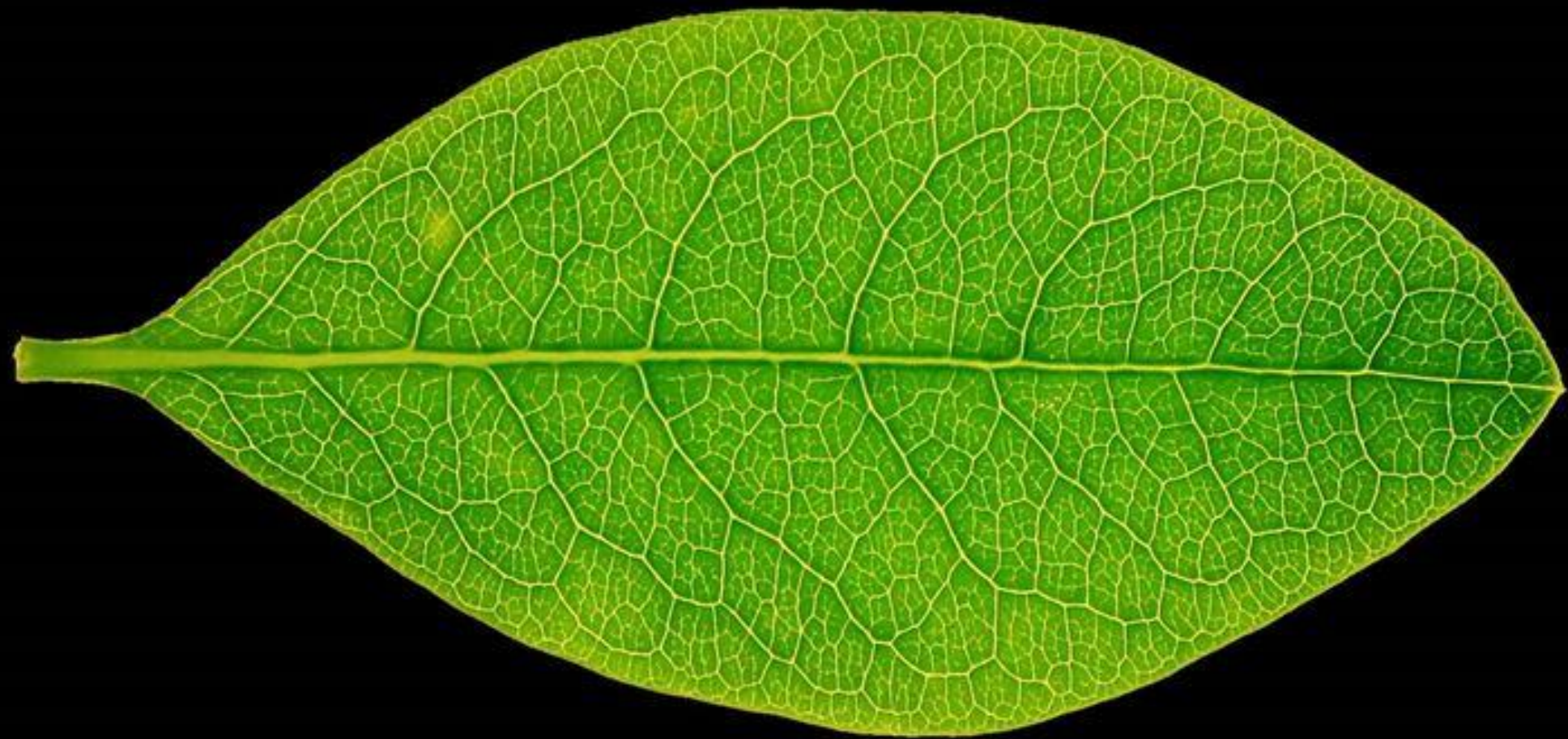


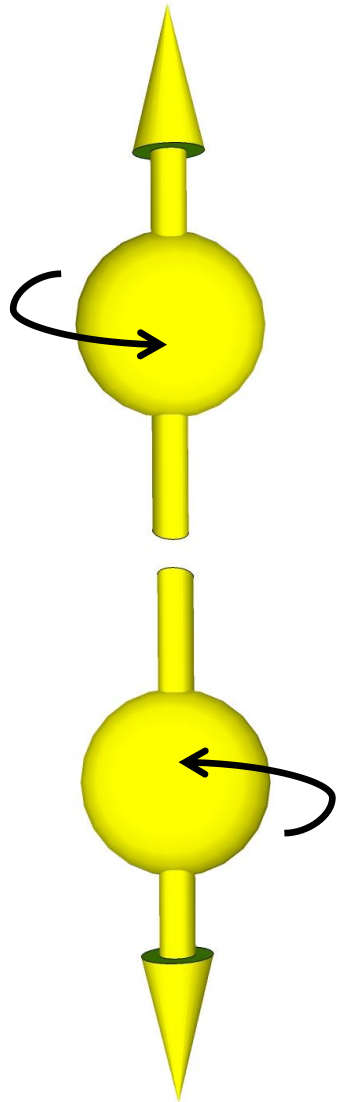
R. P. Feynman, Nobel Laureate 1965

Simulating physics with computers, Int. J. Theor. Phys. 21, 467 (1982)



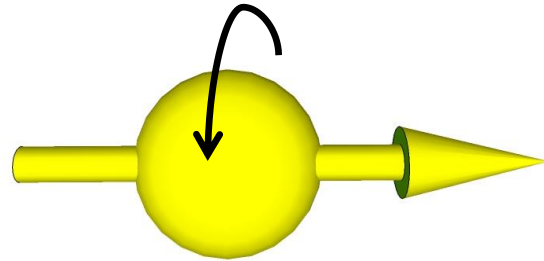
‘...la natura non è classica, accidenti, e se vuoi fare una simulazione della natura, faresti meglio a renderla quantistica, e perbacco è un problema meraviglioso, perché non sembra così facile ...’





1

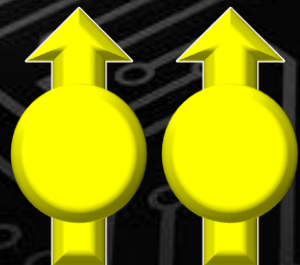
0



01



2



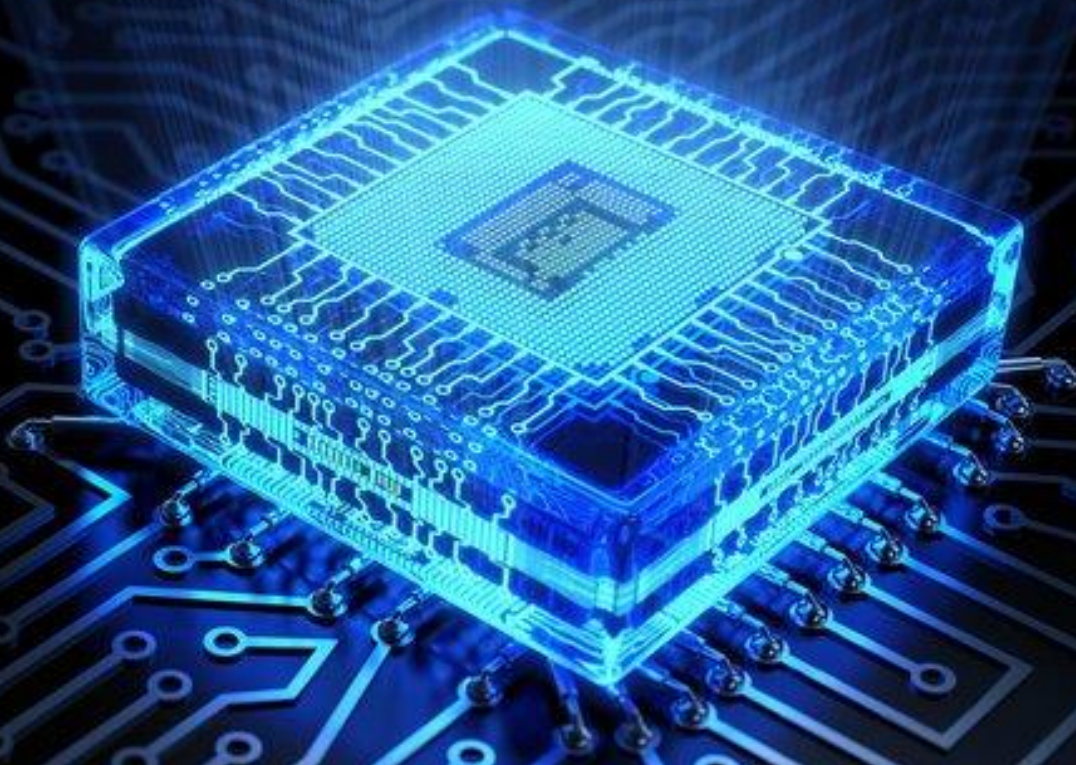
4

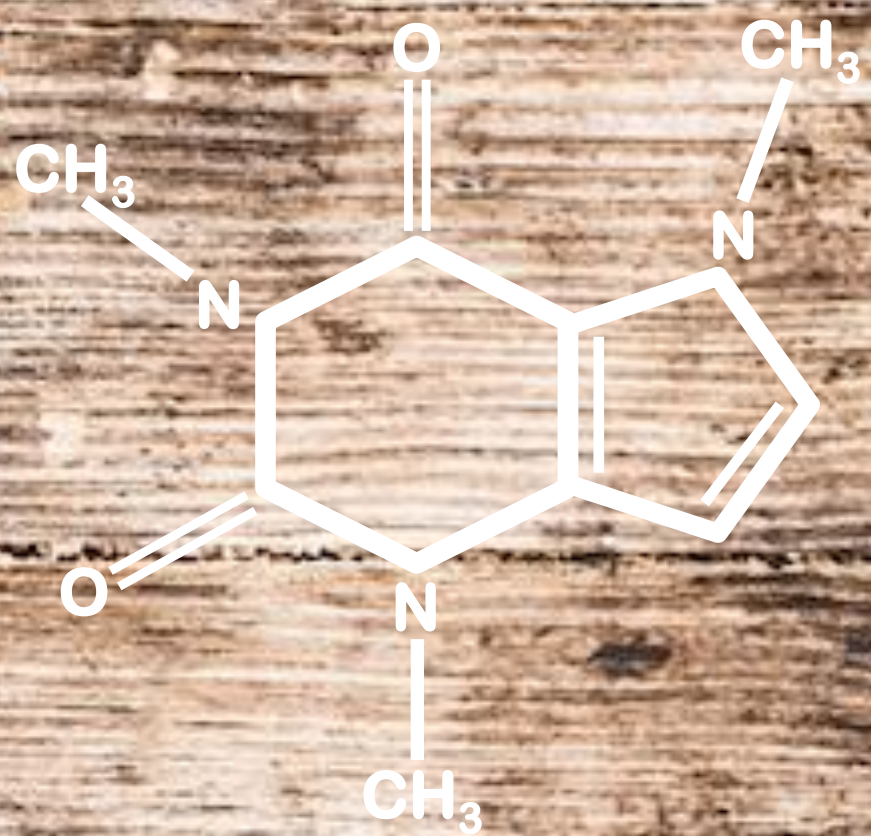
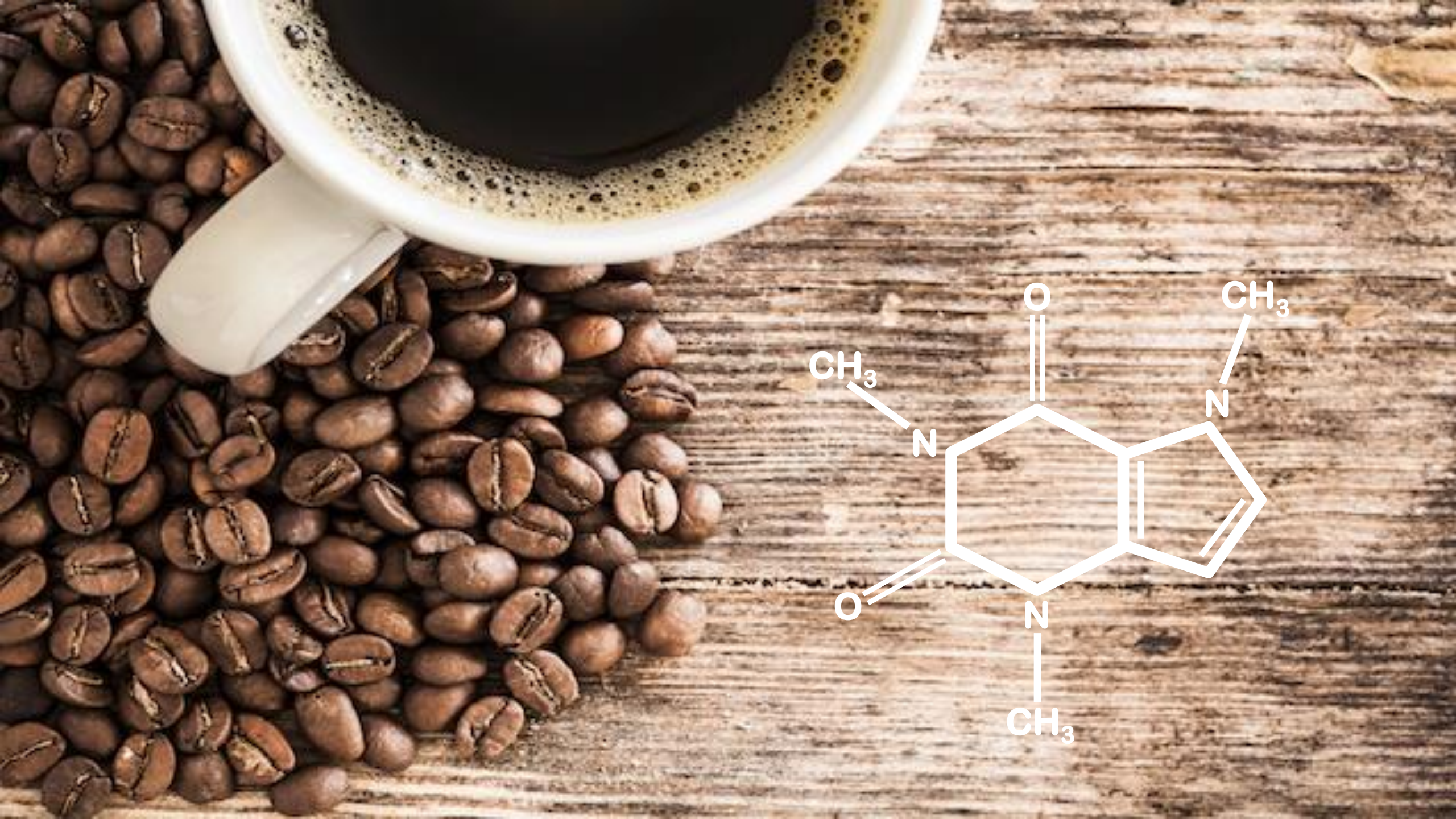


8

...

2^N



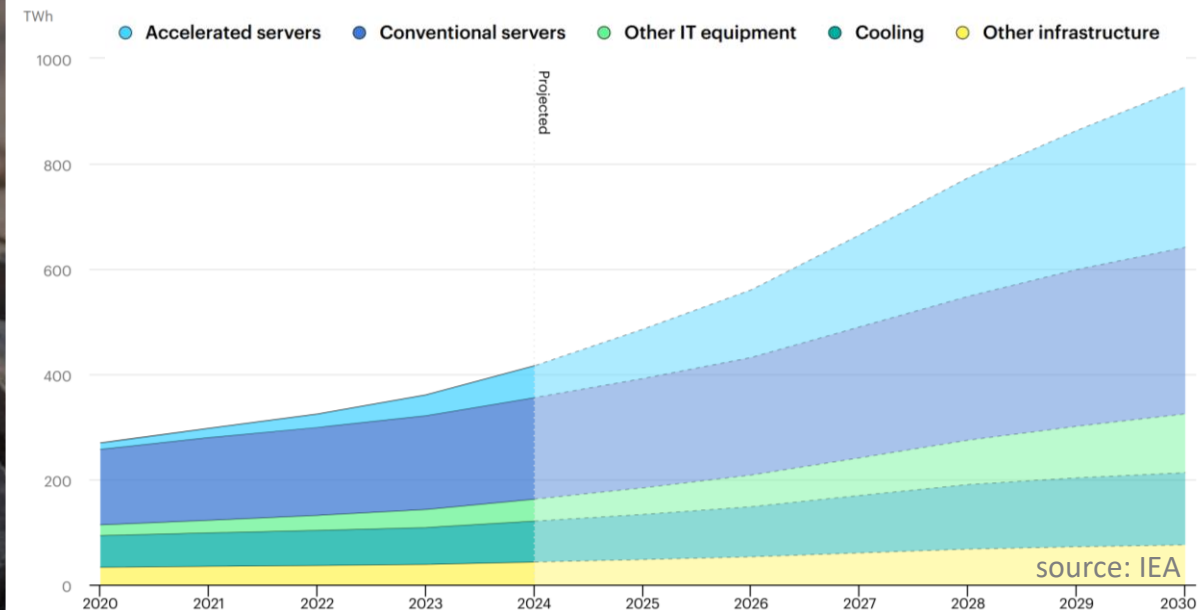


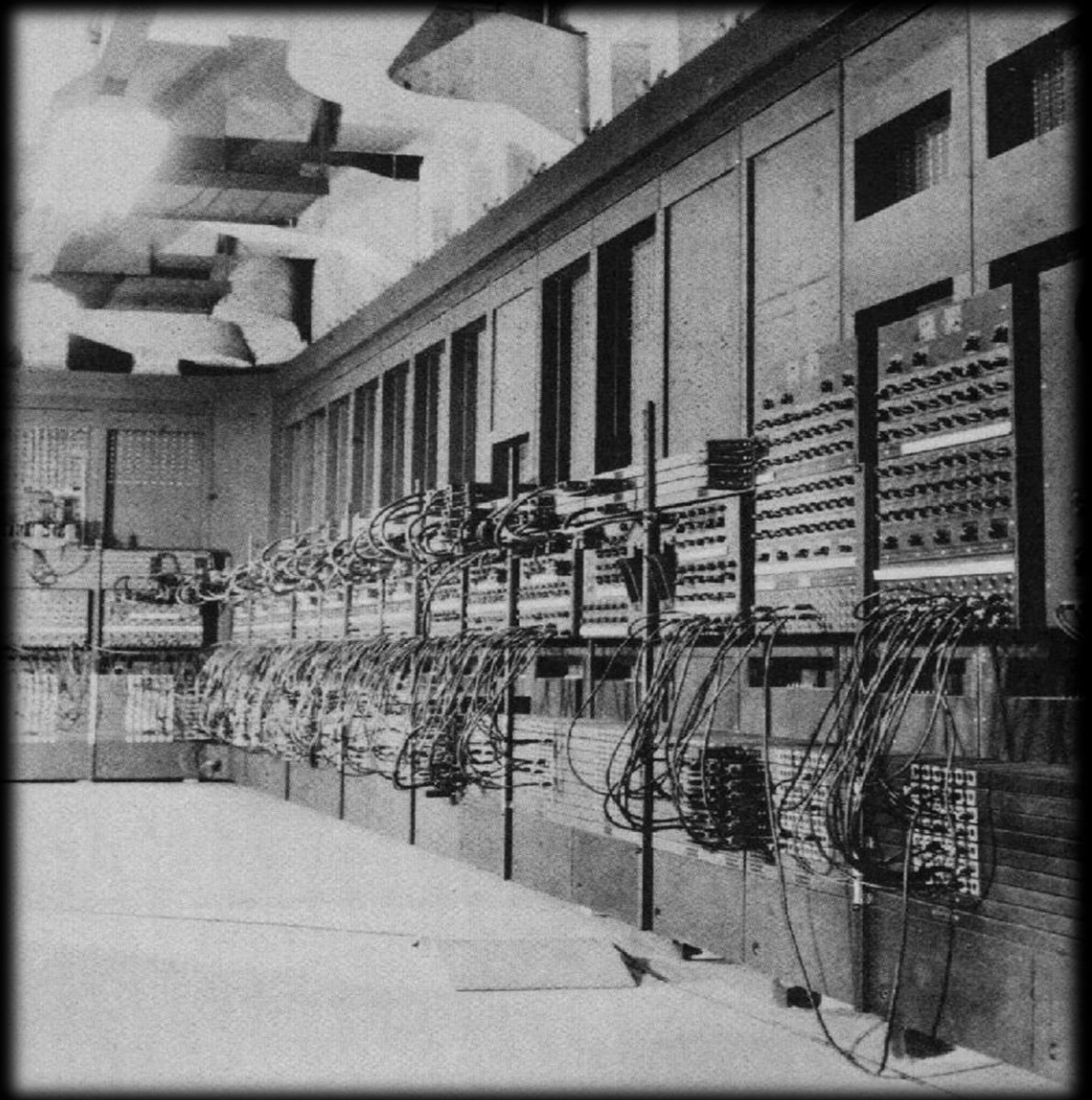
Il settore ICT (data center, reti di trasmissione dati e dispositivi degli utenti finali) ha emesso 1,0-1,7 Gt di CO₂-eq nel 2020.

Ciò equivale all'**1,8-2,8%** delle emissioni globali di gas serra di origine antropica, superando le emissioni di **Australia o Francia**

R. Istrate, et al. Nat Commun 15, 3724 (2024)

Global data centre electricity consumption, by equipment, Base Case, 2020-2030

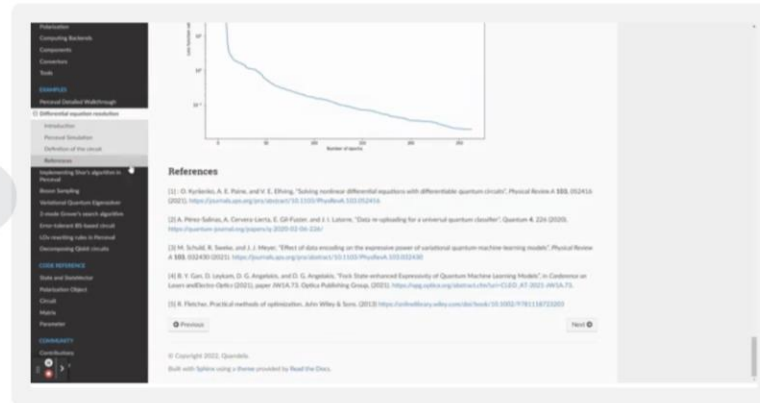






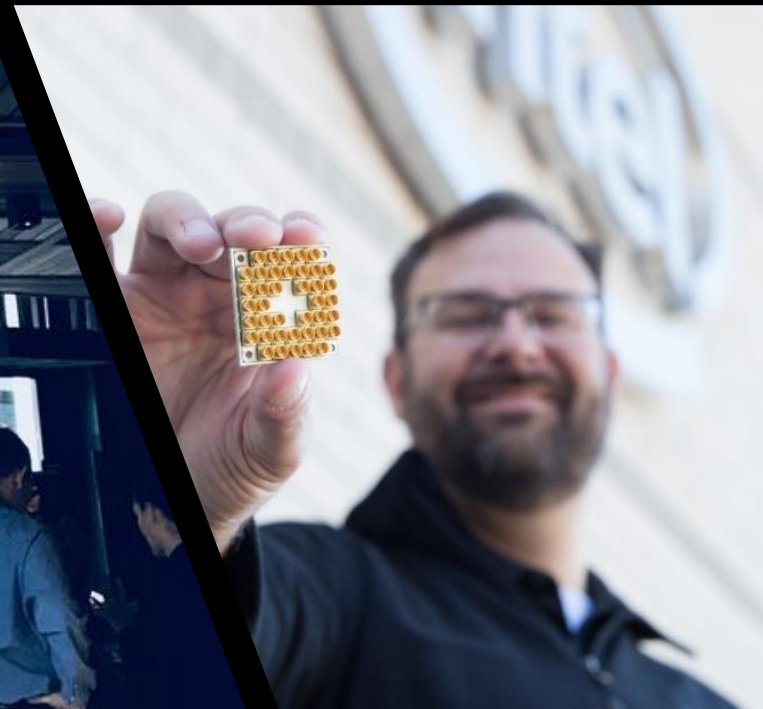
QUANDELA Cloud

Making the future of computing brighter



Quandela's cloud-based platform gives you access to photonic quantum computing, enabling you to develop and deploy algorithms that optimise solutions.

[Get Started for Free](#)



 PsiQuantum

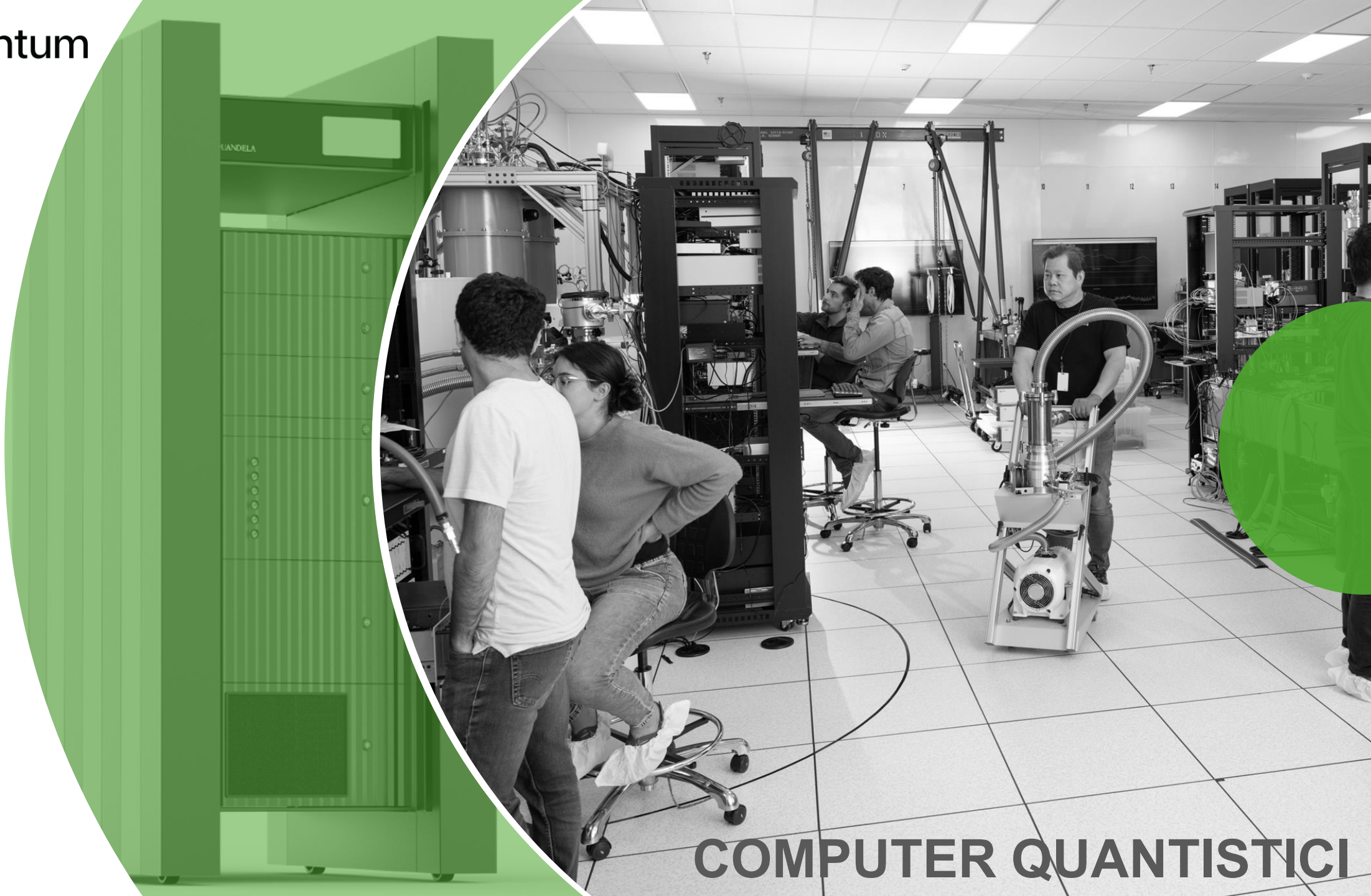
 photonics

 QUANDELA

 dirac

...

Lista non
esaustiva



COMPUTER QUANTISTICI

2016–2019

2020

2021

2022

2023

2024

2025

2026

2027

2028

2029

2033+

Development Roadmap

Applying algorithms to applications

Discovering new algorithms for advantage

Orchestrating workloads for quantum + HPC

Accurately and efficiently executing on quantum computers

Ran quantum circuits on IBM Quantum Platform

Released multi-dimensional roadmap publicly with initial focus on scaling

Enhanced quantum execution speed by 100x with Qiskit Runtime

Brought dynamic circuits to unlock more computations

Enhanced quantum execution speed by 5x with Quantum Serverless and execution modes

Demonstrated accurate execution of a quantum circuit at a scale beyond exact classical simulation (5K gates on 156 qubits)

Deliver quantum + HPC tools that will leverage Nighthawk, a new higher-connectivity quantum processor able to execute more complex circuits

Enable the first examples of quantum advantage using a quantum computer with HPC

Improve quantum circuit quality to allow 10K gates

Improve quantum circuit quality to allow 15K gates

Deliver a fault-tolerant quantum computer with the ability to run 100M gates on 200 logical qubits

Beyond 2033, quantum computers will run circuits comprising a billion gates on up to 2000 logical qubits, unlocking the full power of quantum computing

Code assistant

Functions

Use case benchmarking toolkit

Computation libraries

Advanced classical transpilation tools

Advanced classical mitigation tools

Utility mapping tools

Circuit libraries

Resource Management

Qiskit Serverless

Plugins for HPC

C API

Profiling tools

Workflow accelerators

Execution modes

Qiskit Runtime

IBM Quantum Experience

OpenQASM 3

Dynamic Circuits

Error mitigation

200K CLOPS

Utility-scale dynamic circuits

Fault-tolerant ISA

Early

Falcon

Eagle

Heron (5K)

Nighthawk (5K)

Nighthawk (7.5K)

Nighthawk (10K)

Nighthawk (15K)

Starling (100M)

Blue Jay (1B)

Canary 5 qubits, Albatross 16 qubits, Penguin 20 qubits, Prototype 53 qubits

27 qubits

127 qubits

5K gates | 133 qubits

5K gates | 120 qubits

7.5K gates | 120 qubits

10K gates | 120 qubits

15K gates | 120 qubits

100M gates, 200 logical qubits

1B gates, 2000 logical qubits

Innovation Roadmap

Software innovation

IBM Quantum Experience

Qiskit

Application modules

Qiskit Runtime

Quantum Serverless

AI-enhanced quantum

HPC-Quantum integration

Advantage candidates

Error correction decoder

Workflow accelerator

Fault-tolerant ISA

Open-source SDK for building and compiling circuits for quantum hardware

Modules for domain specific application and algorithm workflows

Performance and abstraction through primitives

Demonstrate concepts of managing quantum and cloud classical compute for an end to end workflow

Prototype demonstrations of AI-enhanced circuit transpilation

Realize an integration of classical HPC and a quantum computer at utility scale

Define problem types for advantage in 2026

Demonstrate a real-time error correction decoder

Demonstrate a workflow accelerator that streamlines execution for a known advantage workflow

Demonstrate a complete instruction set architecture including magic state distillation for FTQC

Hardware innovation

Early

Falcon

Hummingbird

Eagle

Osprey

Condor

Flamingo

Loon

Kookaburra

Cockatoo

Starling

Canary 5 qubits, Albatross 16 qubits

Demonstrate scaling with I/O routing with bump bonds

Demonstrate scaling with multiplexing readout

Demonstrate scaling with MLW and TSV

Enabling scaling with high density signal delivery

Single-system scaling and fridge capacity

Demonstrate scaling with I-couplers

Demonstrate c-couplers and next-generation packaging for FTQC

Demonstrate a complete module consisting of a logical processing unit and quantum memory

Demonstrate entanglement of modules using a universal adapter

Demonstrate multiple modules and magic state distillation

Penguin 20 qubits, Prototype 53 qubits

Egret

Heron

Crossbill

Tunable coupler demonstration

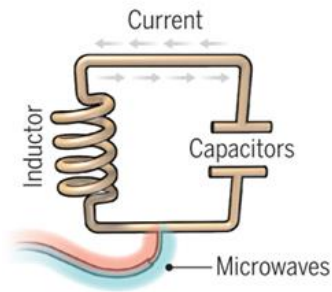
Architecture based on tunable couplers

Demonstrate m-couplers

Completed, On target

A bit of the action

In the race to build a quantum computer, companies are pursuing many types of quantum bits, or qubits, each with its own strengths and weaknesses.



Superconducting loops

A resistance-free current oscillates back and forth around a circuit loop. An injected microwave signal excites the current into superposition states.

Longevity (seconds)

0.00005

Logic success rate

99.4%

Number entangled

9

Company support

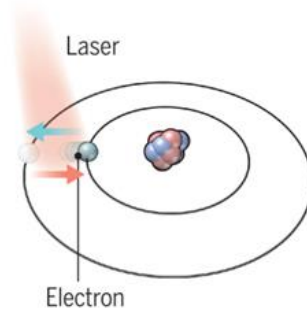
Google, IBM, Quantum Circuits

+ Pros

Fast working. Build on existing semiconductor industry.

- Cons

Collapse easily and must be kept cold.



Trapped ions

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.

>1000

99.9%

14

ionQ

Very stable. Highest achieved gate fidelities.

Slow operation. Many lasers are needed.



Silicon quantum dots

These "artificial atoms" are made by adding an electron to a small piece of pure silicon. Microwaves control the electron's quantum state.

0.03

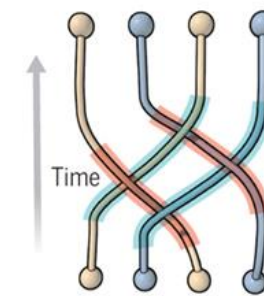
~99%

2

Intel

Stable. Build on existing semiconductor industry.

Only a few entangled. Must be kept cold.



Topological qubits

Quasiparticles can be seen in the behavior of electrons channeled through semiconductor structures. Their braided paths can encode quantum information.

N/A

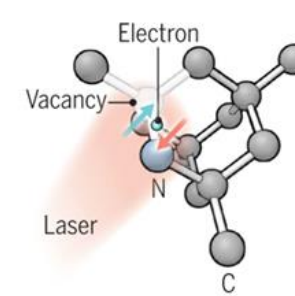
N/A

N/A

Microsoft, Bell Labs

Greatly reduce errors.

Existence not yet confirmed.



Diamond vacancies

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.

10

99.2%

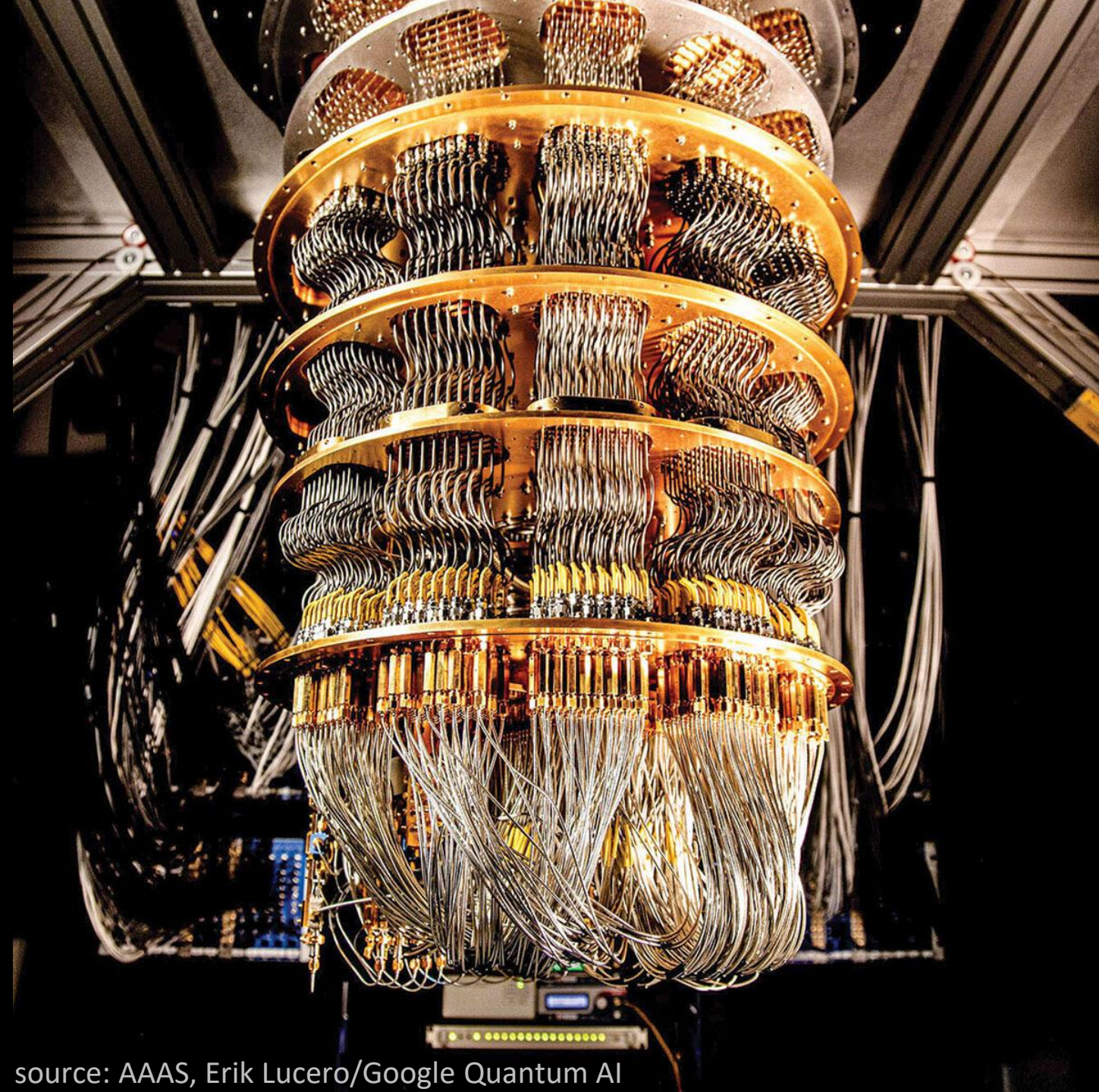
6

Quantum Diamond Technologies

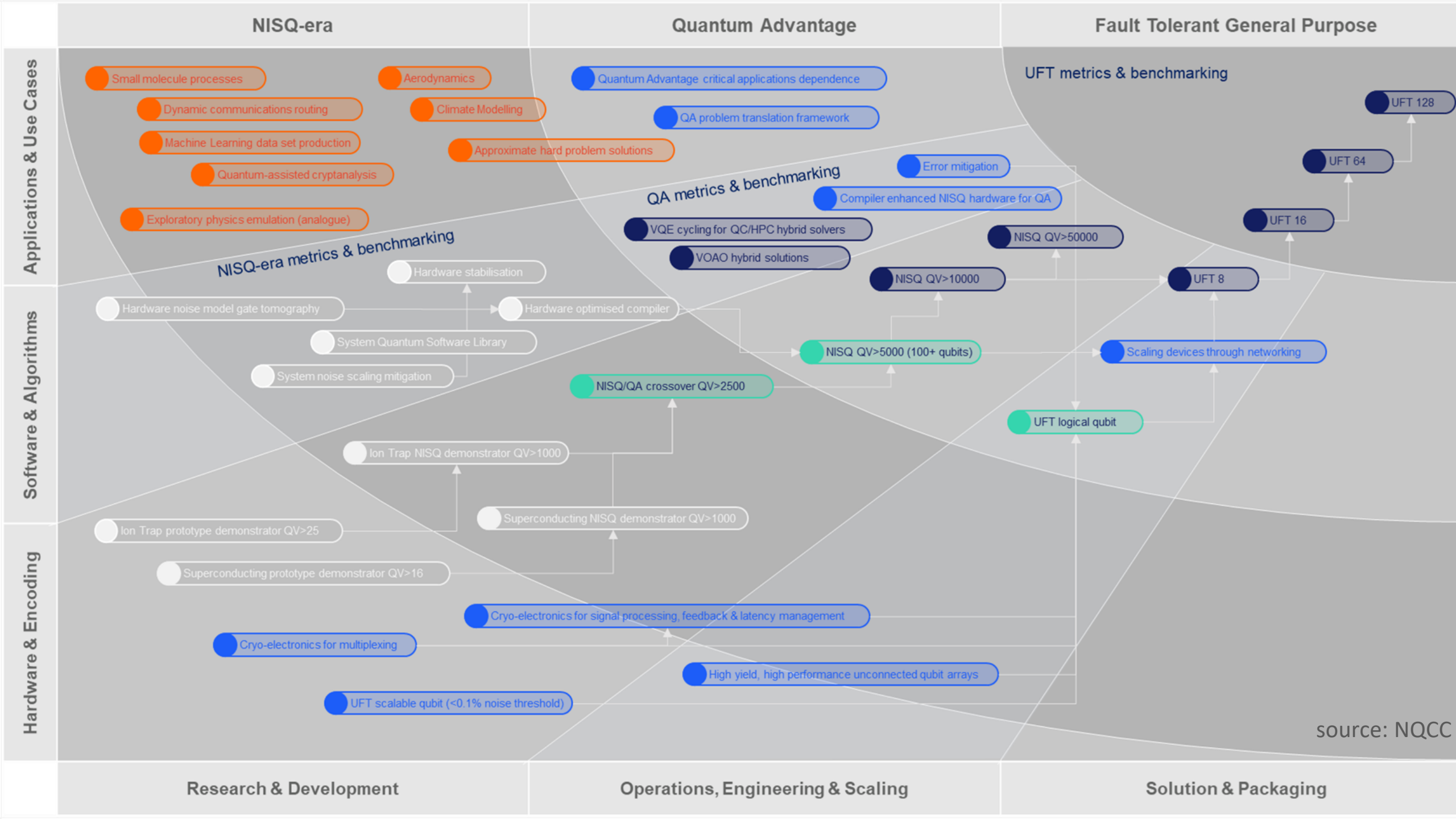
Can operate at room temperature.

Difficult to entangle.

Note: Longevity is the record coherence time for a single qubit superposition state, logic success rate is the highest reported gate fidelity for logic operations on two qubits, and number entangled is the maximum number of qubits entangled and capable of performing two-qubit operations.



Difficoltà tecniche



SPRINGER BRIEFS IN PHYSICS

Mikhail I. Dyakonov

Will We Ever Have a Quantum Computer?

 Springer

