Giuseppe A. Falci

(University of Catania, I)

QuCaT

Quantum Technologies at UniCT

WinterLab, 23-27 Febbraio 2026

download slide

Giuseppe A. Falci

Full Professor of theoretical Condensed Matter Physics @ UniCT
INFN – Sezione di Catania
Local coordinator NQSTI1 & ICSC10
Scientific Advisor @ Scientifica V.C.

download slide

Finanziato dall'Unione europea NextGenerationEU

Ministero dell'Università e della Ricerca

Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

NQSTI
National Quantum Science and Technology Institute

ICSC
Centro Nazionale di Ricerca in HPC, Big Data and Quantum Computing

Missione 4
Istruzione e Ricerca

Giuseppe A. Falci
University of Catania

Quantum Technologies: Research, Industry and Training

Uni ct
FISICA E ASTRONOMIA "ETTORE MAJORANA"

INFN
Istituto Nazionale di Fisica Nucleare

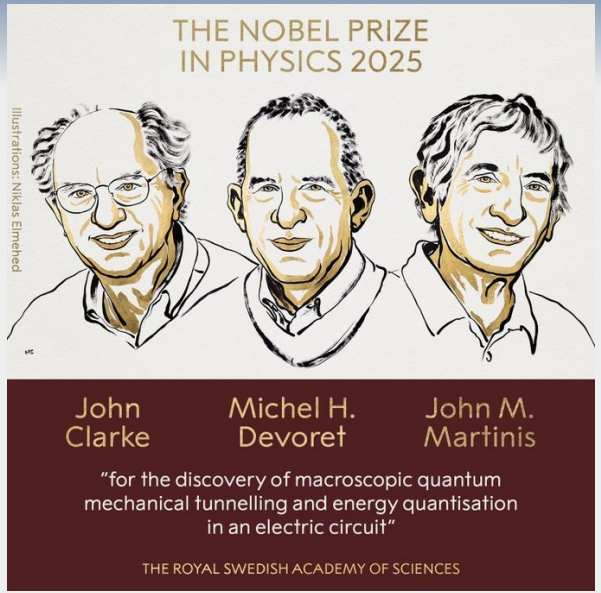
QuCaT
Quantum Technologies at UniCT

download slide

WinterLab, 23-27 Febbraio 2026

QTs on the spot

Render 3D di un computer quantistico.
Credit: Bartlomiej K. Wroblewski/ Shutterstock Image



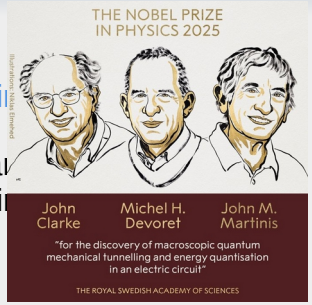
nature

TECHNOLOGY FEATURE | 21 January 2026

From quantum computing to mRNA therapeutics: seven technologies to watch in 2026

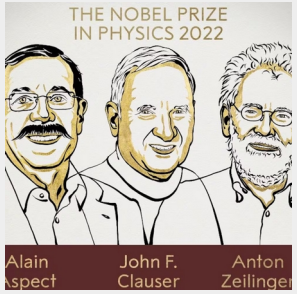
QTs on the spot

Nobel Prize in Physics 2025



John Clarke, Michel H. Devoret and John M. Martinis

"for the discovery of macroscopic quantum mechanical tunnelling and energy quantisation in an electric circuit"

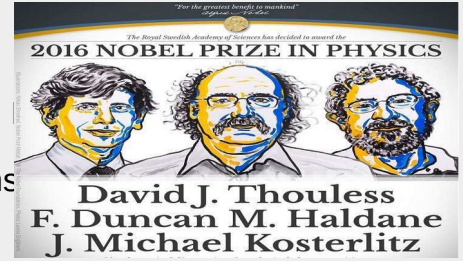


Nobel Prize in Physics 2022

Alain Aspect, John Clauser and Anton Zeilinger

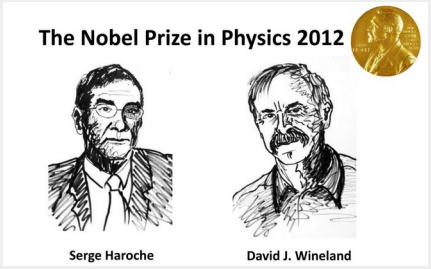
"for experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science"

Nobel Prize in Physics 2016



David J. Thouless, F. Duncan M. Haldane and J. Michael Kosterlitz

"for theoretical discoveries of topological phase transitions and topological phases of matter"



Nobel Prize in Physics 2012

Serge Haroche and David J. Wineland

"for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems"

Quantum Shift 2025

- Signals of a “Quantum Shift”: from Institutions investors and companies

Aumento dei fondi pubblici

Boom di fondi raccolti dalle aziende native

Strategie Governative in crescita

Annunci di roadmap promettenti

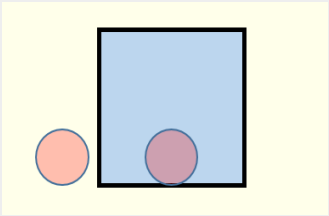
QT riconosciute come *dual-use*

Incremento interesse aziende end user

Quantum Shift

QM in a nutshell

- Not an explanation (useless today)
- **Q-mysteries** put at work
  - **Superposition** (things can exist in multiple states at once)
  - Quantum measurement and **"collapse"**: the state is actualizede only after the mesurement

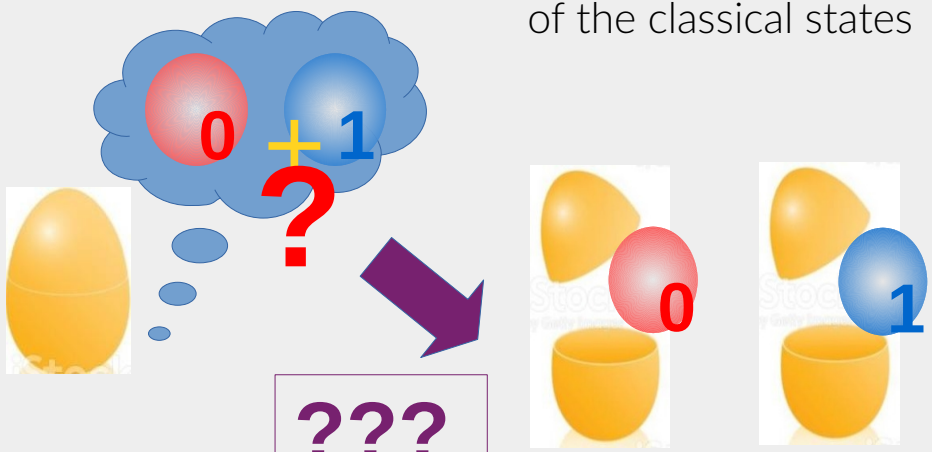


$$\frac{|0\rangle + |1\rangle}{\sqrt{2}}$$

- In a **quantum state** the object may behave as if **at the same time**
  - It is here **and** there it
  - It stands **and** it moves

???

- Until it is observd → then it **collapses** in one of the classical states



QM in a nutshell

- Not an explanation (useless today)
- QTs put at work; **Q-mysteries**
  - **Superposition** (things can exist in multiple states at once)
  - Quantum measurement and **“collapse”**: the state is actualizede only after the mesurement
- How things **“really”** work?
  - A ball or a cube, red or blue
    - Classically four states
    - QM → two crazy states

Q-mysteries 1

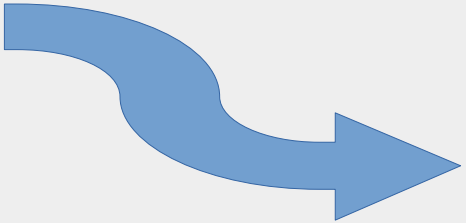
- Not an explanation (useless today)
- QTs put at work: **Q-mysteries**
  - **Superposition** (things can exist in multiple states at once)
  - Quantum measurement and **"collapse"**: the state is actualizede only after the mesurement
  - **Uncertainty**
  - **Quantum interference** (Young experiment)
    - **Q-dualism**: particles may behave as waves (wavefunction) and electromagnetic waves may behave as particles (photons)
    - Wave and particle properties coexist in nature... like Dr Jeckill and Mr Hyde

Q-mysteries 1

- Not an explanation (useless today)
- QTs put at work: **Q-mysteries**
  - **Superposition** (things can exist in multiple states at once)
  - Quantum measurement and **"collapse"**: the state is actualizede only after the mesurement
  - **Uncertainty**
  - **Quantum interference** (Young experiment)
    - **Q-dualism**: particles may behave as waves (wavefunction) and electromagnetic waves may behave as particles (photons)
    - Wave and particle properties coexist in nature... like Dr Jeckill and Mr Hyde
- Shall we believe all that?
  - The first QM revolution, as a matter of fact
  - Bell inequalities (fundamental questions and interpretations ?)
  - Niels Bohr about horseshoes

First quantum revolution

- Today, QM is in everyday life including our pocket



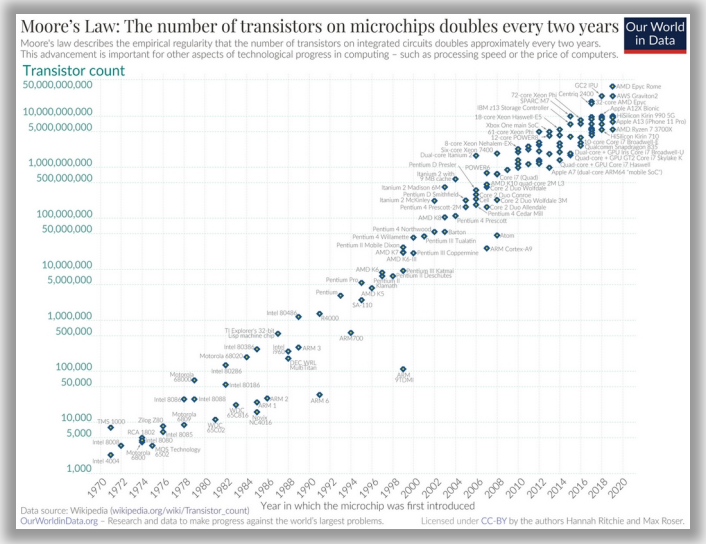
- QM explains certain mysteries:
  - ◊ Why materials may be conductors or insulators?
  - ◊ Why in semiconductors we find negative an positive “electrons”?
  - ◊ Why electrons do not scatter in a perfet crystal?

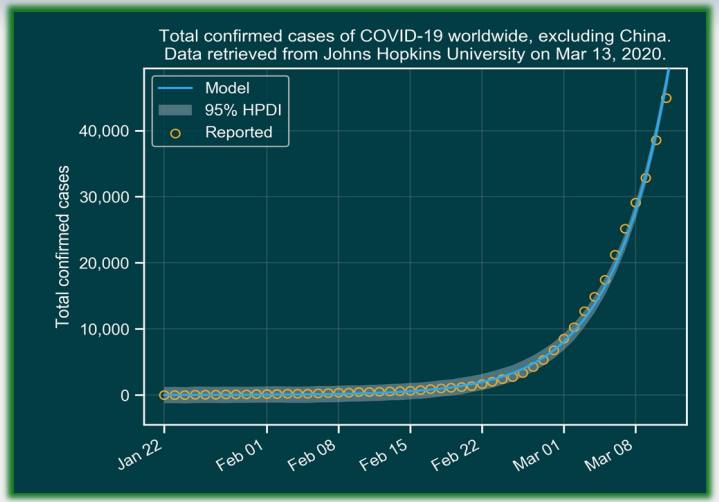
- “Engineer” approach: we don’t need to know/understand QM for using it

but **it had to be discovered first**!

The power of exponential growth

- Exponential growth may mark:
  - **Very** bad instances: exponential growth of an **infectious disease**
  - **Very** powerful achievements: exponential miniaturization/growth of computers (**Moore's law**)





- **Very** expensive promises: the "modest" reward the **Brahmin Sissa** asked to the Indian king Balhait for the invention of the chess game

1	2	
2	4	
3	8	
4	16	
...		
10	1024	in your hands
30	10^9	warehouse
50	10^{15}	skyscraper
60	10^{18}	Himalaya

Q-computer: making possible the impossible

- Possible and impossible ↔ exponential 2^N
  - Encoding a modest-size molecule on a classical computer

N=2	$\|00\rangle, \|01\rangle, \|10\rangle, \|11\rangle \in \mathcal{B}^2$	$\|\psi\rangle = c_{00}\|00\rangle + c_{01}\|01\rangle + c_{10}\|10\rangle + c_{00}\|11\rangle$	dim=2^2

  - Using single-memory cells with size $F = 20$ nanometers, encoding a modest-size N= **350 spin** molecule $\rightarrow L = 10^{27}$ m **larger than the Universe**

due to the **proliferation of entangled states**

- **Classically impossible** because of the exponential growth with the size of the space of its "states" (Feynmann)

Q-computer: making possible the impossible

- Possible and impossible ↔ exponential 2^N
  - Encoding a modest-size molecule on a classical computer

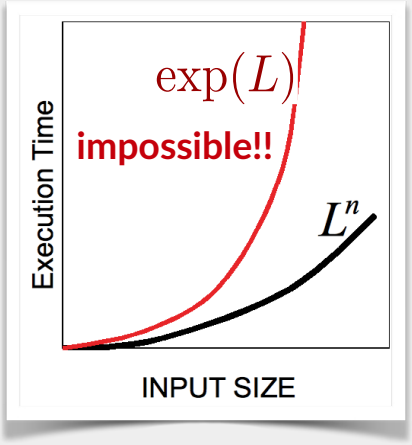
N=2	$\|00\rangle, \|01\rangle, \|10\rangle, \|11\rangle \in \mathcal{B}^2$	$\|\psi\rangle = c_{00}\|00\rangle + c_{01}\|01\rangle + c_{10}\|10\rangle + c_{00}\|11\rangle$	dim=2^2

  - Using single-memory cells with size $F = 20$ nanometers, encoding a modest-size N= **350 spin** molecule $\rightarrow L = 10^{27}$ m **larger than the Universe**

due to the **proliferation of entangled states**

- **Classically impossible** because of the exponential growth with the size of the space of its "states" (Feynmann)

- Computational complexity
  - Scaling of the execution steps (time) with the "length" of the input



Q-computer: making possible the impossible

- Classical computation: Turing machine computes functions – one value at time

$$
\begin{aligned}
&0000000 \;\rightarrow\; f(0000000)\\
&\ldots\\
&0100110 \;\rightarrow\; f(0100110)\\
&\ldots
\end{aligned}
\qquad \equiv |\mathbf{x}\rangle \rightarrow |f(\mathbf{x})\rangle \qquad \mathbf{x} \in \mathcal{B}^N, \quad \mathcal{B} = \{0,1\}
$$

Q-computer: making possible the impossible

- Classical computation: Turing machine computes functions – one value at time

$$\begin{aligned} 0000000 &\rightarrow f(0000000) \\ &\dots \\ 0100110 &\rightarrow f(0100110) \\ &\dots \end{aligned} \qquad \equiv |\mathbf{x}\rangle \rightarrow |f(\mathbf{x})\rangle \qquad \mathbf{x} \in \mathcal{B}^N, \quad \mathcal{B} = \{0,1\}$$

- Quantum computation:
  - Start from **a superposition of all possible inputs** $|\psi_0\rangle = \frac{1}{\sqrt{N!}}\left[|000000\rangle + \dots + |010011\rangle + \dots\right] = \frac{1}{\sqrt{N!}} \sum_{\mathbf{x}\in\mathcal{B}^N} |\mathbf{x}\rangle$
  - Linear evolution in Quantum Mechanics → **processing all inputs at once**

$$|\psi_0\rangle = \sum_{\mathbf{x}\in\mathcal{B}^N} |\mathbf{x}\rangle \otimes |0\rangle \rightarrow U_f|\psi_0\rangle = \sum_{\mathbf{x}\in\mathcal{B}^N} |\dots\rangle \otimes |f(\mathbf{x})\rangle$$

- **→ Q-parallelism:** N cpu-s process 2^N **classical inputs in parallel**
  - May it turn **"impossible" (exp) → "solvable" (poly)** problems?

Q-computer: making possible the impossible

- Classical computation: Turing machine computes functions – one value at time

$$\begin{array}{l} 0000000 \rightarrow f(0000000) \\ \dots \\ 0100110 \rightarrow f(0100110) \\ \dots \end{array} \qquad \equiv |\mathbf{x}\rangle \rightarrow |f(\mathbf{x})\rangle \qquad \mathbf{x} \in \mathcal{B}^N, \quad \mathcal{B} = \{0,1\}$$

- Quantum computation:
  - Start from **a superposition of all possible inputs** $|\psi_0\rangle = \frac{1}{\sqrt{N!}}\left[|000000\rangle + \dots + |010011\rangle + \dots\right] = \frac{1}{\sqrt{N!}} \sum_{\mathbf{x}\in\mathcal{B}^N} |\mathbf{x}\rangle$
  - Linear evolution in Quantum Mechanics → **processing all inputs at once**

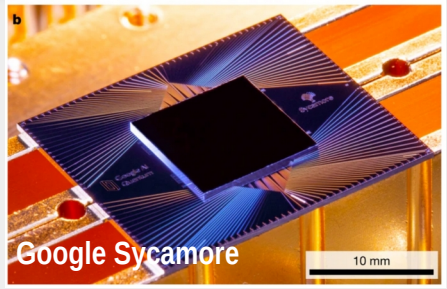
$$|\psi_0\rangle = \sum_{\mathbf{x}\in\mathcal{B}^N} |\mathbf{x}\rangle \otimes |0\rangle \rightarrow U_f|\psi_0\rangle = \sum_{\mathbf{x}\in\mathcal{B}^N} |\dots\rangle \otimes |f(\mathbf{x})\rangle$$

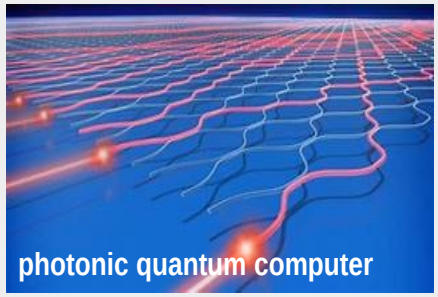
- **→ Q-parallelism:** N cpu-s process 2^N **classical inputs in parallel**
  - May it turn **"impossible" (exp) → "solvable" (poly)** problems?

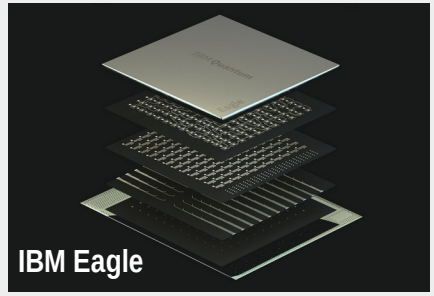
- Watch out: **measurement destroys** much of the output information (**Holevo bound**) → but specially designed algorithm yield **global information** on the function doing the job!!

Computation: hardware & software

- Goal: Build computers that **solve problems classical computers can't**.
  - **Quantum advantage**: is the point at which a quantum computer performs a specific task faster or more efficiently than any possible classical computer.
    - **Google Sycamore** (2019): 53-qubits superconducting system demonstrated random circuit sampling in 200 s instead of 10000 years
    - **Jiuzhang** series (2020-23) at Uni Science and Technology China: photonic quantum computer, demostrated boson sampling beyond classical simulations
  - So far demonstrated **only for specialized artificial tasks**
  - **Quantum utility**: is the point at which a quantum computer solves practical problems over-performing available classical computers.
    - **IBM Eagle** (2023): 127-qubit chip simulating quantum systems at a scale not accessible to classical exact methods.

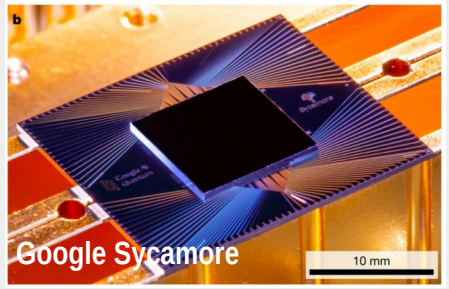


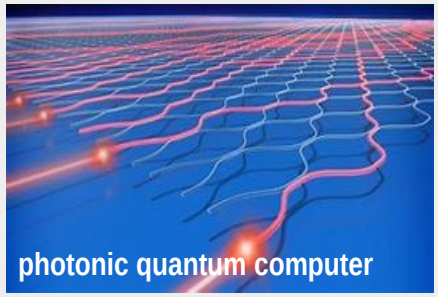


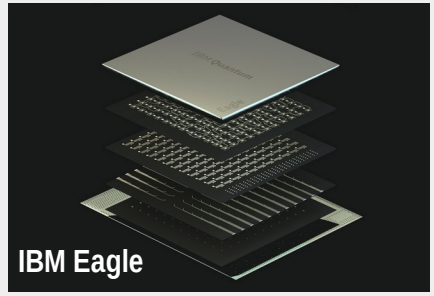


Computation: hardware & software

- Goal: Build computers that **solve problems classical computers can't**.
  - **Quantum advantage**: is the point at which a quantum computer performs a specific task faster or more efficiently than any possible classical computer.
    - **Google Sycamore** (2019): 53-qubits superconducting system demonstrated random circuit sampling in 200 s instead of 10000 years
    - **Jiuzhang** series (2020-23) at Uni Science and Technology China: photonic quantum computer, demostrated boson sampling beyond classical simulations
  - So far demonstrated **only for specialized artificial tasks**
  - **Quantum utility**: is the point at which a quantum computer solves practical problems over-performing available classical computers.
    - **IBM Eagle** (2023): 127-qubit chip simulating quantum systems at a scale not accessible to classical exact methods.
- Main platforms: superconductors & trapped ions / cold atoms
  - Largest-size computer: IBM Condor (1121 qubits), Atom Computing's neutral-atom system (1180), D-wave Advantage annealer (5000), Caltech neutral atom array (6100)







Commercial: Q-hardware & architectures

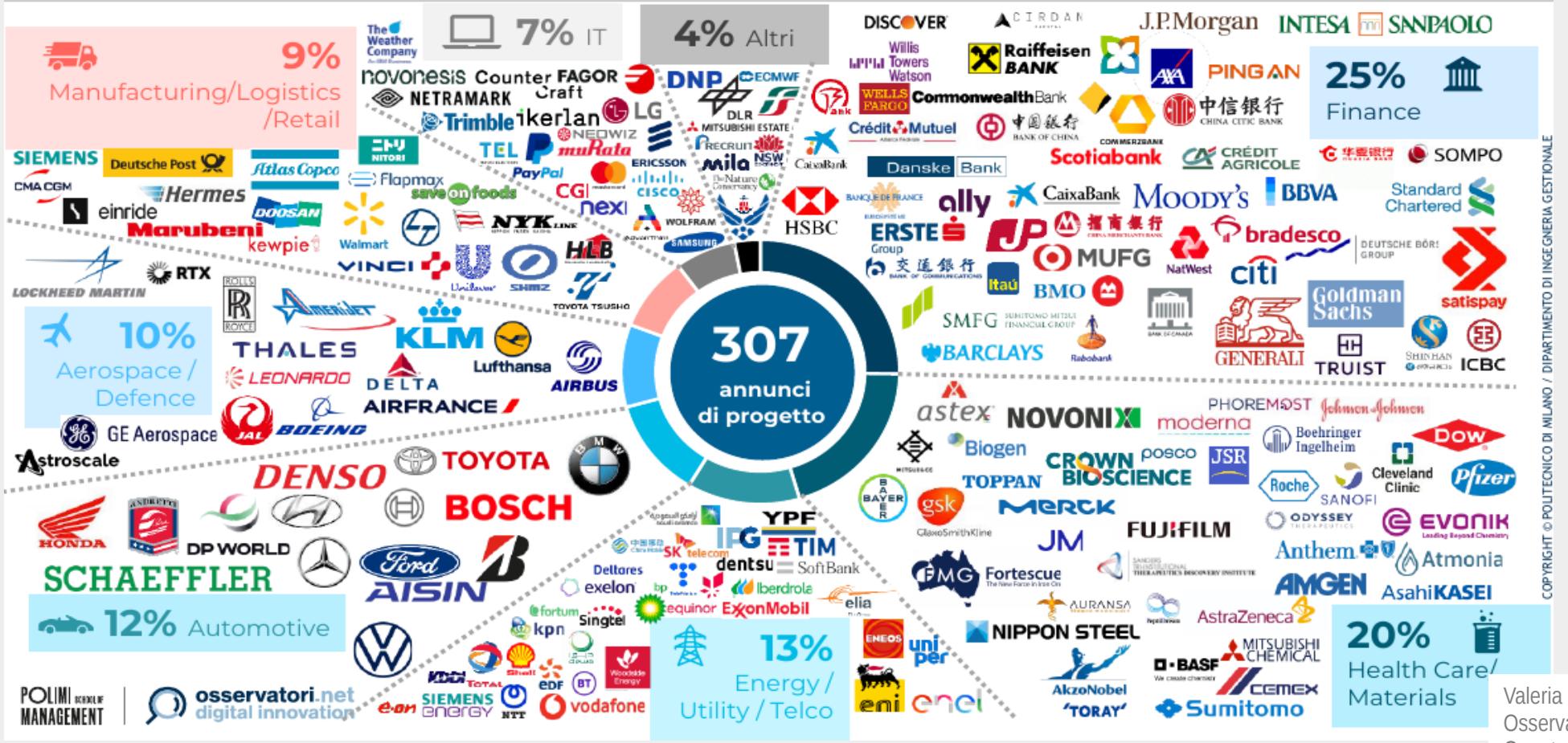
- Build Quantum computers and/or offer access to quantum machines
  - Big Tech & Established Players
  - Dedicated Quantum Hardware Companies

Alessandro Piva: osservatorio Quantum PoliMI

- Specialized Quantum Startups
  - Q-components, Q-computers for research labs, supply chains, ...
    - PsiQuantum, Atom Computing Inc., Alice & Bob, Pasqal, …
    - IQM leading European company in quantum computing superconducting hardware
    - seeqc Quantum measurement devices compatible with superconducting SFQ cryogenic electronics
    - QBLOX Control electronics and software for superconducting qubits

Use cases of Q-software applications

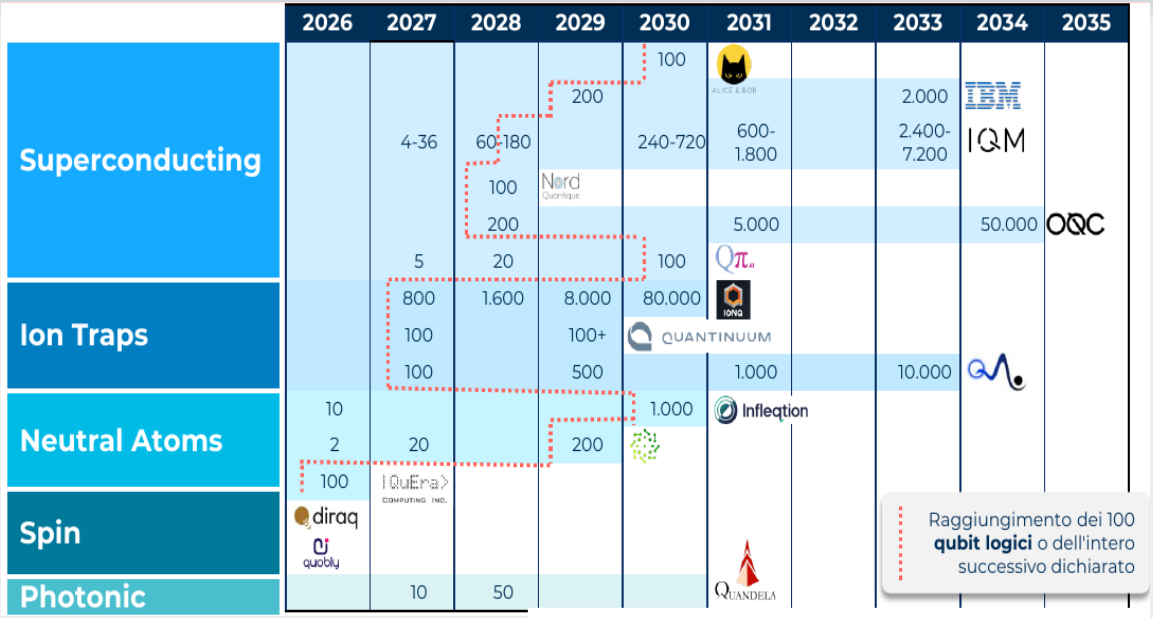
- Software less demanding for investments → rapidly growing



Valeria Portale
Osservatorio
Quantum PoliMI

Software vs hardware & other

- Major problem for quantum hardware: decoherence and errors
  - Fault-tolerant logical qubit made of many physical qubits to implement QEC
- What's the use of software with no hardware?
  - Hybrid quantum-classicalcomputation with NISQ
    - algorithmiq



Da Alessandro Piva: osservatorio Quantum PoliMI

- Q-computation is both
  - The existece of Q-algorithms justified the search for q-hardware
  - Progress in QEC (Nature's main achievement 2026) justifies industrial research on software
- BUT: hardware is not only computing
  - Cristoforo Colombo, looking for India (computation), found America in between (sensing, communication)

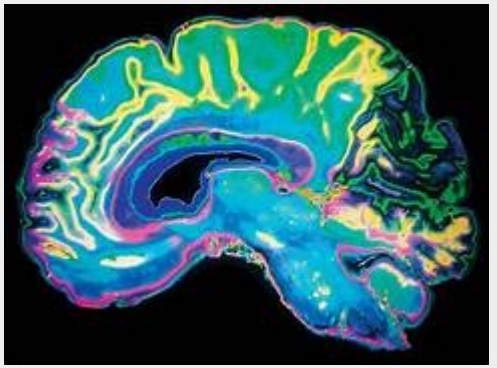
Sensing

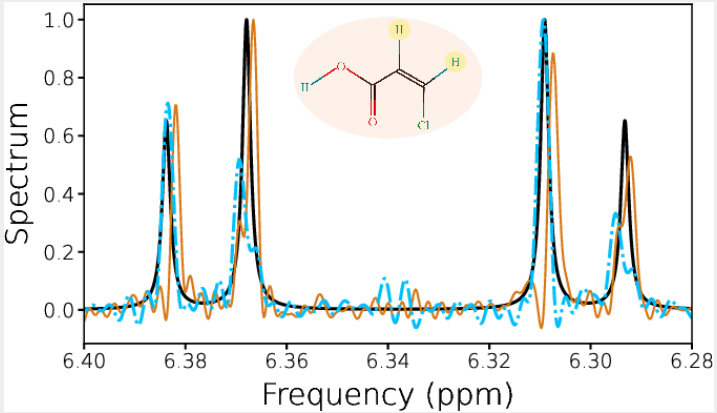
- Sensitivity of superpositions or entangled states to external agents → quantum sensors
  - Goal: mesurements with extreme precision
  - Small architectures of “dirty” qubits (NISQ) → quantum technology already near to maturity, (much before q-computers)

Magnetic & electric fields	Superconductors impurities in solids Alkali atoms	Quantum magnetometers	Positioning Magneto-encelography cardiography Geophysical exploration Defense
Time	Cold atoms	Atomic clocks	GPS Internet data syncronization
Temperature	Impurities in solids Quantum dot Ultracold atoms NS junctions	Q- Thermometers	Measure at the nanoscale/ microchips Temerature inside licving cells
Gravity	Cold atoms	Q-gravimenter by interferometry	Detect underground structure & Civil engineer infrastrucures Environmental monitoring Defense Positioning
Motion-related acceleration	Cold atoms	Q-accelerometers by interferometry	Post GPS navigation Geophysical monitoring Structural monitoring

Case studies (mostly magnetometry)

- Mesoscopic physics
  - Magnetic resonance
  - mesure charge with single-electron precision & single-electron spin $\sim 10^{-9}\,\mathrm{T}$
    - cf. Earth magnetic field $\sim 10^{-5}\,\mathrm{T}@\,1\mu\mathrm{m}$





Case studies (mostly magnetometry)

- Mesoscopic physics
  - Magnetic resonance
  - mesure charge with single-electron precision & single-electron spin $\sim 10^{-9}\,\mathrm{T}$
    - cf. Earth magnetic field $\sim 10^{-5}\,\mathrm{T}@\,1\mu\mathrm{m}$
- Quantum magnetometry
  - Earth's magnetic field fluctuations $\sim 10^{-9} - 10^{-7}\,\mathrm{T}$
    - Post-GPS navigation, geological investigations, submarine detection
  - Brain magnetic fields $\sim 10^{-15}\,\mathrm{T}$ → Magnetoencephalography
  - Heart magnetic signal $\sim 10^{-17} - 10^{-16}\,\mathrm{T}$ → Magnetocardiography
- Platforms
  - Classical SQUIDs or superconducting qubits
  - Atomic magnetometers detect (alkali atoms at room temperature)
  - NV-diamond or SiC sensors

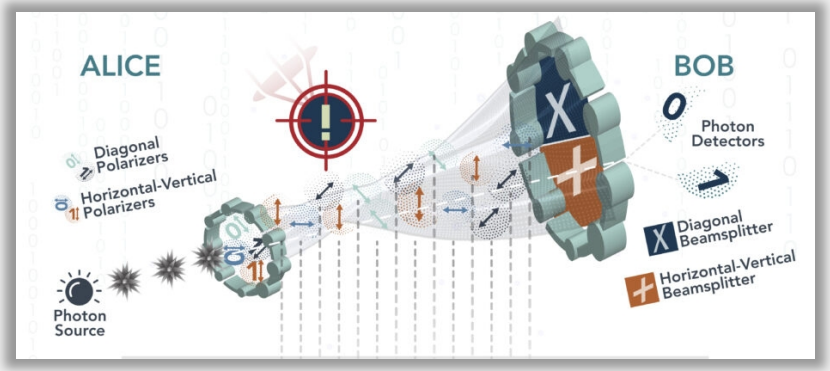
Sensing companies

- Big quantum-tech players (IBM, Google, Honeywell/Quantinuum, IonQ) extending research on quantum hardware to include sensing, metrology and measurement devices.

  - Main companies and startups focusing on quantum sensing, imaging and metrology

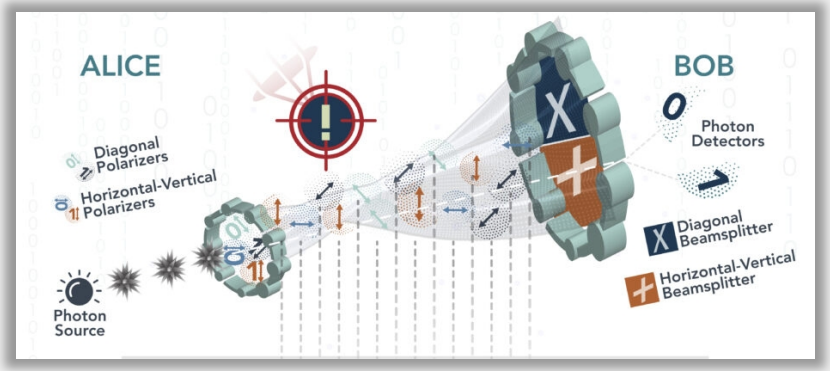
Secure communication

- Unhackable communication using Quantum Key Distribution (QKD).
  - protected by nature: who cracks likely can steel a lot of money and surely will win the Nobel prize!
  - BB82: secure distribution of a private key
  - based on Q-Mysteries 2
    - Uncertainty
    - Quantum collapse
    - No cloning theorem

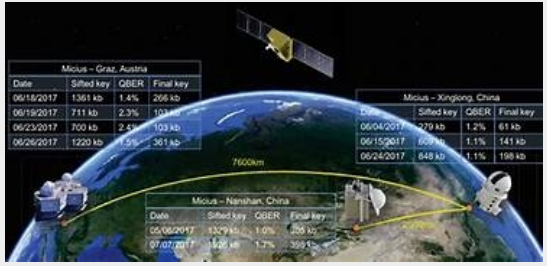


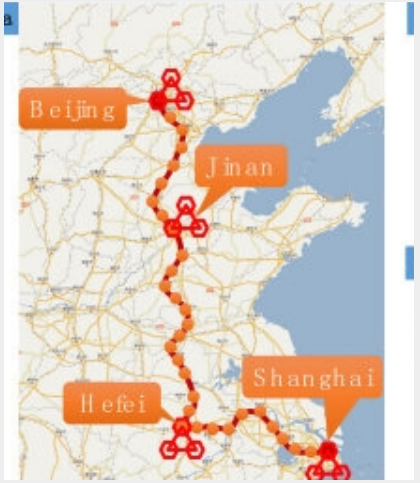
Secure communication

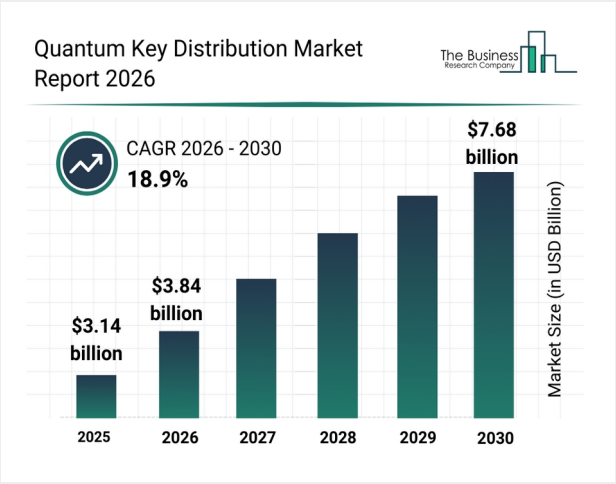
- Unhackable communication using Quantum Key Distribution (QKD).
  - protected by nature: who cracks likely can steel a lot of money and surely will win the Nobel prize!
  - BB82: secure distribution of a private key
  - based on Q-Mysteries 2
    - Uncertainty
    - Quantum collapse
    - No cloning theorem



- Commercially viable in high-security environments
  - China Beijing-Shangai Quantum Backbone + Micius
    - government communications, critical infrastructure security, banking data links,

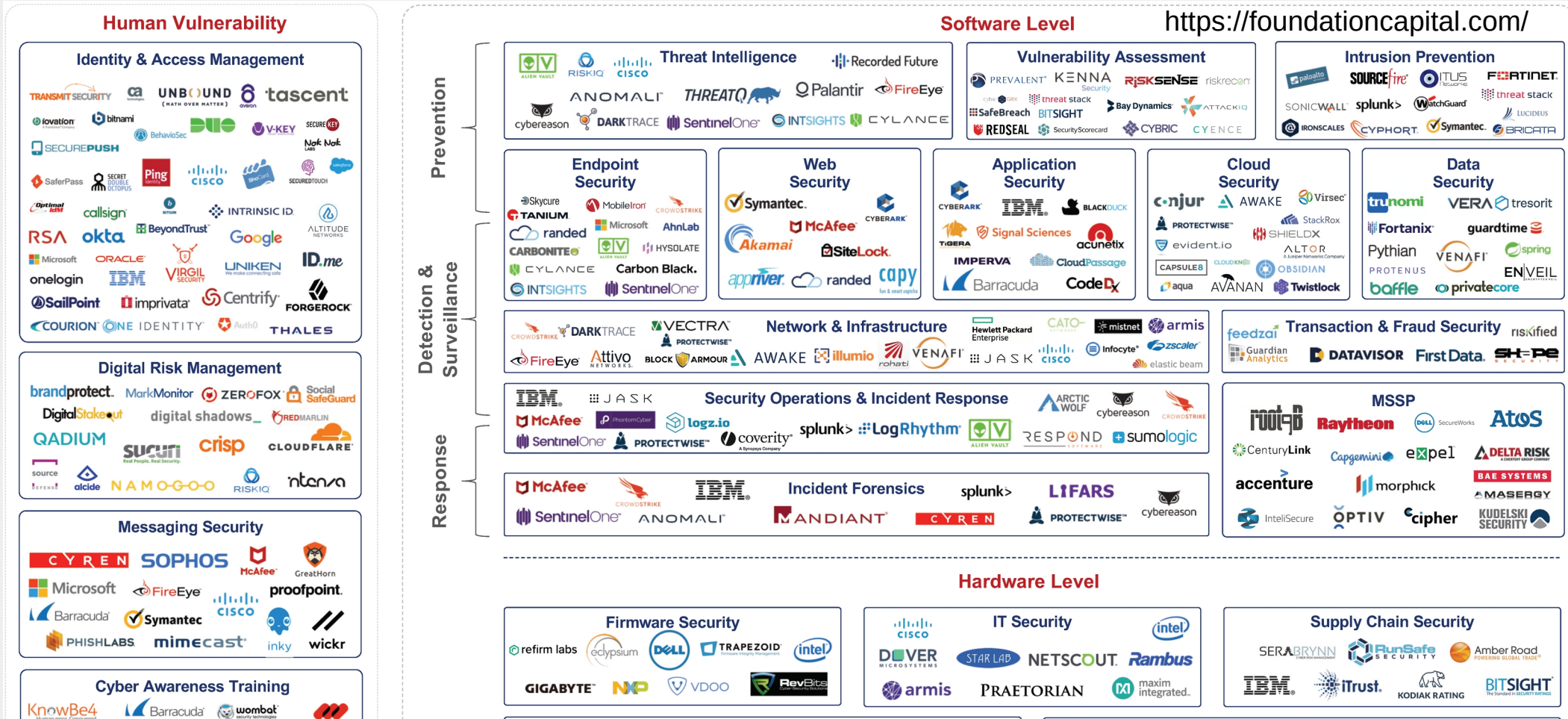






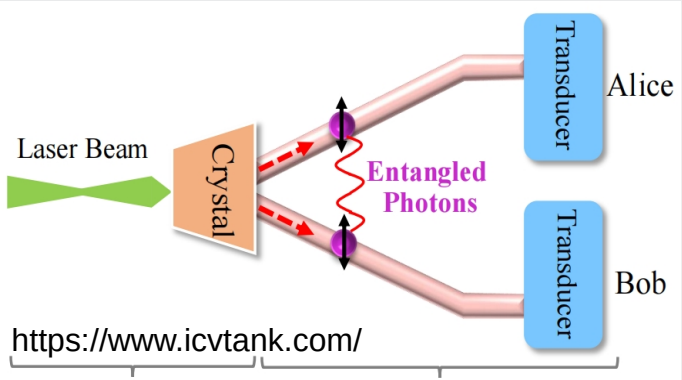
Communication

- Focus: Unhackable communication using Quantum Key Distribution (QKD).



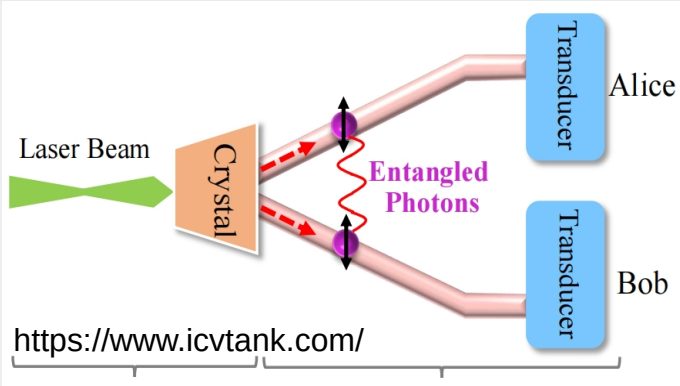
Entanglement → Teleportation

- The **big q-mistery: entanglement** between distant objects
- "Spooky action at distance" for entangled subsystems
  - a mesurement on Alice's subsystem suddenly influences Bob's subsystem
  - NO superluminal signalling (because of uncertainty + no-cloning)

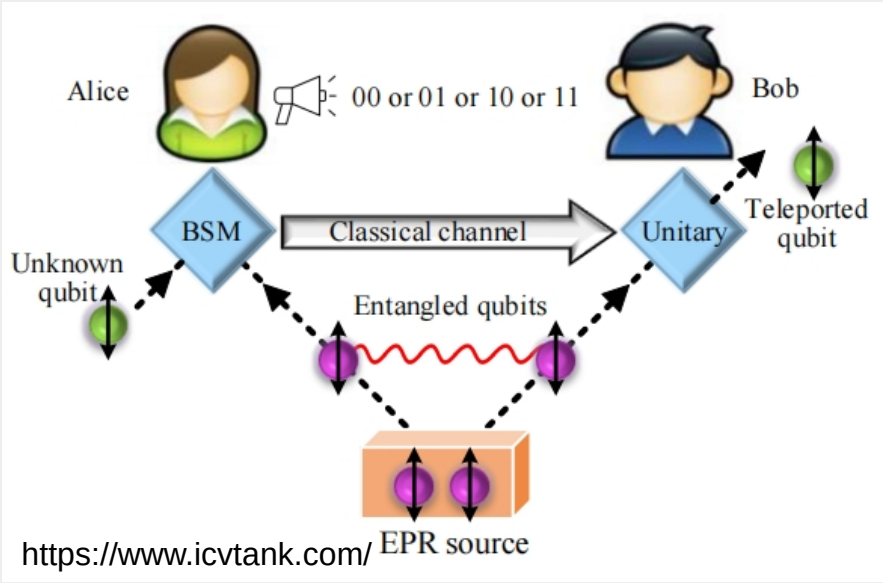


Entanglement → Teleportation

- The **big q-mistery: entanglement** between distant objects
- "Spooky action at distance" for entangled subsystems
  - a mesurement on Alice's subsystem suddenly influences Bob's subsystem
  - NO superluminal signalling (because of uncertainty + no-cloning)

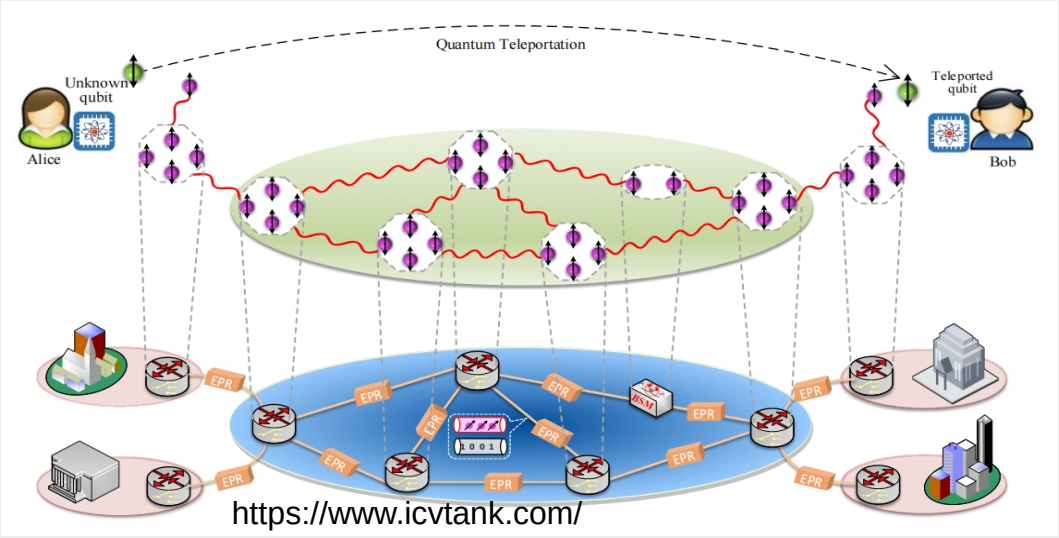


- Many new – classically impossible - **quantum tasks**
  - Archetypal: **quantum teleportation**



Wide-area entanglement-assisted Q-network

- Recent real-world quantum networking deployments/experiments
  - China's 2000 km QKD backbone
  - China's satellite quantum link (Micius)
  - Metro Q-network Manahattan-Brooklyn
  - Teleportation over commercial fiber (D)
  - Commercial fiber teleportation in Illinois/Indiana
  - QKD outside controlled environment
  - Quantum messages over a 254 km fiber (D)
  - UK long-distance q-secure transmission
  - Multi-node q-network (Spain)
  - Italian q-backbone + Q-SUD NA-SA-BA backbone



https://www.icvtank.com/

- Industrial/public players

TOSHIBA

中国科学院 CHINESE ACADEMY OF SCIENCES

U.S. DEPARTMENT OF ENERGY

Google Quantum AI

QUANTUMXCHANGE™ Delivering the Future of Encryption

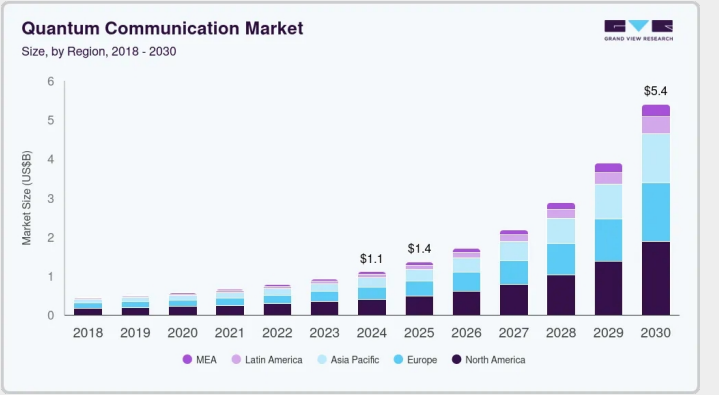
IBM

LEONARDO

IDQ an IonQ company

QUANTINUUM

THALES



What's going on

- The future starts now: oops it has already started!

Quantum Europe Strategy

July 2025

- Forte attenzione alla **scalabilità industriale** delle tecnologie quantistiche - "**from lab to fab**"
- **Attenzione limitata** verso il **software** e gli algoritmi quantistici
- Forte enfasi su **sicurezza e difesa;** collaborazione con *«like-minded partners»*

SOON **Prossimi passi concreti in arrivo**

5 PILASTRI TARGETTIZZATI

degli 8 presenti nel framework Osservatorio

- Research
- Workforce Development
- Ecosystem Creation and Industrialization
- Infrastructure and Supply Chain
- Creating Awareness
- National Security and Cybersecurity
- Regulation and Standardization
- Sustainability

What's going on

- The future starts now: oops it has already started!

Strategia Italiana per le Tecnologie Quantistiche

Settembre 2025

Citata la necessità di un finanziamento di **200 mln €/anno per 5 anni** per sostenere il settore (*non ancora stanziato*)

Raccomandata l'istituzione di:

- un ***Comitato Permanente per le Tecnologie Quantistiche*** (breve termine)
- un ***Polo Quantistico Nazionale*** (medio termine)
- una ***Fondazione Quantistica*** (lungo termine)

Prossimo passo necessario: l'allocazione dei fondi

SOON

7 PILASTRI TARGETTIZZATI

degli 8 presenti nel framework Osservatorio

- Research
- Workforce Development
- Ecosystem Creation and Industrialization
- Infrastructure and Supply Chain
- Creating Awareness
- National Security and Cybersecurity
- Regulation and Standardization
- Sustainability

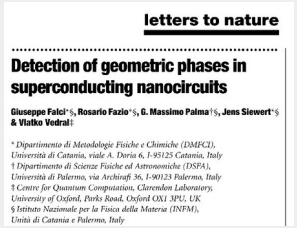
*Anche se il tema della Sicurezza Nazionale non viene citato direttamente come linea d'azione, è trasversalmente presente in tutta la strategia

What’s going on

- NQSTI (2025), Quantum for Italy, G. R. Greco, Edizioni Saletta dell'Uva, Caserta (IT) , pp. 1-188. ISBN: 978-88-6133-170-9
  - Download at www.nqsti.it

Quantum Technologies @ UniCT

- **< 1990** Mesoscopic Josephson effect (2 researchers) ↔ **Nobel Prize 2025**
- **1995 – Quantum Mesoscopic Theory group**
  - 5 researchers & post docs, 1 department, 1 Scientific sector
- Crossing the desert


letters to nature

Detection of geometric phases in superconducting nanocircuits

Giuseppe Falci*§, Rosario Fazio*§, G. Massimo Palma†§, Jens Siewert*§ & Vlatko Vedral‡

* Dipartimento di Metodologie Fisiche e Chimiche (DMFCI), Università di Catania, viale A. Doria 6, I-95125 Catania, Italy
† Dipartimento di Scienze Fisiche ed Astronomiche (DSFA), Università di Palermo, via Archirafi 36, I-90123 Palermo, Italy
‡ Centre for Quantum Computation, Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, UK
§ Istituto Nazionale per la Fisica della Materia (INFM), Unità di Catania e Palermo, Italy


letters to nature

Scaling of entanglement close to a quantum phase transition

A. Osterloh*†, Luigi Amico*†, G. Falci*† & Rosario Fazio†‡

* Dipartimento di Metodologie Fisiche e Chimiche (DMFCI), viale A. Doria 6, 95125 Catania, Italy
† NEST-INFM, Piazza dei Cavalieri 7, I-56126 Pisa, Italy
‡ Scuola Normale Superiore, Piazza dei Cavalieri 7, I-56126 Pisa, Italy


REVIEWS OF MODERN PHYSICS, VOLUME 86, APRIL–JUNE 2014

1/*f* noise: Implications for solid-state quantum information

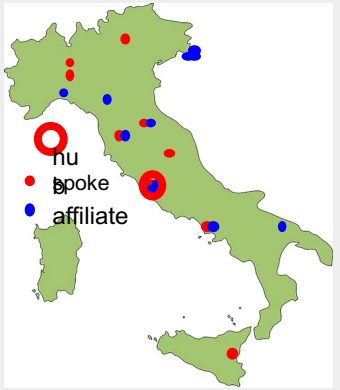
E. Paladino*

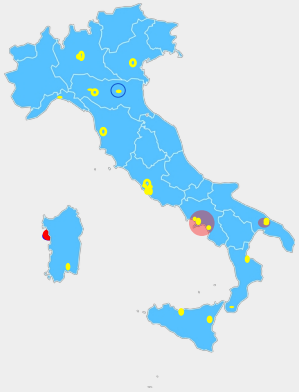
- **2022 PNRR**
  - National Quantun Science and Technology Institute **NQSTI**
  - Centro Nazionale **ICSC**
  - The QuCaT ecosystem @ UniCT
    - ~ 35 reserachers in Theoretical and Experimental Physics, Electric Engineering, Mathematics & Computer Science,
    - 3 Departments, 8 scientific sectors
    - Newly established Lab for Quantum Materials
    - **Education, Outreach** & joint academia-industry projects

NQSTI National Quantum Science and Technology Institute

ICSC Centro Nazionale di Ricerca in HPC, Big Data and Quantum Computing

QuCaT Quantum Technologies at UniCT





Q-SUD

- The **Q-SUD** & **QANTAS** initiative 2026-28

Thank you for your attention

QuCaT

Quantum Technologies at UniCT

download slide