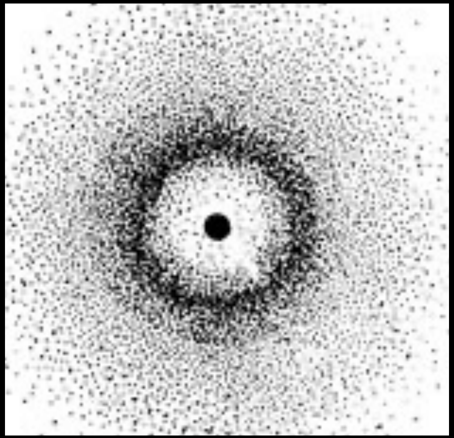
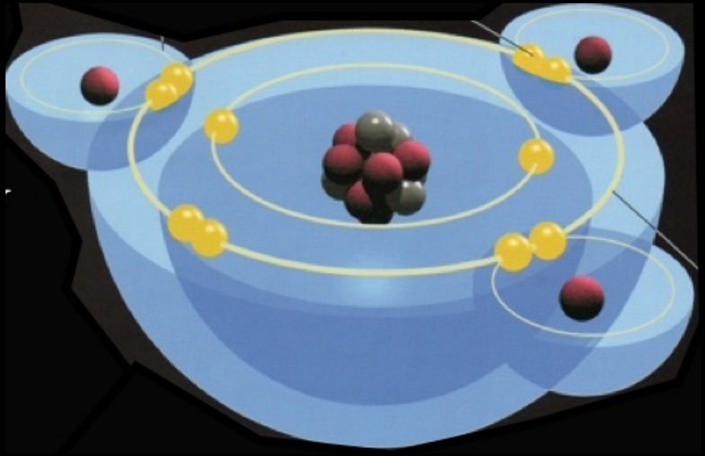
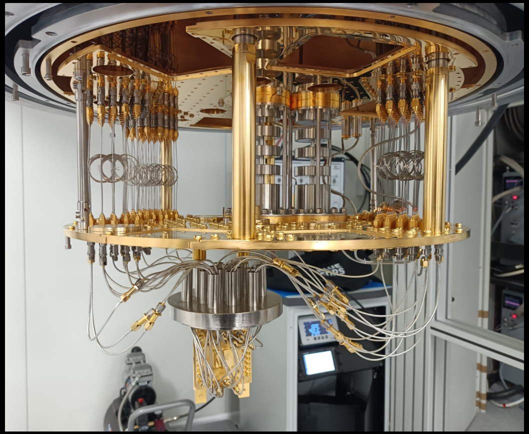
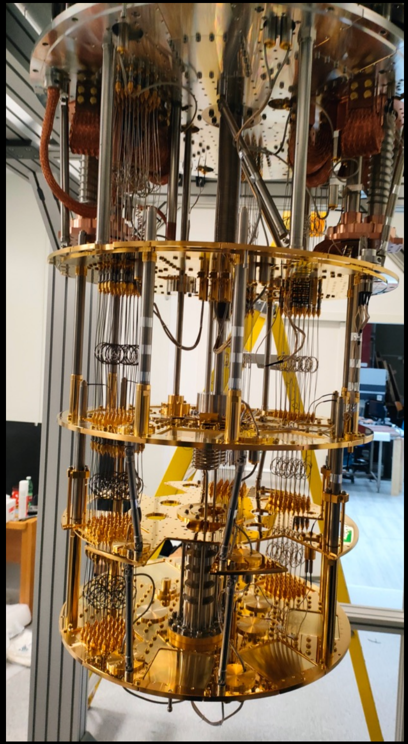
Incerto, quantistico e infine reale



$$-\frac{\hbar^2}{2m}\nabla^2\psi(\vec{r},t)-\frac{e^2}{r}\psi(\vec{r},t)=E\psi(\vec{r},t)$$







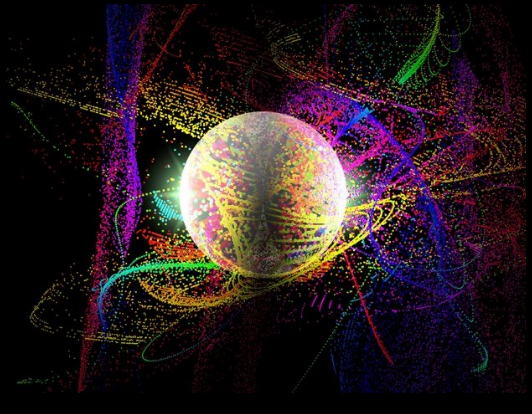
Le risorse dell'incertezza

Scuola Superiore Meridionale

Napoli 2-6 Settembre 2024

SETTIMANA DI ORIENTAMENTO DELLA SCUOLA SUPERIORE MERIDIONALE

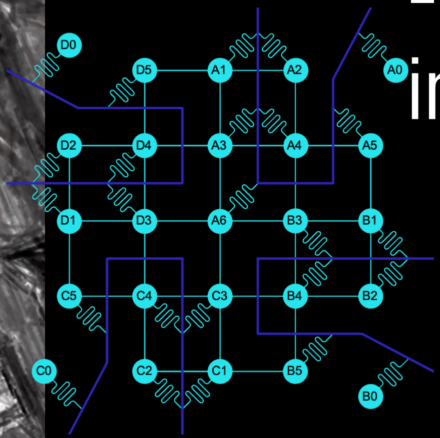
Francesco Tafuri
Università di Napoli Federico II

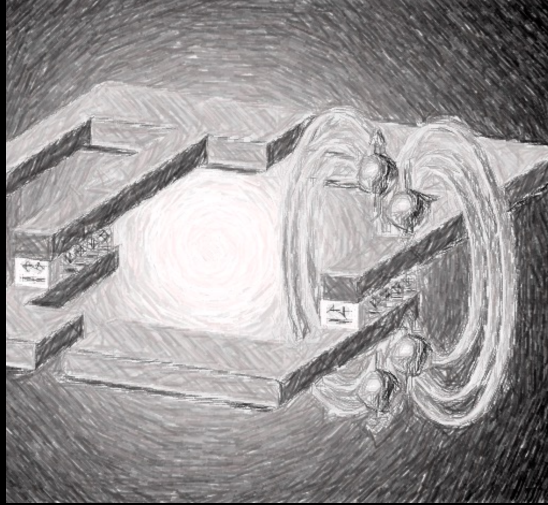
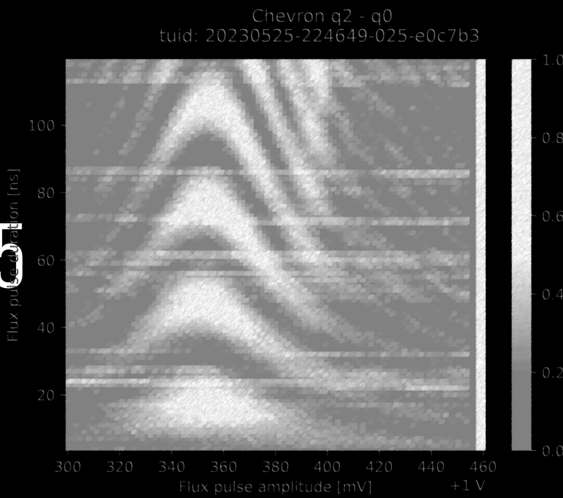


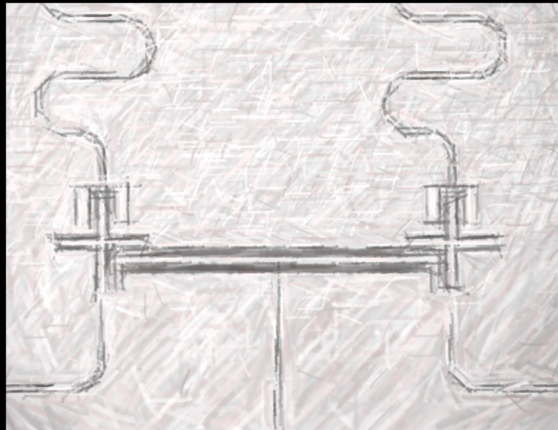
Sommario

- Pillole di fisica classica
- Concetti di meccanica quantistica
- Gli oggetti macroscopici e e la meccanica quantistica, la superconduttività e Harry Potter
- Computer quantistico superconduttivo 25 -> 40 qubits, «intreccio» fra fisica ed informazione
  - Come funziona un computer quantistico: incerto, complesso, quantistico, reale
  - Epilogo,







"Potenza e stranezza del mondo quantistico" di Serge Haroche, Premio Nobel per la Fisica 2012

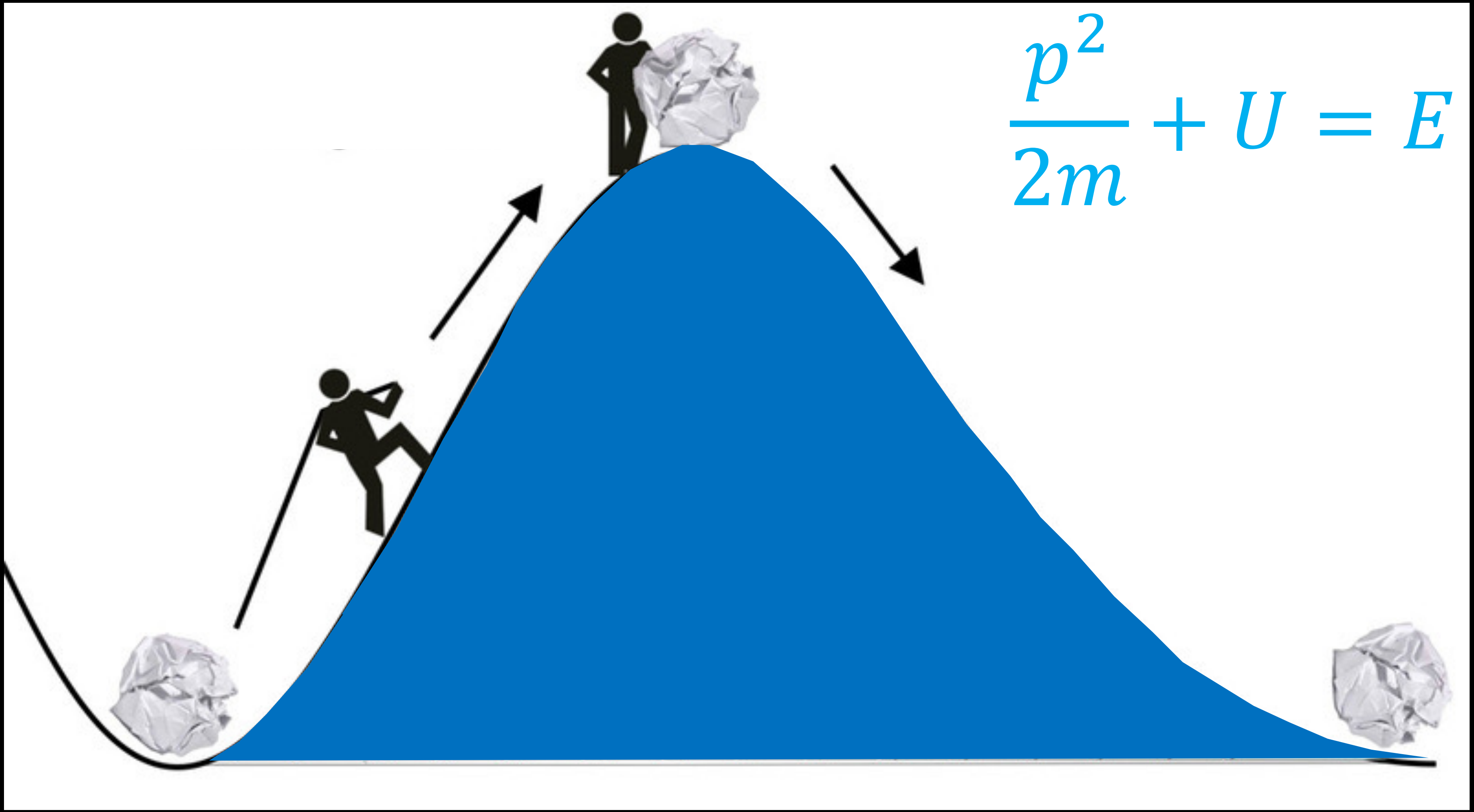
La teoria quantistica è probabilmente il più potente risultato della mente umana. Getta luce sulle leggi della natura, da quelle che spiegano il mondo microscopico a quelle che governano l'evoluzione dell'Universo nel suo complesso.

La fisica quantistica sembra strana perché le sue leggi sono contro la nostra visione intuitiva della realtà derivante dalla nostra visione macroscopica del mondo classico.

I progressi della tecnologia hanno resi reali gli esperimenti che prevedono la manipolazione di sistemi quantistici aprendo quindi la strada per il controllo delle stranezze quantistiche.

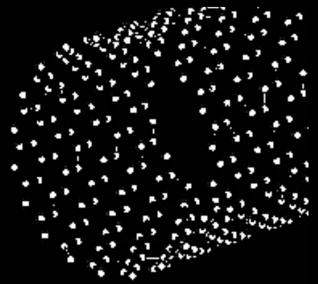
Come attraversare una barriera-considerazioni energetiche

Esempi di stranezze quantistiche: effetto tunnel per un elettrone

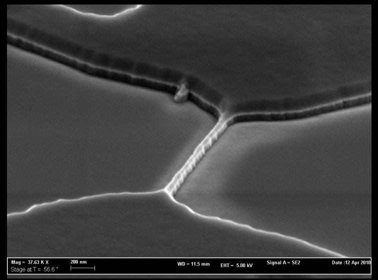


Scale spaziali

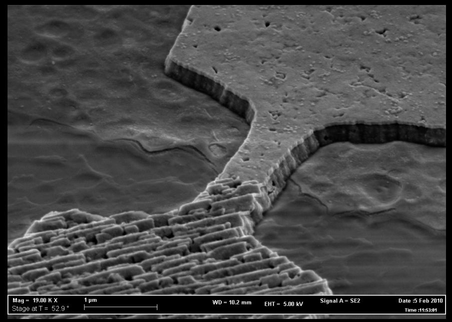
Nanotubo



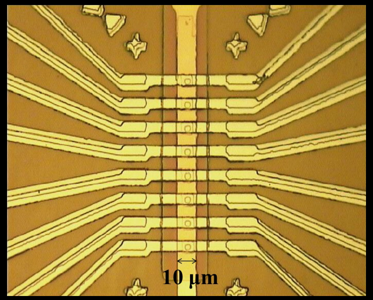
Risoluzione litografica minima



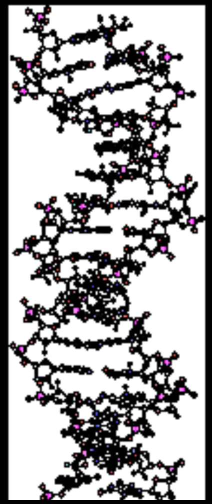
2003 Si transistor (0.13 μm)



1970 Si transistor (10 μm)

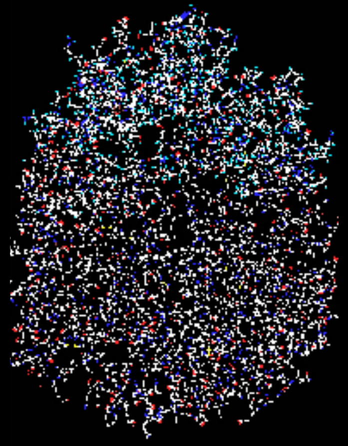


Atomo



DNA

Protein



Virus

Cell

1 Å | 1 nm | 10 nm | 100 nm | 1 μm | 10 μm

Why quantum computers?

Richard Feynman (1982): Nature isn't classical, and if you want to make a simulation of nature, you'd better make it quantum mechanical, and it's a wonderful problem, because it doesn't look so easy!

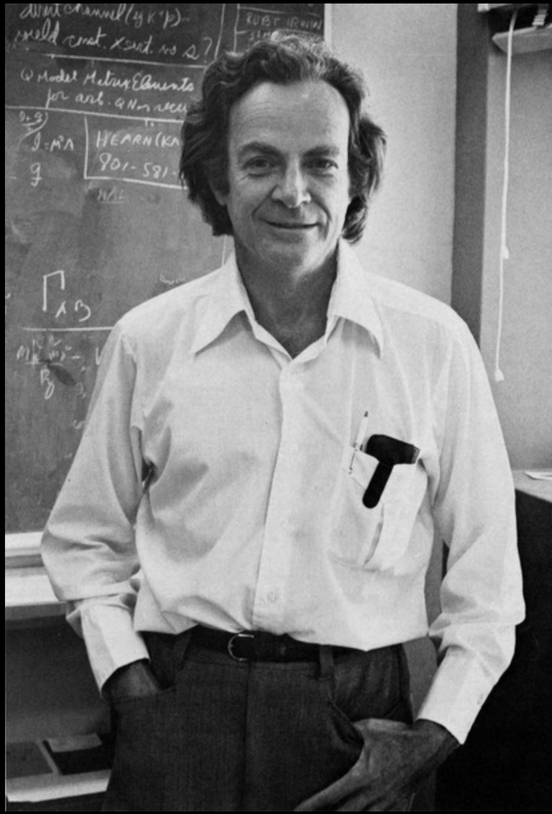
Simulating Physics with Computers

Richard P. Feynman

Department of Physics, California Institute of Technology, Pasadena, California 91107

Received May 7, 1981

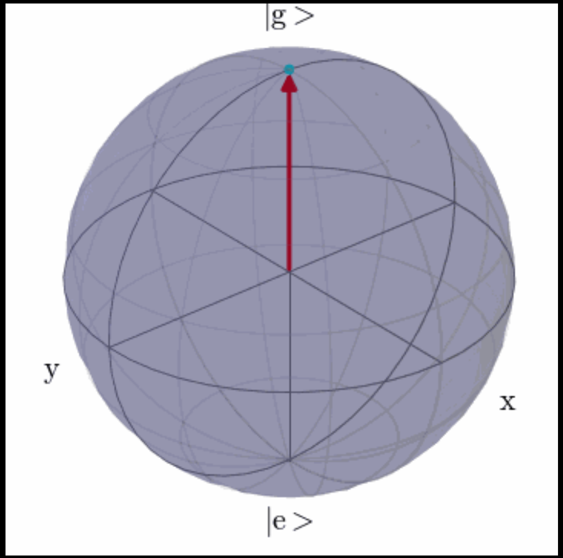
Now, what kind of physics are we going to imitate? First, I am going to describe the possibility of simulating physics in the classical approximation, a thing which is usually described by local differential equations. But the physical world is quantum mechanical, and therefore the proper problem is the simulation of quantum physics—which is what I really want to talk about, but I'll come to that later. So what kind of simulation do I mean? There is, of course, a kind of approximate simulation in which you design numerical algorithms for differential equations, and then use the computer to compute these algorithms and get an approximate view of what physics ought to do. That's an interesting subject, but is not what I want to talk about. I want to talk about the possibility that there is to be an *exact* simulation, that the computer will do *exactly* the same as nature. If this is to be proved and the type of computer is as I've already explained, then it's

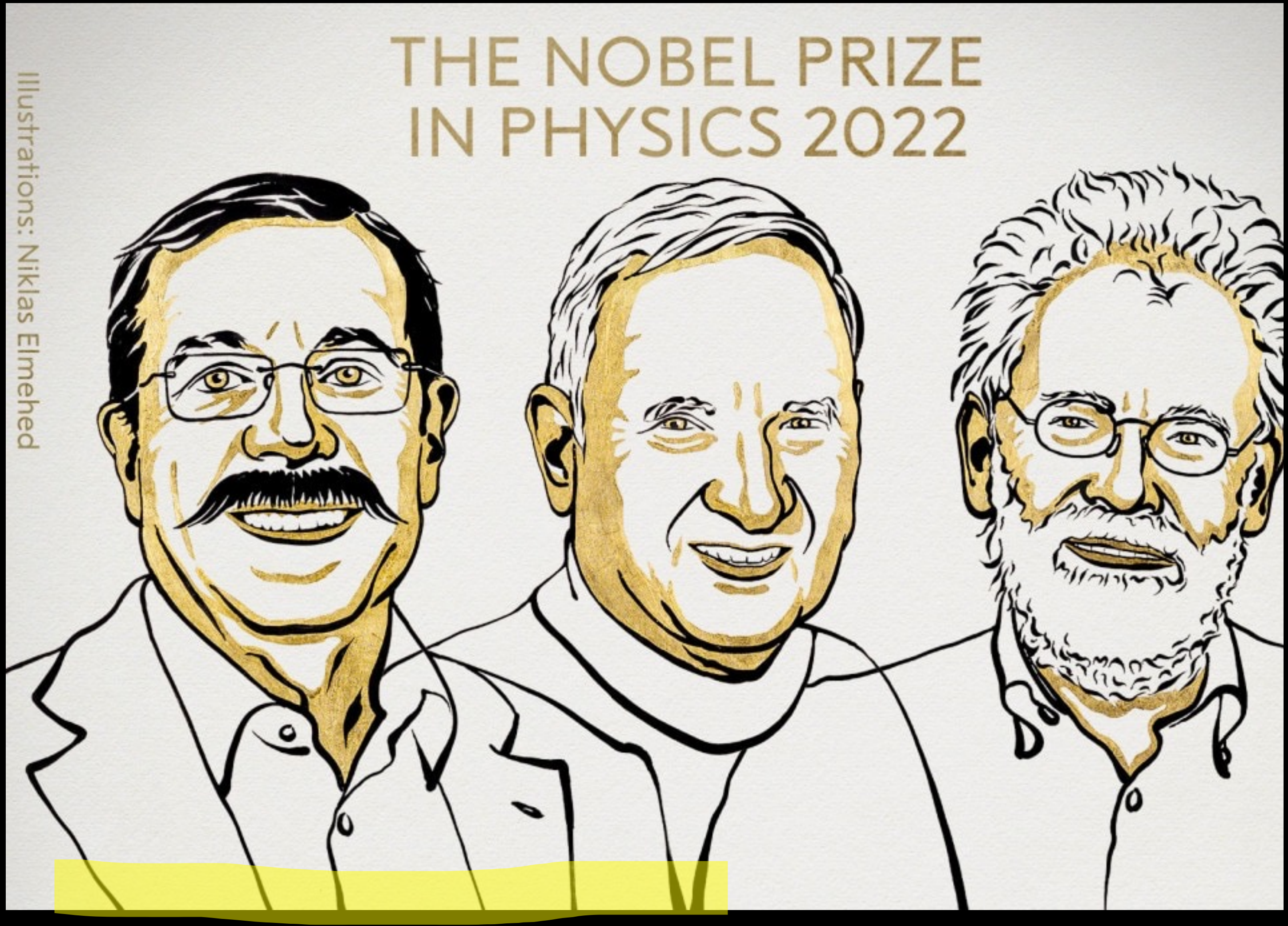


Premio Nobel per la fisica nel 1965 per l'elaborazione dell'elettrodinamica quantistica. Feynman viene considerato un pioniere del campo del computer quantisti e gli è attribuita l'introduzione del concett della nanotecnologia.

Il Nobel per la Fisica 2022 agli studi sui fenomeni quantistici

Alain Aspect, John F. Clauser e Anton Zeilinger hanno vinto il Nobel per la Fisica 2022 per i loro studi nella scienza dell'informazione quantistica.





Article

Quantum supremacy using a programmable superconducting processor

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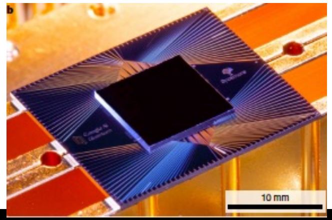

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Expert insight into current research

News & views

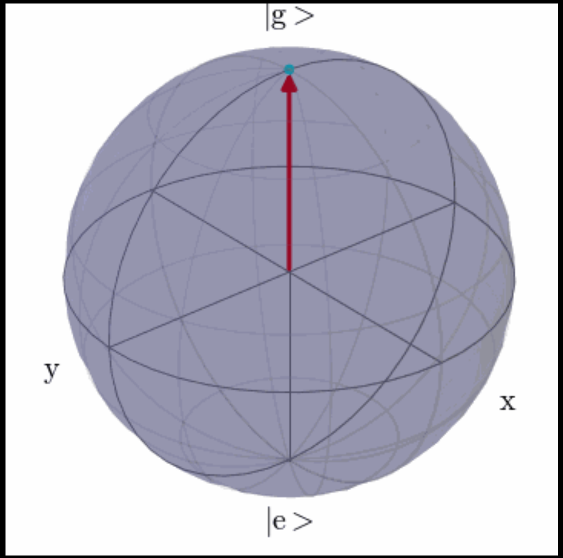
Quantum information

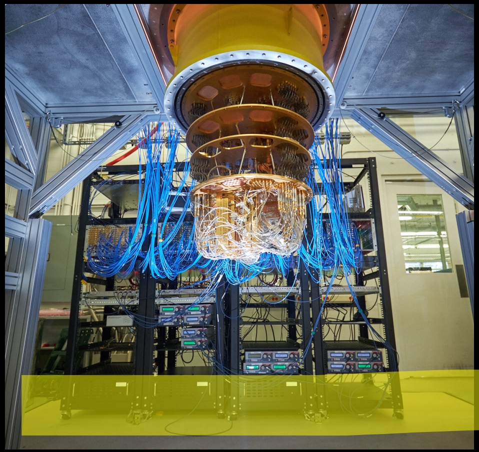
Quantum computing takes flight

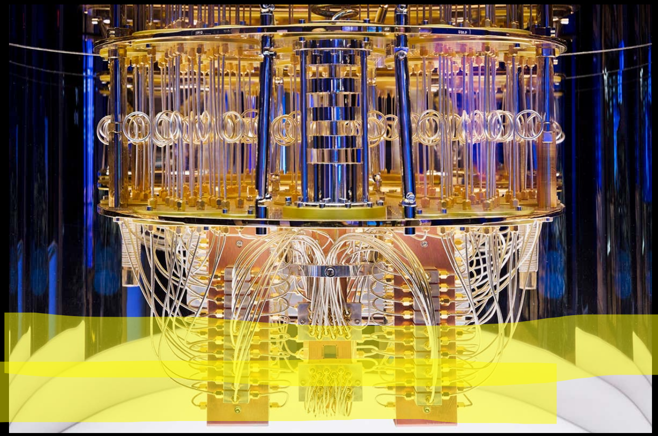
William D. Oliver

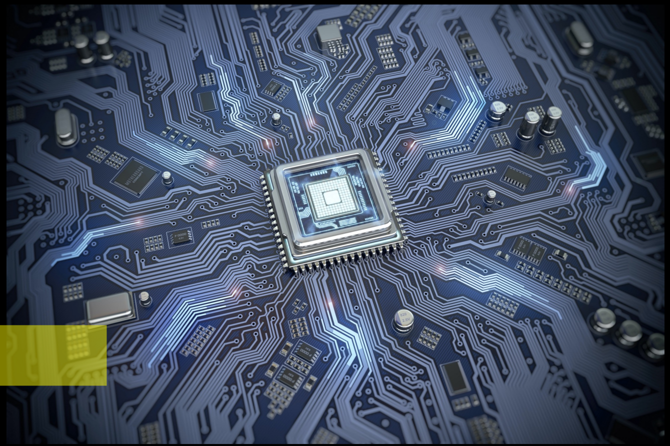
A programmable quantum computer has been reported to outperform the most powerful conventional computers in a specific task – a milestone in computing comparable in importance to the Wright brothers' first flights. See p.505

200 secondi invece di 10^4 anni !!!!!!!!!!!



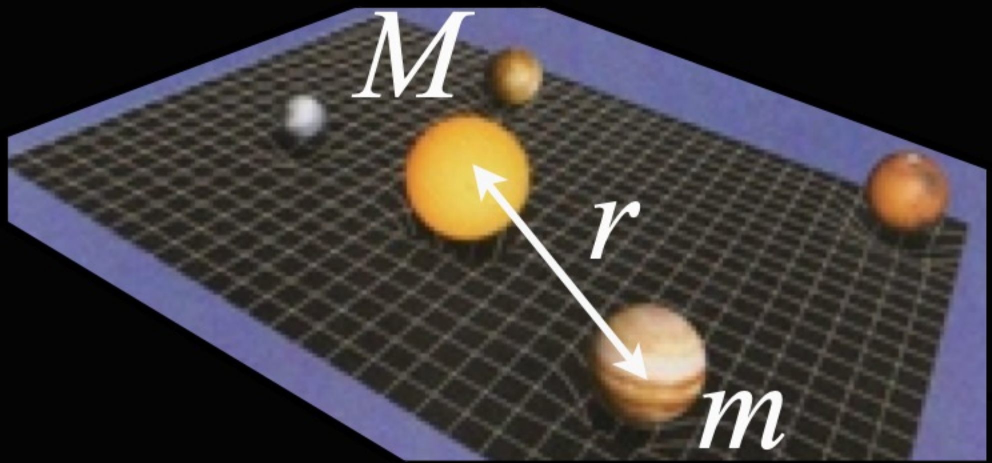






Pillole di meccanica classica

$$\vec{F} = -\frac{GMm}{r^2}\hat{r}$$



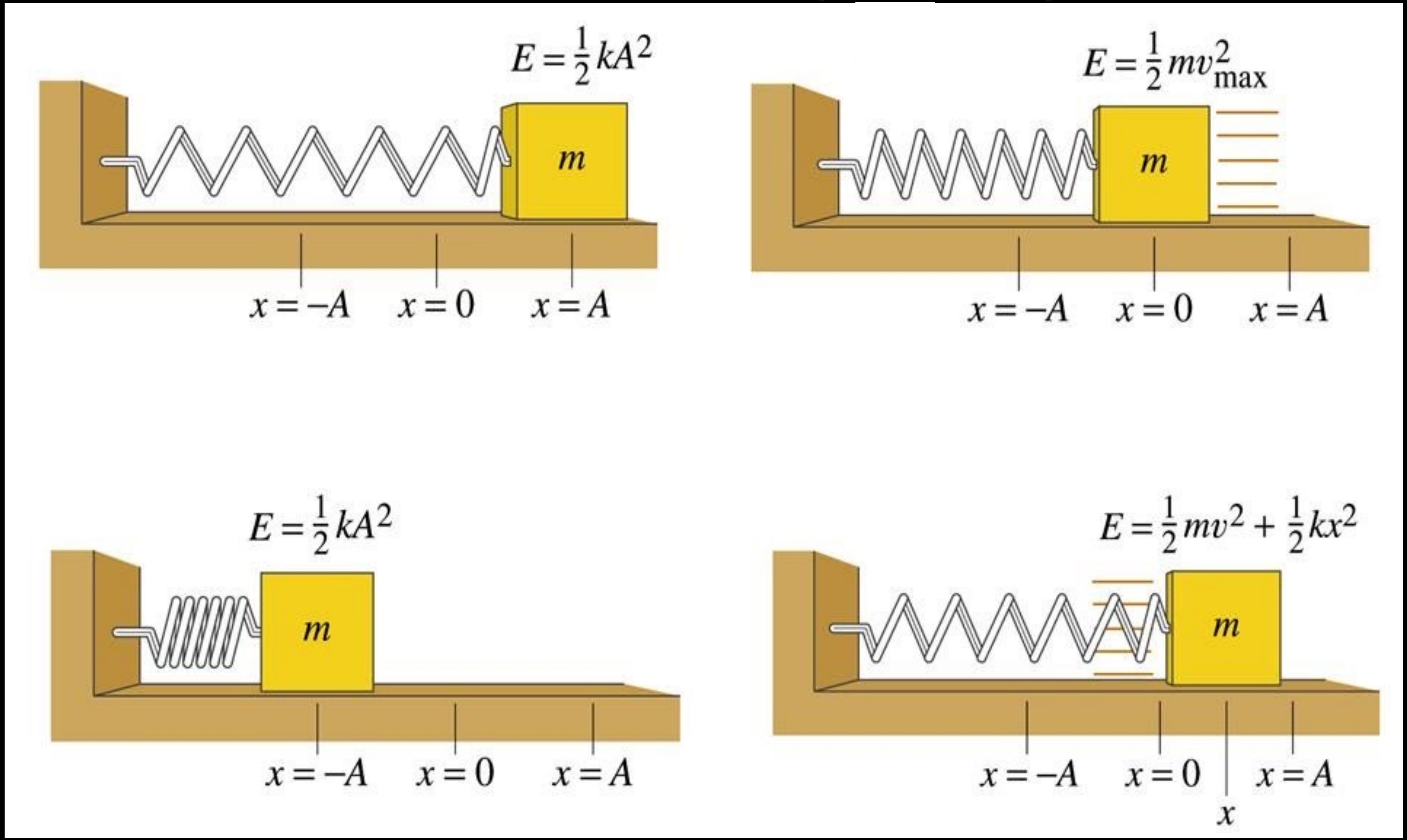
$$\vec{F} = m\vec{a}$$

Oscillatore armonico ....per esempio

$$m\frac{d^2x}{dt^2} = -kx$$

$$\frac{d^2x}{dt^2} + \omega^2 x = 0$$

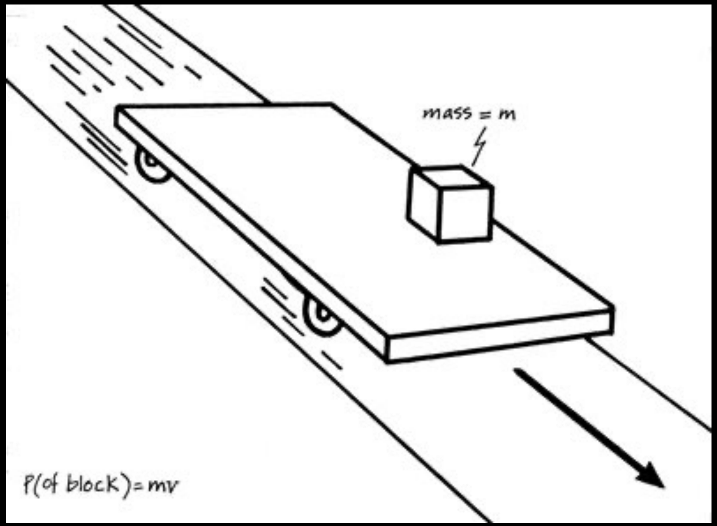
$$\omega^2 = \frac{k}{m}$$

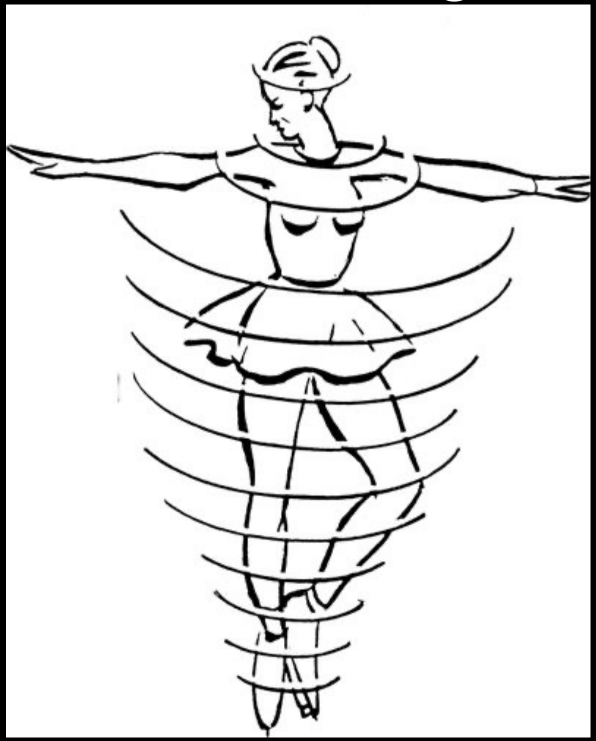


$$x(t) = A\cos(\omega t + \phi)$$

Traduciamo tutto in energia incluso gli urti e usiamo leggi di conservazione dove possibile

quantità moto | momento angolare | energia ....





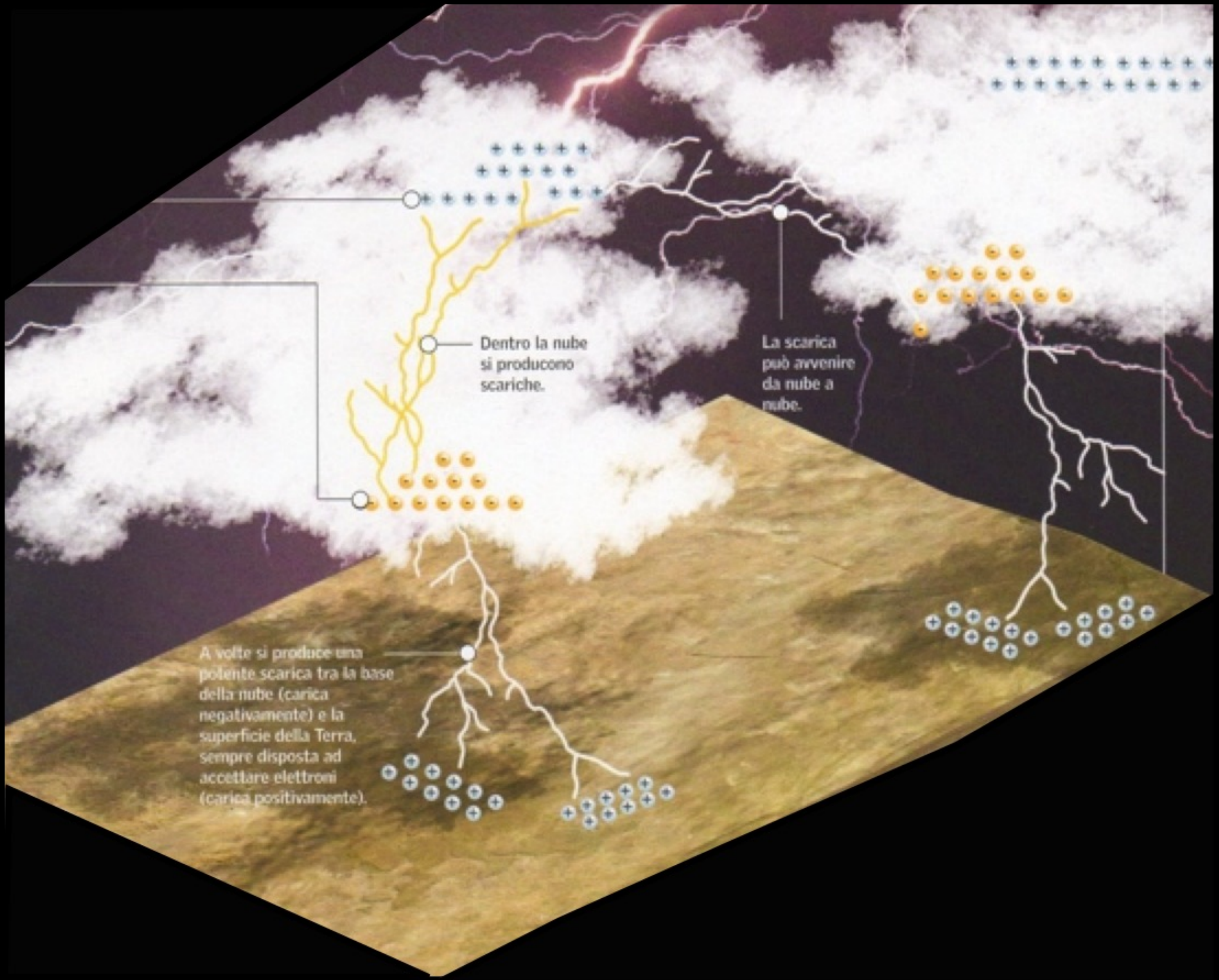
$\vec{p} = m\,\vec{v} = costante$

$\vec{L} = m\vec{r} \times \vec{v} = costante$

$E = \frac{1}{2} m v^2 + E_p = costante$

per esempio forze centrali

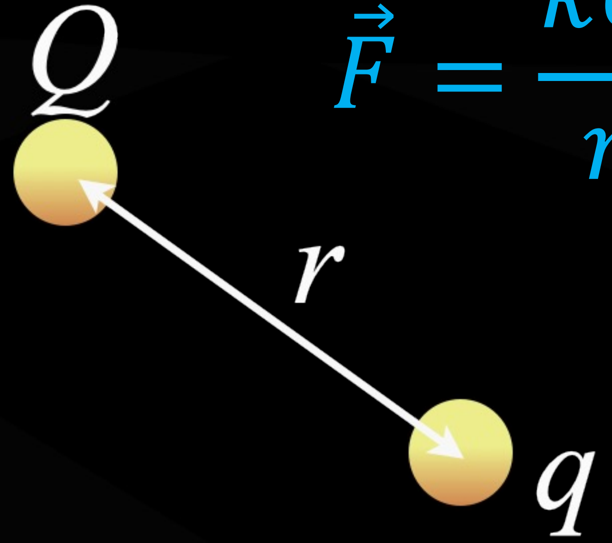
Pillole di elettromagnetismo



$$\int_S \vec{E} \cdot d\vec{A} = \frac{Q_{enc}}{\varepsilon_o}$$

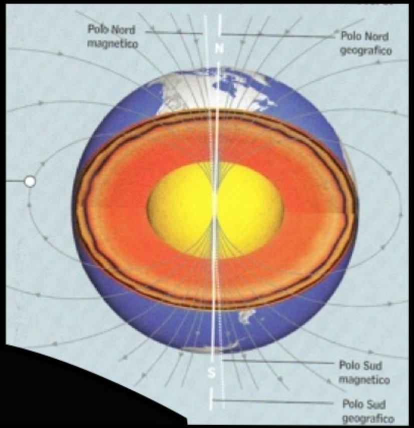
$$\oint \vec{E} \cdot d\vec{l} = 0$$

$$\vec{F} = \frac{kQq}{r^2}\hat{r}$$



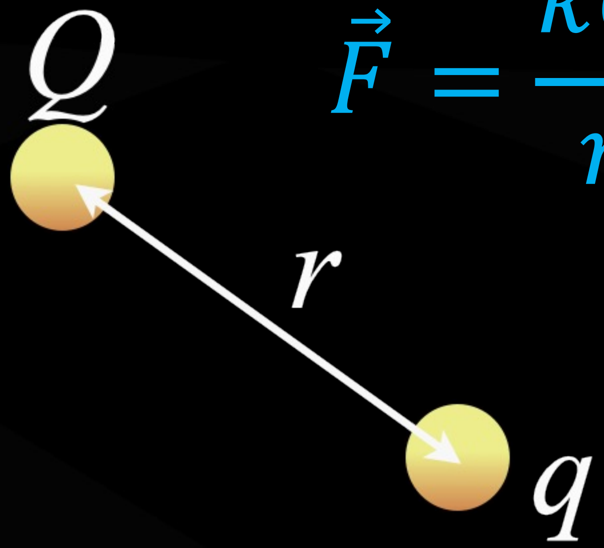
$$\int_S \vec{B} \cdot d\vec{A} = 0$$

$$\oint \vec{B} \cdot d\vec{l} = \mu_o I_{enc}$$



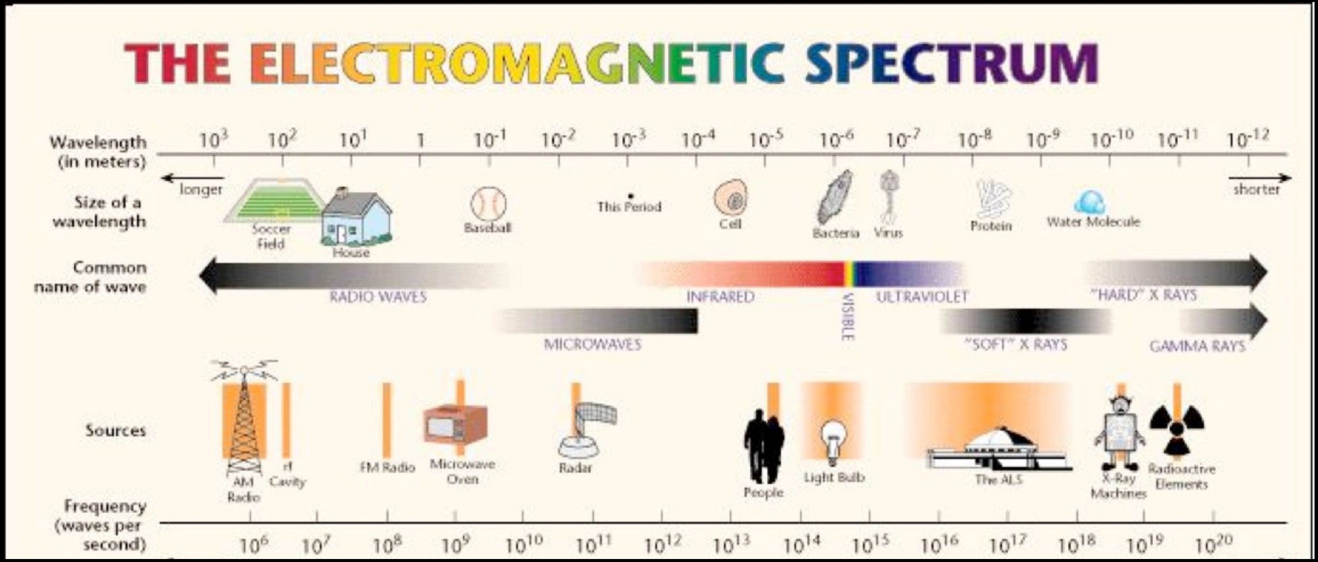
$$\int_S \vec{E} \cdot d\vec{A} = \frac{Q_{enc}}{\varepsilon_o}$$

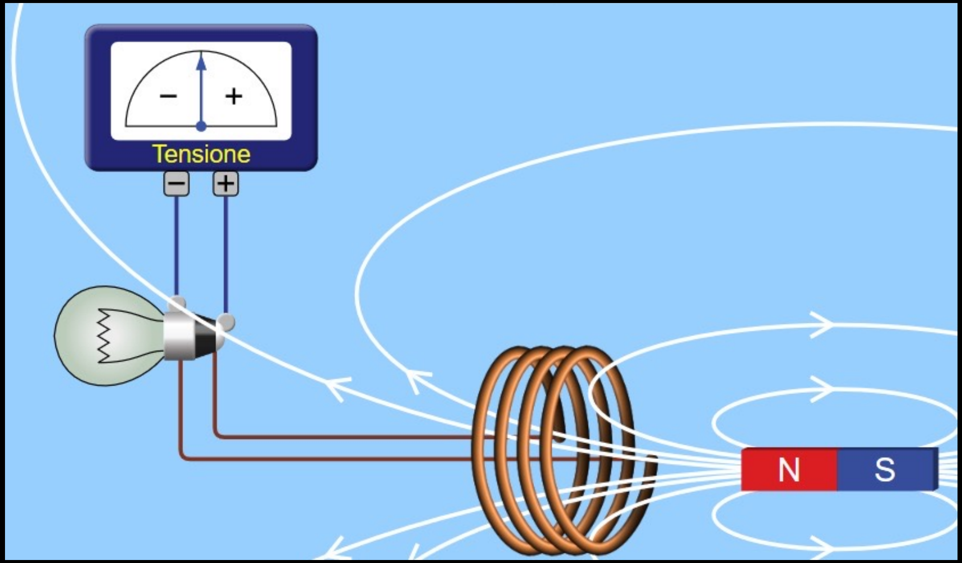
$$\oint \vec{E} \cdot d\vec{l} = 0$$



$$\vec{F} = \frac{kQq}{r^2}\hat{r}$$

Pillole di elettromagnetismo





Maxwell's Equations

Differential form

$$\nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \times \vec{E} = \boxed{-\frac{\partial \vec{B}}{\partial t}}$$

$$\nabla \cdot \vec{B} = 0$$

$$\nabla \times \vec{B} = \mu_0 \vec{J} + \boxed{\mu_0 \varepsilon_0 \frac{\partial \vec{E}}{\partial t}}$$

Maxwell's Equations

Integral form

$$\oint \vec{E} \cdot d\vec{a} = \frac{Q_{enc}}{\varepsilon_0}$$

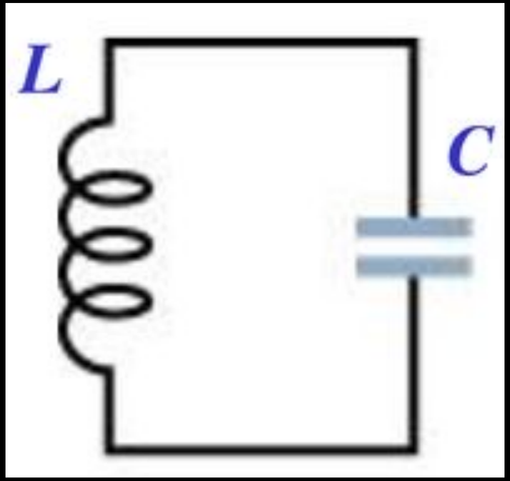
$$\oint \vec{E} \cdot d\vec{l} = \boxed{-\int \frac{\partial \vec{B}}{\partial t} \cdot d\vec{a}}$$

$$\oint \vec{B} \cdot d\vec{a} = 0$$

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc} + \boxed{\mu_0 \varepsilon_0 \int \frac{\partial \vec{E}}{\partial t}}$$

Circuito LC … ancora «oscillatore armonico»

$$L\frac{d^2q}{dt^2}+\frac{1}{C}q=0$$

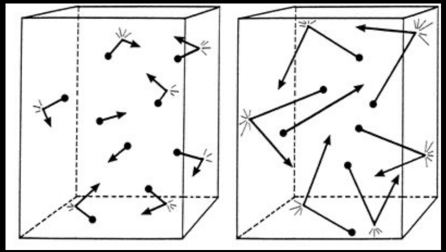


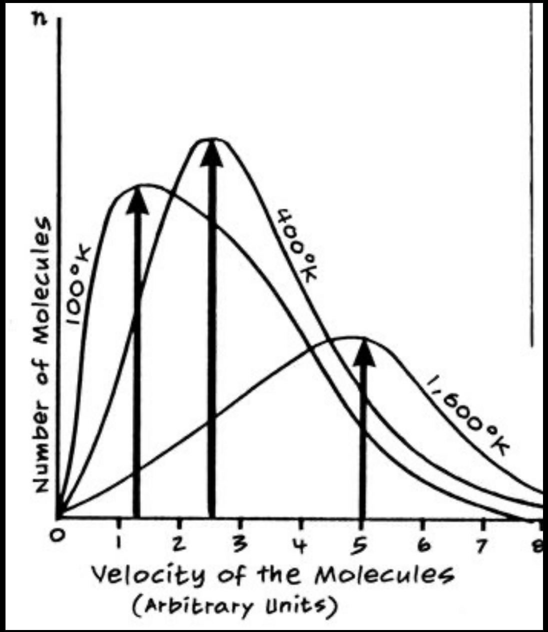
$$\frac{d^2q}{dt^2}+\omega^2 q=0$$

$$\omega^2=\frac{1}{LC}$$

$$\mathrm{q}(t)=A\cos(\omega t+\phi)$$

Teoria cinetica dei gas





La teoria di Maxwell è basata su medie statistiche per valutare se proprietà macroscopiche misurabili in laboratorio possano essere descritte da un modello microscopico applicato ad un gas formato da molecole.

Meccanica statistica

Boltzmann presentò una legge generale per la distribuzione di probabilità, applicabile ad un insieme di entità con libertà di movimento, indipendenti fra loro ed interagenti in maniera casuale. Formalizzò il principio di equipartizione dell'energia, distribuita uniformemente fra tutti i livelli di libertà all'equilibrio termico.

Interpretazione della seconda legge della termodinamica: quando l'energia in un sistema è degradata, gli atomi diventano più disordinati, l'entropia S aumenta e la misura del disordine può essere formulata. La probabilità è definita come il numero di modi nei quali il sistema può essere assemblato sulla basi dei suoi costituenti (atomi):

$S = k_B \text{ Log } W$, dove k_B è la costante di Boltzmann e W è la probabilità che una particolare configurazione di atomi possa essere realizzata.

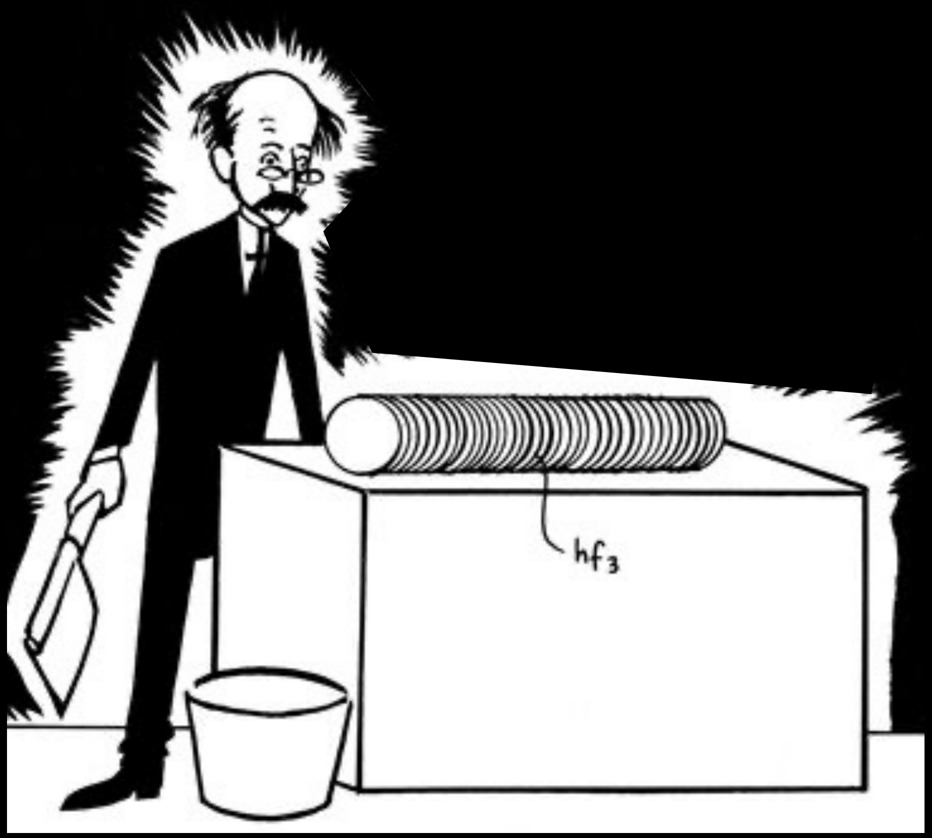
Cosa non si può non immaginare

Quanti di energia

Nell'ambito del problema dello spettro di emissione del corpo nero, Planck postulò che un oscillatore non può assorbire ed emettere energia in maniera continua, ma deve perdere ed assorbire energia in maniera discontinua, in piccole indivisibili e = hν, che Planck chiamò quanti di energia (h costante di Planck, ν frequenza).

$$h = 6.6 \times 10^{-34} joule \cdot sec$$

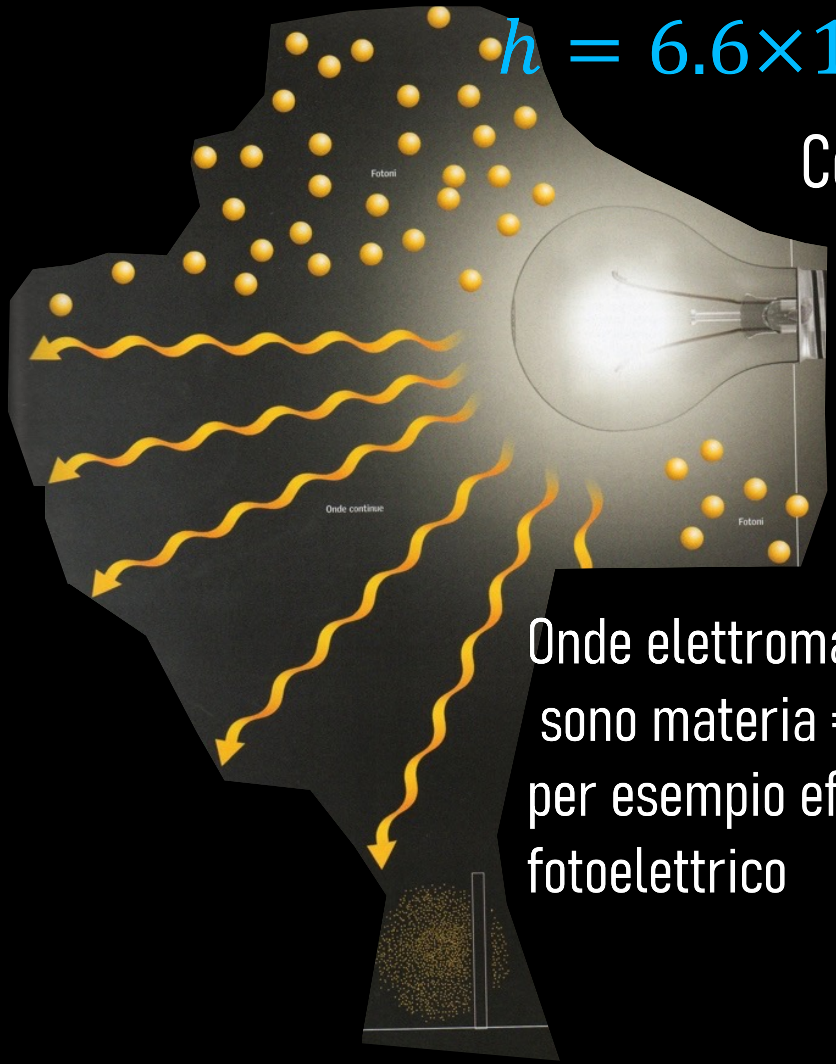
$$\hbar = \frac{h}{2\pi}$$ Costante di Planck



Cosa non si può non immaginare

$$h = 6.6\times10^{-34} joule \cdot sec$$

Costante di Planck

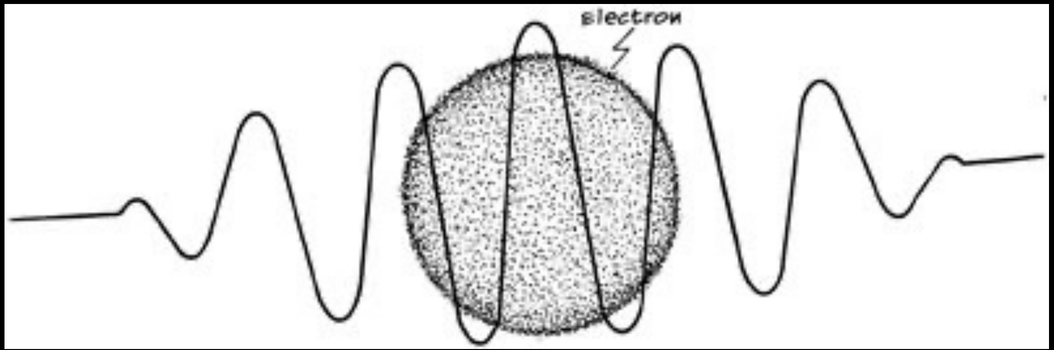


Onde elettromagnetiche sono materia => fotoni per esempio effetto fotoelettrico

$$E = h\nu$$

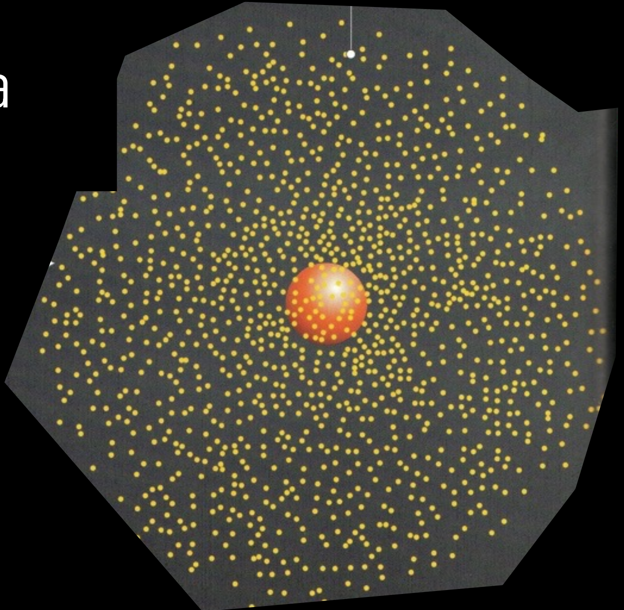
Pillole di meccanica quantistica

Cosa non si può non immaginare



$$\lambda = h/p$$

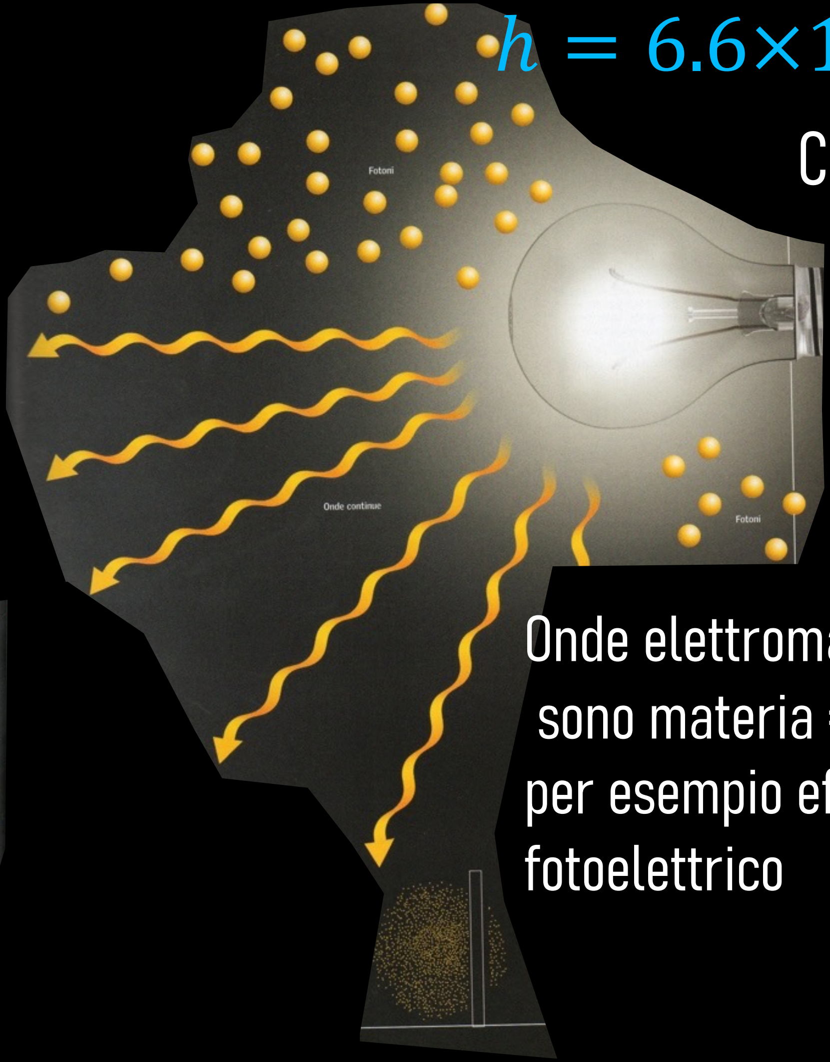
La materia è onda;
associamo l’idea di onda
ad un elettrone



abituiamoci all’idea che le particelle
siano delocalizzate

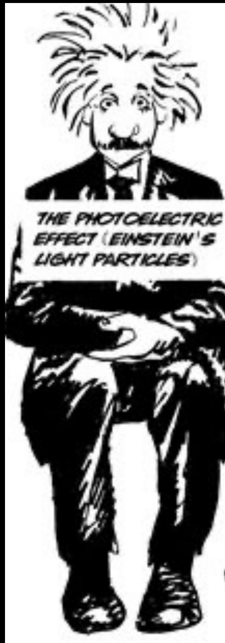
$$h = 6.6\times10^{-34} joule \cdot sec$$

Costante di Planck



Onde elettromagnetiche
sono materia => fotoni
per esempio effetto
fotoelettrico

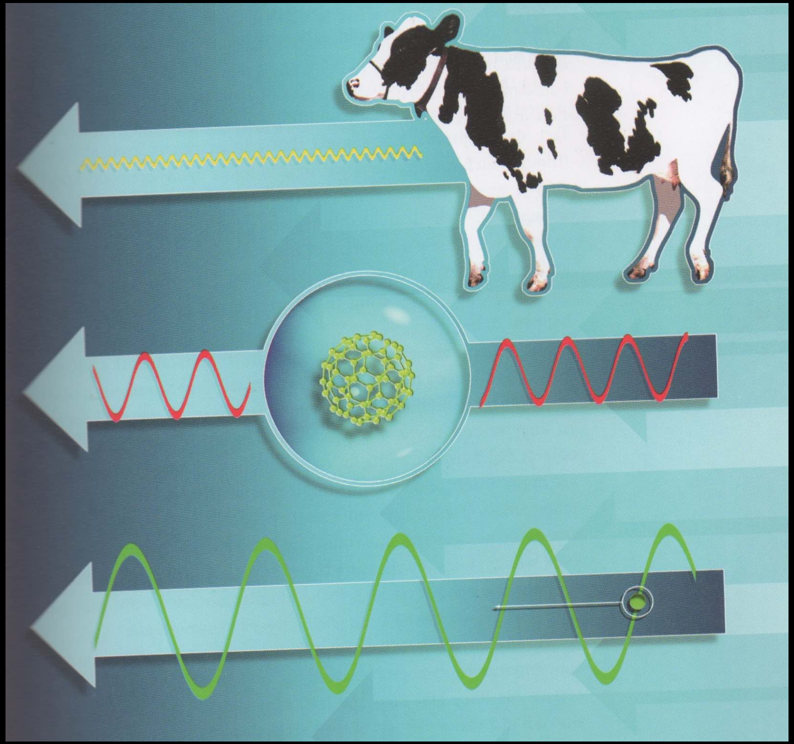
$$E = h\nu$$



Per capire «quanto siamo quantistici»

Lunghezza d'onda λ di De Broglie per una palla da baseball di un 1 kg che si muove ad una velocità di 10 m/s

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.6\times10^{-34}\, joule\cdot sec}{1\, kg\times10 m/sec} = 6.6\times10^{-35} \text{m} = 6.6\times10^{-25} \text{Å}$$

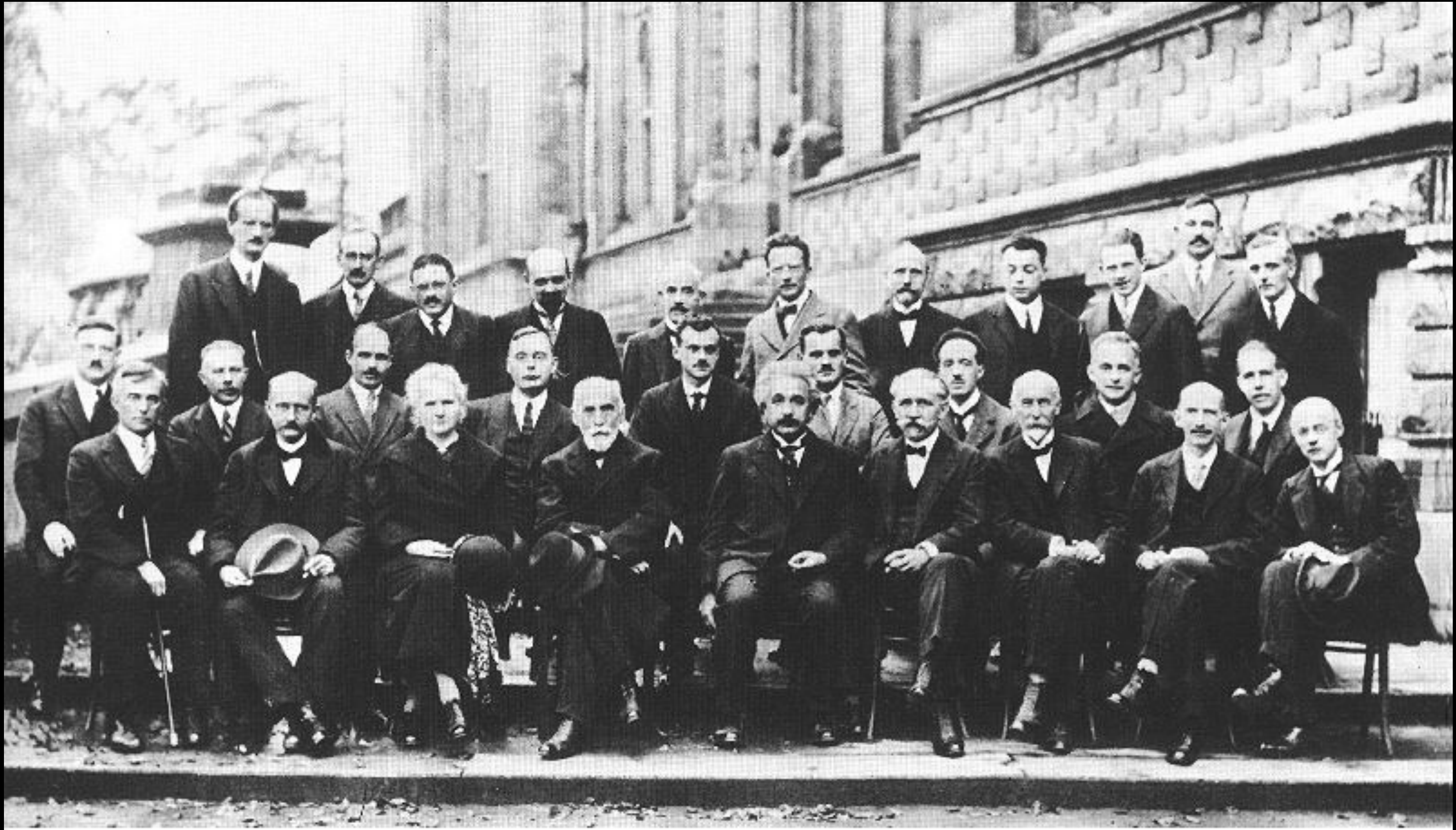


Lunghezza d'onda di un elettrone con energia cinetica K di 100 eV

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mK}} =$$

$$\frac{6.6\times10^{-34}\, joule\cdot sec}{(2\times9.1\times10^{-31} kg\times1.6\times100\, eV\times10^{-19} joule/eV)^{1/2}} = 1.2\times10^{-10} \text{m} = 1.2\ \text{Å}$$

Bruxelles conference 1927

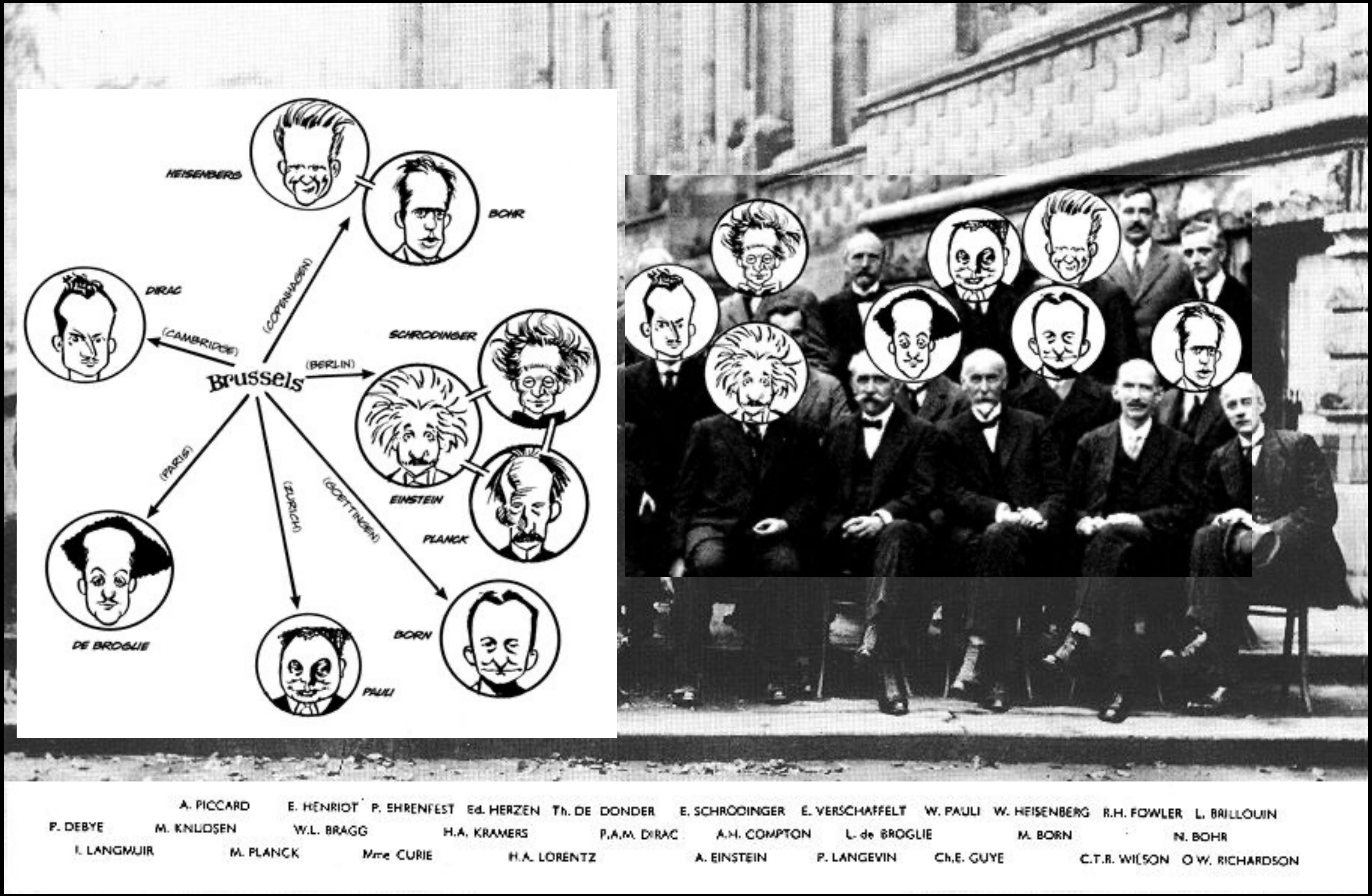


A. PICCARD E. HENRIOT P. EHRENFEST Ed. HERZEN Th. DE DONDER E. SCHRÖDINGER E. VERSCHAFFELT W. PAULI W. HEISENBERG R.H. FOWLER L. BRILLOUIN

P. DEBYE M. KNUDSEN W.L. BRAGG H.A. KRAMERS P.A.M. DIRAC A.H. COMPTON L. de BROGLIE M. BORN N. BOHR

I. LANGMUIR M. PLANCK Mme CURIE H.A. LORENTZ A. EINSTEIN P. LANGEVIN Ch.E. GUYE C.T.R. WILSON O.W. RICHARDSON

Bruxelles conference 1927

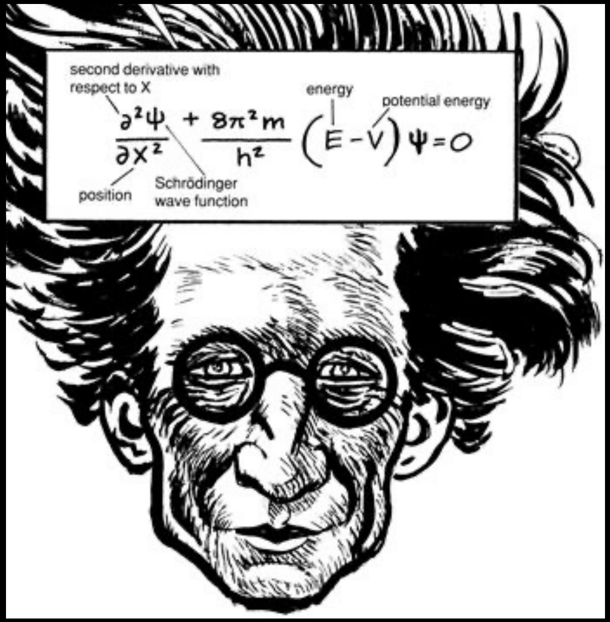


Cosa si può e si deve quantificare

Equazione di Schrodinger

$$\frac{p^2}{2m} + U = E$$

$$-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\psi(x,t) + U(x)\psi(x,t) = E\psi(x,t) = i\hbar\frac{\partial}{\partial t}\psi(x,t)$$



$$\frac{\partial^2}{\partial x^2}E(x,t) = \frac{1}{c^2}\frac{\partial^2}{\partial^2 t}E(x,t)$$

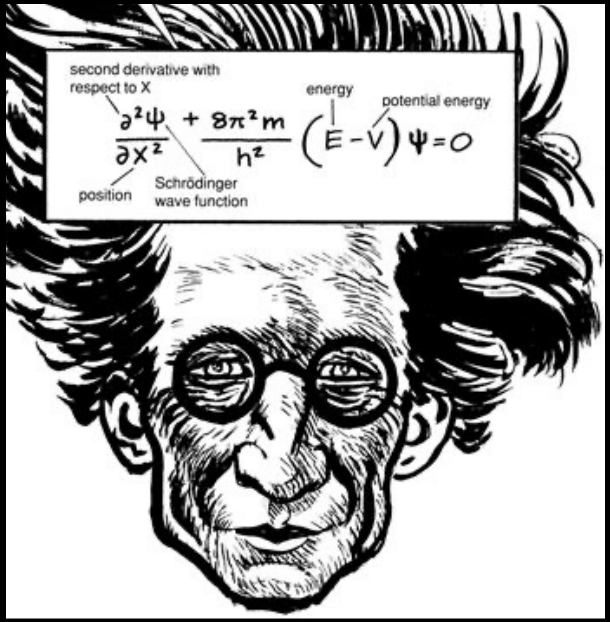
Equazione onda e.m. in una dimensione

Cosa si può e si deve quantificare

Equazione di Schrodinger

$$\frac{p^2}{2m} + U = E$$

$$-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\psi(x,t) + U(x)\psi(x,t) = E\psi(x,t) = i\hbar\frac{\partial}{\partial t}\psi(x,t)$$



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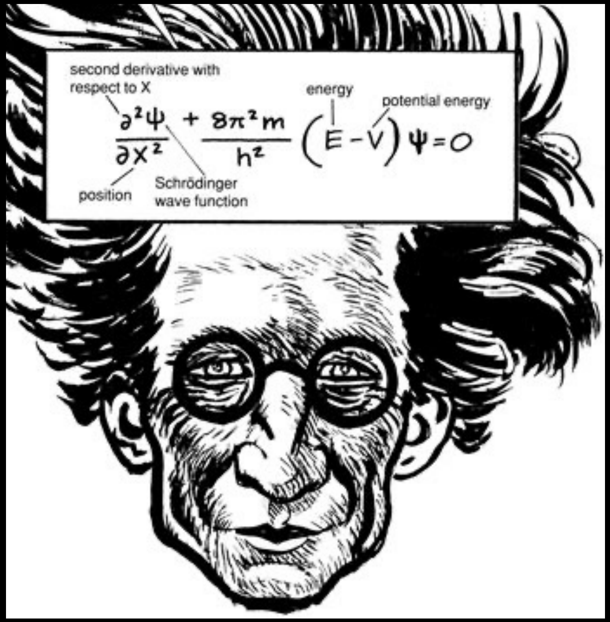


$\psi(x,t)$ codice quantistico

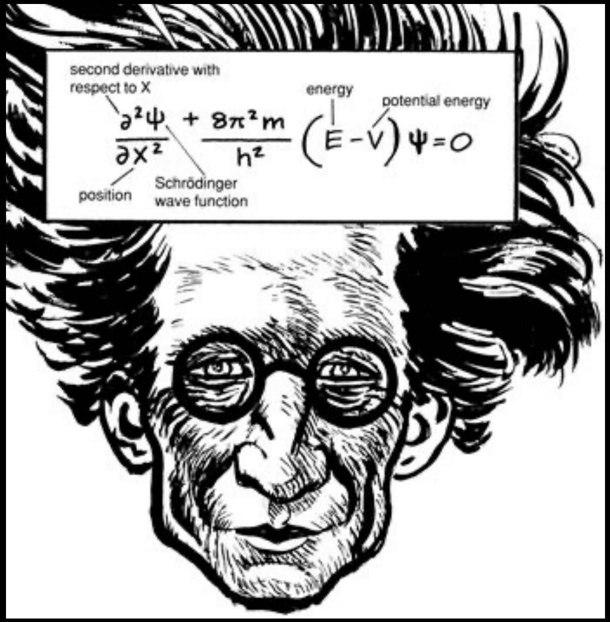
$|\psi(x,t)|^2$ Born definisce la probabilità di esistenza di uno stato come quadrato dell'ampiezza normalizzata della funzione d'onda.

Cosa si può e si deve quantificare

Equazione di Schrodinger

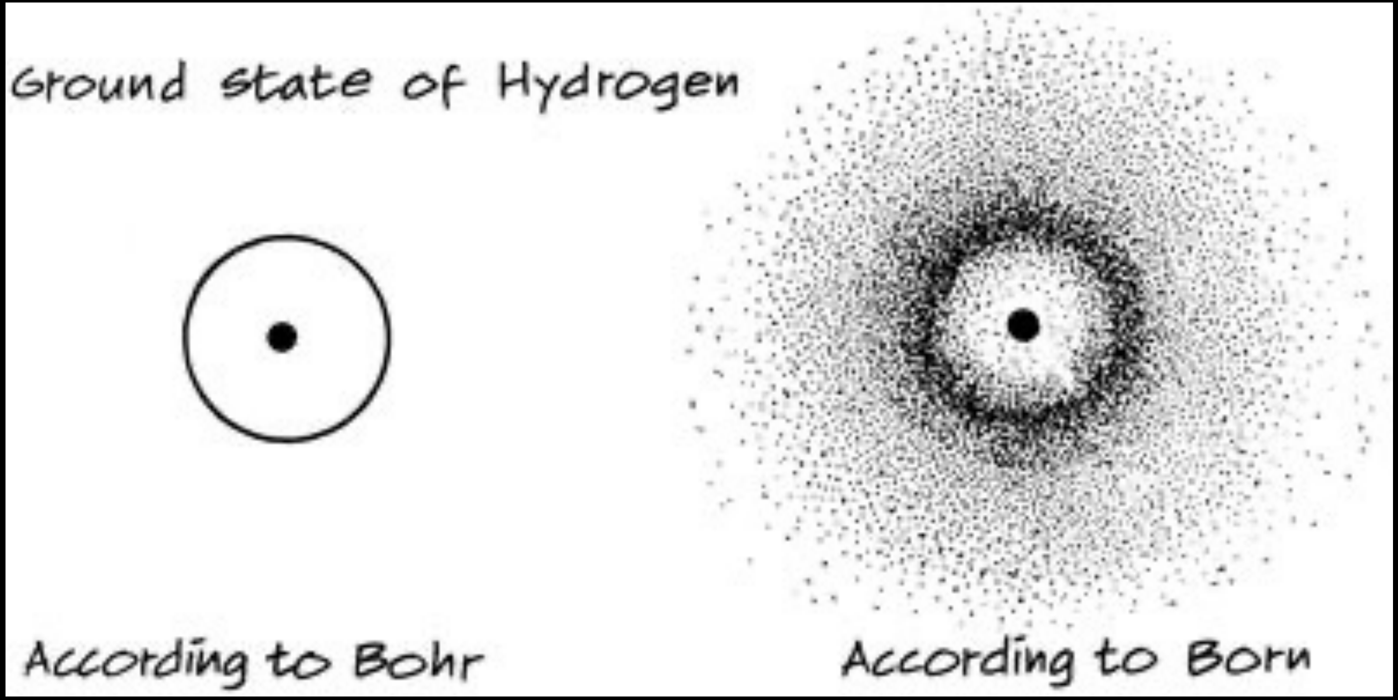
$$\frac{p^2}{2m} + U = E$$

$$-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\psi(x,t) + U(x)\psi(x,t) = E\psi(x,t) = i\hbar\frac{\partial}{\partial t}\psi(x,t)$$



$$\psi(x,t)$$

$$|\psi(x,t)|^2$$



Pillole di meccanica quantistica

Definizione dell'incerto «quantistico»

La probabilità di Born è un nuovo concetto: la probabilità che un certo stato quantistico esista. Non ci sono più risposte esatte. Si parla solo di probabilità.

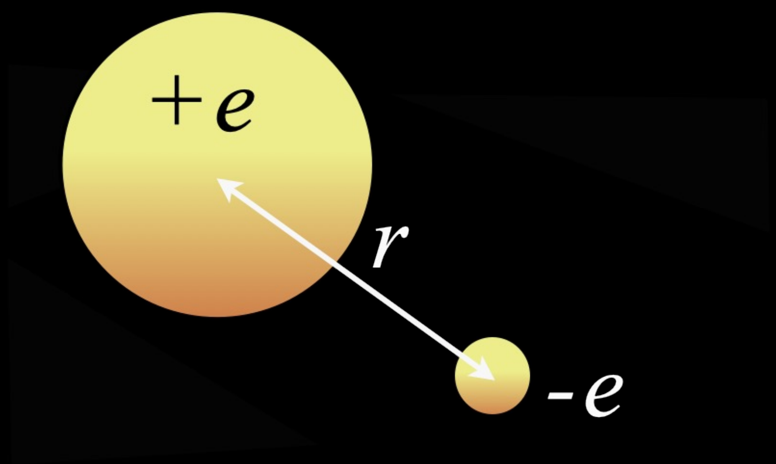
Due diversi tipi di probabilità. La teoria classica di Maxwell-Boltzmann aveva introdotto coordinate microscopiche nella teoria cinetica dei gas, solo per eliminarle a favore di valori medi basati sulla probabilità a causa di informazioni che non possono essere reperite. Impossibile calcolare i valori esatti per tante particelle. Born ha trovato un modo per conciliare particelle e onde introducendo il concetto di probabilità. La funzione d'onda ψ determina la probabilità che l'elettrone sia in una specifica/o posizione/stato.

Pillole di meccanica quantistica

Cosa si può e si deve quantificare

Atomo di idrogeno

$$\frac{p^2}{2m} - \frac{e^2}{r} = E$$

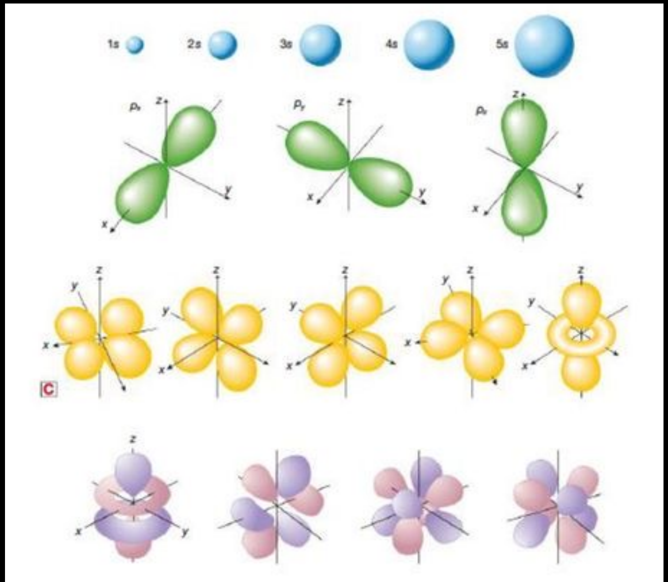


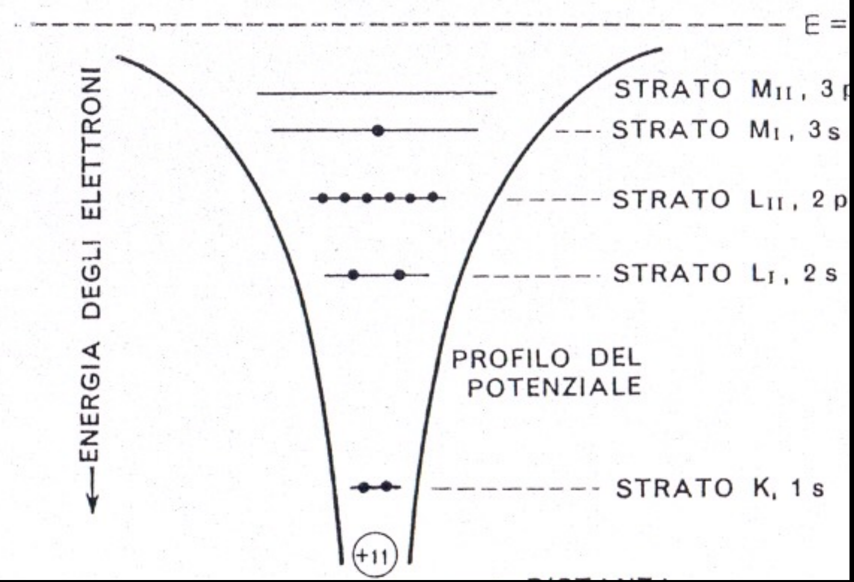
$$-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\psi(x,t) + U(x)\psi(x,t) = E\psi(x,t)$$

$$-\frac{\hbar^2}{2m}\nabla^2\psi(\vec{r},t) - \frac{e^2}{r}\psi(\vec{r},t) = E\psi(\vec{r},t)$$

Numeri quantici

Dimensione orbita (n),
forma dell'orbita (l),
direzione dell'orbita (m)
e spin





Semimetalli

Possiedono proprietà intermedie tra i metalli e i non metalli. Una delle più importanti è che sono semiconduttori (conducono l'elettricità in una sola direzione, invece di farlo in entrambe). Sono molto importanti nella fabbricazione di transistor, rettificatori, ecc. e fanno parte di chip e circuiti integrati. Tra di essi vi sono ad esempio il silicio e il germanio.

Non metalli

Sono alcuni degli elementi più abbondanti nel pianeta, come l'idrogeno, il carbonio, l'ossigeno e l'azoto, presenti anche negli esseri viventi. Sono molto elettronegativi e pessimi conduttori di calore e di elettricità, quando non veri e propri isolanti.

Gas nobili

Dato che ha 8 elettroni nell'ultimo livello ene getico sono estremamente stabili e poco propensi a reagire co altri elementi. Tra questi si trovano il neon, l'argon e lo xeno

Alogeni

Sono gli elementi con maggiore elettronegatività e presentano importanti applicazioni industriali.

Metalli poveri

Sono blandi e con un basso punto di fusione e di ebollizione. Tra questi ricordiamo l'alluminio, lo stagno e il piombo.

Periodi

Gli elettroni orbitano intorno ai nuclei atomici raggruppati in diversi livelli energetici. Il periodo indica quanti livelli energetici ha un atomo. Tuttavia, gli atomi con lo stesso periodo hanno proprietà differenti.

Gruppi

Indicano quanti elettroni ha un atomo nell'ultimo livello energetico. Gli atomi di uno stesso gruppo in genere condividono caratteristiche e proprietà simili.

LA SIMBOLOGIA

- Simbolo e nome dell'elemento
- Numero atomico: indica il numero di protoni presenti nel nucleo dell'atomo.
- Numero di massa: indica la massa dell'atomo in rapporto al Carbonio (valore 12).
- Elemento radioattivo

Esempio: 43 Tc Tecnezio (98)

Metalli alcalini

Sono elementi molto reattivi, per cui li si trova combinati e quasi mai allo stato puro. Sono metalli blandi e a bassa densità. Il più abbondante è il sodio.

Metalli alcalino-terrosi

Sono anch'essi metalli blandi, poco densi e molto reattivi, anche se un po' meno degli alcalini. Reagiscono con l'acqua per formare soluzioni molto alcaline. I più abbondanti di questo gruppo sono il calcio e il magnesio.

Metalli di transizione

Sono metalli duri, con punti di ebollizione e fusione alti e sono buoni conduttori di elettricità e calore. Possono formare leghe tra di loro. Ferro, oro e argento sono alcuni esempi.

Lantanidi

Sono elementi relativamente abbondanti nel pianeta e in genere si trovano sotto forma di ossido.

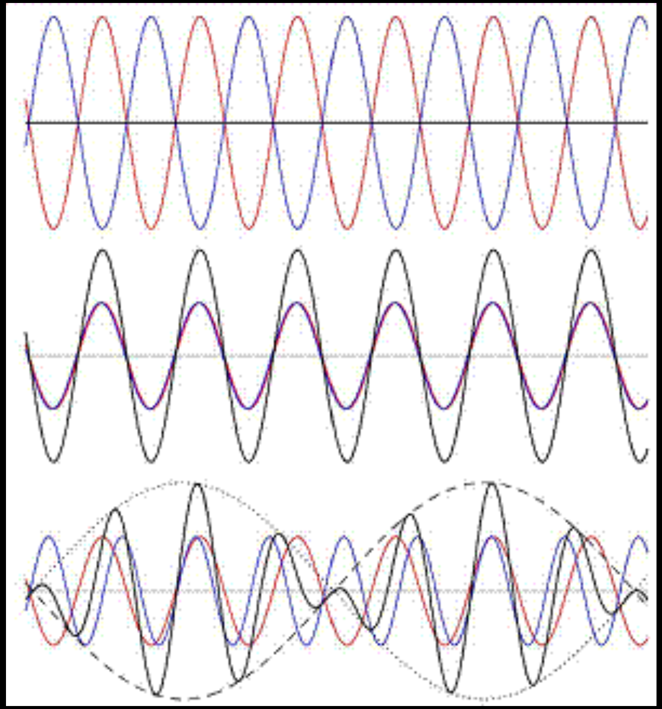
Elementi superpesanti

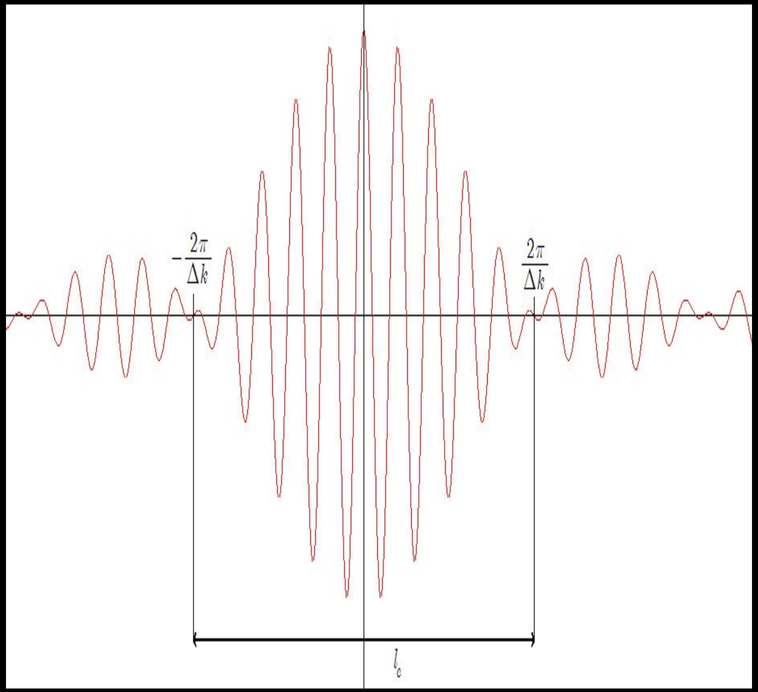
Ottenuti in laboratorio, sono molto instabili e si disintegrano in una frazione di secondo. I ricercatori cercano la teorizzata "isola di stabilità".

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H Idrogeno 1,00																	2 He Elio 4,00
2	3 Li Litio 6,94	4 Be Berillo 9,01											5 B Boro 10,81	6 C Carbonio 12,01	7 N Azoto 14,00	8 O Ossigeno 15,99	9 F Fluoro 18,99	10 Ne Neon 20,18
3	11 Na Sodio 22,99	12 Mg Magnesio 24,30											13 Al Alluminio 26,98	14 Si Silicio 28,08	15 P Fosforo 30,97	16 S Solfo 32,06	17 Cl Cloro 35,45	18 Ar Argo 39,94
4	19 K Potassio 39,1	20 Ca Calcio 40,08	21 Sc Scandio 44,95	22 Ti Titanio 47,87	23 V Vanadio 50,94	24 Cr Cromo 51,99	25 Mn Manganese 54,94	26 Fe Ferro 55,84	27 Co Cobalto 58,93	28 Ni Nichel 58,69	29 Cu Rame 63,54	30 Zn Zinco 65,40	31 Ga Gallio 69,72	32 Ge Germanio 72,64	33 As Arsenico 74,92	34 Se Selenio 78,96	35 Br Bromo 79,90	36 Kr Cripton 83,8
5	37 Rb Rubidio 85,47	38 Sr Stronzio 87,62	39 Y Ittrio 88,90	40 Zr Zirconio 91,22	41 Nb Niobio 92,9	42 Mo Molibdeno 95,9	43 Tc Tecnecio (98)	44 Ru Rutenio 101	45 Rh Rodio 102,9	46 Pd Palladio 106,4	47 Ag Argento 107,9	48 Cd Cadmio 112,4	49 In Indio 114,8	50 Sn Stagno 118,7	51 Sb Antimonio 121,7	52 Te Tellurio 127,6	53 I Iodio 126,9	54 Xe Xeno 131,3
6	55 Cs Cesio 132,9	56 Ba Bario 137,3	57-71	72 Hf Afnio 178,5	73 Ta Tantalio 180,9	74 W Tungsteno 183,8	75 Re Renio 186,2	76 Os Osmio 190,2	77 Ir Iridio 192,2	78 Pt Platino 195,1	79 Au Oro 197	80 Hg Mercurio 200,6	81 Tl Tallio 204,4	82 Pb Piombo 207,2	83 Bi Bismuto 208,9	84 Po Polonio (209)	85 At Astato (210)	86 Rn Radon (222)
7	87 Fr Francio (223)	88 Ra Radio (226)	89-103	104 Rf Rutherfodio (261)	105 Db Dubnio (262)	106 Sg Sealborgio (263)	107 Bh Borio (264)	108 Hs Hassio (265)	109 Mt Meitnerio (268)	110 Uun (281)	111 Uuu (272)	112 Uub (285)	113 Uut	114 Uuq (289)	115 Uup	116 Uuh	117 Uus	118 Uuo

6	57 La Lantano 138,9	58 Ce Cerio 140,1	59 Pr Praseodimio 140,9	60 Nd Neodimio 144,2	61 Pm Promezio (145)	62 Sm Samario 150,3	63 Eu Europio 152	64 Gd Gadolinio 157,2	65 Tb Terbio 158,9	66 Dy Disprosio 162,5	67 Ho Olmio 164,9	68 Er Erbio 167,2	69 Tm Tulio 168,9	70 Yb Iterbio 173	71 Lu Lutezio 175
7	89 Ac Attinio (227)	90 Th Torio 232	91 Pa Protattinio 231	92 U Uranio 238	93 Np Nettunio 237	94 Pu Plutonio (244)	95 Am Americio (243)	96 Cm Curio (247)	97 Bk Berkelio (247)	98 Cf Californio (251)	99 Es Einstenio (252)	100 Fm Fermio (257)	101 Md Mandelevio (258)	102 No Nobelio (259)	103 Lr Laurenzio (262)

Il «prezzo» di essere onda





$$Y(x) = A\sin(k_1 x)$$

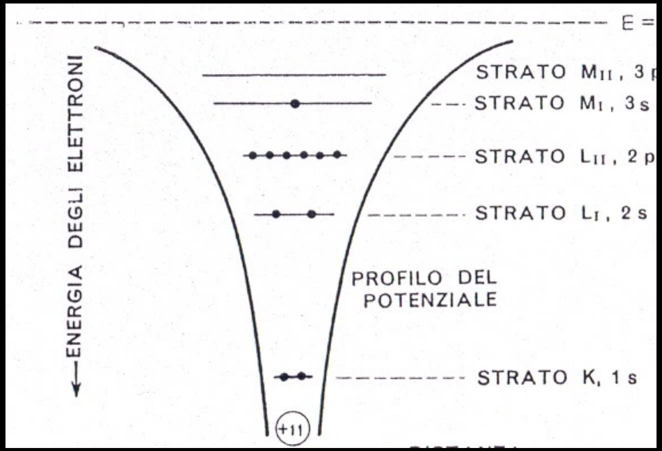
$$Y(x) = A\sin(k_2 x)$$

$$\ldots\ldots\ldots\ldots\ldots$$

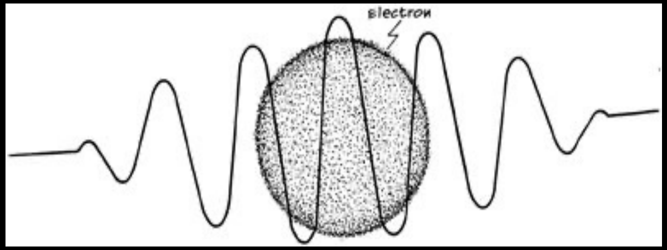
$$\rightarrow \quad \Delta k \Delta x \sim 1$$

Le relazioni di indeterminazione di Heisenberg

$$\Delta E \Delta t \sim h$$



$$\Delta p \Delta x \sim h$$



Vocabolario dell'incerto

Quantum

Indeterminacy = indeterminazione

Unpredictability = imprevedibilità

Classico

Indeterminism= indeterminismo

Oscillatore armonico

Esempio di quantizzazione

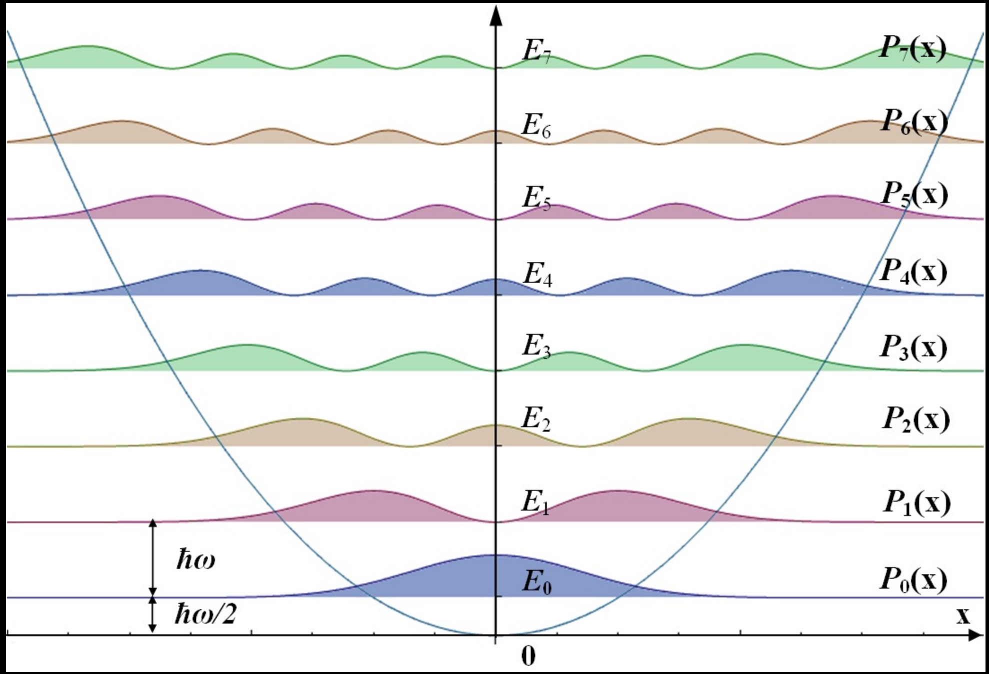
$$\frac{p^2}{2m} + \frac{1}{2}kx^2 = E$$

$$-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\psi(x,t) + U(x)\psi(x,t) = E\psi(x,t)$$

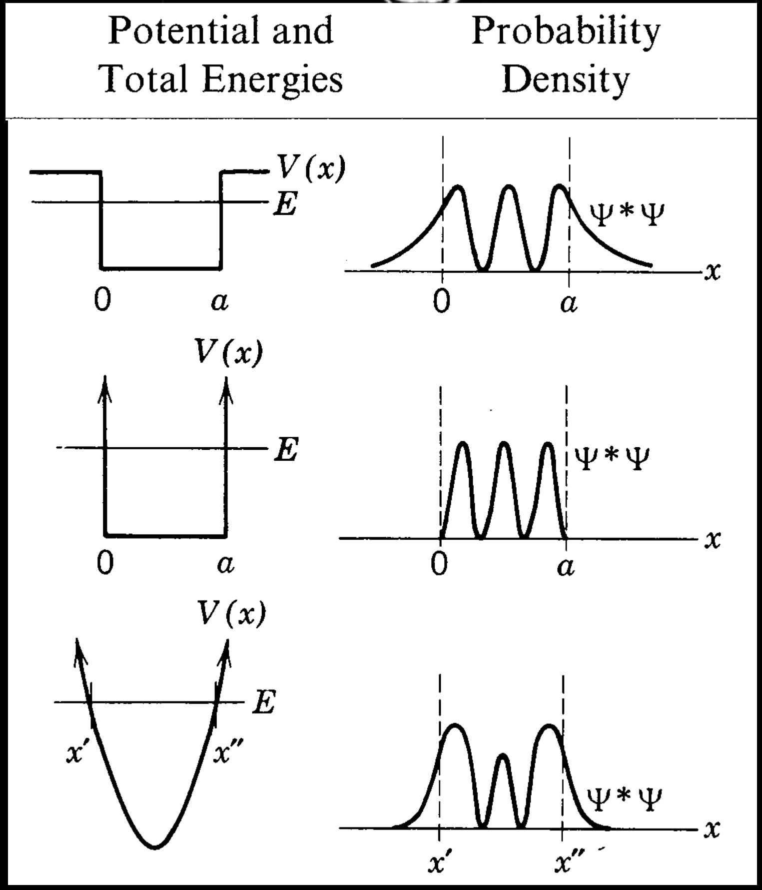
$$-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\psi(x,t) + \frac{1}{2}kx^2\psi(x,t) = E\psi(x,t)$$

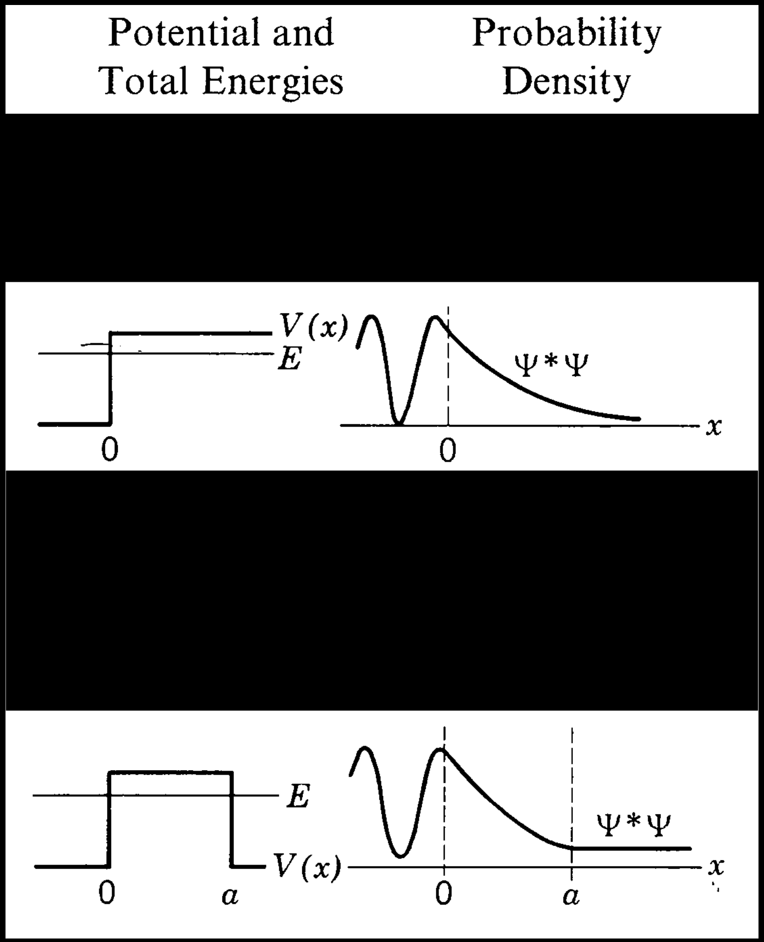
$$E = \left(n + \frac{1}{2}\right)\hbar\omega$$

$$E_o = \frac{1}{2}\hbar\omega$$

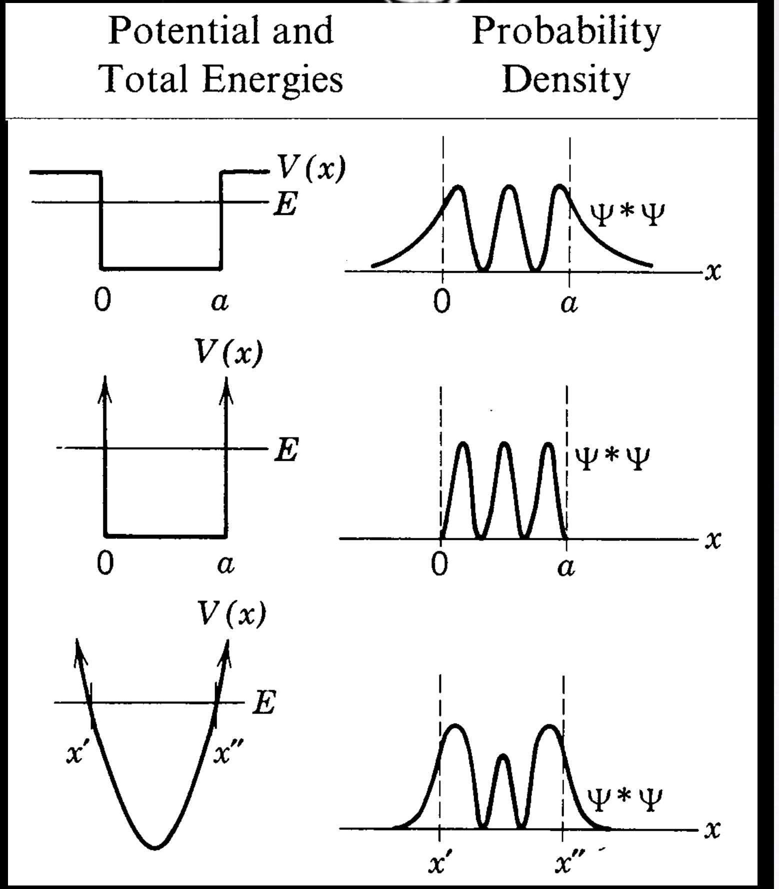


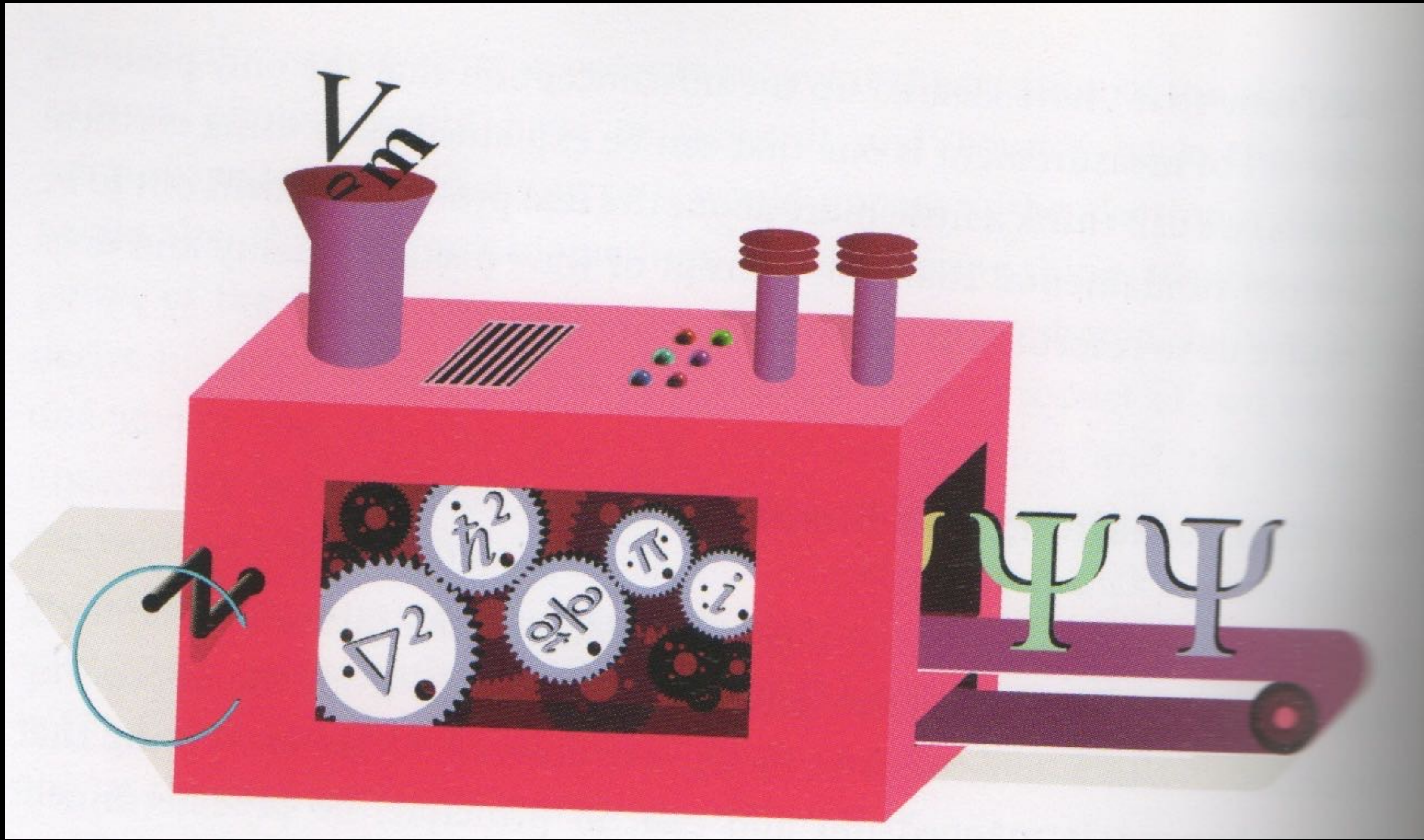
$$-\frac{\hbar^2}{2m}\frac{\partial^2\Psi(x,t)}{\partial x^2} + V(x,t)\Psi(x,t) = i\hbar\frac{\partial\Psi(x,t)}{\partial t}$$





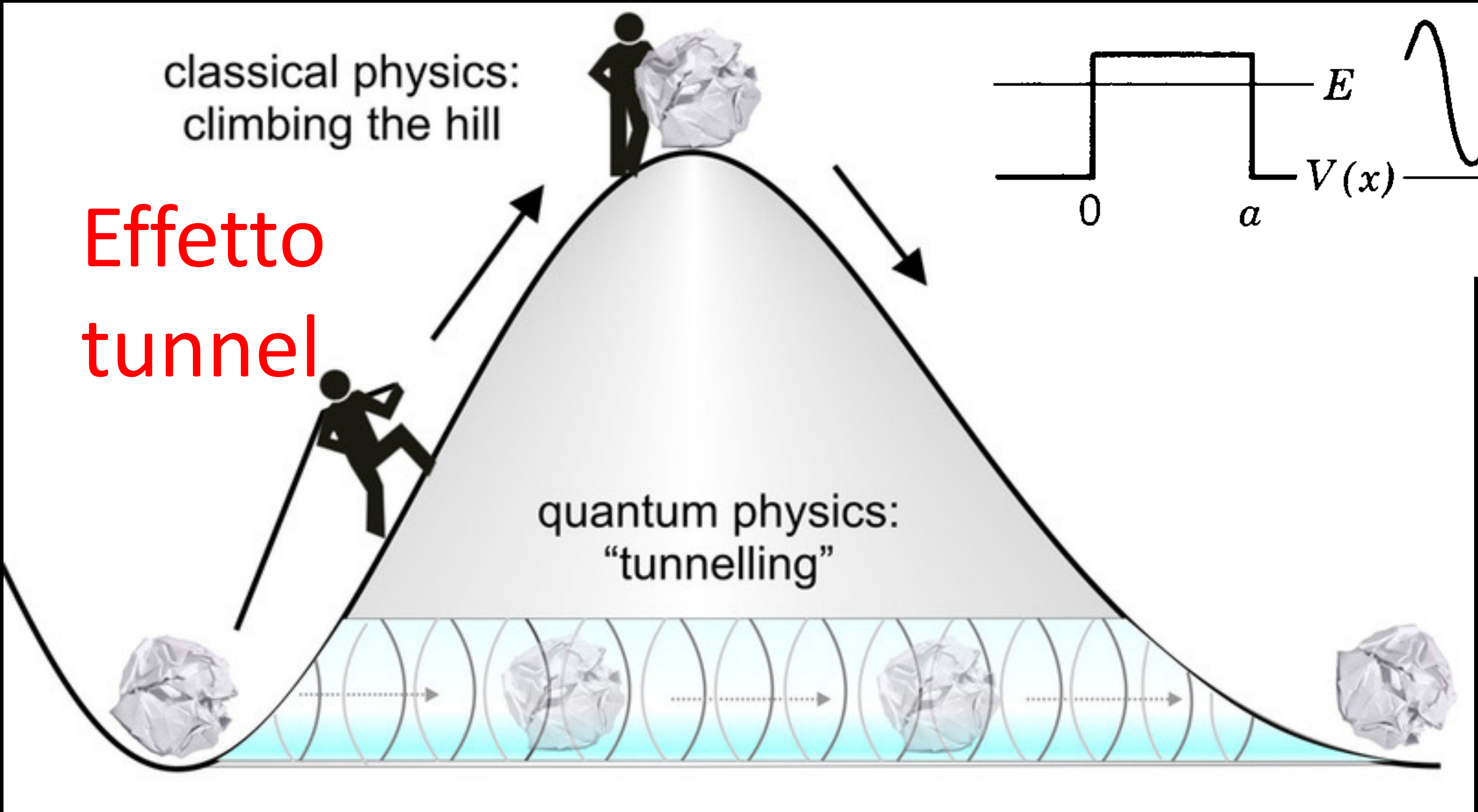
$$-\frac{\hbar^2}{2m}\frac{\partial^2\Psi(x,t)}{\partial x^2} + V(x,t)\Psi(x,t) = i\hbar\frac{\partial\Psi(x,t)}{\partial t}$$

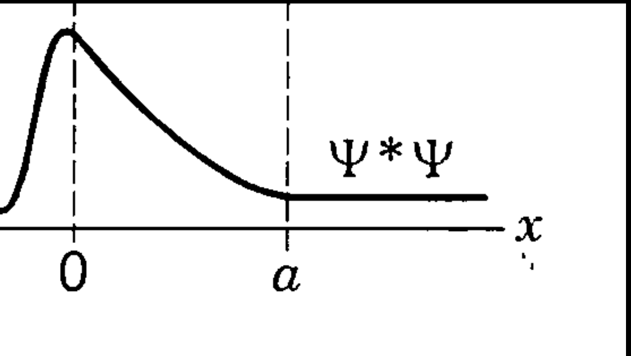


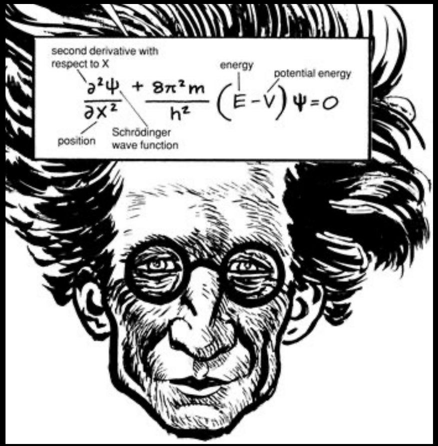


Le nuove regole del gioco

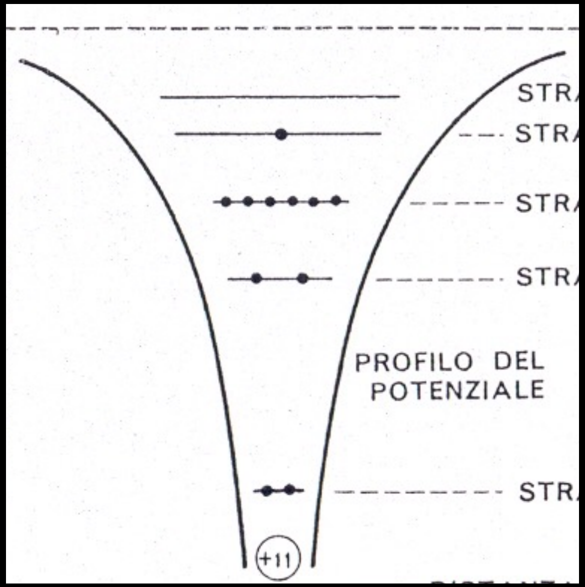
Effetto tunnel

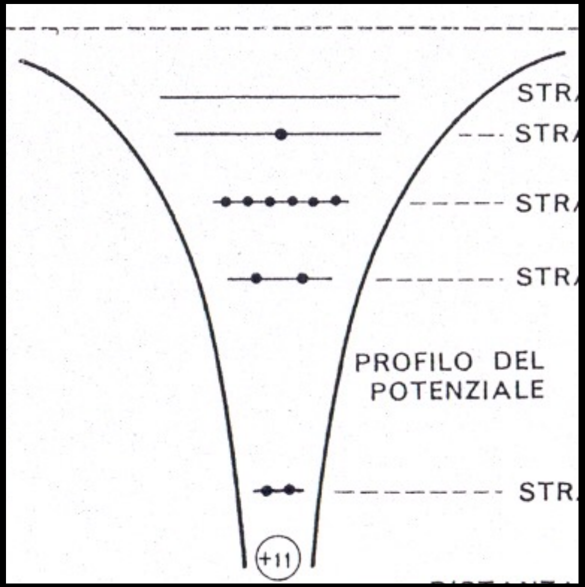


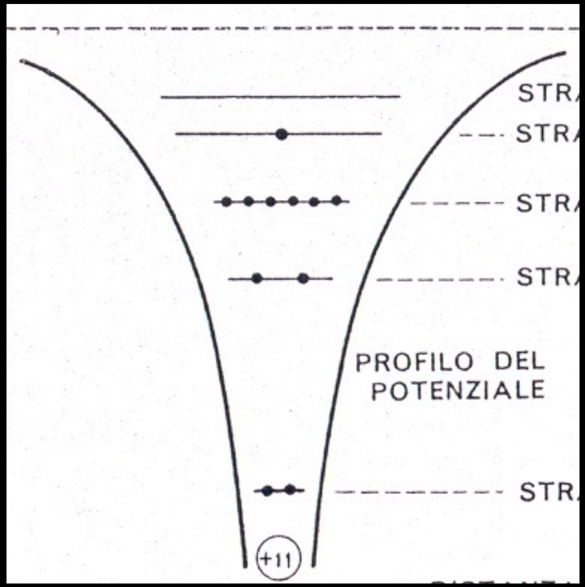




Pillole di meccanica quantistica nei solidi

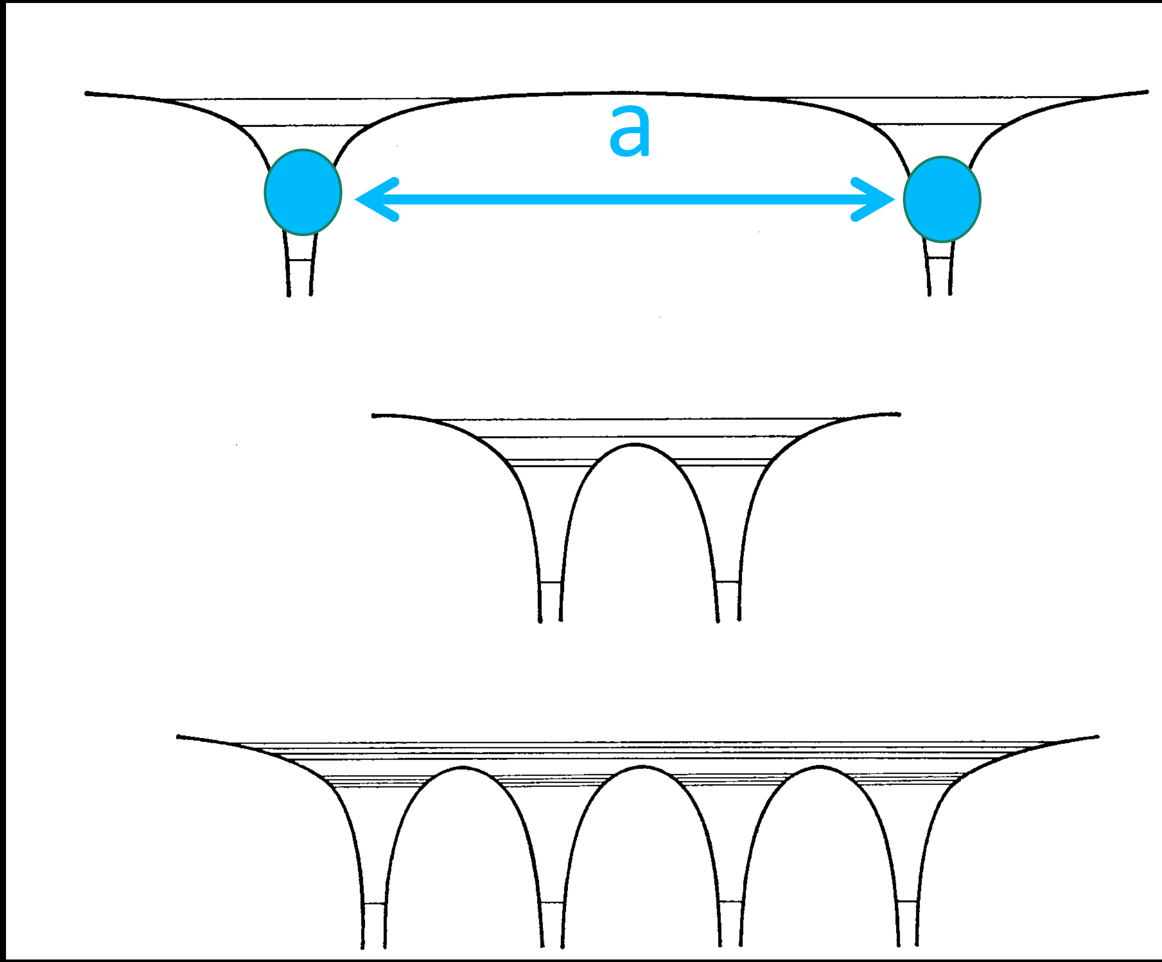




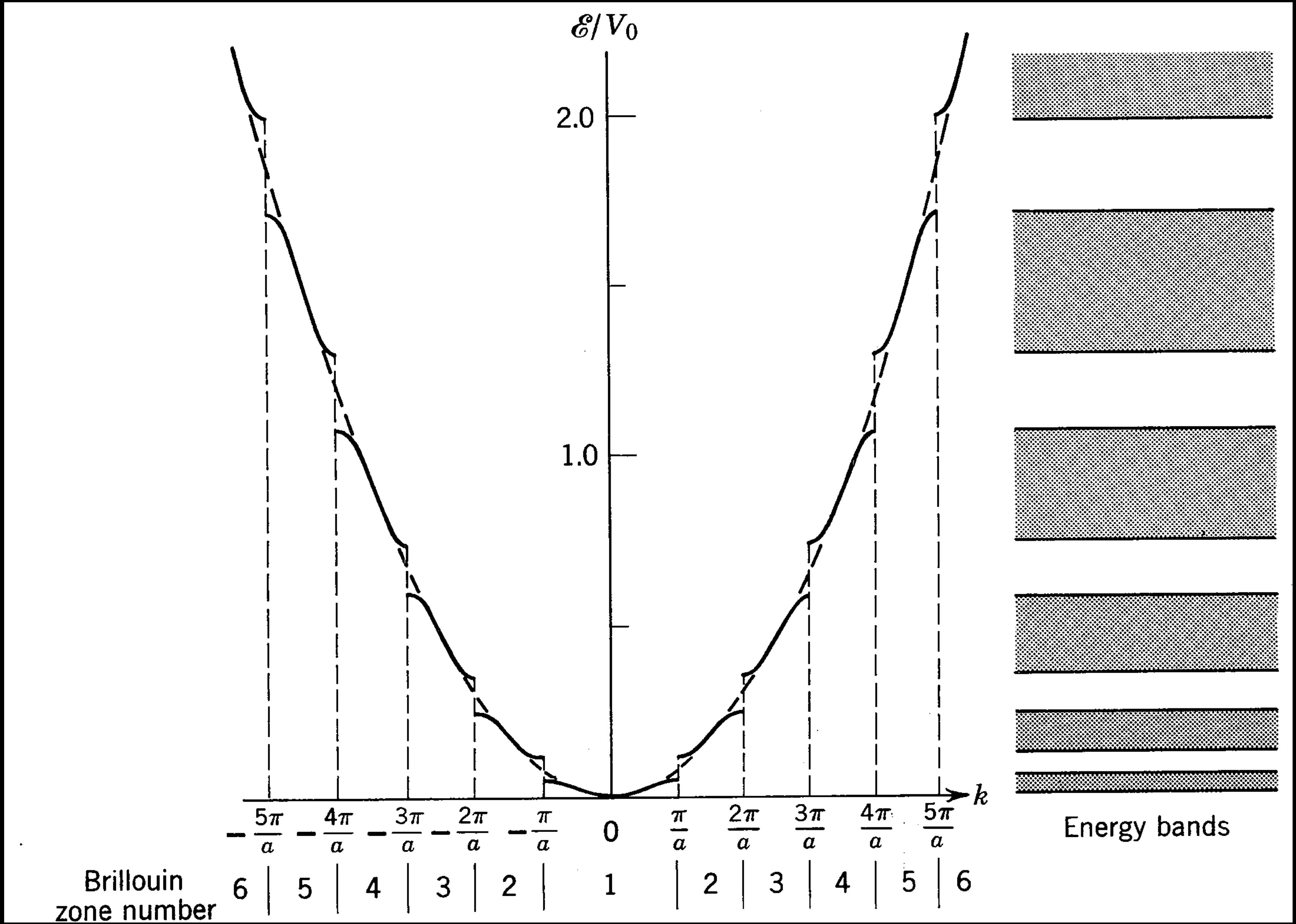


Pillole di meccanica quantistica nei solidi

$$-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\psi(x,t) + U(x)\psi(x,t) = E\psi(x,t) \quad \mathrm{U(x)=U(x+a)}$$



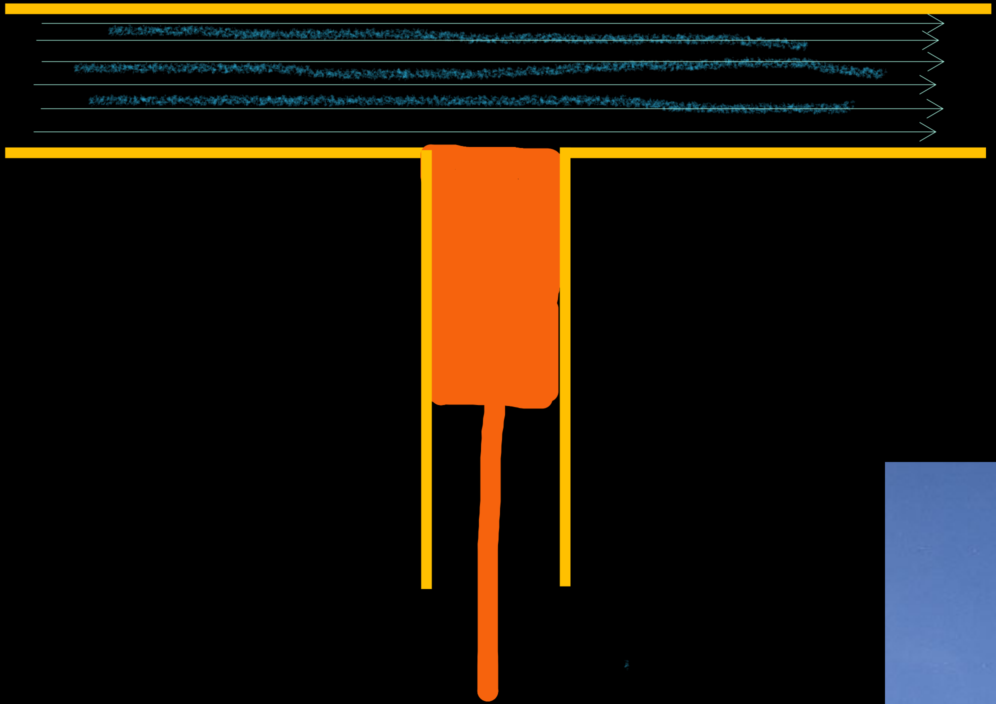
Onde che viaggiano nei cristalli …. Non a tutte le energie

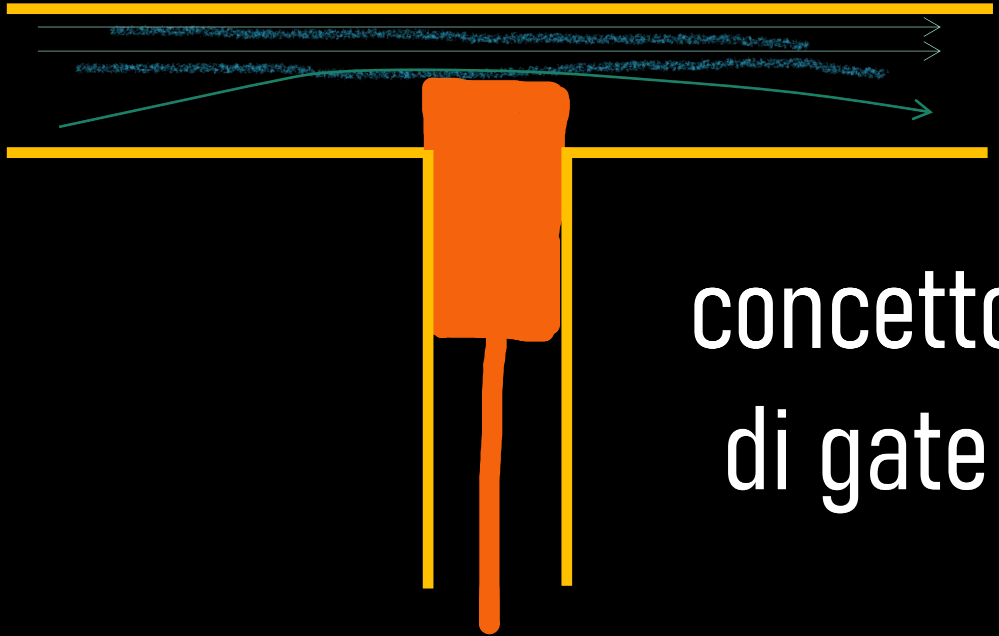


Il principio di un processore «classico»

Il core. E' il circuito integrato (chip) della CPU, realizzato con la tecnologia VLSI (Very Large Scale Integration). Il circuito integrato è formato da migliaia di micro componenti elettronici (transistor, condensatori, diodi e resistori) collegati tra loro. Il core è collocato su una piastra di un materiale semiconduttore, in genere il silicio.

Il transistor, dispositivo a tre terminali





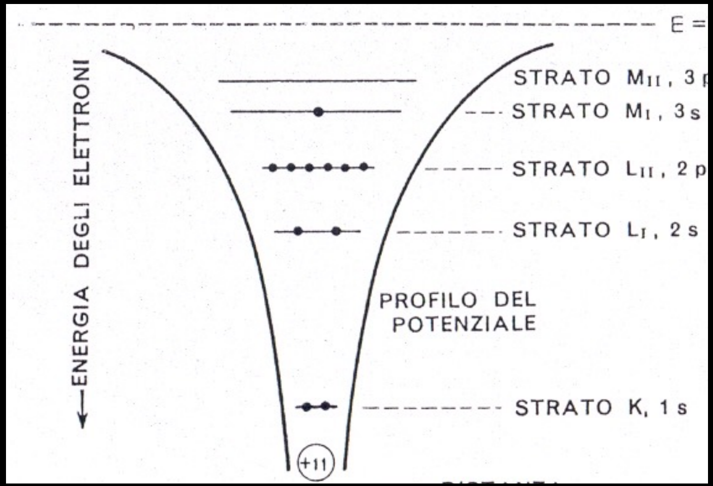
concetto di gate

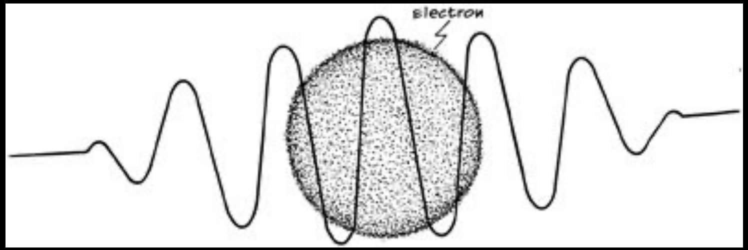
"TRANSferring" e "resISTOR".
dicembre del 1947 Bell Labs: Walter Brattain, John Bardeen, William Shockley.

Nel 1956, i tre ricercatori furono insigniti del premio Nobel per la Fisica, con la motivazione «per le ricerche sui semiconduttori e per la scoperta dell'effetto transistor»

Pillole di meccanica quantistica

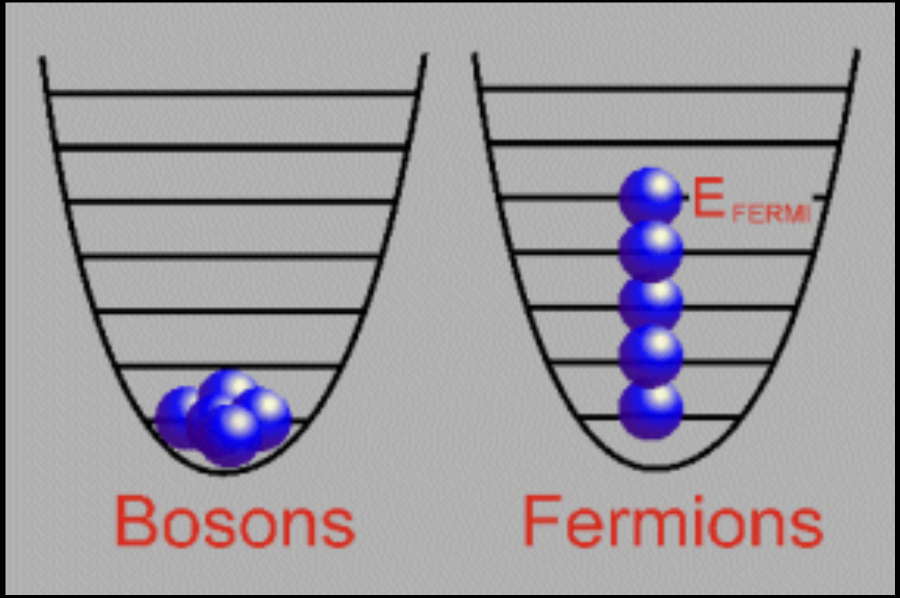
Le nuove regole del gioco

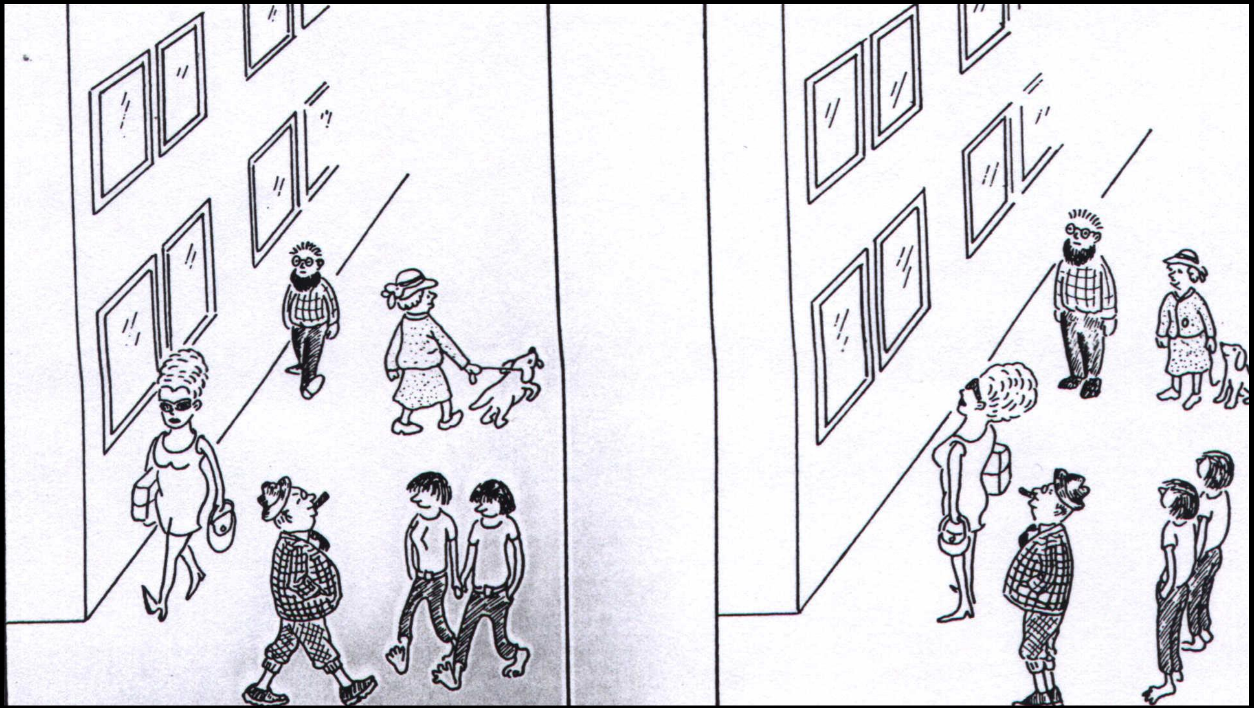




Principio di indeterminazione, posizione-quantità di moto, energia-tempo

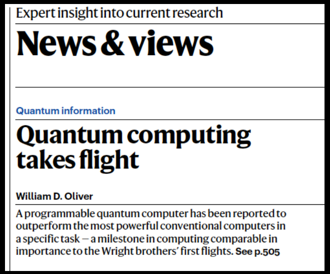
Regole di quantizzazione





Non sono tutti elettroni,
i condensati per esempio

Sfera di Bloch


Expert insight into current research

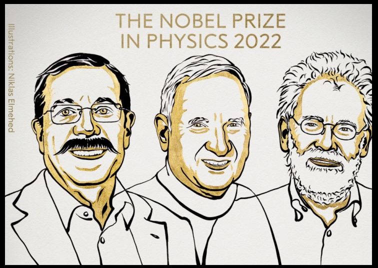
News & views

Quantum information

Quantum computing takes flight

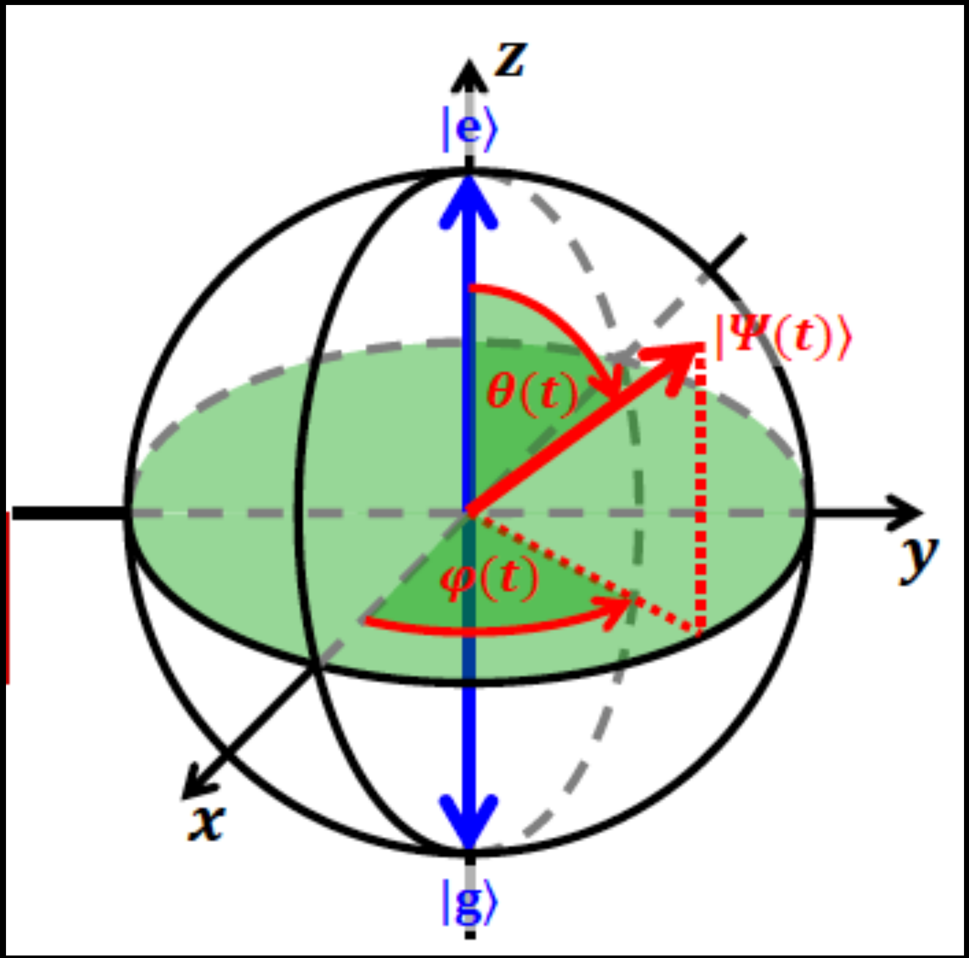
William D. Oliver

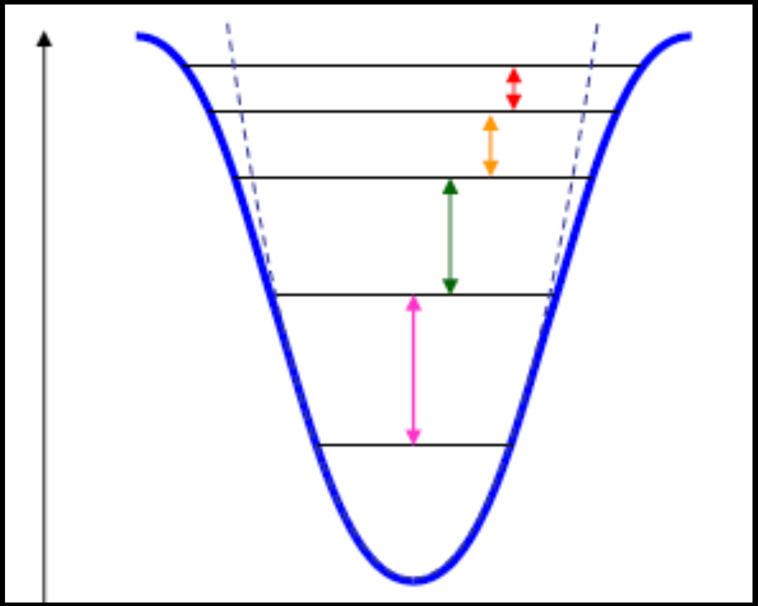
A programmable quantum computer has been reported to outperform the most powerful conventional computers in a specific task – a milestone in computing comparable in importance to the Wright brothers' first flights. See p.505



Bit classico stato «e» o «g»,
come stare al Polo Nord o al Polo Sud

Bit quantistico, sovrapposizione di «e» o «g»,
qualsiasi punto sulla superficie terrestre

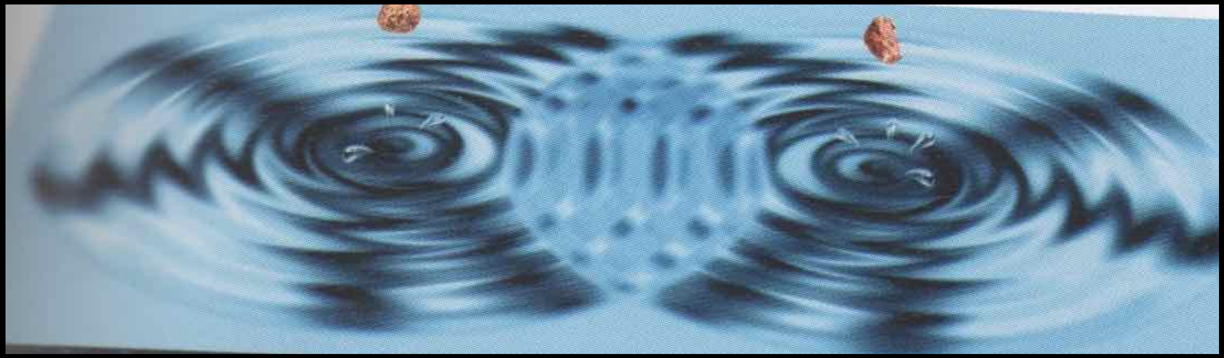




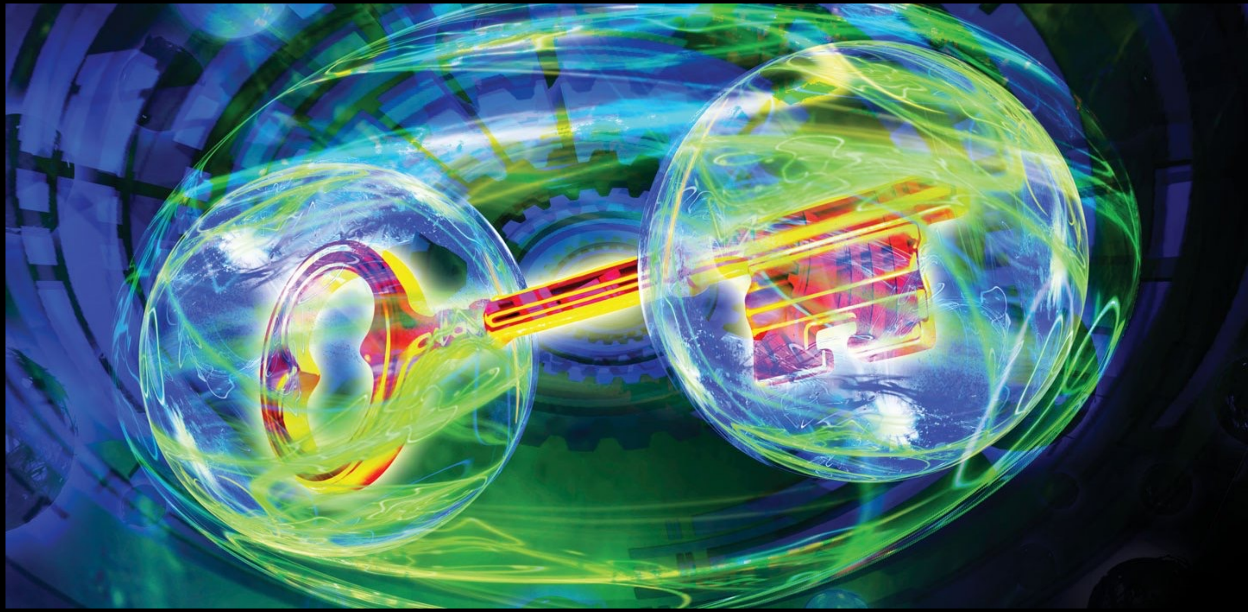
Codifica dell'informazione,
elaborazione dell'informazione

Proprietà dei quantum bit

la sovrapposizione di stati (possono essere contemporaneamente 0 e 1) grazie alla quale si possono fare calcoli paralleli anziché sequenziali come avviene oggi con la capacità computazionale dei computer “tradizionali”;



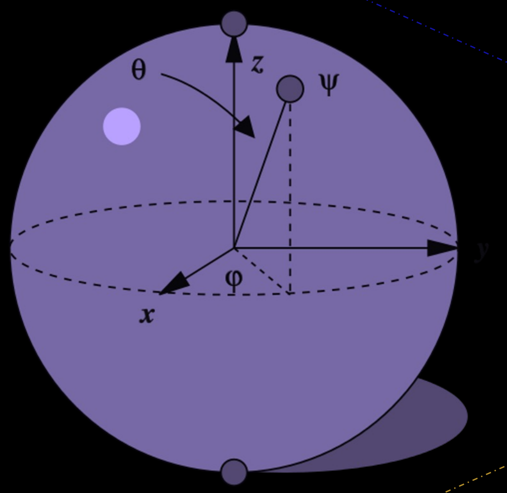
l’entanglement, cioè la correlazione (il legame) che c’è tra un qubit ed un altro, aspetto molto importante perché è da qui che deriva una forte accelerazione nel processo di calcolo grazie all’influenza che un qubit può produrre su un altro anche se distante;



Implementazione fisica?

The quantum logical bit: the qubit

$|1\rangle$

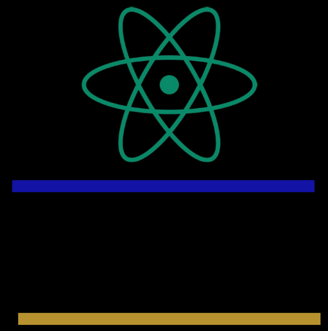


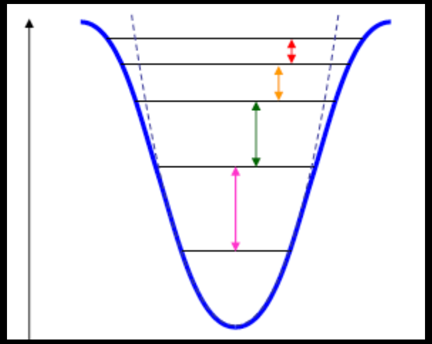
$|0\rangle$

Encoding

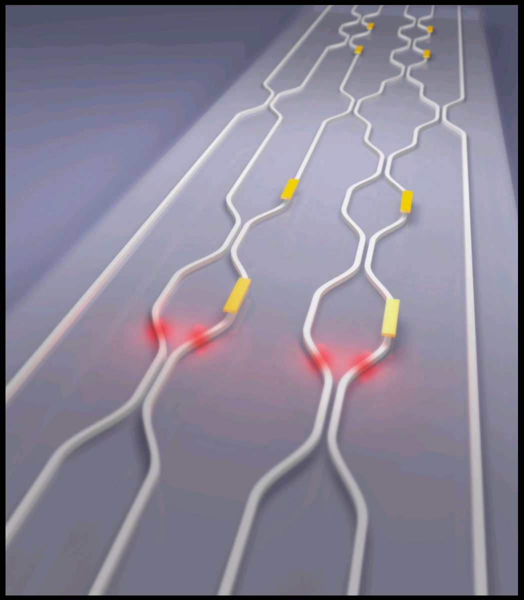
Encoding

Quantum 2-level systems

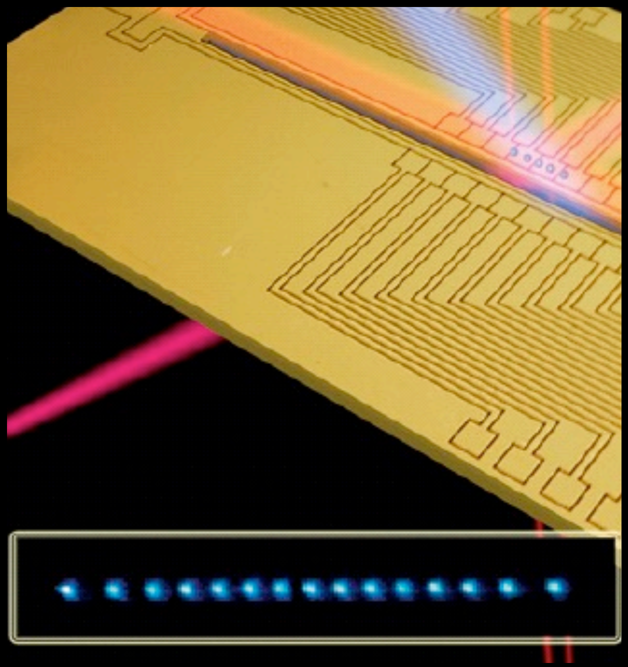




Fotoni

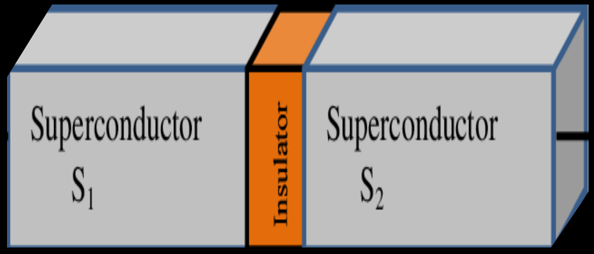


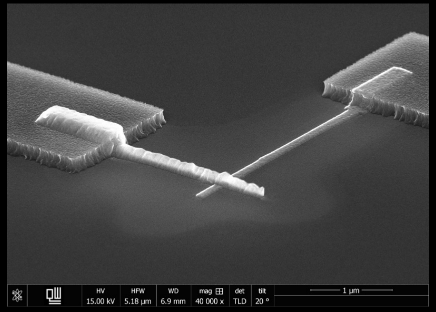
Ioni (o atomi) intrappolati



GiunzioneJosephson = atomo artificiale macroscopico

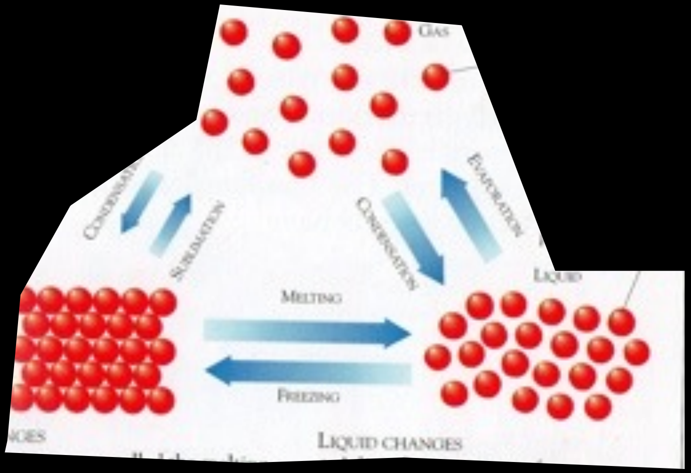
$\longleftarrow 10^{-6} - 10^{-9} m \longrightarrow$





Passaggi di stato

per esempio cambiando la temperatura



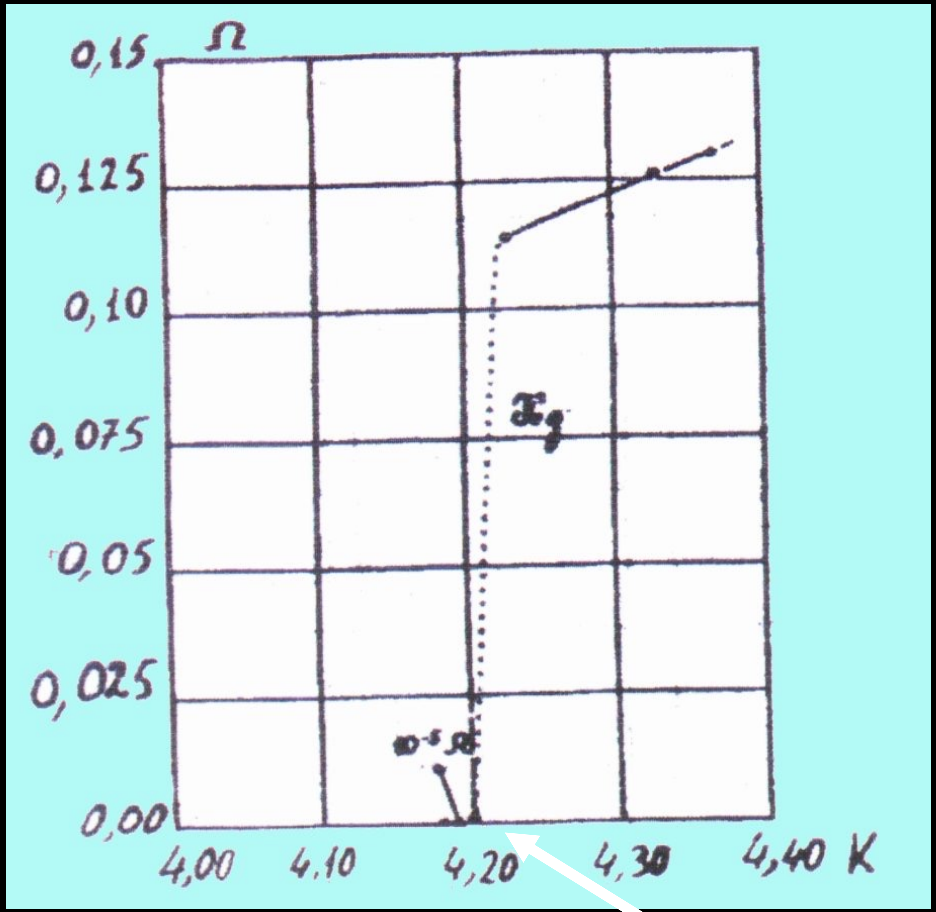
ghiaccio=solido

acqua=liquido

vapore =gas

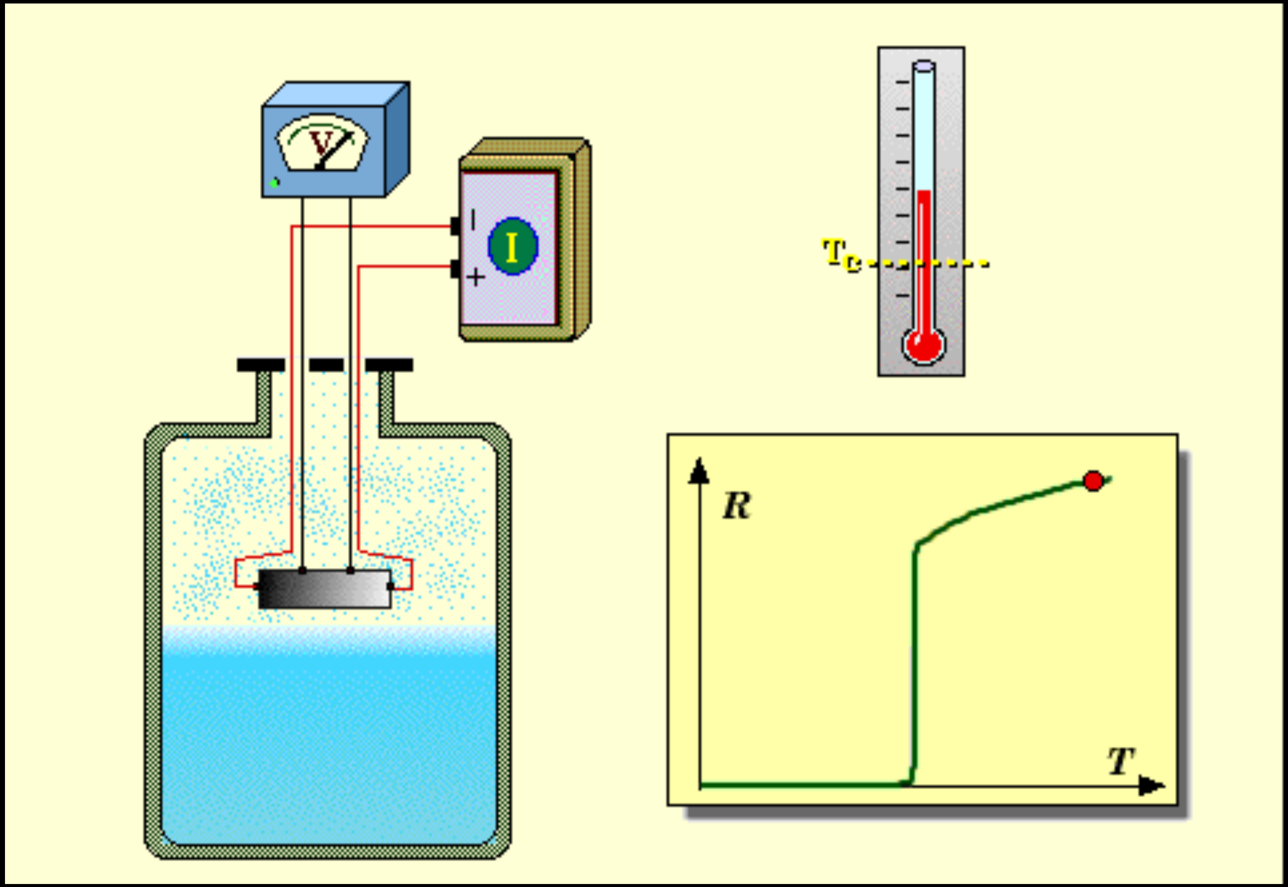
Superconduttività, resistività nulla

Resistenza (Ω)



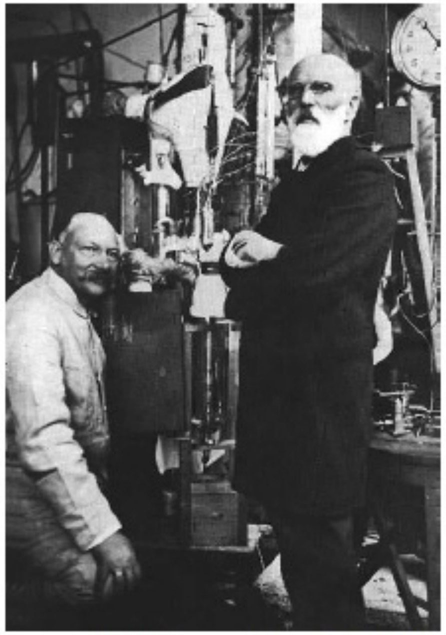
Temperatura (K)

-269 °C



Heike Kammerlingh Onnes (1853-1926)

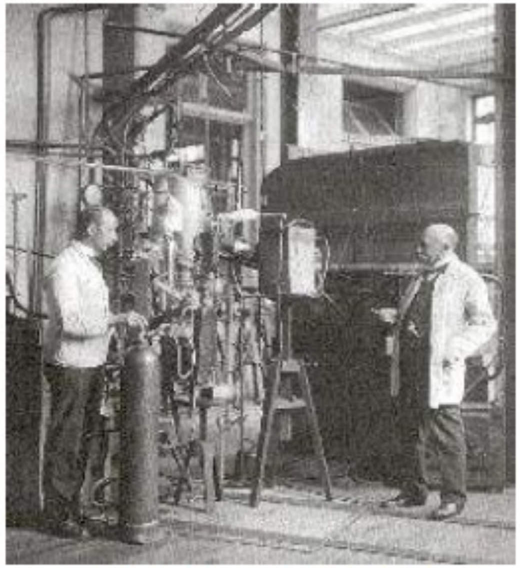
Heike Kamerlingh Onnes (*far right*) shows his helium liquefactor to three theoretical physicists: Niels Bohr (visiting from Kopenhagen), Hendrik Lorentz, and Paul Ehrenfest (*far left*).



Kammerlingh Onnes and van der Waals

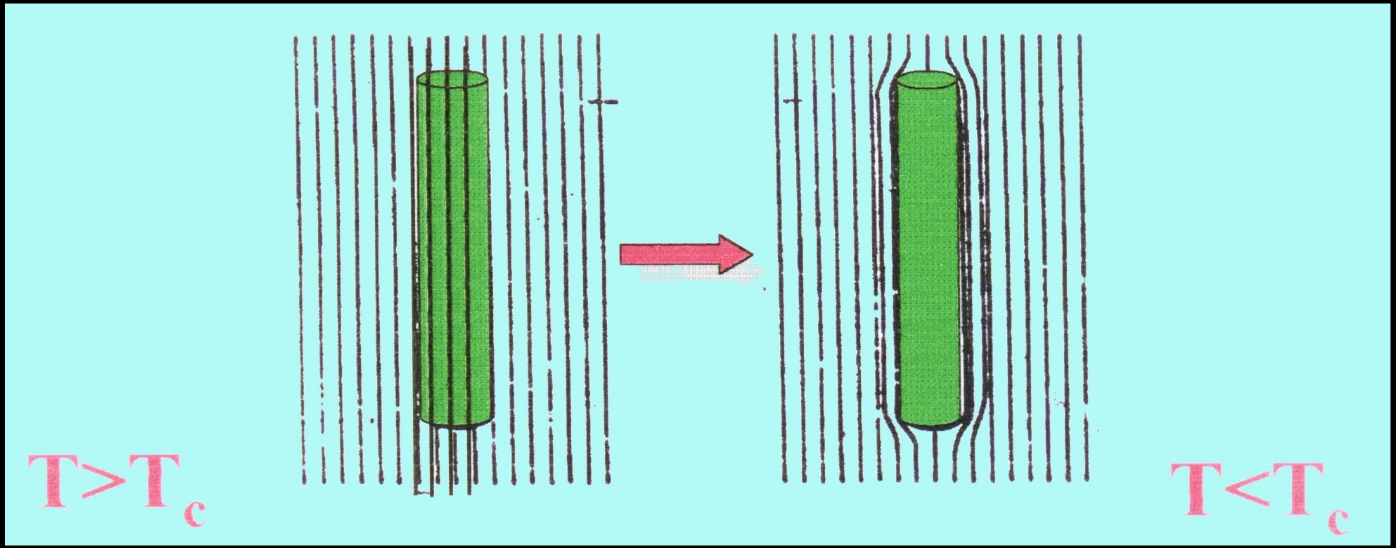
Nobel Prize in Physics

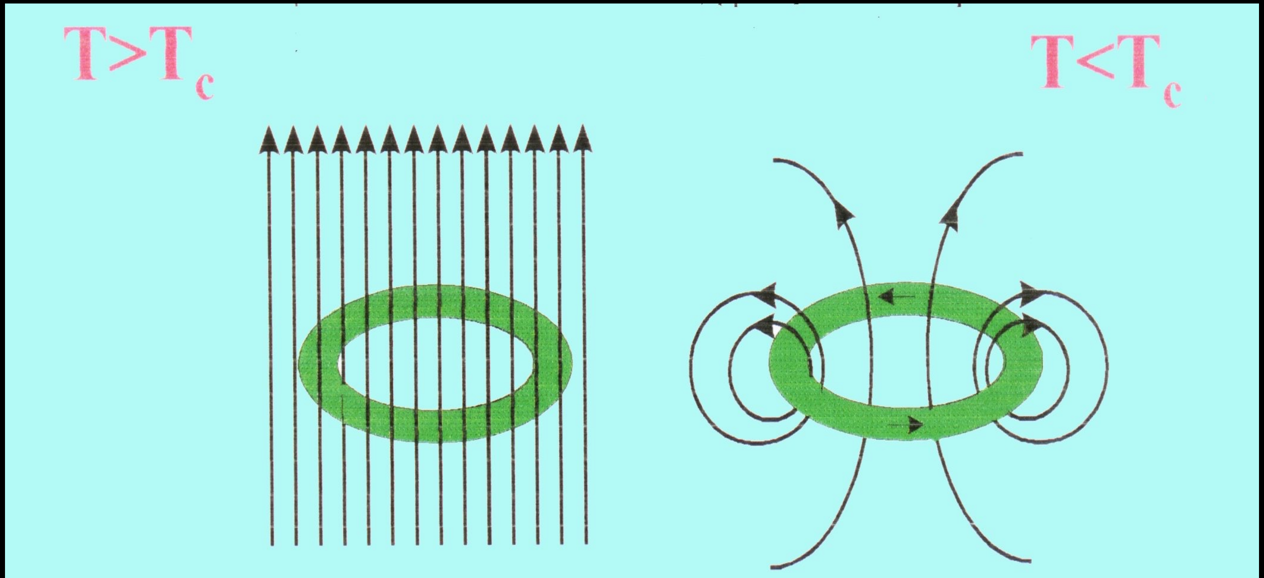
Prof. Heike Kamerlingh Onnes and his wife with some colleages among them their friend Albert Einstein (*standing behind Mrs. Kamerlingh Onnes*), ca. 1920.



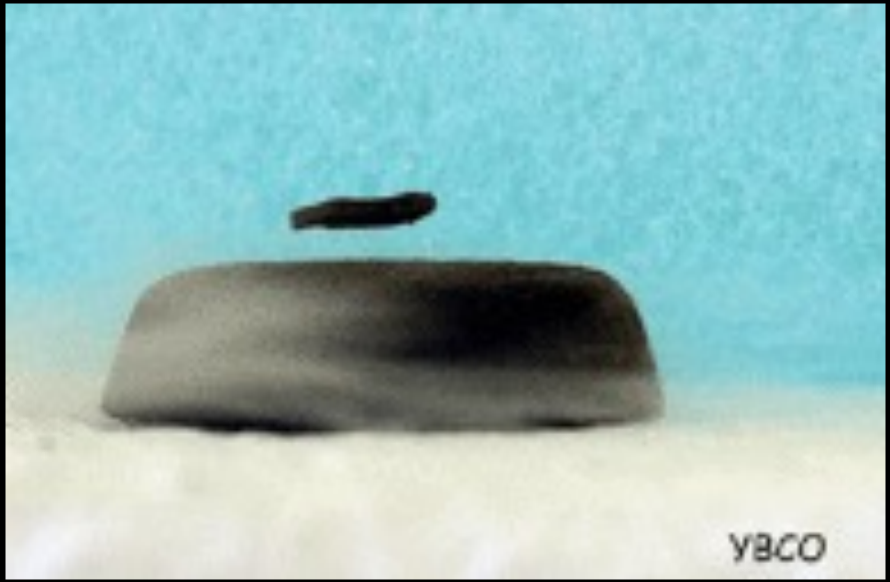
Kammerlingh Onnes and Techniker Flim

Superconduttività, diamagnetismo perfetto

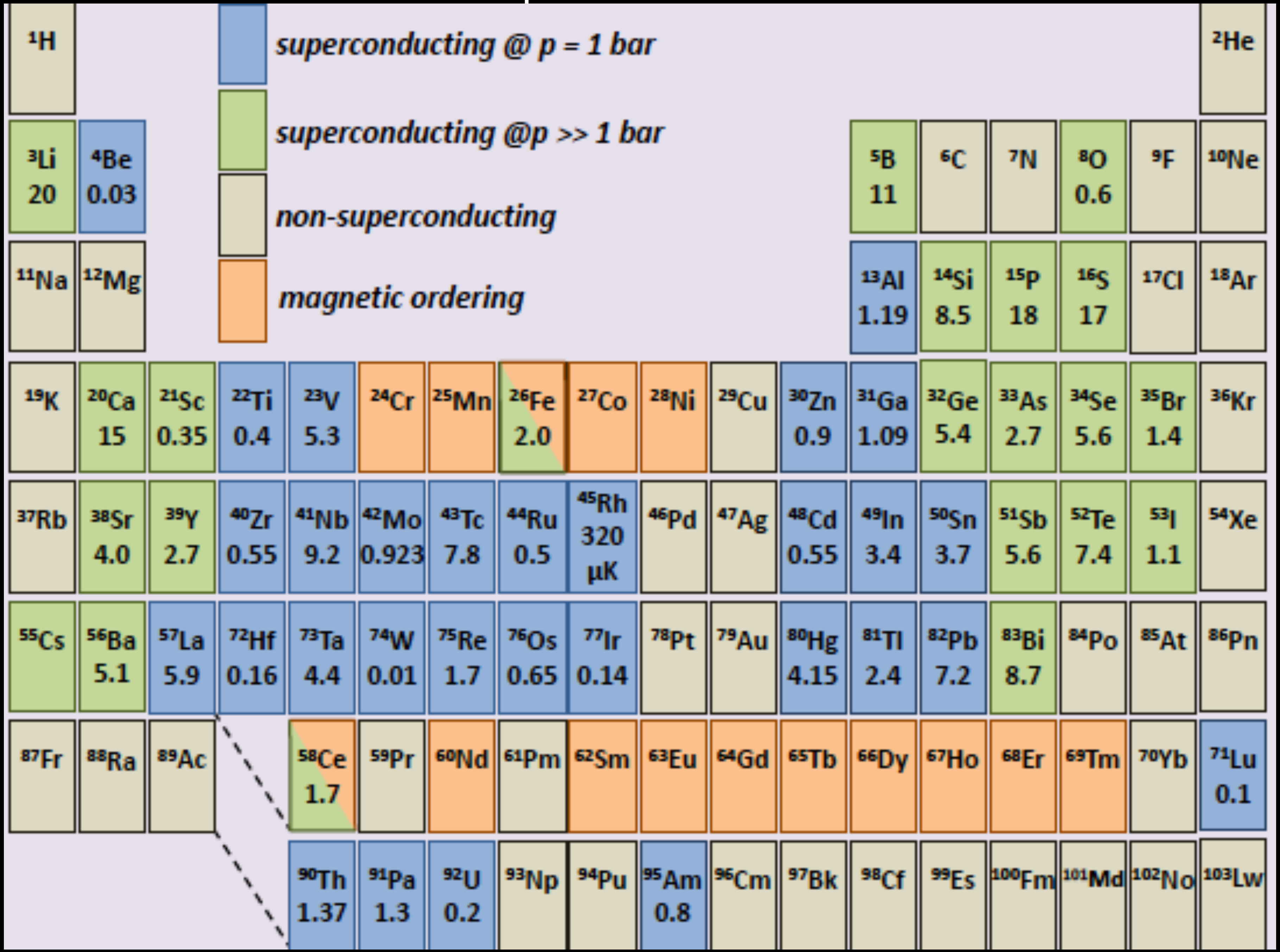




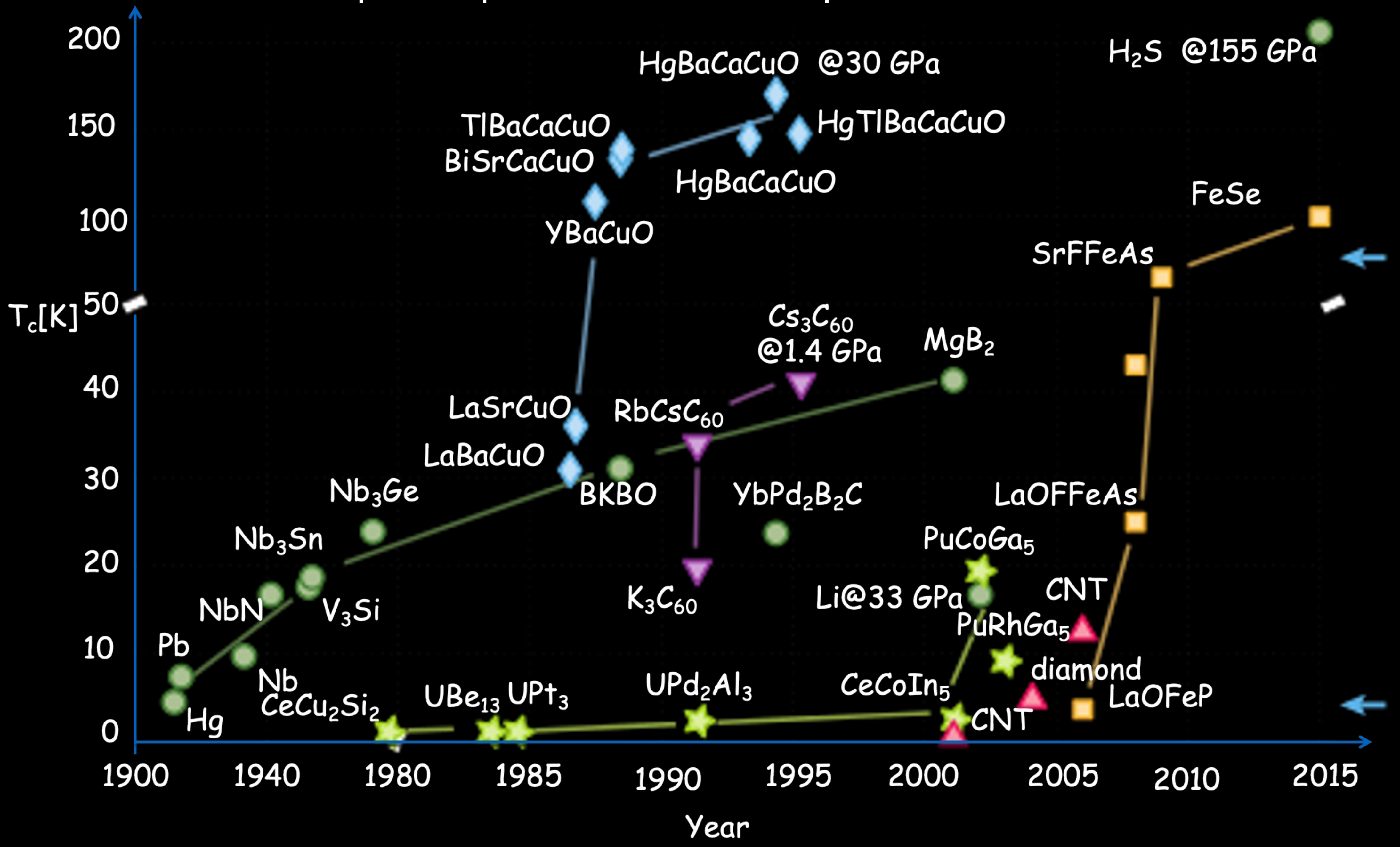
Per esempio
Levitazione magnetica



Elementi superconduttivi

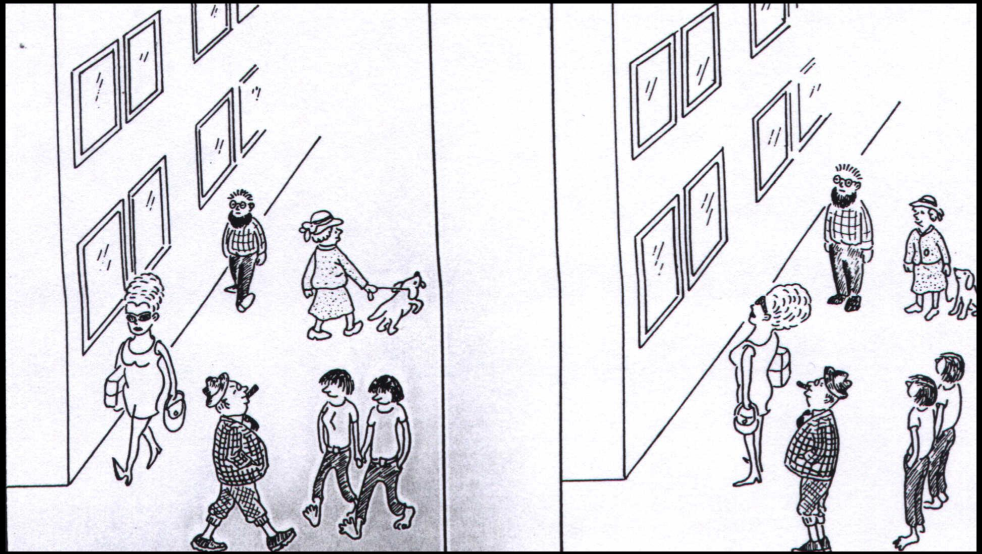


Composti superconduttivi nel tempo

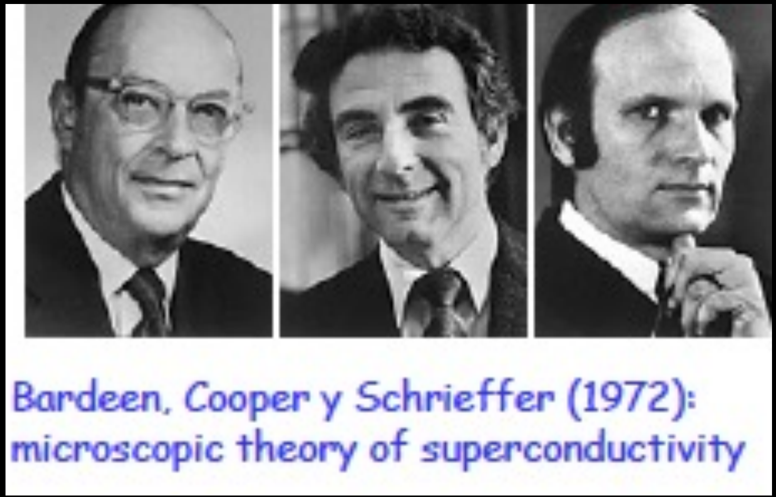


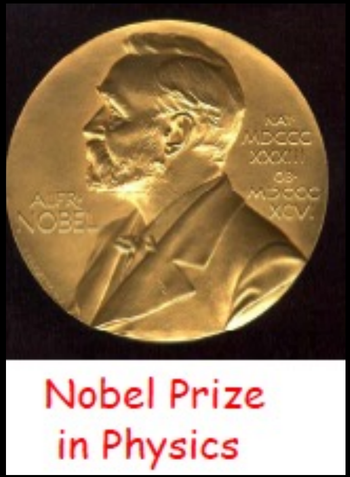
La teoria BCS, le coppie di Cooper e il ruolo del reticolo

Formazione coppie di Cooper

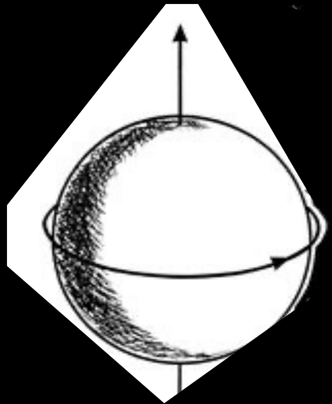


Condensato di Bose





$$\Psi_s = |\Psi_s| e^{i\varphi_s}$$

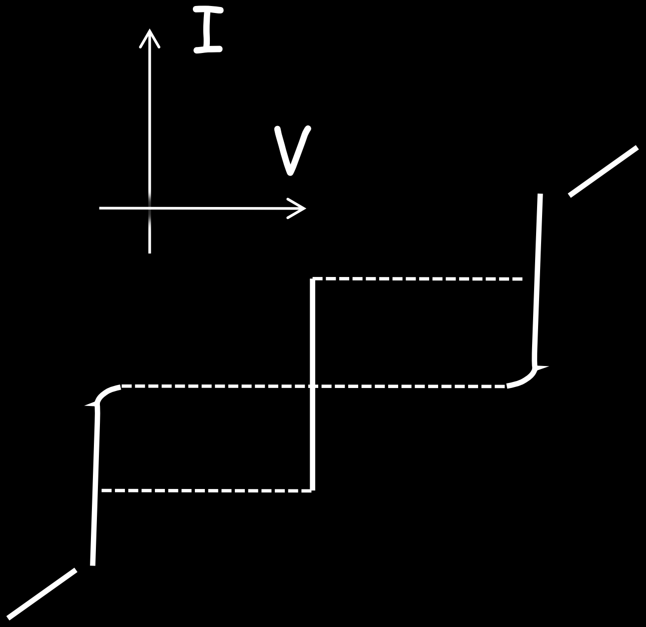


superconduttore = atomo macroscopico

Giunzione Josephson

$$\begin{cases} I_S(\varphi) = I_c \sin\varphi \\ \dfrac{\partial\varphi}{\partial t} = \dfrac{2eV}{\hbar} \end{cases}$$

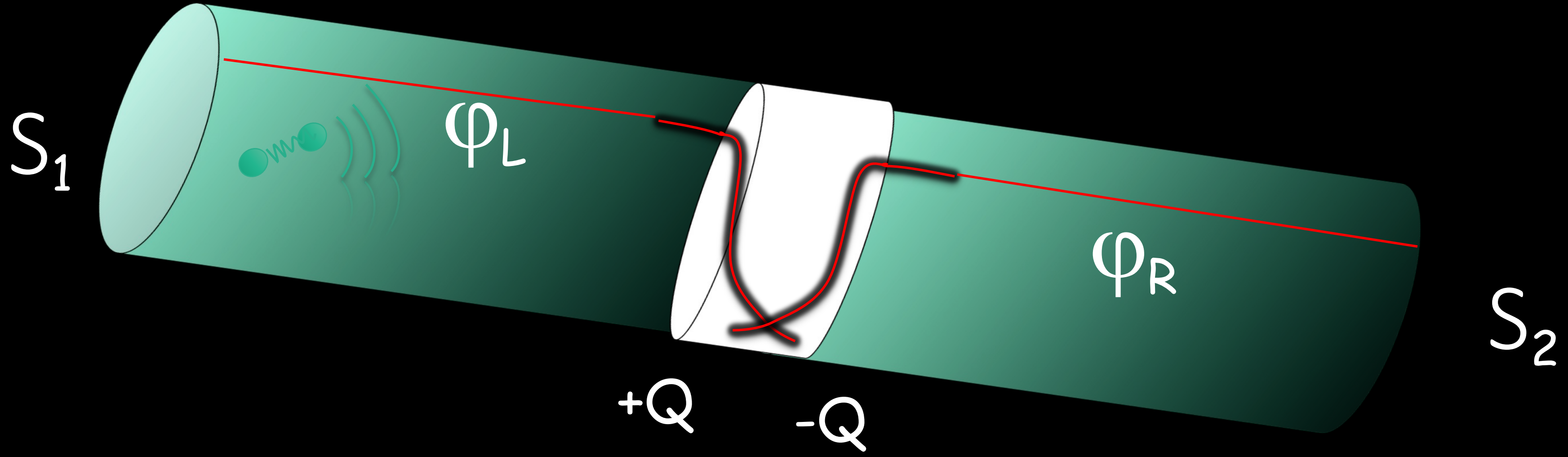
$$\varphi = \varphi_L - \varphi_R$$



Giaever y Josephson (1973): tunnelling in superconductors and Josephson´s effects

Nobel Prize in Physics

$$\mathrm{H} = E_c - E_J \cos\varphi - \frac{\hbar}{2e} I\varphi$$



$$E_J = \frac{\hbar I_c}{2e}$$

$$E_c = \frac{(2en)^2}{2C}$$

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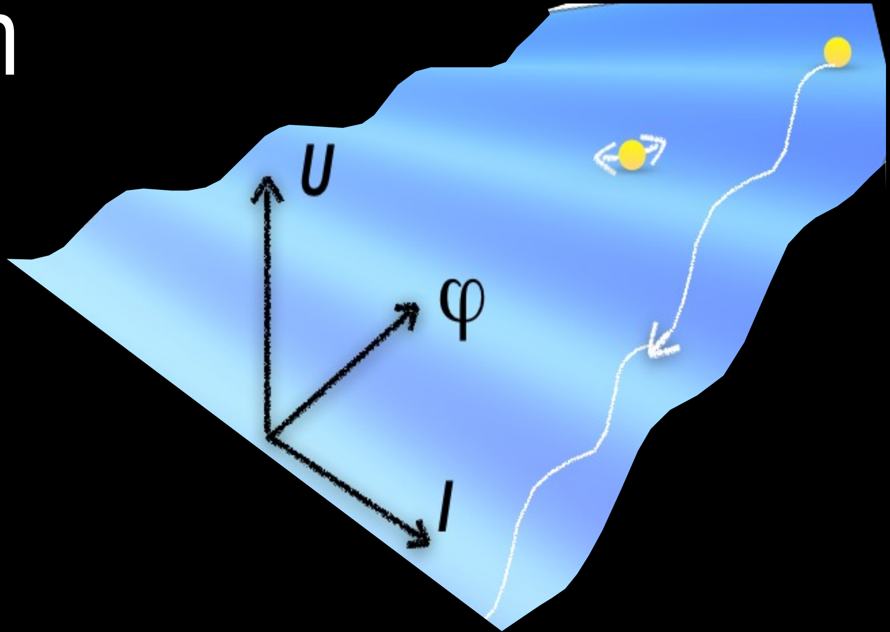
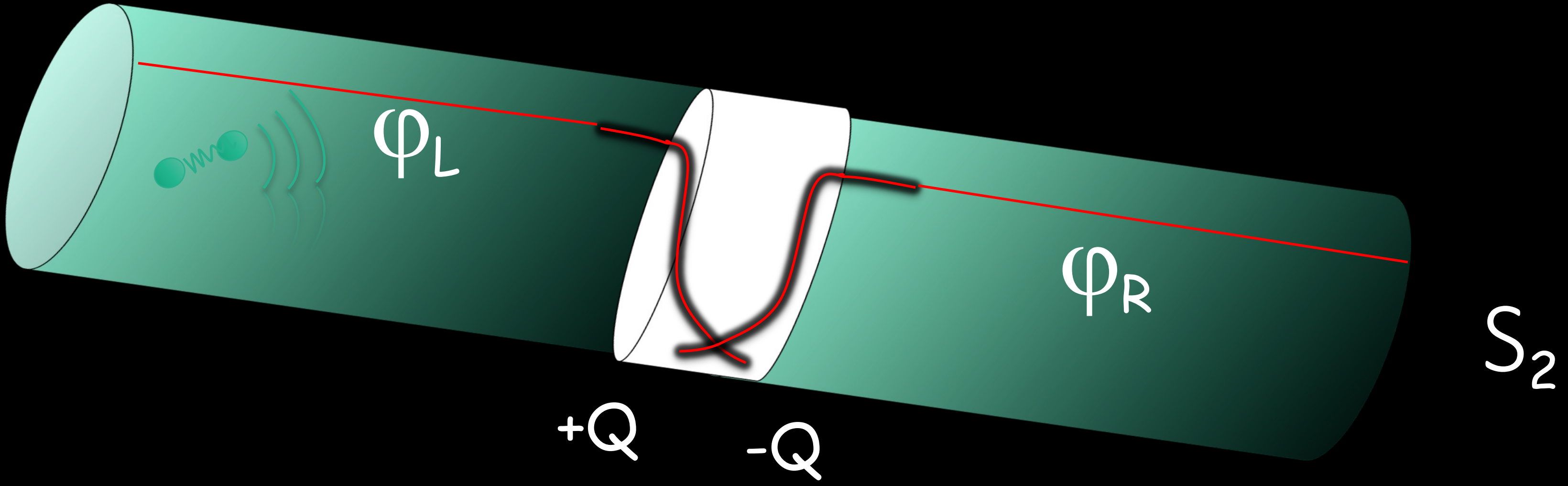


$$H_\varphi = \cancel{E_c} - E_J\cos\varphi - \frac{\hbar}{2e} I\varphi$$



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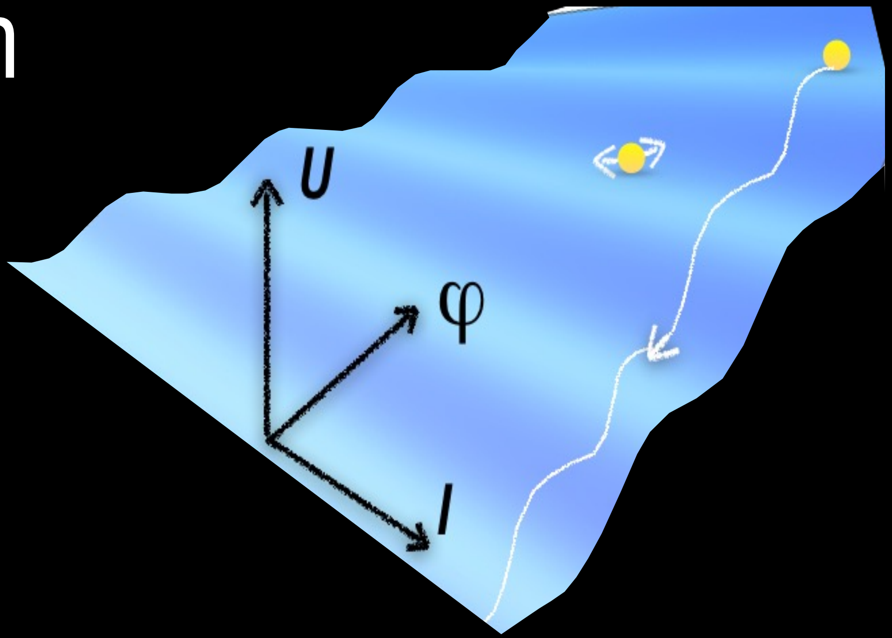
Giunzione Josephson



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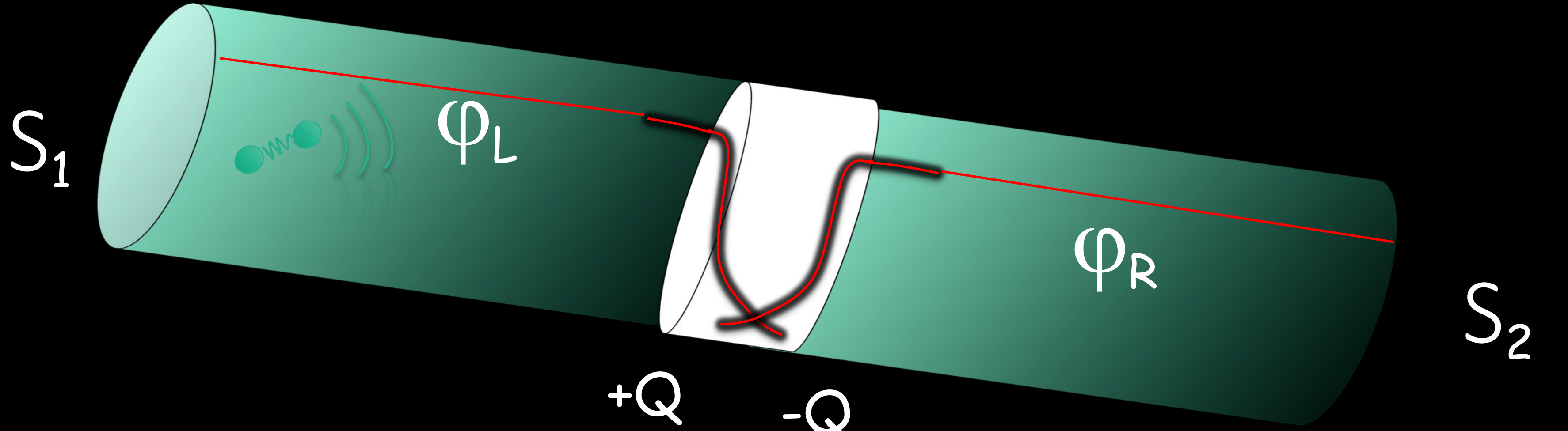

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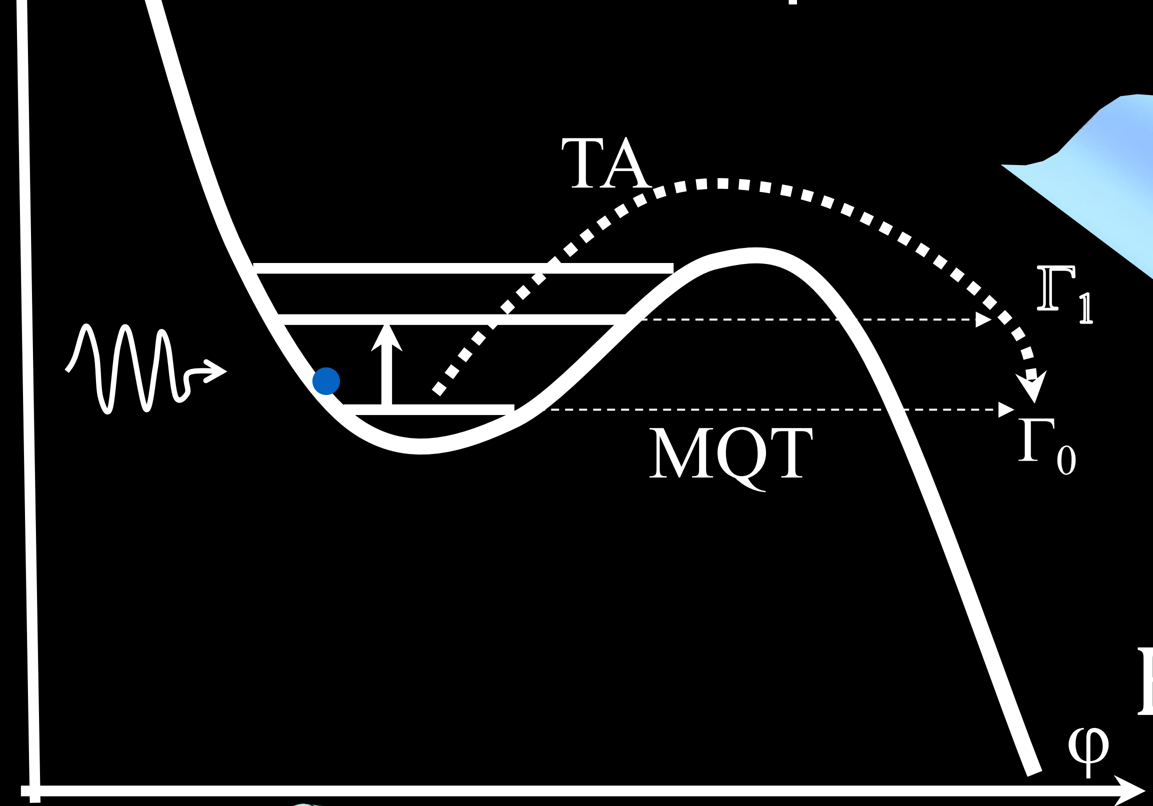
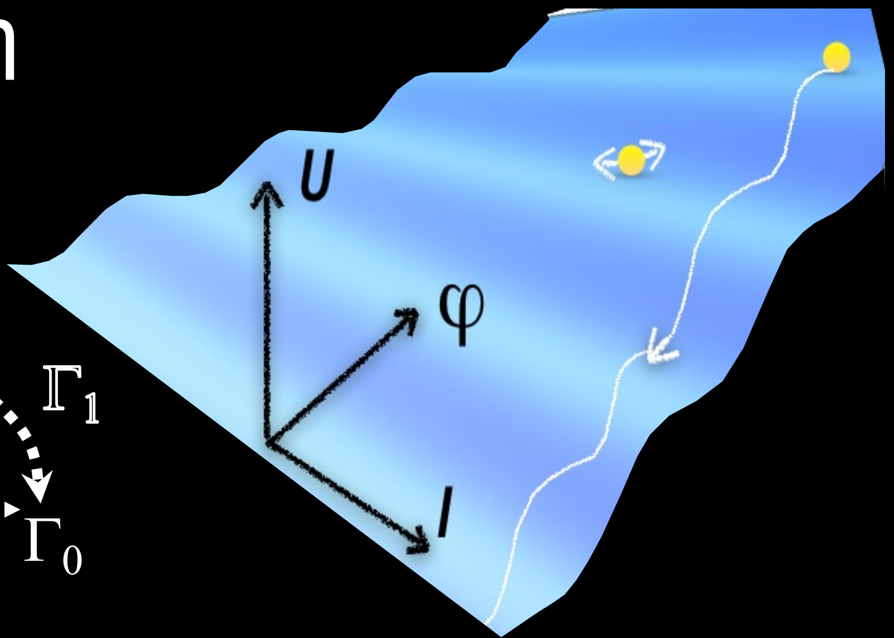
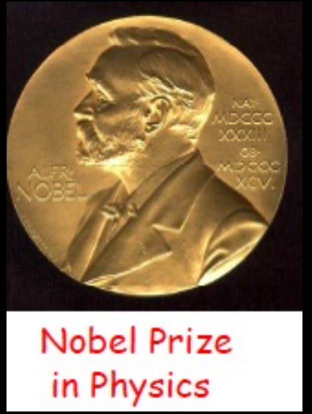
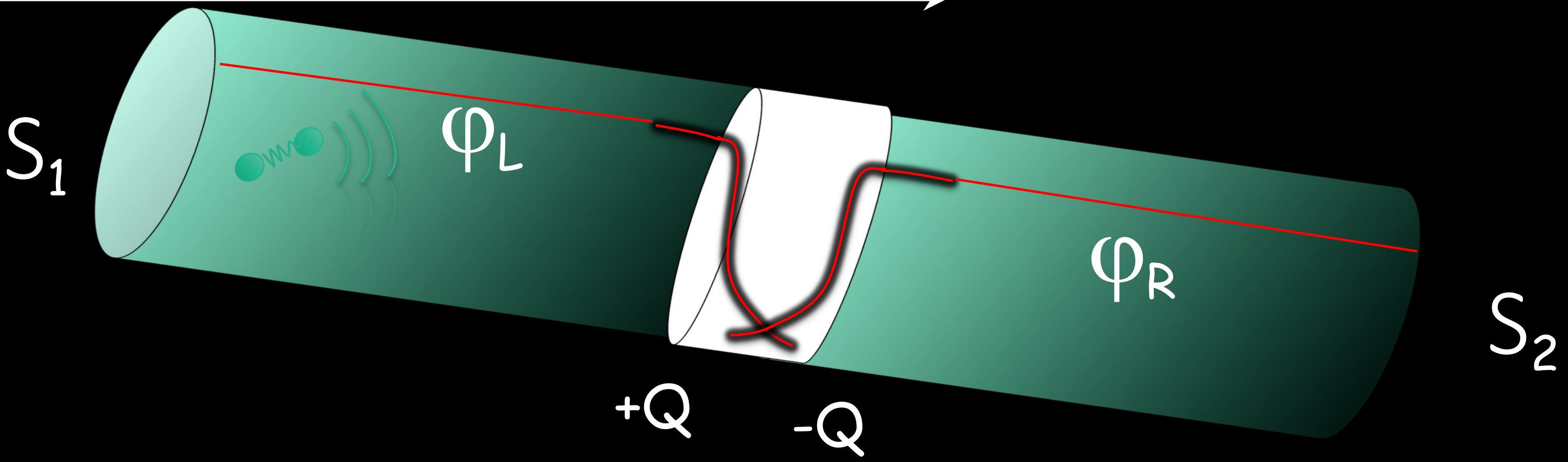
Giunzione Josephson







$$H = \cancel{E_c} - E_J \cos\varphi - \frac{\hbar}{2e} I\varphi$$



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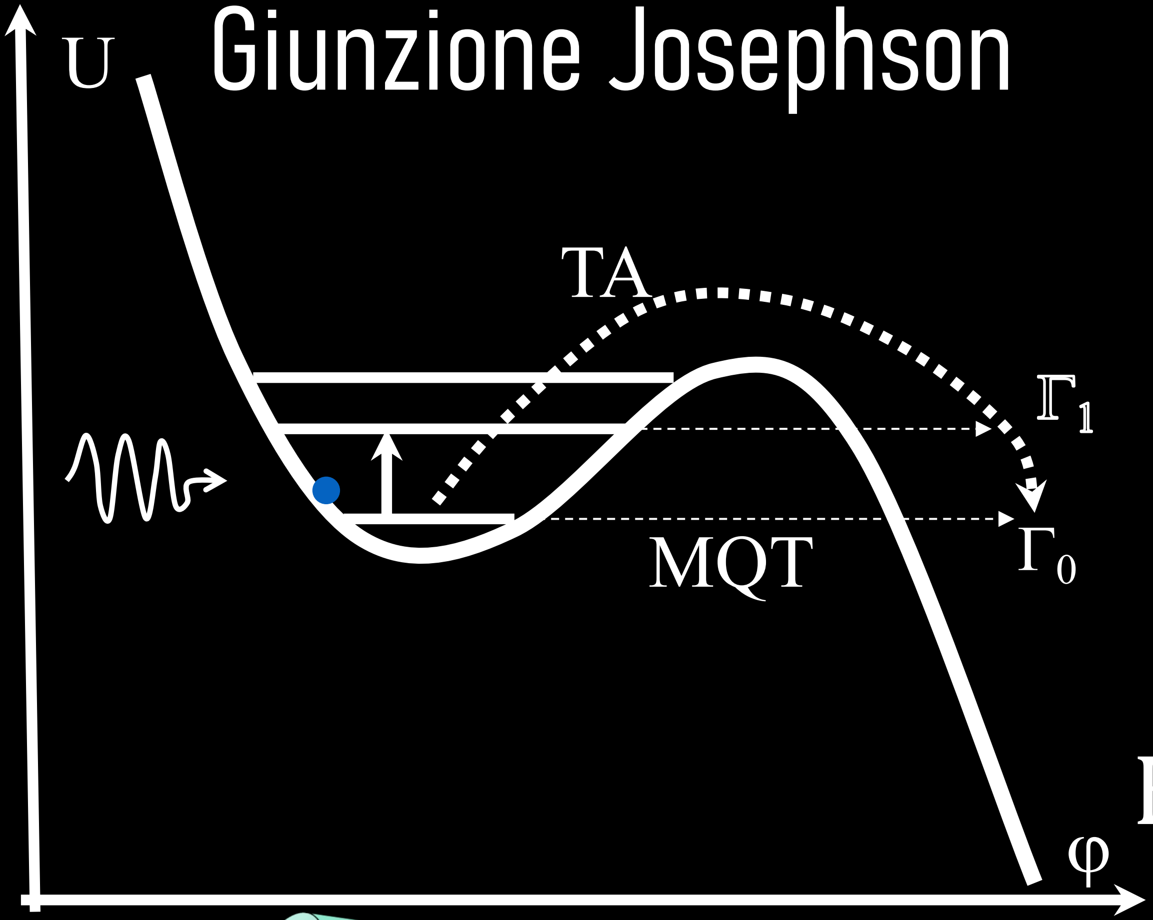
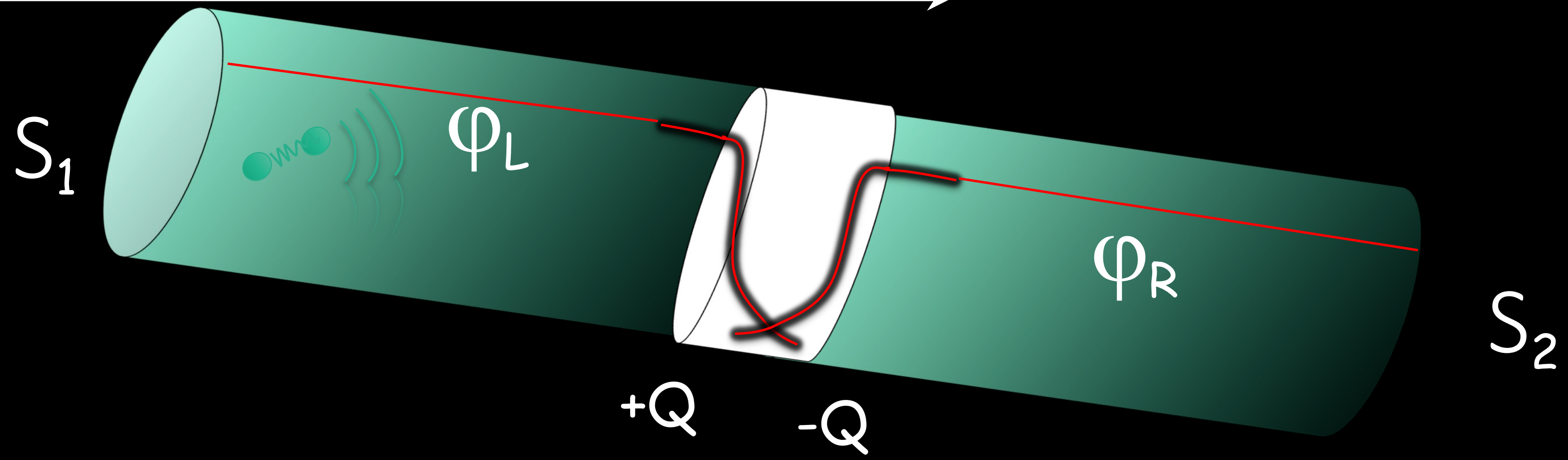


Effetti quantistici macroscopici: tunnel di un oggetto macroscopico, i.e. un circuito

$$H = \cancel{E_c} - E_J \cos\varphi - \frac{\hbar}{2e} I\varphi$$



$$E_J = \frac{\hbar I_c}{2e}$$

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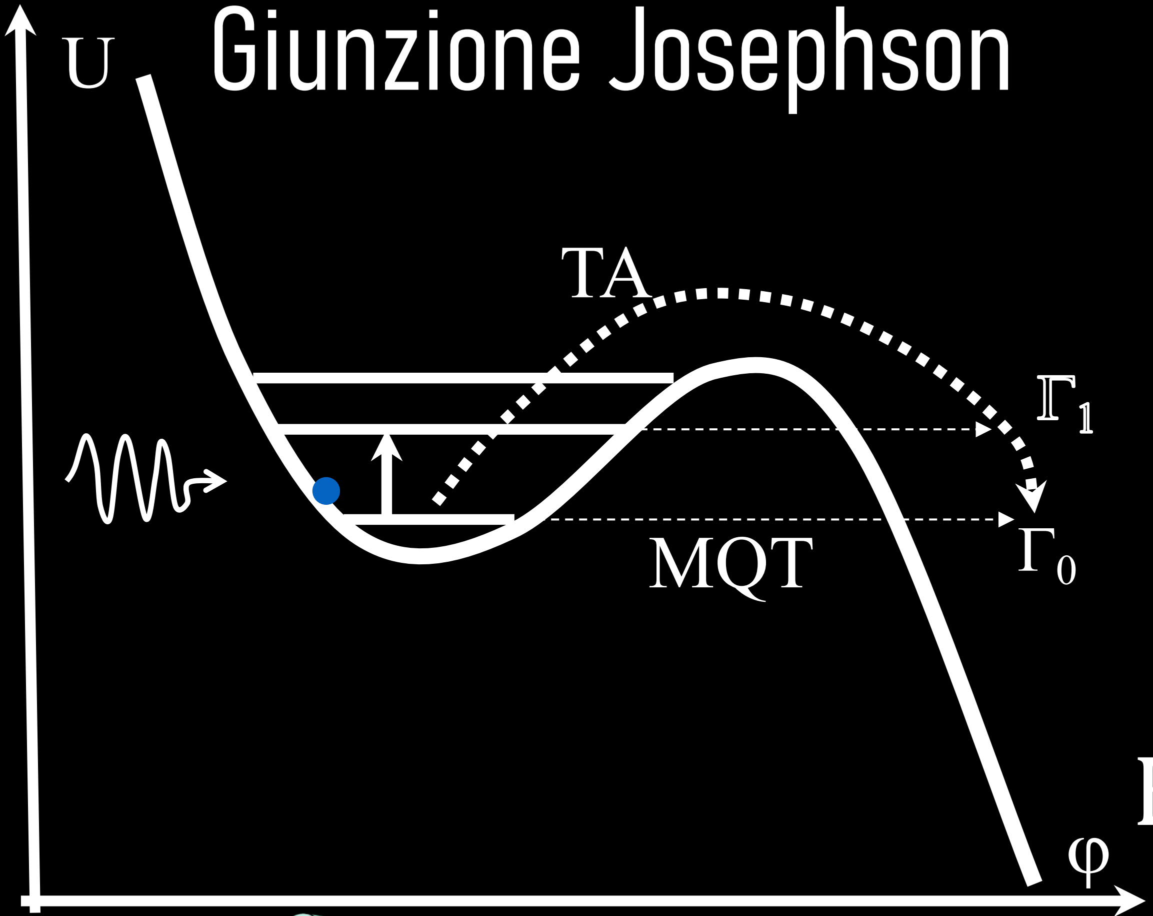
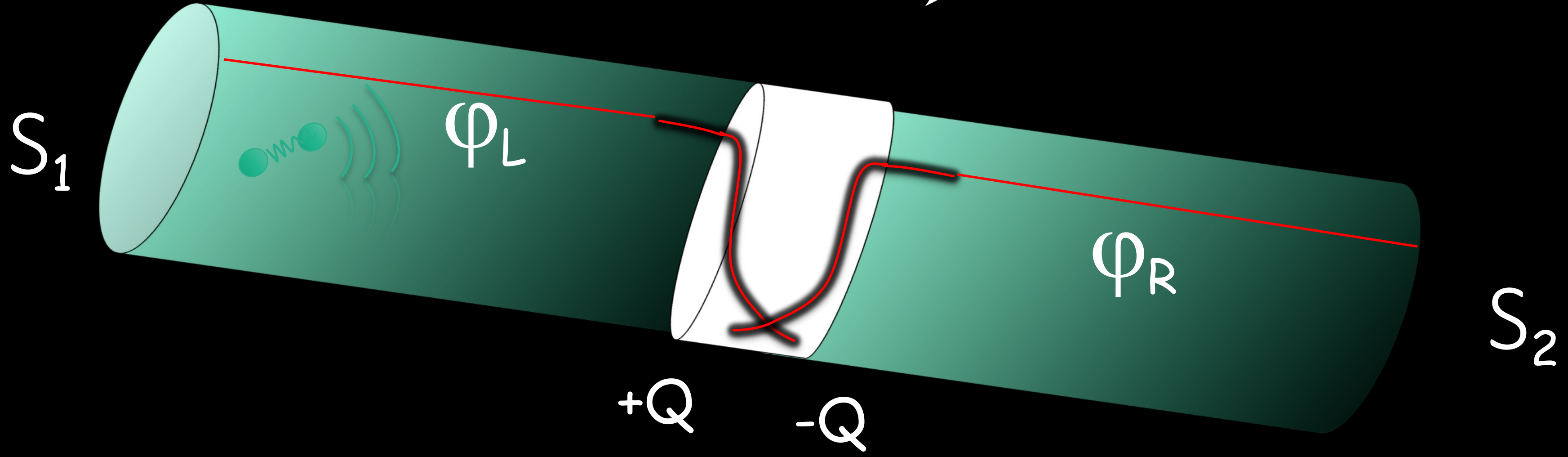
Giunzione Josephson



$$H = \cancel{E_c} - E_J \cos\varphi - \frac{\hbar}{2e} I\varphi$$

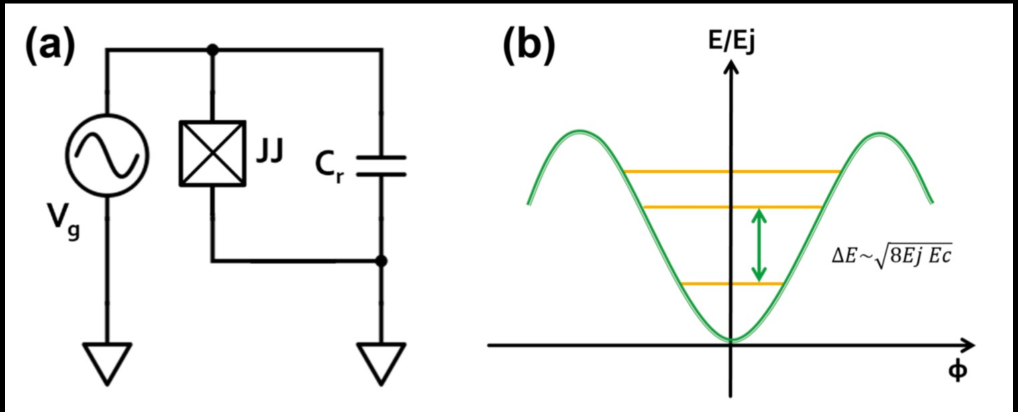


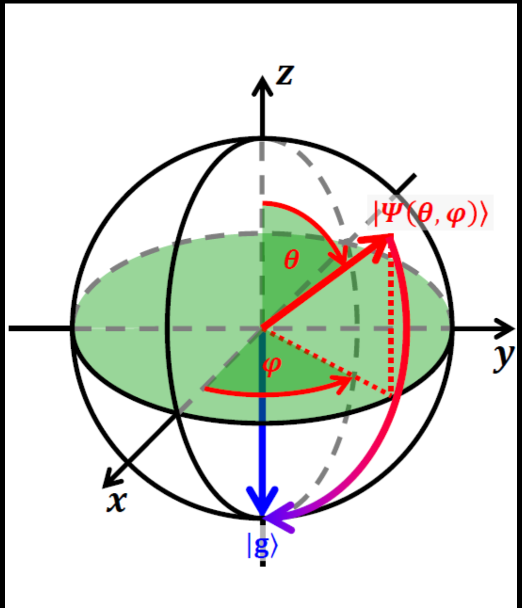
$$E_J = \frac{\hbar I_c}{2e}$$

$$E_c = \frac{(2en)^2}{2C}$$

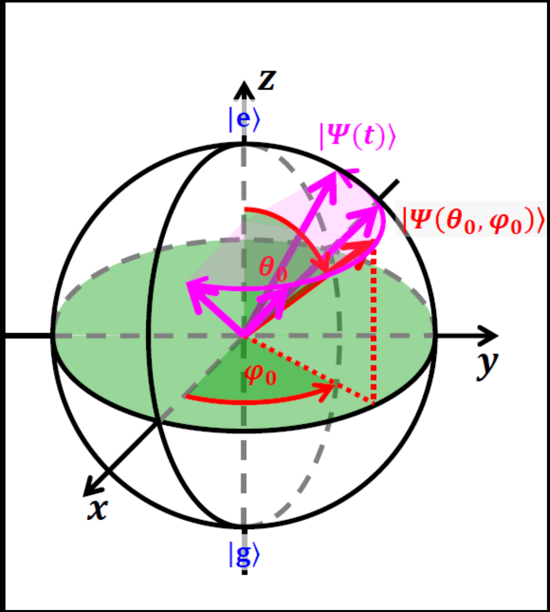
Qubits superconduttivi costituiscono atomo artificiale costruiti ed ideati artificialmente

- Lo spettro energetico può essere ingegnerizzato
- Interazioni forti
- Parametri regolabili
- micro fabbricazione => sistemi scalabili
- Controllati a micro-onde oppure con elettronica superconduttiva
- Componenti commercialmente disponibili





Rilassamento T_1



Sfasamento T_φ

IBM, Google, Rigetti, Quantware, SeeQc, per esempio

IBM | Quantum | Technology | Qiskit | Research | Pricing | Community | Resources

Bringing useful quantum computing to the world

Our users access the largest quantum computing fleet in the world through Qiskit Runtime—our quantum computing service and programming model for utility.

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Making the world quantum safe

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01 Quantum technology | 02 Development roadmap | 03 Scaling quantum computing | 04 IBM Quantum System Two™ | 05 IBM Quantum Safe™

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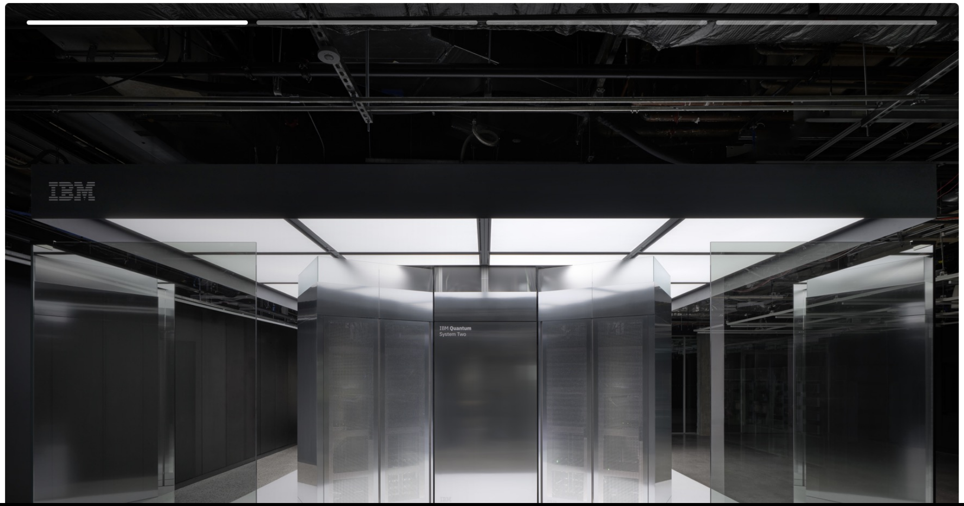
01 Quantum technology | 02 Development roadmap | 03 Scaling quantum computing | 04 IBM Quantum System Two™ | 05 IBM Quantum Safe™

Quantum-centric supercomputing

Quantum-centric supercomputing is a heterogeneous computing architecture which takes advantage of parallelism, concurrent quantum and classical computation, and dynamic circuit execution.

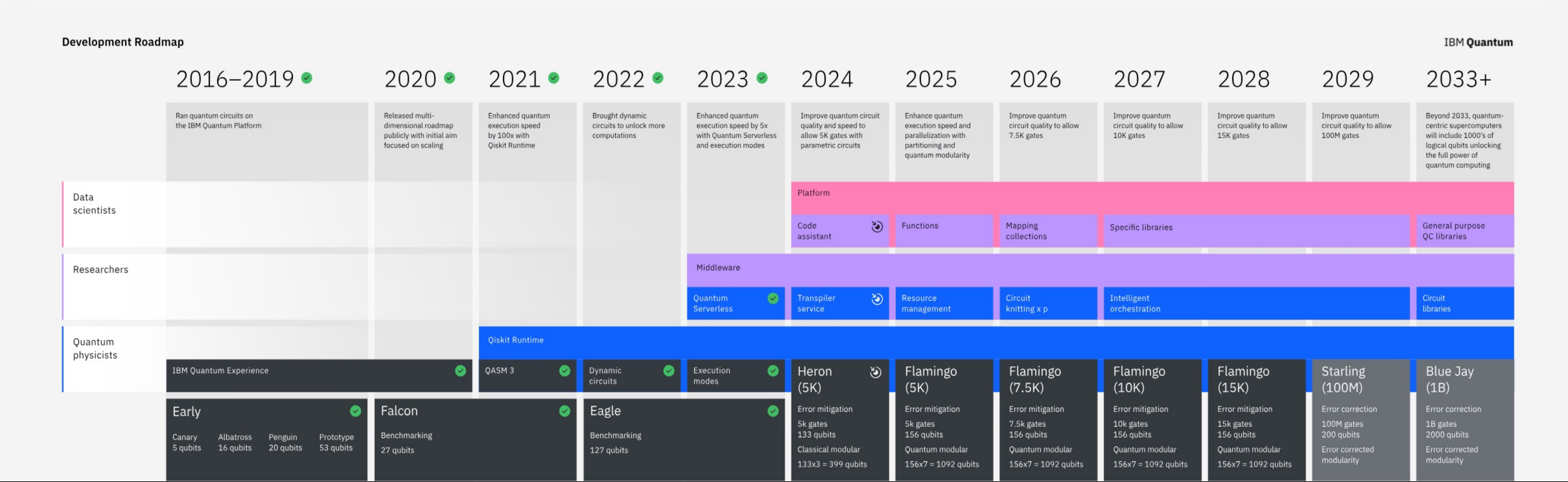
Utility-scale quantum computation

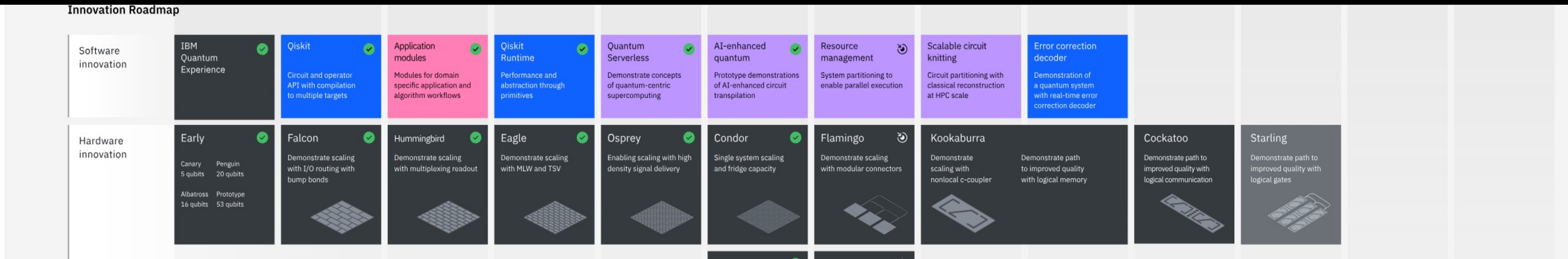
This architecture scales with our processors, to explore more complex problems and advance scientific discovery beyond the limits of



IBM Quantum | Technology | Qiskit | Research | Pricing | Community | Resources | Sign in to Platform

01 Quantum technology | 02 Development roadmap | 03 Scaling quantum computing | 04 IBM Quantum System Two™ | 05 IBM Quantum Safe™



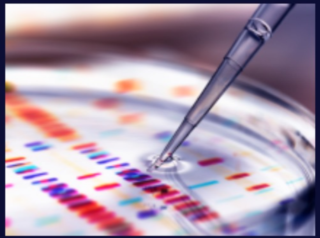


Industry Use Cases

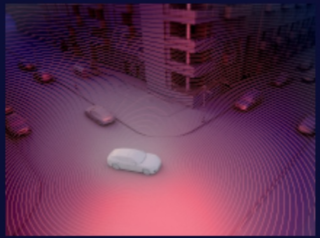
The true value of quantum computing will be unlocked through practical applications. With new tools and new ways of thinking, quantum computing will forever change the way we solve problems across industries.

Design and optimize new druglike molecules for known targets

Optimize returns and risks for large financial portfolios



Aid drug discovery for 'undruggables' e.g. neurodegenerative diseases



Train better AI with less computational overhead

Develop synthetic enzymes and catalysts for food and energy production

Reduce fuel costs by optimizing vehicle routing

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Why What Novera About Careers Investors GET QUANTU

Think quantum

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Why What Novera About

The Technology Stack

Building quantum computers combines advances in engineering, physics, computer science, ar manufacturing. Integrating all these specialties under one roof and in one technology stack allo us to move further, faster.

Chip Design and Fabrication +

Superconducting Quantum Processors +

Control Systems +

QCS Platform +

Software Tools +

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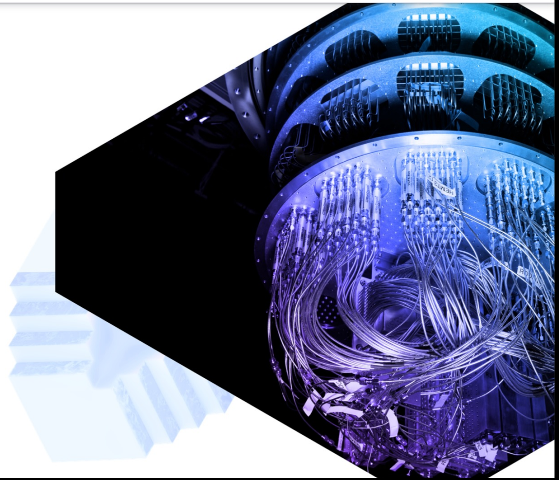
FEATURED

XPRIZE Quantum Applications | Google Quantum AI

XPRIZE Quantum Applications | Google Quantum AI is a 3-year, $5M global competition designed to advance the field of quantum algorithms towards pro-society real-world applications, with funding from Google.org.

Learn more



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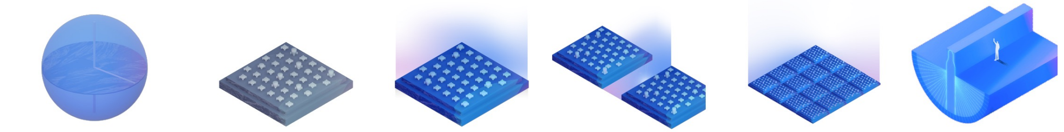

MILESTONE 1	MILESTONE 2	MILESTONE 3	MILESTONE 4	MILESTONE 5	MILESTONE 6
BEYOND CLASSICAL	QUANTUM ERROR CORRECTION	BUILDING A LONG-LIVED LOGICAL QUBIT	CREATING A LOGICAL GATE	ENGINEERING SCALE UP	LARGE ERROR-CORRECTED QUANTUM COMPUTER
Physical Qubits: 54	Physical Qubits: 10^2	Physical Qubits: 10^3	Physical Qubits: 10^4	Physical Qubits: 10^5	Physical Qubits: 10^6
Logical Qubit Error Rate: -	Logical Qubit Error Rate: 10^{-2}	Logical Qubit Error Rate: 10^{-6}	Logical Qubit Error Rate: 10^{-6}	Logical Qubit Error Rate: 10^{-6}	Logical Qubit Error Rate: 10^{-13}
2019	2023	2025+			

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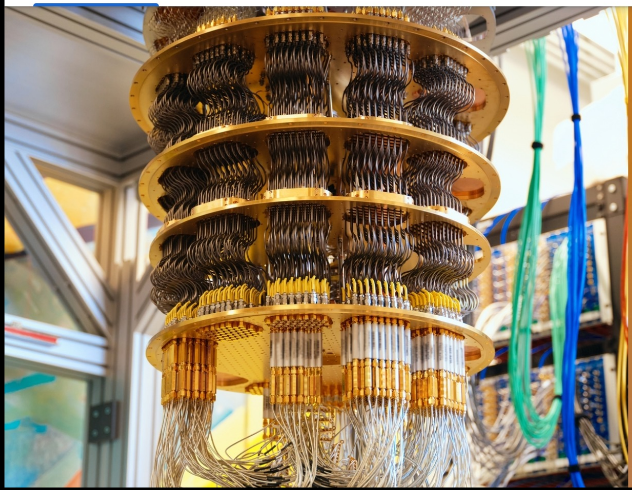
Quantum Computer | Research Publications | Open Source Tools



Building scalable quantum systems

Quantum AI's approach to co-developing hardware and software components is paving the way towards an end-state quantum computer.

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The future of quantum hardware

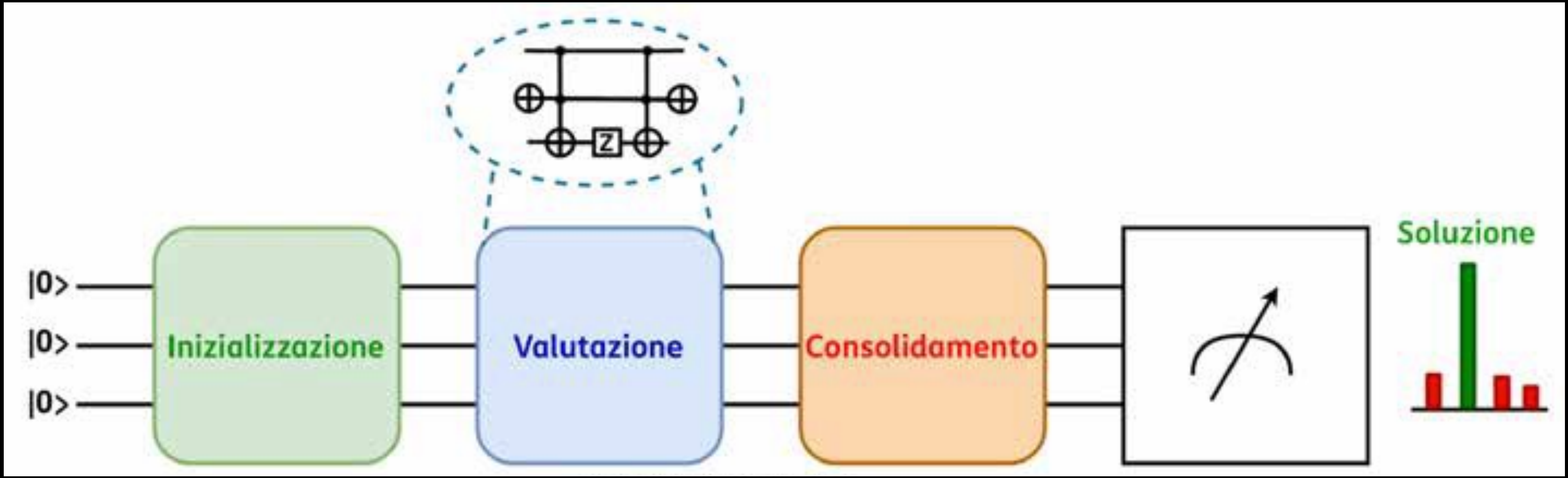
Our hardware is focused on superconducting qubits, requiring specialized cryogenic environments and custom control electronics. To achieve greater computational power, we are continuously working to scale up the number and quality of qubits while implementing error correction techniques. A key emphasis is placed on the tight integration of hardware components, all within a framework of ongoing research and development to drive advancements in the capabilities of the full quantum system.

Effective quantum volume is a key metric we use to measure the capabilities of our quantum processors. This metric considers not only the number of qubits but also their quality and error rates, ensuring we provide users with hardware optimized for meaningful research and the development of long-term applications.

Read the blog post

Quantum Gate Array

Il computer quantistico basato su modello Quantum Gate Array (QGA) è caratterizzato dall’esecuzione di operazioni sotto forma di porte quantistiche - una sorta di estensione al qubit della progettazione logica dell’elettronica digitale classica. A differenza delle porte logiche classiche, che possono essere progettate con un opportuno circuito a transistor, le porte quantistiche sono implementate da campi elettromagnetici oscillanti per esempio per i qubit superconduttivi nella banda delle microonde.



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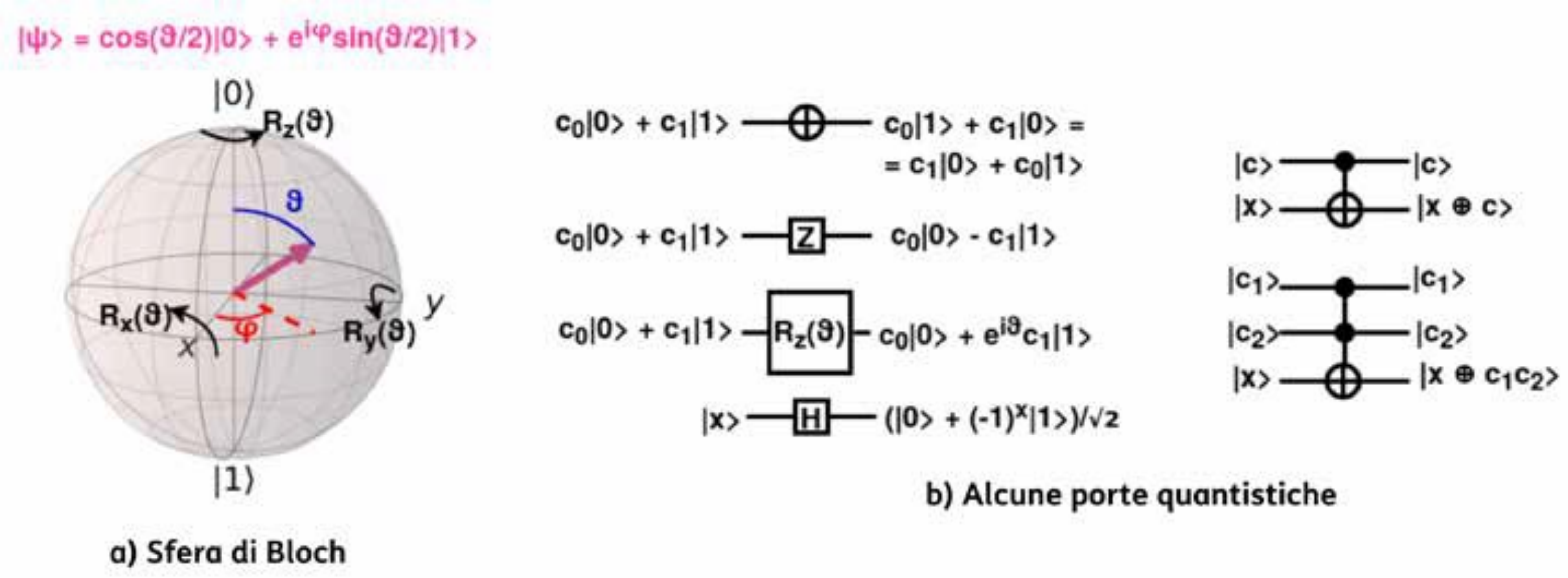
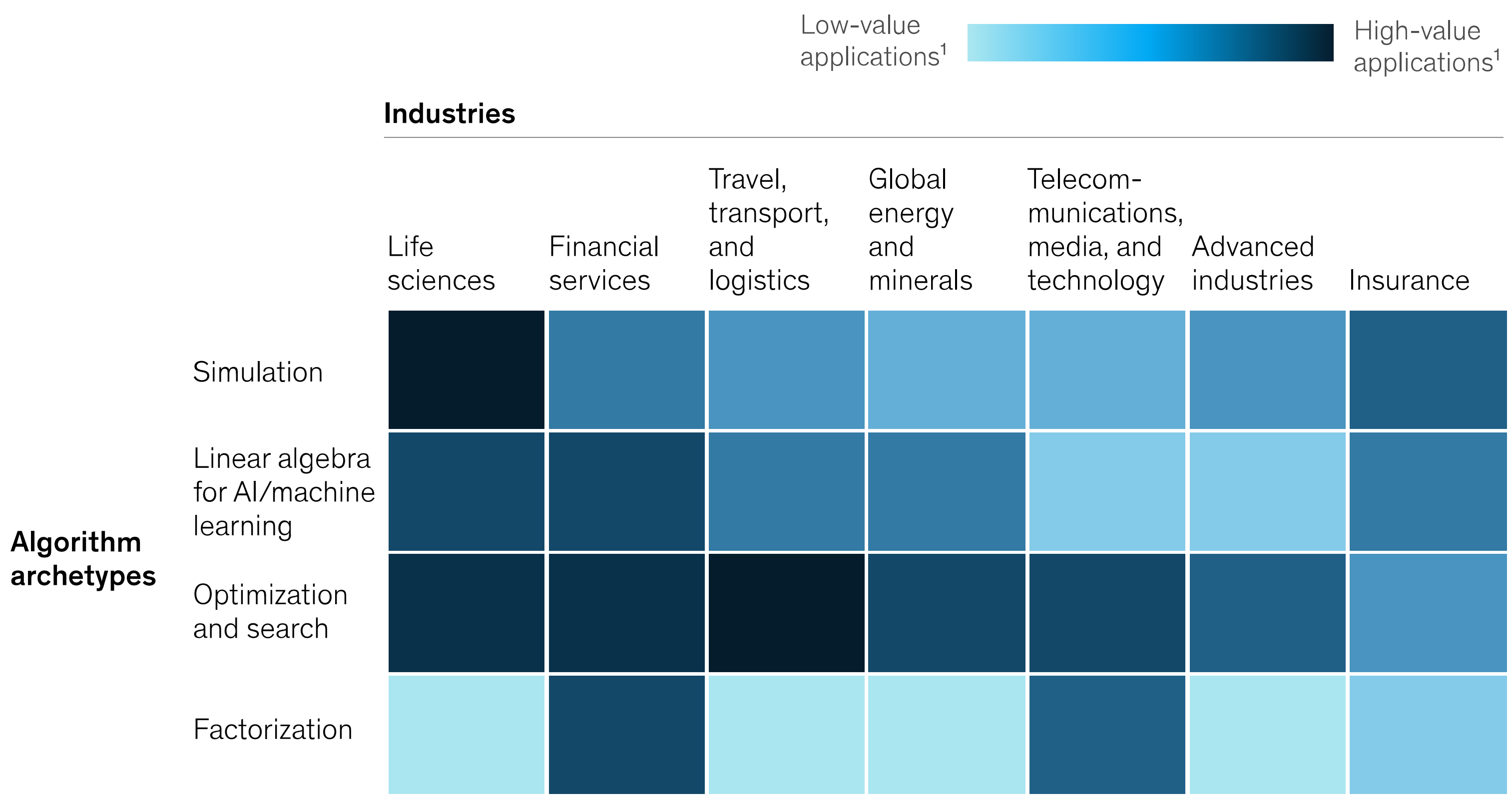


Quantum computing funding remains strong, but talent gap raises concern

June 15, 2022 | Article

promise. Four industries—pharmaceuticals, chemicals, automotive, and finance—remain on track to become the first beneficiaries of quantum advantages, with the potential to capture nearly $700 billion in value as early as 2035. Our analysis points to financial services and life sciences grounds for the highest-value quantum computing use cases over the longer term (Exhibit 1).

Qualitative estimate of expected value unlocked by the application of quantum computing by 2030



McKinsey & Company

Grandi players industriali mondiali

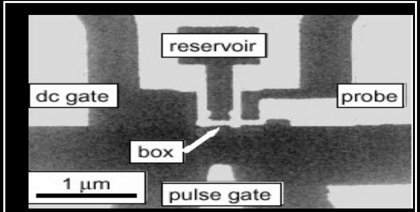
IBM, Google,

Rigetti, Quantware, SeeQc, …

La ricerca di base e il ruolo dell’Accademia: Innovazione e alta formazione

La ricerca di base e il ruolo dell'Accademia: Innovazione e alta formazione

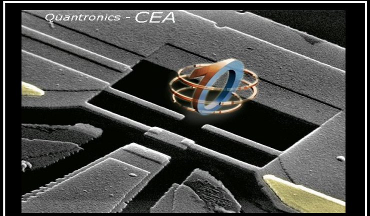
Charge



$E_J < E_C$

Quantum box

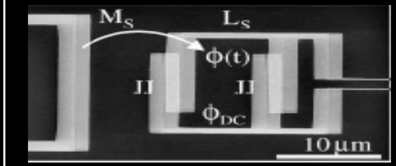
Charge/phase



$E_J \sim E_C$

Quantronium

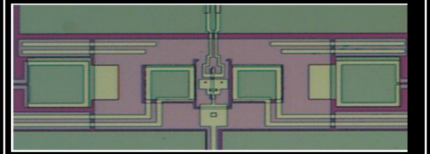
Phase



$E_J > E_C$

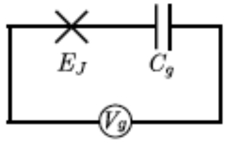
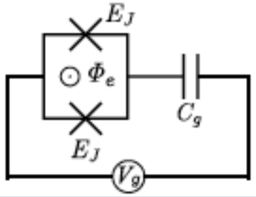
Junctions, dc and rf SQUID

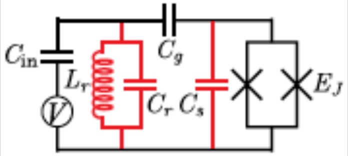
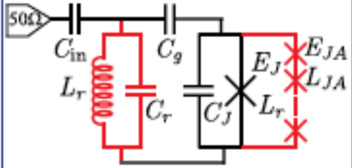
Flux



$E_J > E_C$

rf SQUID, double SQUID

	Circuit	Properties	Dominant noise
Charge qubit		$E_J/E_C < 1$ Controlled by V_g.	Charge fluctuations; mainly 1/f noise.
		$E_J/E_C < 1$ Controlled by both V_g and Φ_e.	

Transmon		Shunt capacitance C_s. $E_J/E_C > 1$ Behaves like a phase qubit	Charge noise can be suppressed.
Fluxonium		Needs an array of larger-area tunnel junctions. $E_J/E_C > 1$ Behaves like a phase qubit	Charge noise can be suppressed with appropriate parameters.

A quantum engineer's guide to superconducting qubits

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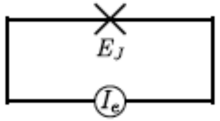
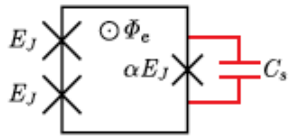
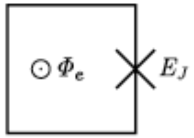
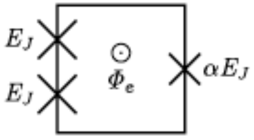
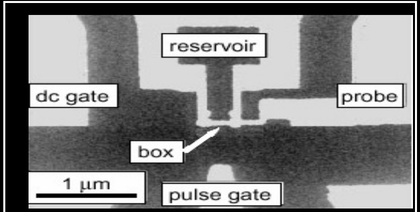
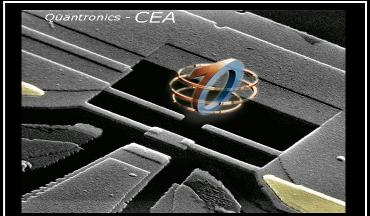
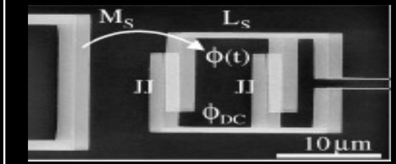
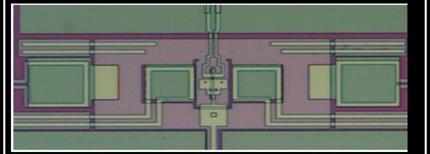
Submitted: 20 January 2019 . Accepted: 03 May 2019 . Published Online: 17 June 2019

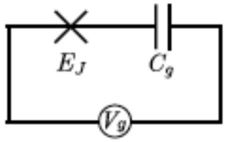
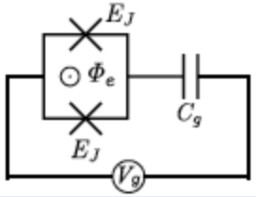
P. Krantz, M. Kjaergaard, F. Yan, T. P. Orlando, S. Gustavsson, and W. D. Oliver

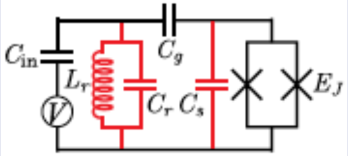
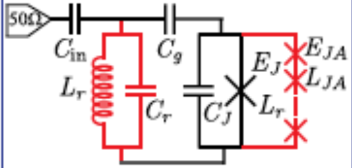
Phase qubit		$E_J/E_C \gg 1$ Controlled by I_e.	Flux fluctuations; mainly 1/f noise.
Low-decoherence qubit		Shunt capacitance C_s. $E_J/E_C > 1$ Controlled by Φ_e flux qubit: $0.5 < \alpha < 1$ phase qubit: $\alpha < 0.5$	Both charge noise and flux noise can be suppressed.

Flux qubit		$E_J/E_C > 1$ Controlled by Φ_e.	Flux fluctuations; mainly 1/f noise.
		$E_J/E_C > 1$ $0.5 < \alpha < 1$ Controlled by Φ_e.	

La ricerca di base e il ruolo dell'Accademia: Innovazione e alta formazione

Charge	Charge/phase	Phase	Flux
			
$E_J < E_C$ Quantum box	$E_J \sim E_C$ Quantronium	$E_J > E_C$ Junctions, dc and rf SQUID	$E_J > E_C$ rf SQUID, double SQUID

	Circuit	Properties	Dominant noise
Charge qubit		$E_J/E_C < 1$ Controlled by V_g.	Charge fluctuations; mainly 1/f noise.
		$E_J/E_C < 1$ Controlled by both V_g and Φ_e.	

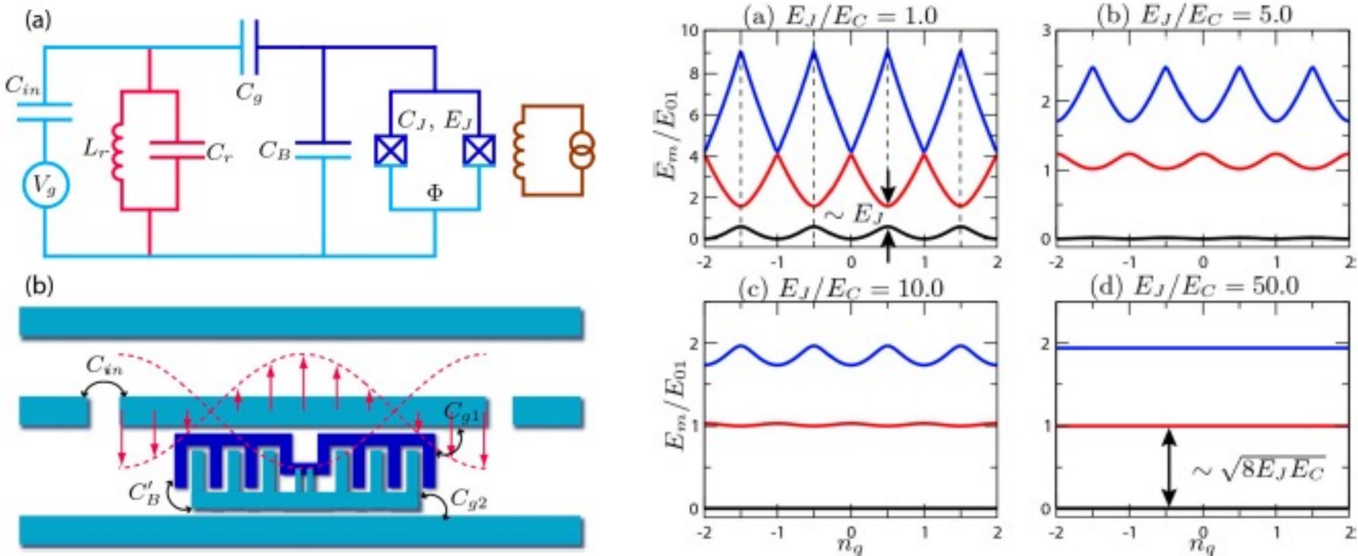
Transmon		Shunt capacitance C_s. $E_J/E_C > 1$ Behaves like a phase qubit	Charge noise can be suppressed.
Fluxonium		Needs an array of larger-area tunnel junctions. $E_J/E_C > 1$ Behaves like a phase qubit	Charge noise can be suppressed with appropriate parameters.

PHYSICAL REVIEW A **76**, 042319 (2007)

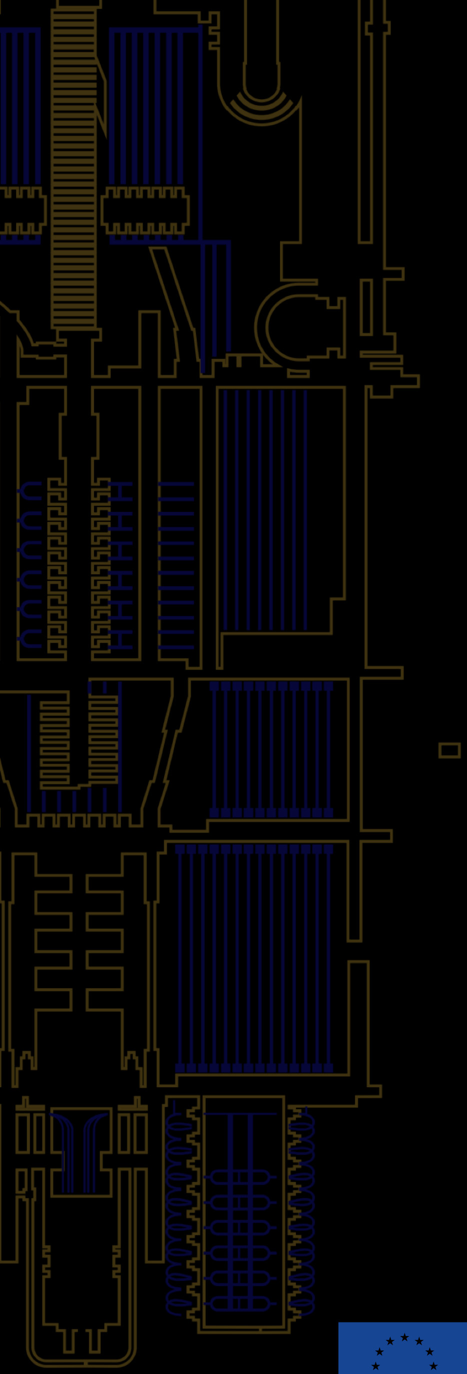
Charge-insensitive qubit design derived from the Cooper pair box

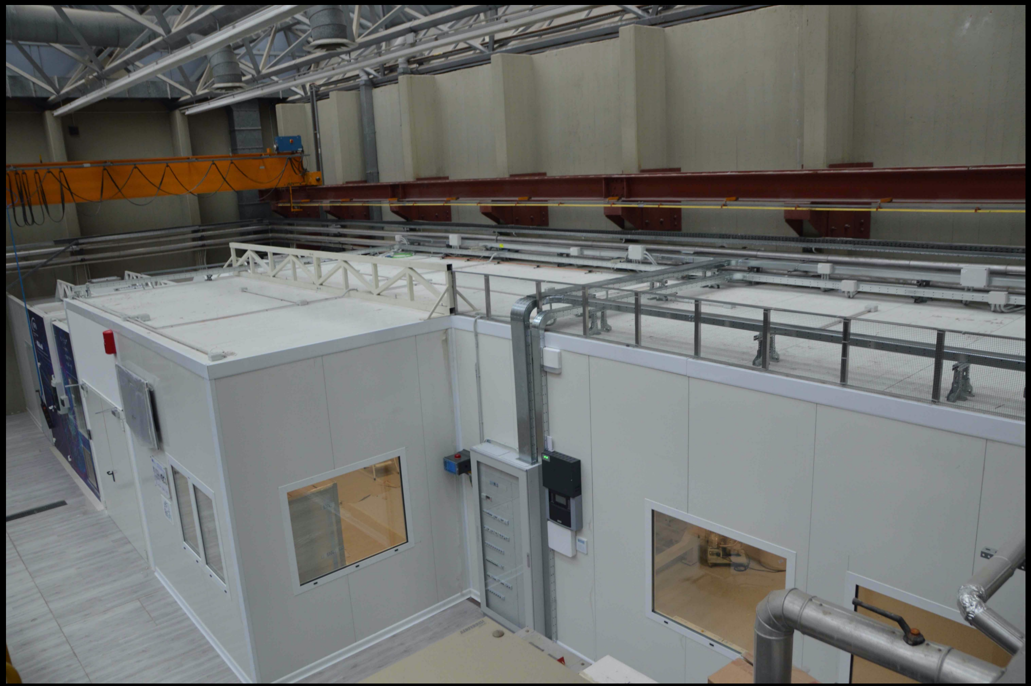
Jens Koch,[1] Terri M. Yu,[1] Jay Gambetta,[1] A. A. Houck,[1] D. I. Schuster,[1] J. Majer,[1] Alexandre Blais,[2] M. H. Devoret,[1] S. M. Girvin,[1] and R. J. Schoelkopf[1]
[1]*Departments of Physics and Applied Physics, Yale University, New Haven, Connecticut 06520, USA*
[2]*Département de Physique et Regroupement Québécois sur les Matériaux de Pointe, Université de Sherbrooke, Sherbrooke, Québec, Canada J1K 2R1*

(Received 22 May 2007; published 12 October 2007)



Il computer quantistico a 25-40 qubit a piattaforma superconduttiva @Napoli- Federico II





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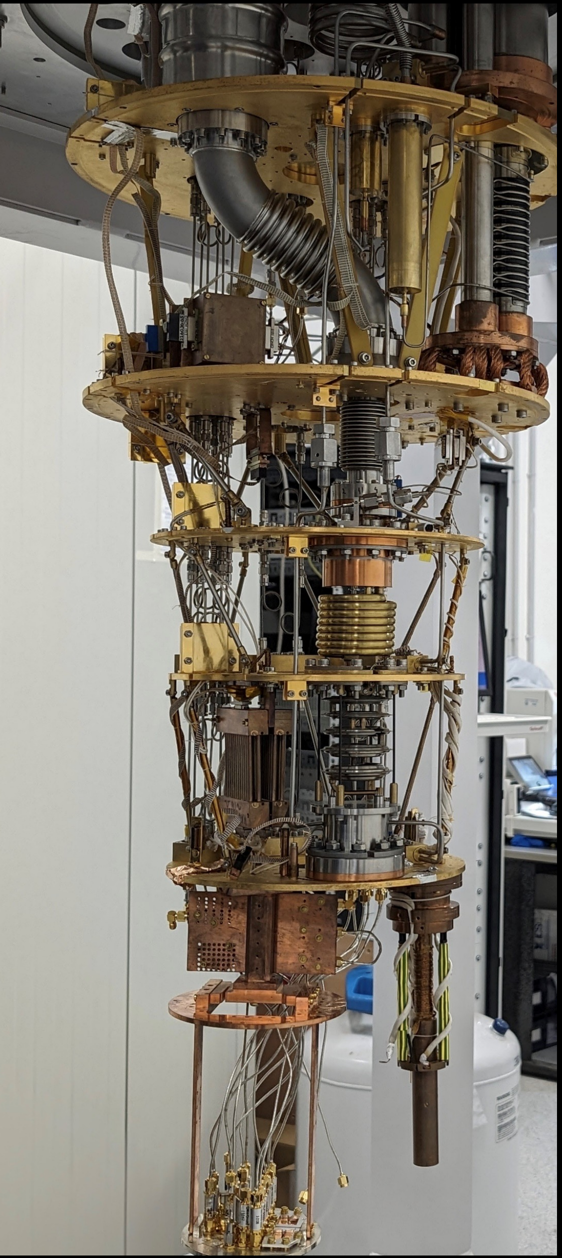

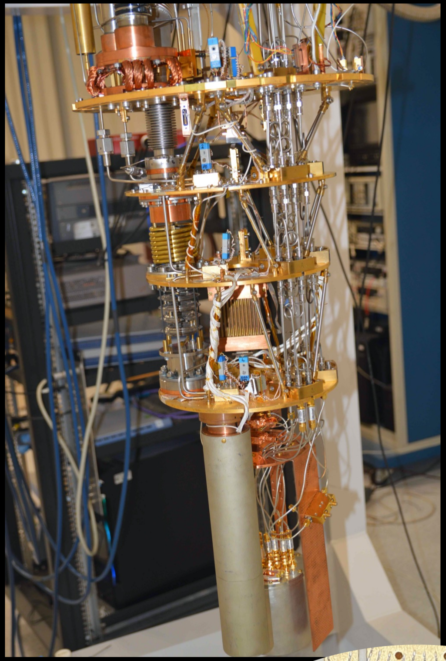

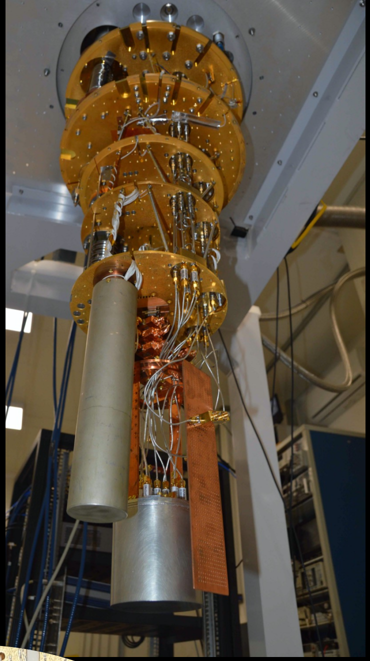

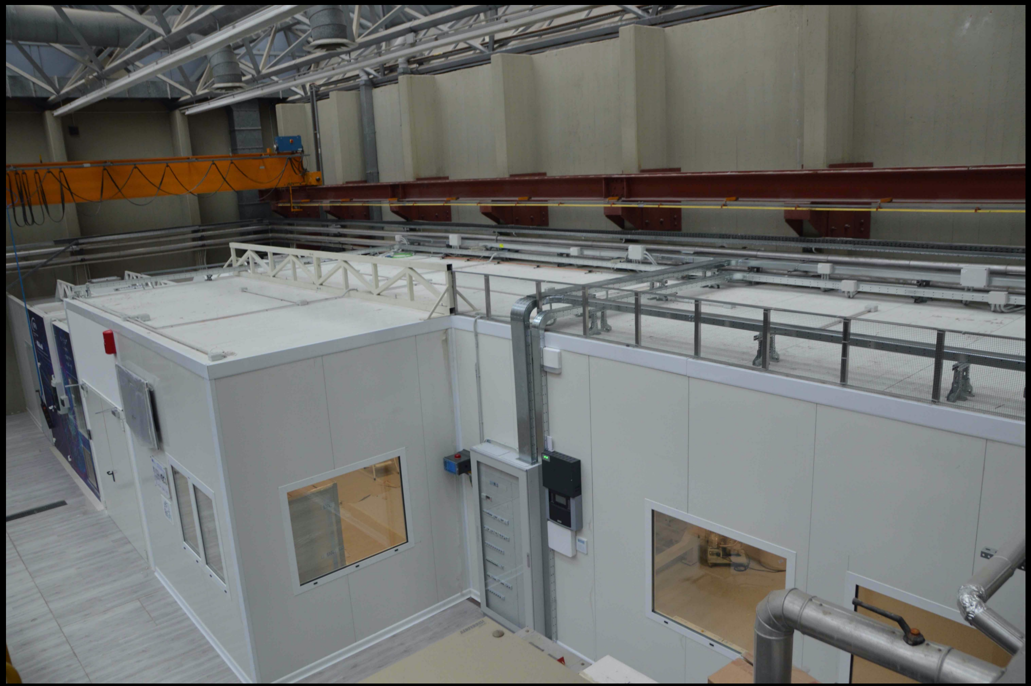

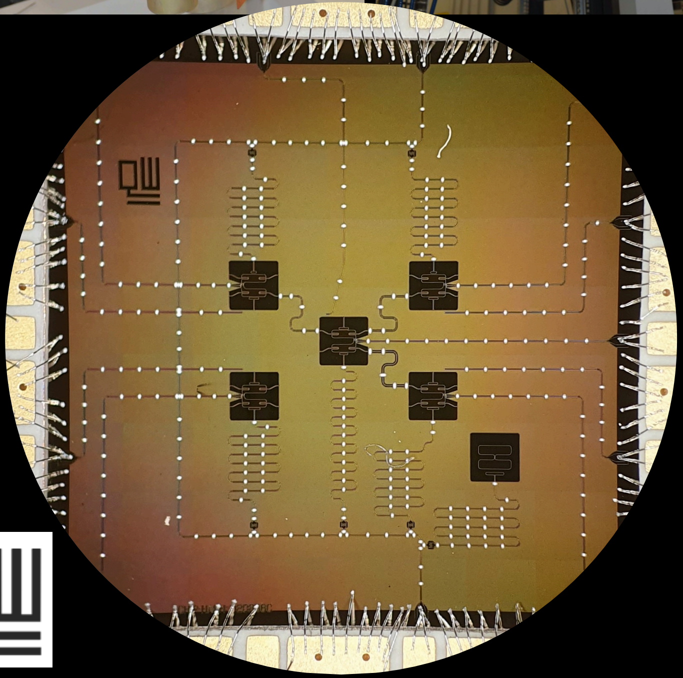

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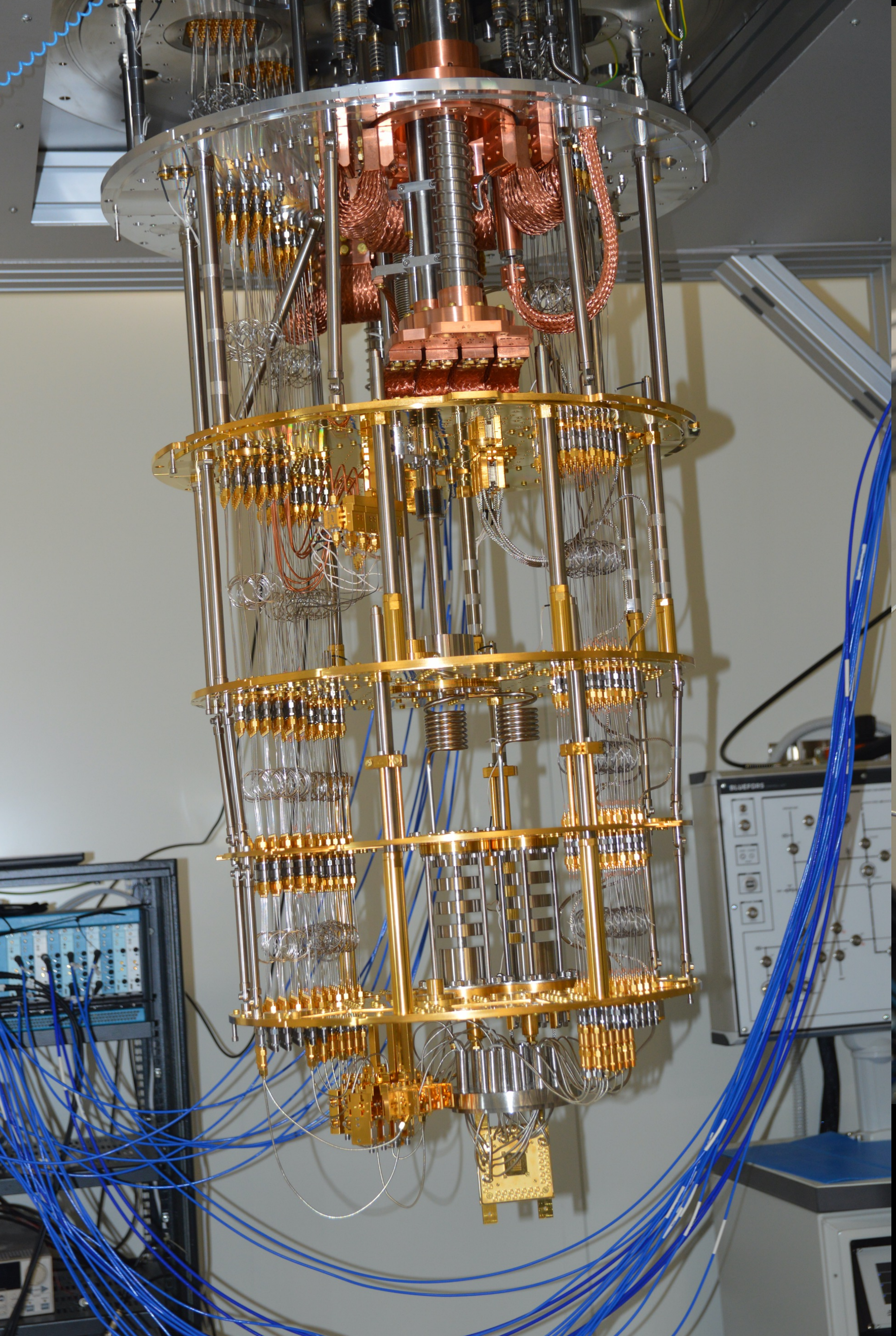
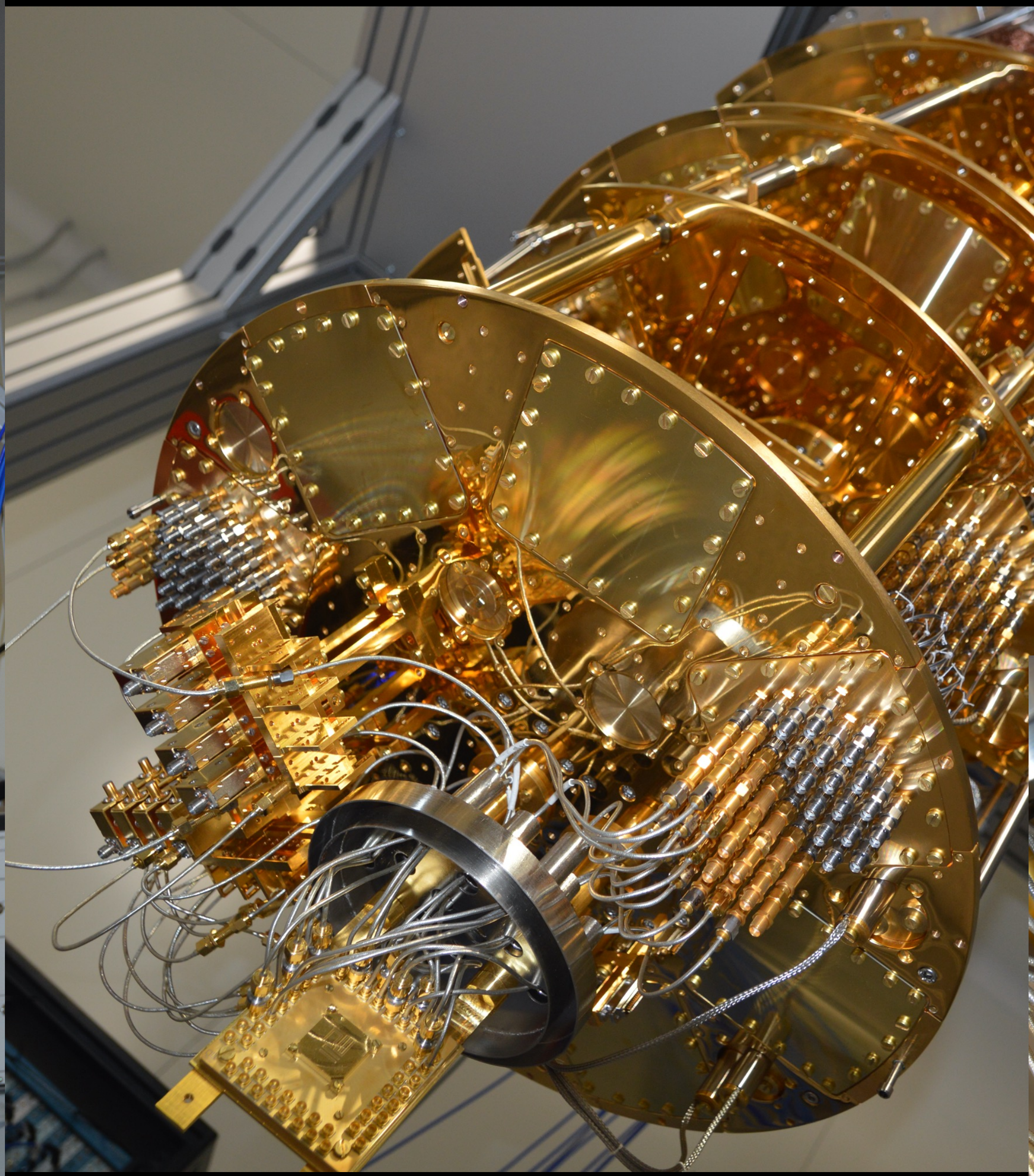
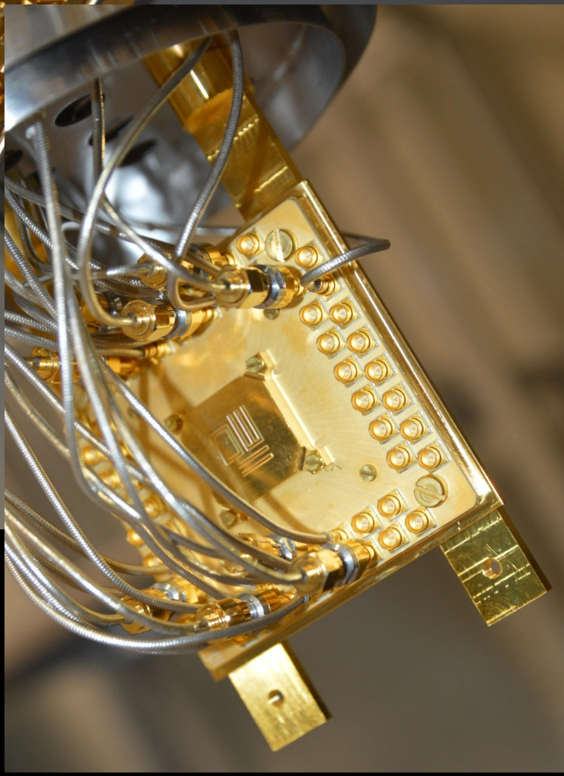

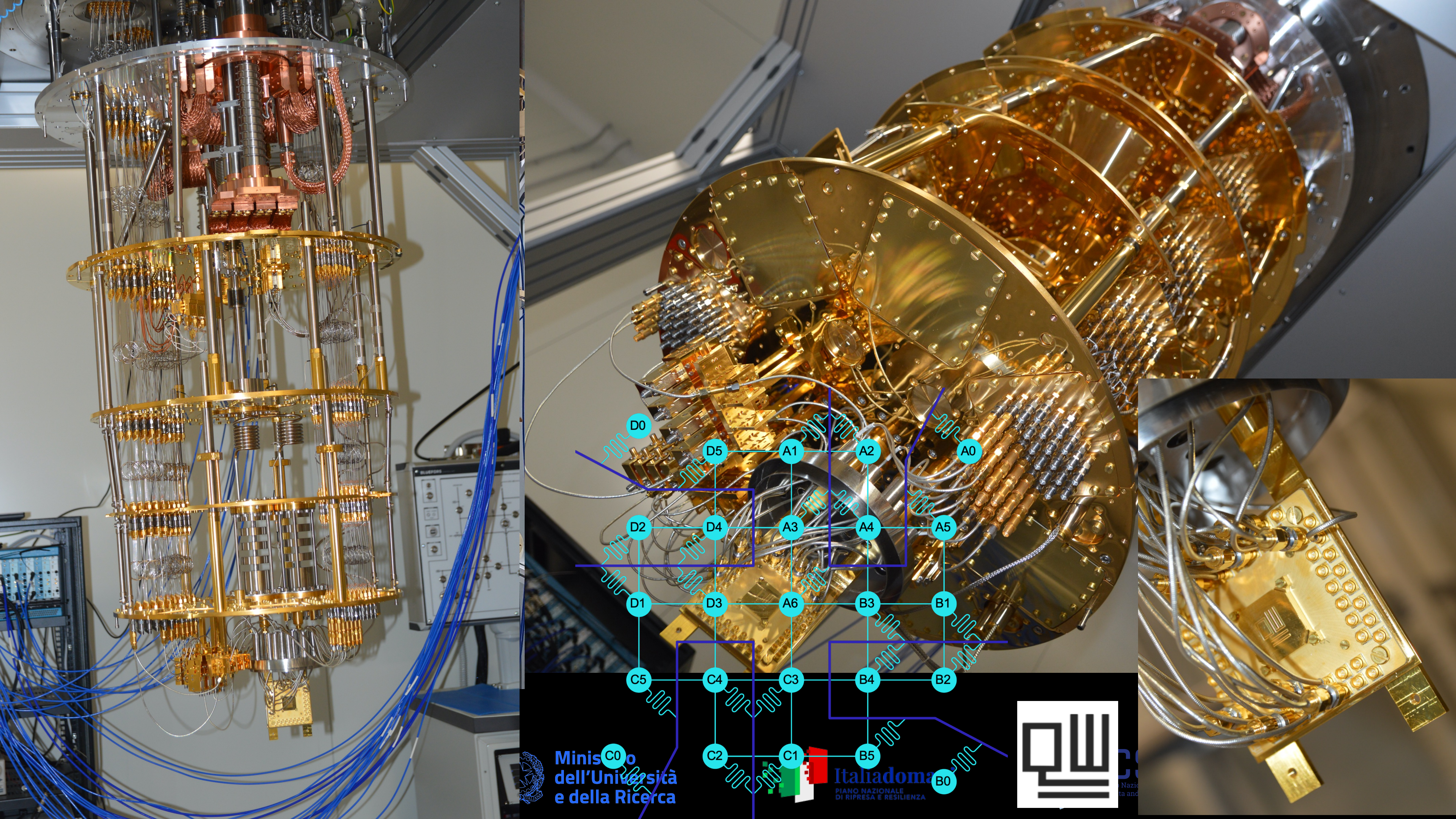
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D5
A1
A2
A0
D2
D4
A3
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A5
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D3
A6
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C5
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e della Ricerca
PIANO NAZIONALE
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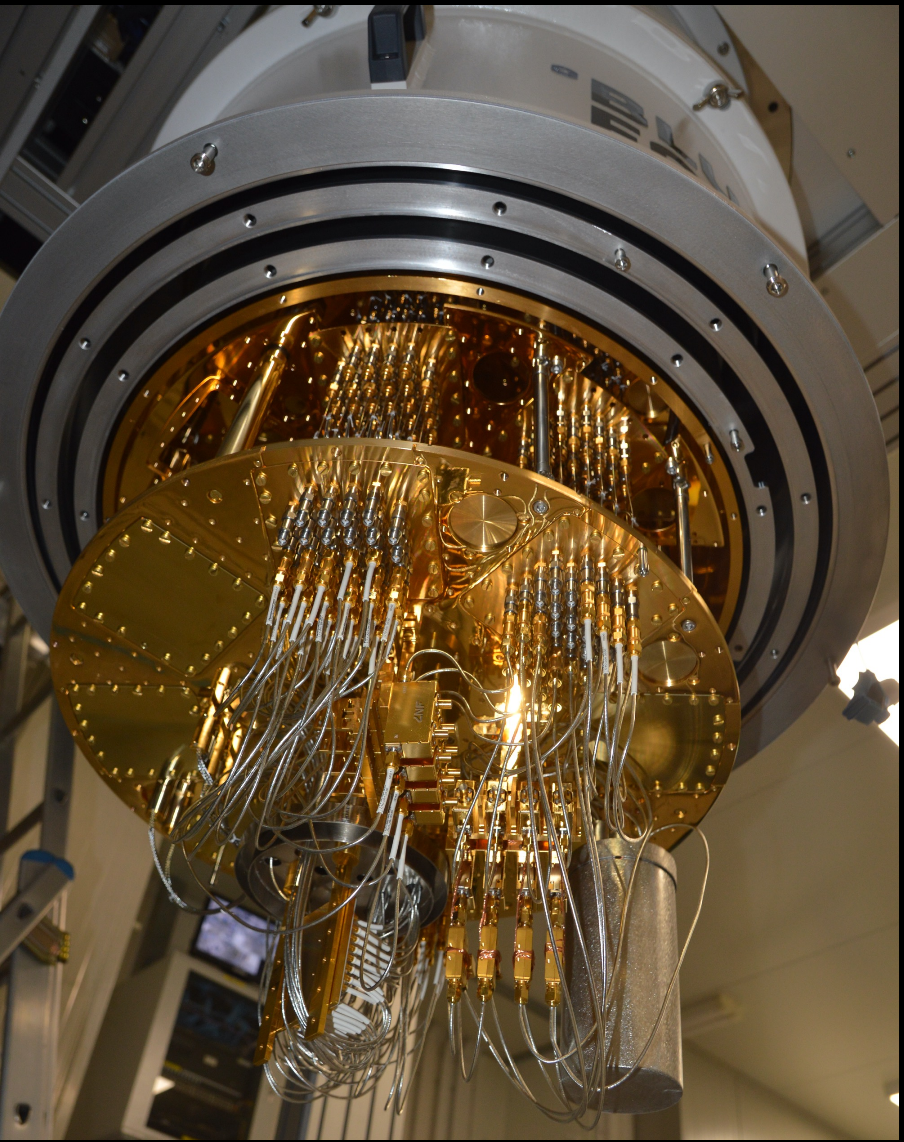
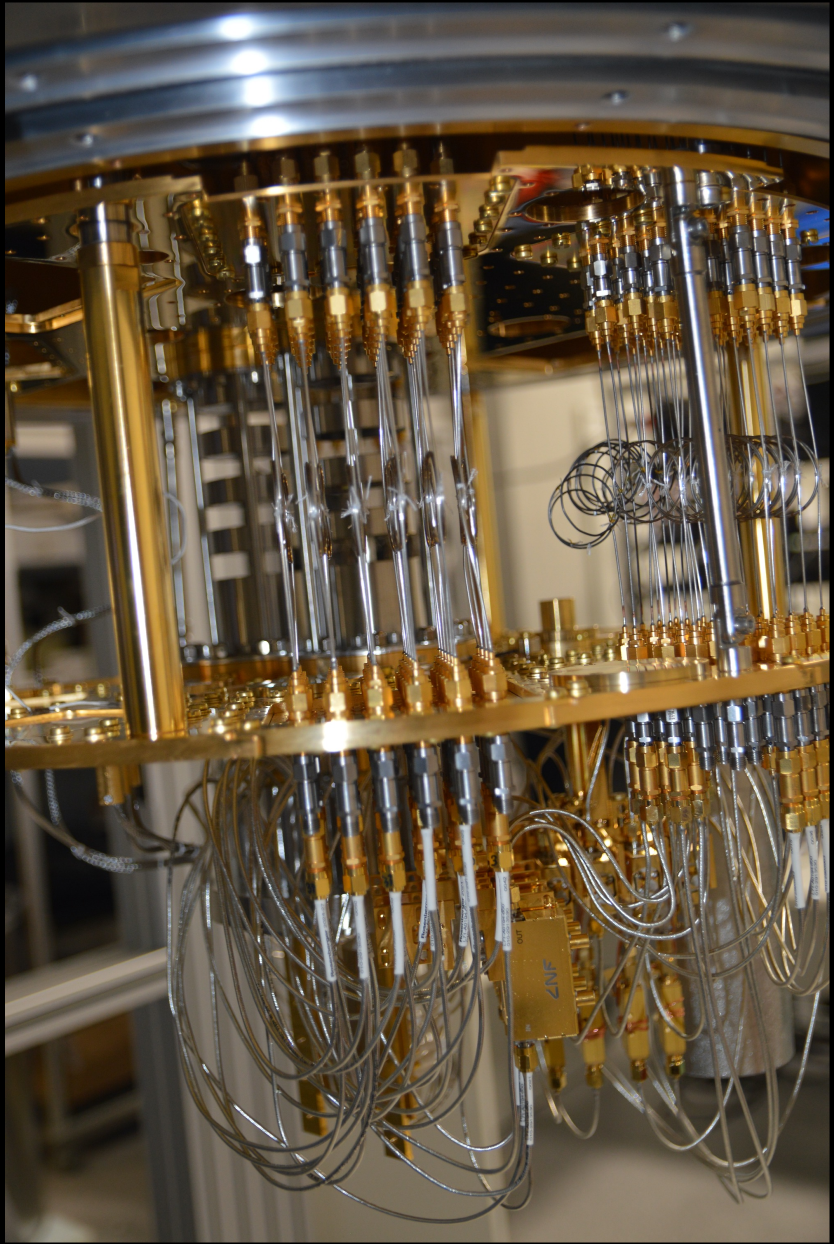
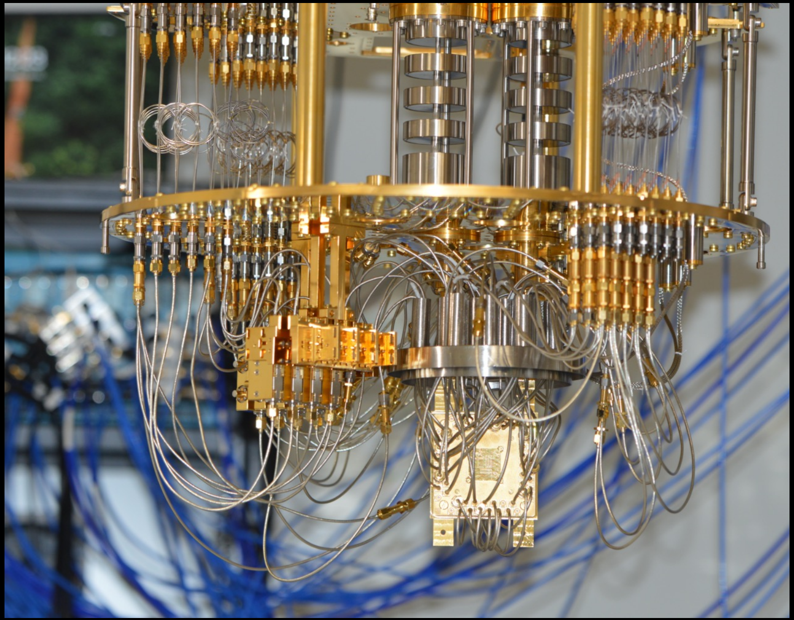
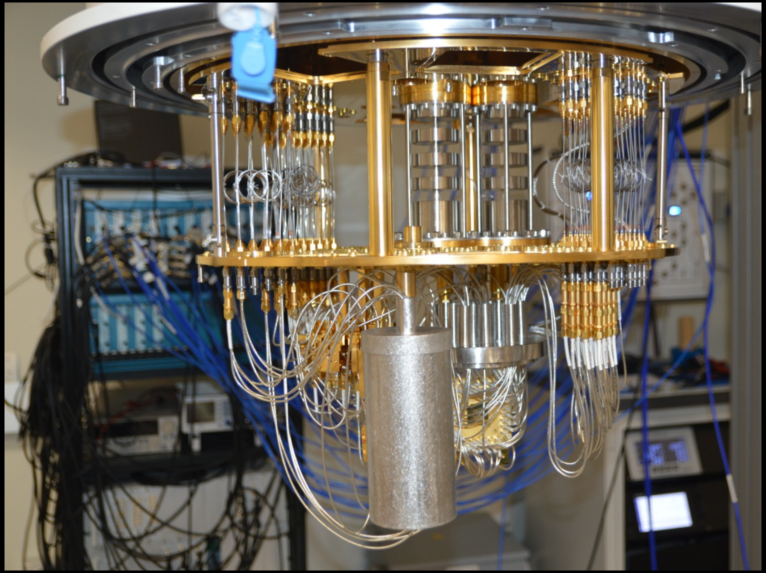






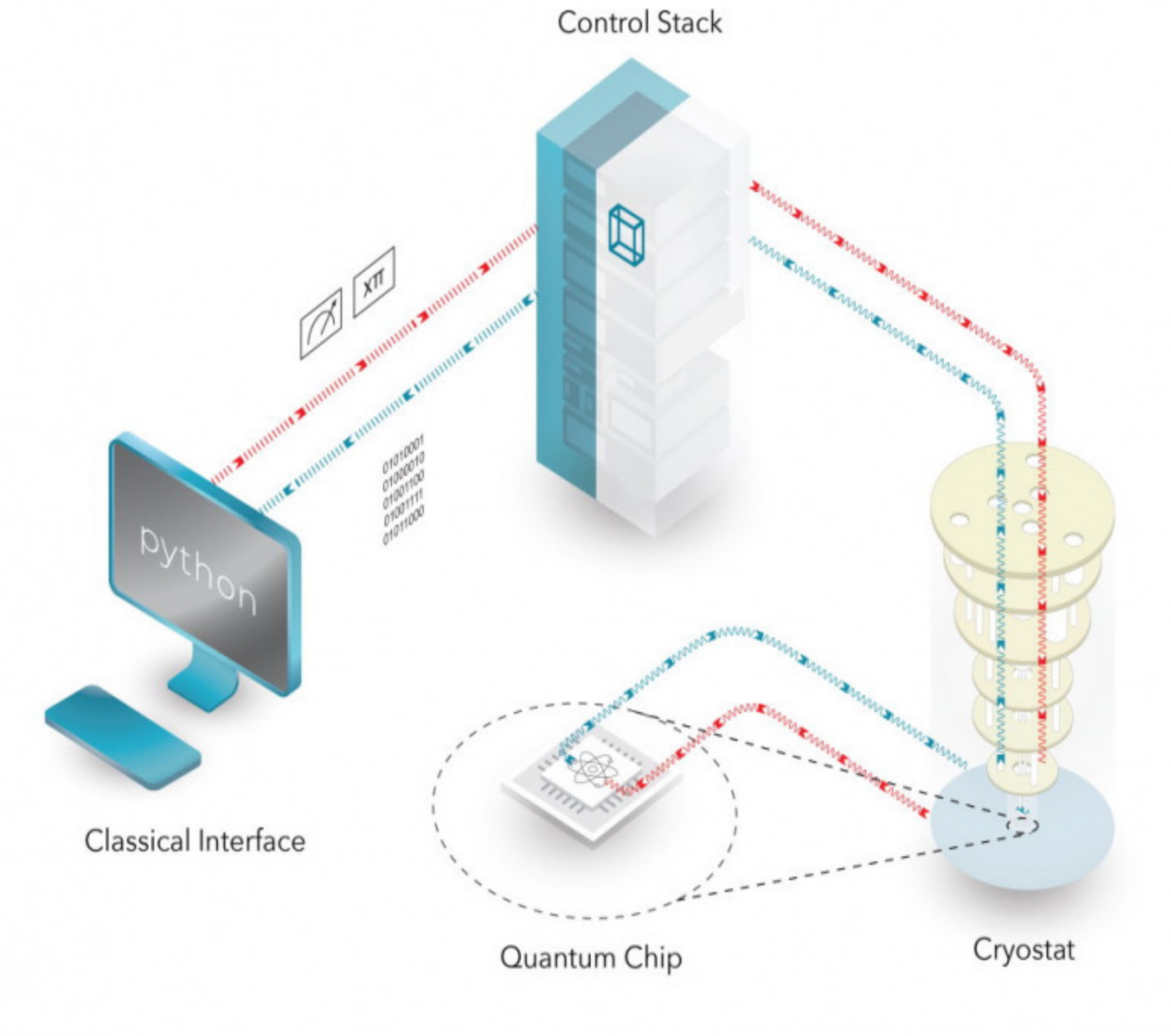


Crescendo

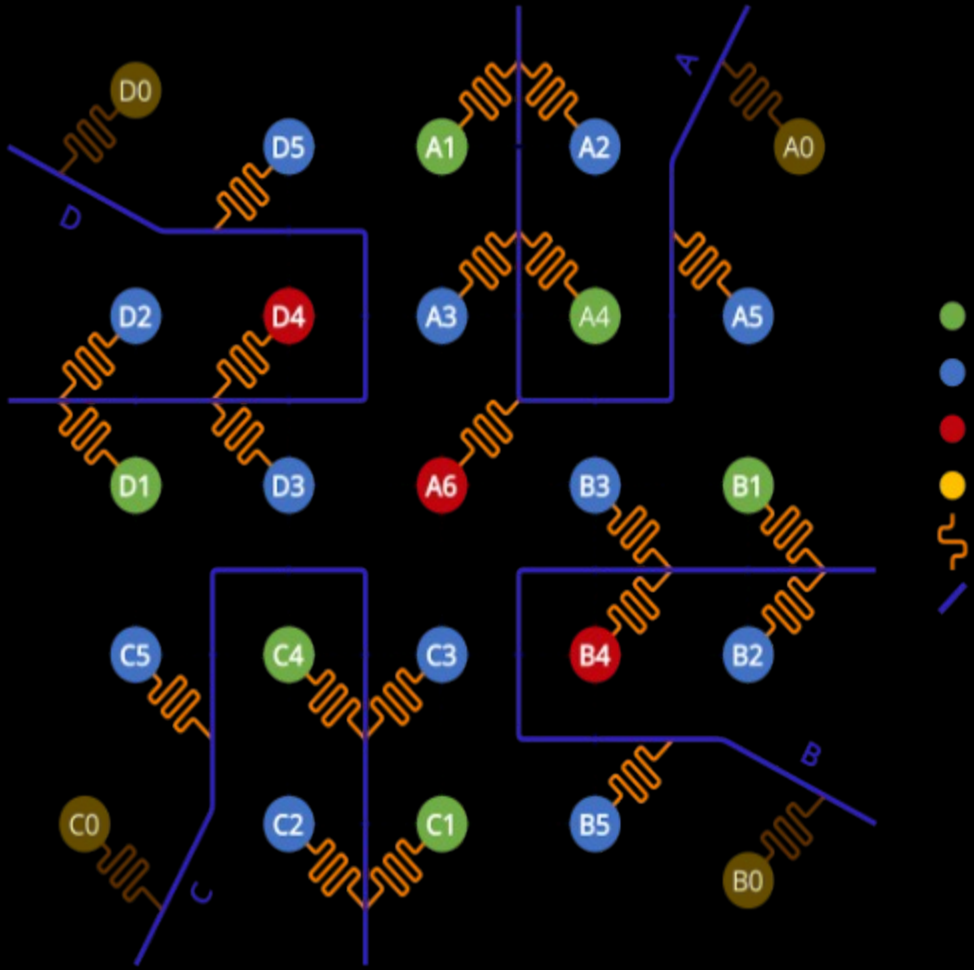

VIETATO L'ACCESSO
ALLE PERSONE
NON AUTORIZZATE

Componenti Computer Quantistico

Approccio modulare



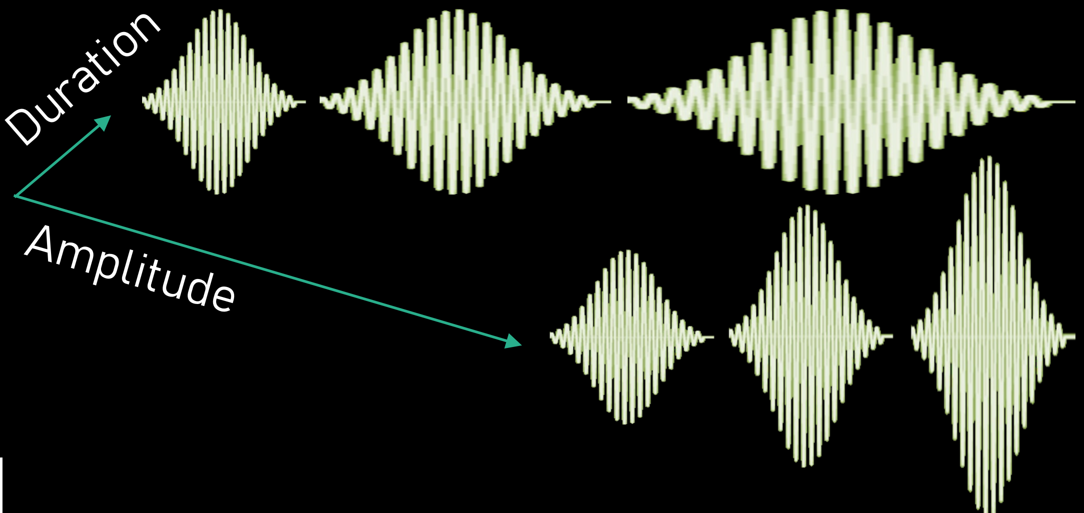
Sample and measurements

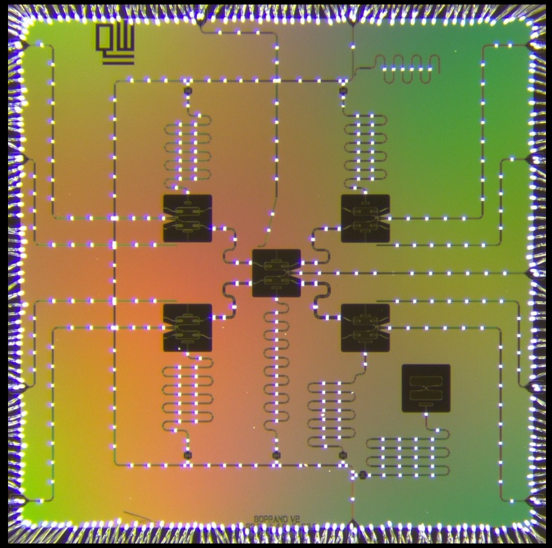


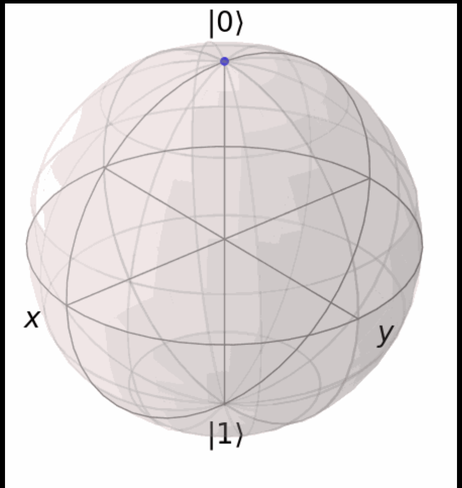
- Resonator power sweeps
- Resonator flux sweeps
- Qubit spectroscopies vs. power
- Qubit spectroscopy vs. flux
- Few one-shot coherence time experiments on subset D1-D5

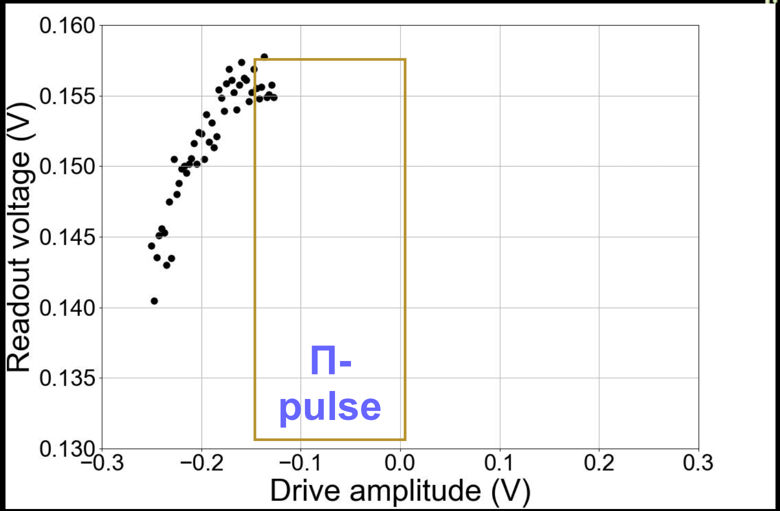
Oscillazioni Rabi: esempio di coerenza quantistica

By continuosly changing the duration or amplitude of the control pulses, coherent oscillations between the $|0\rangle$ and $|1\rangle$ states of the qubit



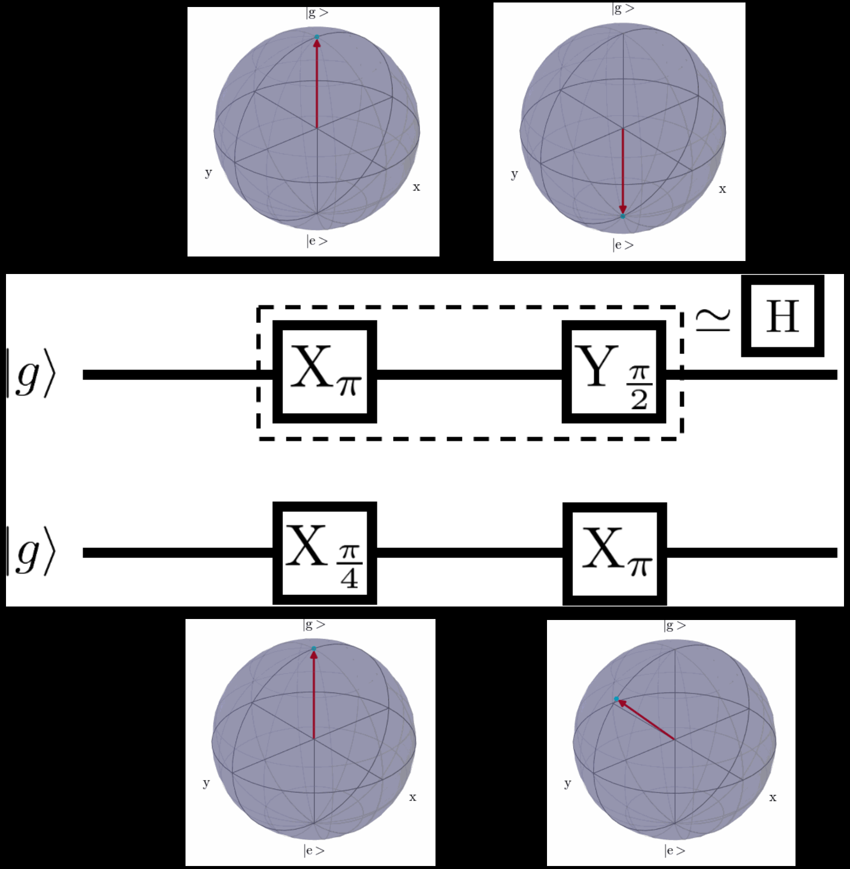




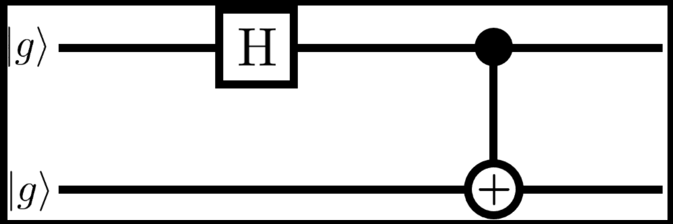


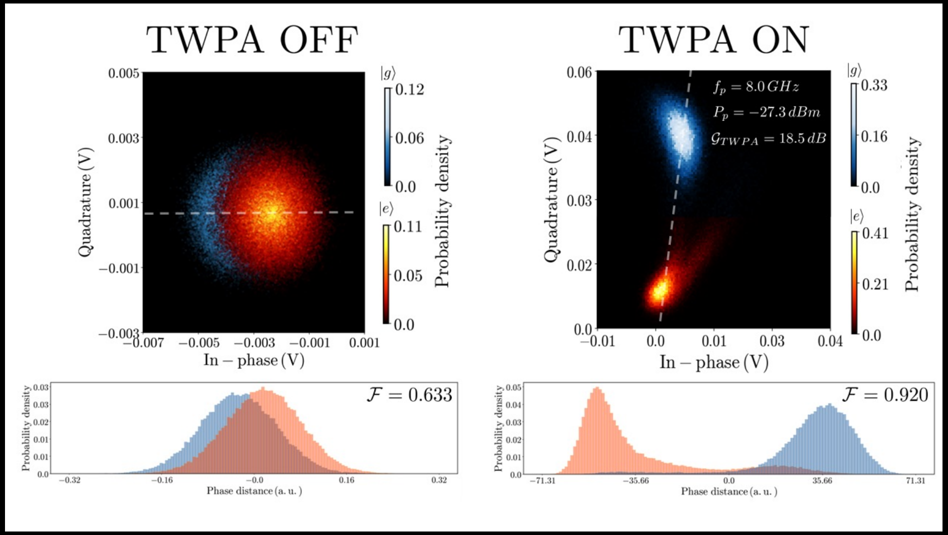
We are moving coherently between the two states of the computational basis!

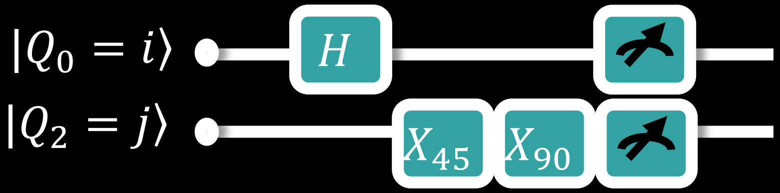
Single Qubit Gates

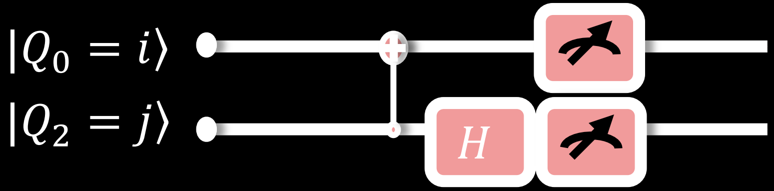


Two Qubit Gates





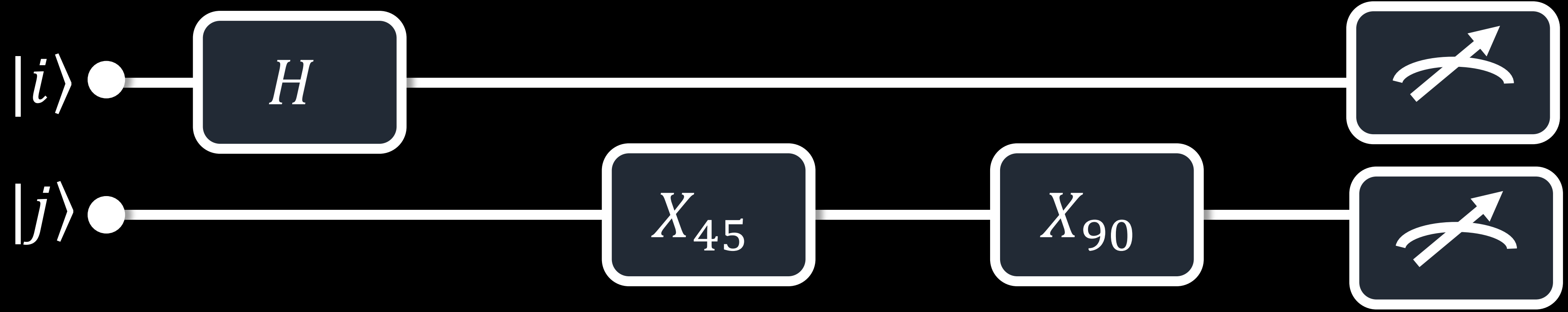


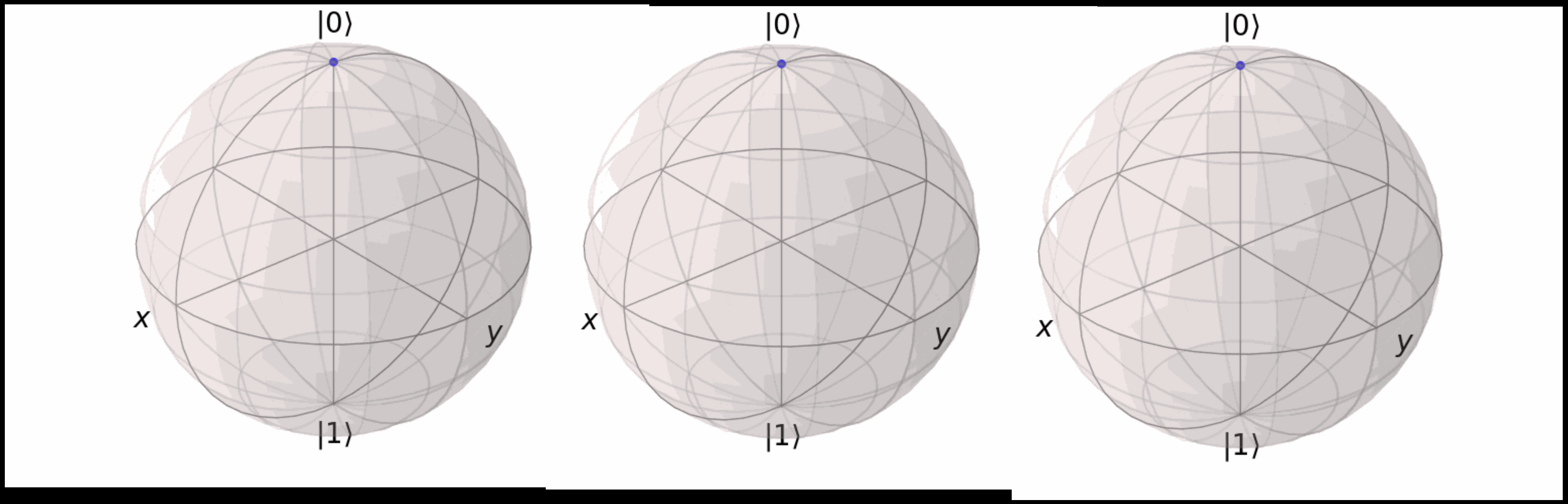


Quantum Algorithms

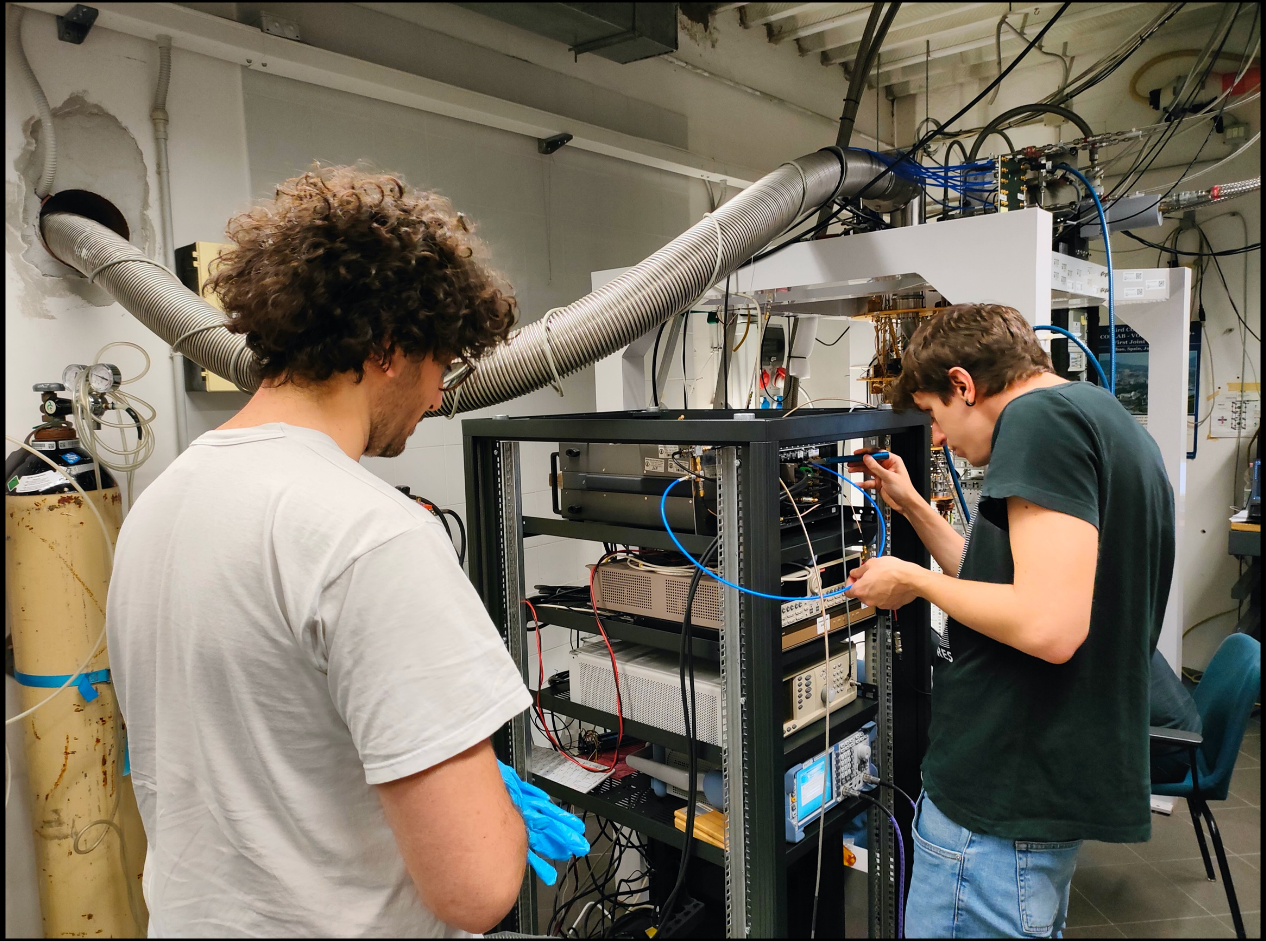
Mitigating Errors on Superconducting Quantum Processors through Fuzzy Clustering

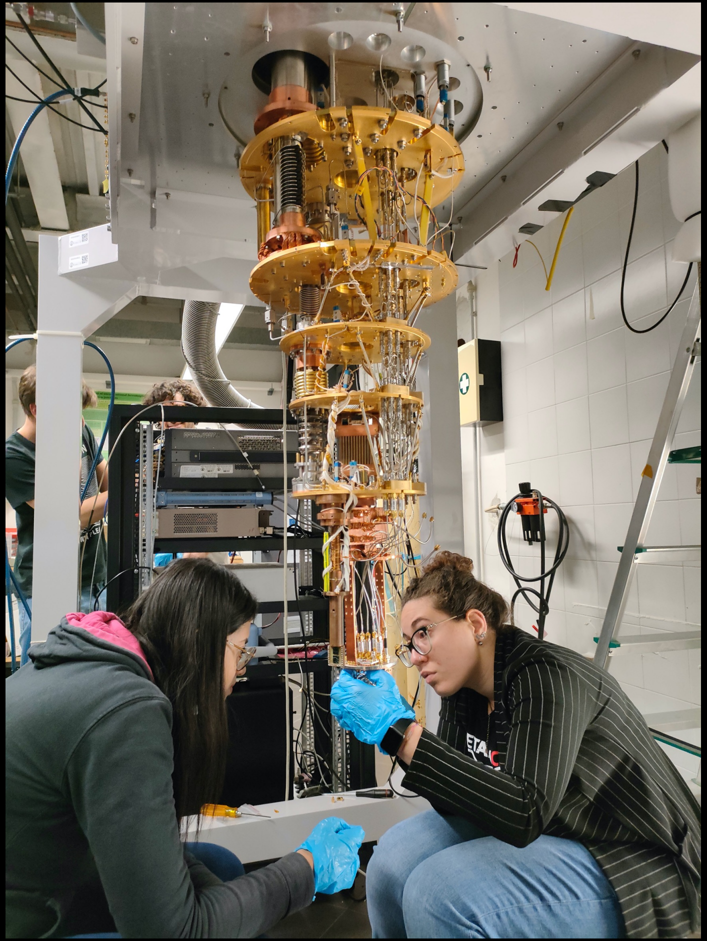
Running random single- and two-qubit quantum circuits & algorithms

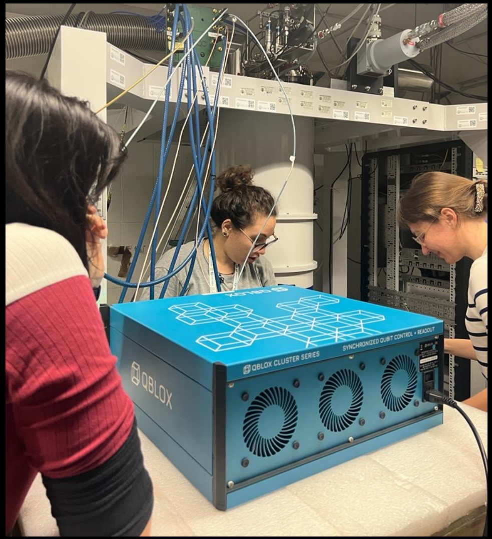




First implementation of a hybrid classical/quantum algorithm for Quantum Error Mitigation on a 5-qubit superconducting device in Italy







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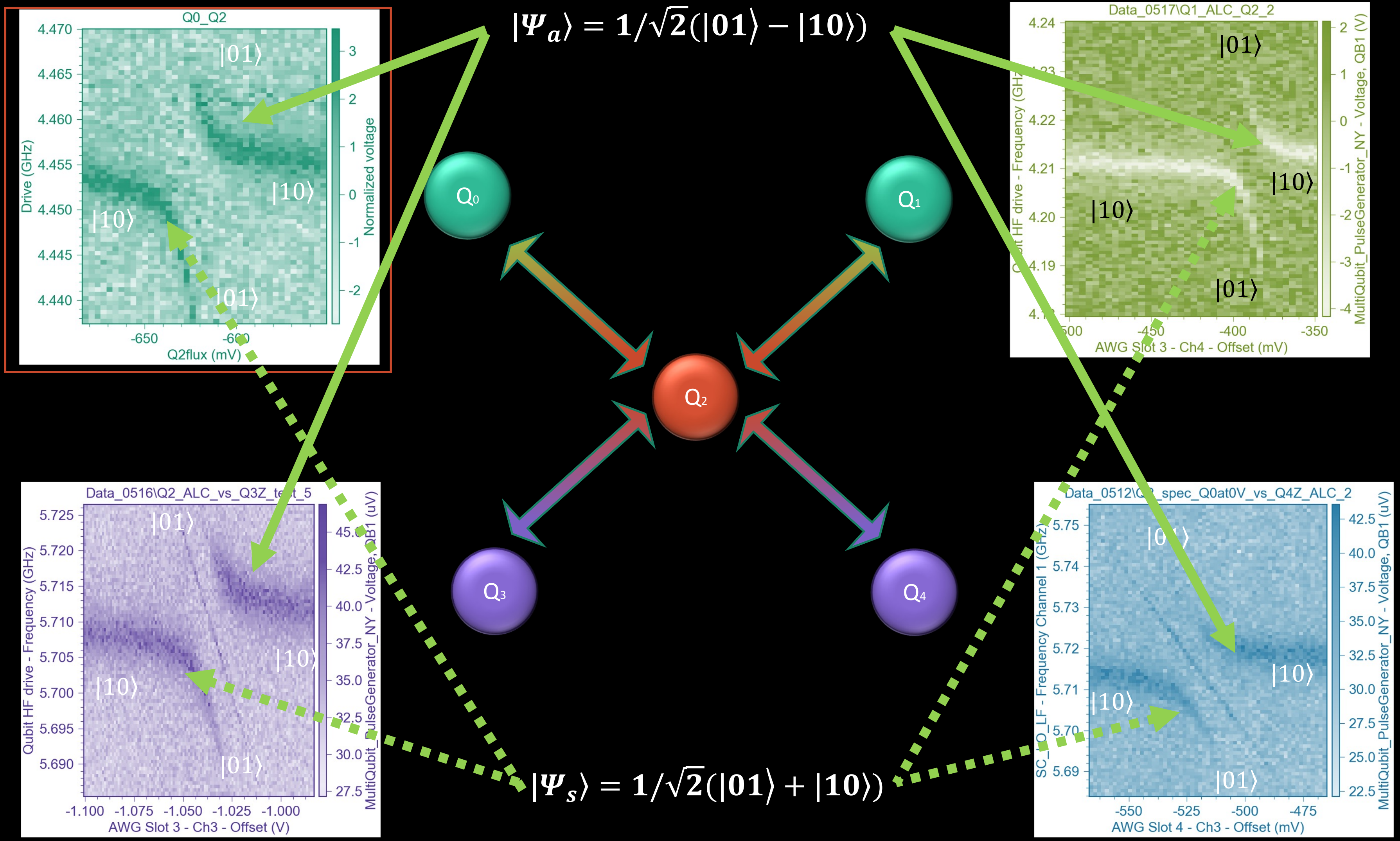
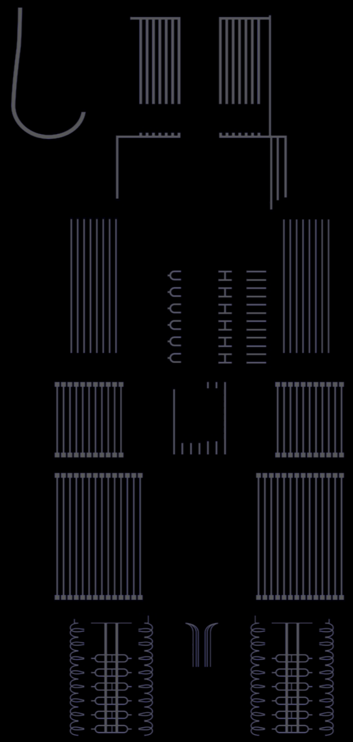
Systematic investigation on 2-qubits entanglement





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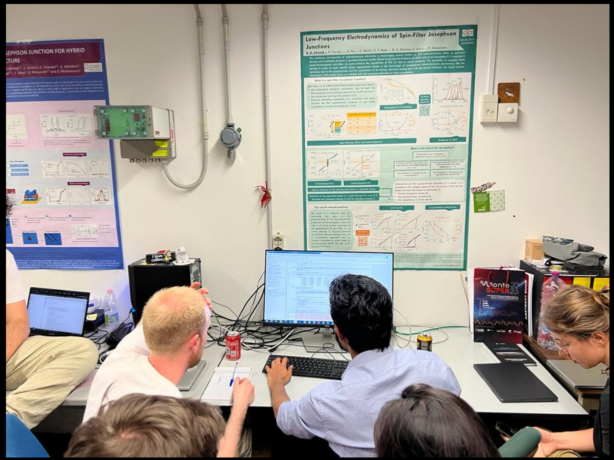
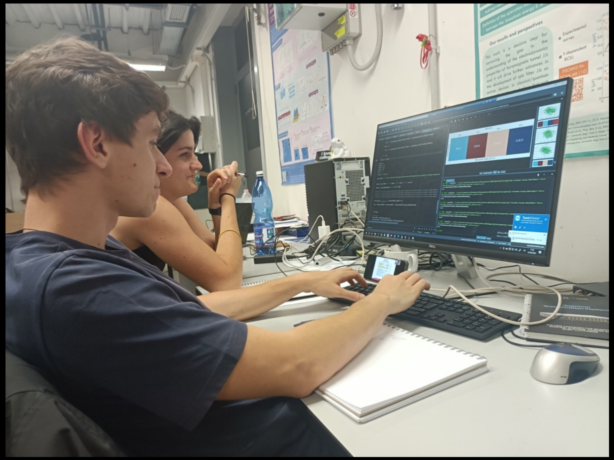
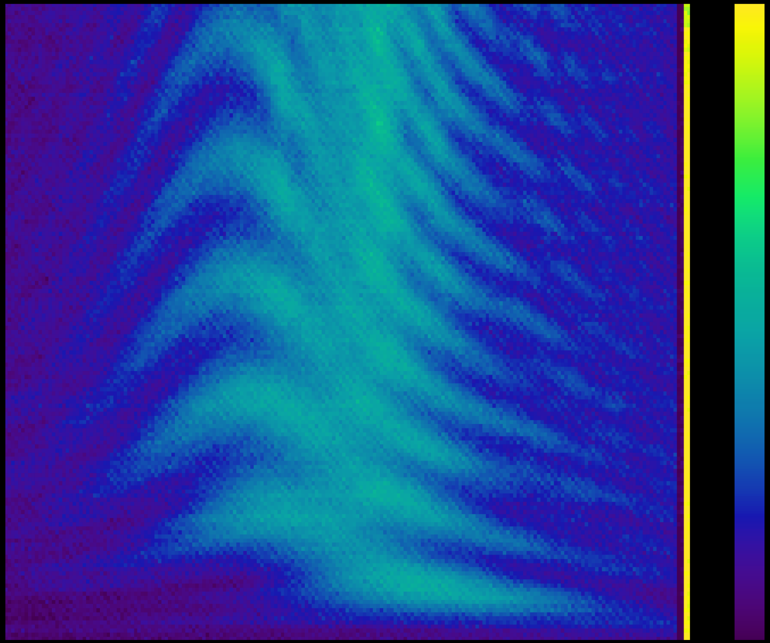
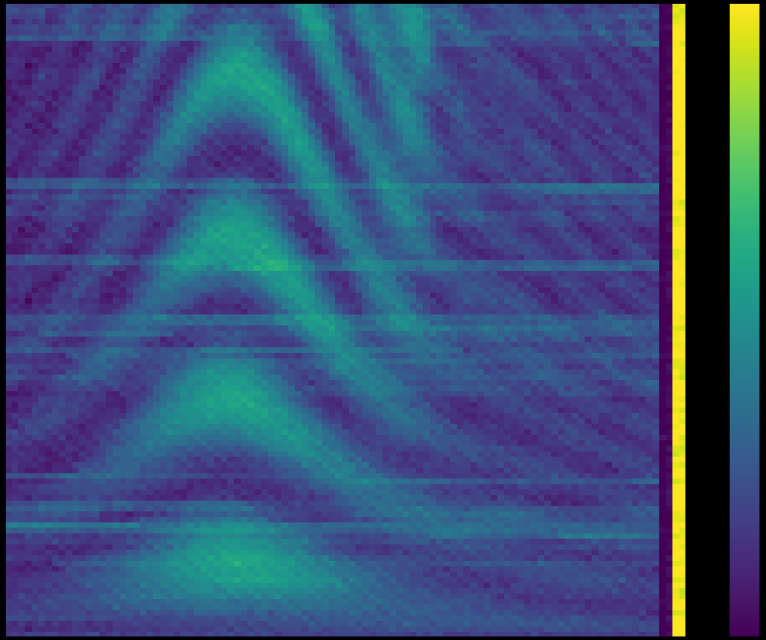
Controlled exchange of energy between two qubits: CZ gates optimization and calibration







Pre-calibration (distorted pattern)



After-calibration (symmetric pattern)

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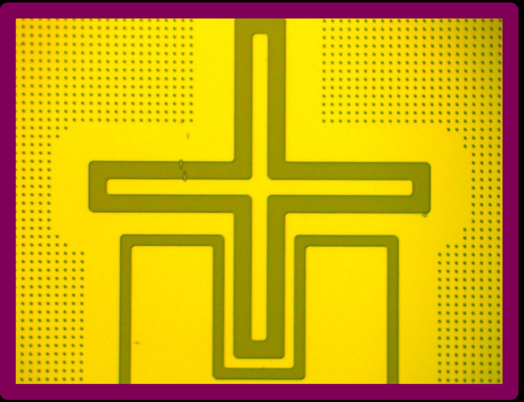
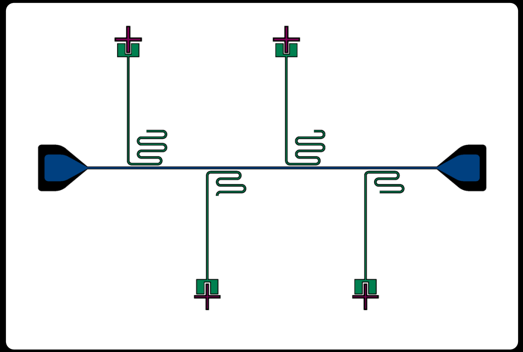
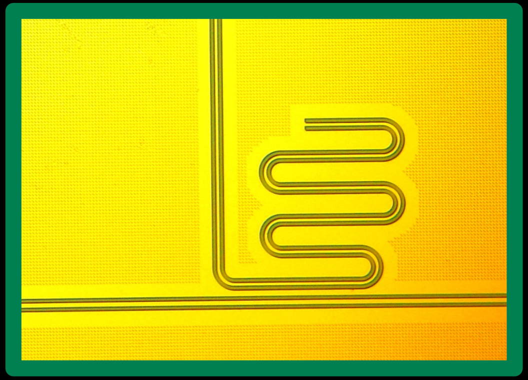
Made in Napoli

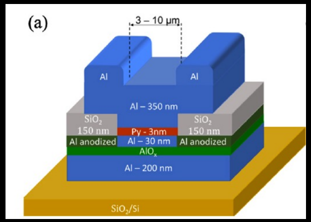
Hardware

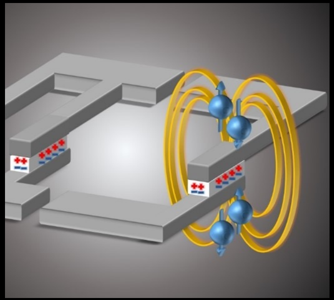


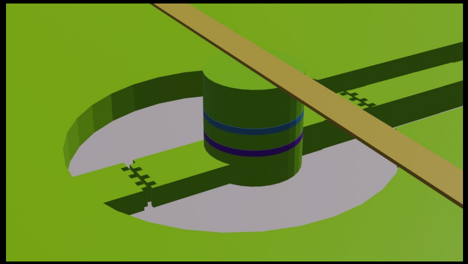




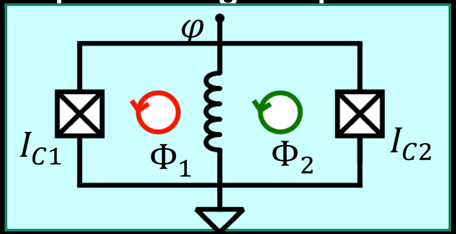
Transmon qubit based on ferromagnetic JJs-ferrotransmon



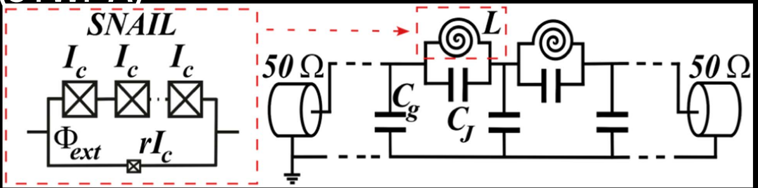




Josephson digital phase detector



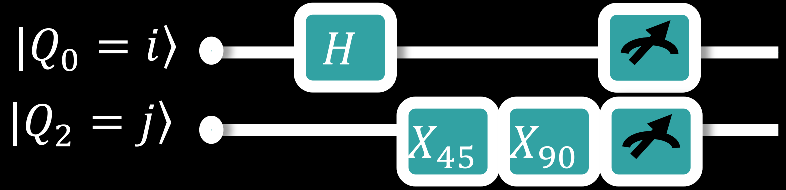
Josephson Travelling wave parametric amplifier (JTWPA)

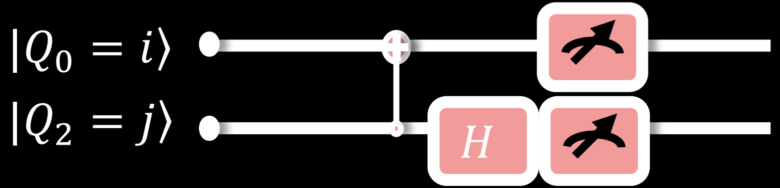


On-chip microwave source of coherent states in superconducting quantum circuits

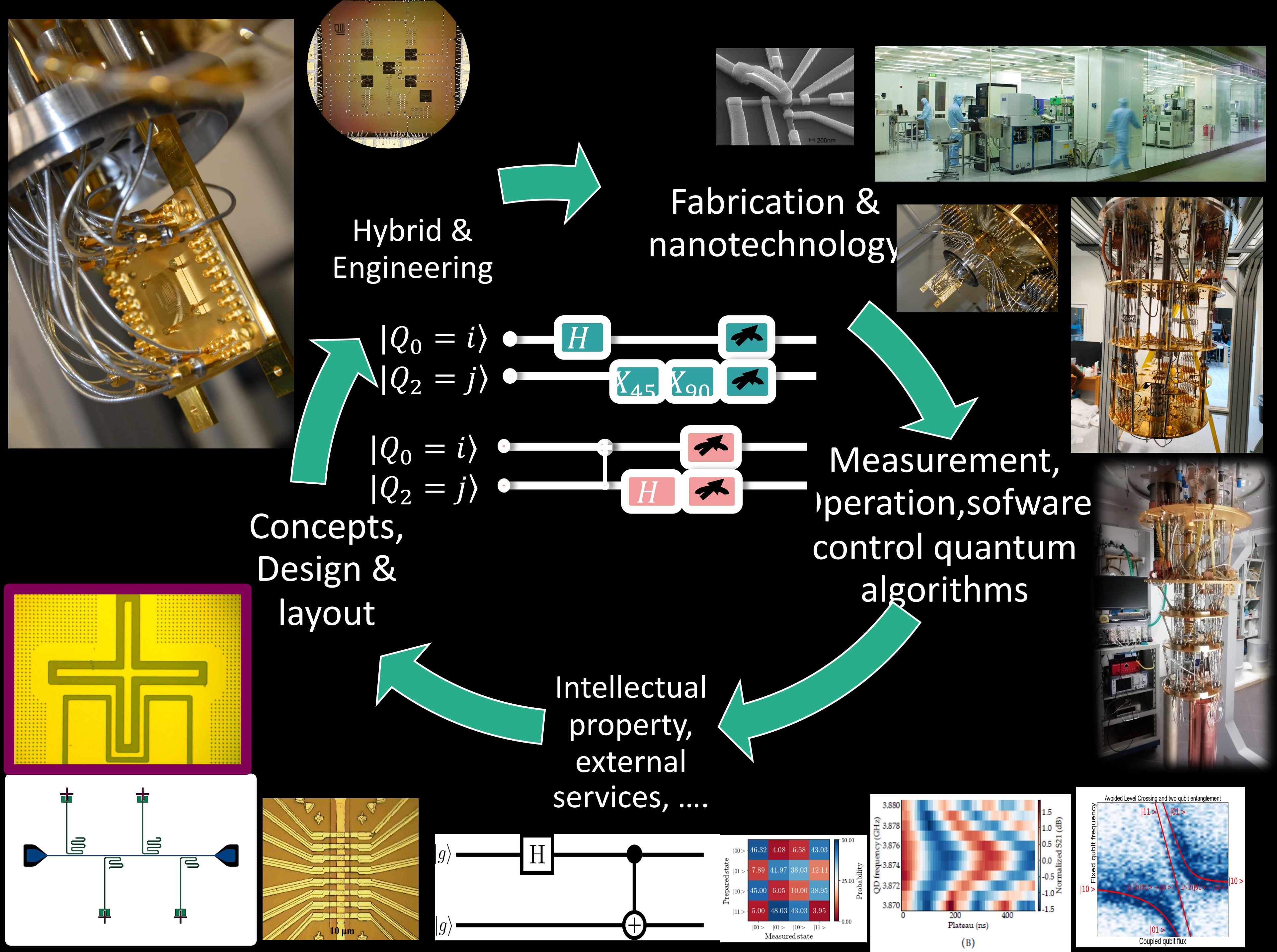
Software

Mitigating Errors on Superconducting Quantum Processors through Fuzzy Clustering

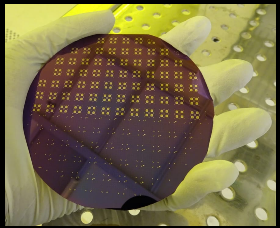


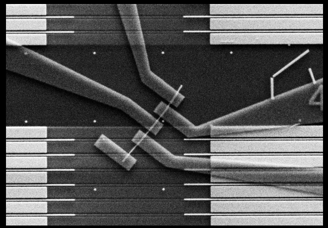


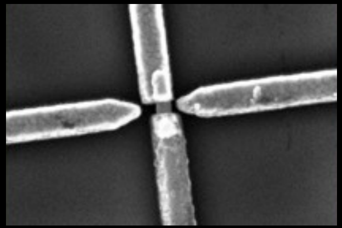
Flexibility in building Hamiltonians (Hamiltonian Engineering) control & read out

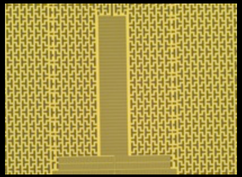

Hybrid &
Engineering
Fabrication &
nanotechnology
$|Q_0 = i\rangle$
$|Q_2 = j\rangle$
H
X_{45}
X_{90}
$|Q_0 = i\rangle$
$|Q_2 = j\rangle$
H
Measurement,
peration,sofware
control quantum
algorithms
Concepts,
Design &
layout
Intellectual
property,
external
services, ….
10 µm
$|g\rangle$
$|g\rangle$
H
Prepared state
Measured state
Probability
QD frequency (GHz)
Plateau (ns)
Normalized S21 (dB)
(B)
Avoided Level Crossing and two-qubit entanglement
Fixed qubit frequency
Coupled qubit flux

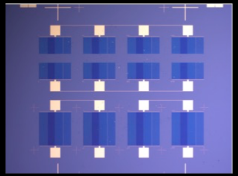
UniNAno: Nanotech facility

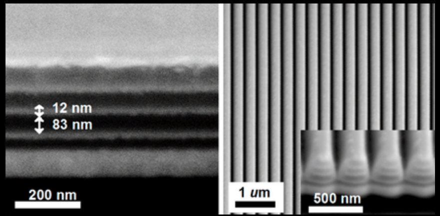












DIPARTIMENTO DI INGEGNERIA ELETTRICA E DELLE TECNOLOGIE DELL'INFORMAZIONE

UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II - DIPARTIMENTO DI FISICA "ETTORE PANCINI"

I protagonisti

Davide Massarotti, Halima G. Ahmad, Domenico Montemurro, Roberta Satariano, Anna Levochkina, Pasquale Mastrovito, Carlo Cosenza, Viviana Stasino, Giuseppe Serpico, Giovanni Ausanio, Loredana Parlato, Nicola Poccia, Giampiero Pepe & Francesco Tafuri

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Università degli Studi di Napoli Federico II

Martina Esposito, Pegah Darvehi, Isita Chatterjee (SPIN)

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and Oleg Mukanhov

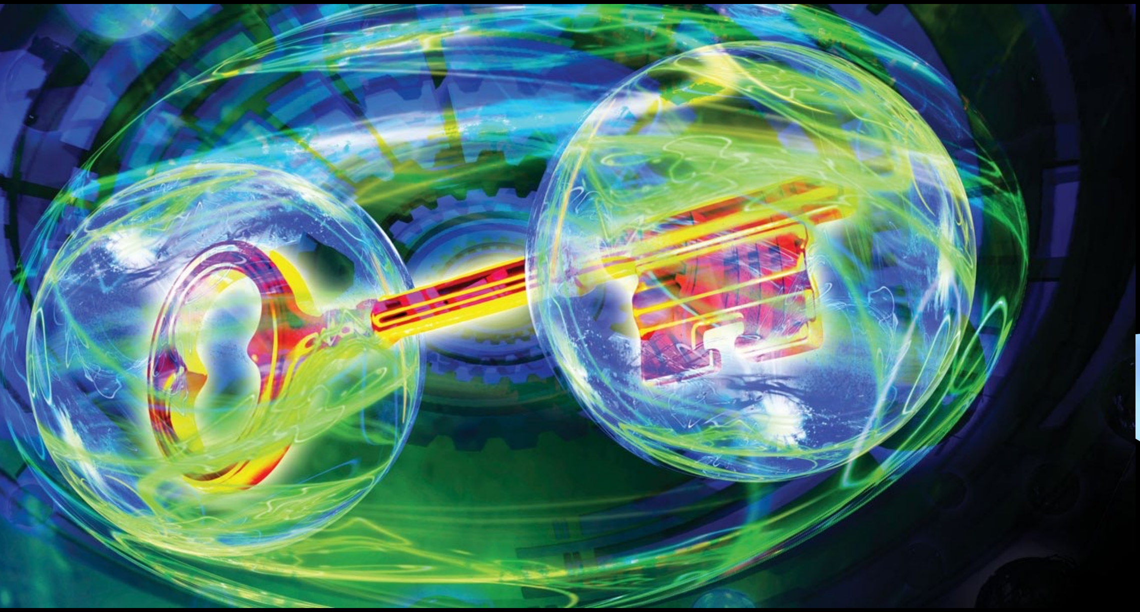
SeeQC

Alessandro Bruno, Raffaella Ferraiuolo

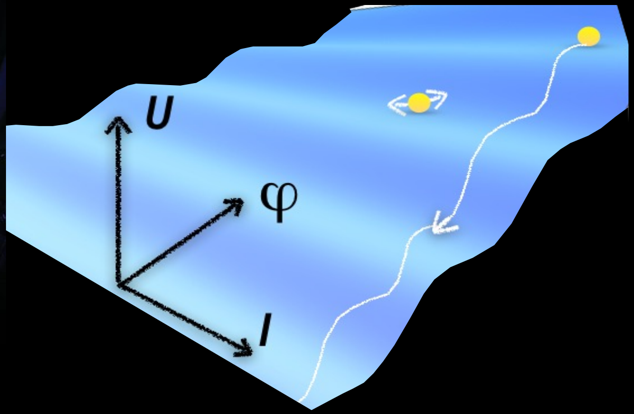
https://www.qtlab.unina.it/

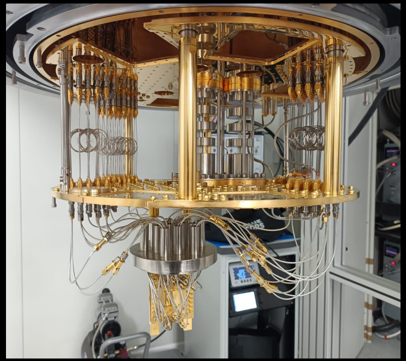
Antonio Barone

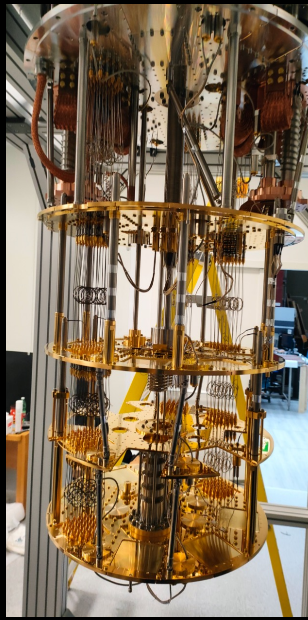
Incerto, quantistico e infine reale



$$-\frac{\hbar^2}{2m}\nabla^2\psi(\vec{r},t) - \frac{e^2}{r}\psi(\vec{r},t) = E\psi(\vec{r},t)$$

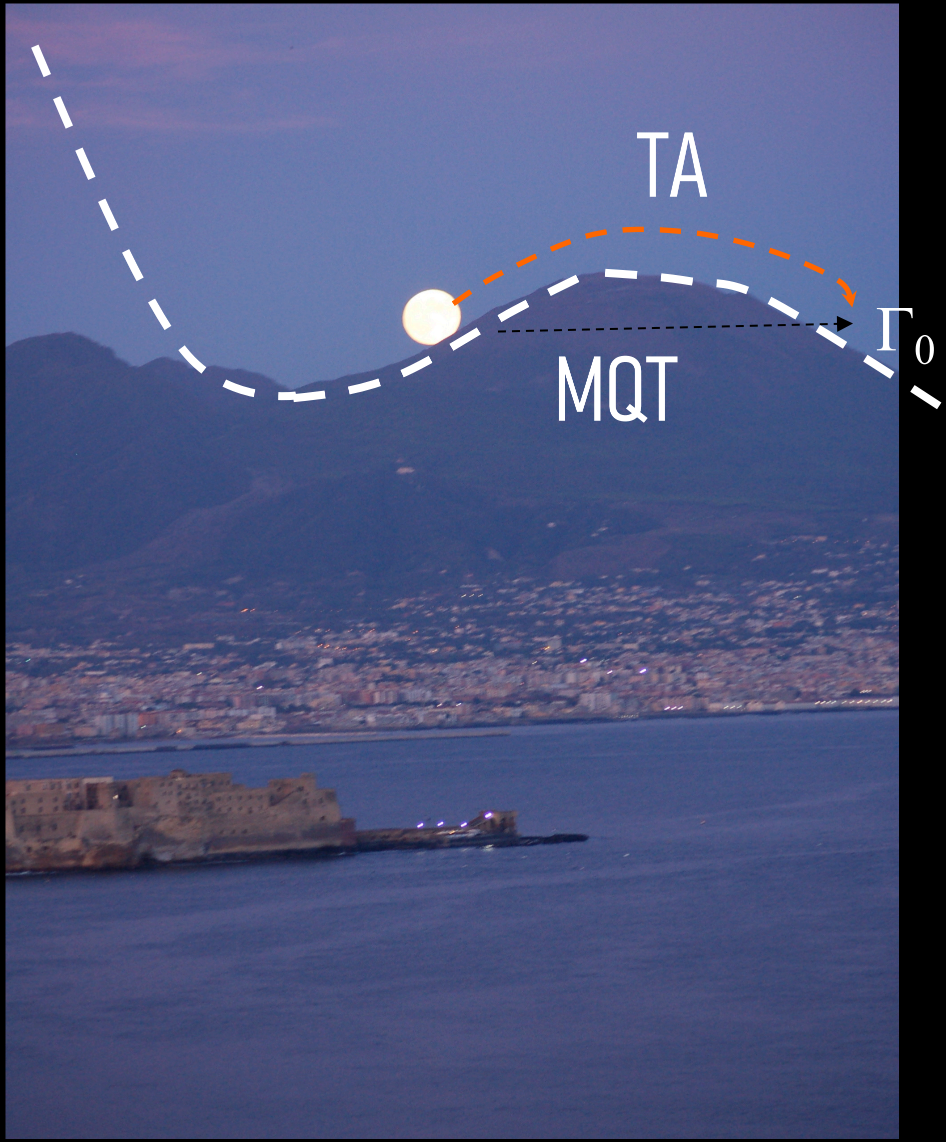






The sense of Macroscopic

The sense of Macroscopic



In bocca al lupo per il vostro futuro

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