SAPIENZA
UNIVERSITÀ DI ROMA

Un cammino nel mondo quantistico:
...dai fondamenti della fisica alla tecnologia del futuro...

Fabio Sciarrino

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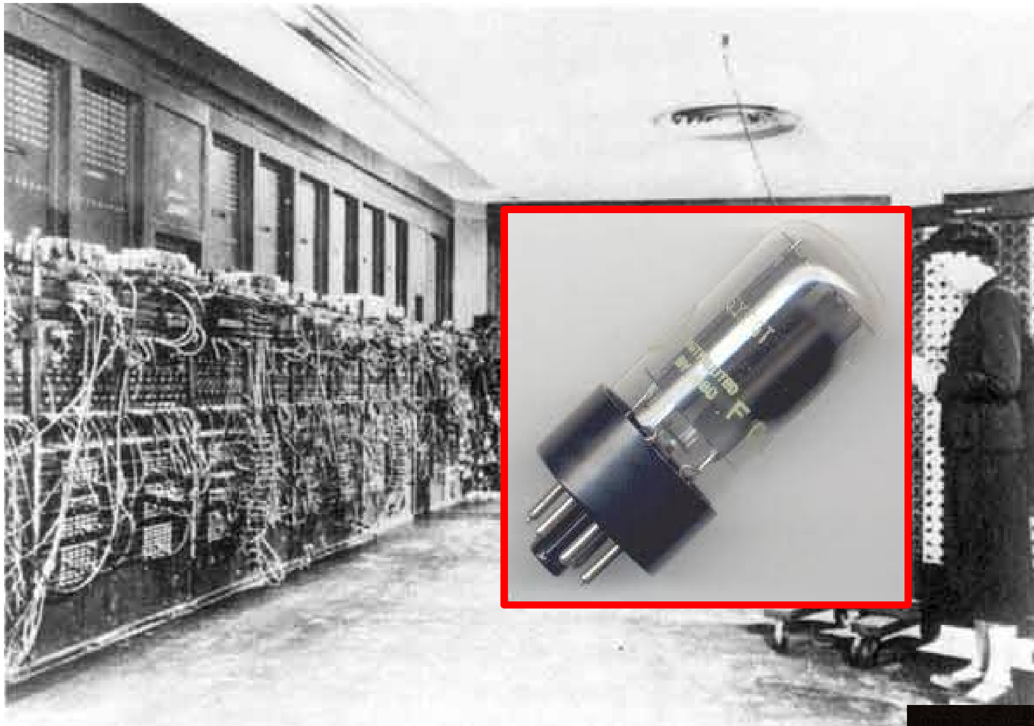
Dipartimento di Fisica, Sapienza Università di Roma

http://quantumoptics.phys.uniroma1.it

www.3dquest.eu



ENIAC (1946)

Electronic Numerical Integrator And Computer

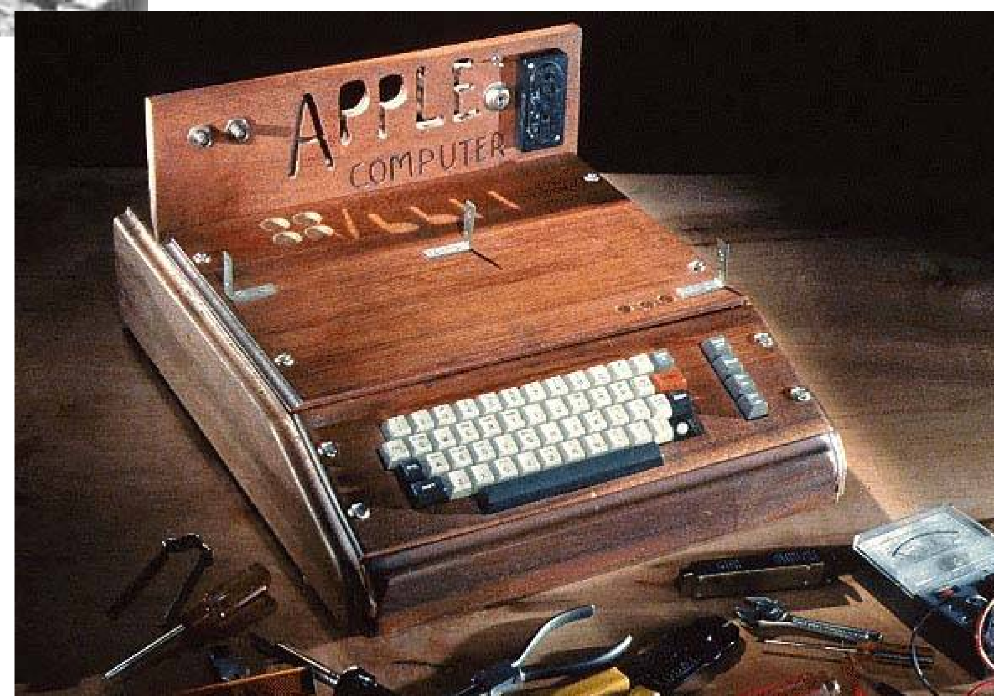
18.000 valvole termoioniche,

30 tonnellate,

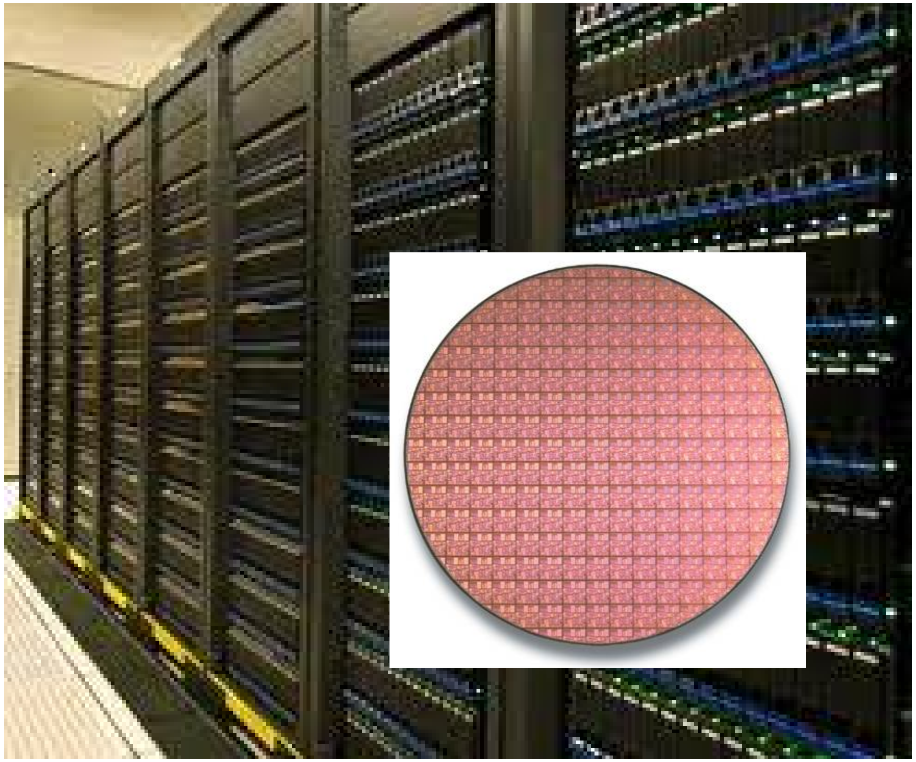
180 mq

Apple I (1976)

.. 4 Kb di Ram...!



OGGI...



Tianhe-1A (2010)

Supercomputer

Operazioni per secondo 1 PetaFlops

I-Phone 4s (2012)

RAM 512 Mb

news & views

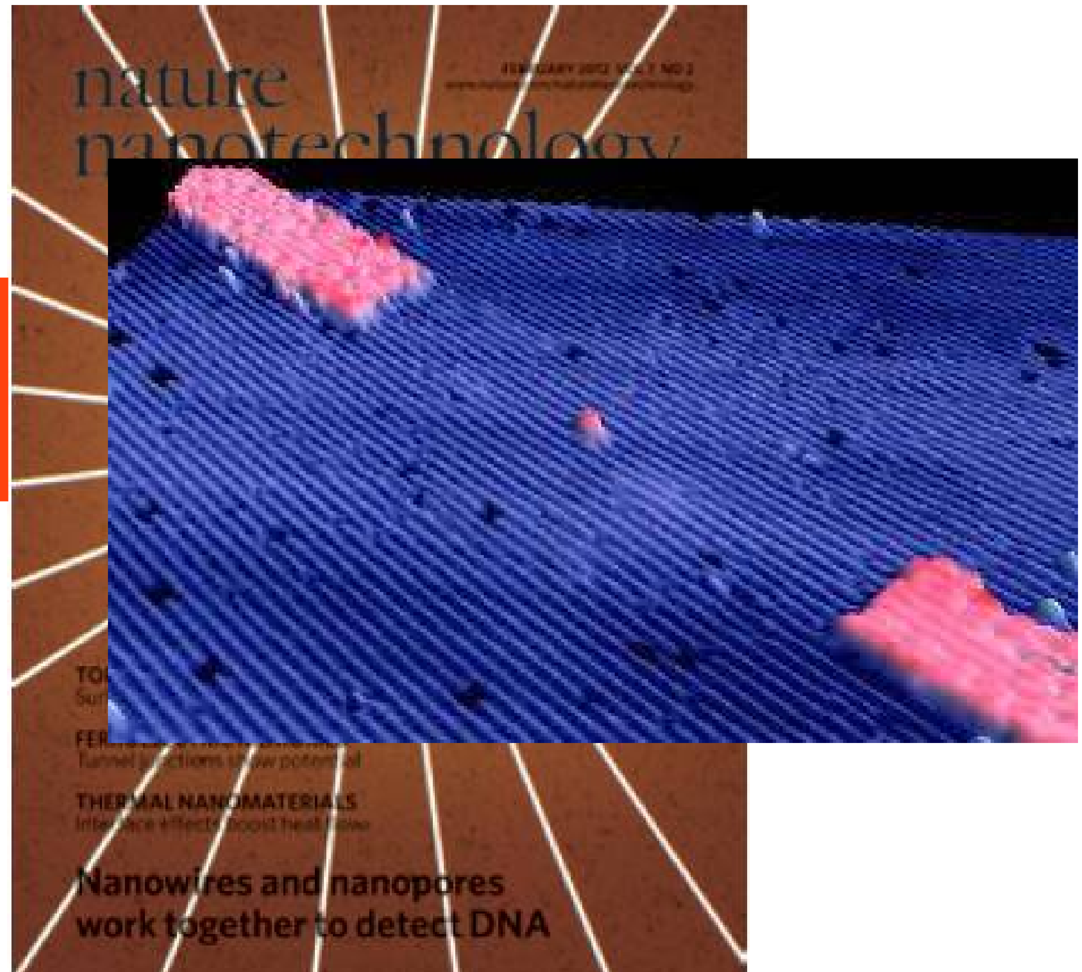
NANOELECTRONICS

Transistors arrive at the atomic limit

A single-atom transistor has been made by positioning a phosphorus atom between metallic electrodes, also made of phosphorus, on a silicon surface.

Gabriel P. Lansbergen

Breaking news!
19 Febbraio 2012



NANOELECTRONICS

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A single-atom transistor has been made by posi… …us atom between metallic electrodes, also made of phosphorus, on a silicon surface.

Gabriel P. Lansbergen

TECNOLOGÍA | Construido en Australia

Un transistor del tamaño de un átomo como antesala del ordenador cuántico

Efe | Sidney
Actualizado lunes 20/02/2012 10:57 horas

NANOELECTRONICS

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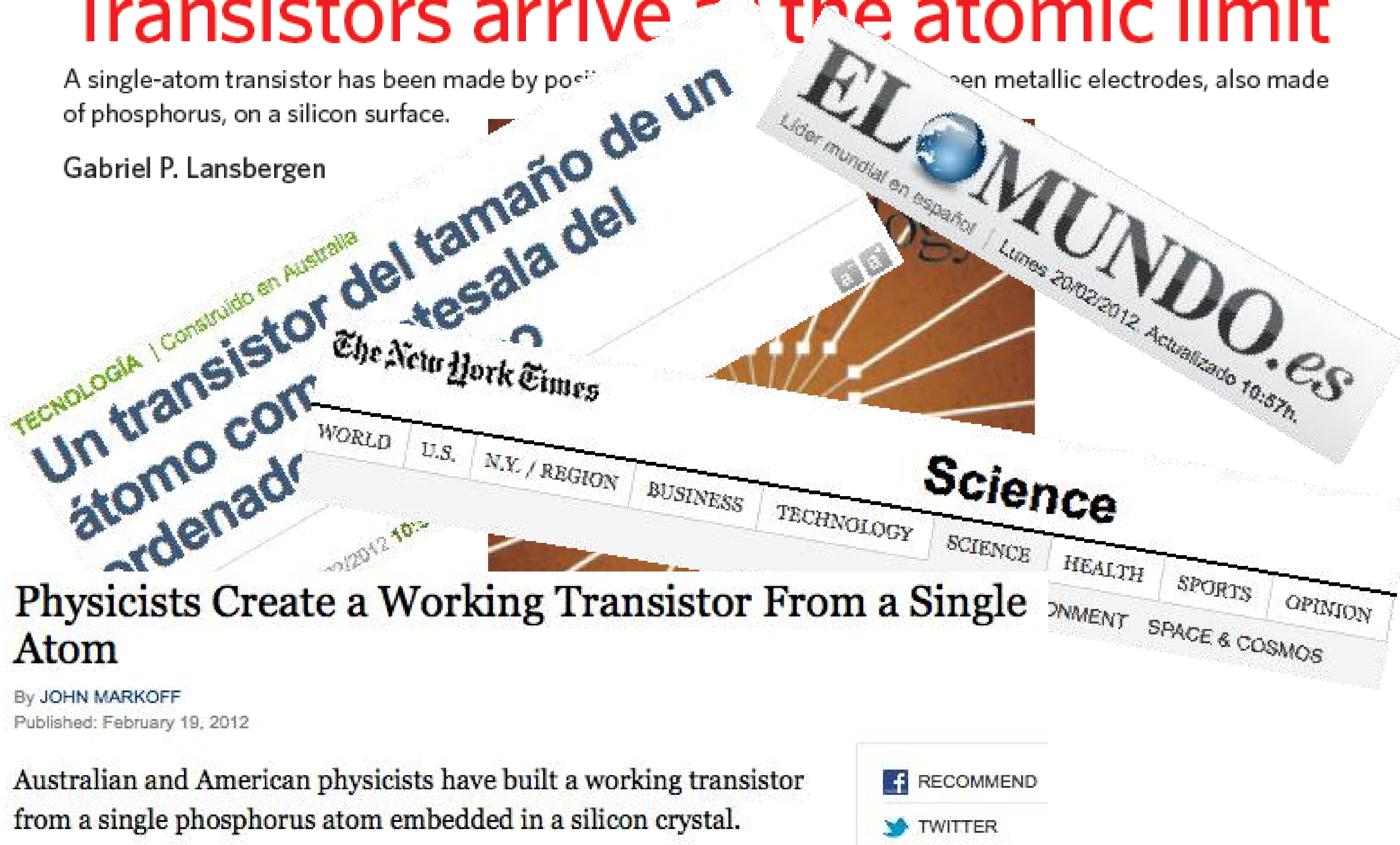

“ […] Un importante passo in avanti verso i super computer quantistici del futuro, realizzato dai fisici dell'università australiana del Nuovo Galles del Sud a Sydney .”

La Repubblica

“ [...] Científicos australianos han construido el transistor más pequeño del mundo a partir de un único átomo, lo que supone un gran paso hacia el desarrollo de los futuros ordenadores cuánticos.”

El Mundo

“ [...]they had laid the groundwork for a futuristic quantum computer that might one day function in a nanoscale world and would be orders of magnitude smaller and quicker than today’s silicon-based machines.”

The New York Times

NANOELECTRONICS

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A single-atom transistor has been made by pos... een metallic electrodes, also made of phosphorus, on a silicon surface.

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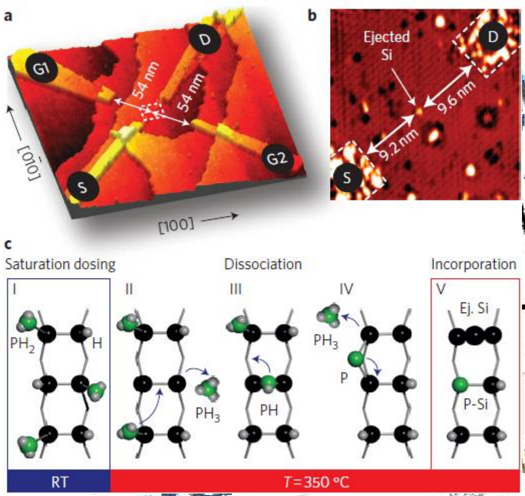


...l tamaño de un
...tesala del

EL MUNDO.es
Líder mundial en español | Lunes 20/02/2012. Actualizado 10:57h.

The New York Times

U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH | SPORTS

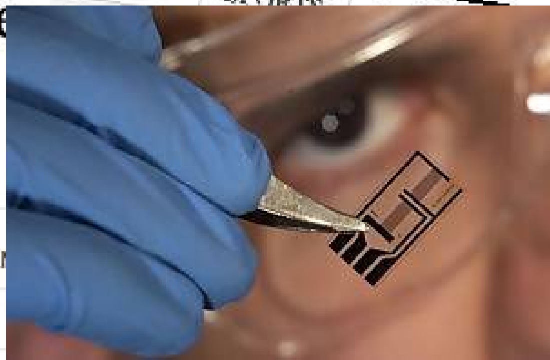
Science

Physicists Create a Working Transistor From a Single Atom

By JOHN MARKOFF
Published: February 19, 2012

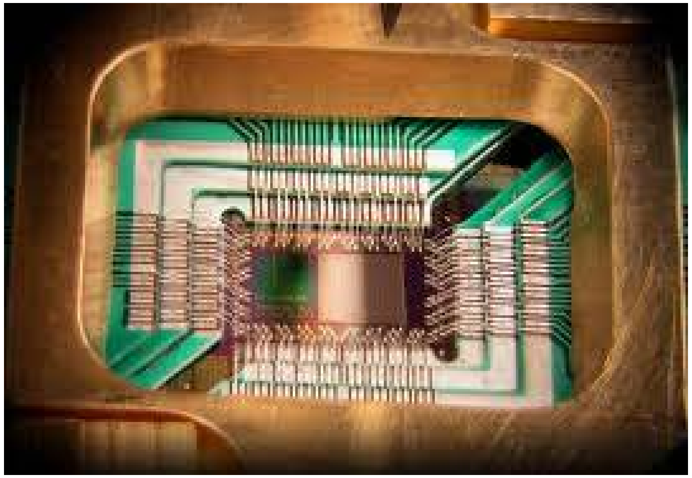
Australian and American physicists have built a working transistor from a single phosphorus atom embedded in a silicon crystal.

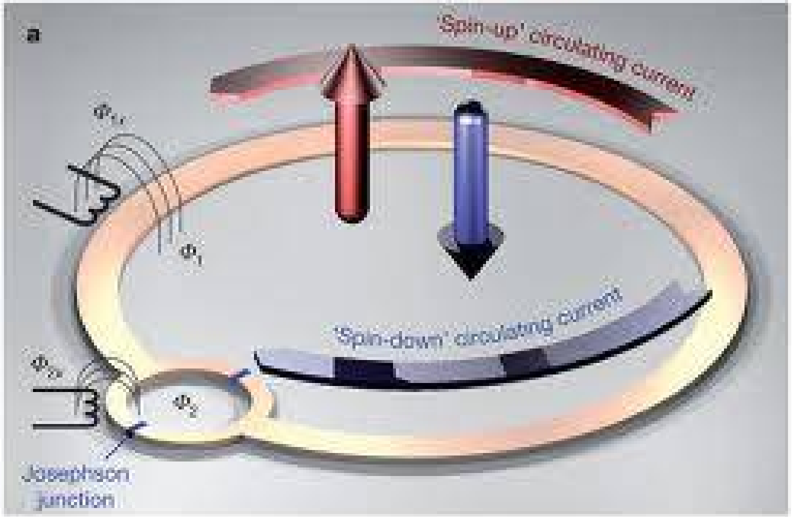
RECOMMEN...
TWITTER



D-wave: un quantum computer commerciale ?!?

512 qubit....
Costo: 10.000.0000 $
Comprato da NASA, google..





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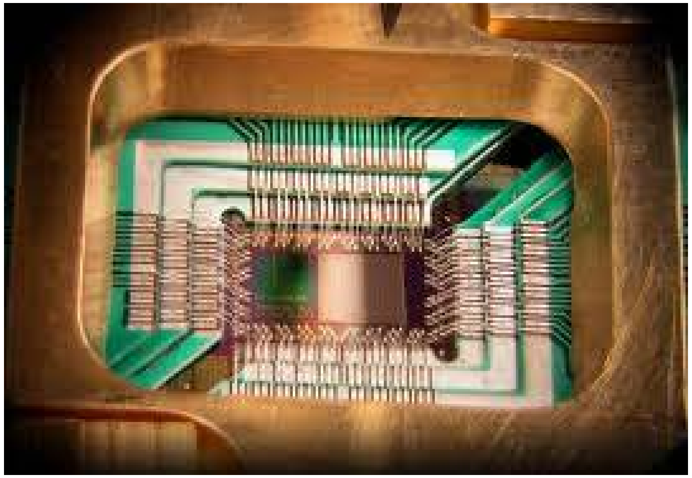


E' « veramente » quantistico ?
E' superiore ad un computer classico ?

Risultati della Fisica Classica:

Alla fine del 1800...

La teoria fisica predominante ammetteva come unici costituenti dell'Universo la **materia** e la **radiazione**

costituita da particelle perfettamente localizzabili, soggette alla legge di Newton

presenta un comportamento ondulatorio ed obbedisce alle leggi della elettrodinamica di Maxwell;

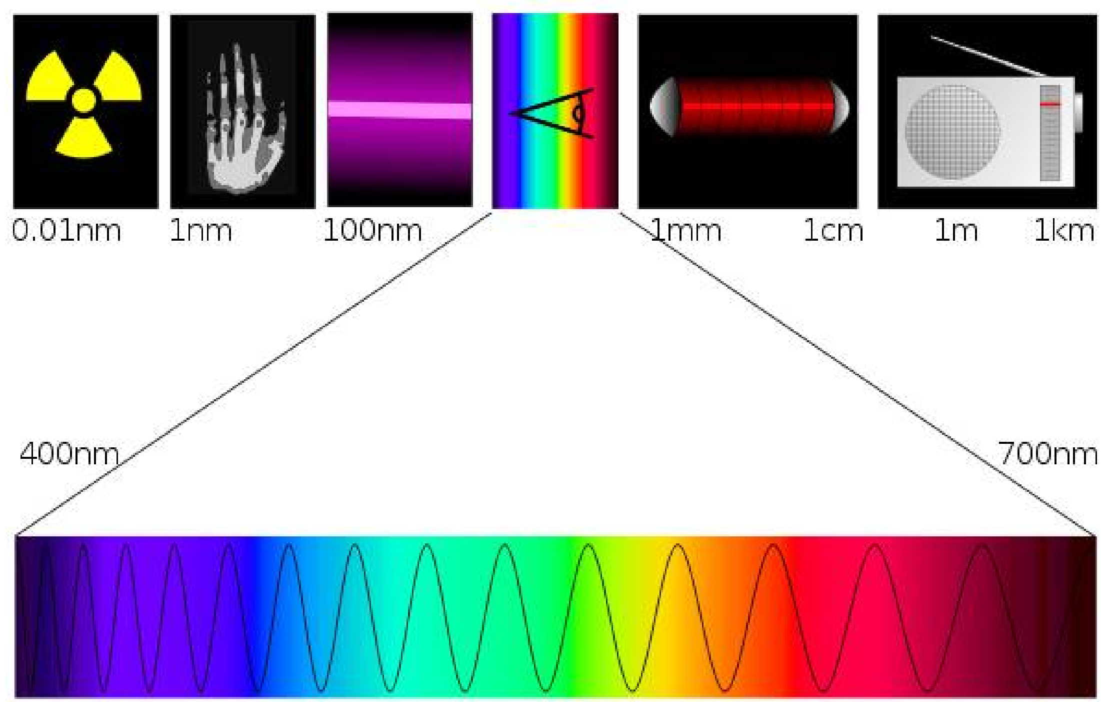
Le equazioni della fisica classica....

La cinematica dei corpi

$$\begin{cases} \mathbf{F} = m\mathbf{a} \\ \mathbf{M} = \dfrac{d\mathbf{L}}{dt} \end{cases}$$

L'Elettromagnetismo (Equazioni di Maxwell)

$$\begin{cases} \nabla \cdot \mathbf{D} = \rho \\ \nabla \times \mathbf{E} + \dfrac{\partial \mathbf{B}}{\partial t} = 0 \\ \nabla \cdot \mathbf{B} = 0 \\ \nabla \times \mathbf{H} - \dfrac{\partial \mathbf{D}}{\partial t} = \mathbf{J} \end{cases}$$



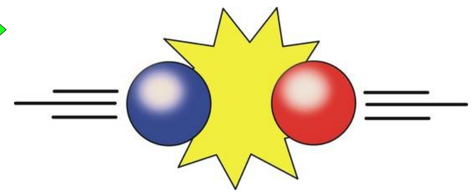
Le equazioni della fisica classica....

Equazione

$$
\begin{cases}
\mathbf{F} = m\mathbf{a} \\
\mathbf{M} = \dfrac{d\mathbf{L}}{dt}
\end{cases}
$$

Fenomeno

Urto tra particelle



Descrizione

$$
\begin{cases}
m_1 v_1 + m_2 v_2 = m_1 V_1 + m_2 V_2 \\
\frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 = \frac{1}{2} m_1 V_1^2 + \frac{1}{2} m_2 V_2^2
\end{cases}
$$

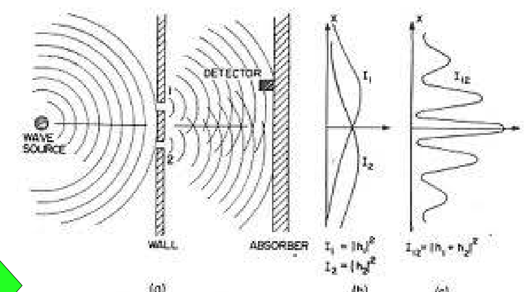
Equazione

$$
\begin{cases}
\nabla \cdot \mathbf{D} = \rho \\
\nabla \times \mathbf{E} + \dfrac{\partial \mathbf{B}}{\partial t} = 0 \\
\nabla \cdot \mathbf{B} = 0 \\
\nabla \times \mathbf{H} - \dfrac{\partial \mathbf{D}}{\partial t} = \mathbf{J}
\end{cases}
$$

Fenomeno

Interferenza tra onde

Descrizione



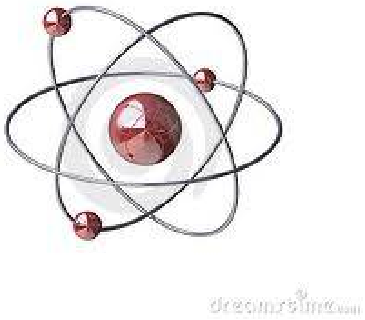
$$
I = E^2 = 4\left|E_A^2\right| \cos^2 \frac{kd \sin \alpha}{2}
$$

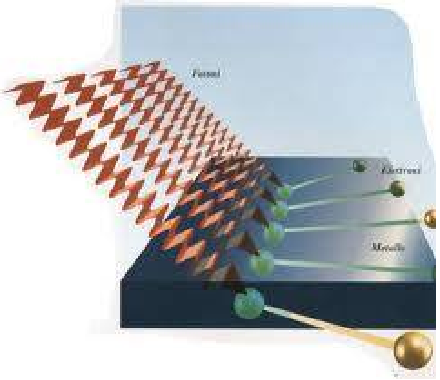
La crisi della fisica classica

La fisica classica non riesce a spiegare quello che succede nel mondo microscopico...

...Perchè un elettrone non cade sul nucleo emettendo radiazione elettromagnetica?

...Come si spiega l'energia emessa da una superficie metallica irradiata ?

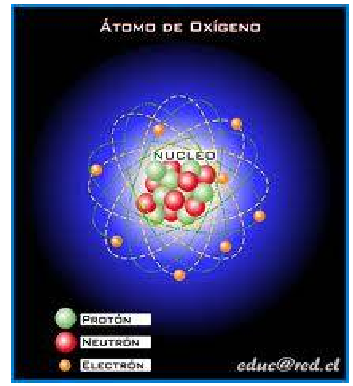


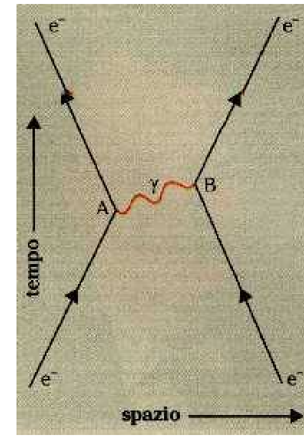


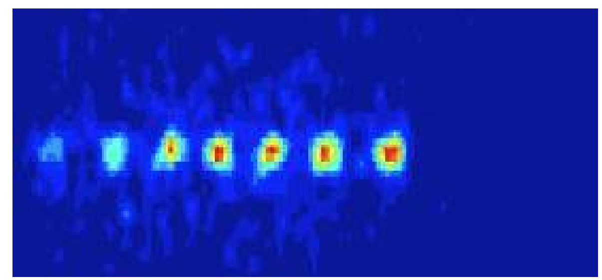
MONDO MACROSCOPICO

FISICA CLASSICA

MONDO MICROSCOPICO





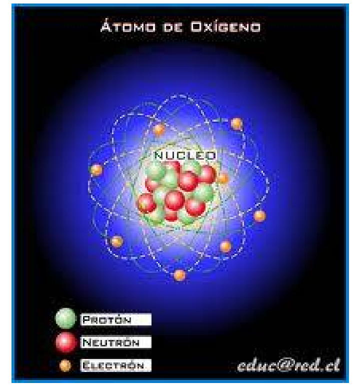


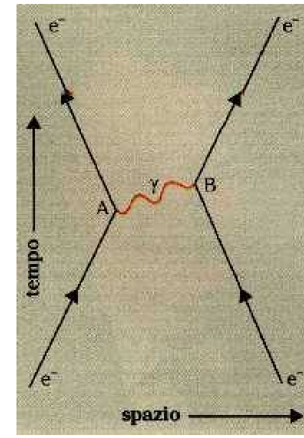
FISICA QUANTISTICA

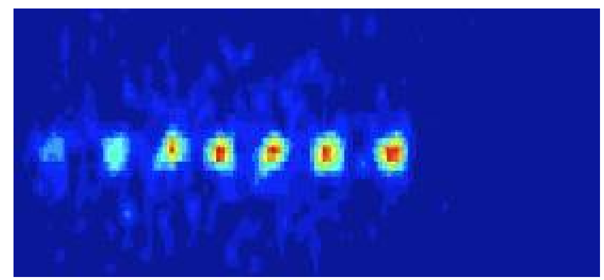
MONDO MACROSCOPICO

FISICA CLASSICA

MONDO MICROSCOPICO





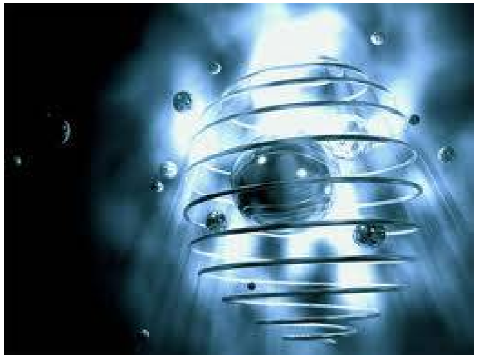


FISICA QUANTISTICA

Le risposte della Meccanica Quantistica...

L'energia, al pari della materia, presenta una natura discontinua essendo formata da quantità elementari.

TEORIA DEI QUANTI



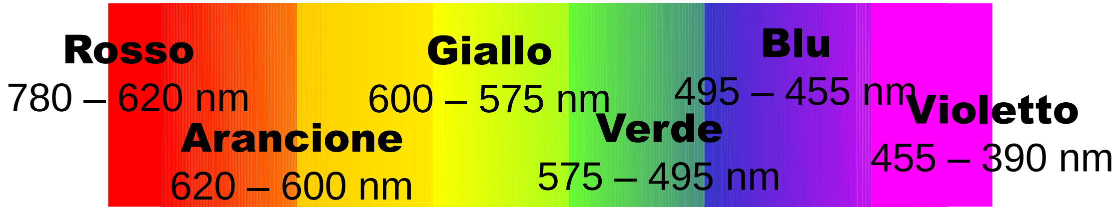
Tutti i processi di interazione tra i corpi (i "campi di forza") sono "quantizzati" ["particelle elementari": fotoni, elettroni etc.]

Il quanto di luce: il fotone

Onda elettromagnetica trasporta energia

Energia cambiata in modo discreto:

il quanto (l'unità) fondamentale di energia è il **FOTONE**



Fotone:

I) Massa nulla

II) Energia

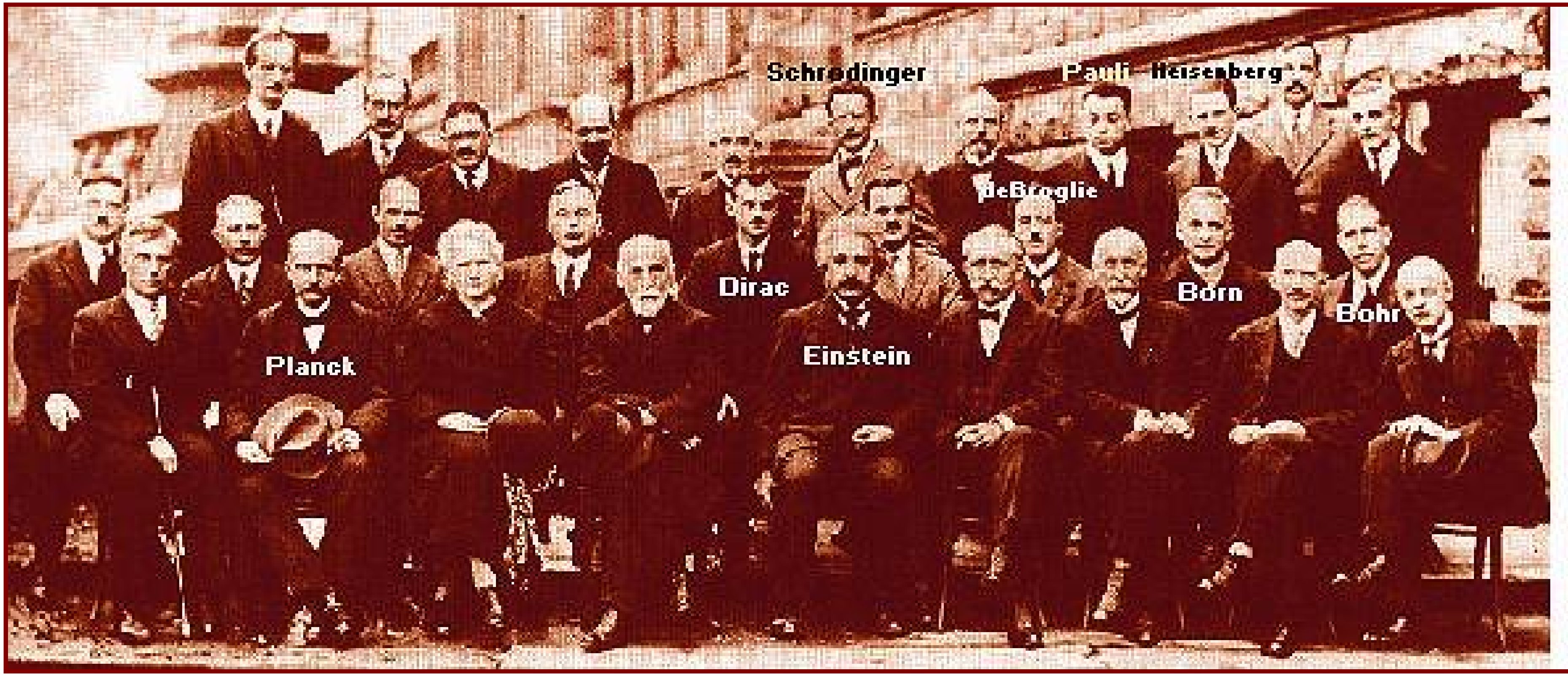
$$\boxed{E = h\,\nu}$$

Energia

Costante di Planck

Frequenza

Gli “anni d'oro” della Meccanica Quantistica: Conferenza di Solvay (1927)



Fisica dei quanti: Planck, Einstein, Bohr, Dirac, Schroedinger, Heisenberg, Pauli,...

Primo Principio della dinamica

$$\mathbf{F} = m\,\mathbf{a}$$

Primo Principio della dinamica

$$\mathbf{F} = m\,\mathbf{a}$$

Forza che agisce
sul sistema

Massa
che descrive il sistema

Accelerazione
effetto della forza

L'Equazione di Schroedinger

$$i\hbar \frac{d|\psi(t)\rangle}{dt} = \hat{H}|\psi(t)\rangle$$

L'Equazione di Schroedinger

$$i\hbar \frac{d|\psi(t)\rangle}{dt} = \hat{H}|\psi(t)\rangle$$

h costante
di Planck

Hamiltoniana
(descrive il sistema
considerato)

**FUNZIONE
D'ONDA**

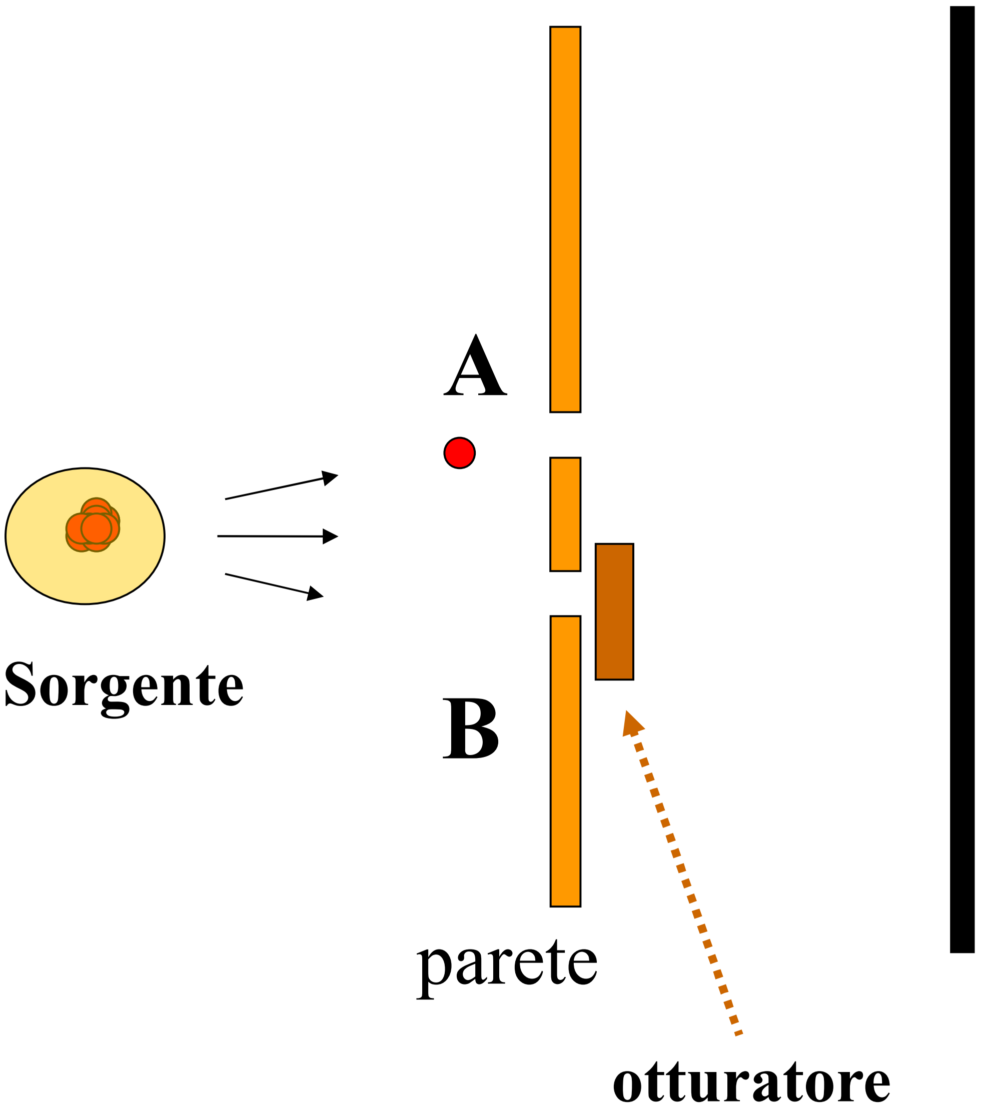
L'interferenza

"…the heart of quantum mechanics. In reality it contains the only mystery ..."

R.P. Feynman (1965)

Interferenza fra onde

Interferenza a singola particella



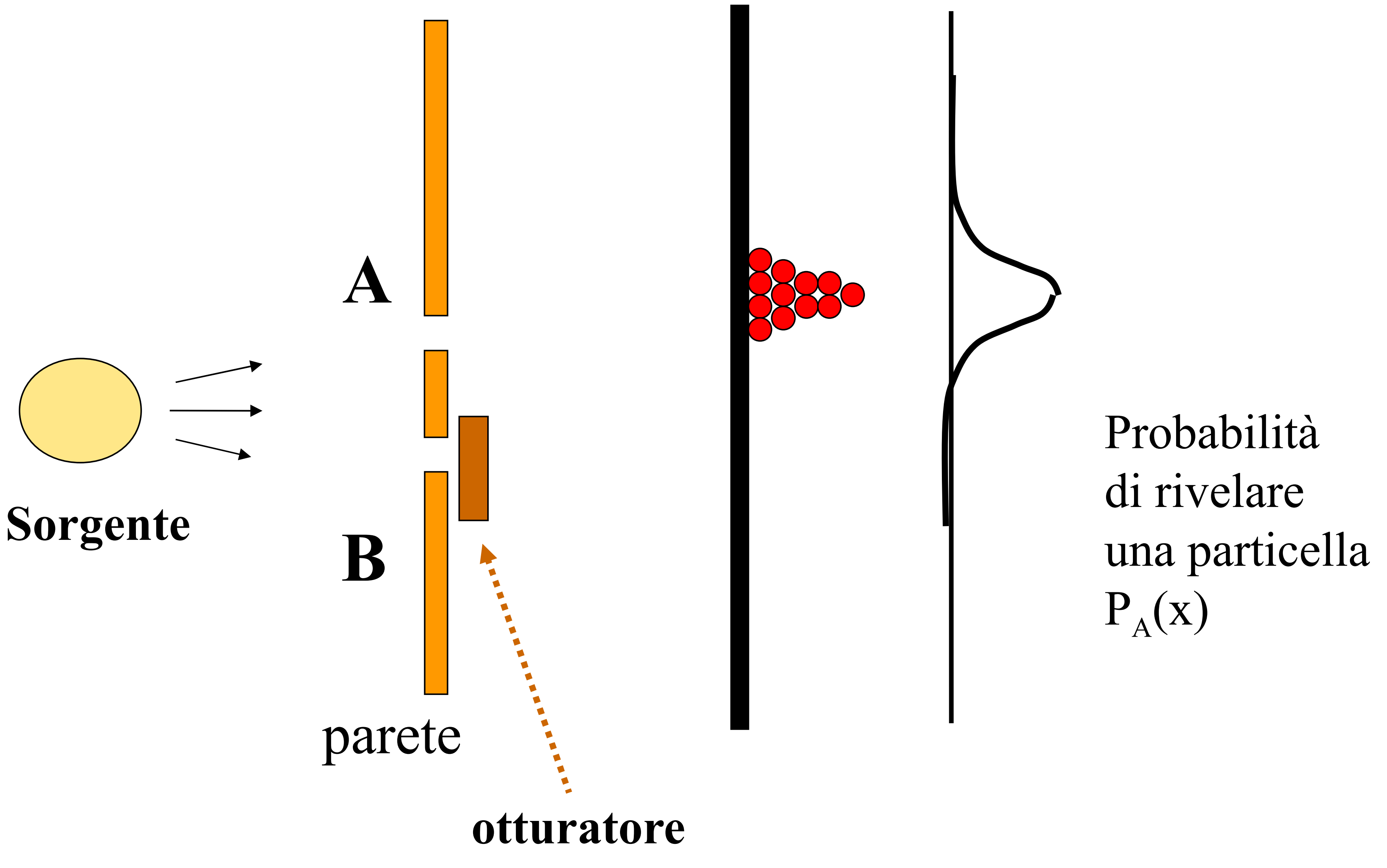
Interferenza a singola particella

A

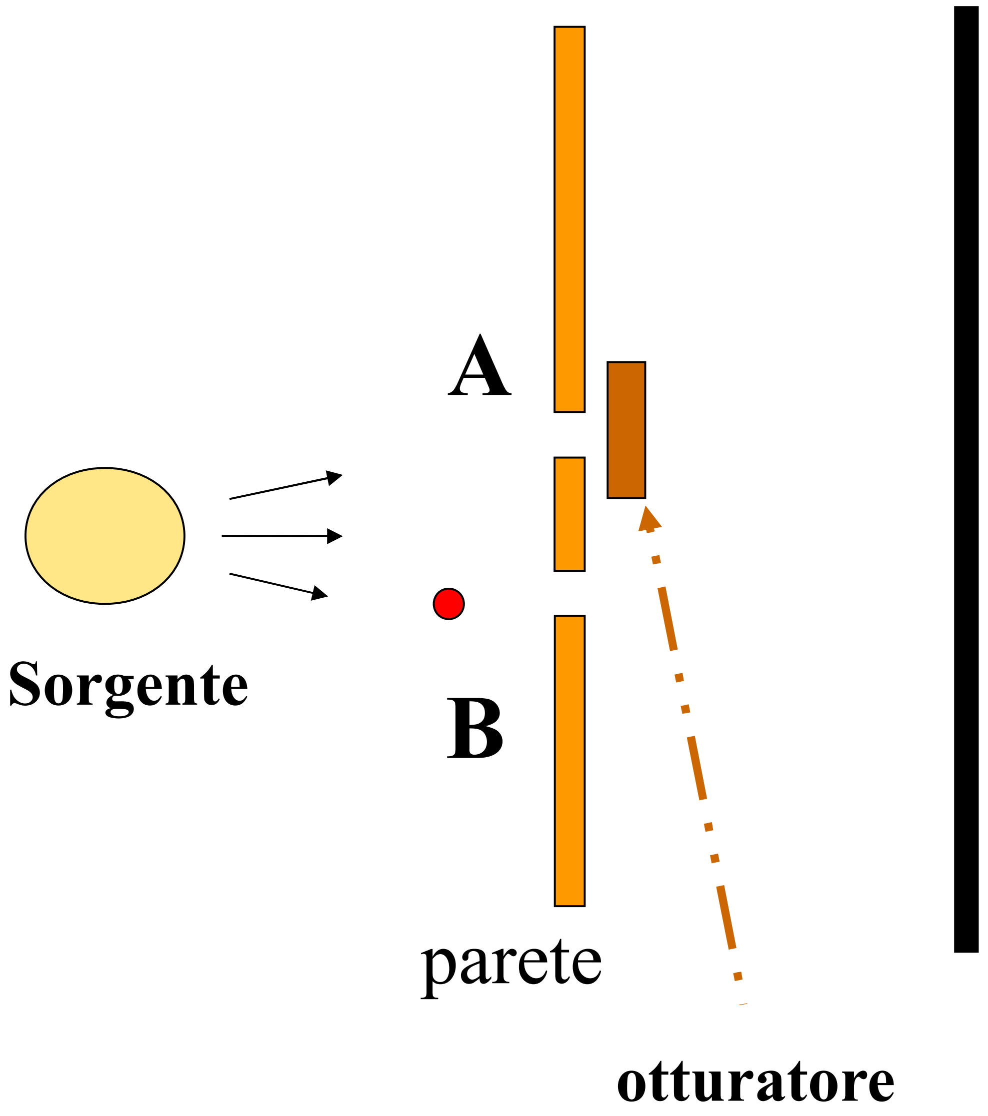
Probabilità
di rivelare
una particella
$P_L(x)$

B

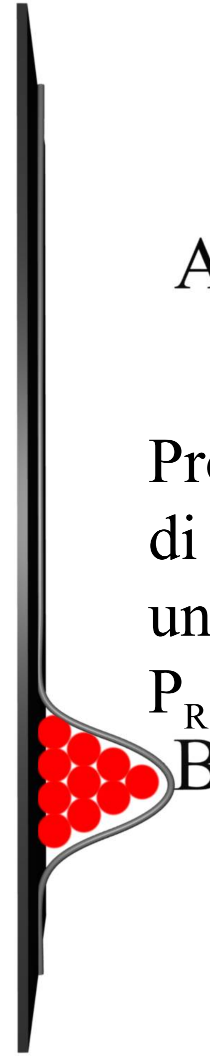
Interferenza a singola particella



Interferenza a singola particella

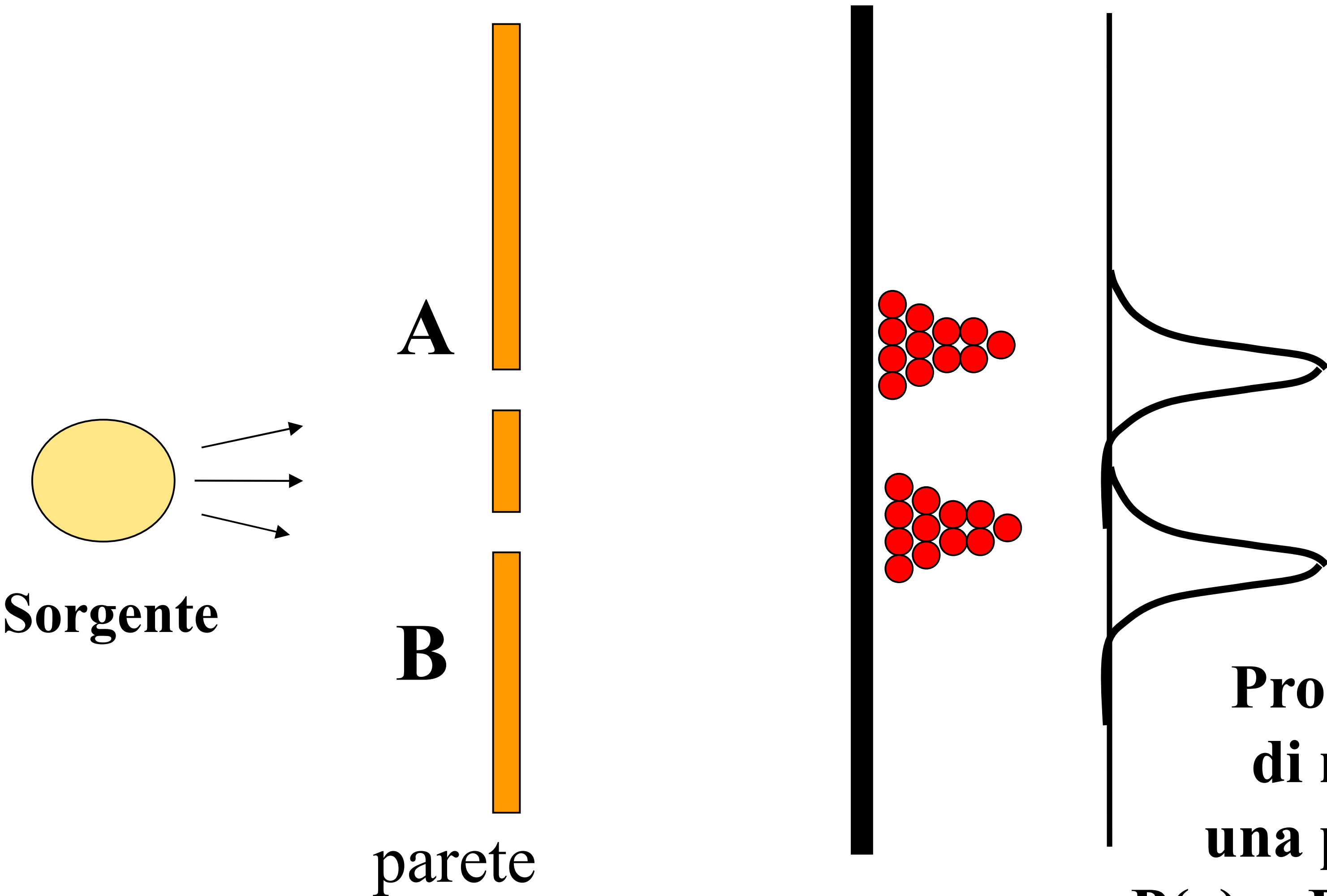


Interferenza a singola particella



Probabilità
di rivelare
una particella
$P_R(x)$

Comportamento "classico"



Probabilità di rivelare una particella

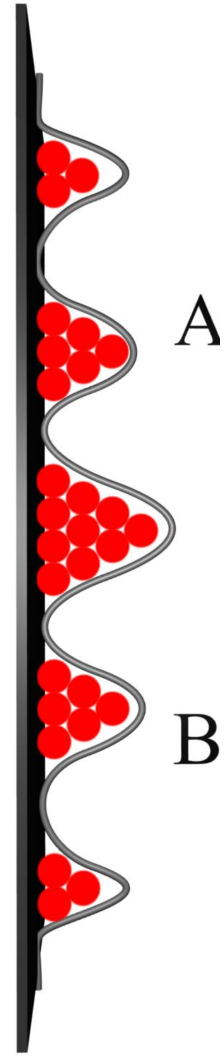
$$P(x) = P_A(x) + P_B(x)$$

Comportamento "classico"

Probabilità di rivelare una particella

$$P(x) = P_L(x) + P_R(x)$$

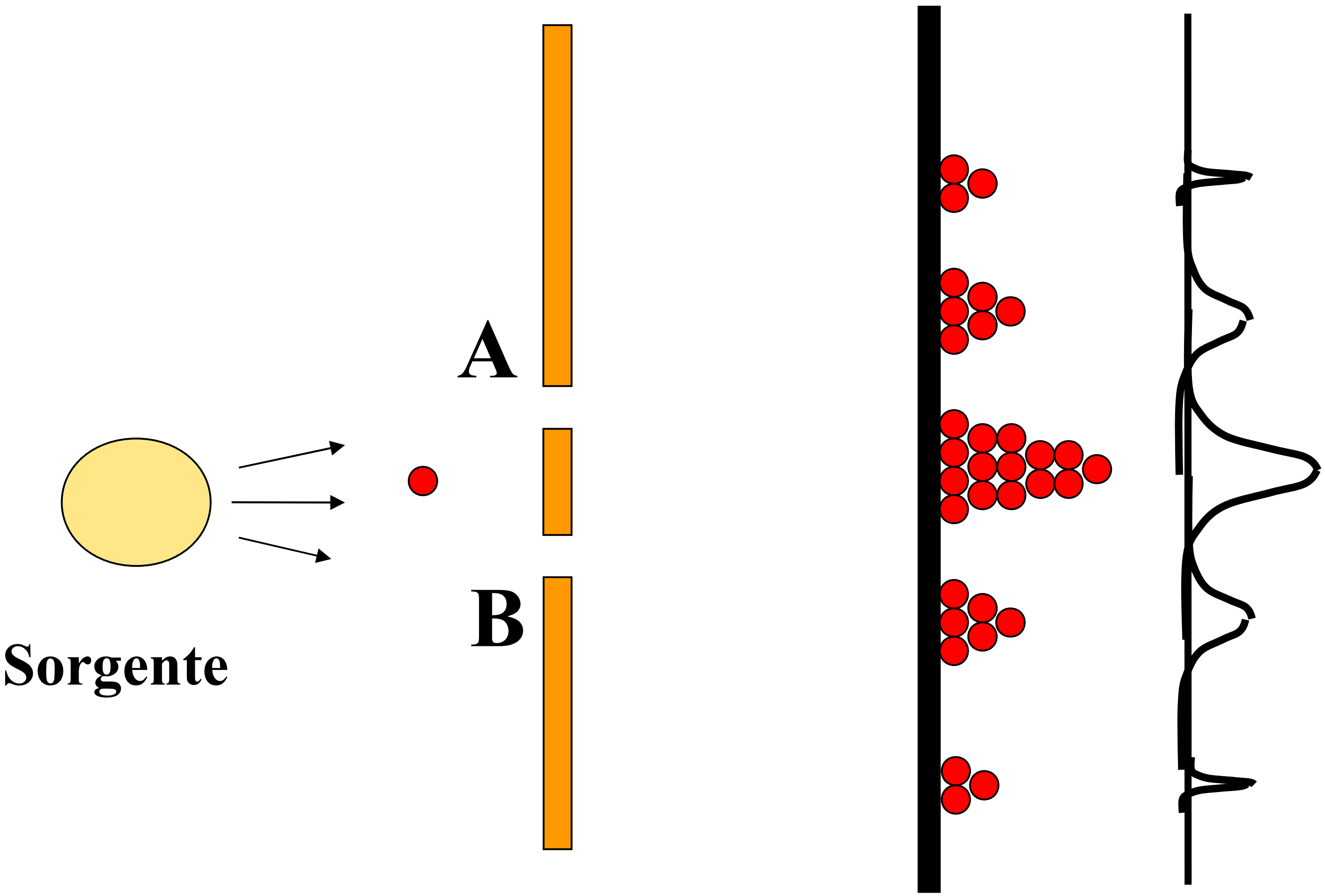
Interferenza quantistica



Probabilità di rivelare una particella P(x)

Frange di interferenza

Interferenza quantistica



Probabilità di rivelare una particella P(x)

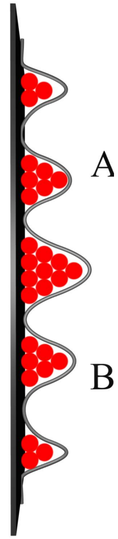
Frange di interferenza

Comportamento “classico”

Probabilità
di rivelare
una particella

$$P(x) = P_L(x) + P_R(x)$$

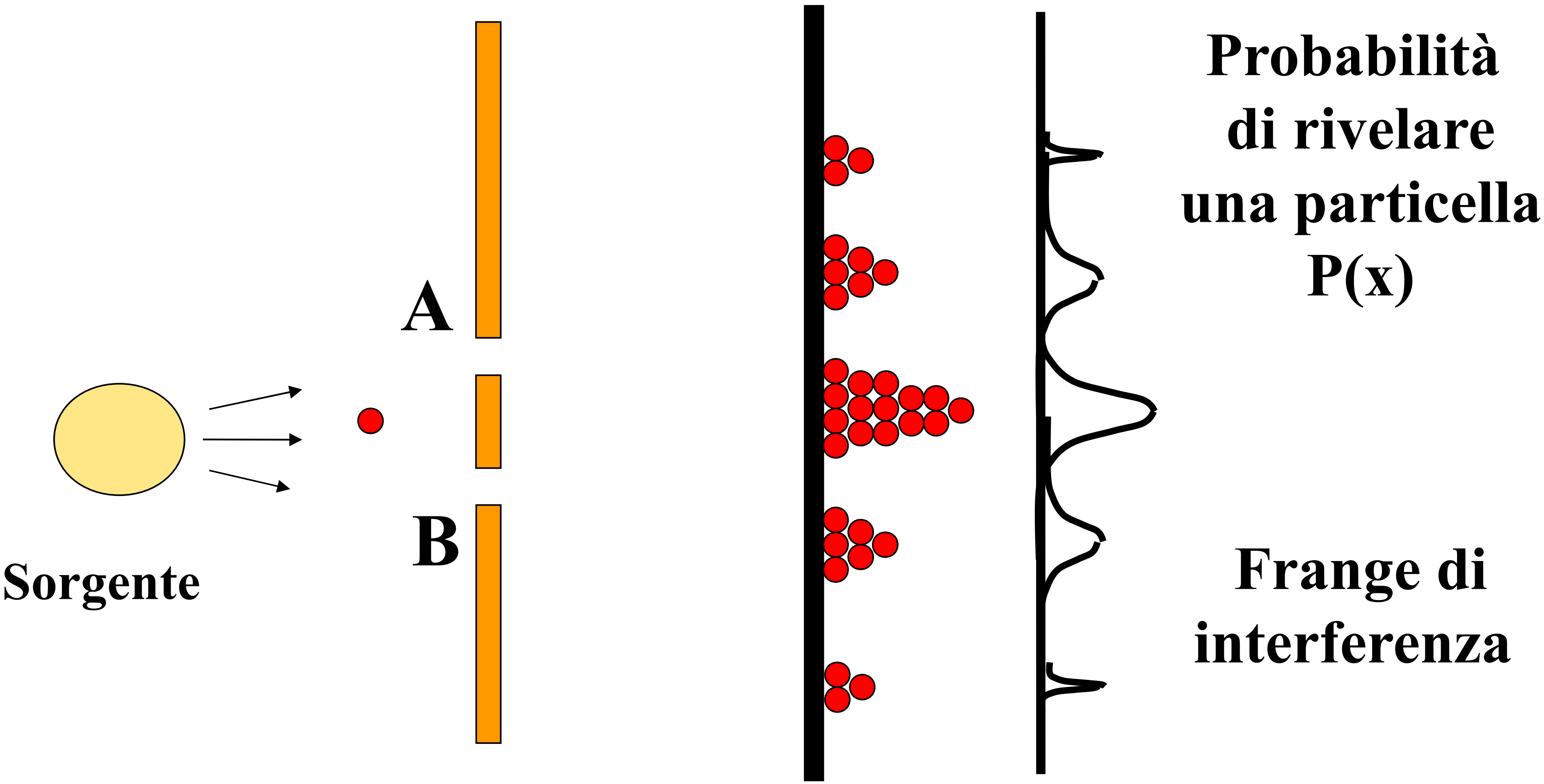
Funzione d'onda



Da quale fenditura passa il fotone ?

E' come se passasse da entrambe !

Interferenza quantistica



Da quale fenditura passa il fotone ? E' come se passasse da entrambe !

Interferenza quantistica

Fisica classica: una particella può viaggiare lungo il cammino A **o** lungo il cammino B

Fisica quantistica: "una particella può viaggiare lungo il cammino A **e** lungo il cammino B"

Interferenza quantistica

Fisica classica: una particella può viaggiare lungo il cammino A **o** lungo il cammino B

Fisica quantistica: “una particella può viaggiare lungo il cammino A **e** lungo il cammino B”

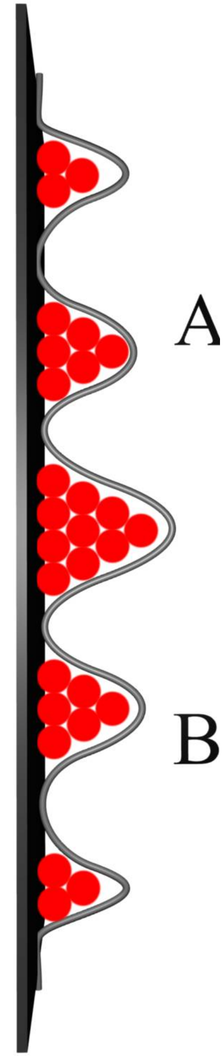
La particella si trova in uno stato di sovrapposizione delle due traiettorie.

La **funzione d’onda** che caratterizza il sistema si scrive......

FUNZIONE D'ONDA

$$\left| fotone\ in\ \ A \right\rangle + \left| fotone\ in\ \ B \right\rangle$$

$$\left| fotone\ in\ A \right\rangle + \left| fotone\ in\ B \right\rangle$$

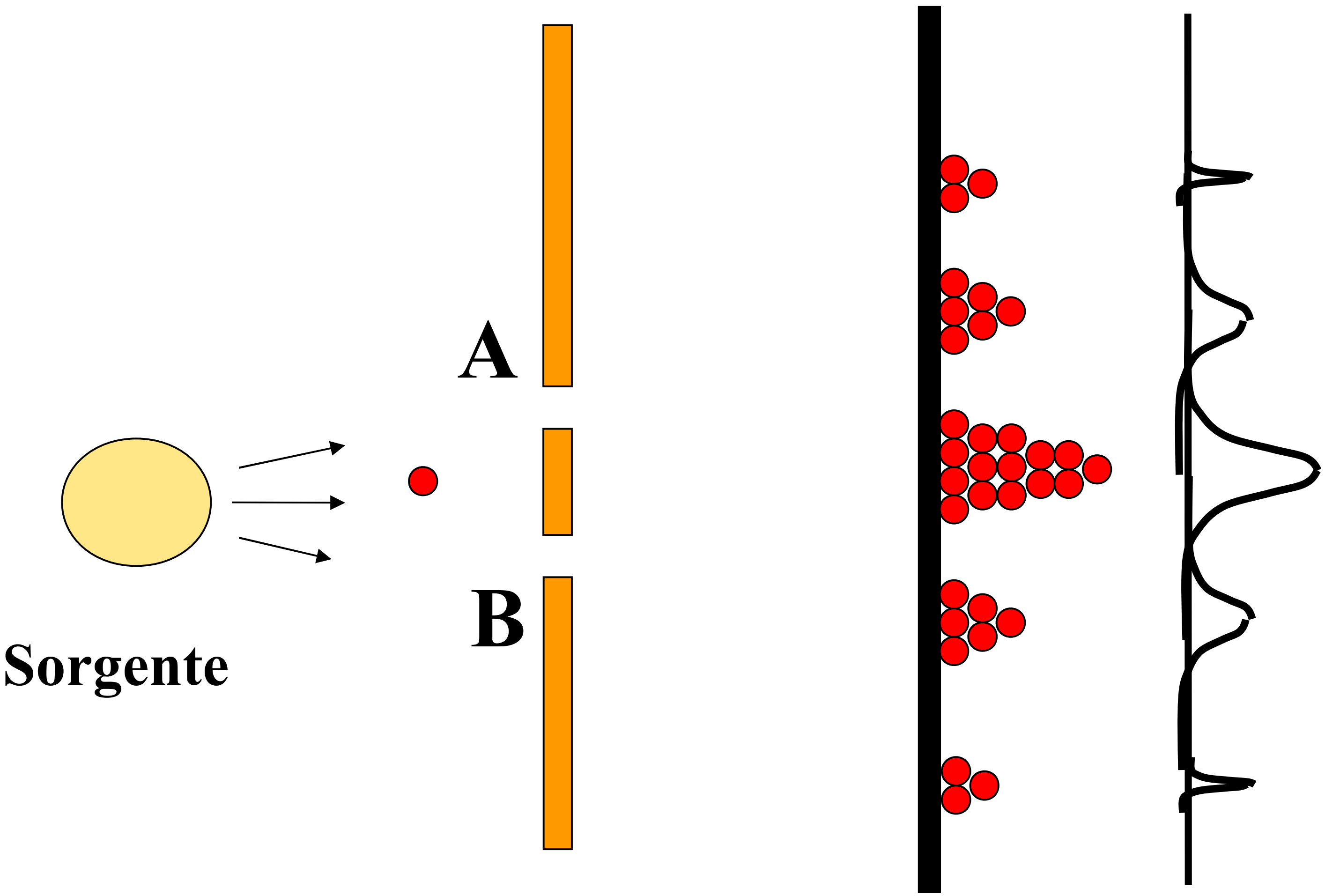


Osservazione

da dove passa la particella ?

La figura di interferenza sparisce!

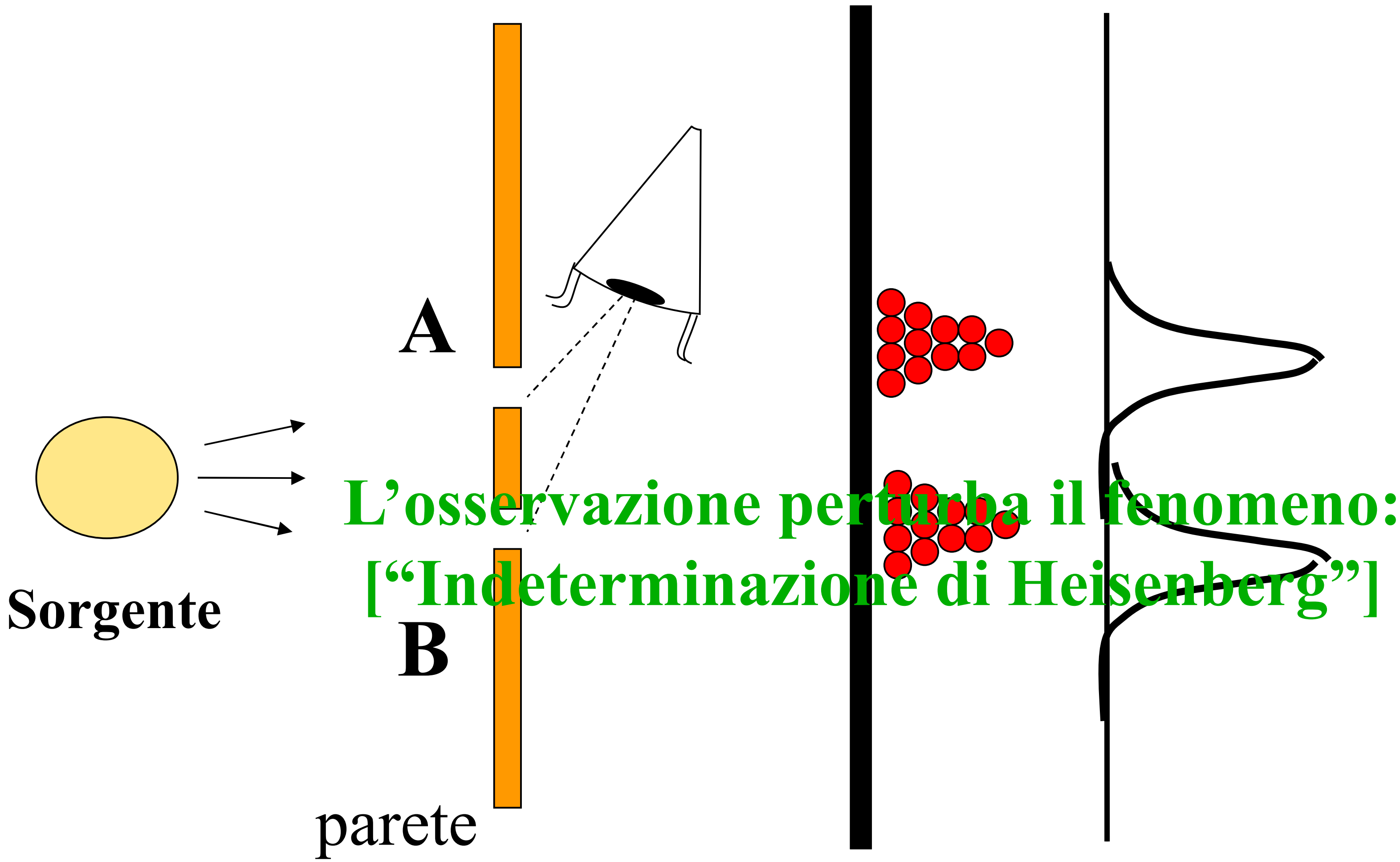
Da quale fenditura passa il fotone ?



Probabilità di rivelare una particella P(x)

Frange di interferenza

Osservazione



Sparisce la figura di interferenza!

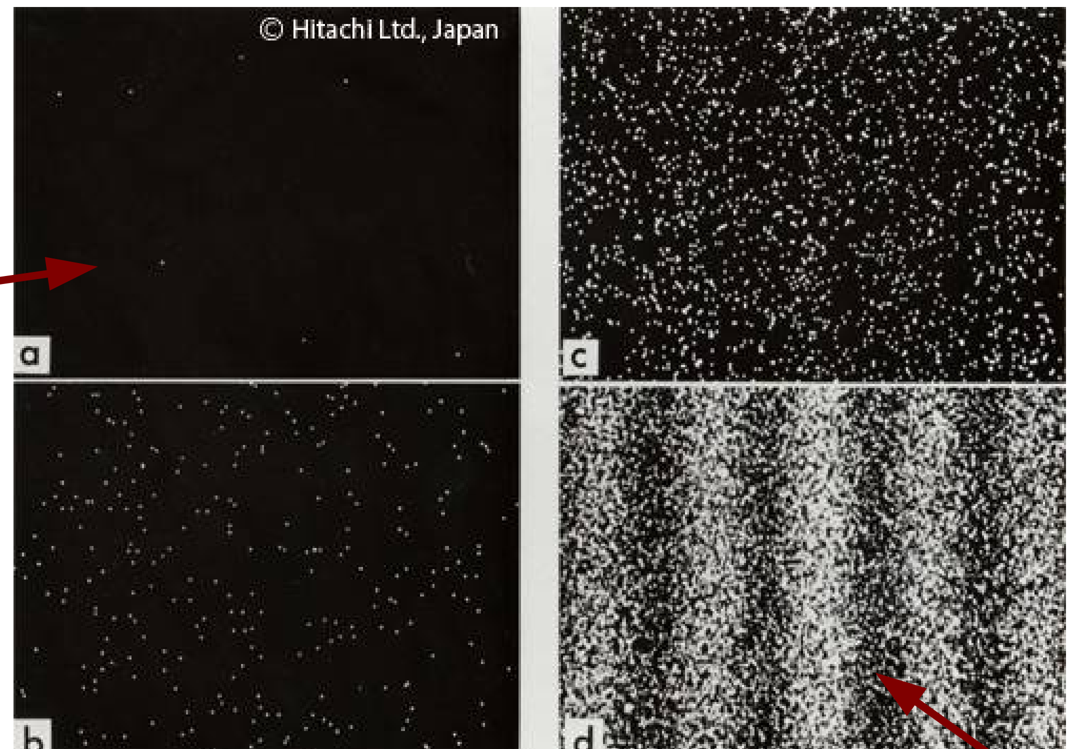
“It from bit”

J.A.Wheeler

La realtà è creata anche dalle nostre domande, ovvero dall'informazione acquisita.

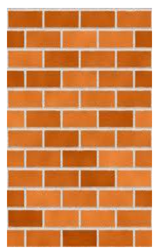
L’osservazione perturba il fenomeno: [“Indeterminazione di Heisenberg”]

Interferenza con particelle massive: elettroni



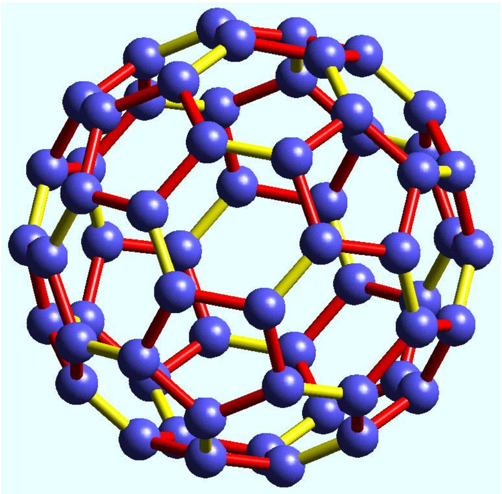
8 elettroni

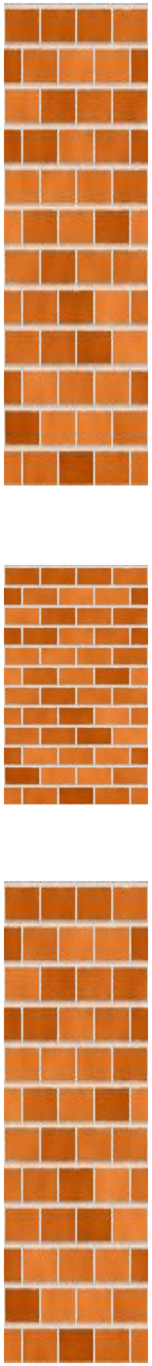
60.000 elettroni



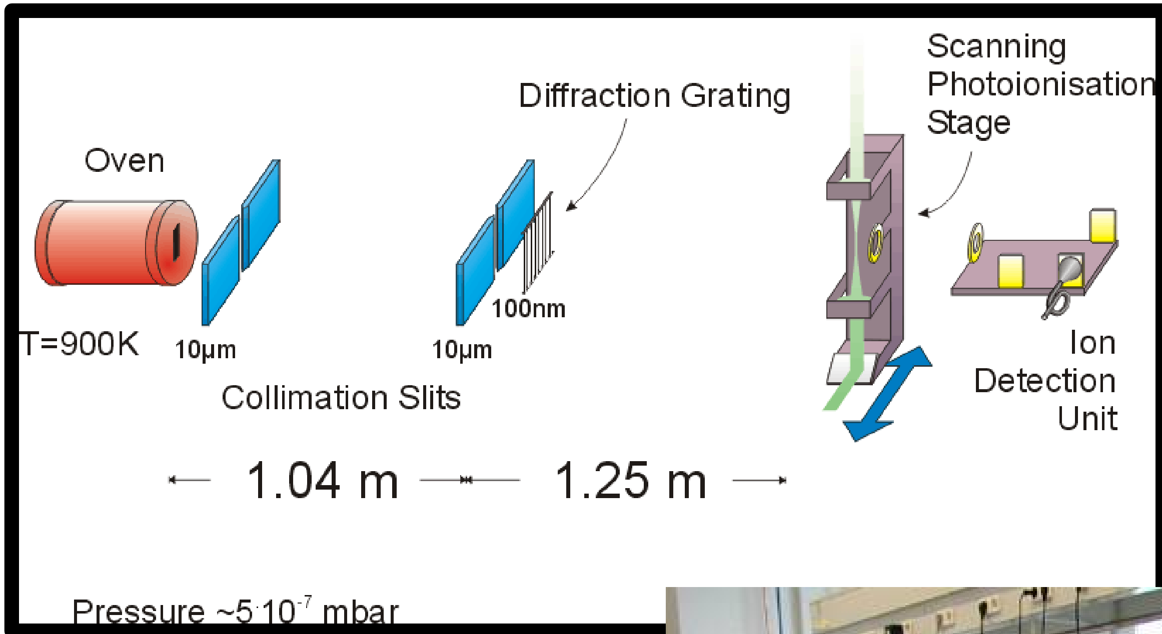

10

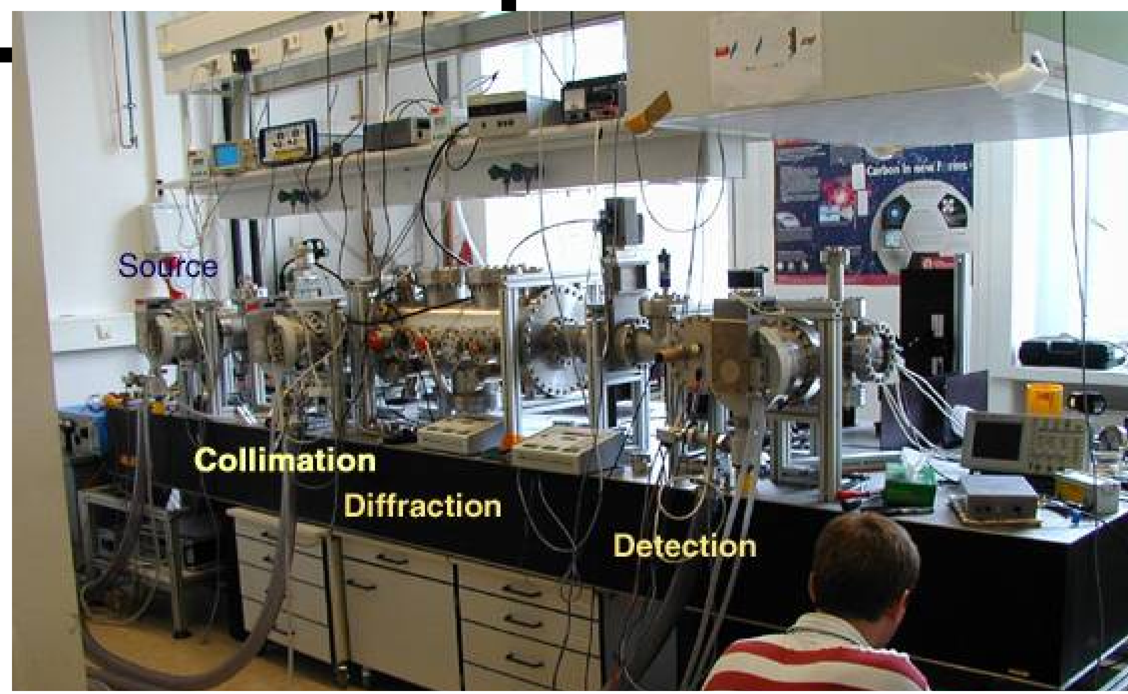
Fullerene C_{60}





?


Scanning
Photoionisation
Stage
Diffraction Grating
Oven
100nm
T=900K
10µm
10µm
Collimation Slits
Ion
Detection
Unit
1.04 m
1.25 m
Pressure ~5·10⁻⁷ mbar


Source
Collimation
Diffraction
Detection

Fullerene C_{60}

$C_{168}H_{94}F_{152}O_8N_4S_4$

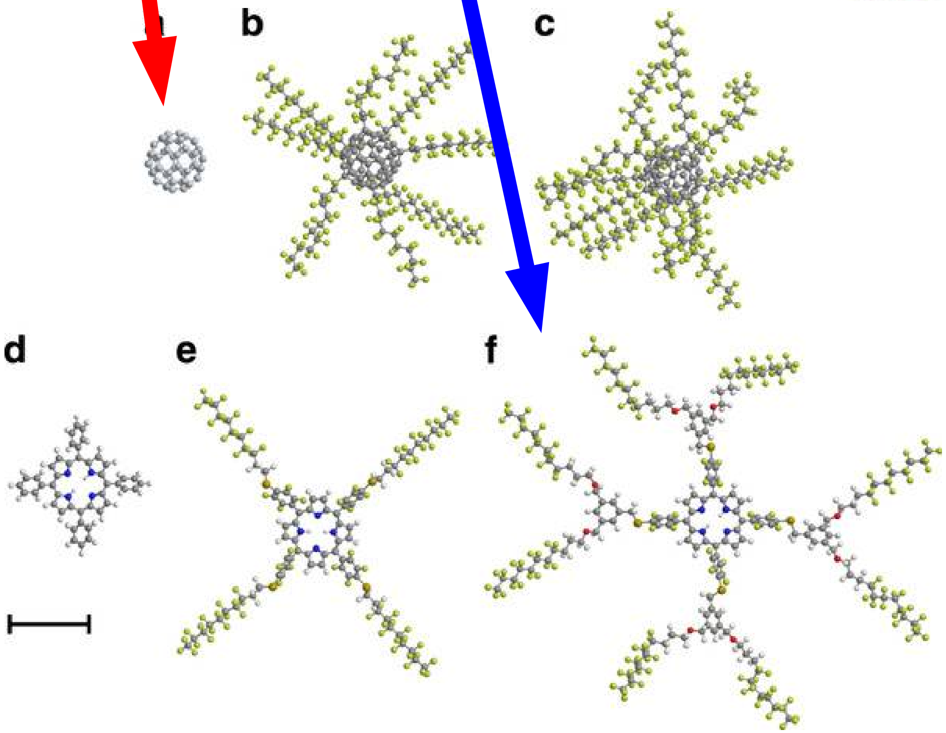
430 atomi

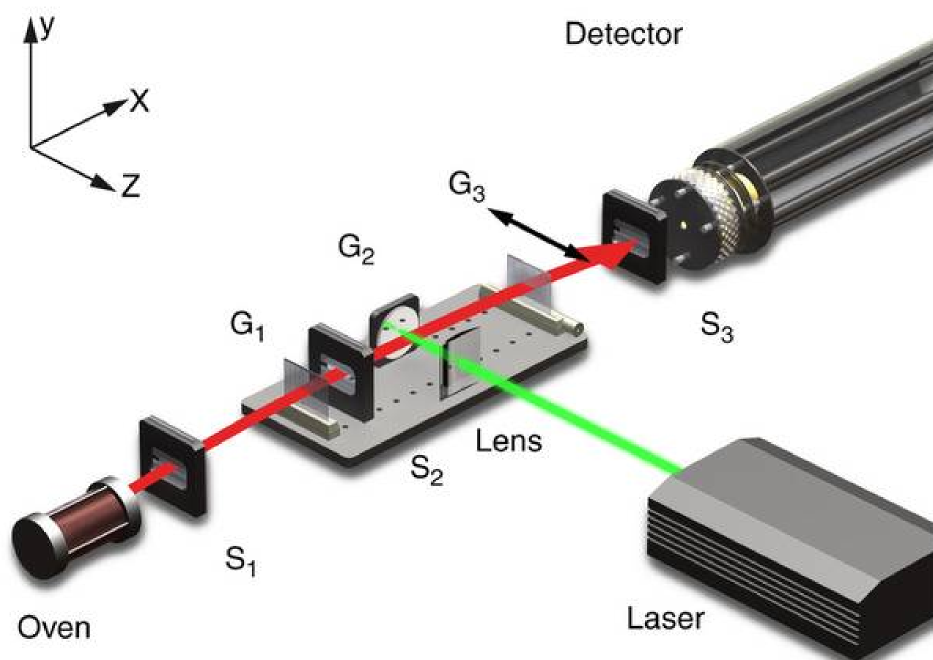
NATURE COMMUNICATIONS | ARTICLE OPEN

Quantum interference of large organic molecules

Stefan Gerlich, Sandra Eibenberger, Mathias Tomandl, Stefan Nimmrichter, Klaus Hornberger, Paul J. Fagan, Jens Tüxen, Marcel Mayor & Markus Arndt

Nature Communications **2**, Article number: 263
doi:10.1038/ncomms1263
Received 05 January 2011 Accepted 02 March 2011

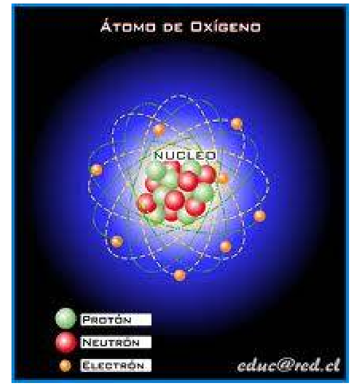


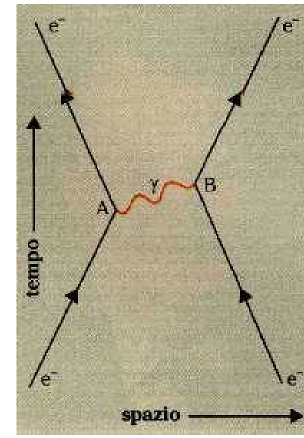


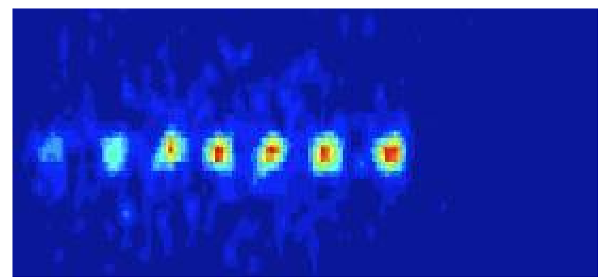
MONDO MACROSCOPICO

FISICA CLASSICA

MONDO MICROSCOPICO



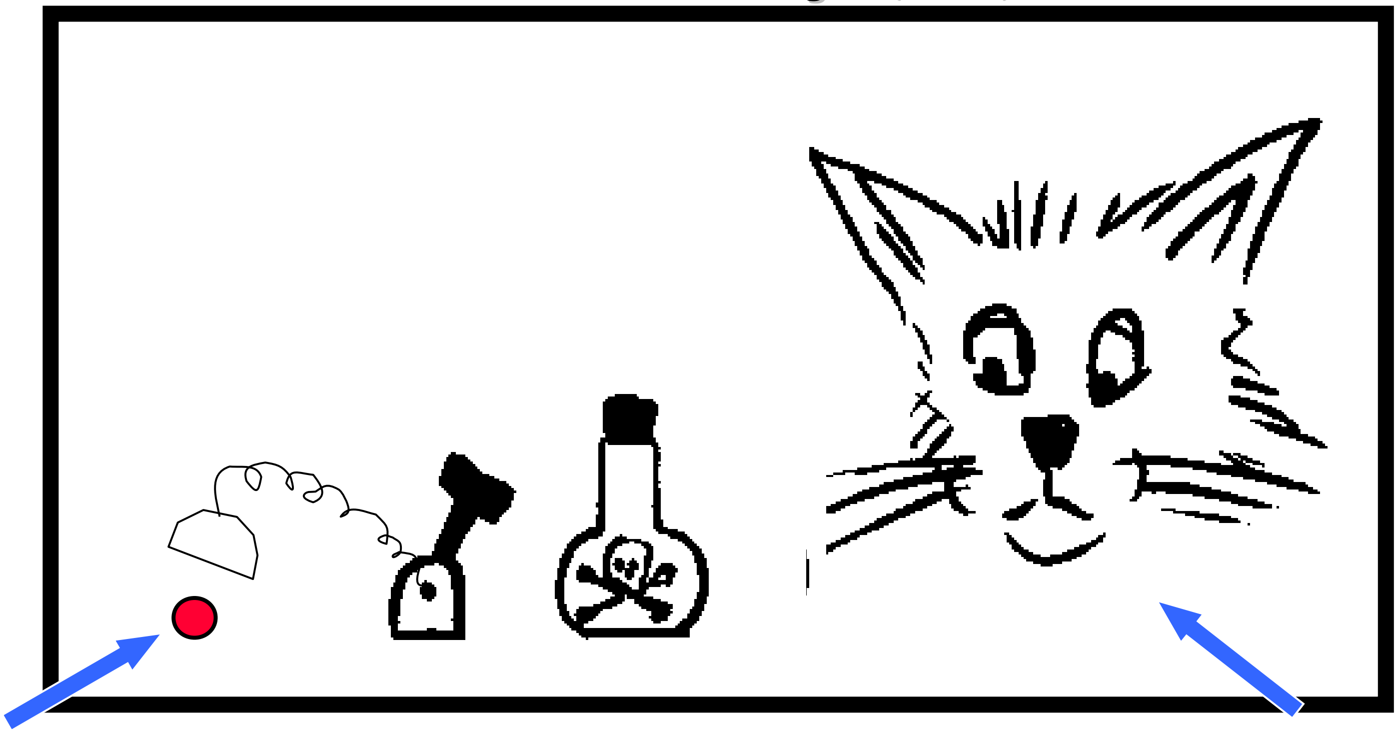




FISICA QUANTISTICA

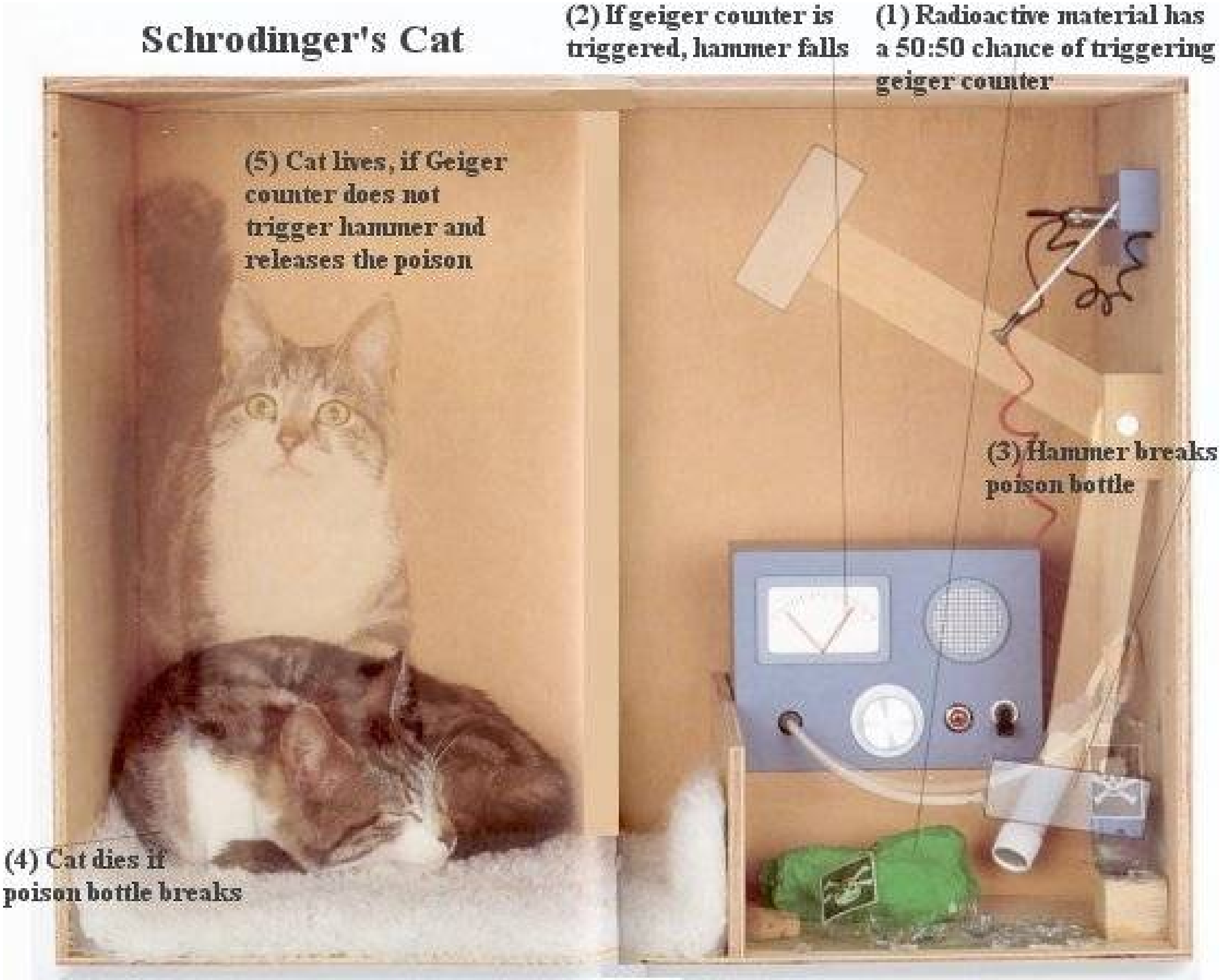
Il paradosso del gatto di Schroedinger

E. Schrödinger (1935)

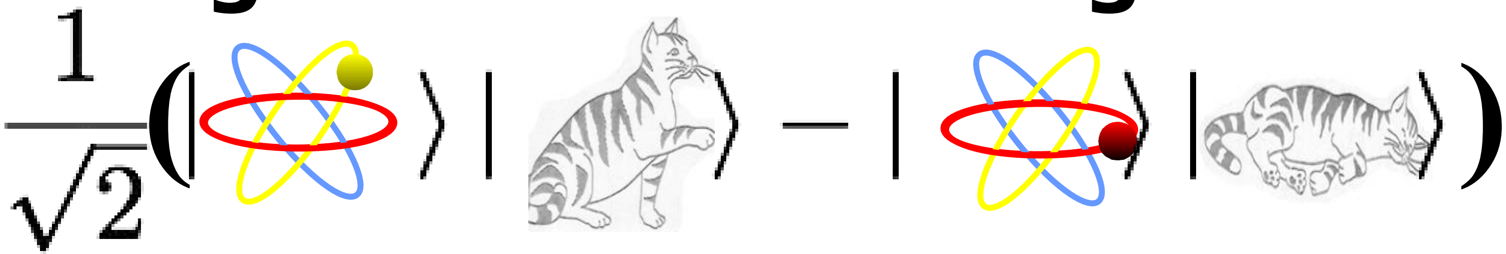


Oggetto quantistico – particella radioattiva.
50% probabilità di decadimento in un'ora.
Il decadimento causa la rottura della fiala con veleno

Oggetto classico: gatto


Schrodinger's Cat
(2) If geiger counter is triggered, hammer falls
(1) Radioactive material has a 50:50 chance of triggering geiger counter
(5) Cat lives, if Geiger counter does not trigger hammer and releases the poison
(3) Hammer breaks poison bottle
(4) Cat dies if poison bottle breaks

Il paradosso del gatto di Schroedinger



Atomo non decaduto — Gatto vivo — Atomo decaduto — Gatto morto

Non si osservano gatti vivi e morti allo stesso tempo!

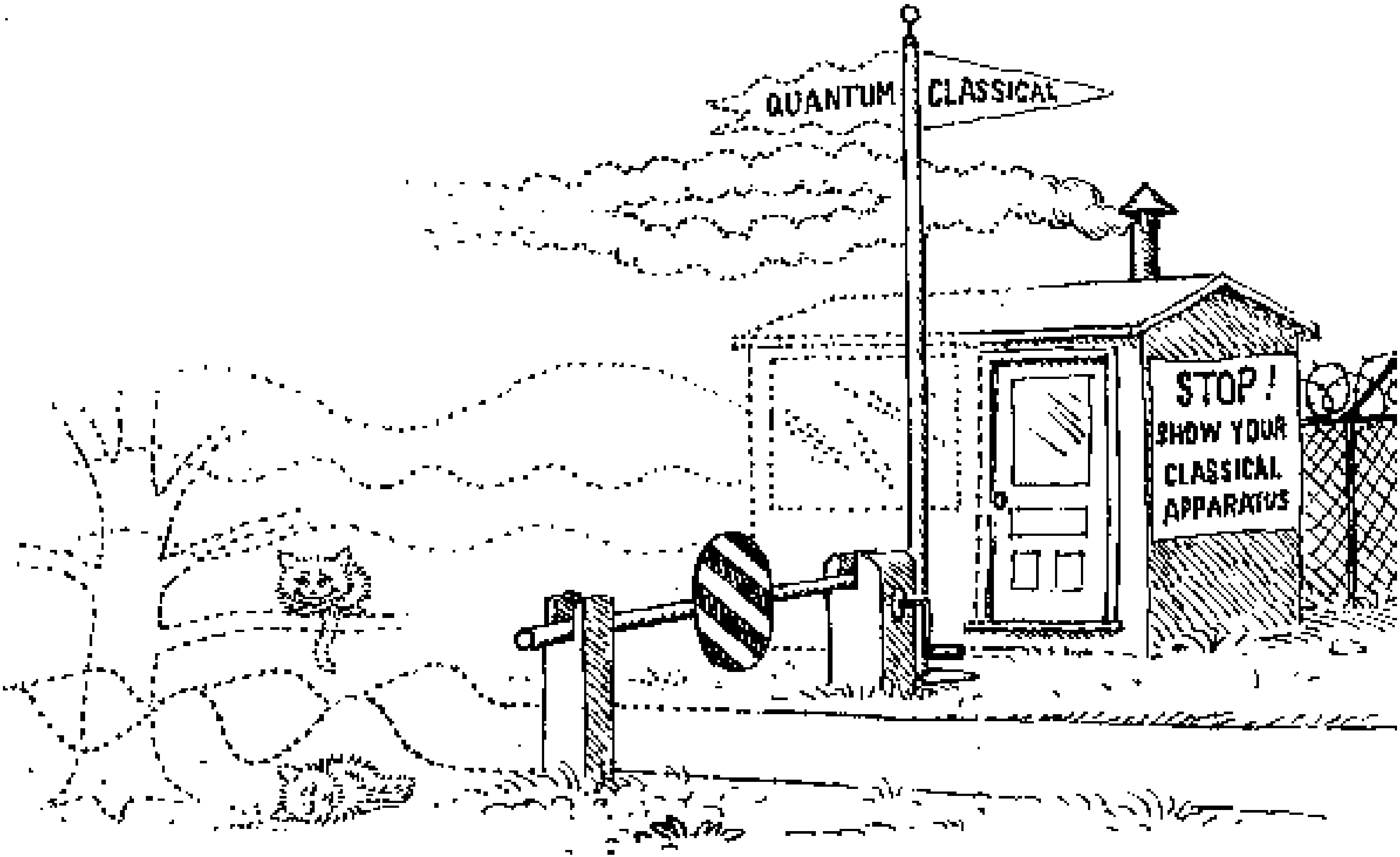
Interazione con l’ambiente: perdita di coerenza

Stato di sovrapposizione *(vivo e morto)* → mistura statistica *(vivo o morto)*

Computazione: stati di sovrapposizione di molti qubits

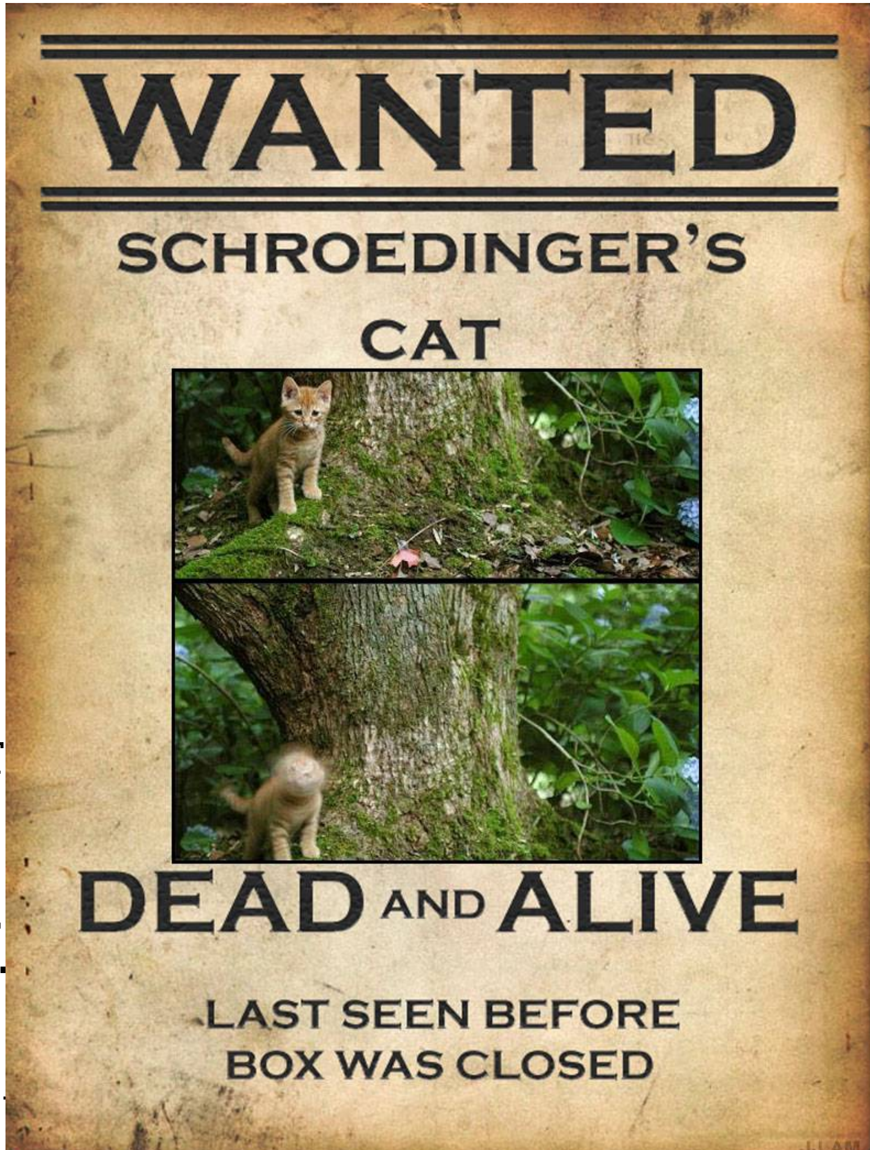
Tecniche di Quantum Error Correction

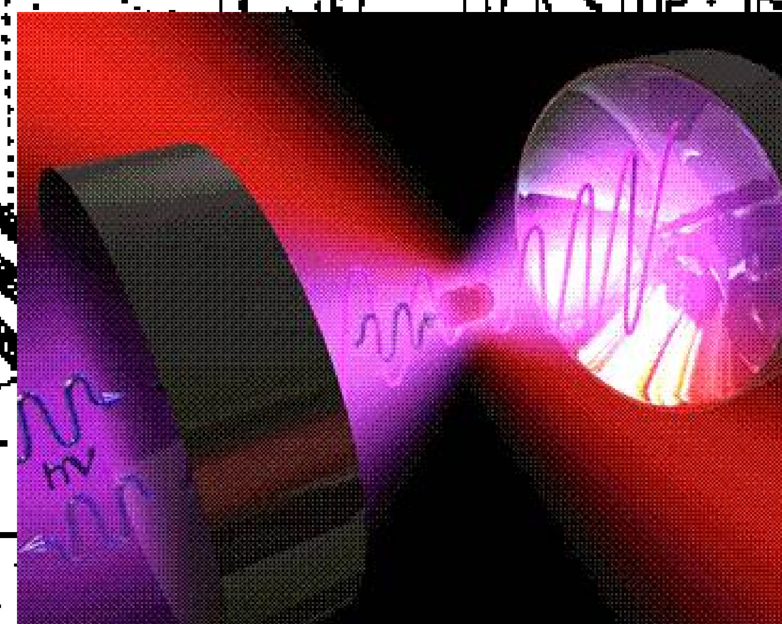
La frontiera fra il mondo classico e quello quantistico



Zurek, Physics Today, October 1991, page 38

La frontiera fra il mondo classico e quello quantistico





Zurek, Physics Today, October 1991, page 38

“A phenomenon is not a phenomenon until is a measured phenomenon…”

J. A. Wheeler

“Esiste la luna in cielo se io non la guardo ?”

A. Einstein

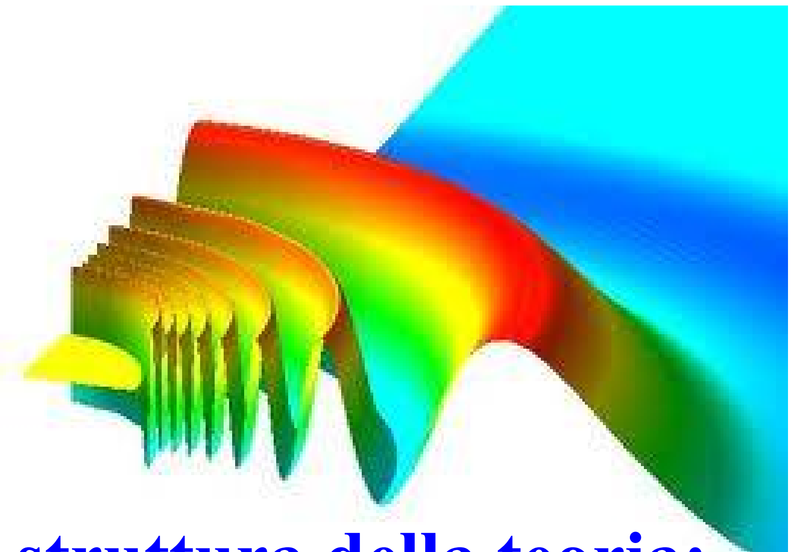
Esistono le “proprietà oggettive”, gli “elements of physical reality” ?

A. Einstein

Che cos'è la funzione d'onda ?

La **funzione d'onda** rappresenta uno stato fisico del sistema quantistico.

Ψ



La matematica domina la struttura della teoria:
["funzione d'onda" | > strumento per descrivere la realtà o sua essenza ?]

$$\left|\, \textit{fotone in } A \right\rangle + \left|\, \textit{fotone in } B \right\rangle$$

La funzione d'onda:

EPISTEMOLOGIA
«discorso sulla conoscenza»

oppure

ONTOLOGIA
«discorso sull'essere»

L'interpretazione di Copenhagen della Meccanica Quantistica:

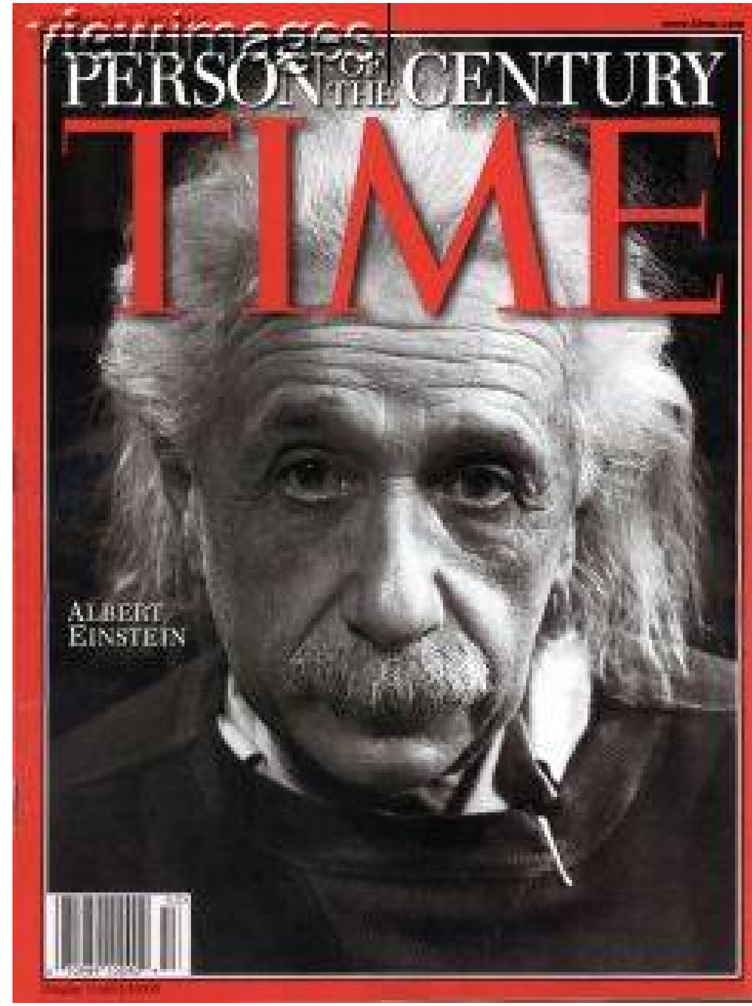
"Lo scopo della nostra descrizione della natura non è il cercare l'essenza reale dei fenomeni ma soltanto l'indagare con la massima profondità possibile le relazioni tra i molteplici aspetti della nostra esperienza."

Niels Bohr (1934)

<u>FAPP</u> interpretation (For All Practical Purposes)

Per tutti i fini pratici

Einstein:
« Dio non gioca a dadi »



EINSTEIN ATTACKS QUANTUM THEORY

Scientist and Two Colleagues Find It Is Not 'Complete' Even Though 'Correct.'

SEE FULLER ONE POSSIBLE

Believe a Whole Description of 'the Physical Reality' Can Be Provided Eventually.

PRINCETON, N. J., May 3.—Professor Albert Einstein will attack science's important theory of quantum mechanics, a theory of which he was a sort of grandfather. He concludes that while it is "correct" it is not "complete."

With two colleagues at the Institute for Advanced Study here, the noted scientist is about to report to the American Physical Society what is wrong with the theory of quantum mechanics, it has been learned exclusively by Science Service.

The quantum theory, with which science predicts with some success inter-atomic happenings, does not meet the requirements for a satisfactory physical theory, Professor Einstein will report in a joint paper with Dr. Boris Podolsky and Dr. N. Rosen.

In the quantum theory as now used, the latest Einstein paper will point out that where two physical quantities such as the position of a particle and its velocity interact, a knowledge of one quantity precludes knowledge about the other. This is the famous principle of uncertainty put forward by Professor Werner Heisenberg and incorporated in the quantum theory. This very fact, Professor Einstein feels, makes the quantum theory fail in the requirements necessary for a satisfactory physical theory.

Two Requirements Listed.

These two requirements are:

1. The theory should make possible a calculation of the facts of nature and predict results which can be accurately checked by experiment; the theory should be, in other words, correct.

2. Moreover, a satisfactory theory should, as a good image of the objective world, contain a counterpart for things found in the objective world; that is, it must be a complete theory.

Quantum theory, Professor Einstein and his colleagues will report, fulfills the correctness requirement but fails in the completeness requirement.

While proving that present quantum theory does not give a complete description of physical reality, Professor Einstein believes some later, still undeveloped, theory will make this possible. His conclusion is:

"While we have thus shown that the wave function [of quantum theory] does not provide a complete description of the physical reality, we left open the question of whether or not such a description exists. We believe, however, that such a theory is possible."

The development of quantum mechanics has proved very useful in exploring the atom. Six Nobel Prizes in physics, including one to Einstein, have been awarded for various phases of the researches leading up to quantum mechanics. The names of Planck, Bohr, de Broglie, Heisenberg, Dirac and Schroedinger, as well as Einstein, are linked with quantum mechanics.

The exact title of the Einstein-Podolsky-Rosen paper is: "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?"

Explanation by Podolsky.

In explaining the latest view of the physical world as revealed in their researches Dr. Podolsky, one of the authors, said:

"Physicists believe that there exist real material things independent of our minds and our theories. We construct theories and invent words (such as electron, positron, &c.) in an attempt to explain to ourselves what we know about our external world and to help us to obtain further knowledge of it. Before a theory can be considered to be satisfactory it must pass two very severe tests. First, the theory must enable us to calculate facts of nature, and these calculations must agree very accurately with observations and experiments. Second, we expect a satisfactory theory, as a good image of objective reality, to contain a counterpart for every element of the physical world. A theory satisfying the first requirement may be called a correct theory while, if it satisfies the second requirement, it may be called a complete theory.

"Hundreds of thousands of experiments and measurements have shown that, at least in cases when matter moves much slower than light, the theory of Planck, Einstein, Bohr Heisenberg and Schroedinger known as quantum mechanics is a correct theory. Einstein, Podolsky and Rosen now discuss the question of the completeness of quantum mechanics. They arrive at the conclusion that quantum mechanics, in its present form, is not complete.

"In quantum mechanics the condition of any physical system, such as an electron, an atom, &c., is supposed to be completely described by a formula known as a 'wave function.' Suppose that we know the wave function for each of two physical systems, and that these two systems come together, interact, and again separate (as when two particles collide and move apart). Quantum mechanics, although giving us considerable information about such a process, does not enable us to calculate the wave function of each physical system after the separation. This fact is made use of in showing that the wave function does not give a complete description of physical reality. Since, however, description of physical systems by wave functions is an essential step of quantum mechanics, this means that quantum mechanics is not a complete theory."

Raises Point of Doubt.

Special to THE NEW YORK TIMES.

PRINCETON, N. J., May 3.—Asked to comment on the new ideas of Professor Einstein and his collaborators, Professor Edward U. Condon, mathematical physicist of Princeton University, said tonight:

"Of course, a great deal of the argument hinges on just what meaning is to be attached to the word 'reality' in connection with physics. They have certainly discussed an interesting point in connection with the theory. Dr. Einstein has never been satisfied with the statistical causality which in the new theories replaces the strict causality of the old physics.

"It is reported that when he first learned of the work of Schroedinger and Dirac, he said, 'Der lieber Gott wuerfelt nicht, [the good Lord does not throw dice]. For the last five years he has subjected the quantum mechanical theories to very searching criticism from this standpoint. But I am afraid that thus far the statistical theories have withstood criticism."

Paradosso di Einstein-Podolsky-Rosen

Per dimostrare che la Meccanica Quantistica

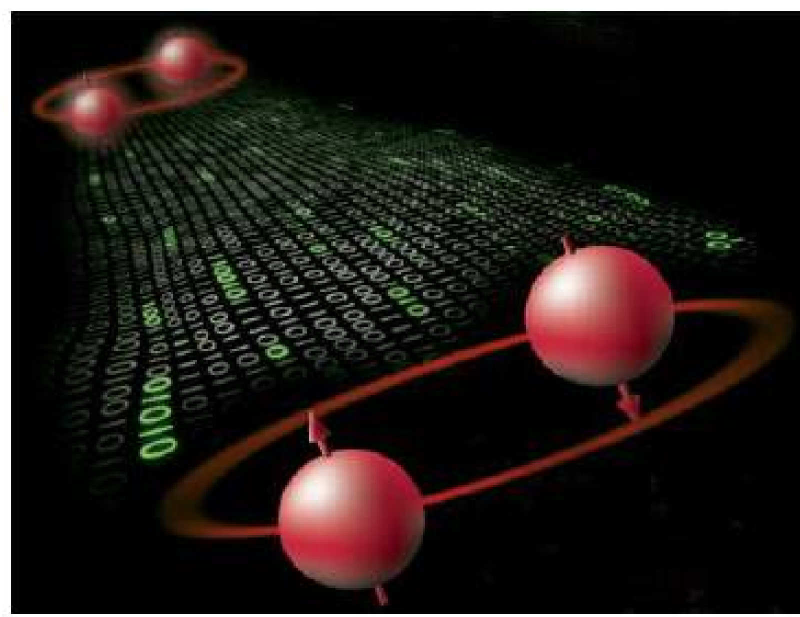
NON è la teoria definitiva

introducono il concetto di entanglement

$$\left|\Psi\right\rangle_{AB} = \frac{\left|0\right\rangle_A \left|1\right\rangle_B - \left|1\right\rangle_A \left|0\right\rangle_B}{\sqrt{2}}$$

Entanglement:

due particelle aggrovigliate



THE NEW YORK TIMES, SATURDAY, MAY 4, 1935.

EINSTEIN ATTAC[KS] QUANTUM THE[ORY]

Scientist and Two Colle[agues] Find It Is Not 'Compl[ete'] Even Though 'Correct'

SEE FULLER ONE POSS[IBLE]

Believe a Whole Descript[ion of] 'the Physical Reality' Ca[n Be] Provided Eventually.

MAY 15, 1935 PHYSICAL REVIEW VOLUME 47

Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?

A. Einstein, B. Podolsky and N. Rosen, *Institute for Advanced Study, Princeton, New Jersey*

(Received March 25, 1935)

In a complete theory there is an element corresponding to each element of reality. A sufficient condition for the reality of a physical quantity is the possibility of predicting it with certainty, without disturbing the system. In quantum mechanics in the case of two physical quantities described by non-commuting operators, the knowledge of one precludes the knowledge of the other. Then either (1) the description of reality given by the wave function in quantum mechanics is not complete or (2) these two quantities cannot have simultaneous reality. Consideration of the problem of making predictions concerning a system on the basis of measurements made on another system that had previously interacted with it leads to the result that if (1) is false then (2) is also false. One is thus led to conclude that the description of reality as given by a wave function is not complete.

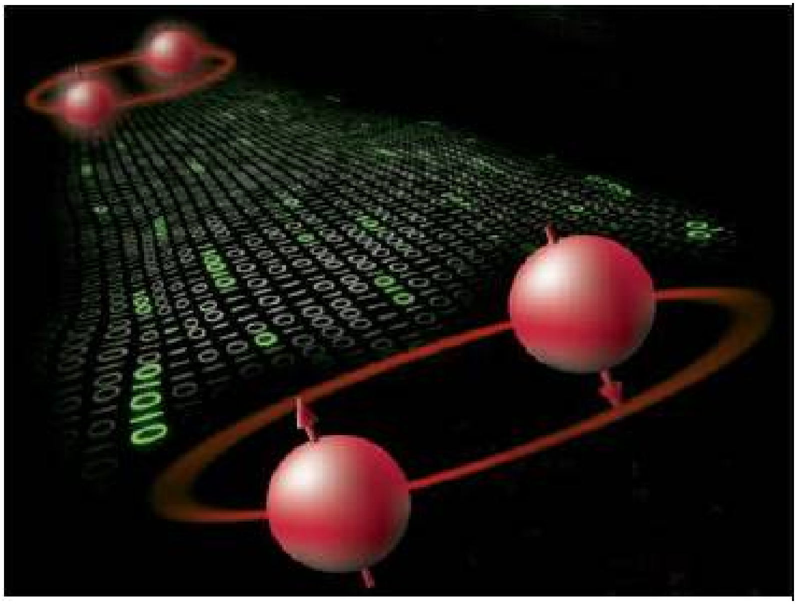
« While we have shown that the wave function does not provide a complete description of the physical reality, we left open the question of whether or not such a description exists.

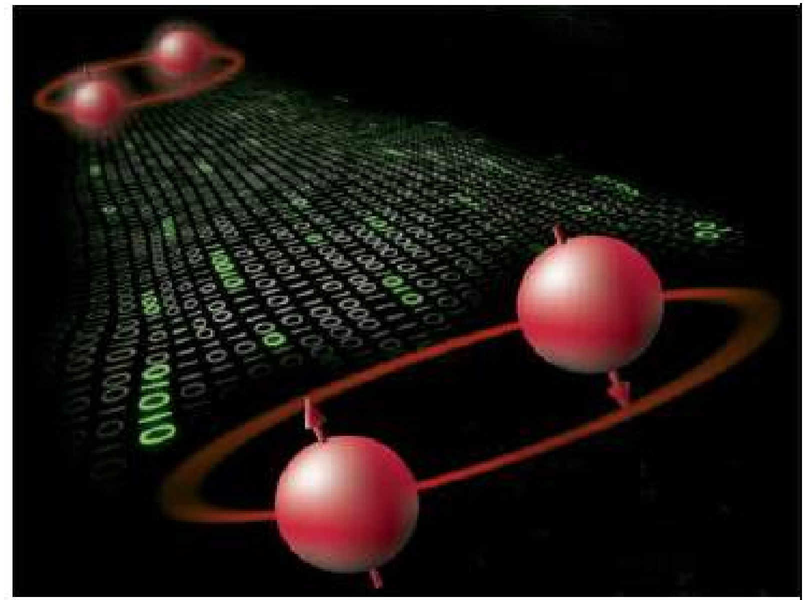
We believe, however, that such a theory is possible. »

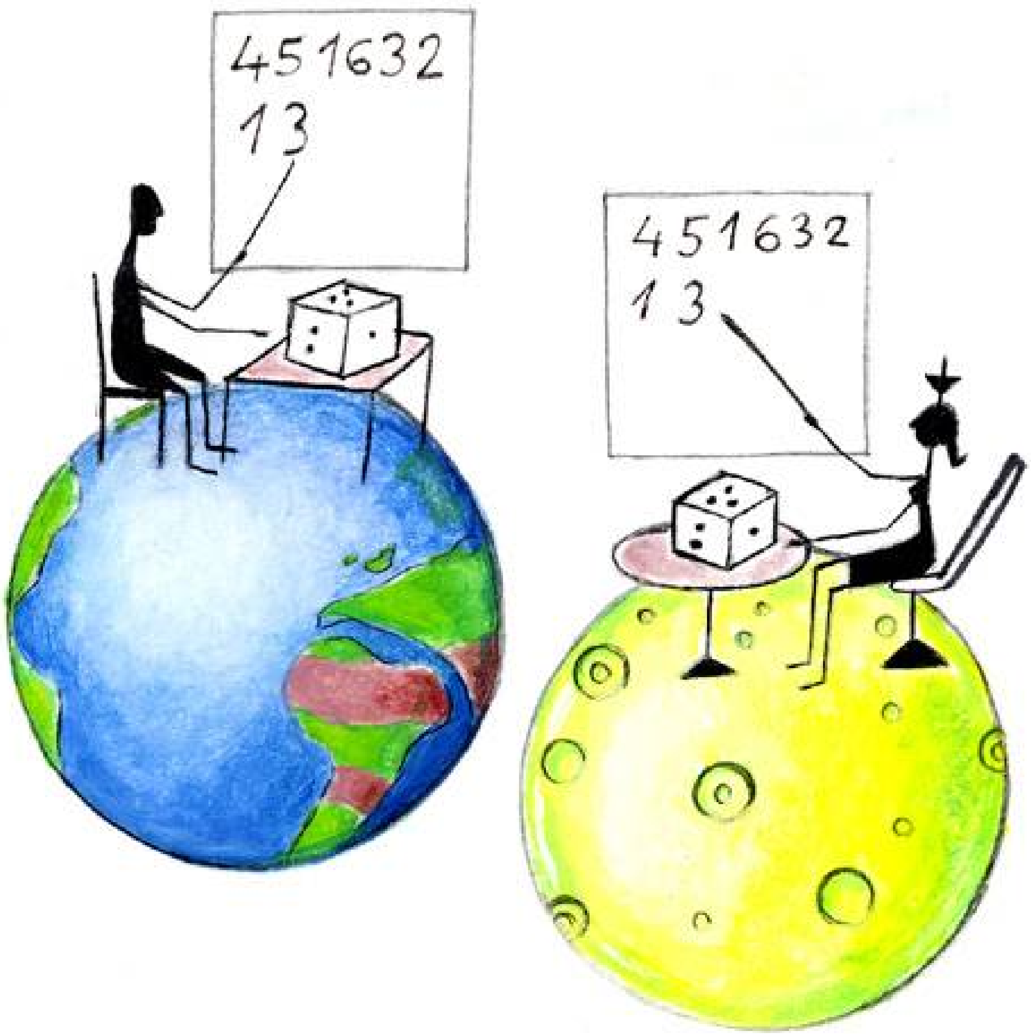
$$\boxed{|\Psi\rangle_{AB} = \frac{|0\rangle_A|1\rangle_B - |1\rangle_A|0\rangle_B}{\sqrt{2}}}$$

« I would not call **entanglement** one but rather the **characteristic trait of quantum mechanics**, the one that enforces its entire departure from classical lines of thought. »

E. Schroedinger



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13
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13

« spooky action at distance »

... *folle azione a distanza...*

Quanto veloce ?!?

… se fosse un'azione a distanza..
andrebbe almeno 100.000 più veloce della luce

… ma non può servire a comunicare direttamente!!

Vol 454|14 August 2008|**doi:10.1038/nature07121** nature

LETTERS

Testing the speed of 'spooky action at a distance'

Daniel Salart[1], Augustin Baas[1], Cyril Branciard[1], Nicolas Gisin[1] & Hugo Zbinden[1]

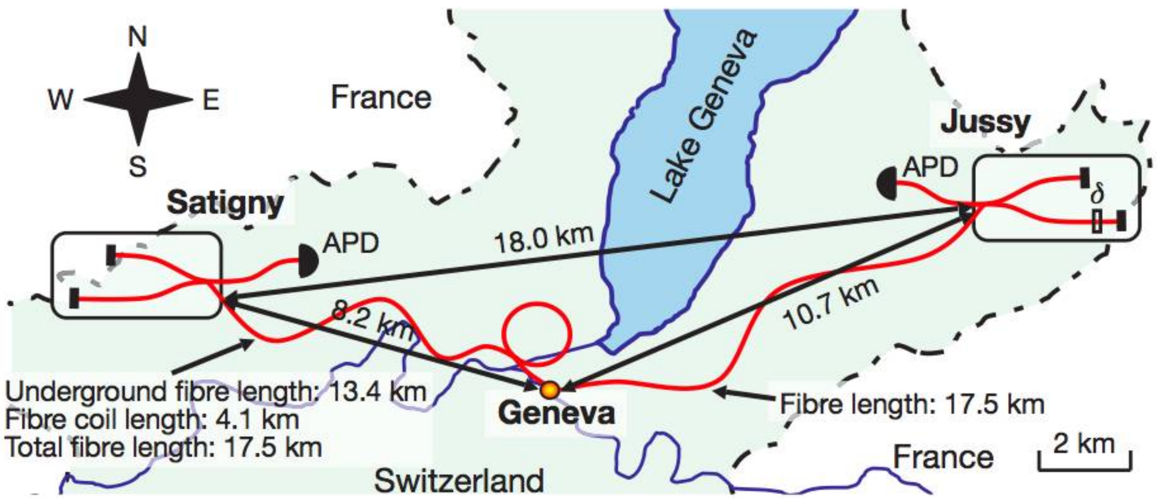
« spooky action at distance »

... *folle azione a distanza...*

Quanto veloce ?!?

… se fosse un'azione a distanza..
andrebbe almeno 100.000 più veloce della luce

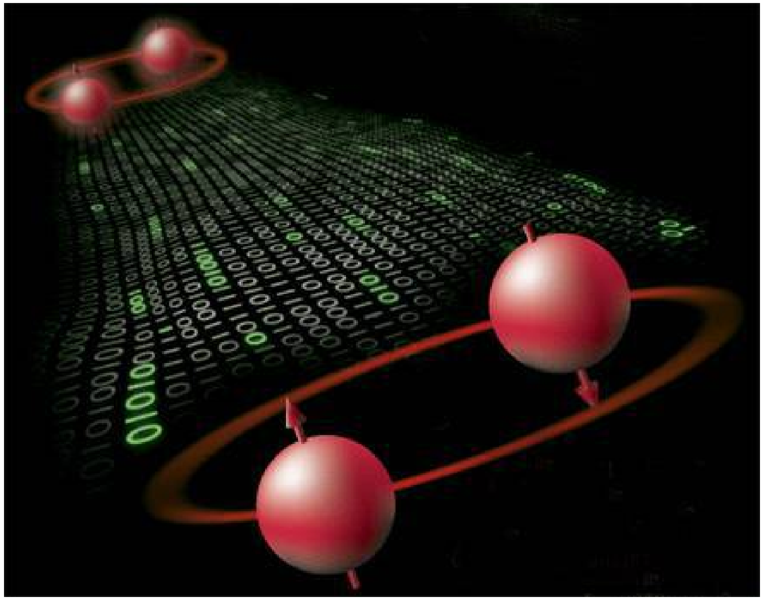
… ma non può servire a comunicare direttamente!!




nature
LETTERS
:tion at a distance'
ıgo Zbinden[1]

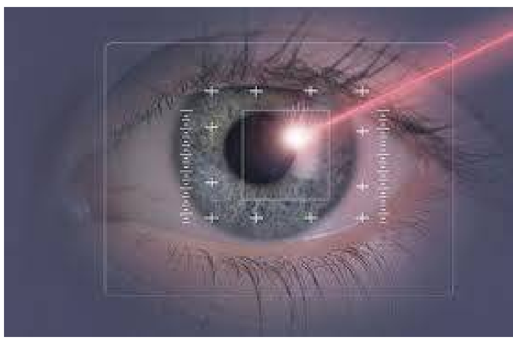
Non-località quantistica

...non importa quanto spazio intercorra tra due particelle correlate, queste comunicheranno fra di loro come se non ci fosse alcuno spazio...



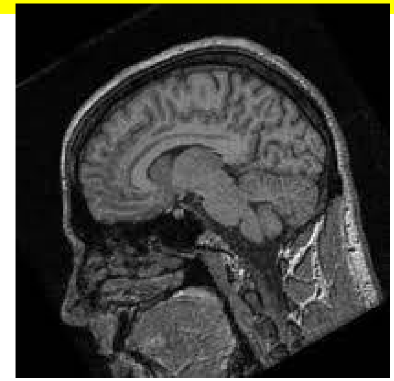
1960- Theodore Harold Maiman

Laser

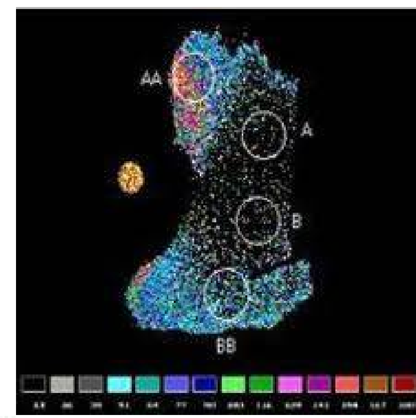


1946- Felix Bloch e Edward Purcell

Risonanza Magnetica Nucleare

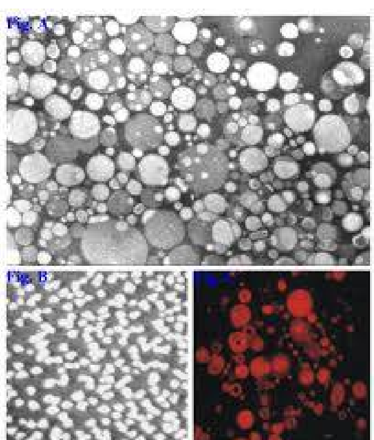


Meccanica Quantistica



1931- Ernst Ruska

Microscopio Elettronico



L'informazione quantistica

Teoria dell'informazione + Meccanica quantistica:
Sfrutta le leggi della meccanica quantistica per comunicare, manipolare e processare l'informazione

Fisica fondamentale

Non-località

Transizione mondo microscopico-mondo macroscopico

Fisica applicata

Crittografia

Computazione

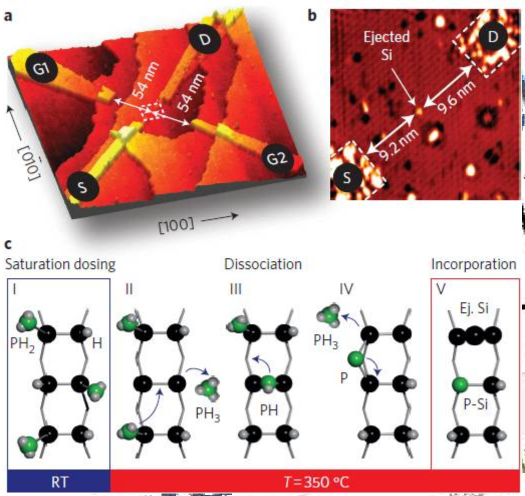
Metrologia

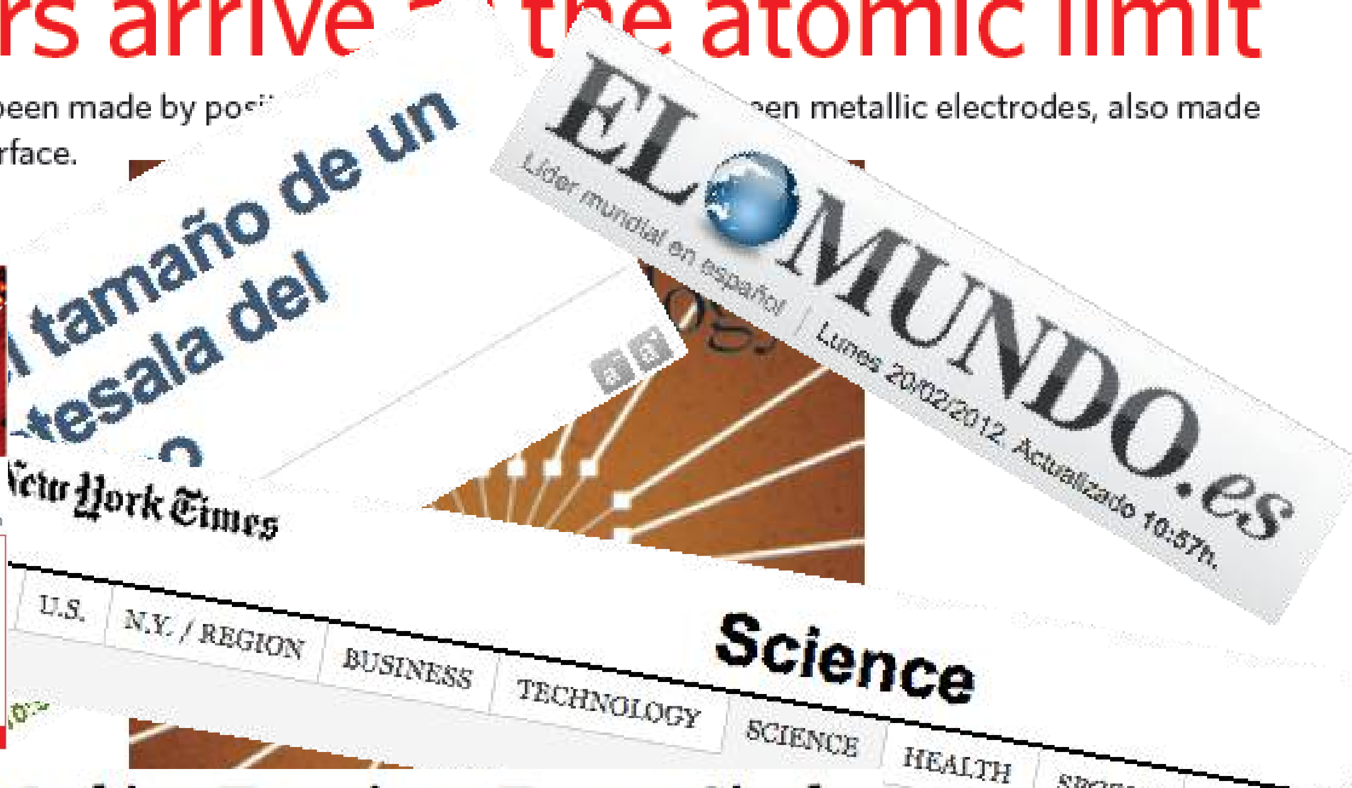
NANOELECTRONICS

Transistors arrive at the atomic limit

A single-atom transistor has been made by pos… …een metallic electrodes, also made of phosphorus, on a silicon surface.

Gabriel P. Lansbergen





Physicists Create a Working Transistor From a Single Atom

By JOHN MARKOFF
Published: February 19, 2012

Australian and American physicists have built a working transistor from a single phosphorus atom embedded in a silicon crystal.

RECOMMEN…
TWITTER

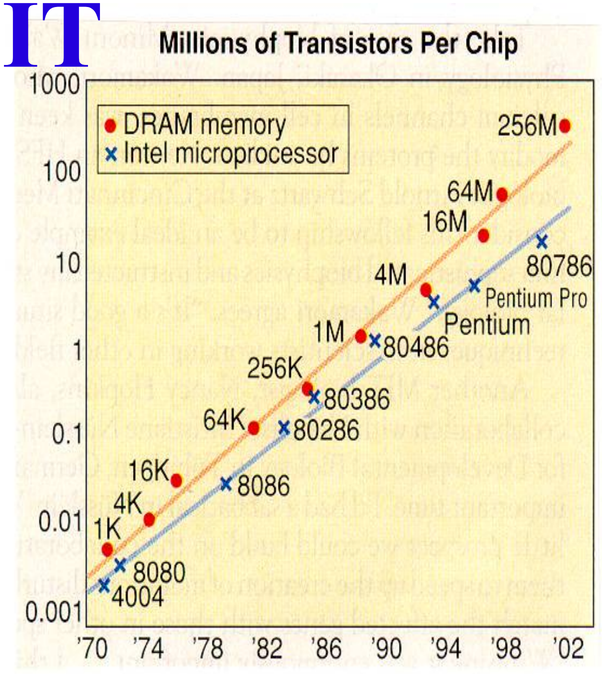
“L'informazione è fisica”

R. Landauer

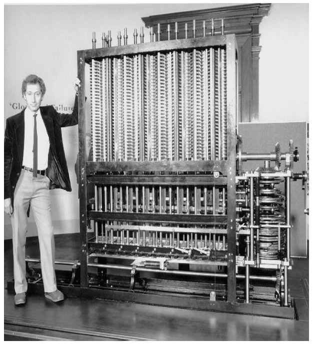
La manipolazione dell'informazione è governata dalle leggi della fisica.

L'evoluzione della Information Technology

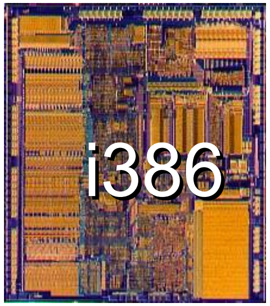
BIT



1879

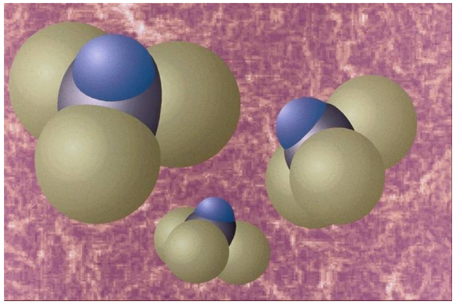


1986



1 micron

2020



1 nanometro

BIT: **Variabile dicotomica**

0 *o* 1

QUBIT (Quantum Bit)

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

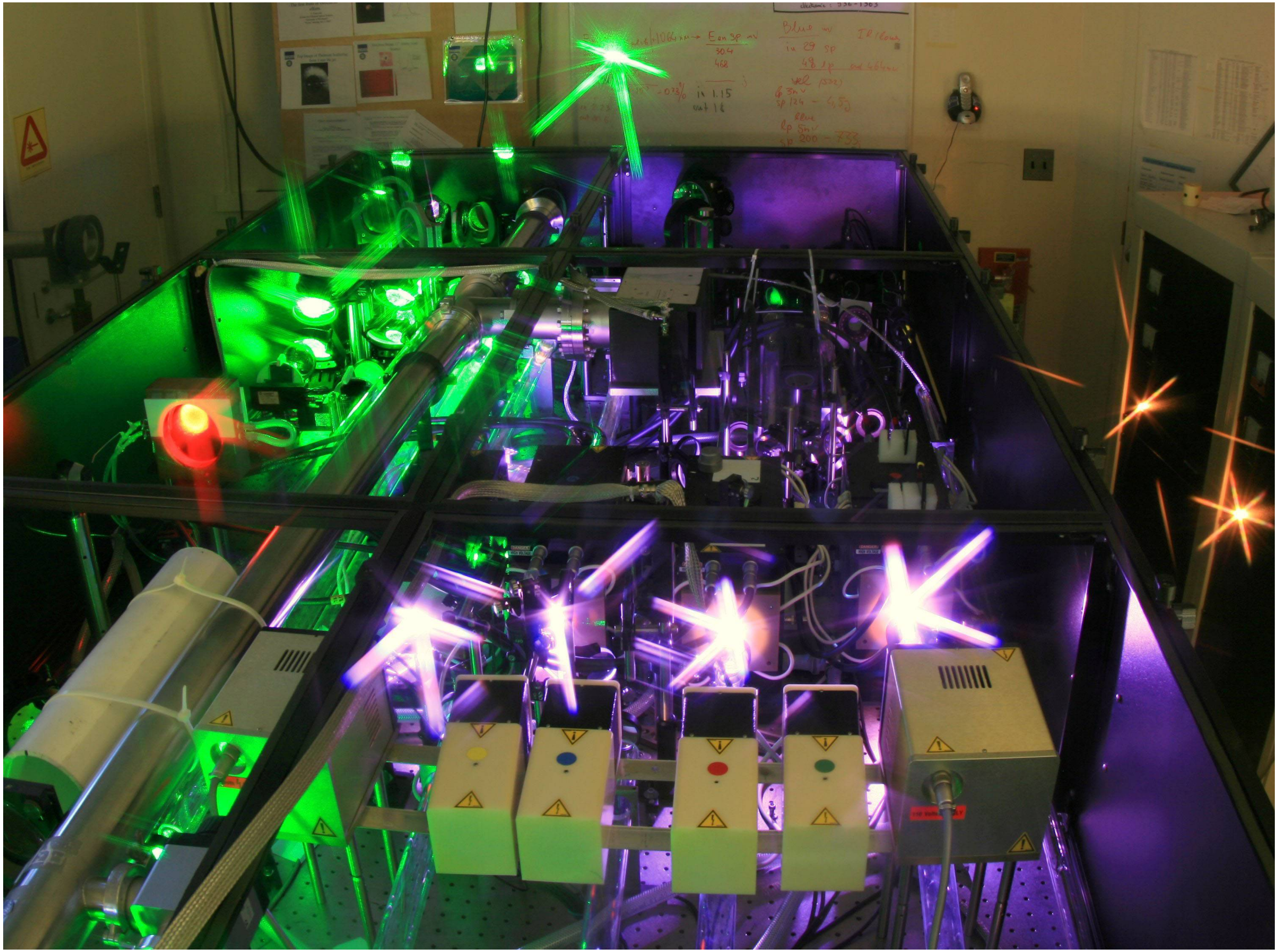
QUANTUM INFORMATION

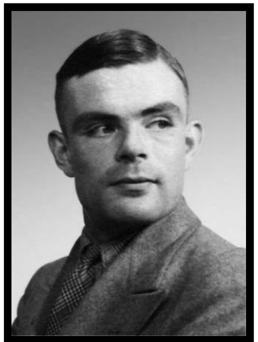
QUBIT (Quantum Bit)

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

OBIETTIVO:
SFRUTTARE IL PARALLELISMO QUANTISTICO

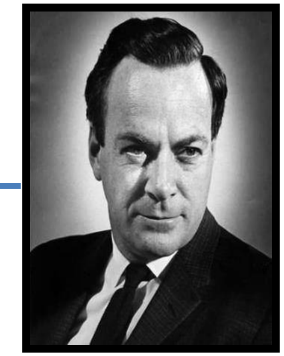
QUBIT (Quantum Bit)

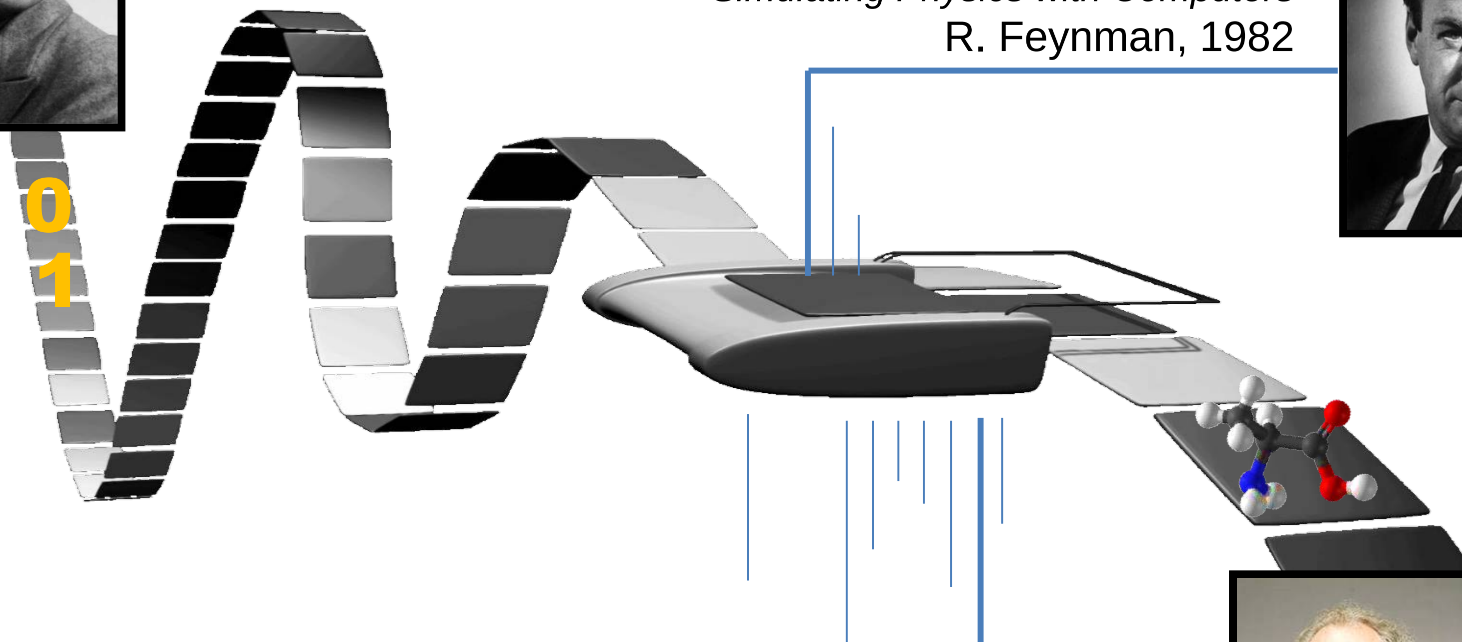




On computable numbers, with an application to the Entscheidungsproblem
A. Turing, 1936

Simulating Physics with Computers
R. Feynman, 1982

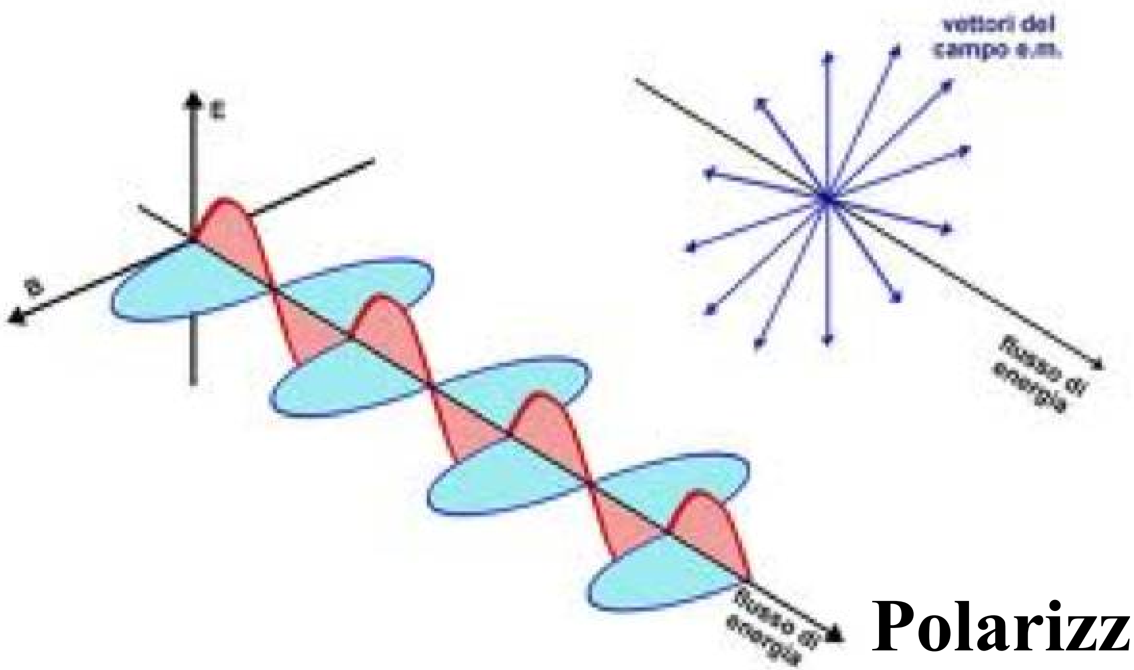




Quantum theory, the Church-Turing principle and the universal quantum computer
D. Deutsch, 1984

Algorithms for quantum computation: Discrete log and factoring
P. W. Shor, 1994

Polarizzazione della luce



Qubit → **Polarizzazione del singolo fotone**

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

$$\alpha|H\rangle + \beta|V\rangle$$

H: orizzontale

V: verticale

Polarizzazione della luce

Polarizzazione: direzione di oscillazione del campo elettromagnetico

Polarizzazione orizzontale $|\boldsymbol{H}\rangle$

Polarizzazione verticale $|\boldsymbol{V}\rangle$

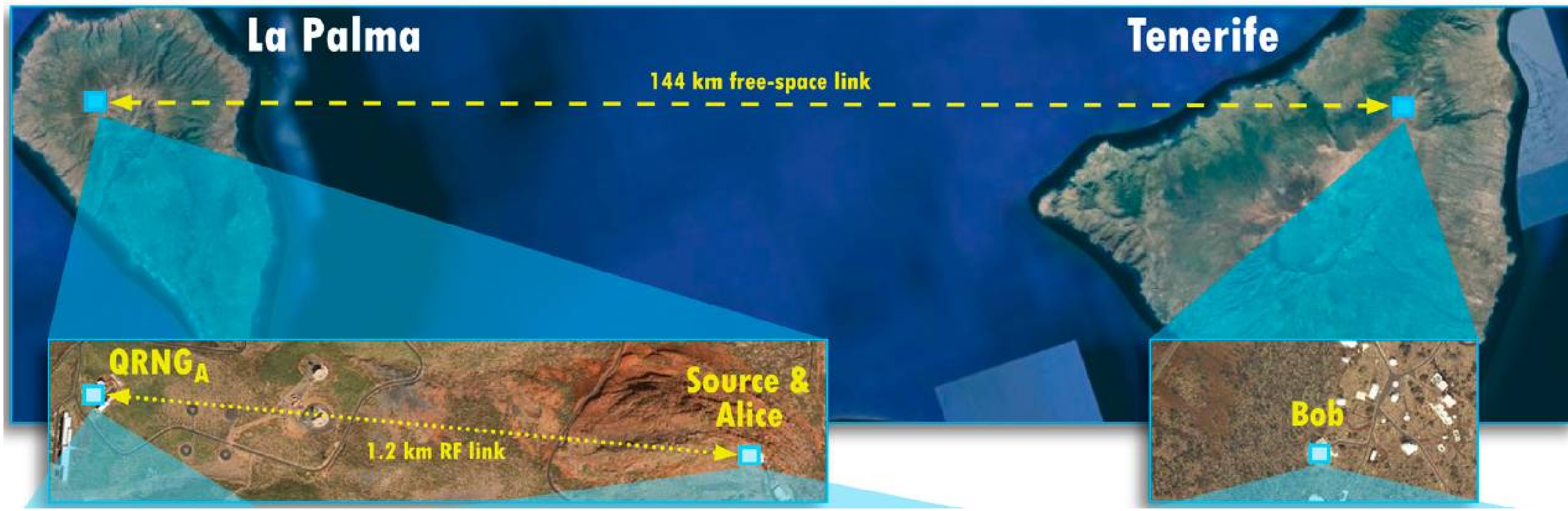
Polarizzazione a + 45° $|\boldsymbol{H}\rangle + |\boldsymbol{V}\rangle$

Polarizzazione a - 45° $|\boldsymbol{H}\rangle - |\boldsymbol{V}\rangle$

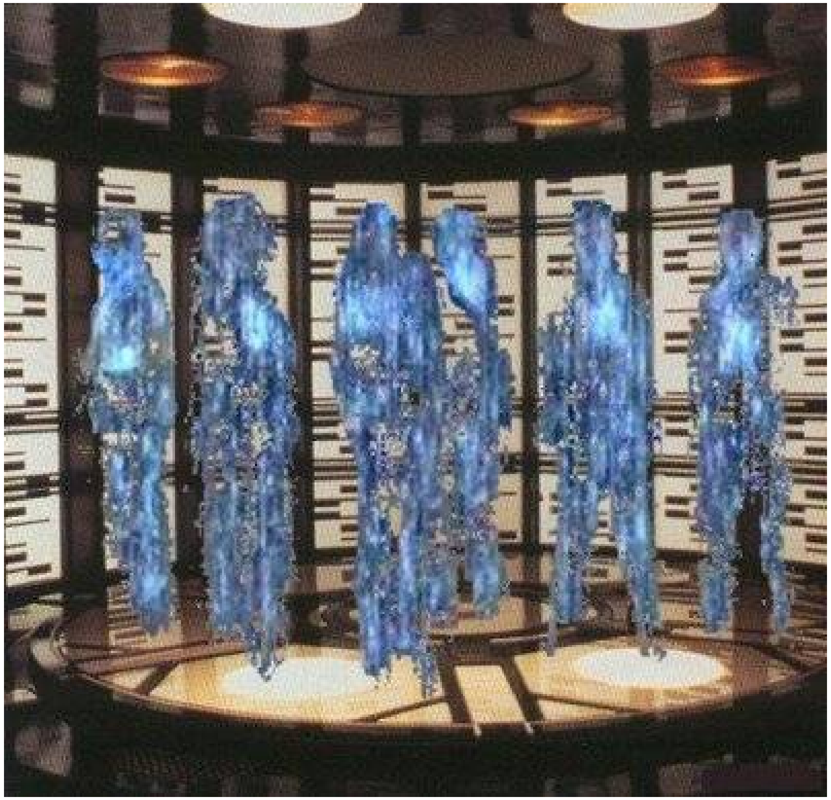
Violation of local realism with freedom of choice

Thomas Scheidl[a], Rupert Ursin[a], Johannes Kofler[a,b,1], Sven Ramelow[a,b], Xiao-Song Ma[a,b], Thomas Herbst[b], Lothar Ratschbacher[a,2], Alessandro Fedrizzi[a,3], Nathan K. Langford[a,4], Thomas Jennewein[a,5], and Anton Zeilinger[a,b,1]

[a]Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Boltzmanngasse 3, 1090 Vienna, Austria; and [b]Faculty of Physics, University of Vienna, Boltzmanngasse 5, 1090 Vienna, Austria



… fino al teletrasporto quantistico...

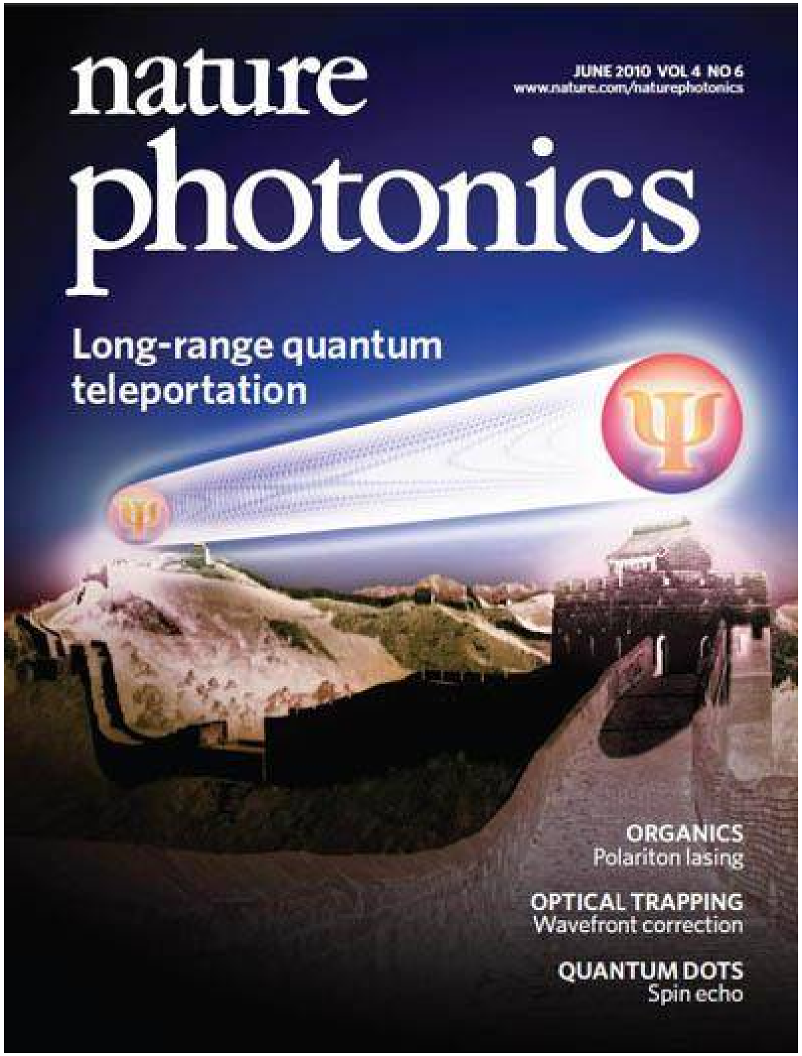


Cosa si teletrasporta ?

$$\Psi$$

La funzione d'onda

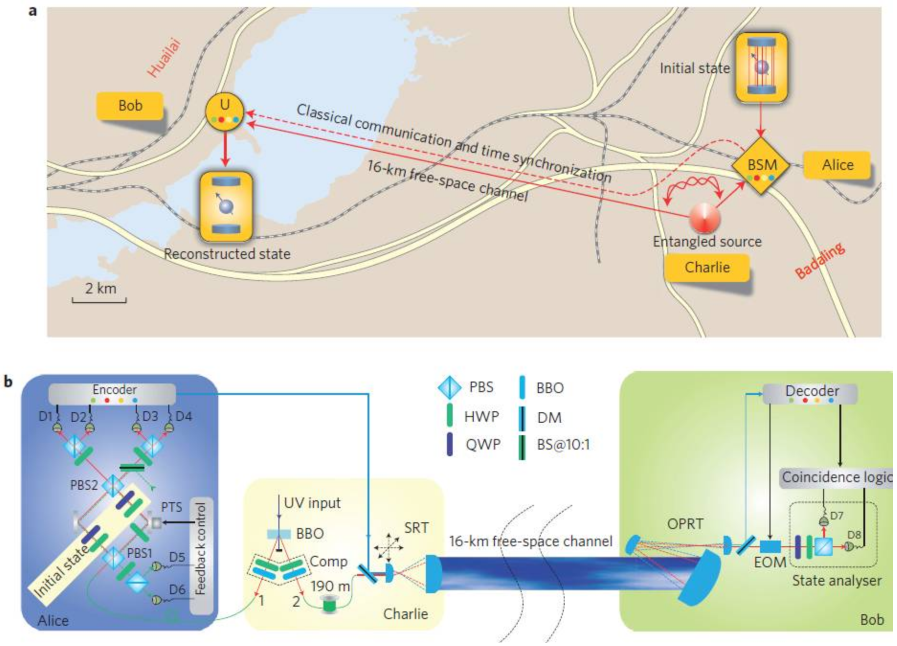
… fino al teletrasporto quantistico...



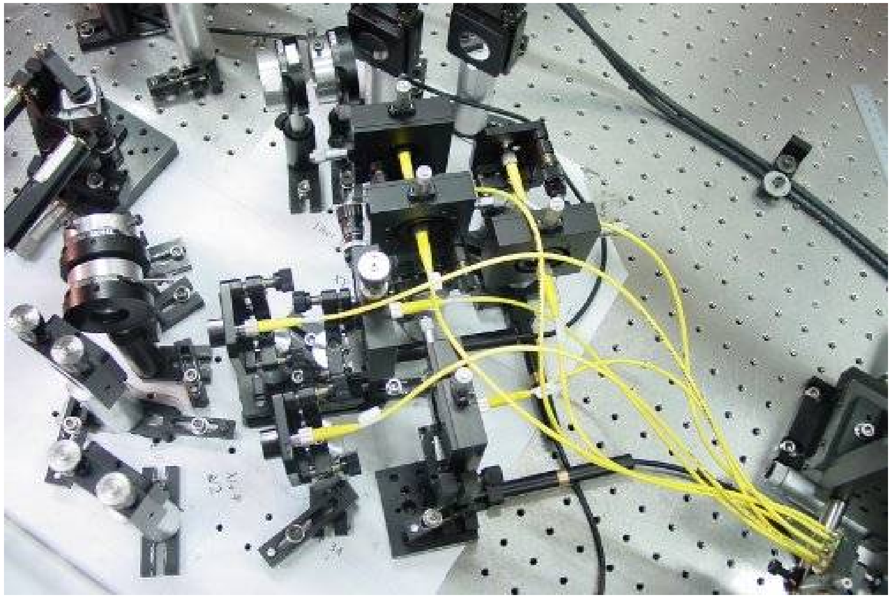
LETTERS
PUBLISHED ONLINE: 16 MAY 2010 | DOI: 10.1038/NPHOTON.2010.87
nature photonics

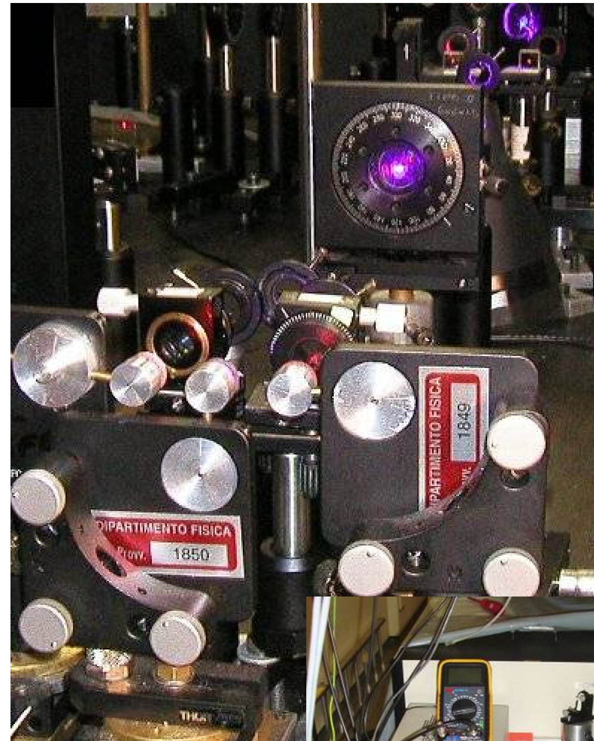
Experimental free-space quantum teleportation

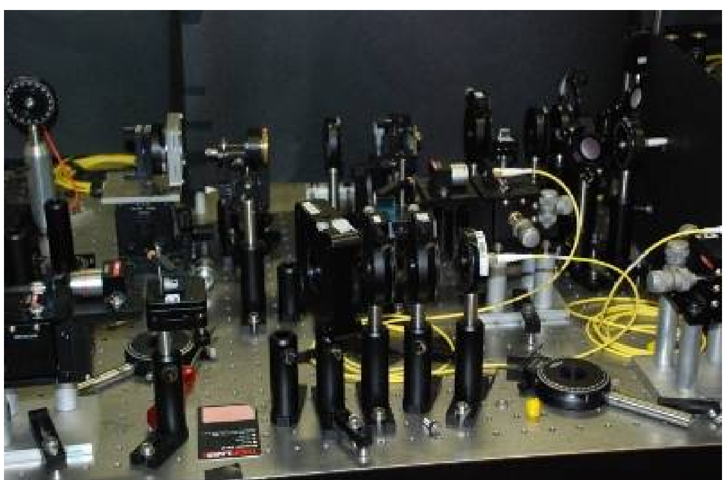
Xian-Min Jin[1†], Ji-Gang Ren[1,2†], Bin Yang[1], Zhen-Huan Yi[2], Fei Zhou[2], Xiao-Fan Xu[1], Shao-Kai Wang[2], Dong Yang[2], Yuan-Feng Hu[1], Shuo Jiang[2], Tao Yang[1], Hao Yin[1], Kai Chen[1], Cheng-Zhi Peng[2]* and Jian-Wei Pan[1,2]*

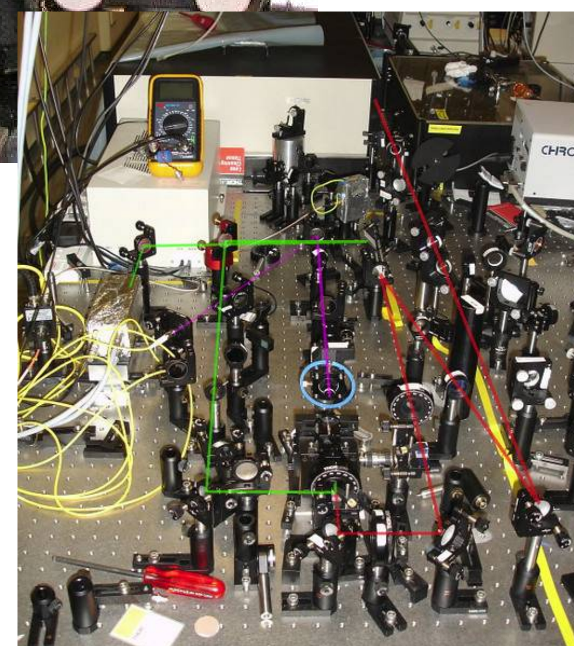


Non-località in laboratorio...







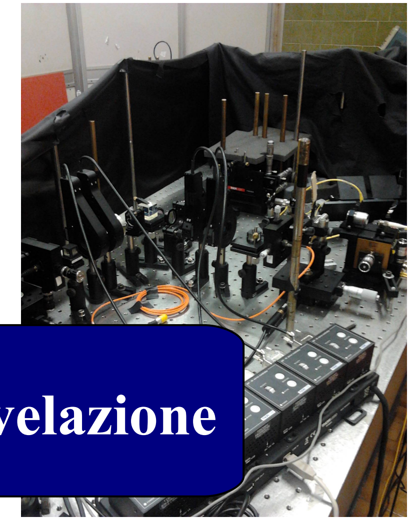


Verso l'informazione quantistica integrata

Preparazione

Manipulazione

Rivelazione



Verso l'informazione quantistica integrata

Preparazione

Manipulazione

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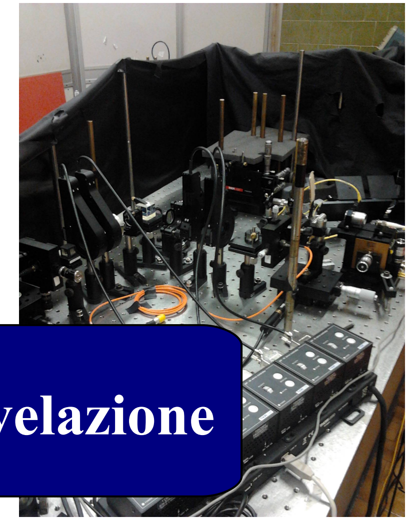

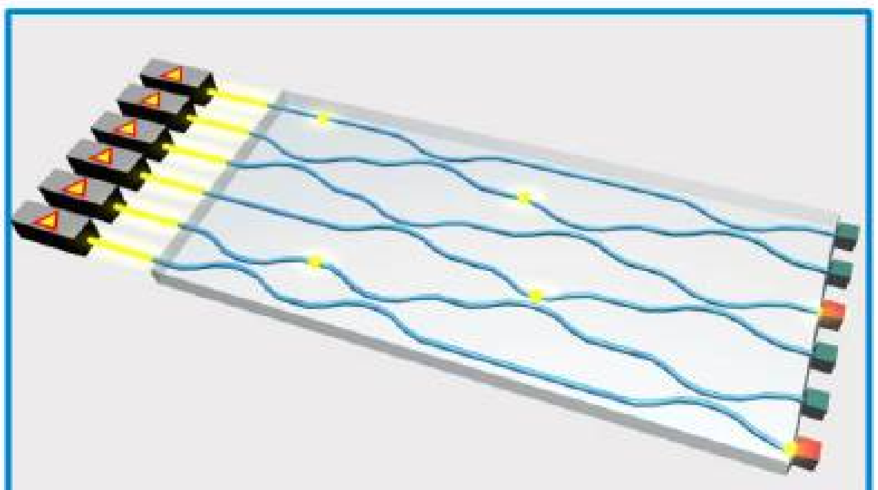

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Verso l'informazione quantistica integrata

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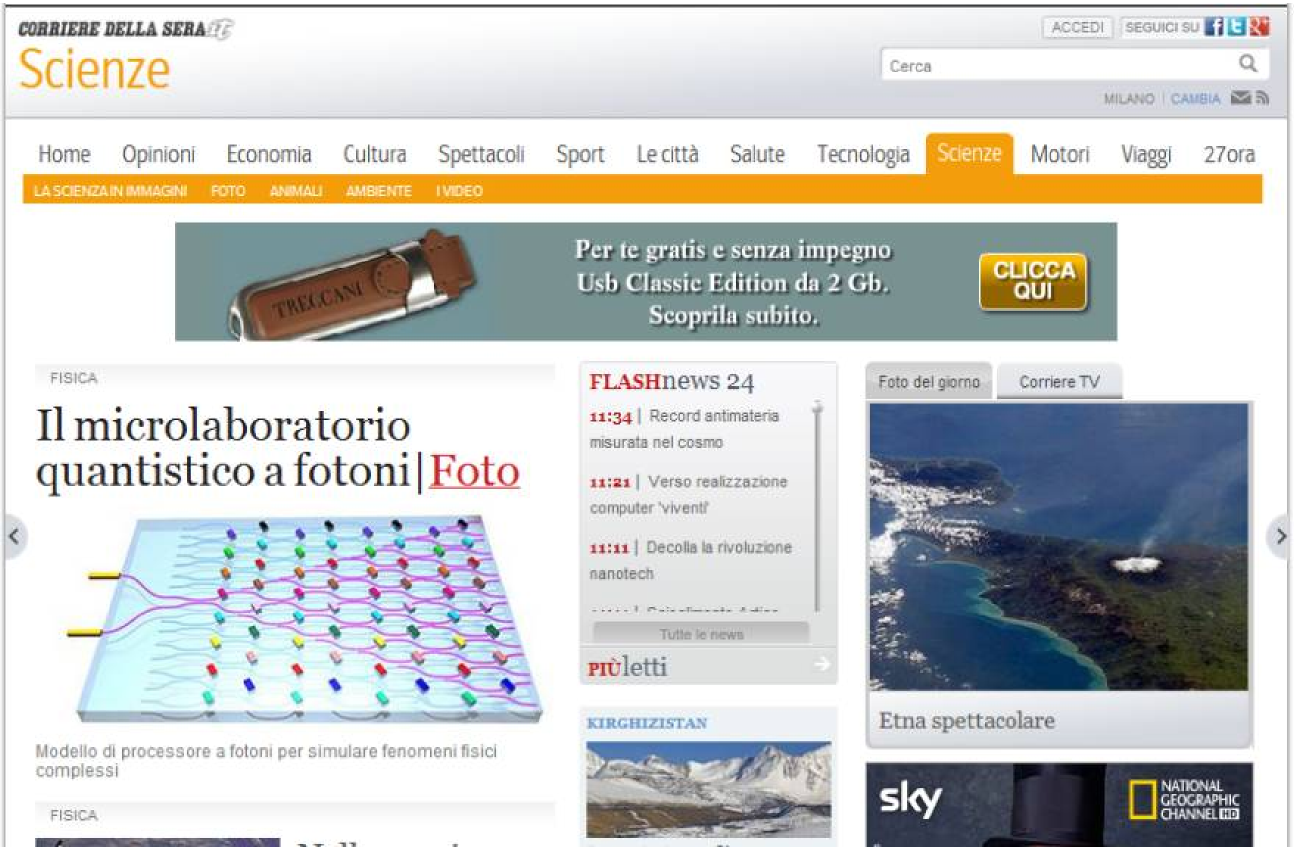

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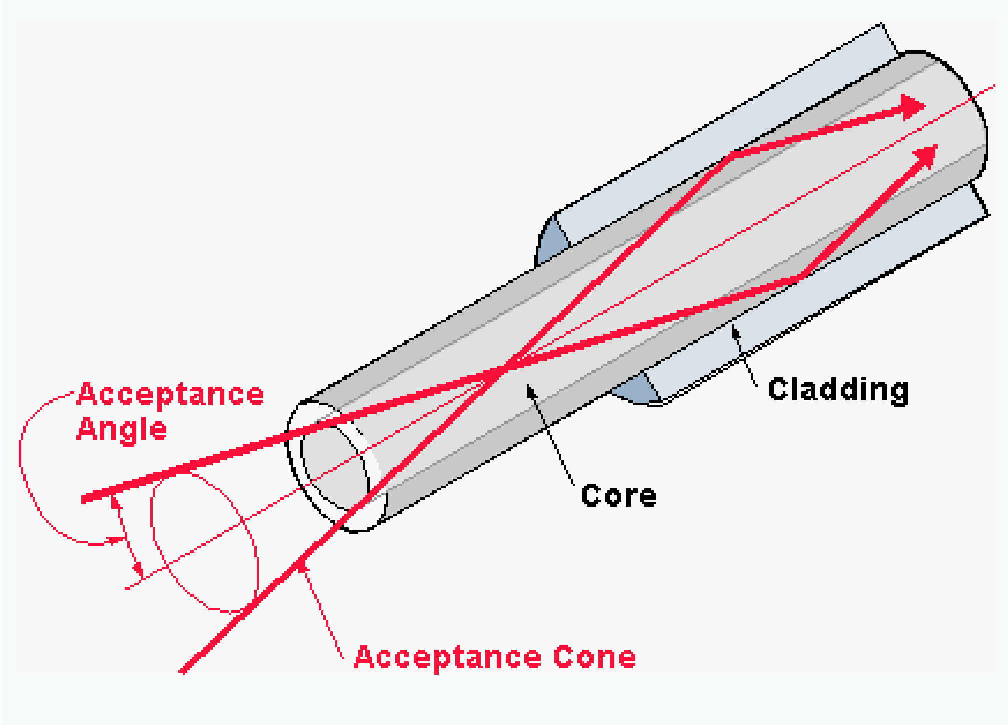
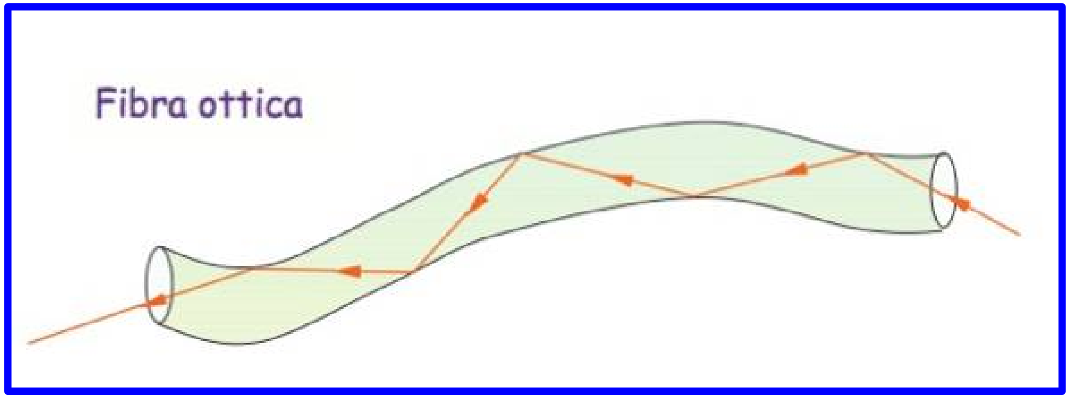
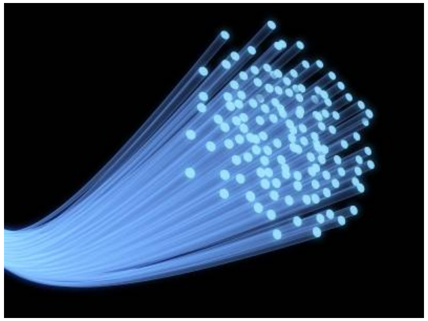
Come guidare la luce su un chip ?

Fibra ottica:

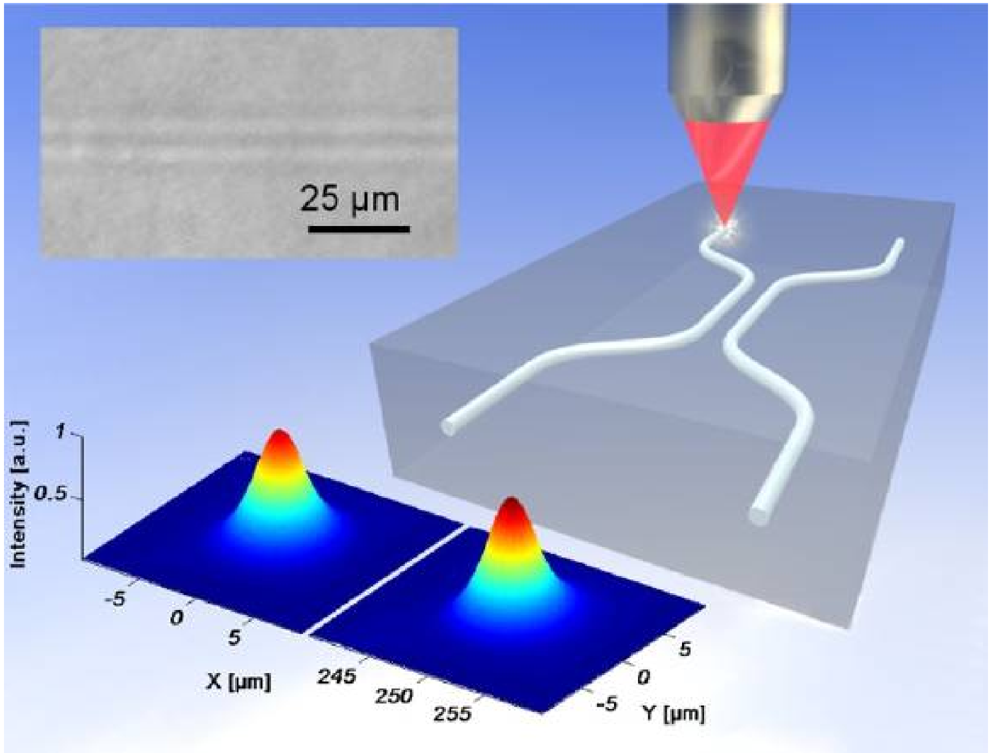
guidare la luce

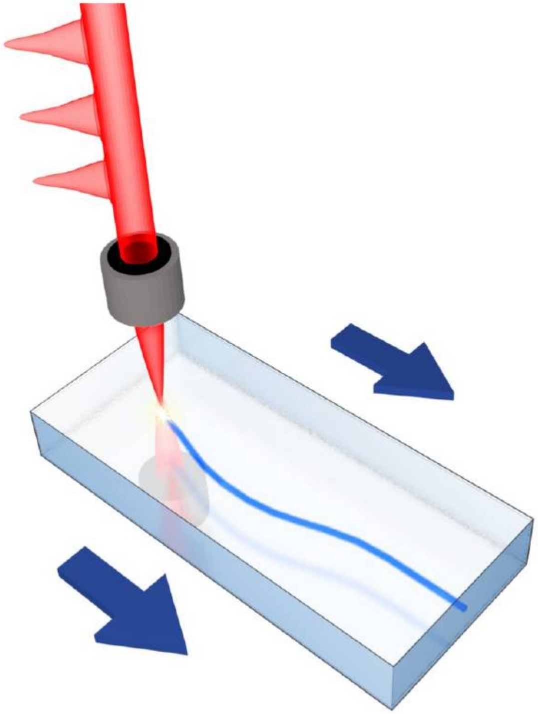


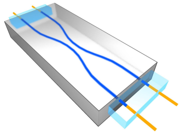




Circuito integrato scritto con LASER

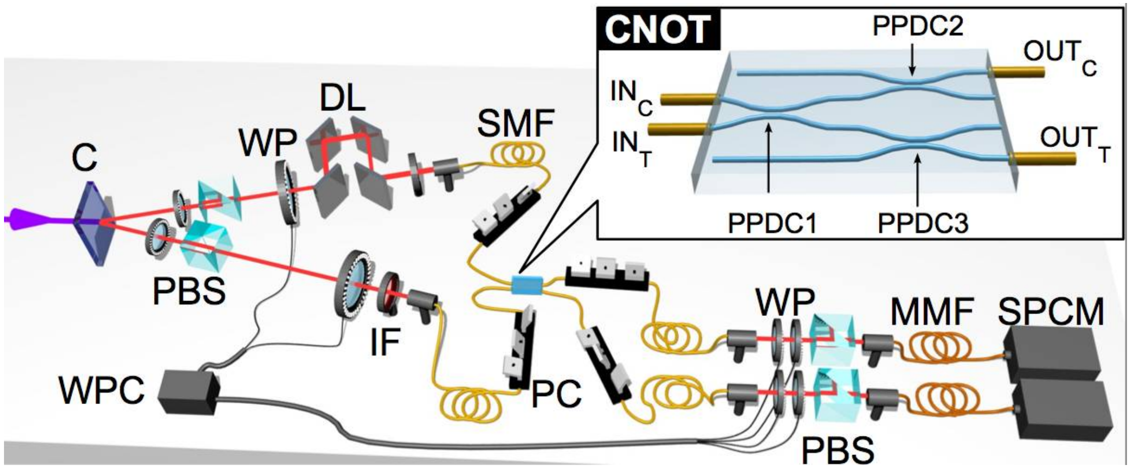


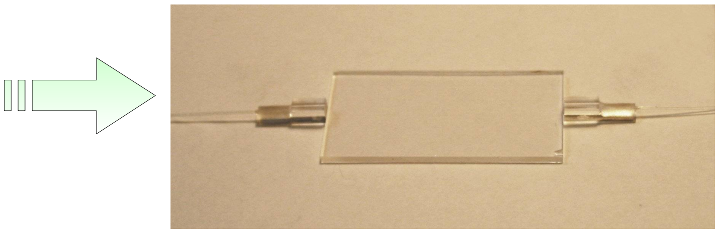




Scrittura con LASER al femtosecondo

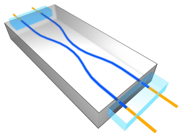
Porta logica quantistica su chip





Input		Output	
Control C	Target T	Control C’	Target T’
0	0	0	0
0	1	0	1
1	0	1	1
1	1	1	0

Operazione fondamentale del computer quantistico



Come funziona la porta logica CNOT ?

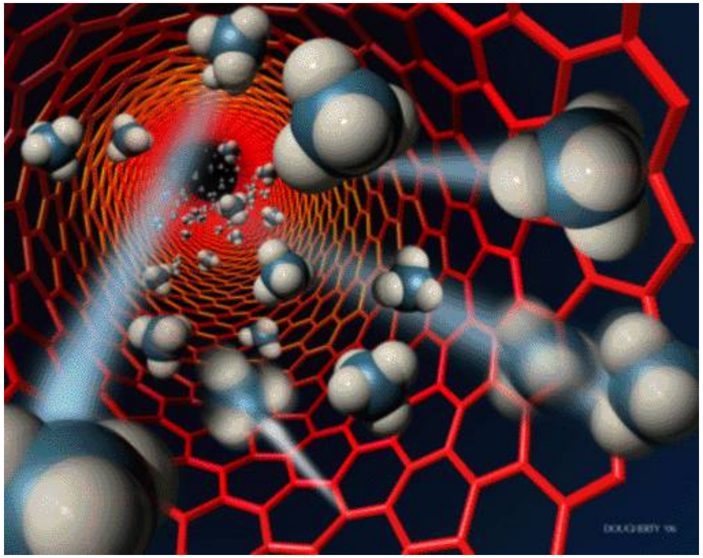
Verso la simulazione quantistica...

Richard Feynman:

« There is a plenty of room at the bottom»

Sfruttare un hardware quantistico
per simulare un sistema quantistico

Richard Feynman



Grazie dell'attenzione!

QUANTUM OPTICS GROUP
Dipartimento di Fisica, Sapienza Università di Roma

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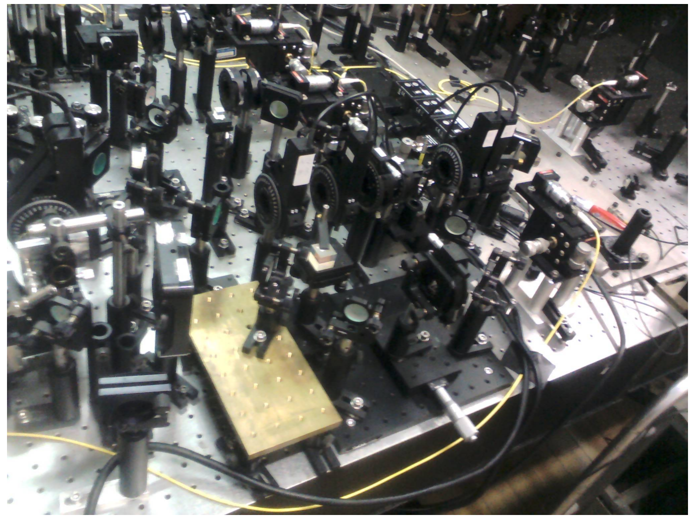

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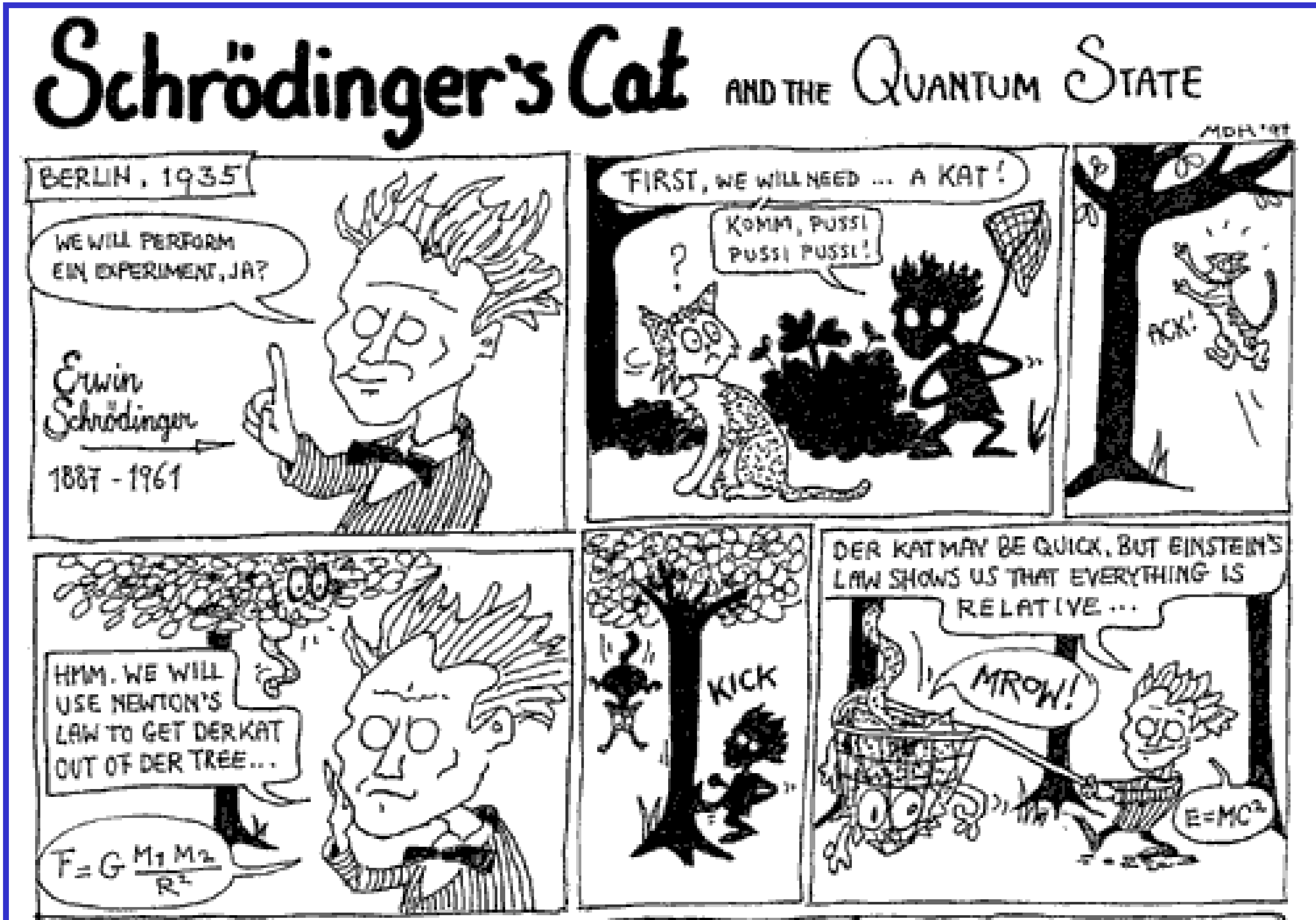
Enjoy life, enjoy quantum!

http://quantumoptics.phys.uniroma1.it



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