La Seconda Rivoluzione Quantistica

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www.quantumlab.it

Il computer quantistico secondo Microsoft

..ora facciamo un salto nel passato…

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

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

La 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.]

Interferenza a singola particella

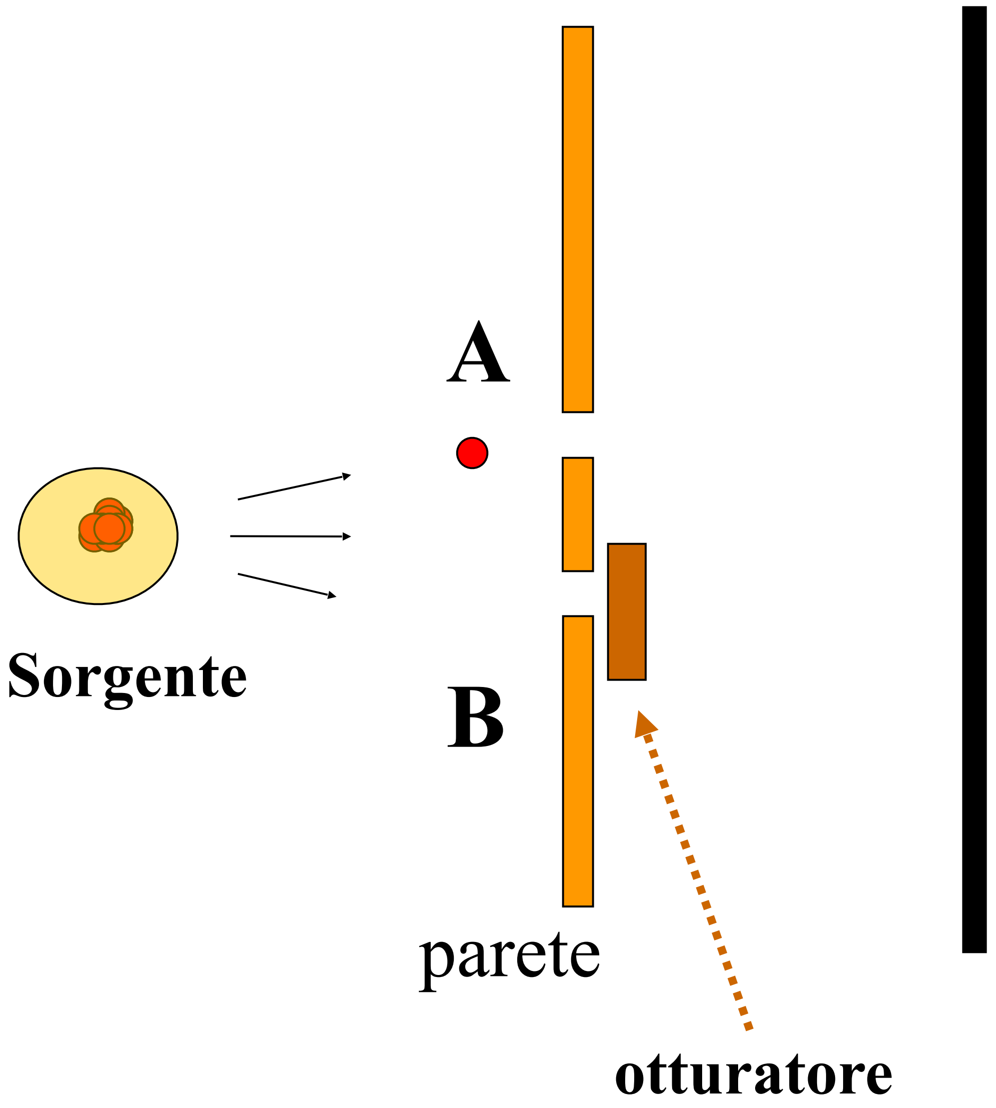
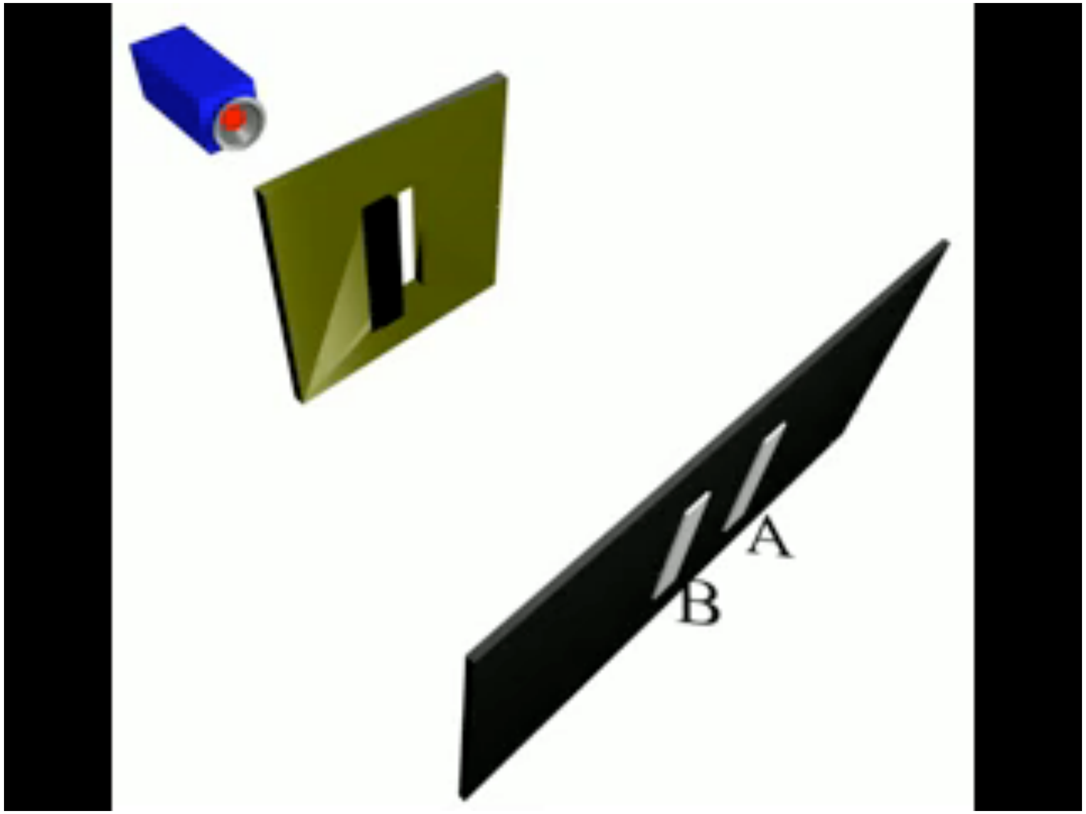
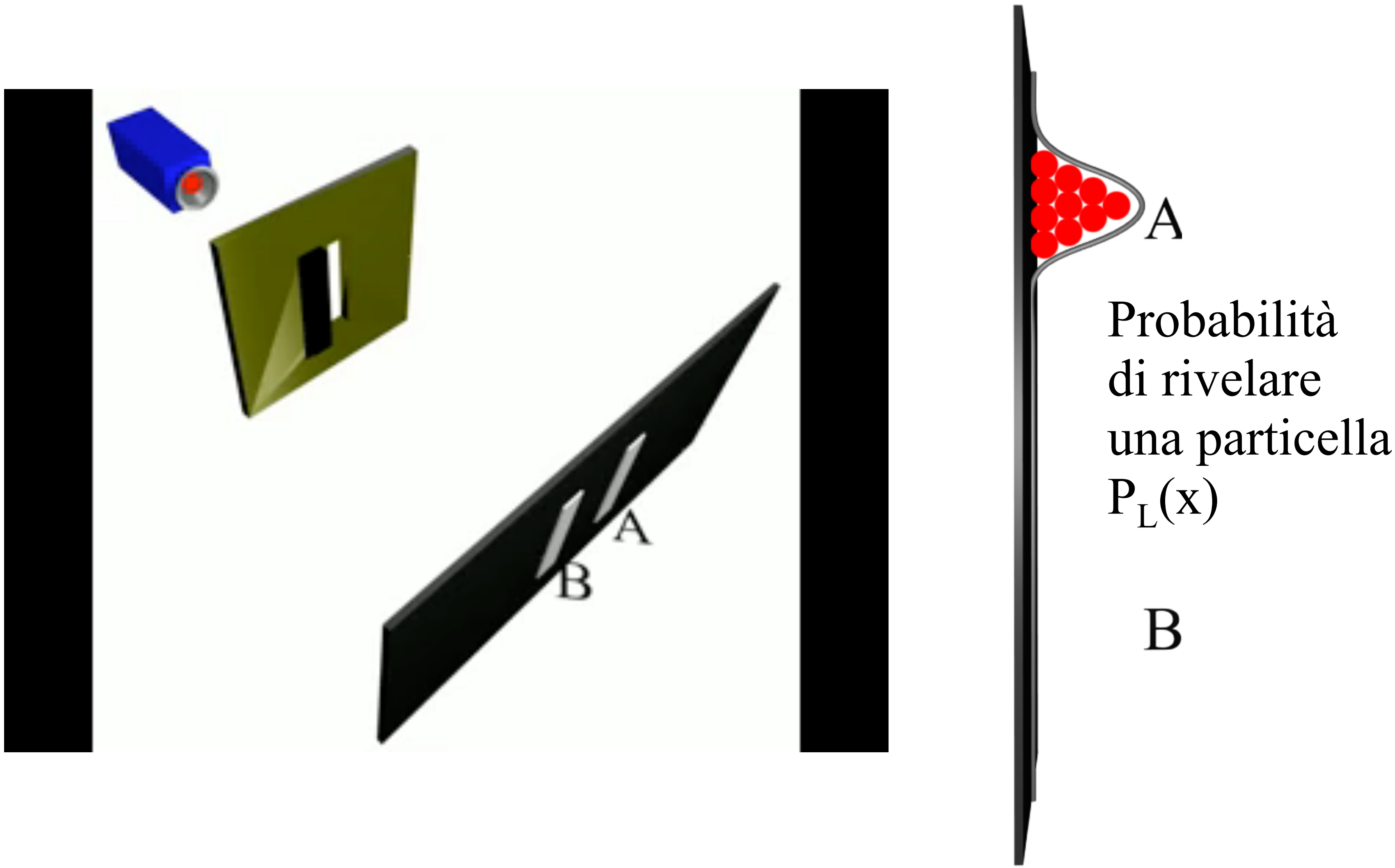


Immagine vista
Di fronte

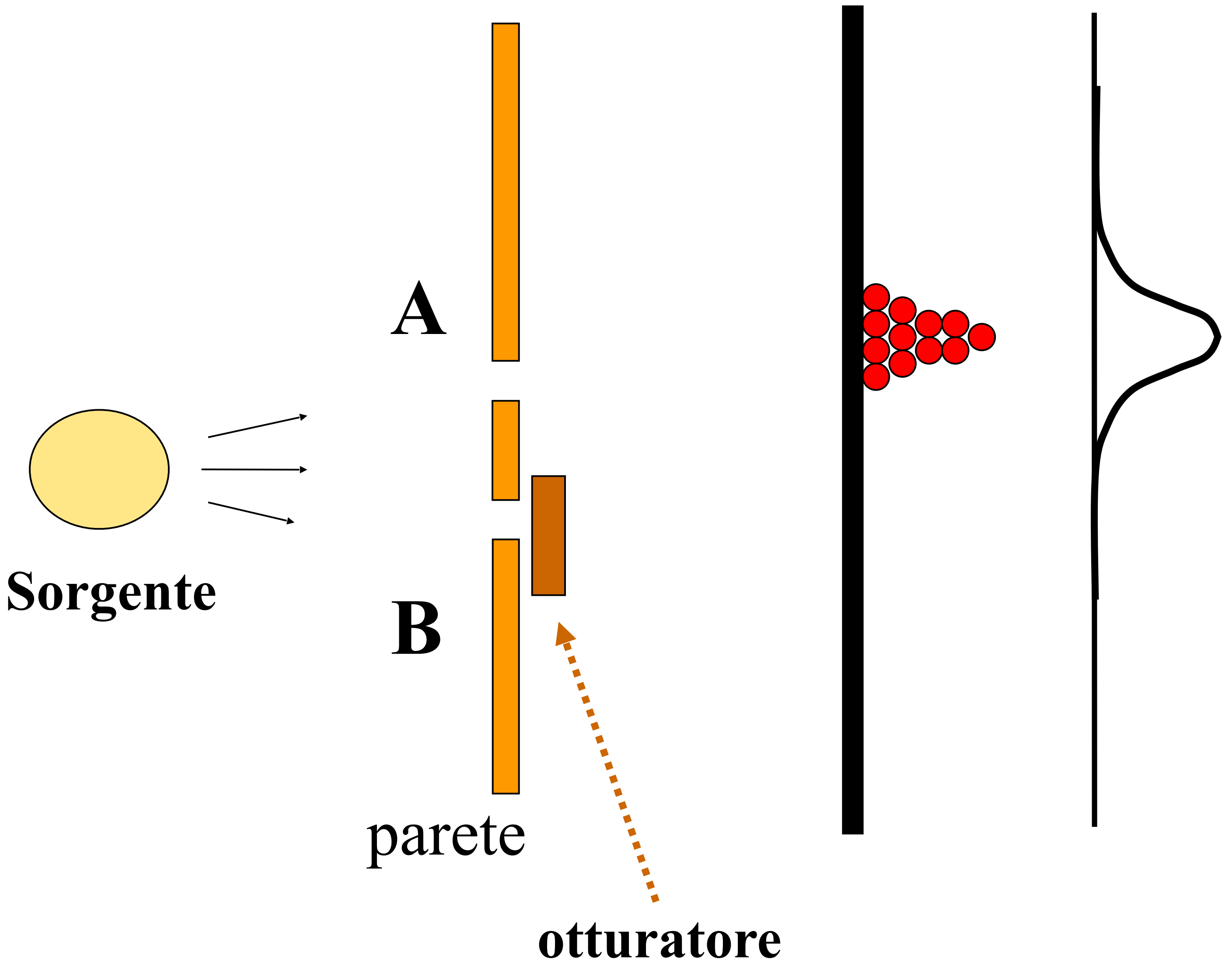
Interferenza a singola particella



Interferenza a singola particella

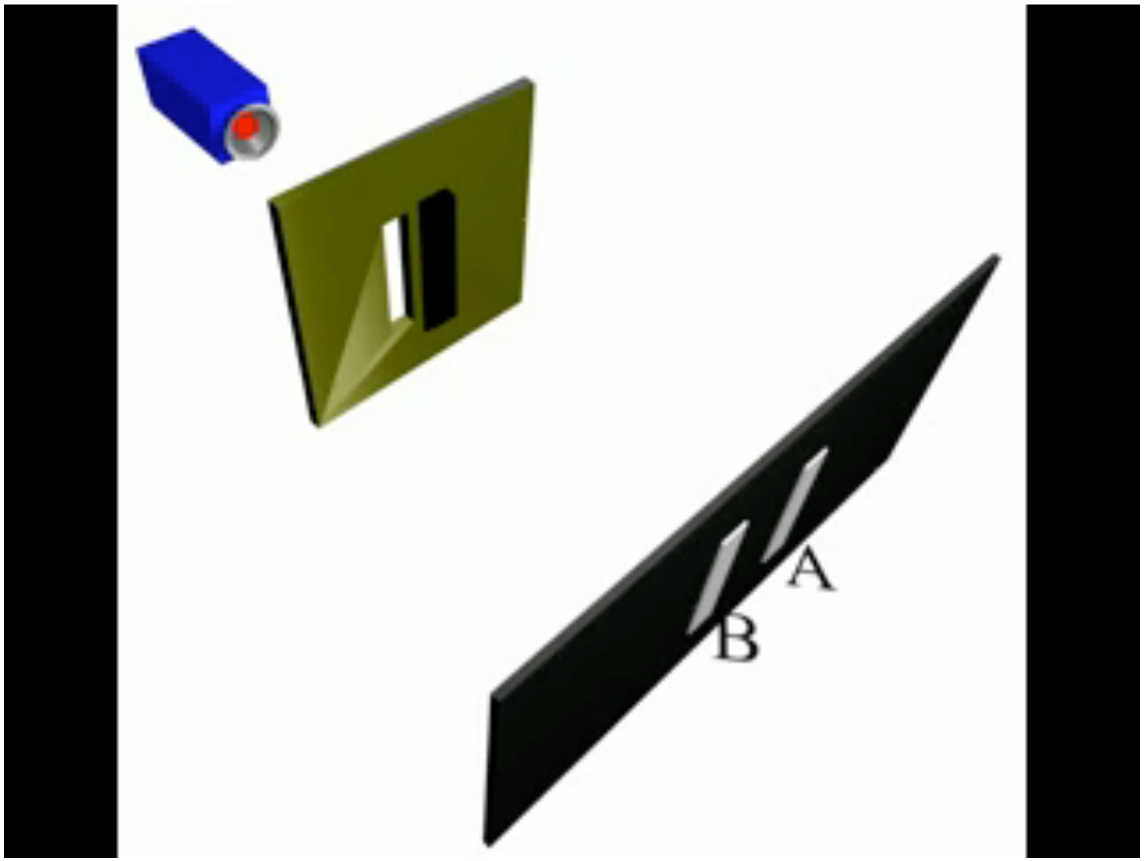


Interferenza a singola particella

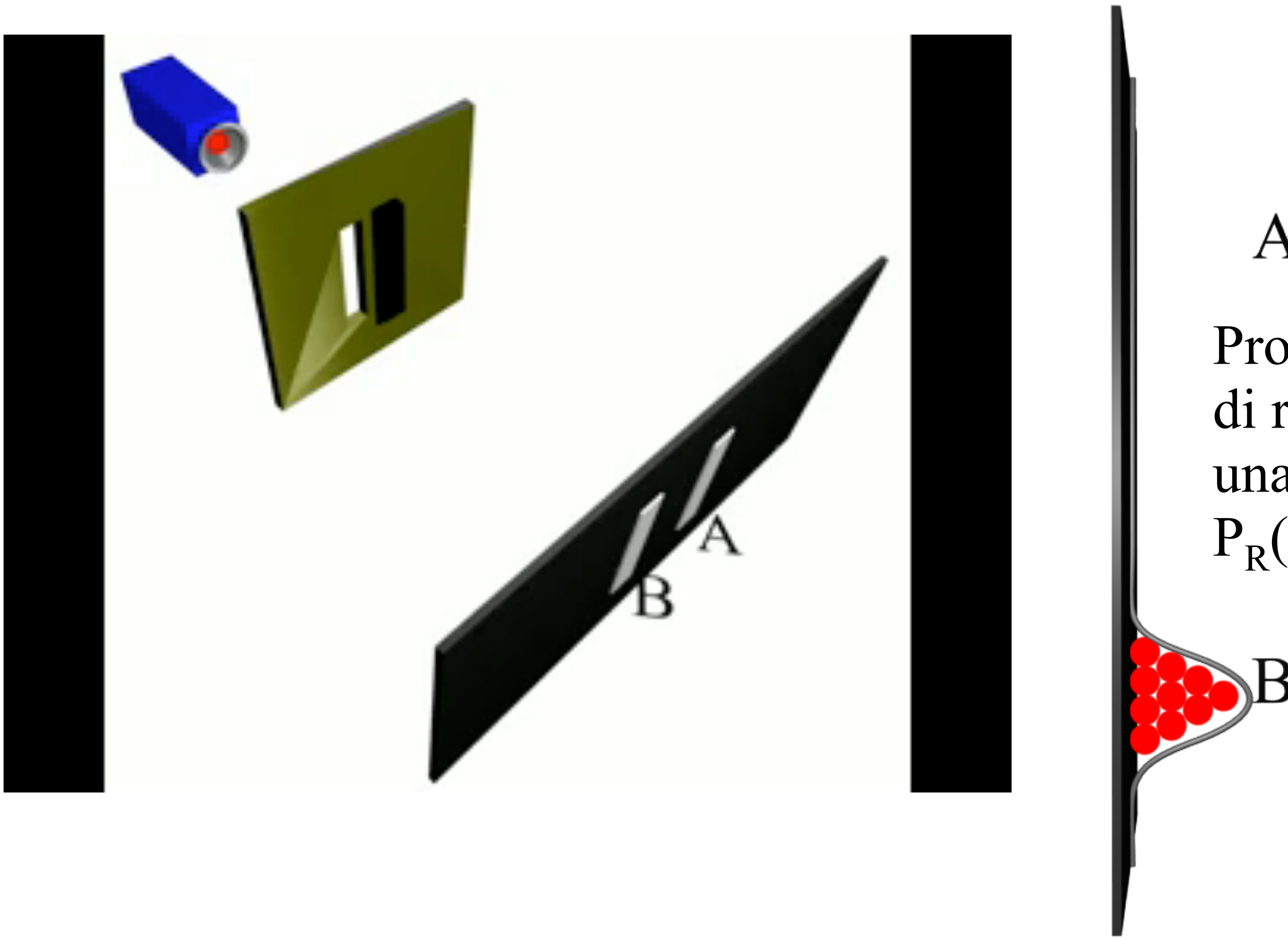


Probabilità
di rivelare
una particella
$P_A(x)$

Interferenza a singola particella

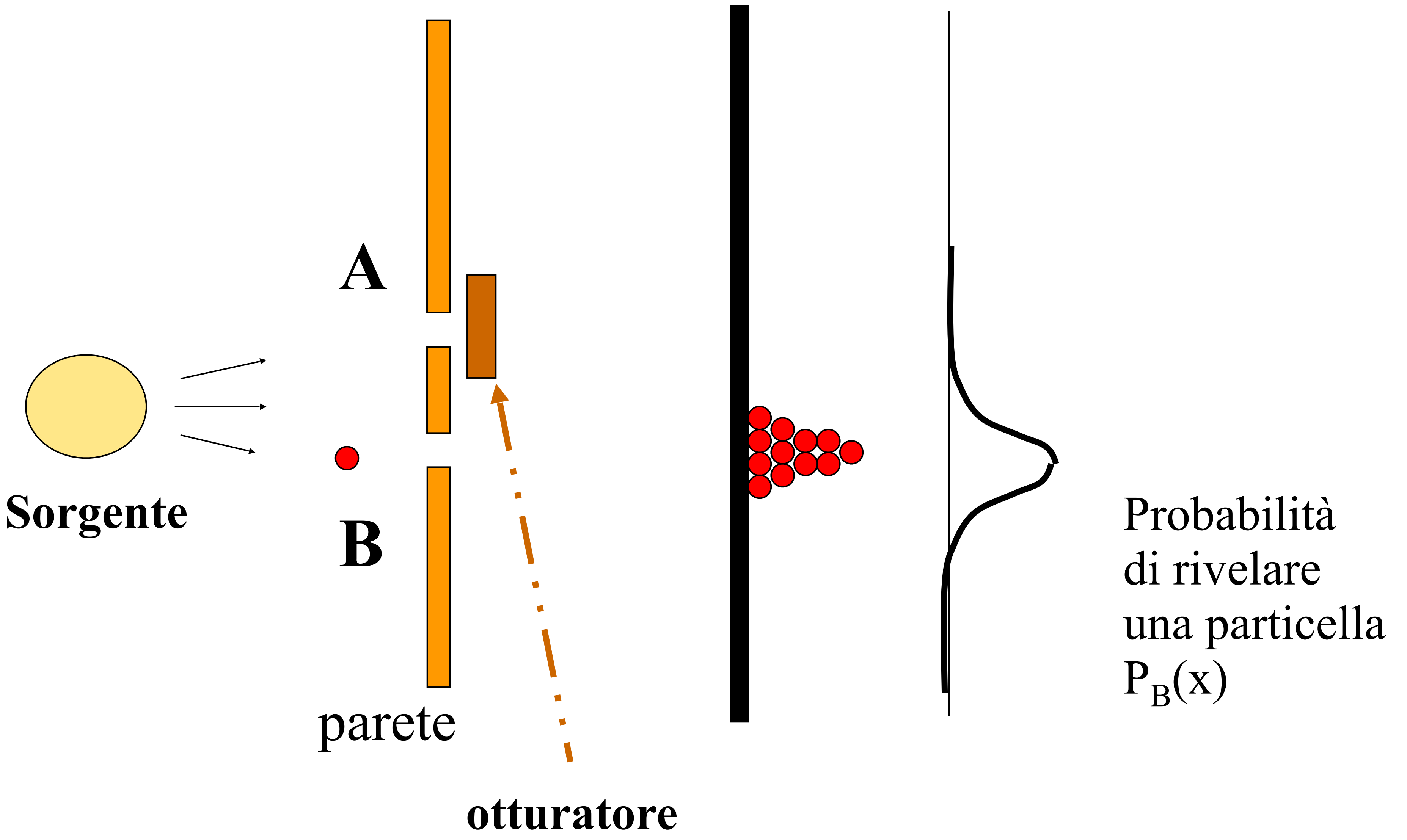


Interferenza a singola particella

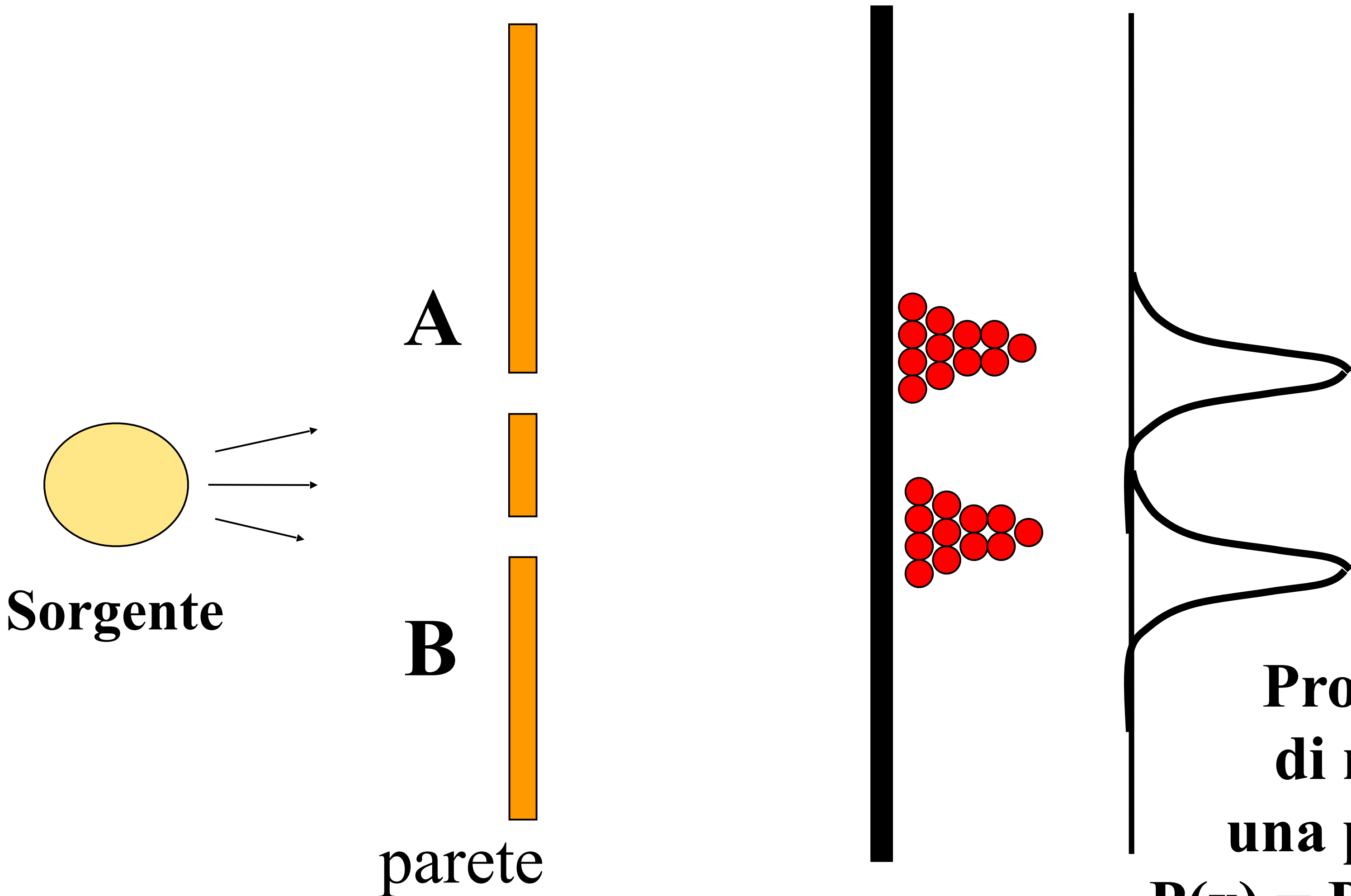


Probabilità
di rivelare
una particella
$P_R(x)$

Interferenza a singola particella



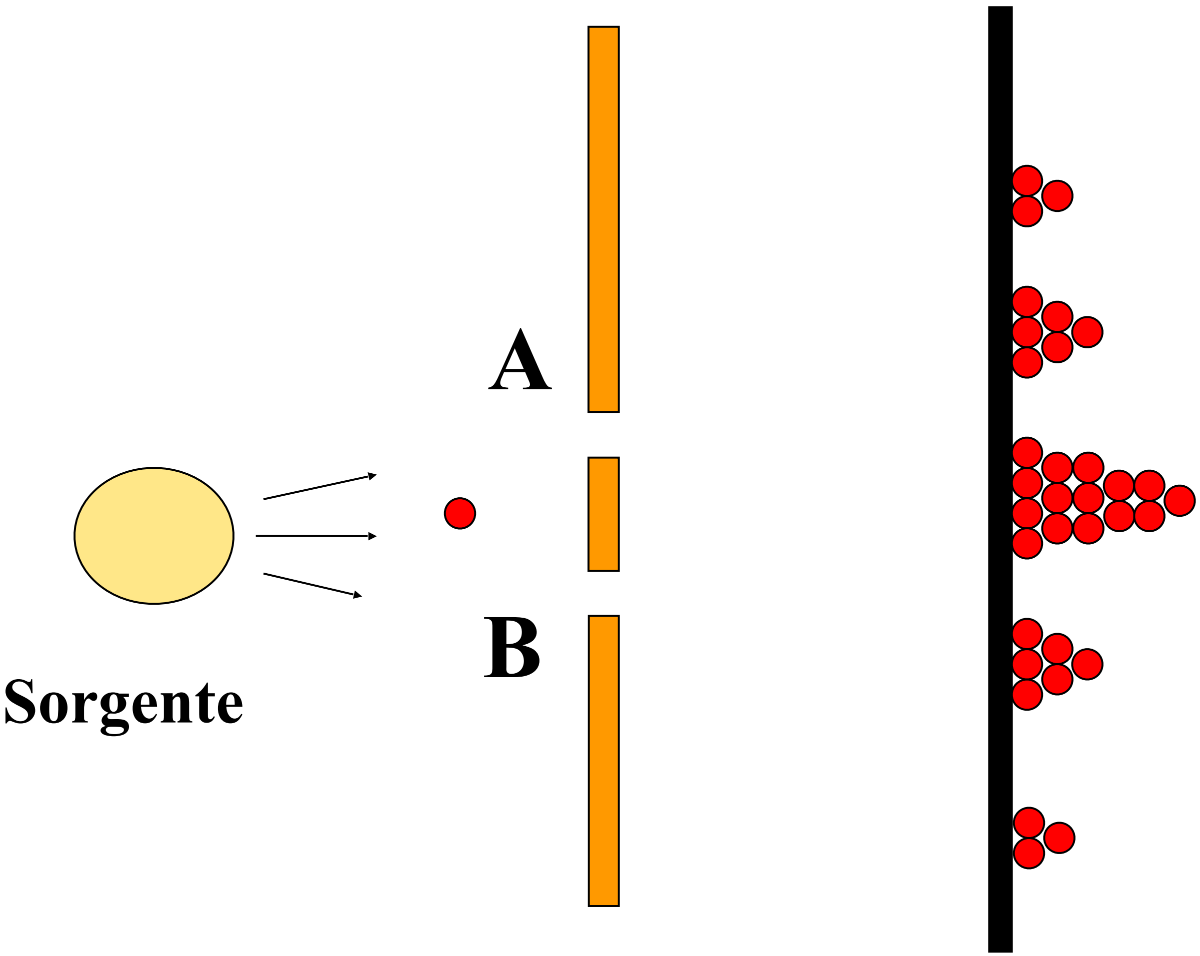
Comportamento “classico”



Probabilità di rivelare una particella

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

Interferenza quantistica



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

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

Coesistenza di due realtà diverse

L’interferenza

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

R.P. Feynman (1965)

Interferenza quantistica

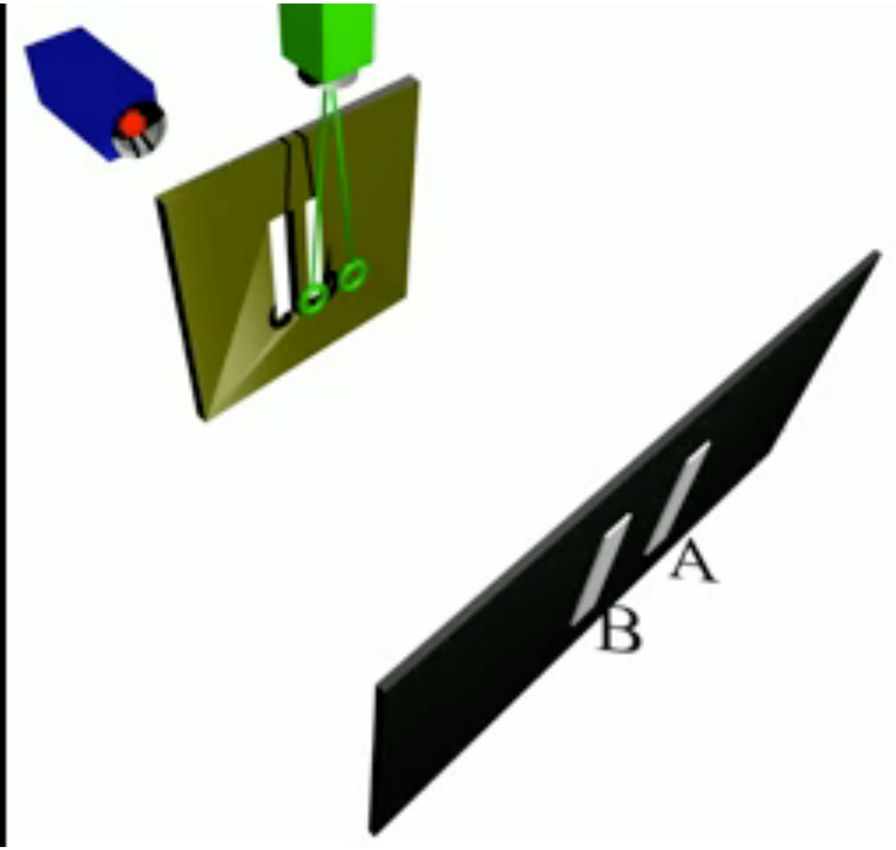
Fisica classica: una particella può viaggiare lungo il cammino A **o** lungo il cammino B

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

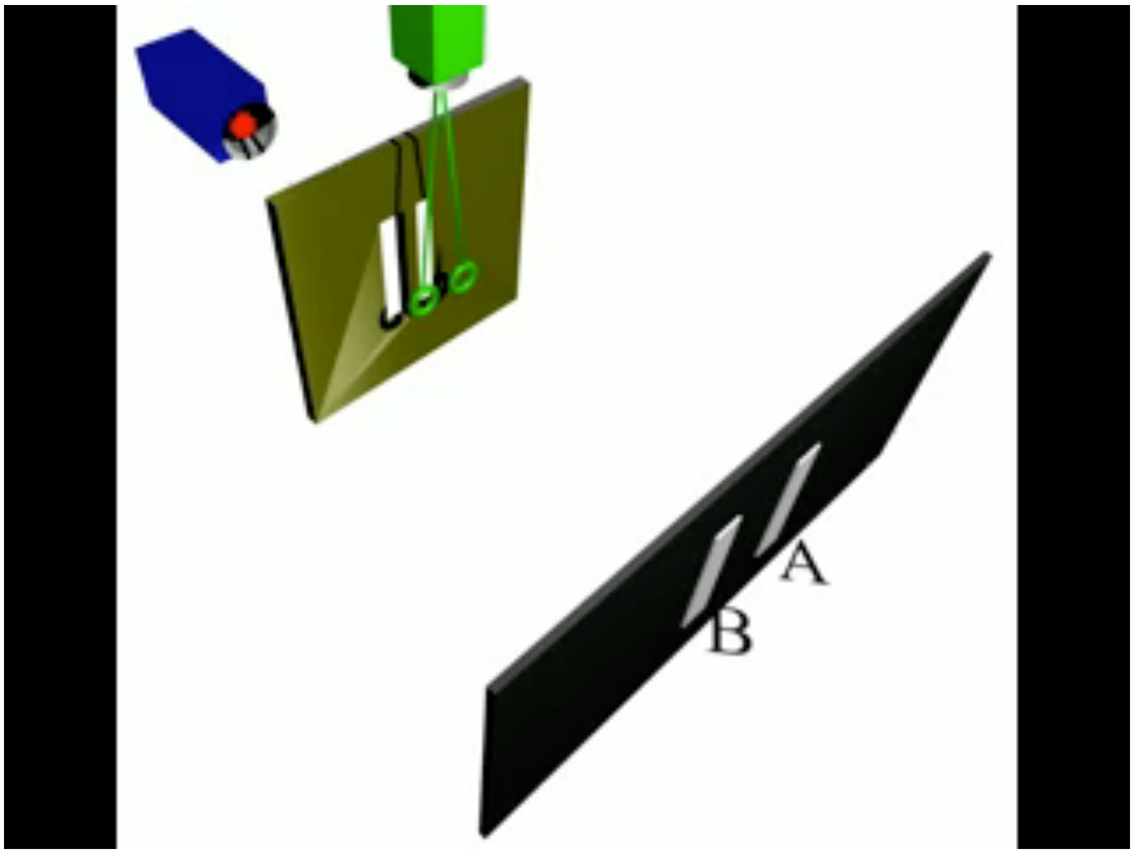
La particella si trova in uno stato di sovrapposizione delle due traiettorie.

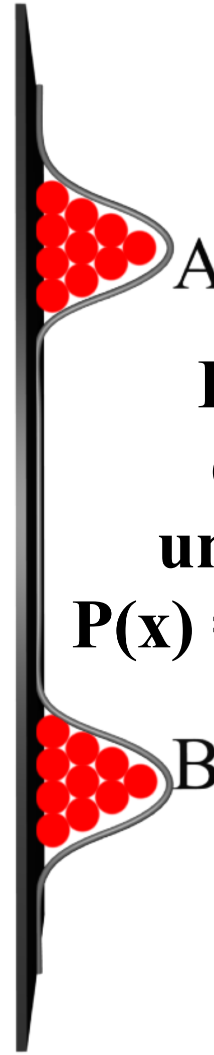
La **funzione d'onda** che caratterizza il sistema si scrive......

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


A
B

Comportamento “classico”





Probabilità di rivelare una particella

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

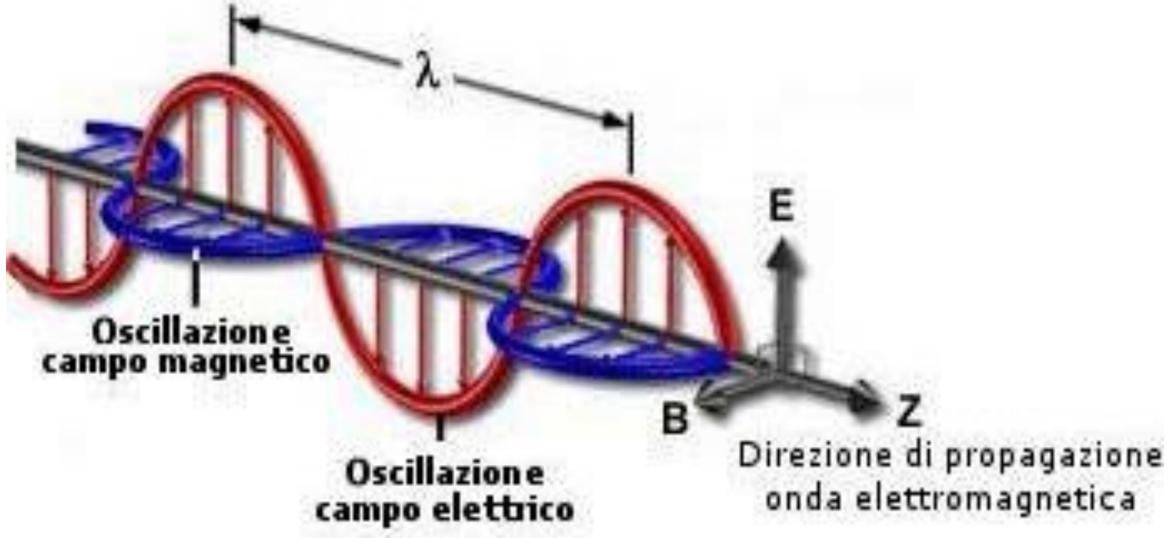
“It from bit”

J.A.Wheeler

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

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

Polarizzazione di un singolo fotone

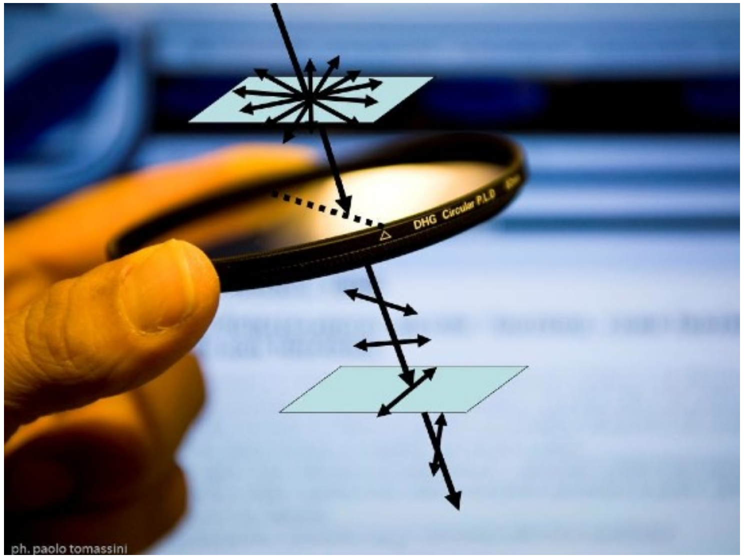


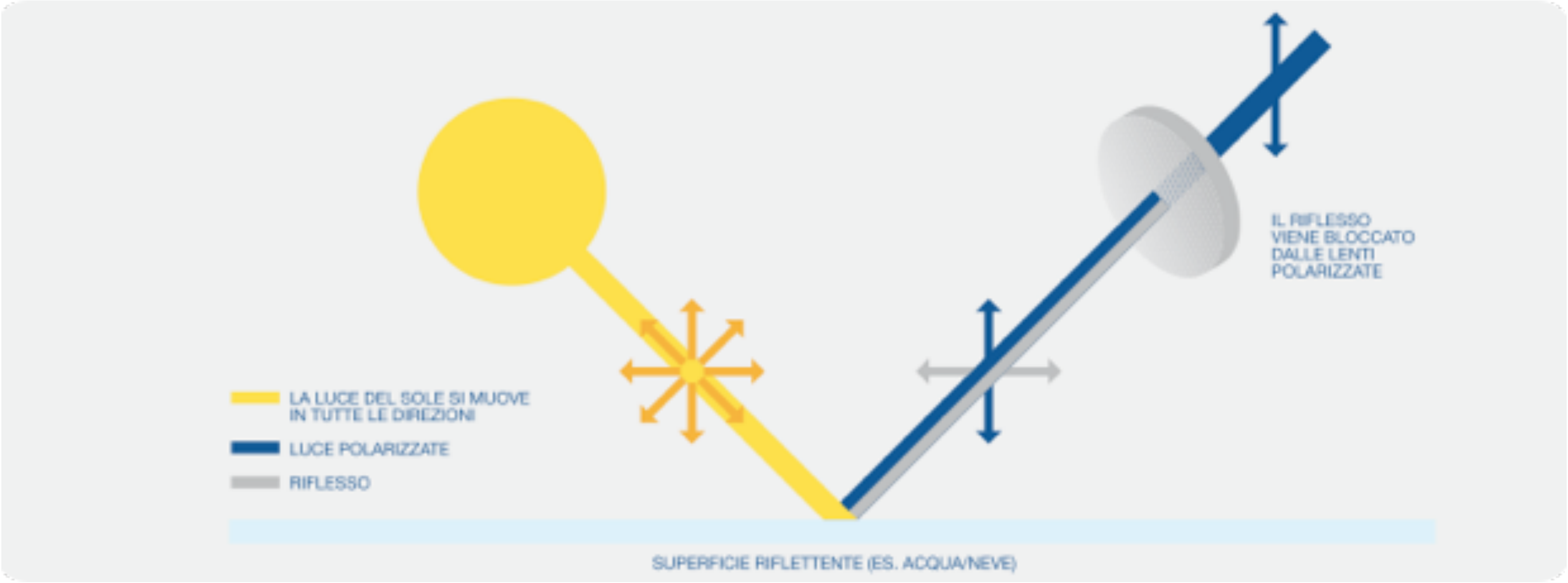
Polarizzazione del singolo fotone

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

H: orizzontale
V: verticale

Occhiali polarizzati





Polarizzazione di un singolo fotone

Polarizzazione: direzione di oscillazione del campo elettromagnetico

Polarizzazione orizzontale $|H\rangle$

Polarizzazione verticale $|V\rangle$

Polarizzazione a + 45° $|H\rangle + |V\rangle$

Polarizzazione a - 45° $|H\rangle - |V\rangle$

“It from bit”

J.A. Wheeler

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

A. Einstein

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

A. Einstein

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

A. Einstein

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

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 Ein-

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Broglie,
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Podolsky
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Physical
Complete

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Paradosso di Einstein-Podolsky-Rosen

Per dimostrare che la Meccanica Quantistica

NON è la teoria definitiva

introducono il concetto di <u>entanglement</u>

Paradosso di Einstein-Podolsky-Rosen

Per dimostrare che la Meccanica Quantistica

NON è la teoria definitiva

introducono il concetto di entanglement

Consideriamo due particelle (fotoni A e B)

$$\boxed{|0\rangle_A |1\rangle_B}$$

Paradosso di Einstein-Podolsky-Rosen

Per dimostrare che la Meccanica Quantistica NON è la teoria definitiva introducono il concetto di entanglement

Consideriamo due particelle (fotoni A e B)

$$\boxed{|1\rangle_A |0\rangle_B}$$

Paradosso di Einstein-Podolsky-Rosen

Per dimostrare che la Meccanica Quantistica

NON è la teoria definitiva

introducono il concetto di entanglement

Consideriamo due particelle (fotoni A e B)

$$\boxed{|0\rangle_A |1\rangle_B} \quad \boxed{+} \quad \boxed{|1\rangle_A |0\rangle_B}$$

Paradosso di Einstein-Podolsky-Rosen

Per dimostrare che la Meccanica Quantistica

NON è la teoria definitiva

introducono il concetto di entanglement

Consideriamo due particelle (fotoni A e B)

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

Entanglement:

due particelle aggrovigliate

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

EINSTEIN ATTAC[K]
QUANTUM THE[ORY]

Scientist and Two Colle[agues] Find It Is Not 'Comple[te]' Even Though 'Correct'

SEE FULLER ONE POSS[IBLE]

Believe a Whole Descripti[on of] 'the Physical Reality' Can 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.

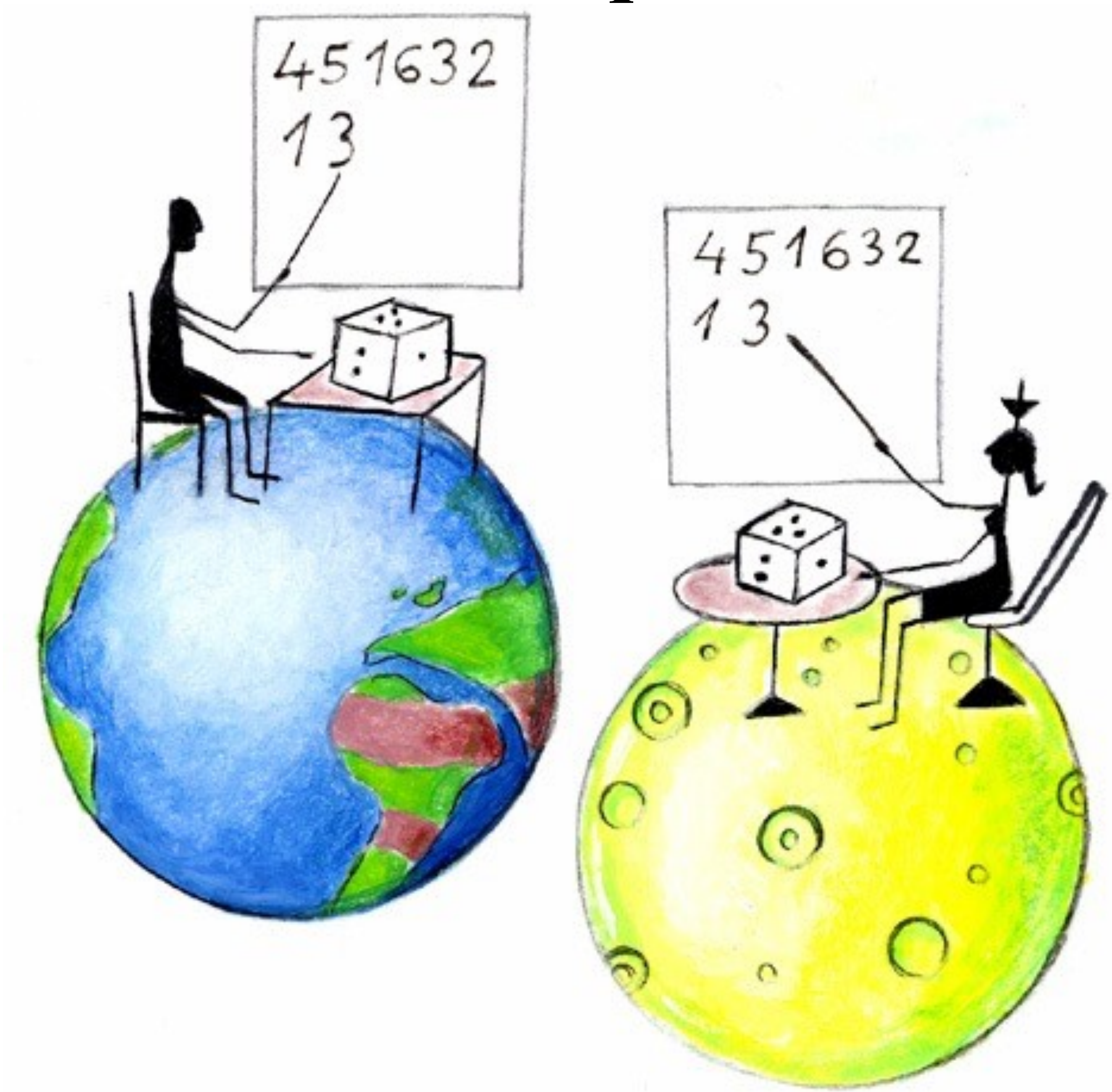
We believe, however, that such a theory is possible. »

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

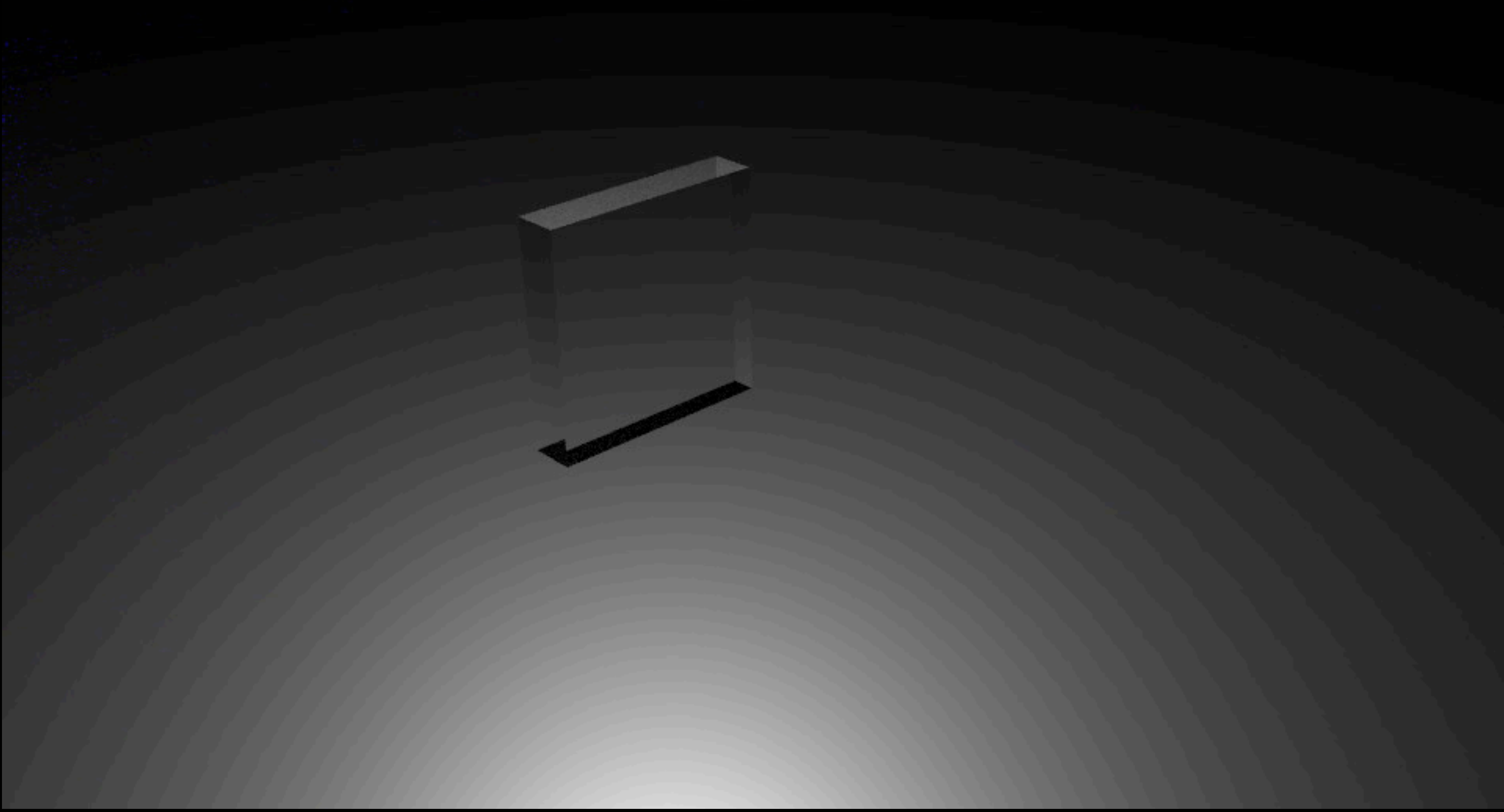
« I would not call **entanglement** one but rather the **characteristic trait of quantum mechanics**,
the one that enforces its entire departure from classical lines of thought. »

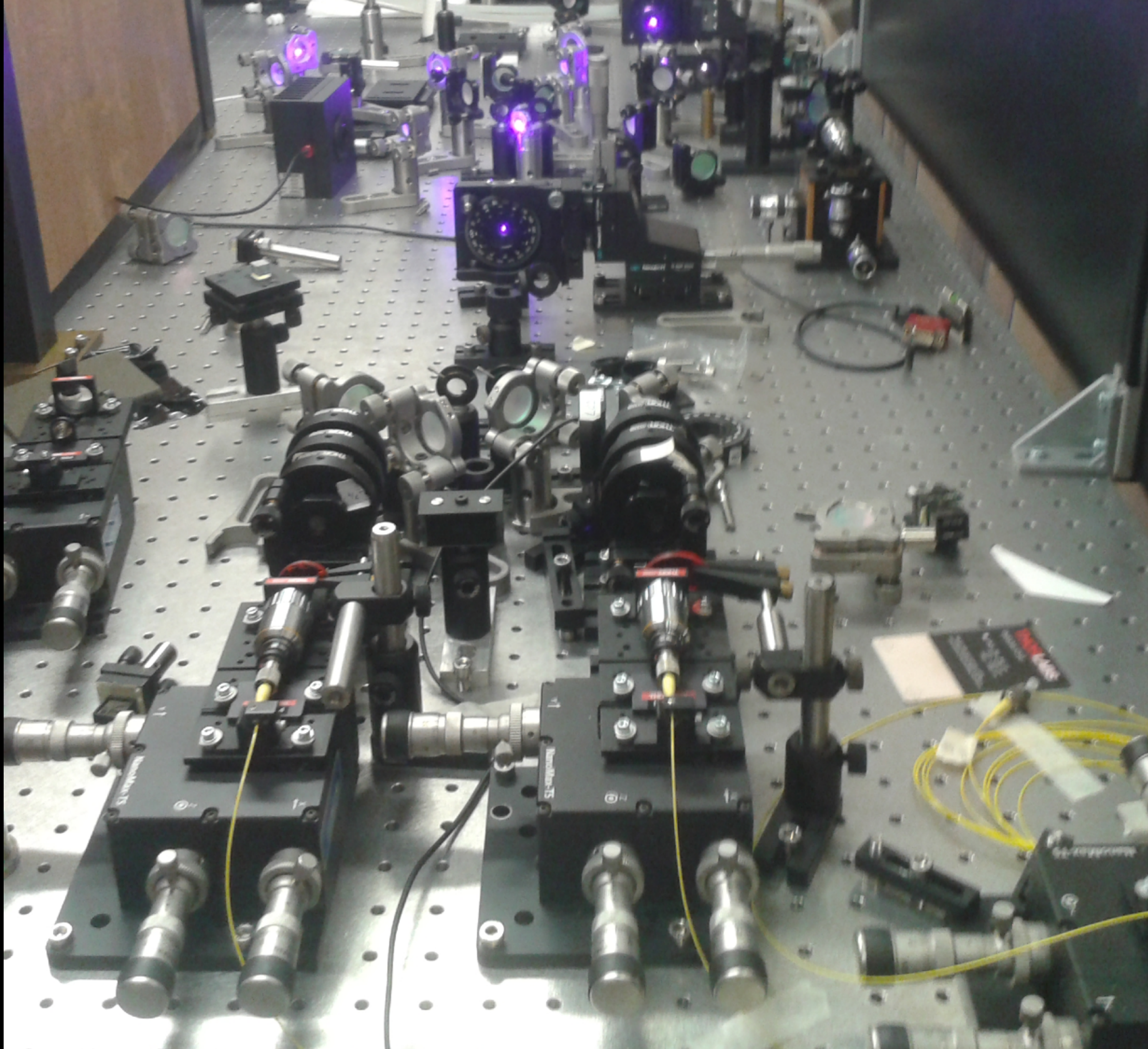
E. Schroedinger

Non-località quantistica



Generazione di stati entangled





SCIENCE

710 COMMENTS

Sorry, Einstein. Quantum Study Suggests 'Spooky Action' Is Real.

By JOHN MARKOFF OCT. 21, 2015

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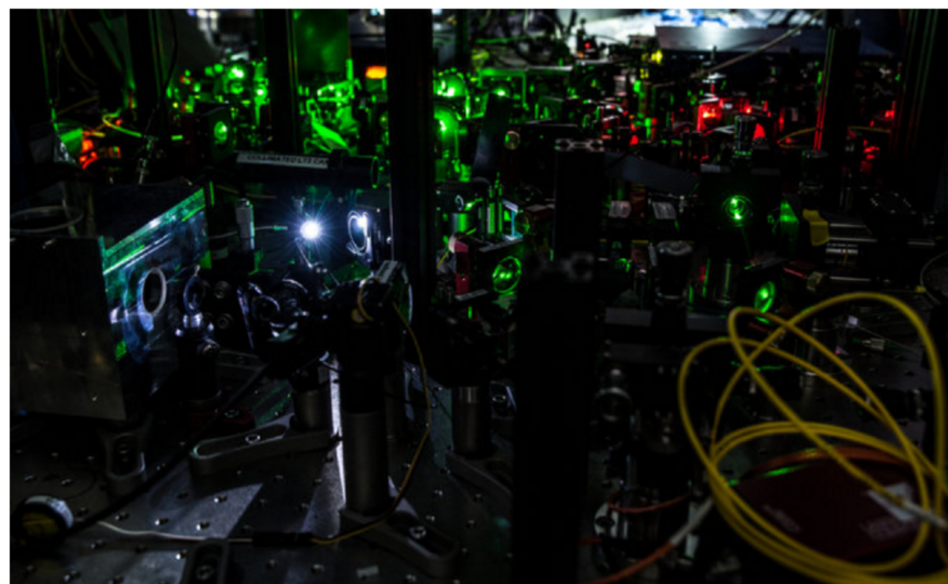
In a landmark study, scientists at Delft University of Technology in the Netherlands reported that they had conducted an experiment that they say proved one of the most fundamental claims of quantum theory — that objects separated by great distance can instantaneously affect each other's behavior.

The finding is another blow to one of the bedrock principles of standard physics known as "locality," which states that an object is directly influenced only by its immediate surroundings. The Delft study, published Wednesday in the journal Nature, lends further credence to an idea that Einstein famously rejected. He said



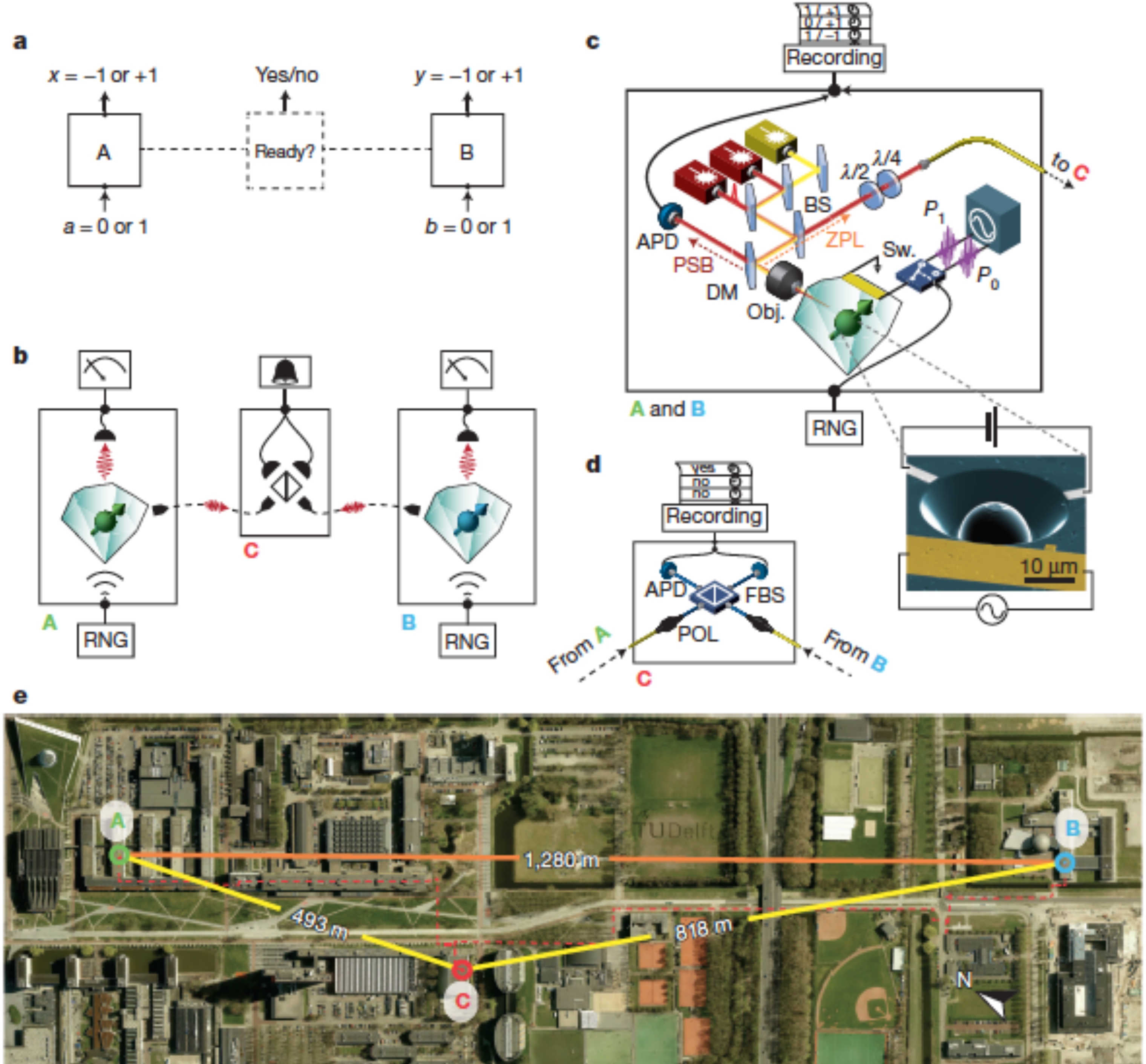
Part of the laboratory setup for an experiment at Delft University of Technology, in which two diamonds were set 1.3 kilometers apart, entangled and then shared information.
Frank Auperle/Delft University of Technology

LETTER

doi:10.1038/nature15759

Loophole-free Bell inequality violation using electron spins separated by 1.3 kilometres

B. Hensen[1,2], H. Bernien[1,2]†, A. E. Dréau[1,2], A. Reiserer[1,2], N. Kalb[1,2], M. S. Blok[1,2], J. Ruitenberg[1,2], R. F. L. Vermeulen[1,2], R. N. Schouten[1,2], C. Abellán[3], W. Amaya[3], V. Pruneri[3,4], M. W. Mitchell[3,4], M. Markham[5], D. J. Twitchen[5], D. Elkouss[1], S. Wehner[1], T. H. Taminiau[1,2] & R. Hanson[1,2]

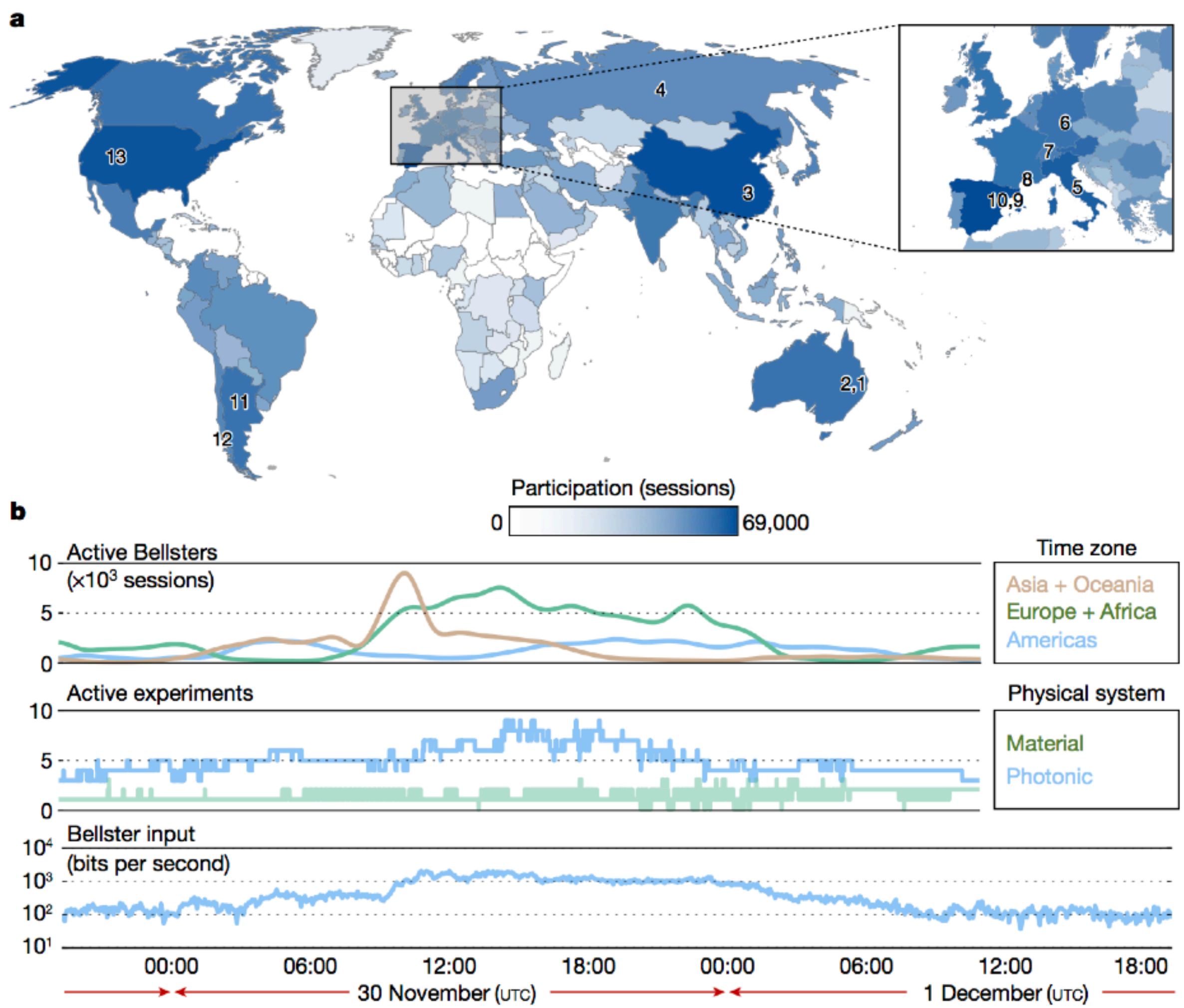

a
x = –1 or +1
Yes/no
y = –1 or +1
A
Ready?
B
a = 0 or 1
b = 0 or 1
b
A
C
B
RNG
RNG
c
Recording
λ/2
λ/4
to C
BS
APD
PSB
ZPL
P1
Sw.
P0
DM
Obj.
A and B
RNG
10 μm
d
Recording
APD
FBS
POL
From A
From B
C
e
A
B
C
1,280 m
493 m
818 m
N

https://doi.org/10.1038/s41586-018-0085-3

Challenging local realism with human choices

The BIG Bell Test Collaboration*

A Bell test is a randomized trial that compares experimental observations against the philosophical worldview of local realism[1], in which the properties of the physical world are independent of our observation of them and no signal travels faster than light. A Bell test requires spatially distributed entanglement, fast and high-efficiency detection and unpredictable measurement settings[2,3]. Although technology can satisfy the first two of these requirements[4–7], the use of physical devices to choose settings in a Bell test involves making assumptions about the physics that one aims to test. Bell himself noted this weakness in using physical setting choices and argued that human 'free will' could be used rigorously to ensure unpredictability in Bell tests[8]. Here we report a set of local-realism tests using human choices, which avoids assumptions about predictability in physics. We recruited about 100,000 human participants to play an online video game that incentivizes fast, sustained input of unpredictable selections and illustrates Bell-test methodology[9]. The participants generated 97,347,490 binary choices, which were directed via a scalable web platform to 12 laboratories on five continents, where 13 experiments tested local realism using photons[5,6], single atoms[7], atomic ensembles[10] and superconducting devices[11]. Over a 12-hour period on 30 November 2016, participants worldwide provided a sustained data flow of over 1,000 bits per second to the experiments, which used different human-generated data to choose each measurement setting. The observed correlations strongly contradict local realism and other realistic positions in bi-partite and tri-partite[12] scenarios. Project outcomes include closing the 'freedom-of-choice loophole' (the possibility that the setting choices are influenced by 'hidden variables' to correlate with the particle properties[13]), the utilization of video-game methods[14] for rapid collection of human-generated randomness, and the use of networking techniques for global participation in experimental science.



Nature **557**, 212 (2018)

https://doi.org/10.1038/s41586-018-0085-3

Challenging local realism with human choices

Nature **557**, 212 (2018)

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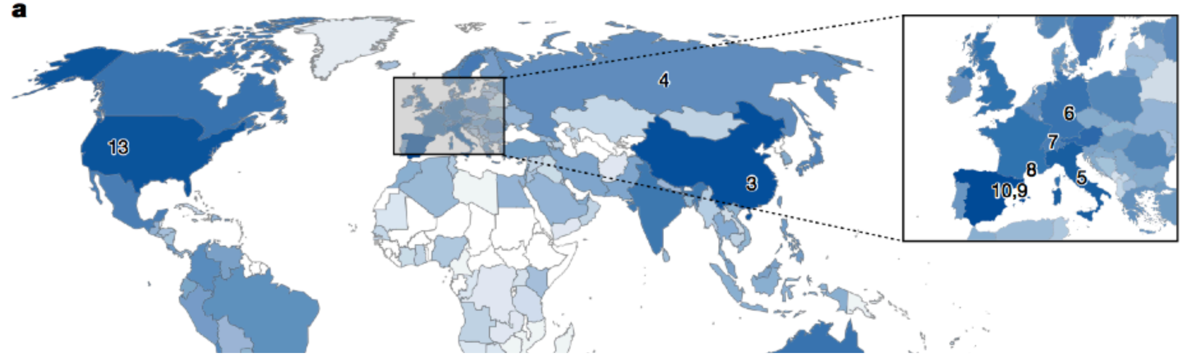


Table 1 | Experiments carried out as part of the BBT, ordered by longitude, from East to West

Experiment	Lead Institution	Location	Entangled system	Rate (bps)	Inequality	Result	Stat. sig
(1)	Griffith University	Brisbane, Australia	Photon polarization	4	$S_{16} \leq 0.511$	$S_{16}=0.965\pm0.008$	57σ
(2)	EQUS	Brisbane, Australia	Photon polarization	3	$\|S\| \leq 2$	$S_{AB}=2.75\pm0.05$	15σ
						$S_{BC}=2.79\pm0.05$	16σ
(3)	USTC	Shanghai, China	Photon polarization	103	PRBLG[30]	$I_0=0.10\pm0.05$	N/A
(4)	IQOQI	Vienna, Austria	Photon polarization	1.61×10^3	$\|S\| \leq 2$	$S_{HRN}=2.639\pm0.008$	81σ
						$S_{QRN}=2.643\pm0.006$	116σ
(5)	Sapienza	Rome, Italy	Photon polarization	0.62	$B \leq 1$	$B=1.225\pm0.007$	32σ
(6)	LMU	Munich, Germany	Photon–atom	1.7	$\|S\| \leq 2$	$S_{HRN}=2.427\pm0.0223$	19σ
						$S_{QRN}=2.413\pm0.0223$	18.5σ
(7)	ETHZ	Zurich, Switzerland	Transmon qubit	3×10^3	$\|S\| \leq 2$	$S=2.3066\pm0.0012$	$P<10^{-99}$
(8)	INPHYNI	Nice, France	Photon time bin	2×10^3	$\|S\| \leq 2$	$S=2.431\pm0.003$	140σ
(9)	ICFO	Barcelona, Spain	Photon–atom ensemble	125	$\|S\| \leq 2$	$S=2.29\pm0.10$	2.9σ
(10)	ICFO	Barcelona, Spain	Photon multi-frequency bin	20	$\|S\| \leq 2$	$S=2.25\pm0.08$	3.1σ
(11)	CITEDEF	Buenos Aires, Argentina	Photon polarization	1.02	$\|S\| \leq 2$	$S=2.55\pm0.07$	7.8σ
(12)	UdeC	Concepción, Chile	Photon time bin	5.2×10^4	$\|S\| \leq 2$	$S=2.43\pm0.02$	20σ
(13)	NIST	Boulder, USA	Photon polarization	10^5	$K \leq 0$	$K=(1.65\pm0.20)\times10^{-4}$	8.7σ

Descriptions of the experiments are given in Supplementary Information. Stat. sig., statistical significance; indicates the number of standard deviations assuming independent and identically distributed trials, unless otherwise indicated. Rate indicates the peak rate (in bits per second, bps) at which bits were used by the experiments. Owing to the limited rate of Bellster input, some experiments had dead times. B, K, S, S_{AB}, S_{BC}, S_{HRN} and S_{QRN} indicate Bell parameters for the respective experiments and S_{16} is the steering parameter (see Supplementary Information). I_0 indicates the minimum Pütz–Rosset–Barnea–Liang–Gisin measure of setting–choice independence, consistent with the observed BIV.

USTC, University of Science and Technology of China; EQUS, Centre for Engineered Quantum Systems; IQOQI, Institute for Quantum Optics and Quantum Information; INFYNI, Institut de Physique de Nice; ICFO, Institut de Ciencies Fotoniques; LMU, Ludwig-Maximilians-Universität; ETHZ, ETH Zurich; CITEDEF, Institute of Scientific and Technical Research for Defence; UdeC, University of Concepción; NIST, National Institute of Standards and Technology.

La seconda rivoluzione quantistica…

l'informazione quantistica

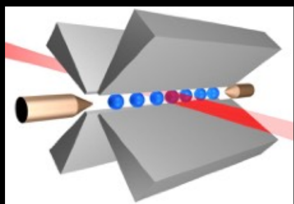
$$\alpha|0\rangle + \beta|1\rangle$$

Quantum bit (qubit)

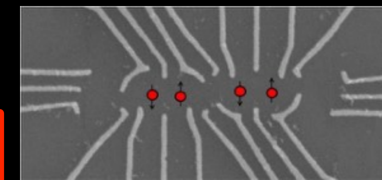
Programma Europeo di Ricerca sulle Quantum Technologies

Implementation of Quantum Information

Trapped ions



Spin qubit



Single photons

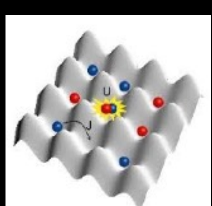
Quantum computation

Quantum simulation

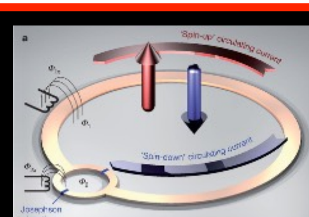
Quantum communication

Quantum metrology

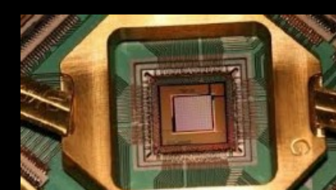
Foundations of Quantum Mechanics



Cold atoms in optical lattices

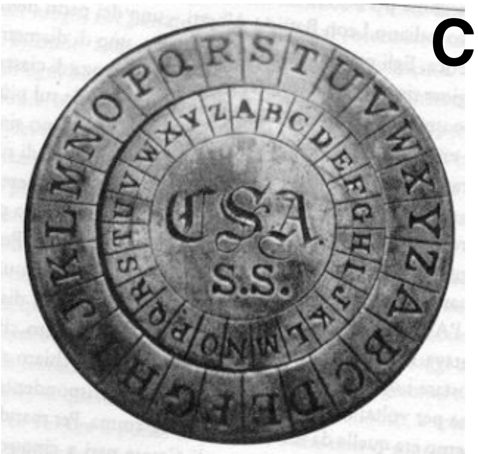


Superconducting qubits



Quantum annealers

Crittografia Classica



Cifrario di Cesare:
I sec a.C

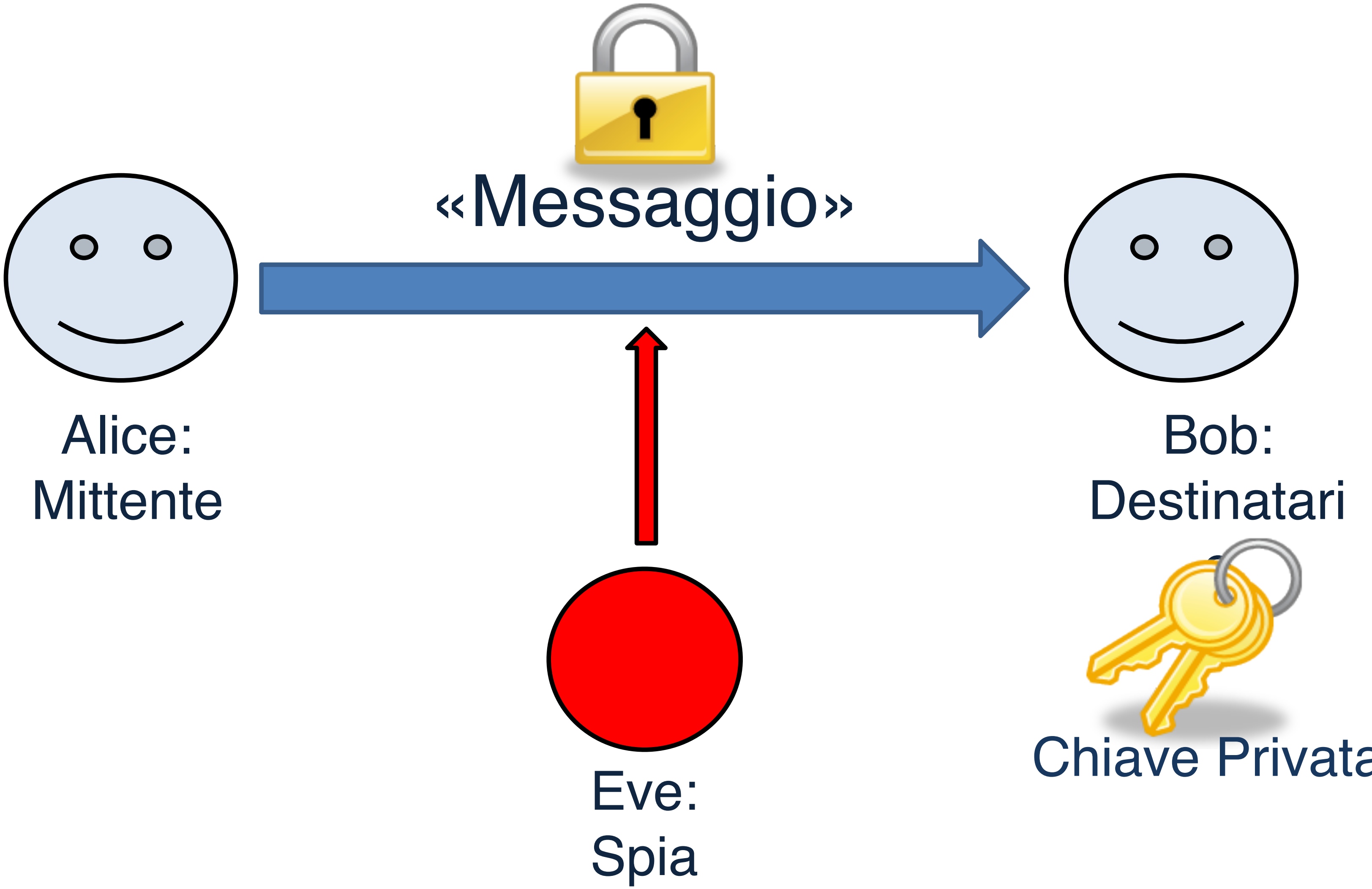
Manoscritto di Voynich:
XV sec d.C

ENIGMA:
1940 II guerra mondiale

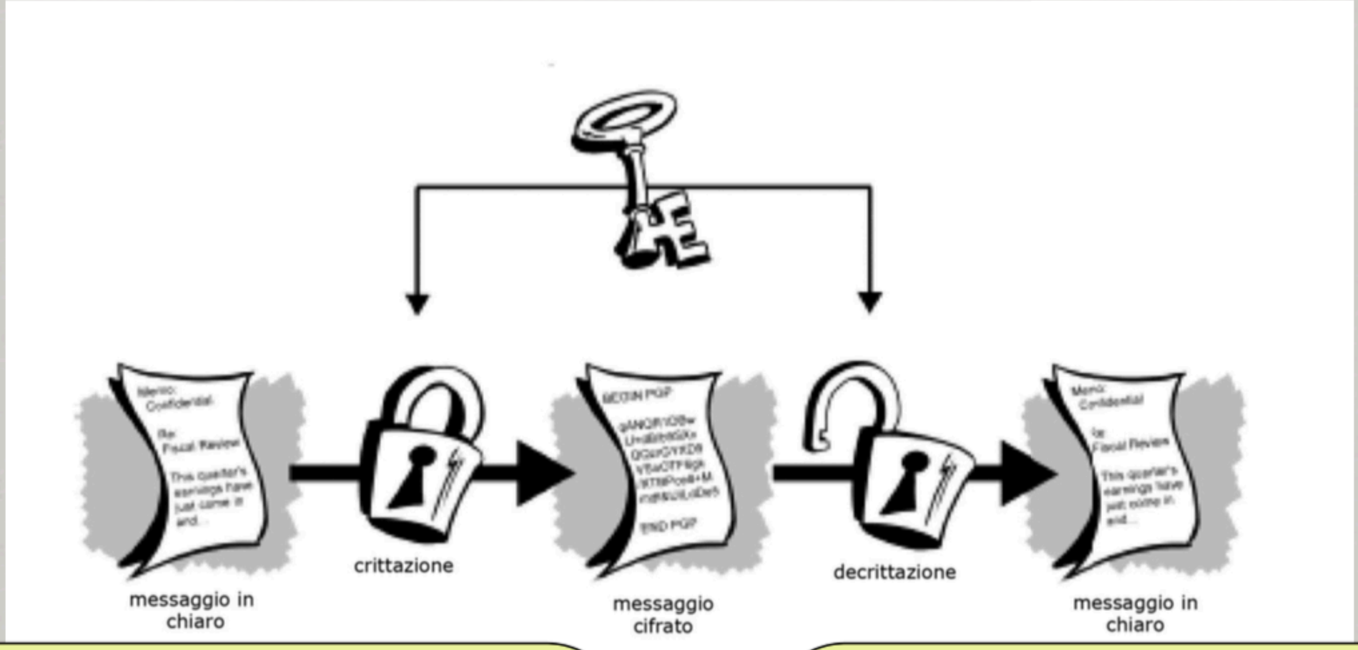
Internet:
1990 - oggi

La Crittografia Classica: Chiave Privata

Protocollo a chiave privata: scambio di chiave tramite canale sicuro!



Crittografia classica



Crittografia a chiave privata

Chiave di crittazione e chiave di decrittazione coincidono

La sua sicurezza è basata sulla segretezza della chiave

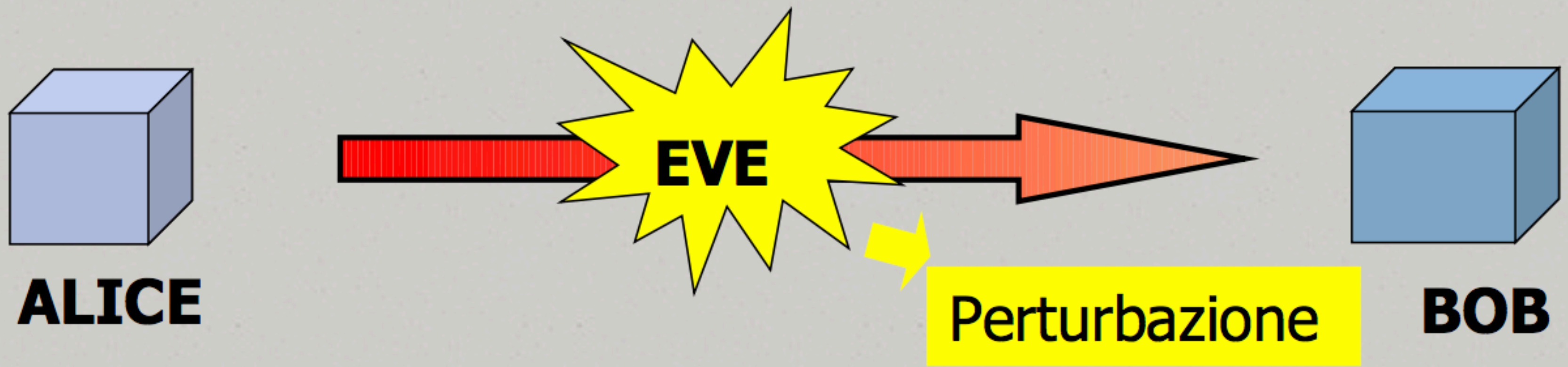
Crittografia a chiave pubblica

Chiave di crittazione pubblica
Chiave di decrittazione segreta

La sua sicurezza è basata sulla difficoltà di risolvere un problema matematico

Crittografia quantistica: l'idea

Affidare la sicurezza della trasmissione alle leggi della fisica: *"Non è possibile effettuare una misura su un sistema quantistico senza perturbarlo"*

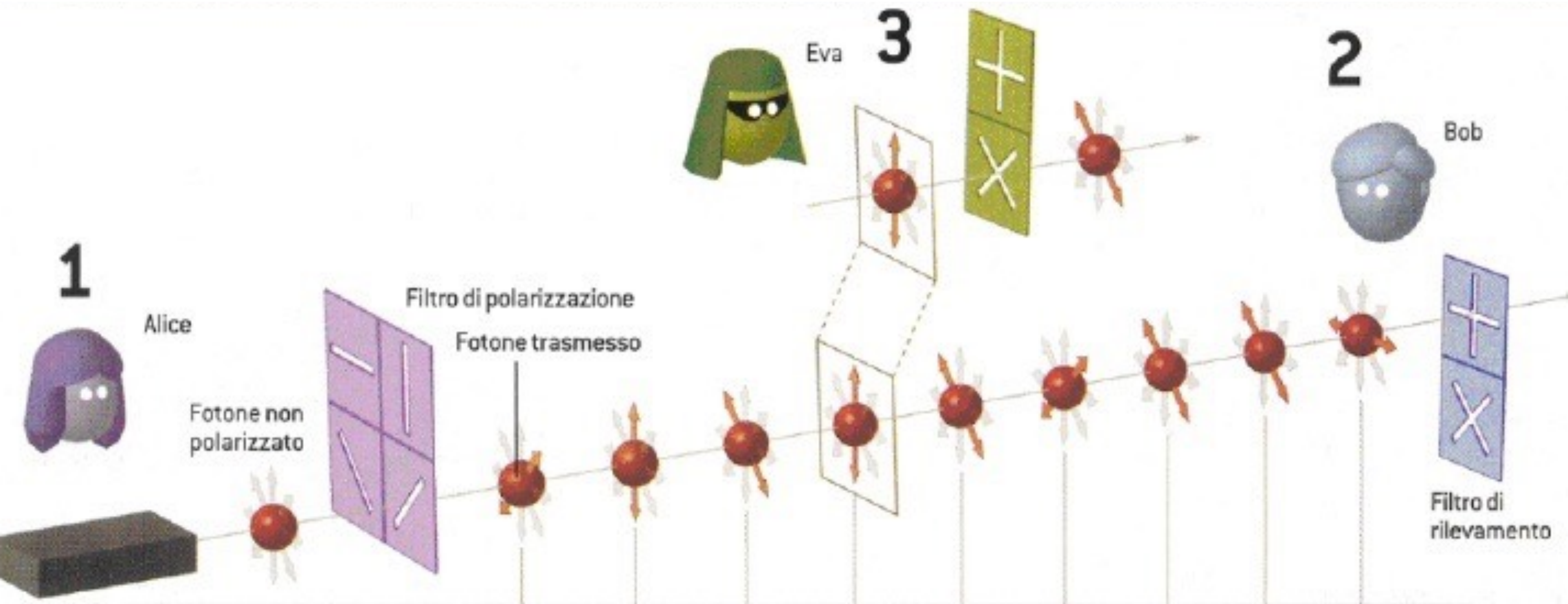


Spionaggio $\Longrightarrow$ Misura $\Longrightarrow$ Perturbazione

Scopo della crittografia quantistica: distribuire una chiave segreta tra due utenti da usare come one-time pad

Nessuna perturbazione $\Longrightarrow$ Chiave sicura

Crittografia quantistica



Sequenza di bit di Alice:	0	0	1	0	1	0	1	1	1
Schema di filtraggio di Alice:	/	|	\	|	\	/	\	\	—
Schema di rilevamento di Bob:	+	+	+	+	×	+	+	×	+
Misurazione dei bit di Bob:	1	0	1	0	1	0	0	1	1
Sequenza ottenuta (chiave):	–	0	–	0	1	–	–	1	1

Micius: "Quantum Sputnik"

ScienceNews
MAGAZINE OF THE SOCIETY FOR SCIENCE & THE PUBLIC

MENU TOPICS BLOGS

YEAR IN REVIEW QUANTUM PHYSICS, 2017 TOP 10

A quantum communications satellite proved its potential 2017

Intercontinental video call sets distance record for cryptography via entangled ph

BY EMILY CONOVER 8:28AM, DECEMBER 13, 2017

Magazine issue: Vol. 192, No. 11, December 23, 2017, p. 27

Science & Environment

China's quantum satellite in big leap

By Roland Pease
BBC Radio Science Unit

INSIDE SCIENCE Reliable news for an expanding universe

CREATURE CULTURE EARTH HUMAN PHYSICS SPACE SPORTS TECHNOLOGY

Is China the Leader in Quantum Communications?

Chinese scientists have built two major quantum infrastructure projects, and the race is on to take the next step.

TECHNOLOGY

Friday, January 19, 2018 - 10:30

Science Home News Journals Topics Careers

China's quantum satellite achieves 'spooky action' at record distance

By Gabriel Popkin | Jun. 15, 2017 , 2:

The Economist Topics Current edition More

Keeping telecommunications secret

The first quantum-cryptographic satellite network will be Chinese

Quantum cryptography's early birds

Micius Quantum Communication Satellite

Micius was launched aboard Long March 2D rocket in August 2016. Image: courtesy of Xinhua/Jin Liwang.

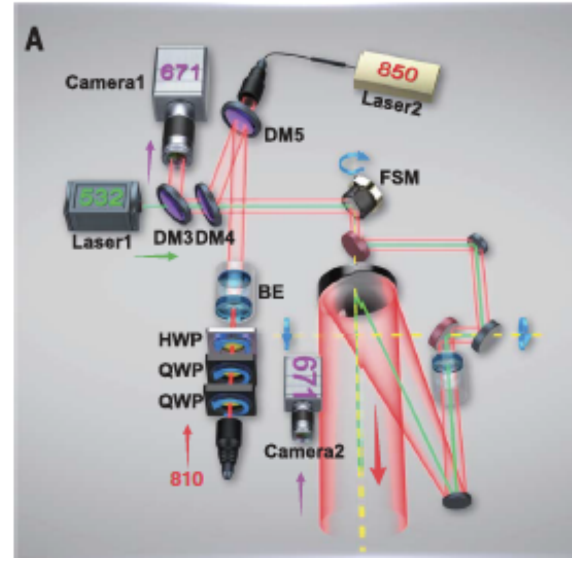
State-of-the-art in Satellite-based quantum key distribution

RESEARCH ARTICLE

QUANTUM OPTICS   Yin *et al.*, *Science* **356**, 1140–1144 (2017)   16 June 2017

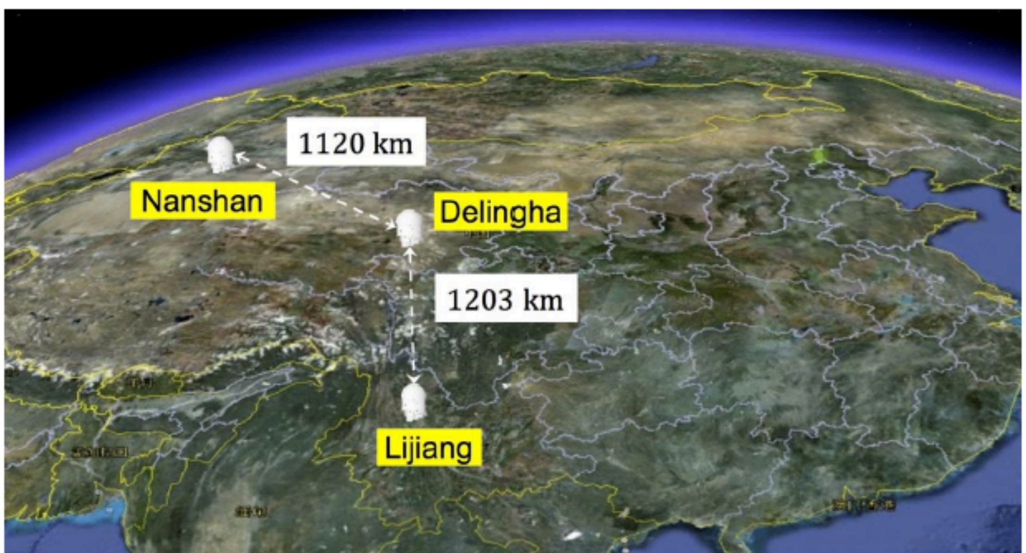
Satellite-based entanglement distribution over 1200 kilometers

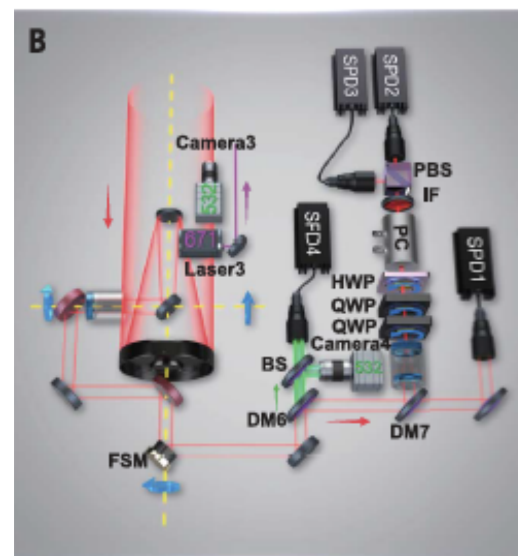
Juan Yin,[1,2] Yuan Cao,[1,2] Yu-Huai Li,[1,2] Sheng-Kai Liao,[1,2] Liang Zhang,[2,3] Ji-Gang Ren,[1,2] Wen-Qi Cai,[1,2] Wei-Yue Liu,[1,2] Bo Li,[1,2] Hui Dai,[1,2] Guang-Bing Li,[1,2] Qi-Ming Lu,[1,2] Yun-Hong Gong,[1,2] Yu Xu,[1,2] Shuang-Lin Li,[1,2] Feng-Zhi Li,[1,2] Ya-Yun Yin,[1,2] Zi-Qing Jiang,[3] Ming Li,[3] Jian-Jun Jia,[3] Ge Ren,[4] Dong He,[4] Yi-Lin Zhou,[5] Xiao-Xiang Zhang,[6] Na Wang,[7] Xiang Chang,[8] Zhen-Cai Zhu,[5] Nai-Le Liu,[1,2] Yu-Ao Chen,[1,2] Chao-Yang Lu,[1,2] Rong Shu,[2,3] Cheng-Zhi Peng,[1,2]* Jian-Yu Wang,[2,3]* Jian-Wei Pan[1,2]*



Distribution of entanglement (Bell's inequality)
air-to-ground via two-link satellite

sender module





receiver module

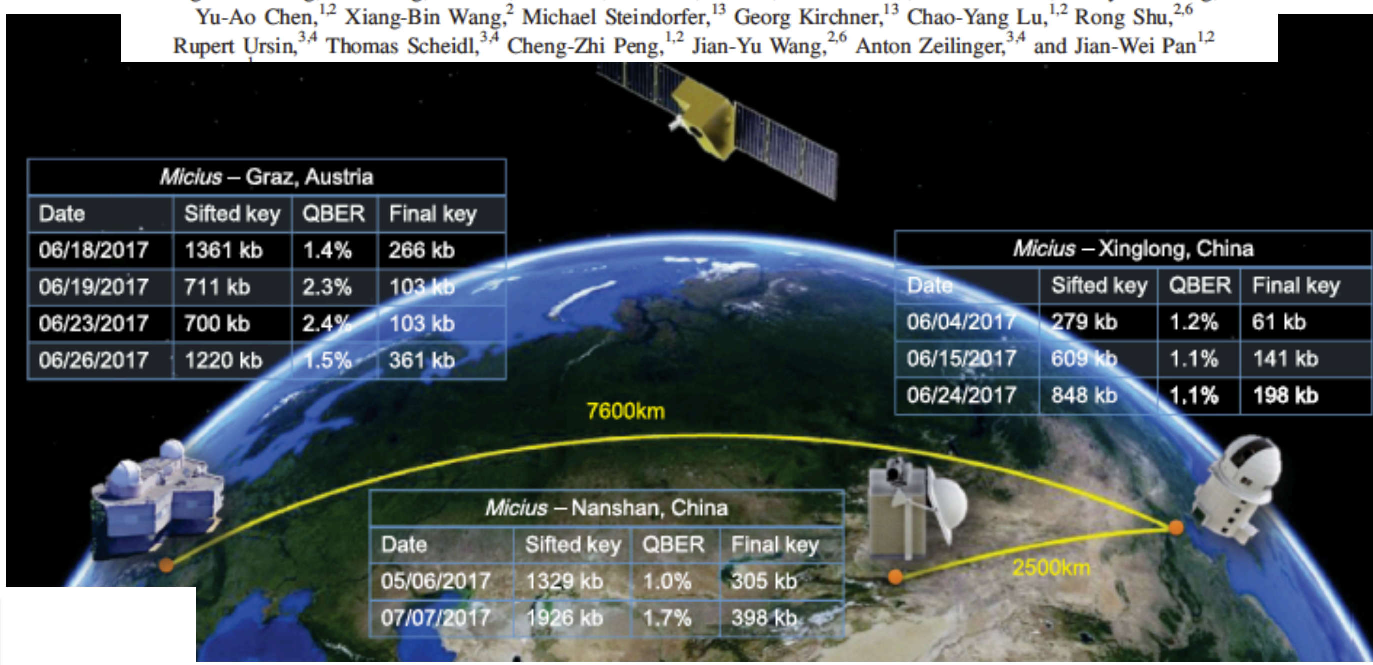
State-of-the-art in Satellite-based quantum key distribution

PHYSICAL REVIEW LETTERS **120**, 030501 (2018)

Editors' Suggestion | Featured in Physics

Satellite-Relayed Intercontinental Quantum Network

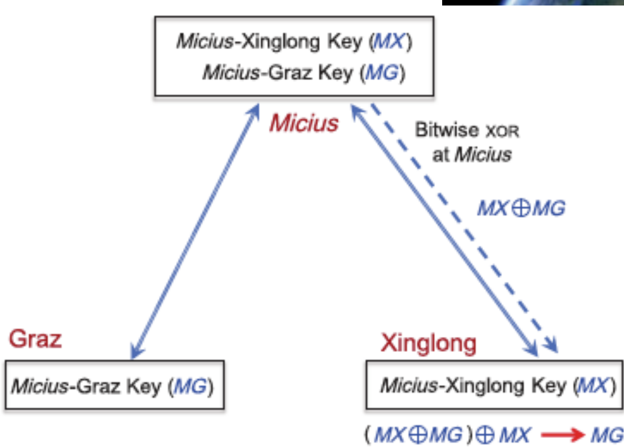
Sheng-Kai Liao,[1,2] Wen-Qi Cai,[1,2] Johannes Handsteiner,[3,4] Bo Liu,[4,5] Juan Yin,[1,2] Liang Zhang,[2,6] Dominik Rauch,[3,4] Matthias Fink,[4] Ji-Gang Ren,[1,2] Wei-Yue Liu,[1,2] Yang Li,[1,2] Qi Shen,[1,2] Yuan Cao,[1,2] Feng-Zhi Li,[1,2] Jian-Feng Wang,[7] Yong-Mei Huang,[8] Lei Deng,[9] Tao Xi,[10] Lu Ma,[11] Tai Hu,[12] Li Li,[1,2] Nai-Le Liu,[1,2] Franz Koidl,[13] Peiyuan Wang,[13] Yu-Ao Chen,[1,2] Xiang-Bin Wang,[2] Michael Steindorfer,[13] Georg Kirchner,[13] Chao-Yang Lu,[1,2] Rong Shu,[2,6] Rupert Ursin,[3,4] Thomas Scheidl,[3,4] Cheng-Zhi Peng,[1,2] Jian-Yu Wang,[2,6] Anton Zeilinger,[3,4] and Jian-Wei Pan[1,2]

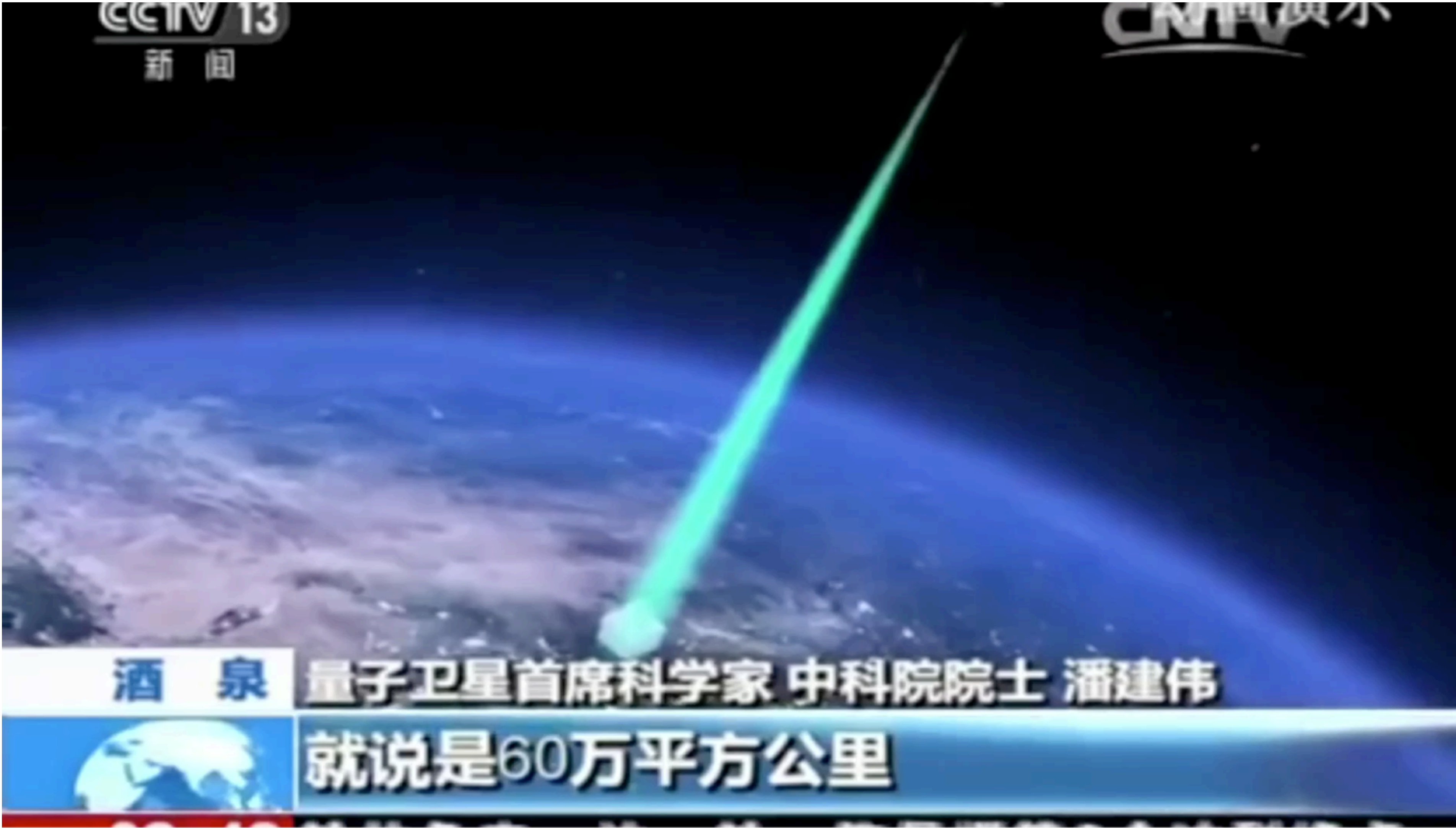


Micius – Graz, Austria			
Date	Sifted key	QBER	Final key
06/18/2017	1361 kb	1.4%	266 kb
06/19/2017	711 kb	2.3%	103 kb
06/23/2017	700 kb	2.4%	103 kb
06/26/2017	1220 kb	1.5%	361 kb

Micius – Xinglong, China			
Date	Sifted key	QBER	Final key
06/04/2017	279 kb	1.2%	61 kb
06/15/2017	609 kb	1.1%	141 kb
06/24/2017	848 kb	1.1%	198 kb

Micius – Nanshan, China			
Date	Sifted key	QBER	Final key
05/06/2017	1329 kb	1.0%	305 kb
07/07/2017	1926 kb	1.7%	398 kb




CCTV 13
新闻
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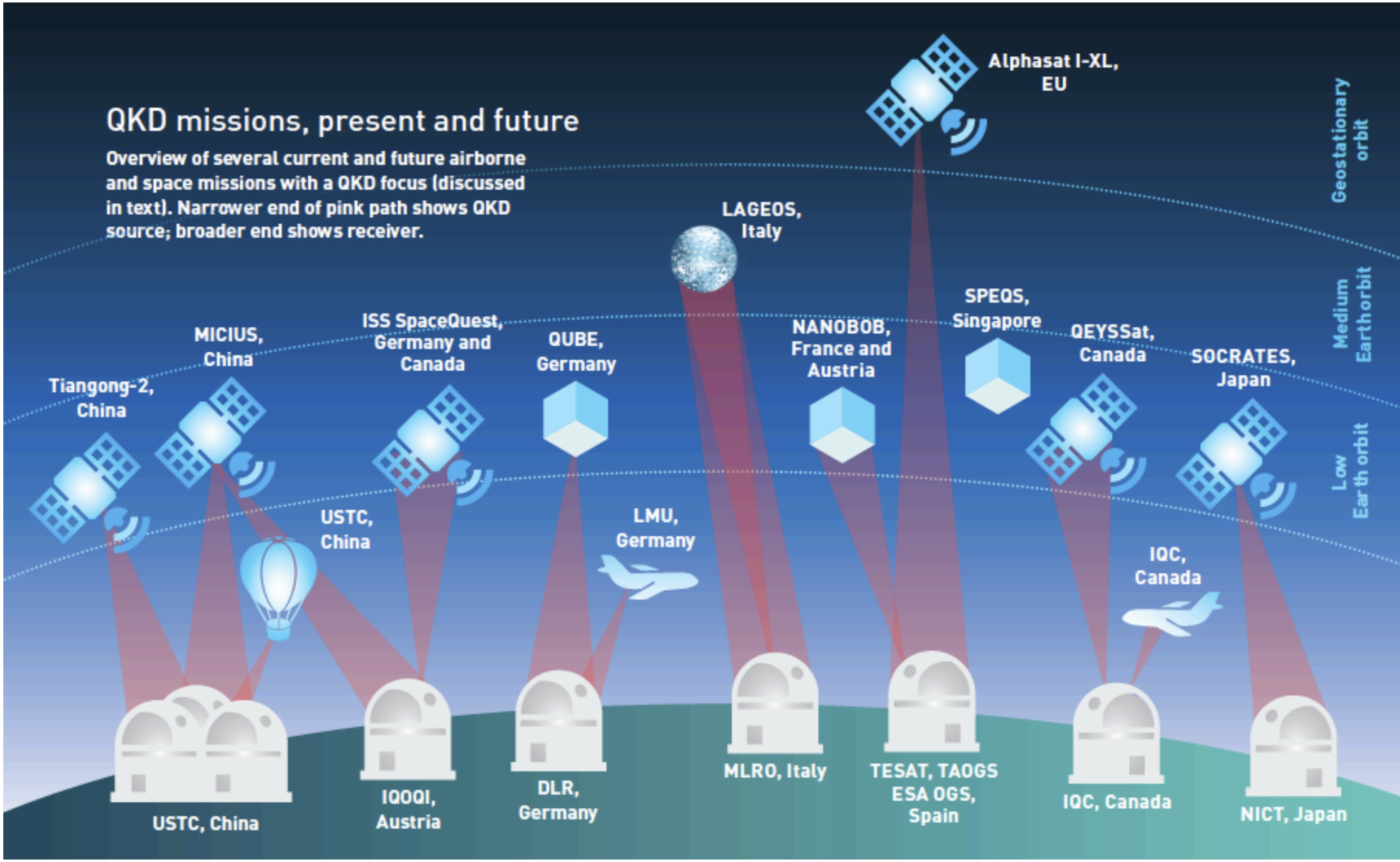
量子卫星首席科学家 中科院院士 潘建伟
就说是60万平方公里

State-of-the-art in Satellite-based quantum key distribution



Satellite-based QKD, Optics and Photonics News (2018)

QUBIT (Quantum Bit)

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

OBIETTIVO:
SFRUTTARE IL PARALLELISMO QUANTISTICO

Parallelismo quantistico

Classicamente:

Stato della computazione di 3 bits

000

Quantisticamente:

Stato della computazione di 3 qubits

$$|0\rangle_A|0\rangle_B|0\rangle_C + |0\rangle_A|0\rangle_B|1\rangle_C + |0\rangle_A|1\rangle_B|0\rangle_C + |0\rangle_A|1\rangle_B|1\rangle_C +$$
$$+ |1\rangle_A|0\rangle_B|0\rangle_C + |1\rangle_A|0\rangle_B|1\rangle_C + |1\rangle_A|1\rangle_B|0\rangle_C + |1\rangle_A|1\rangle_B|1\rangle_C$$

Golden Rules of Quantum Mechanics

1. Gli stati quantistici appartengono a spazi di Hilbert e possono esistere in stati di sovrapposizione

"quantum bit": $\alpha|0\rangle + \beta|1\rangle$

2. Una misura proiettiva su un qubit fornisce un'informazione parziale sullo stato del qubit

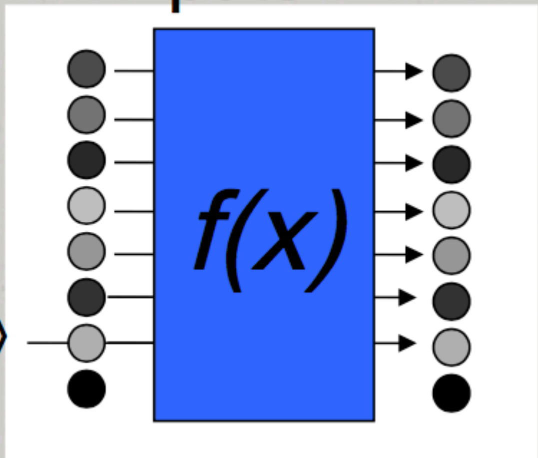
$$\alpha|0\rangle + \beta|1\rangle \quad \begin{cases} \nearrow |0\rangle & \text{Probabilità } |\alpha|^2 \\ \text{o} & \\ \searrow |1\rangle & \text{Probabilità } |\beta|^2 \end{cases}$$

Inaccessibilità di tutta l'informazione presente nel mondo quantistico

GOOD NEWS…

Computazione quantistica parallela su 2^N inputs

Example: N=3 qubits

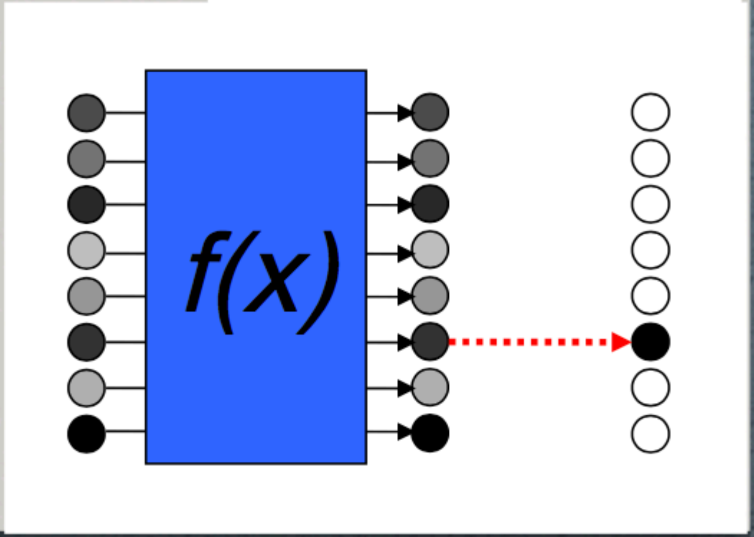


$$\Psi = a_0|000\rangle + a_1|001\rangle + a_2|010\rangle + a_3|011\rangle$$
$$+ a_4|100\rangle + a_5|101\rangle + a_6|110\rangle + a_7|111\rangle$$

…BAD NEWS…

La misura fornisce uno degli stati presenti in Ψ a seconda di $|a_i|^2$

e.g., $\Psi \Rightarrow |101\rangle$



Algoritmi quantistici

- Scopo: sfruttare il parallelismo quantistico ed estrarre l'informazione desiderata dal sistema
- Algoritmi quantistici devono essere elaborati in modo opportuno
- Per valutare la "bontà" dell'algortimo si utilizza la complessità computazionale (C)

  Risorse richieste per effettuare il calcolo (tempo, dimensioni della memoria, numero di porte logiche) in funzione della dimensione del problema

Algoritmi quantistici

- Ricerca di un elemento in un database con N elementi

classicamente $C \propto N$

quantisticamente $C \propto \sqrt{N}$

Algoritmo di Grover

- Fattorizzazione di un numero primo di dimensione L

classicamente $C \propto \exp(L)$ (non dimostrato)

quantisticamente $C \propto poly(L)$

Algoritmo di Shor

- Simulazione di un sistema quantistico con N elementi

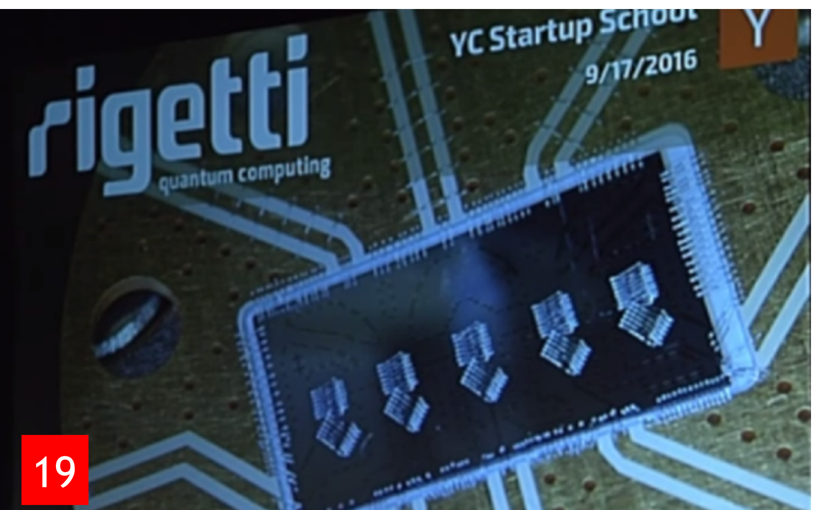
classicamente $C \propto \exp(N)$

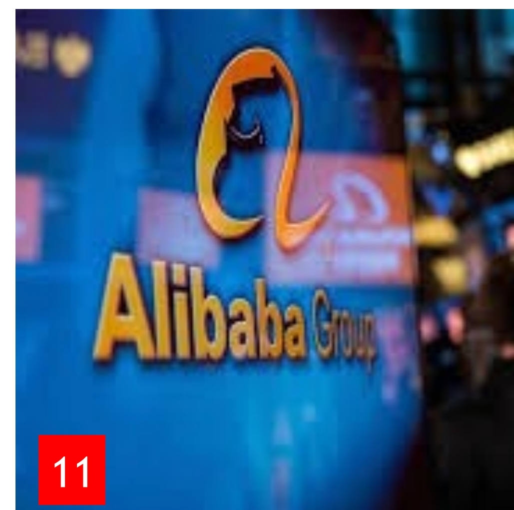
quantisticamente $C \propto poly(N)$

Quantum processors based on superconducting qubits

49

intel
Core
Q
inside

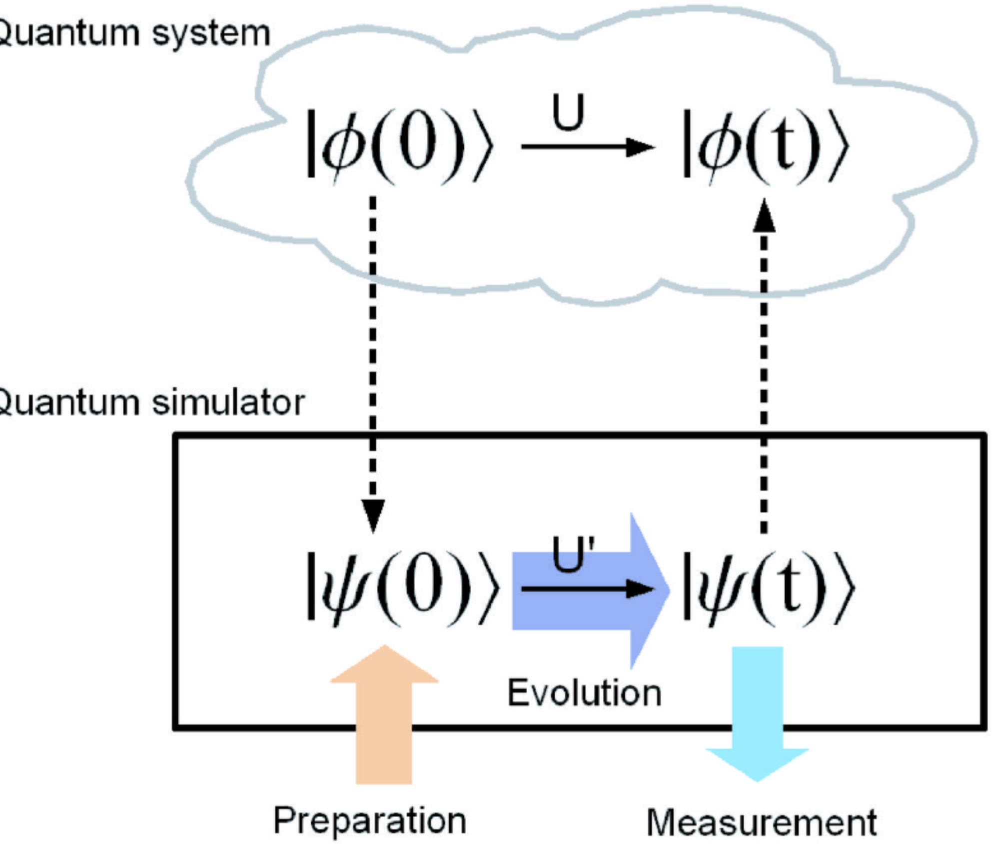


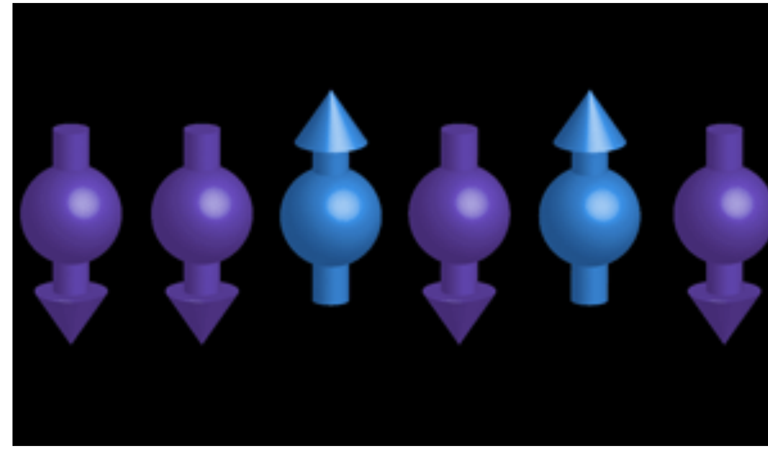


Quantum processors based on superconducting qubits

Manufacturer	Number Qubits	Release
Google	20	2017
	49	2017
	72	March 2018
IBM	5	2016
	16	2017
	17	2017
	20	2017
	50	November 2017
Intel	17	October 2017
	49	January 2018
Rigetti	19	December 2017
Alibaba	-	-

Simulatori quantistici





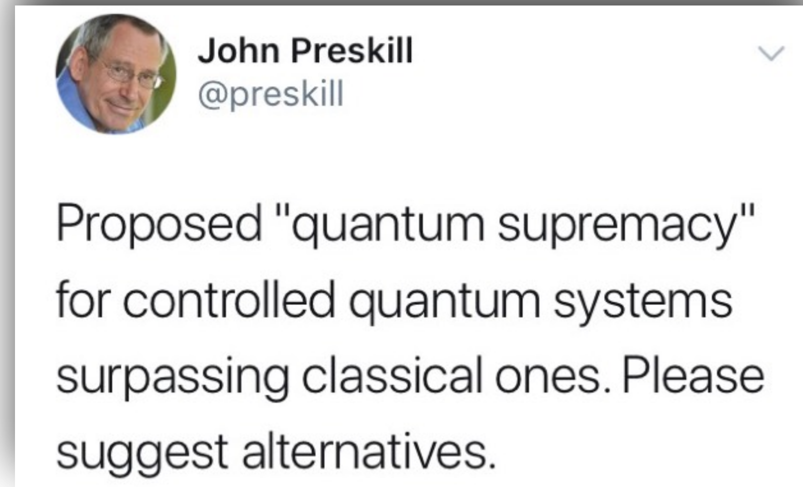
Il sistema più semplice:
catena di N spin

Dimensione spazio 2^N
Simulazione classica:
Risorse esponenziali

Lo spazio è isomorfo a quello di **N** qubit

How to achieve quantum supremacy?

(Quantum advantage)


John Preskill
@preskill

Proposed "quantum supremacy" for controlled quantum systems surpassing classical ones. Please suggest alternatives.

How to achieve quantum supremacy?

(Quantum advantage)

John Preskill
@preskill

Proposed "quantum supremacy" for controlled quantum systems surpassing classical ones. Please suggest alternatives.

Nature Special Issue on "Quantum software"

REVIEW

doi:10.1038/nature23458

Quantum computational supremacy

Aram W. Harrow[1] & Ashley Montanaro[2]

The field of quantum algorithms aims to find ways to speed up the solution of computational problems by using a quantum computer. A key milestone in this field will be when a universal quantum computer performs a computational task that is beyond the capability of any classical computer, an event known as quantum supremacy. This would be easier to achieve experimentally than full-scale quantum computing, but involves new theoretical challenges. Here we present the leading proposals to achieve quantum supremacy, and discuss how we can reliably compare the power of a classical computer to the power of a quantum computer.

[1]Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA. [2]School of Mathematics, University of Bristol, Bristol BS8 1TW, UK.

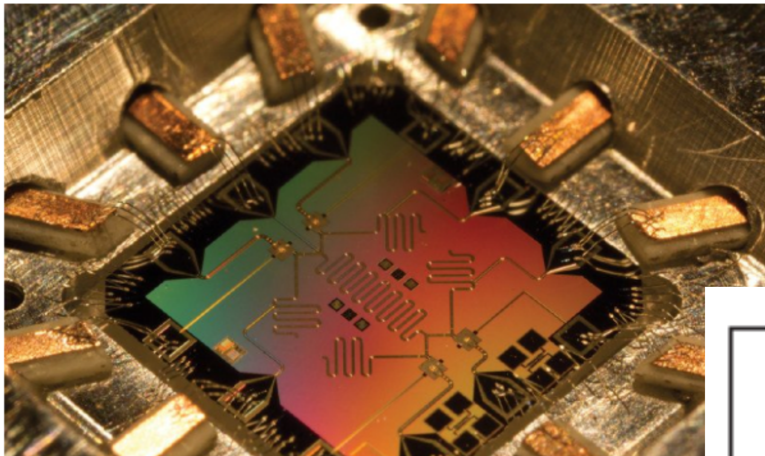
New Scientist

HOME NEWS TECHNOLOGY SPACE PHYSICS HEALTH EARTH HUMANS LIFE TOPICS EVENTS JOBS

THIS WEEK 31 August 2016

Revealed: Google's plan for quantum computer supremacy

The field of quantum computing is undergoing a rapid shake-up, and engineers at Google have quietly set out a plan to dominate



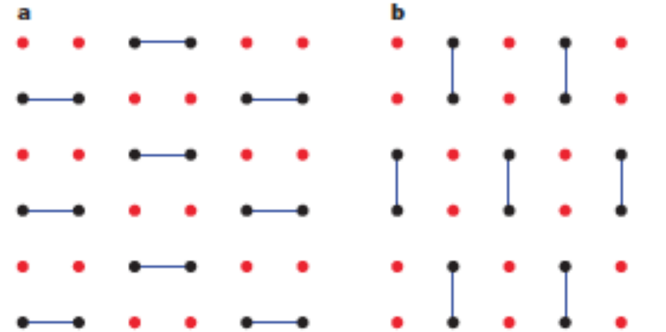


Figure 1 | A 2D lattice of superconducting qubits proposed as a way to demonstrate quantum supremacy. Panels **a** and **b** depict the condition of the lattice at two illustrative timesteps. At each timestep, two-qubit gates (blue) are applied across some pairs of neighbouring qubits, and random one-qubit gates (red) are applied on other qubits. This experiment was proposed[12] by the quantum-AI group at Google; see Box 2 for more details.

Intelligent Machines

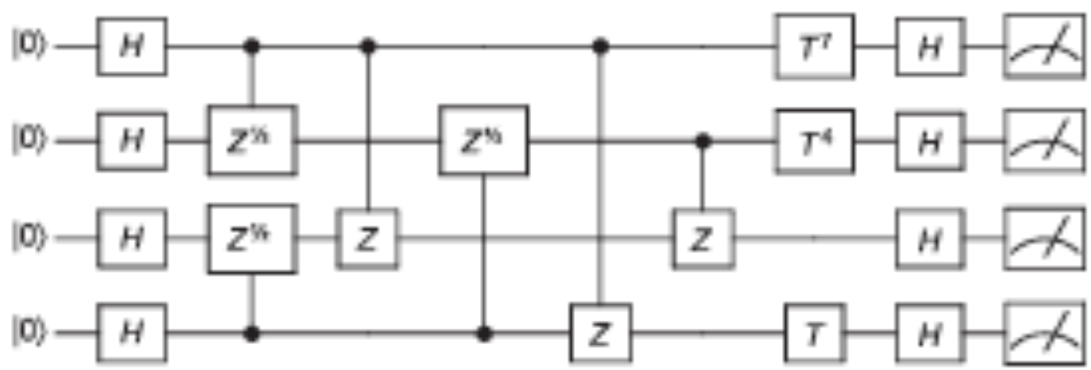
Google Reveals Blueprint for Quantum Supremacy

The ability of quantum machines to outperform classical computers is called quantum supremacy. Now Google says it has this goal firmly in its sights.

by Emerging Technology from the arXiv October 4, 2017

BOX 2

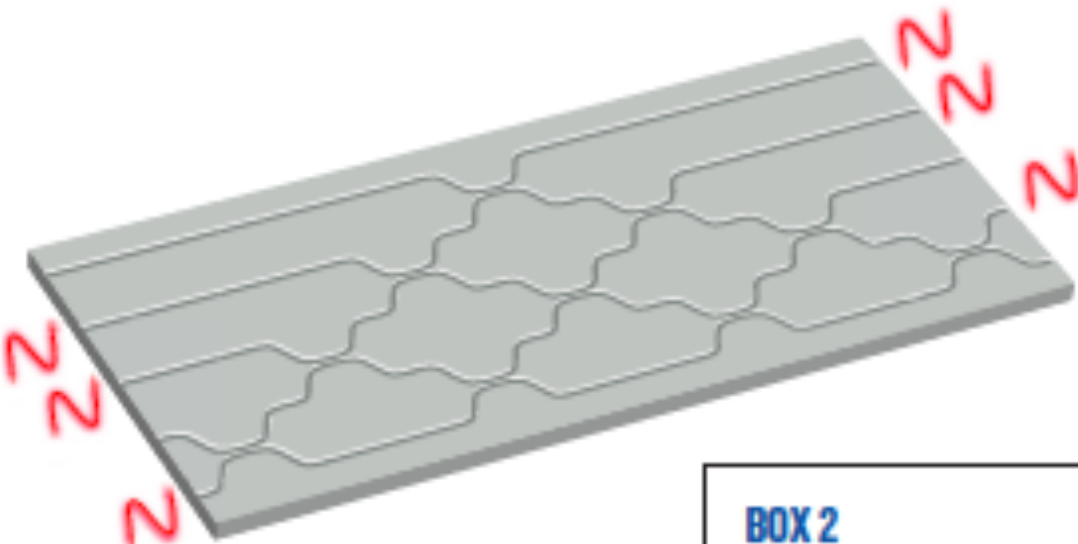
Random quantum circuits



Box 2 Figure | Example of an IQP circuit. Between two columns of Hadamard gates (H) is a collection of diagonal gates (T and controlled-$\sqrt{Z}$). Although these diagonal gates may act on the same qubit many times

BOX 1

Boson sampling



Box 1 Figure | Diagram of a boson sampling e
(red waveforms) are injected on the left-hand s
beamsplitters (shown black) that is set up to ge
transformation. Photons are detected on the ri
to a probability distribution conjectured to be h
classically. Photonic modes are represented by
are represented by two lines coming together, c
directional couplers in an integrated photonic c

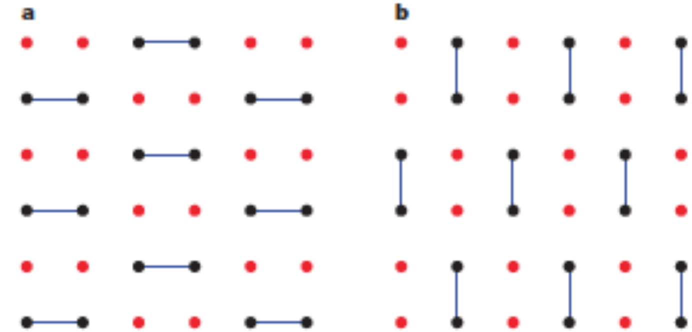
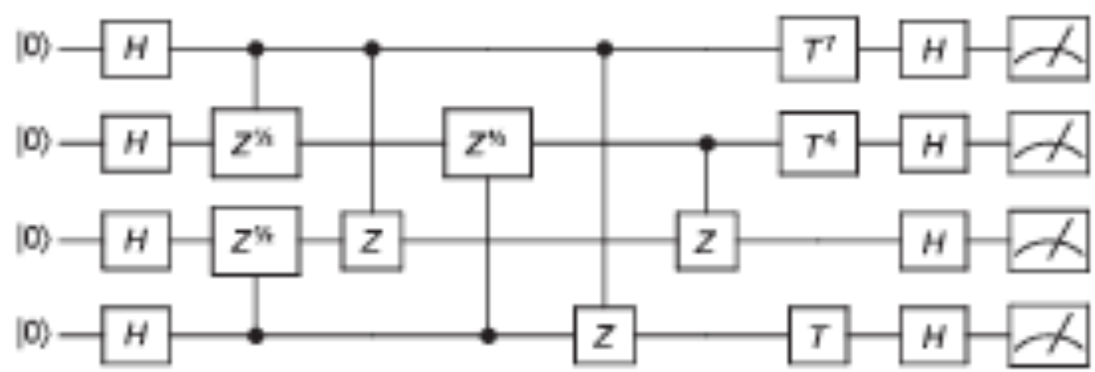


Figure 1 | A 2D lattice of superconducting qubits proposed as a way to demonstrate quantum supremacy. Panels **a** and **b** depict the condition of the lattice at two illustrative timesteps. At each timestep, two-qubit gates (blue) are applied across some pairs of neighbouring qubits, and random one-qubit gates (red) are applied on other qubits. This experiment was proposed[12] by the quantum-AI group at Google; see Box 2 for more details.

BOX 2

Random quantum circuits



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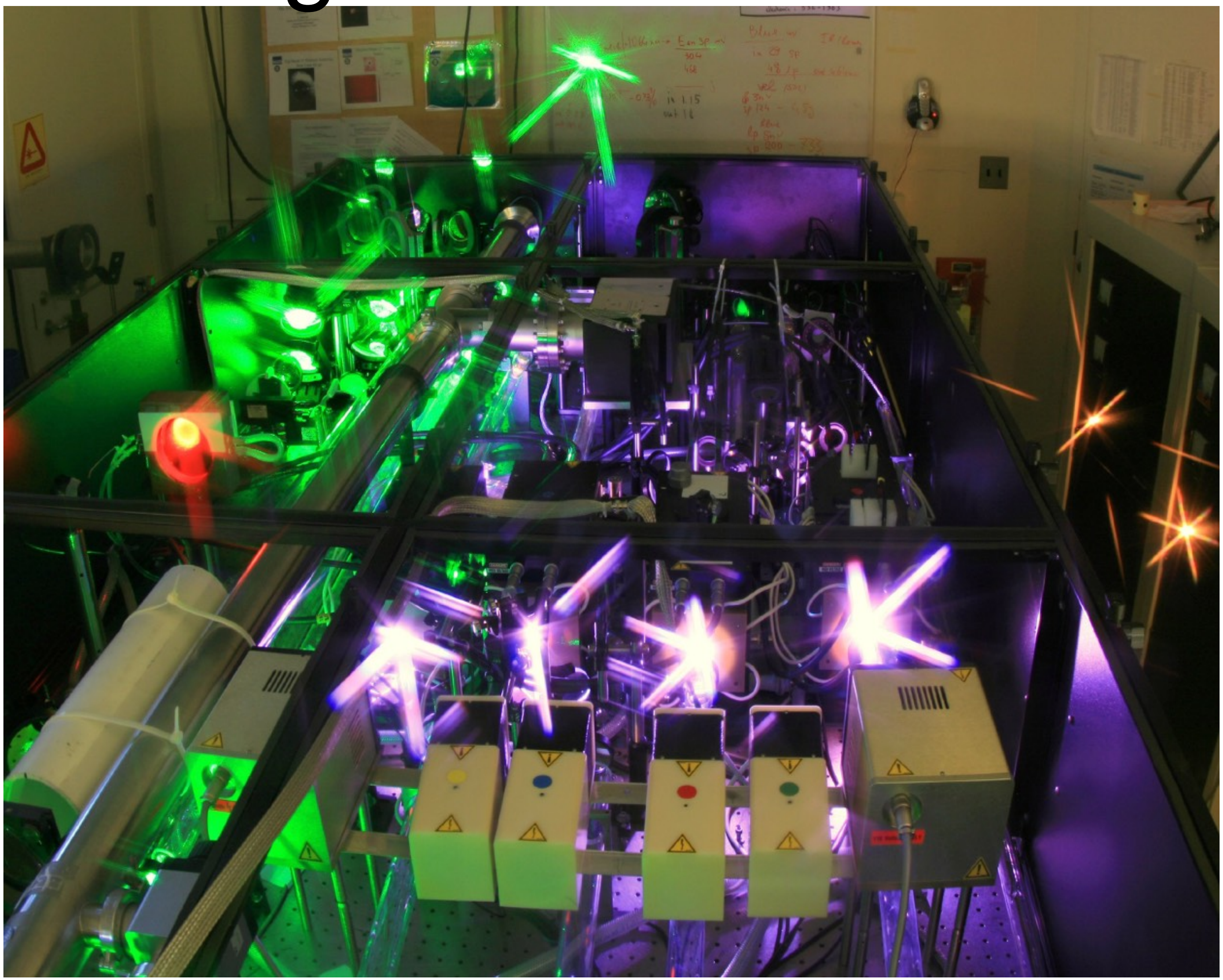
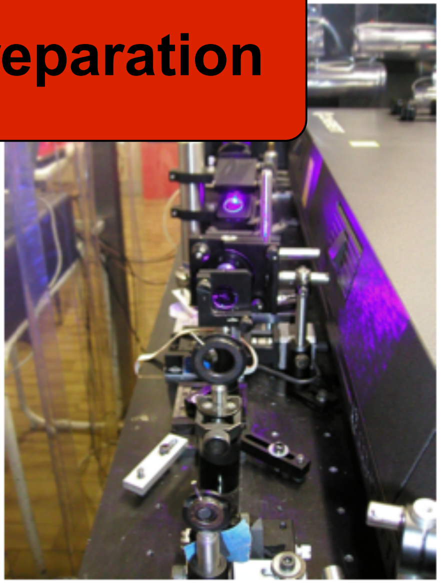
Un computer quantistico grande così??



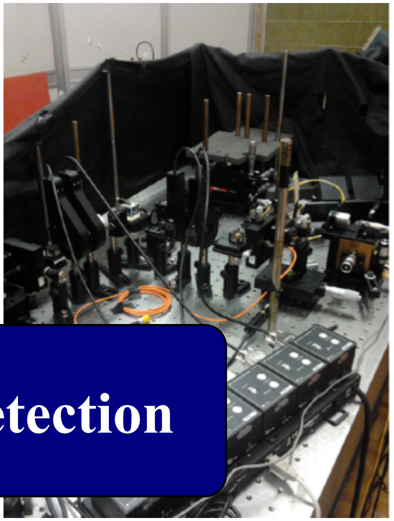
Integrated quantum photonics

Preparation



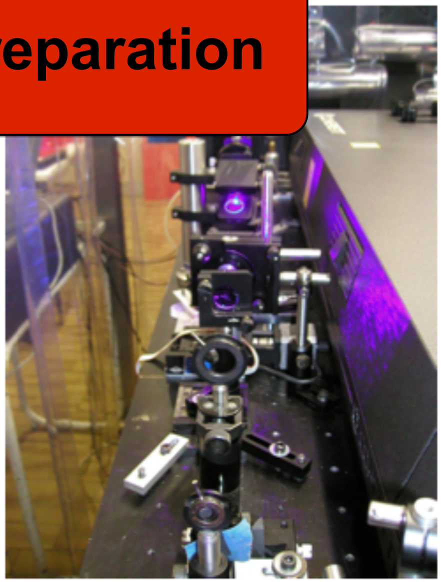
Manipulation

Detection

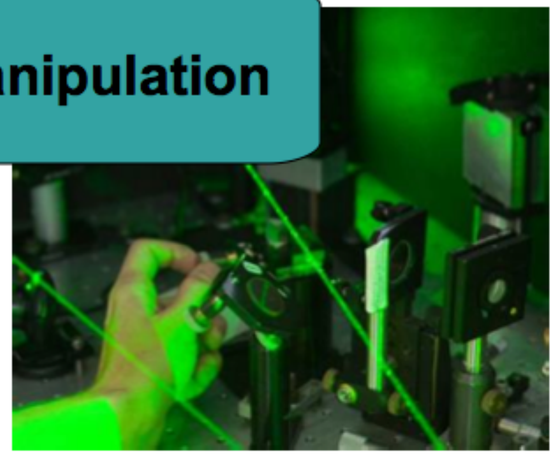


Integrated quantum photonics

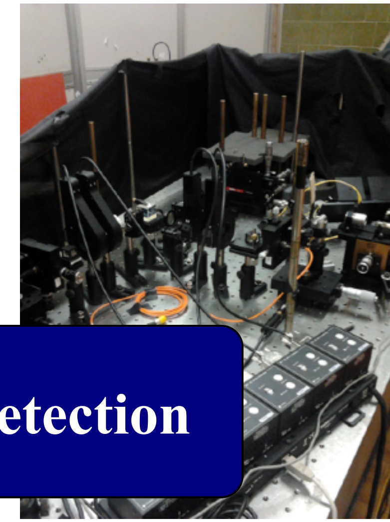
Preparation

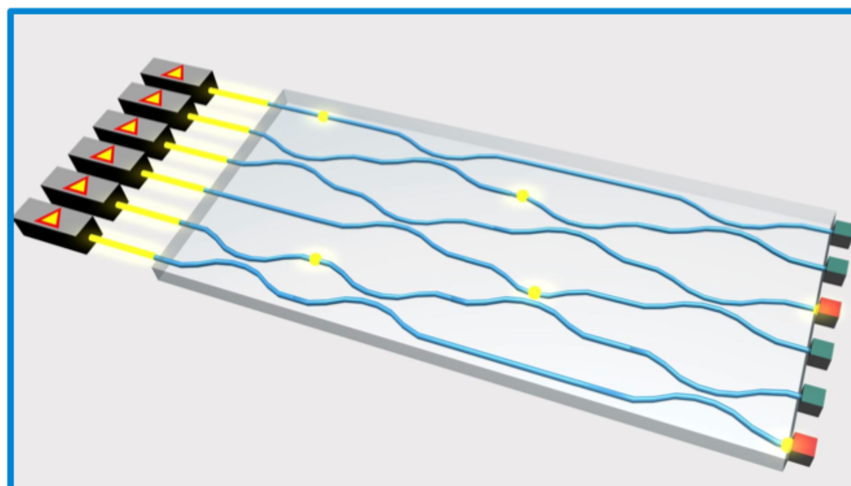


Manipulation



Detection





- Single photon sources
- Manipulation
- Single photon detectors

ON THE SAME CHIP

How to guide light inside the chip ?

From Computer Desktop Encyclopedia
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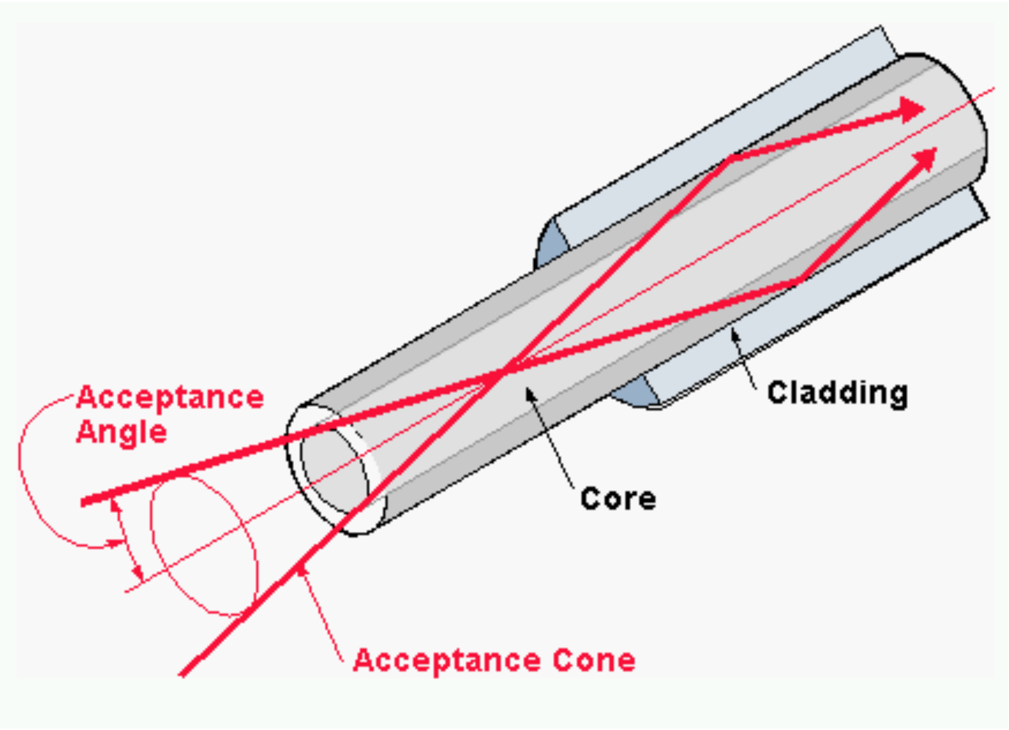
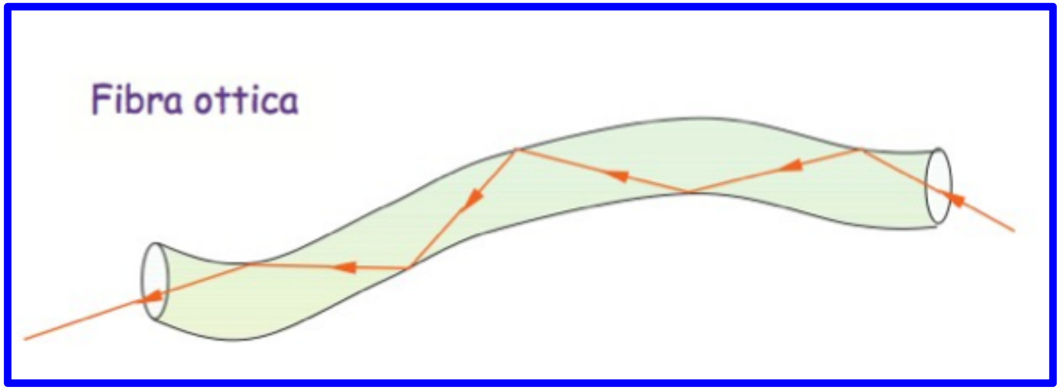
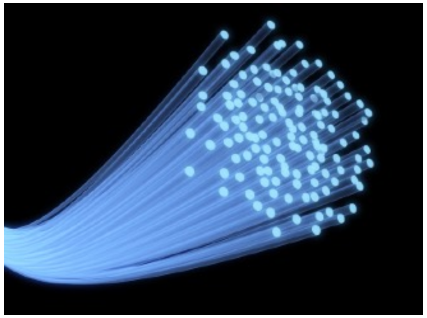


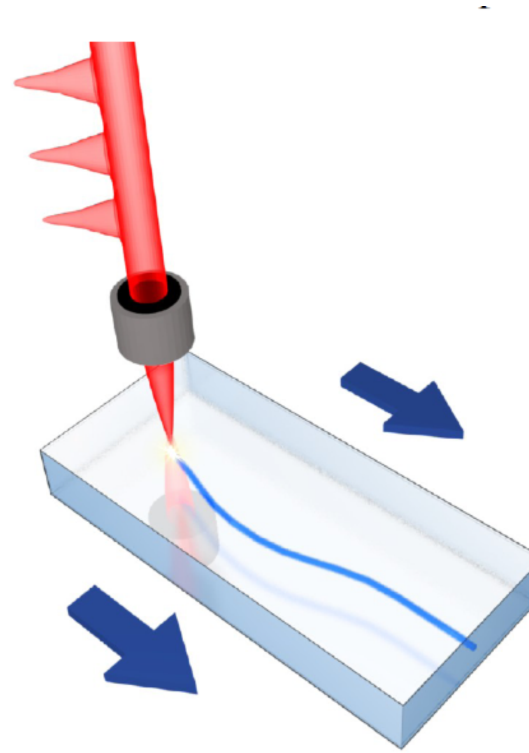
Optical fibre:

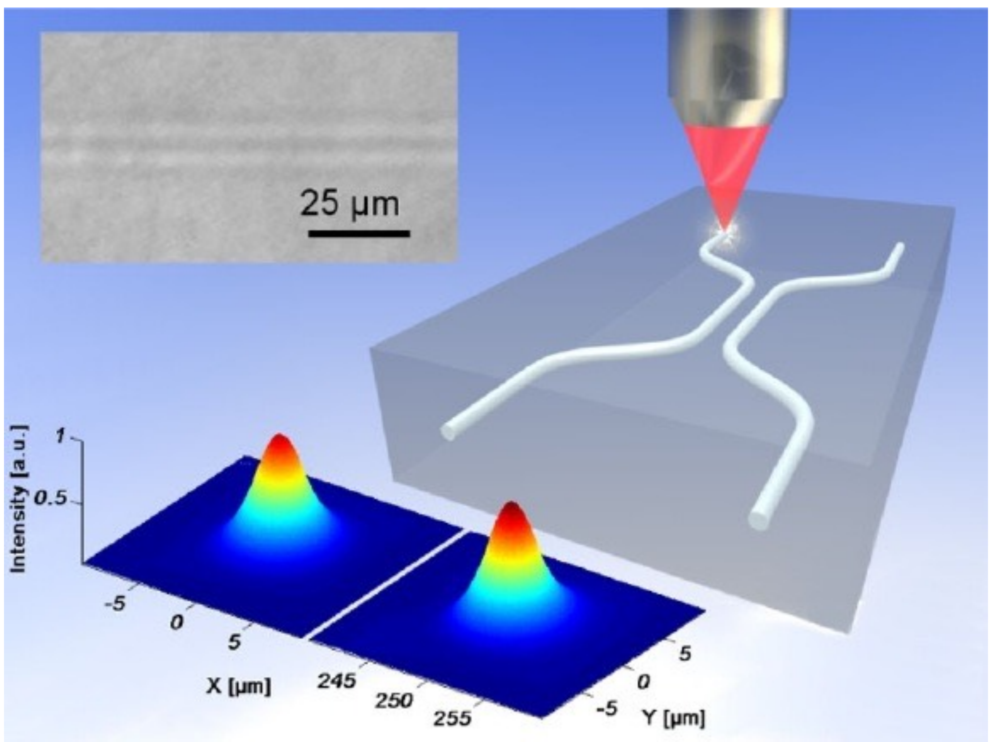
Guide the light

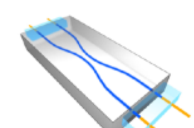




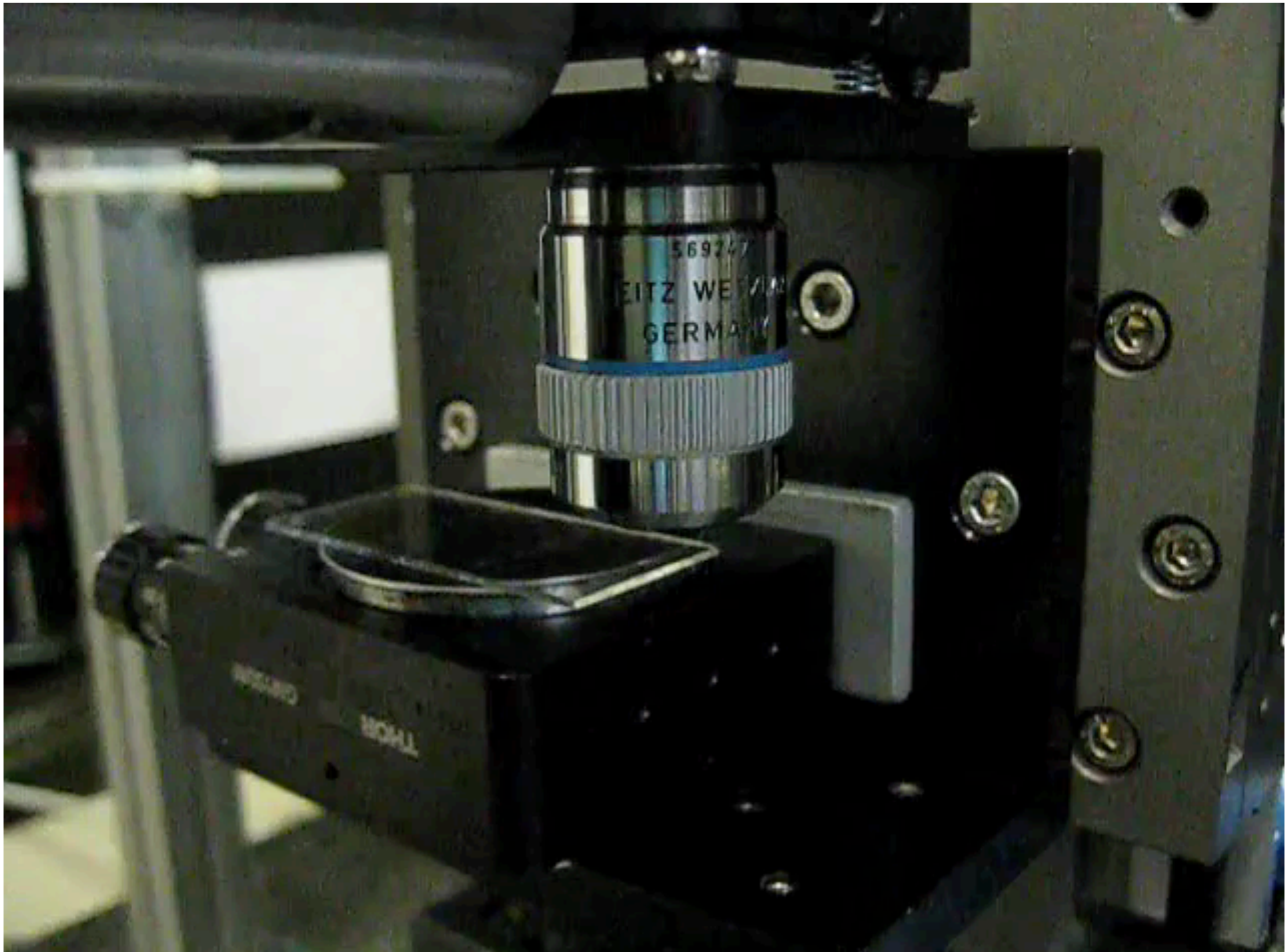
Laser written integrated circuit

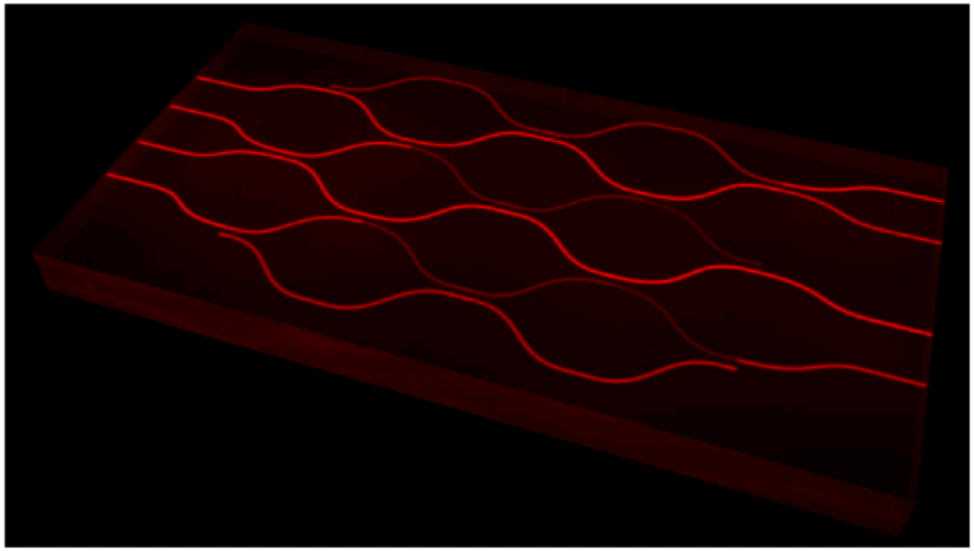


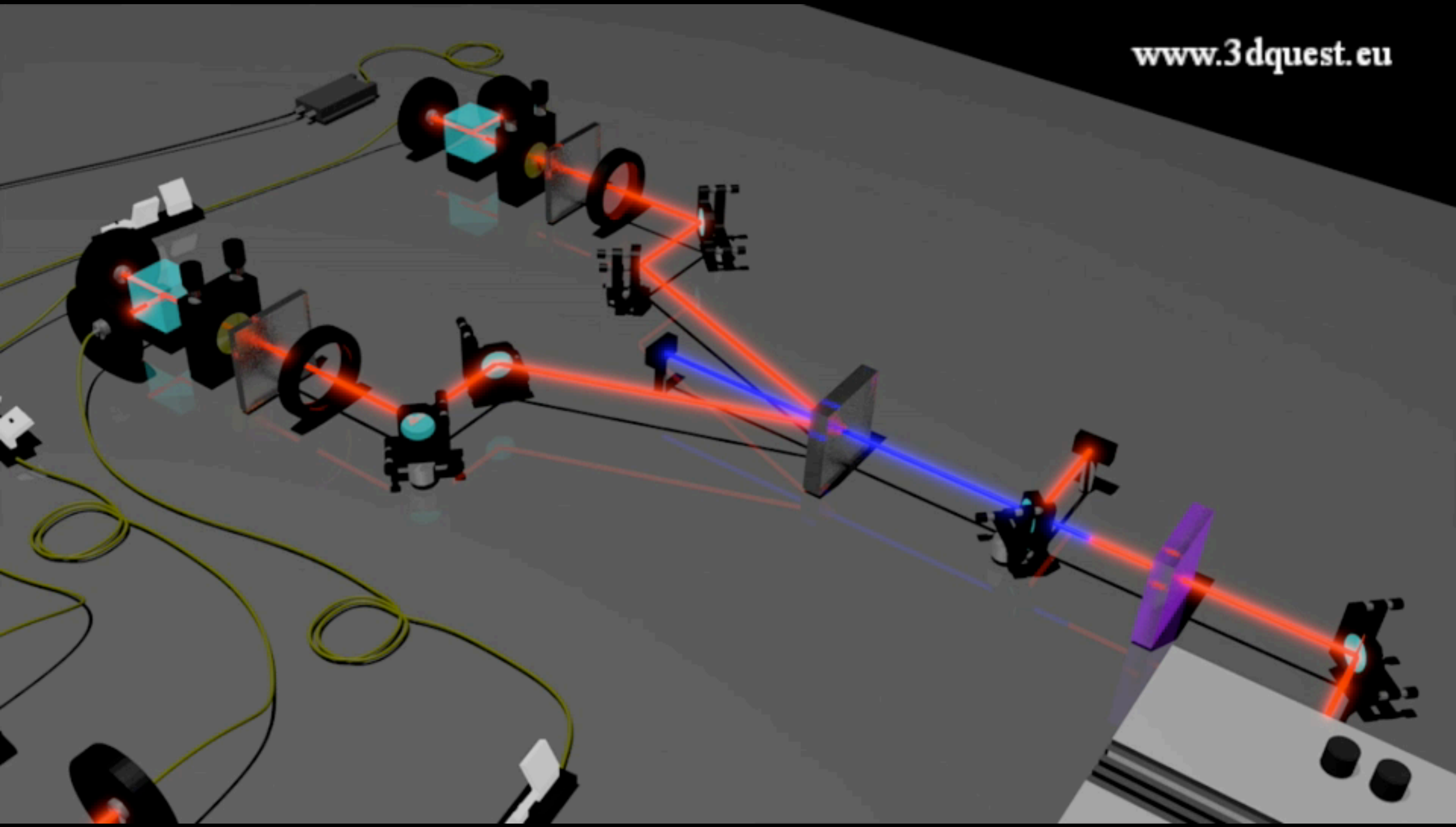




Femtosecond laser writing



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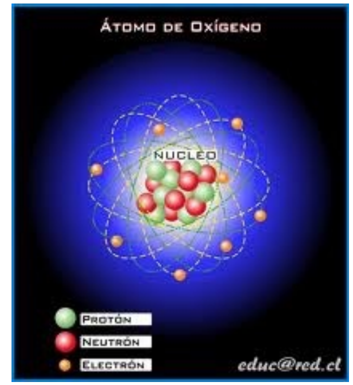
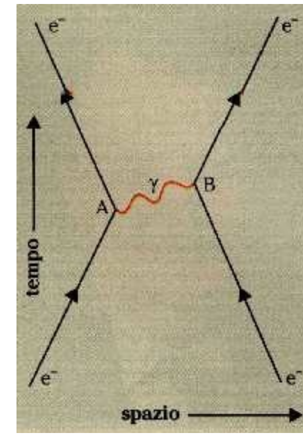
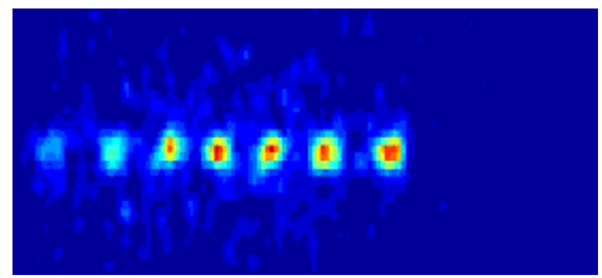
FISICA CLASSICA

MONDO MICROSCOPICO

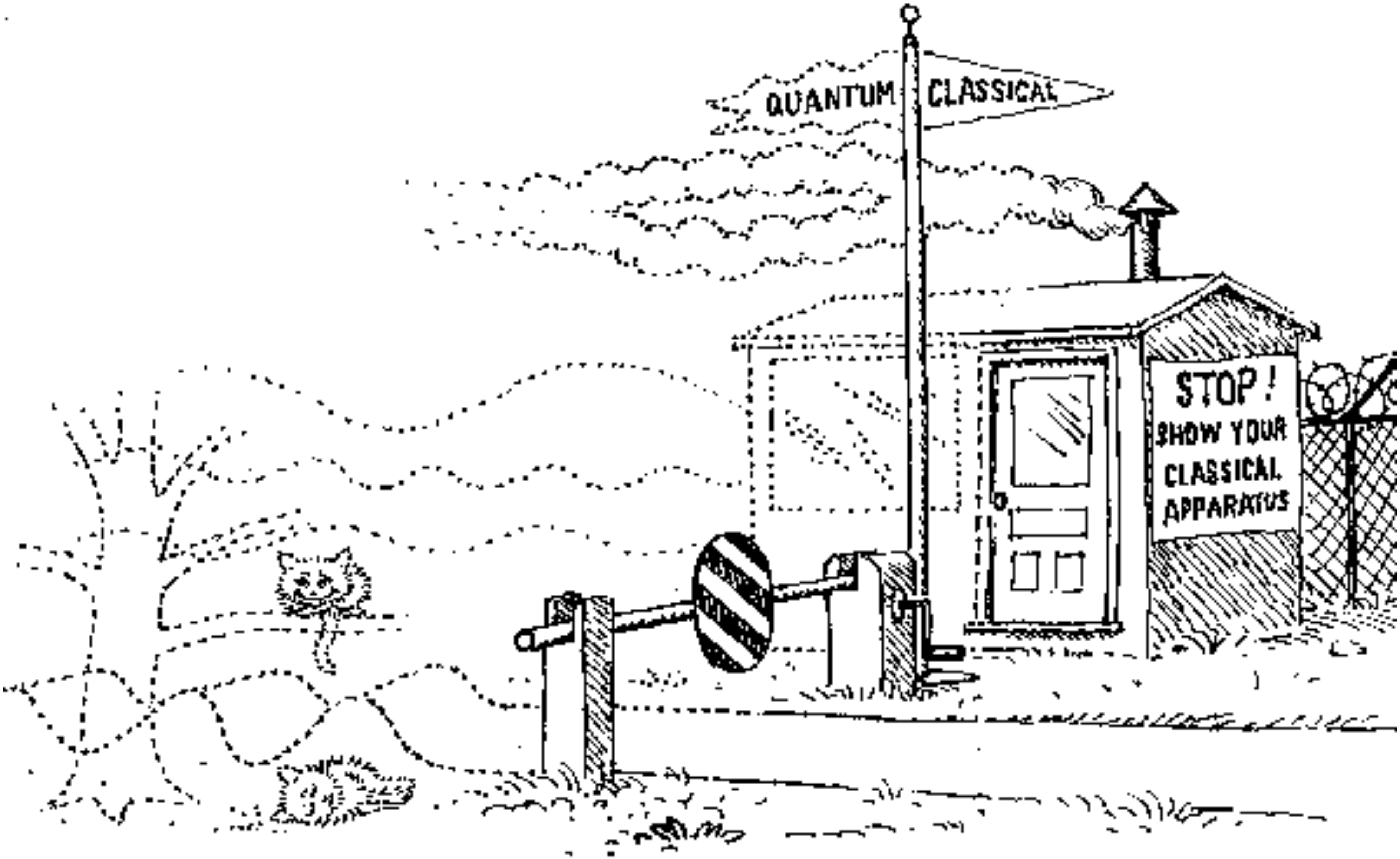




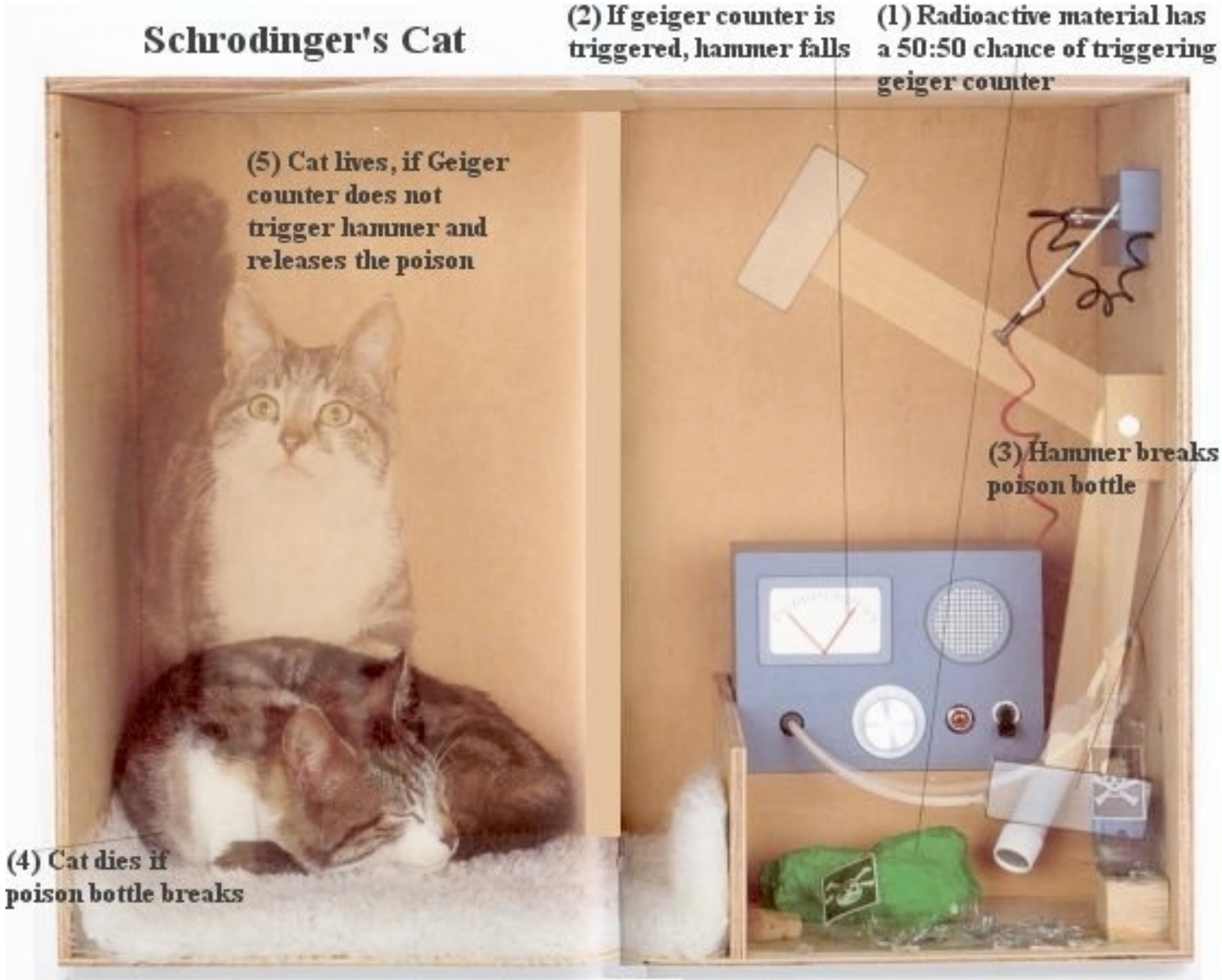


FISICA QUANTISTICA

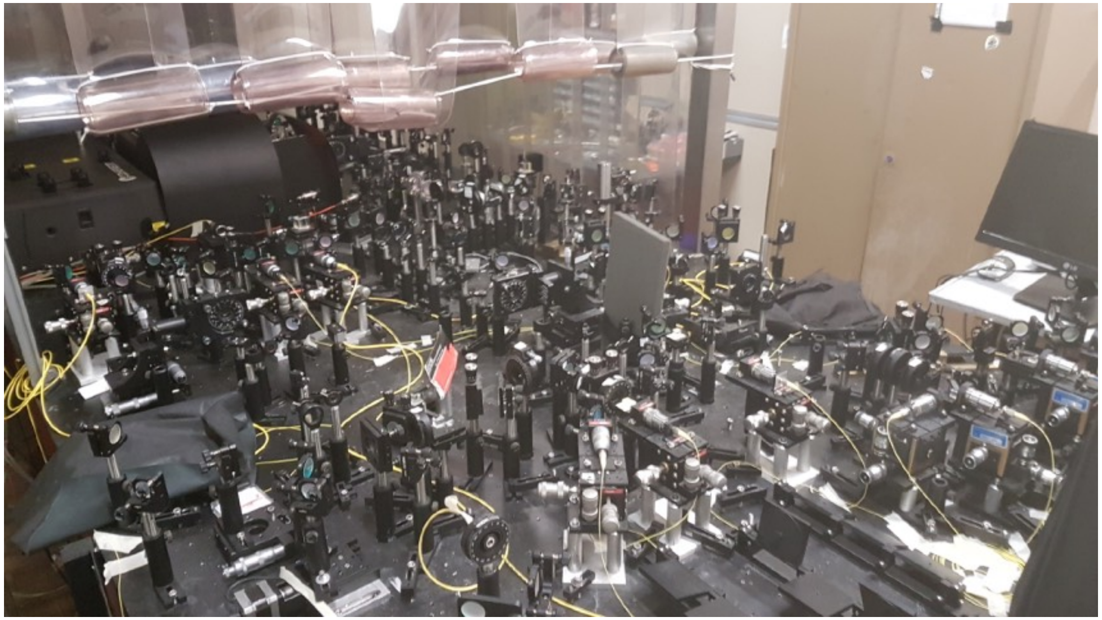
La frontiera fra il mondo classico e quello quantistico

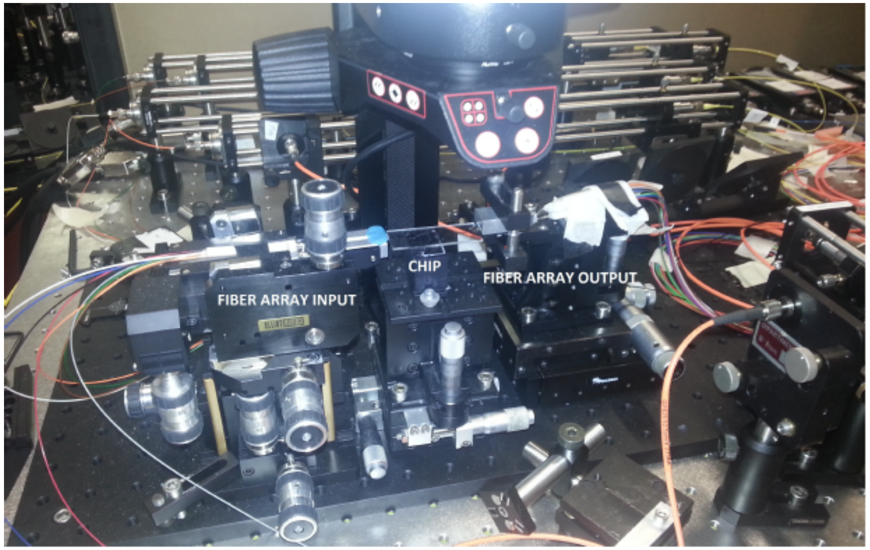


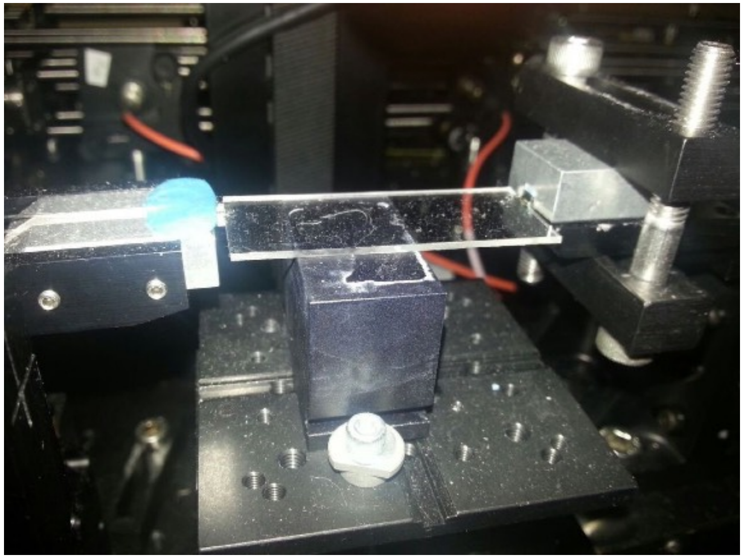
Zurek, Physics Today, October 1991, page 38


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

Boson sampling: the lab....







Thank you!

PICQUE

MARIE CURIE ACTIONS

erc

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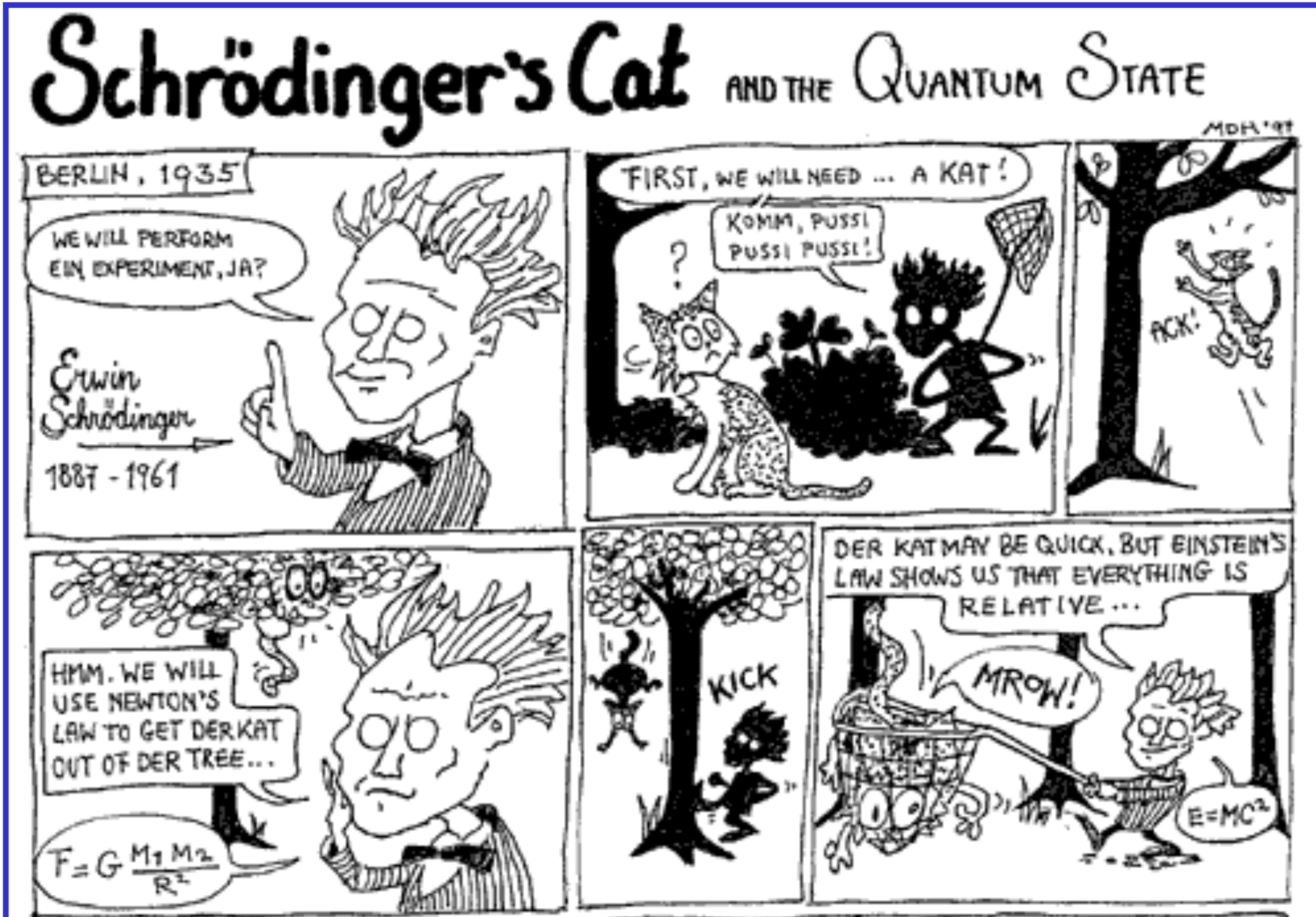
Schrödinger's Cat AND THE QUANTUM STATE
MDH '97
BERLIN, 1935
WE WILL PERFORM EIN EXPERIMENT, JA?
Erwin Schrödinger
1887 - 1961
FIRST, WE WILL NEED ... A KAT!
?
KOMM, PUSSI PUSSI PUSSI!
ACK!
HMM. WE WILL USE NEWTON'S LAW TO GET DER KAT OUT OF DER TREE...
F = G M1 M2 / R2
KICK
DER KAT MAY BE QUICK, BUT EINSTEIN'S LAW SHOWS US THAT EVERYTHING IS RELATIVE...
MROW!
E=MC2


MAXI! ALBERTCHEN! KOMM QUICK! I HAVE DER KAT!
LAB
HERE WE ARE, ERWIN! I BROUGHT DER CYANIDE!
JA, UND I BROUGHT DER RADIOACTIVE SOURCE!
GOOD! NOW WE PUT DER KAT IN THIS BOX, WITH DAS POISON UND DAS RADIO-ACTIVE MATERIAL -HEH HEH- UND WE WAIT...
Experiment
THERE IS A 50% CHANCE THE MATERIAL WILL DECAY AND THE POISON WILL BE RELEASED...
AND DER KAT WILL DIE - IN THE NAME OF SCIENCE, OF COURSE...
BUT AS LONG AS THE BOX IS CLOSED, HOW DO WE KNOW DER KAT IS DEAD OR ALIVE?
AHA! DER KAT IS IN A QUANTUM STATE - IT IS NEITHER DEAD NOR ALIVE!
ONLY WHEN WE OPEN THE BOX AND SEE, DER KAT WILL BE DEAD - OR ALIVE OF COURSE
YES, WE ARE NO ANIMAL HATERS. WE ARE SCIENTISTS!
MEIN GOTT!! THEY... THEY ARE KRAZY!
TO BE CONTINUED...