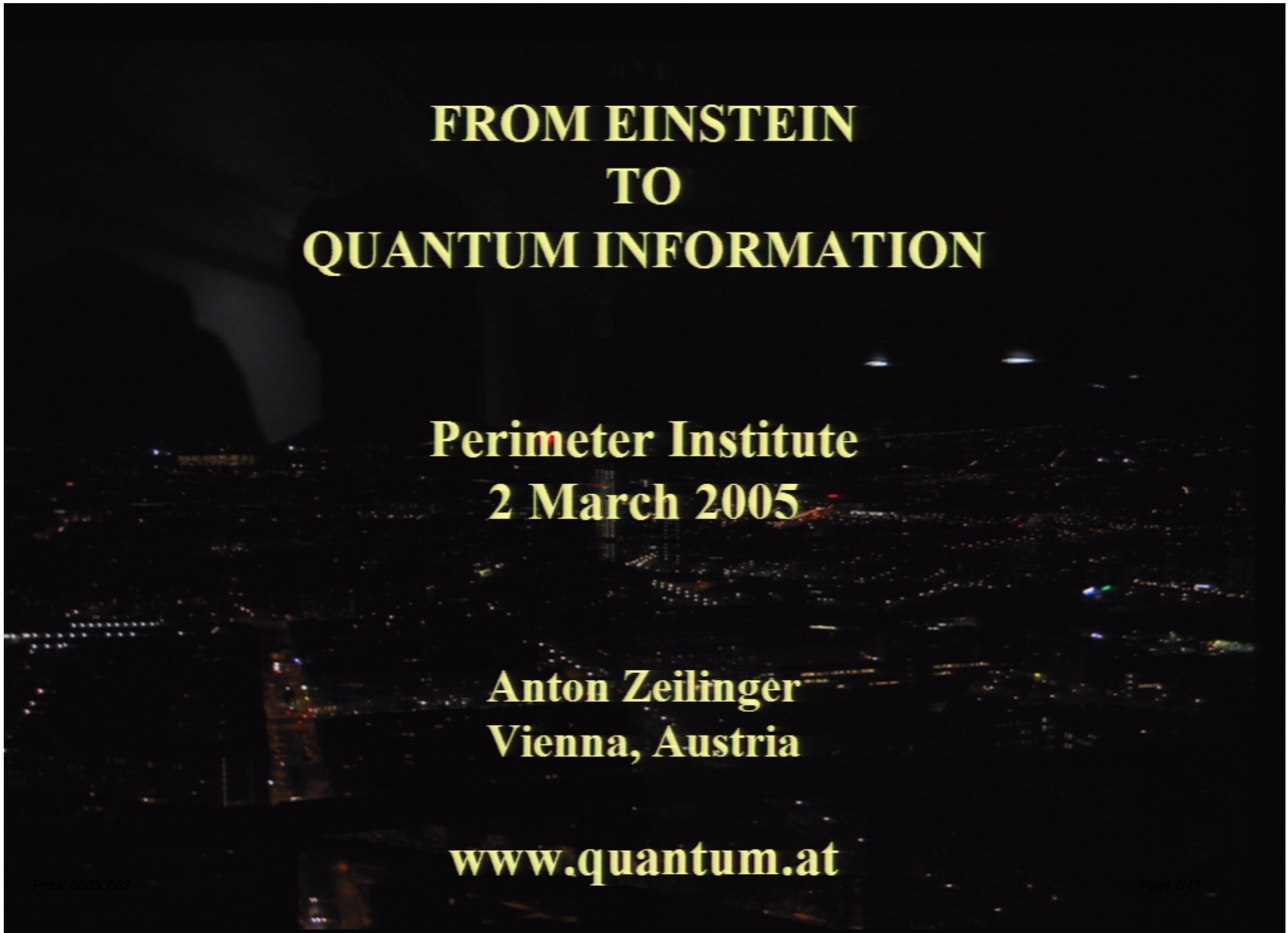
Title: From Einstein to Quantum Information

Date: Mar 02, 2005 07:00 PM

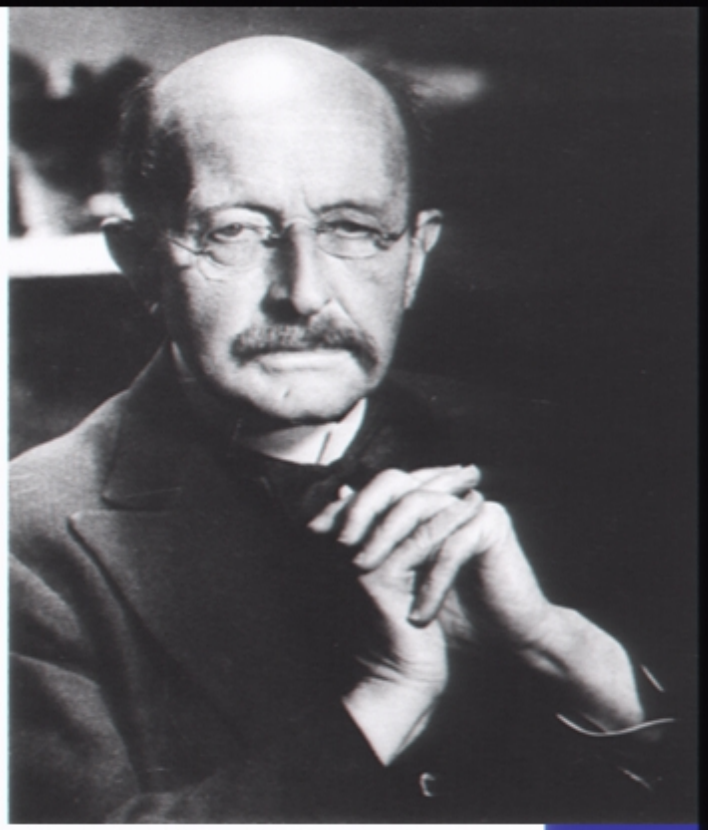
URL: http://pirsa.org/05030082

Abstract: Anton Zeilinger, a renowned physicist who successfully teleported light particles, will explain how quantum properties are used today to process and transmit information. <kw>Anton Zeilinger, Einstein, quantum information, quantum physics, entanglement, cryptography, quantum mechanics, teleportation, quantum computer </kw>


FROM EINSTEIN
TO
QUANTUM INFORMATION
Perimeter Institute
2 March 2005
Anton Zeilinger
Vienna, Austria
www.quantum.at

The Birth of Quantum Physics

Max Planck 1900

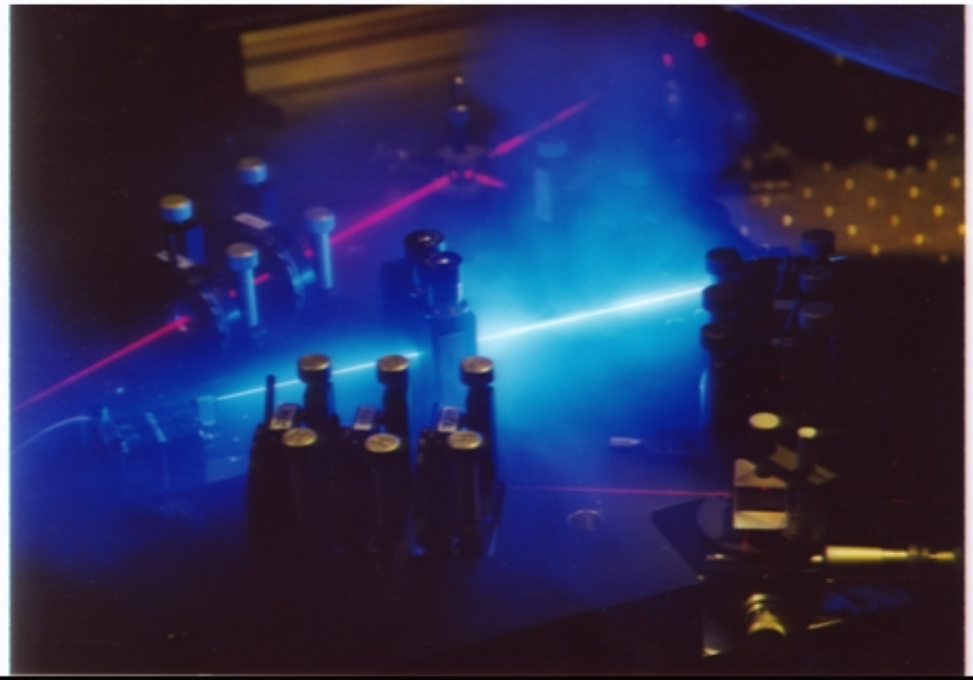


Quanta are Indivisible

UNIVERSITÄT WIEN

Quantum Physics: Basis of High-Tech

- Explanation of Chemistry
- Semiconductors Computers
- Laser



UNIVERSITÄT WIEN

„I think I can safely say that nobody today understands quantum mechanics“

Richard P. Feynman

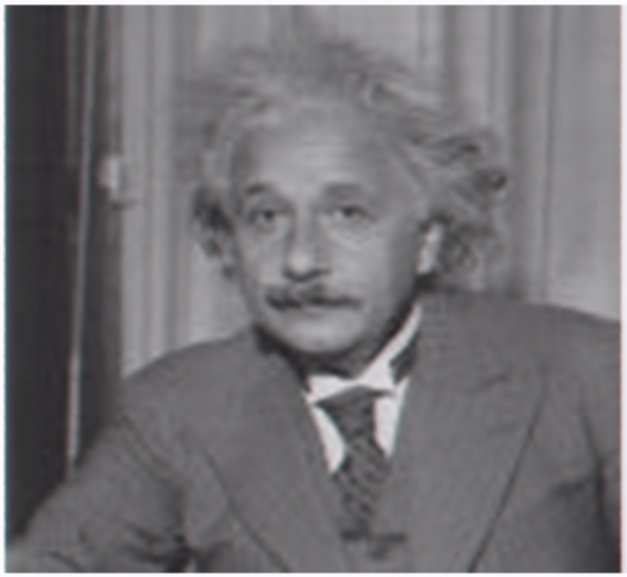
Since ca. 1970:
Philosophically motivated experiments with Individual Quantum Systems

Since ca. 1990:
Ideas of a new Information Technology

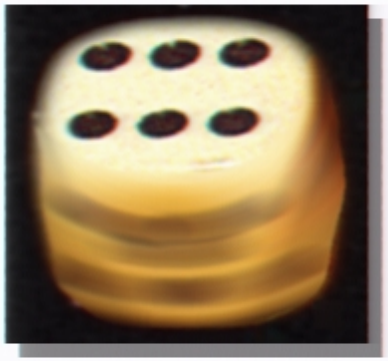
UNIVERSITÄT WIEN

Albert Einstein 1909

Jahresversammlung der Gesellschaft der Deutschen Naturforscher und Ärzte Salzburg



„Discomfort“ about the new Role of Randomness



Photoelectric Effect

UNIVERSITÄT WIEN

Albert Einstein
annus mirabilis 1905

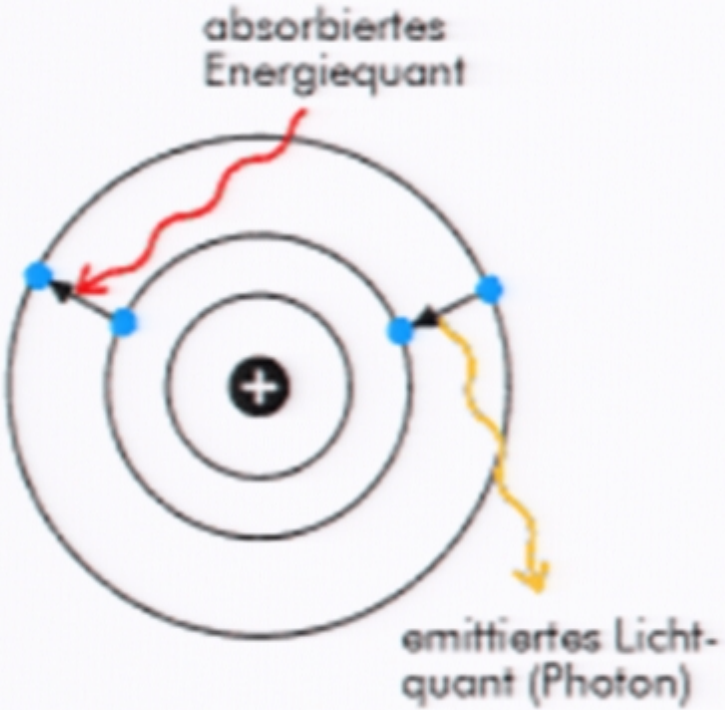
Nobel 1921

World Year of PHYSICS 2005

The Quantum Jump in the Atom

UNIVERSITÄT WIEN

Bohr's model of the atom ca. 1915



„I would rather work in a casino"

Albert Einstein


CAVSARVM
INVESTIGATIO

UNIVERSITÄT WIEN

Quantentheorie

Werner Heisenberg 1925

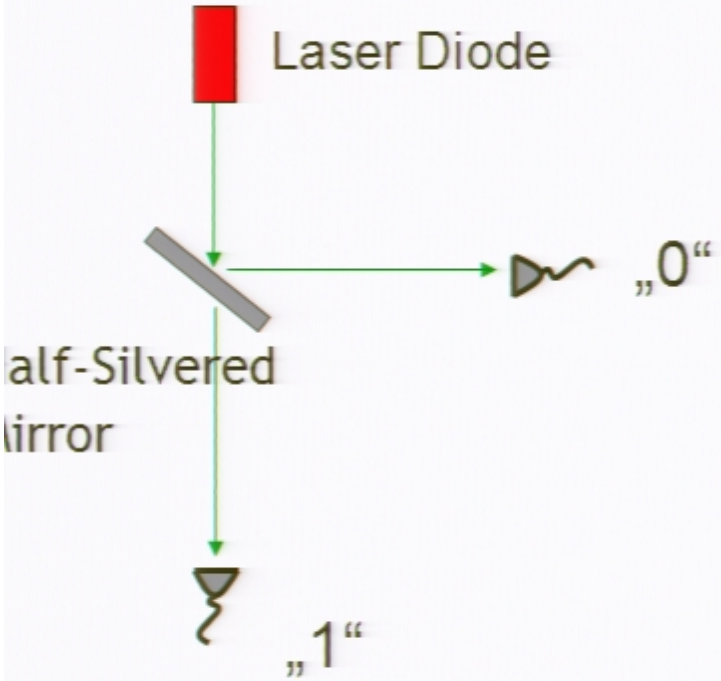
Heligoland

Erwin Schrödinger 1926

Quantum Jump

UNIVERSITÄT WIEN

A Random Number Generator



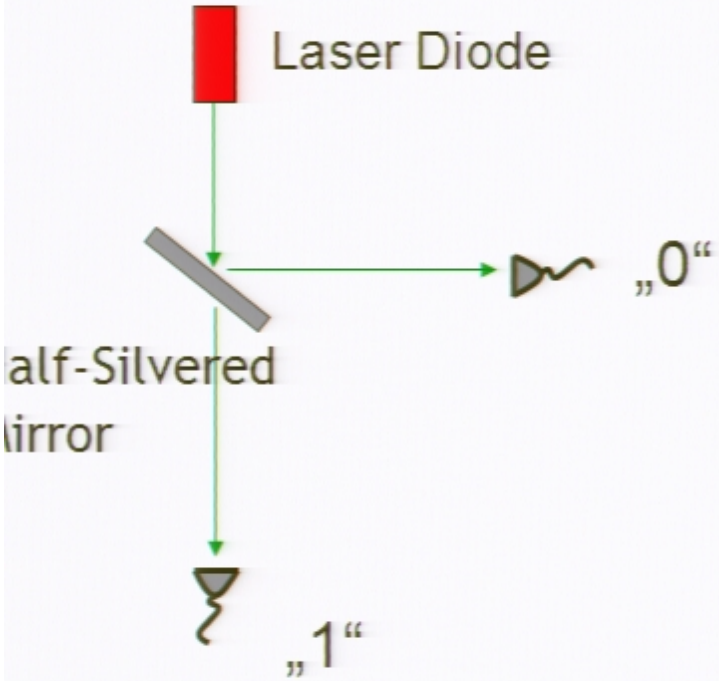
Bit Rate: 1 Mbit/s

01100110100101001010
00100010101011010010
01010010011110100010
10100101010110010110

T. Jennewein, U. Achleitner, G. Weihs, H. Weinfurter, and A. Zeilinger
A fast and compact quantum random number generator
Rev. Sci. Inst. 71, 1675-1680 (2000)

UNIVERSITÄT WIEN

A Random Number Generator



Bit Rate: 1 Mbit/s

01100110100101001010
01000101010110100101
01010010011110100101
01010010101011001011

T. Jennewein, U. Achleitner, G. Weihs, H. Weinfurter, and A. Zeilinger
A fast and compact quantum random number generator
Rev. Sci. Inst. 71, 1675-1680 (2000)

UNIVERSITÄT WIEN

The statistical character of the psi-function will determine the character of natural law at least for a couple of centuries

Wolfgang Pauli 1952

Nobelpreis 1945

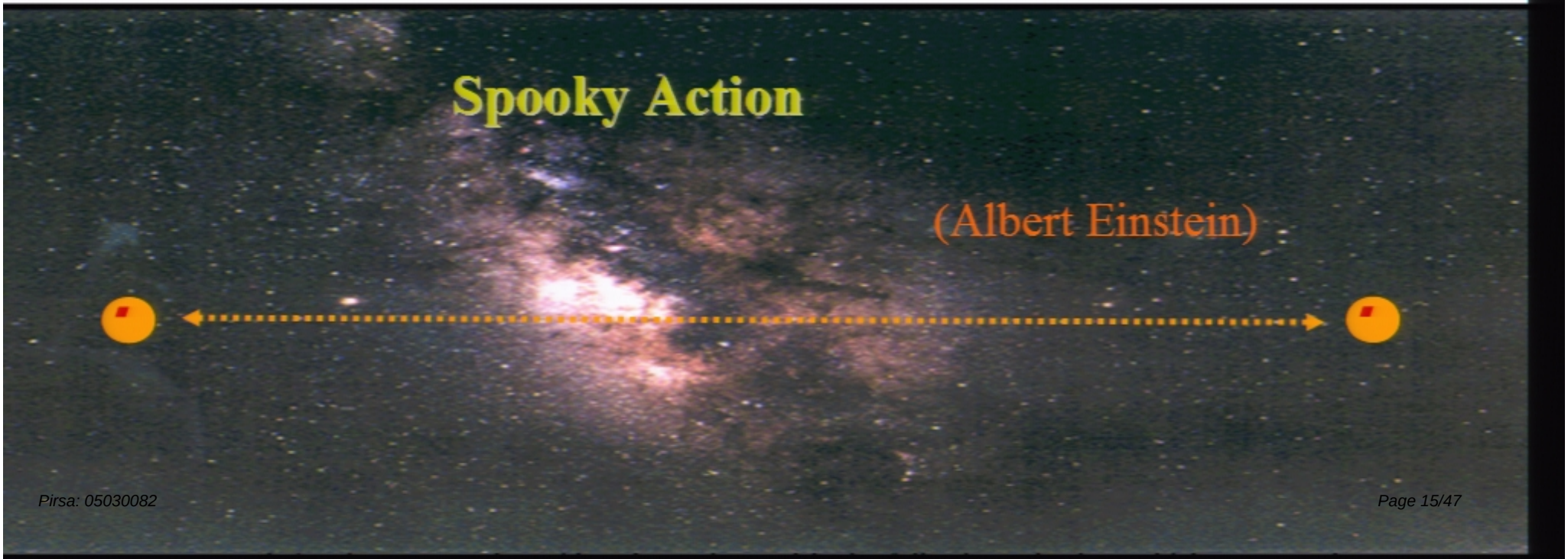
MAY 15, 1935 PHYSICAL REVIEW VOLUME 47

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

A. EINSTEIN, B. PODOLSKY AND N. ROSEN, *Institute for Advanced Study, Princeton, New Jersey*

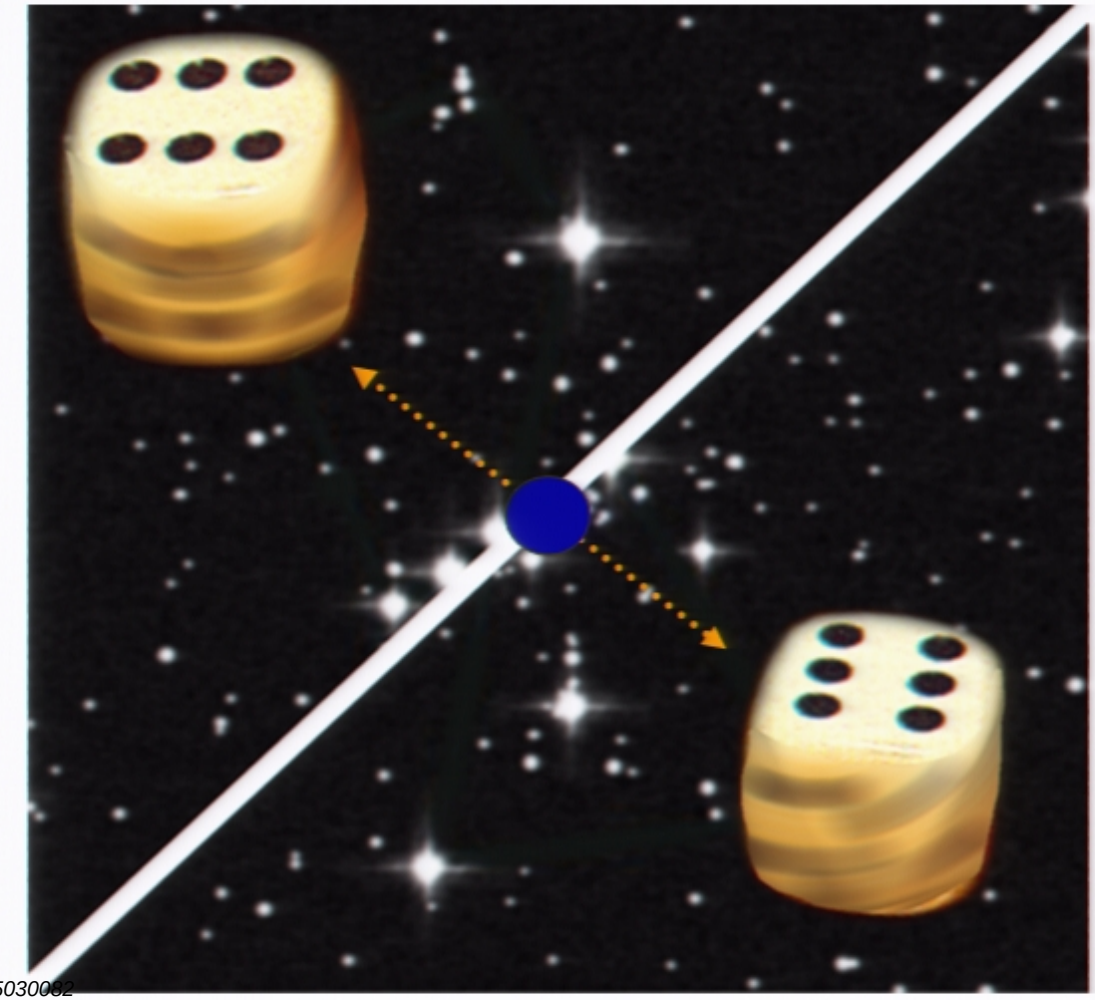
(Received March 25, 1935)

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.



UNIVERSITÄT WIEN

Entanglement



E. Schrödinger 1935

$$\Psi(x_1, x_2) = \int_{-\infty}^{\infty} \varphi_x(x_2) v_x(x_1) dx, \quad (15)$$

where

$$\varphi_x(x_2) = \int_{-\infty}^{\infty} e^{(2\pi i/h)(x - x_2 + x_0)p} dp$$

$$= h\delta(x - x_2 + x_0). \quad (16)$$

This φ_x, however, is the eigenfunction of the operator

$$Q = x_2 \quad (17)$$

corresponding to the eigenvalue $x + x_0$ of the coordinate of the second particle. Since

$$PQ - QP = h/2\pi i, \quad (18)$$

we have shown that it is in general possible for ψ_k and φ_r to be eigenfunctions of two noncommuting operators, corresponding to physical quantities.

Returning now to the general case contemplated in Eqs. (7) and (8), we assume that ψ_k and φ_r are indeed eigenfunctions of some noncommuting operators P and Q, corresponding to the eigenvalues p_k and q_r, respectively. Thus, by measuring either A or B we are in a position to predict with certainty, and without in any way

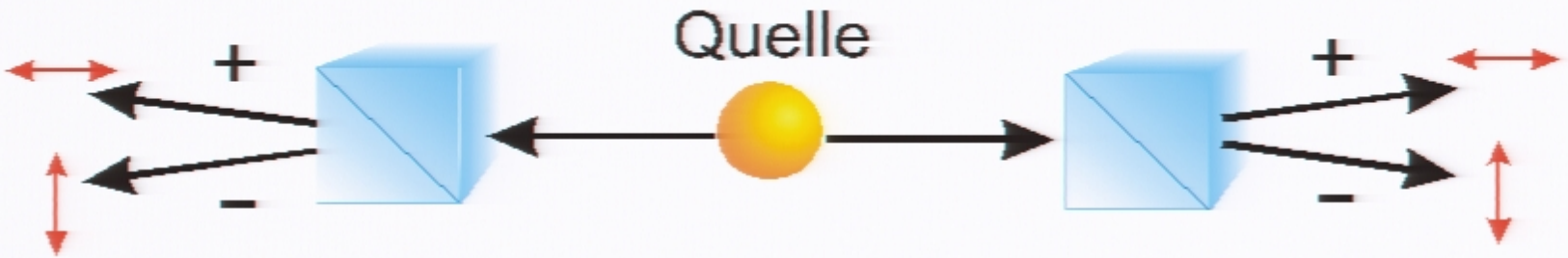
ators, can have simultaneous reality. Thus the negation of (1) leads to the negation of the only other alternative (2). We are thus forced to conclude that the quantum-mechanical description of physical reality given by wave functions is not complete.

One could object to this conclusion on the grounds that our criterion of reality is not sufficiently restrictive. Indeed, one would not arrive at our conclusion if one insisted that two or more physical quantities can be regarded as simultaneous elements of reality *only when they can be simultaneously measured or predicted*. On this point of view, since either one or the other, but not both simultaneously, of the quantities P and Q can be predicted, they are not simultaneously real. This makes the reality of P and Q depend upon the process of measurement carried out on the first system, which does not disturb the second system in any way. No reasonable definition of reality could be expected to permit this.

While we have thus 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.

Bell's Theorem

UNIVERSITÄT WIEN



John Bell 1965

Conflict of

Quantum Mechanics with

Local Realism

Bell's Theorem

UNIVERSITÄT WIEN

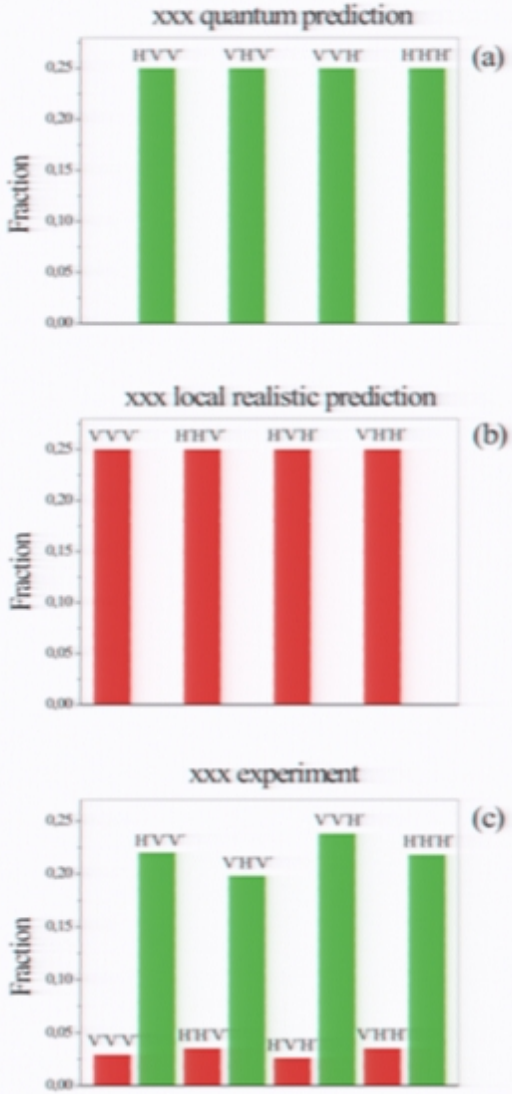
John Bell 1965

Conflict of

Quantum Mechanics with

Local Realism

GHZ Experiment



J.-W. Pan, D. Bouwmeester, M. Daniell
H. Weinfurter & A. Zeilinger
Nature 403, 515 (2000)

PHYSICAL REVIEW
LETTERS

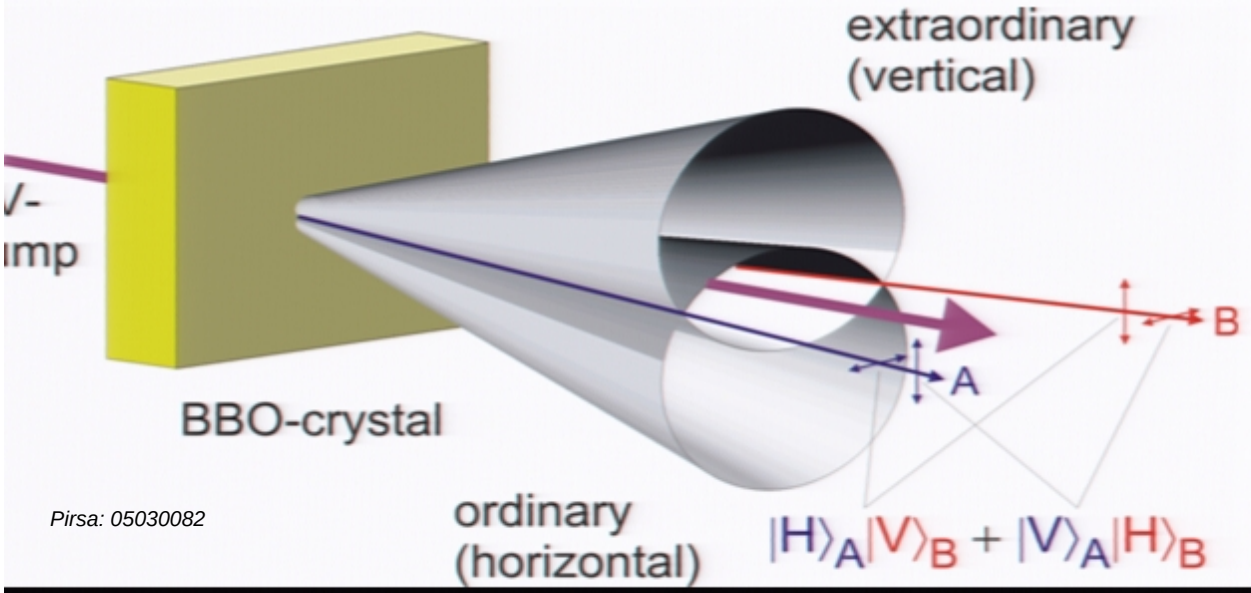
VOLUME 75 | 11 DECEMBER 1995 | NUMBER 24

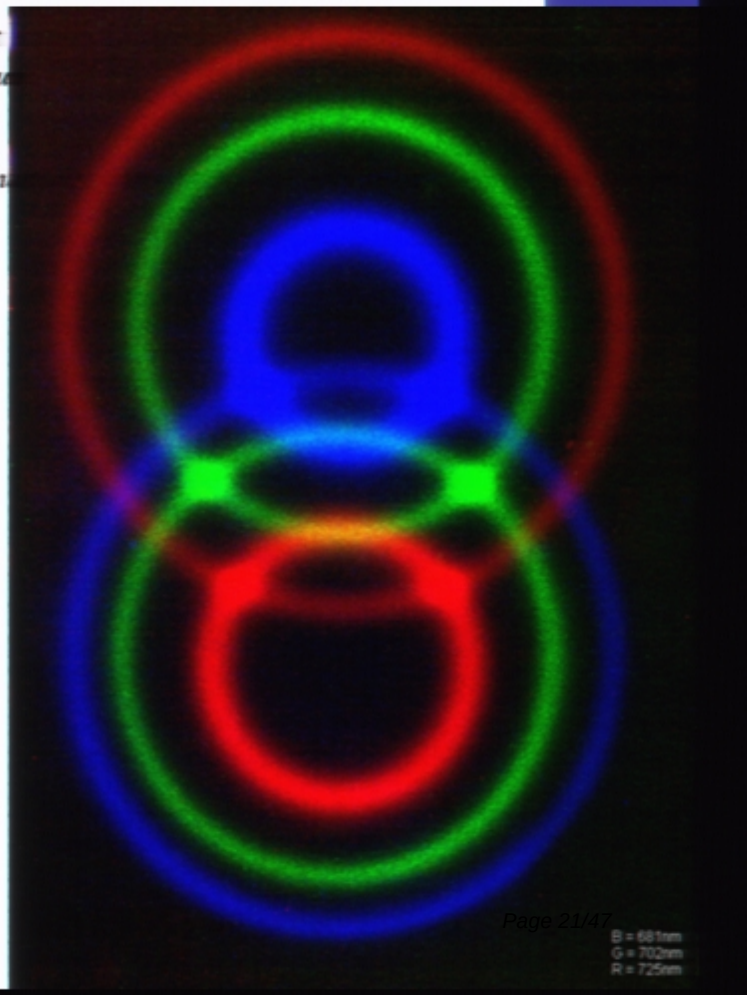
WIEN

New High-Intensity Source of Polarization-Entangled Photon Pairs

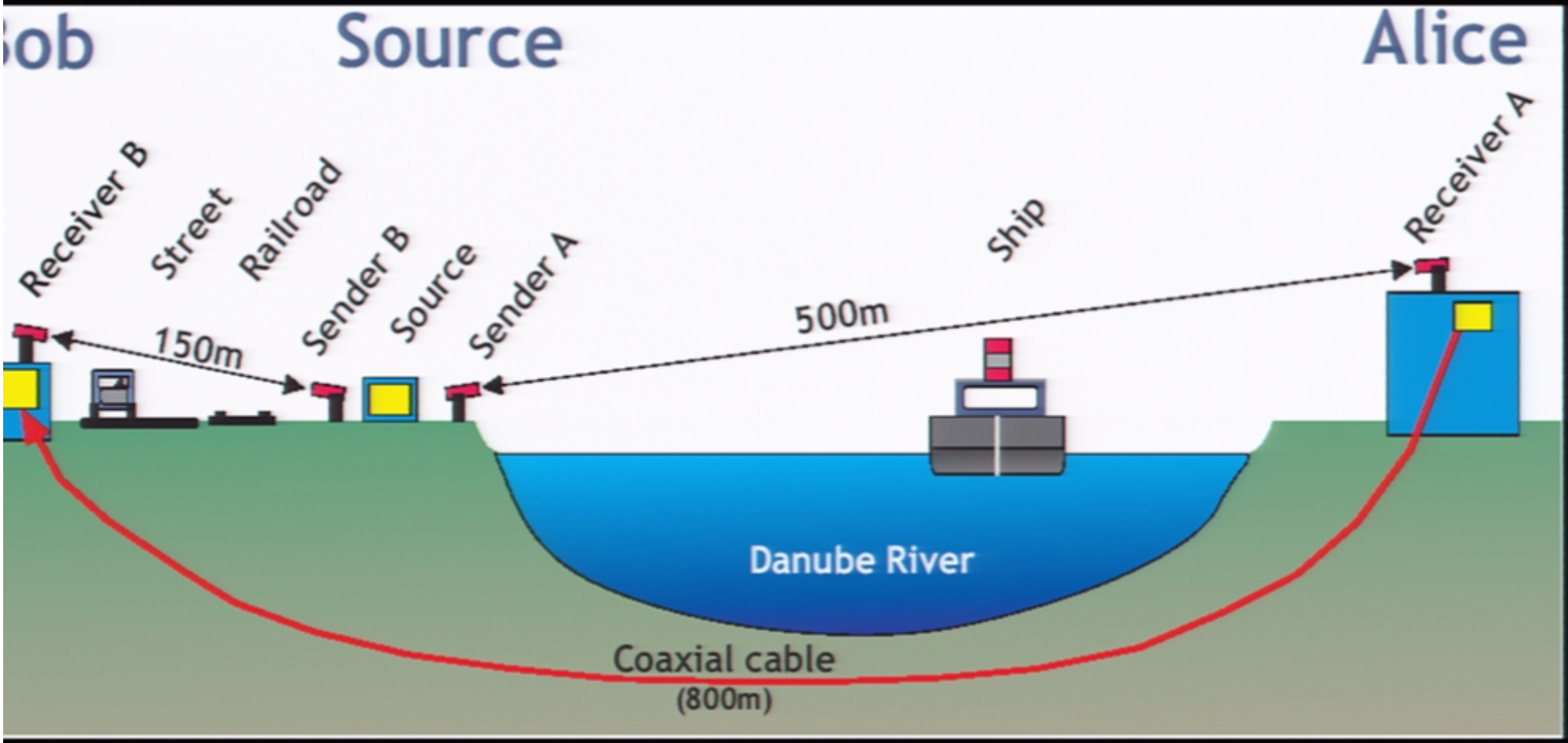
Paul G. Kwiat,* Klaus Mattle, Harald Weinfurter, and Anton Zeilinger
Institut für Experimentalphysik, Universität Innsbruck, Technikerstrasse 25, 6020 Innsbru

Alexander V. Sergienko and Yanhua Shih
Department of Physics, University of Maryland Baltimore County, Baltimore, Marylan





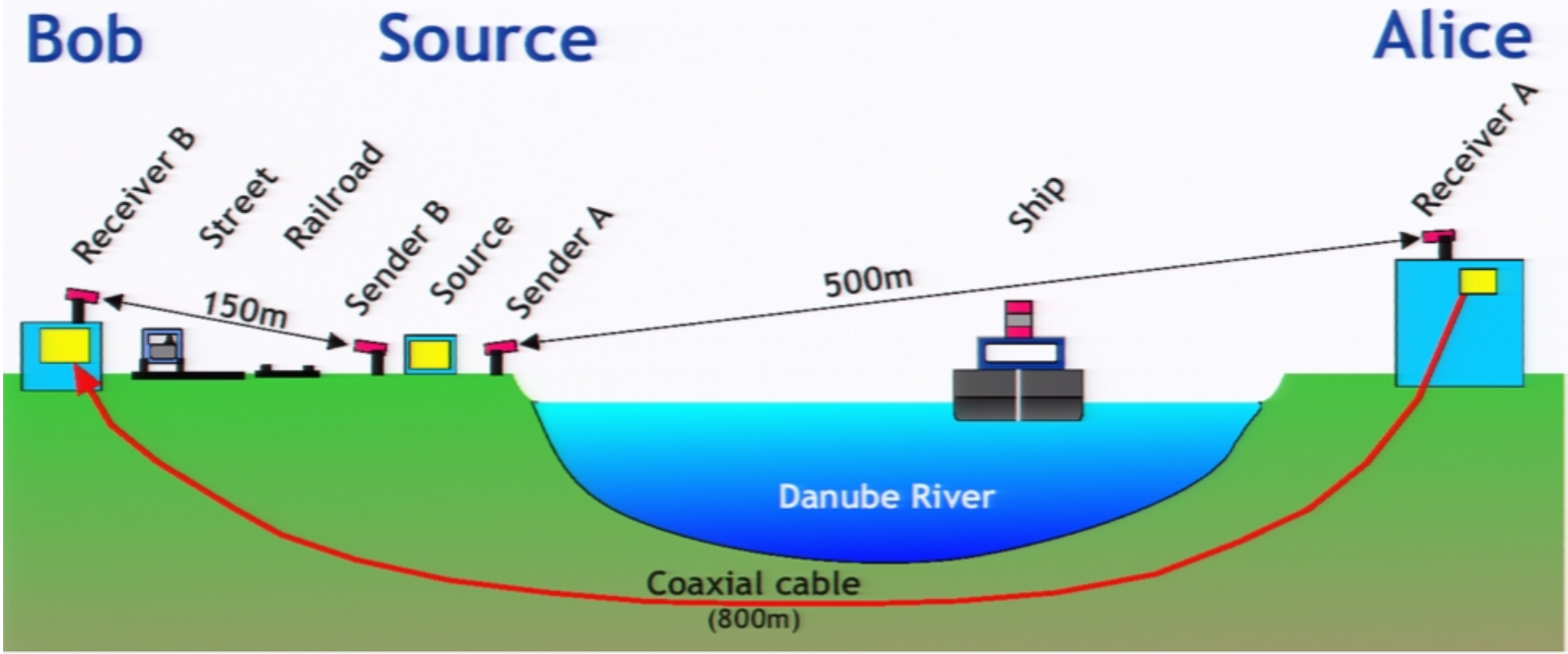
Outdoors Entanglement



. Aspelmeyer, H.R. Böhm, T. Gyatso, T. Jennewein, R. Kaltenbaek, M. Lindenthal,
. Molina-Tereza, A. Poppe, K. Resch, M. Taraba, R. Ursin, P. Walther, A.Z.
cience (2003)

UNIVERSITÄT WIEN

Outdoors Entanglement



UNIVERSITÄT WIEN

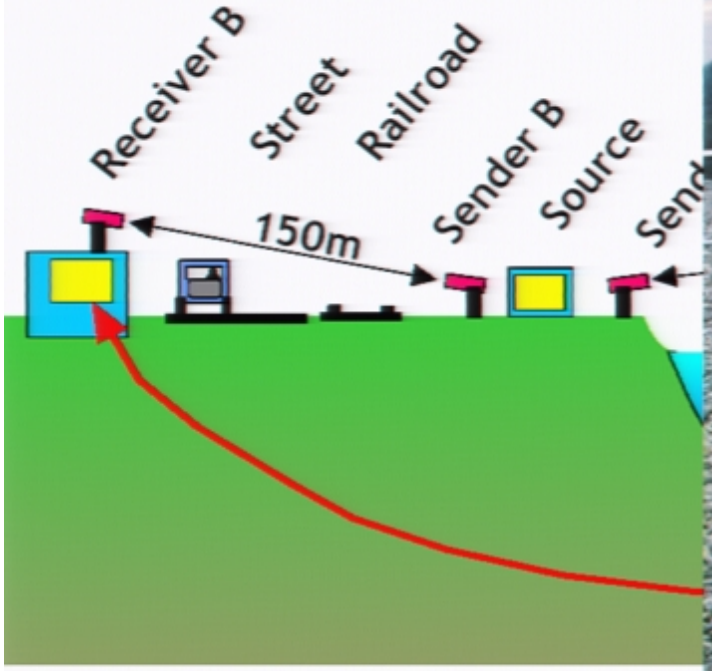
Outdoors Entanglement

Bob Source Alice

UNIVERSITÄT WIEN

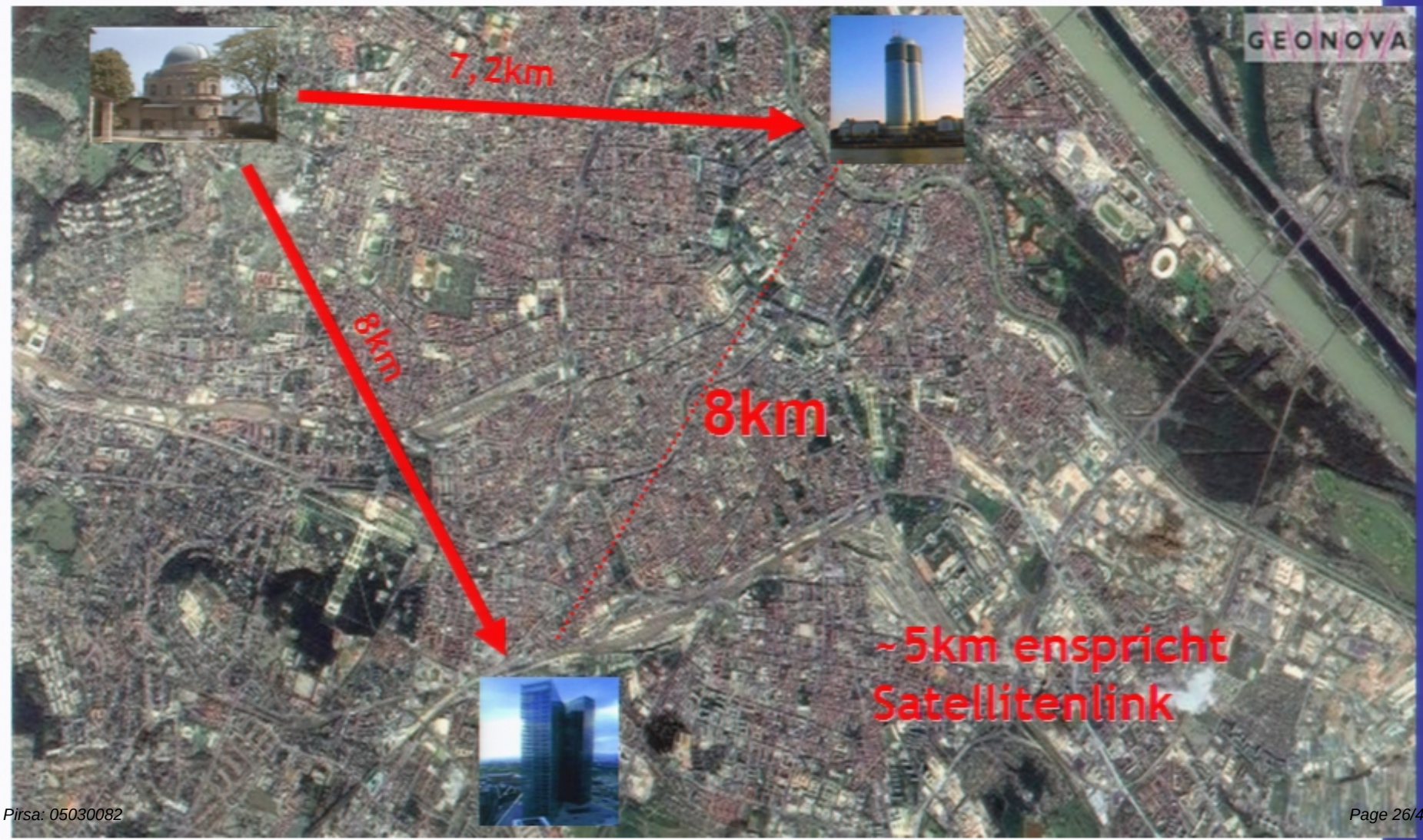
Outdoors Entanglement

Bob **Source** **Alice**



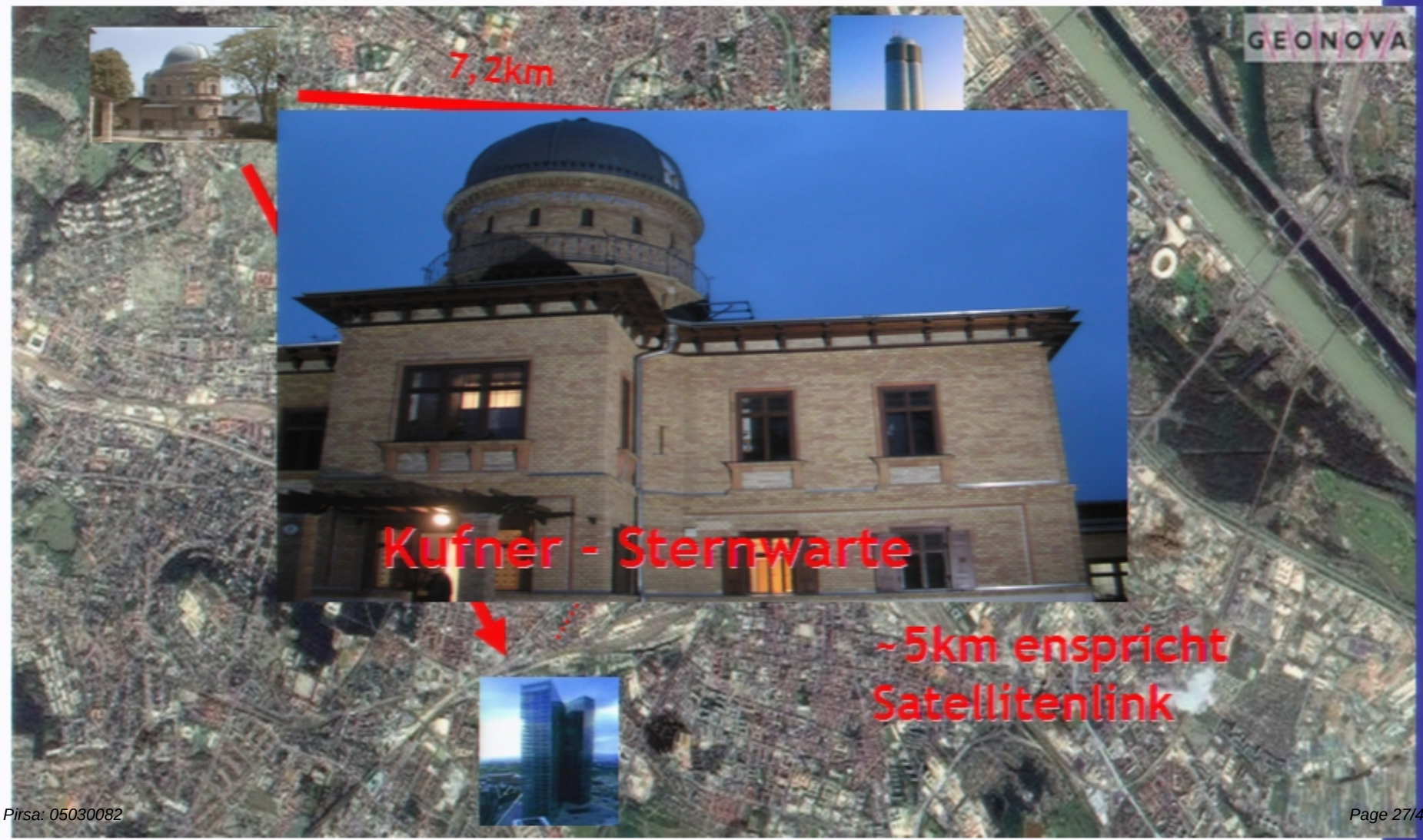
Freespace II

UNIVERSITÄT WIEN



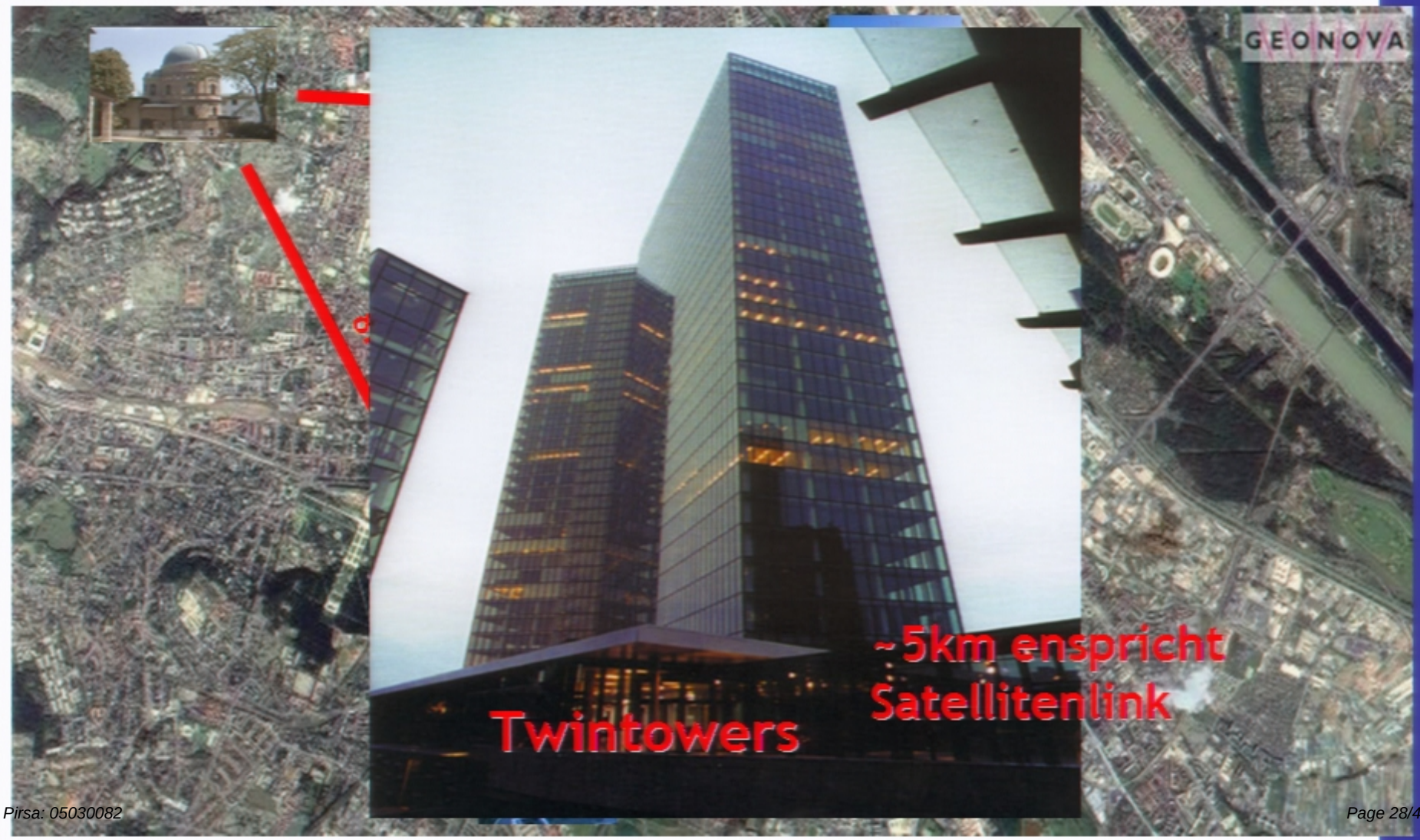
Freespace II

UNIVERSITÄT WIEN



Freespace II

UNIVERSITÄT WIEN

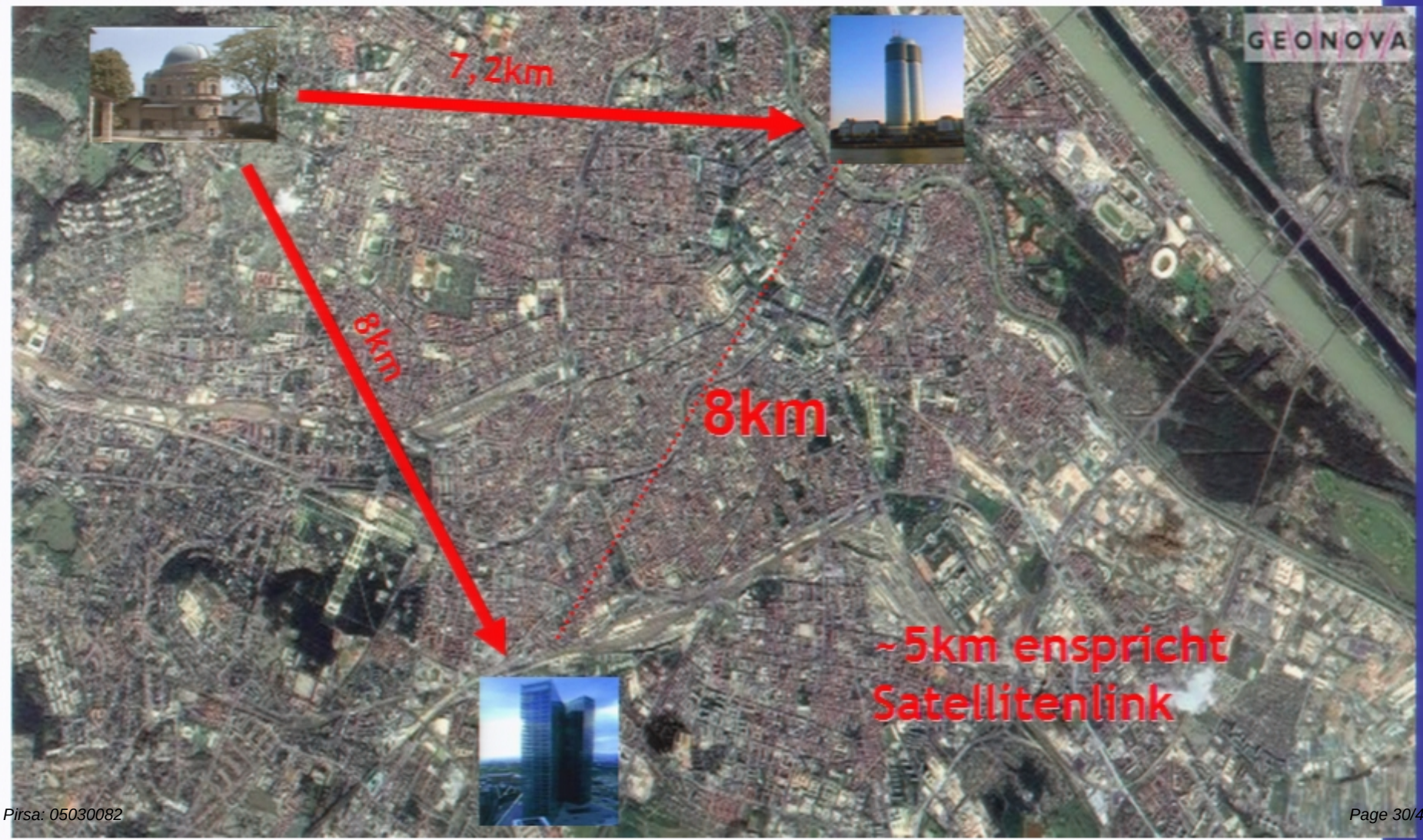


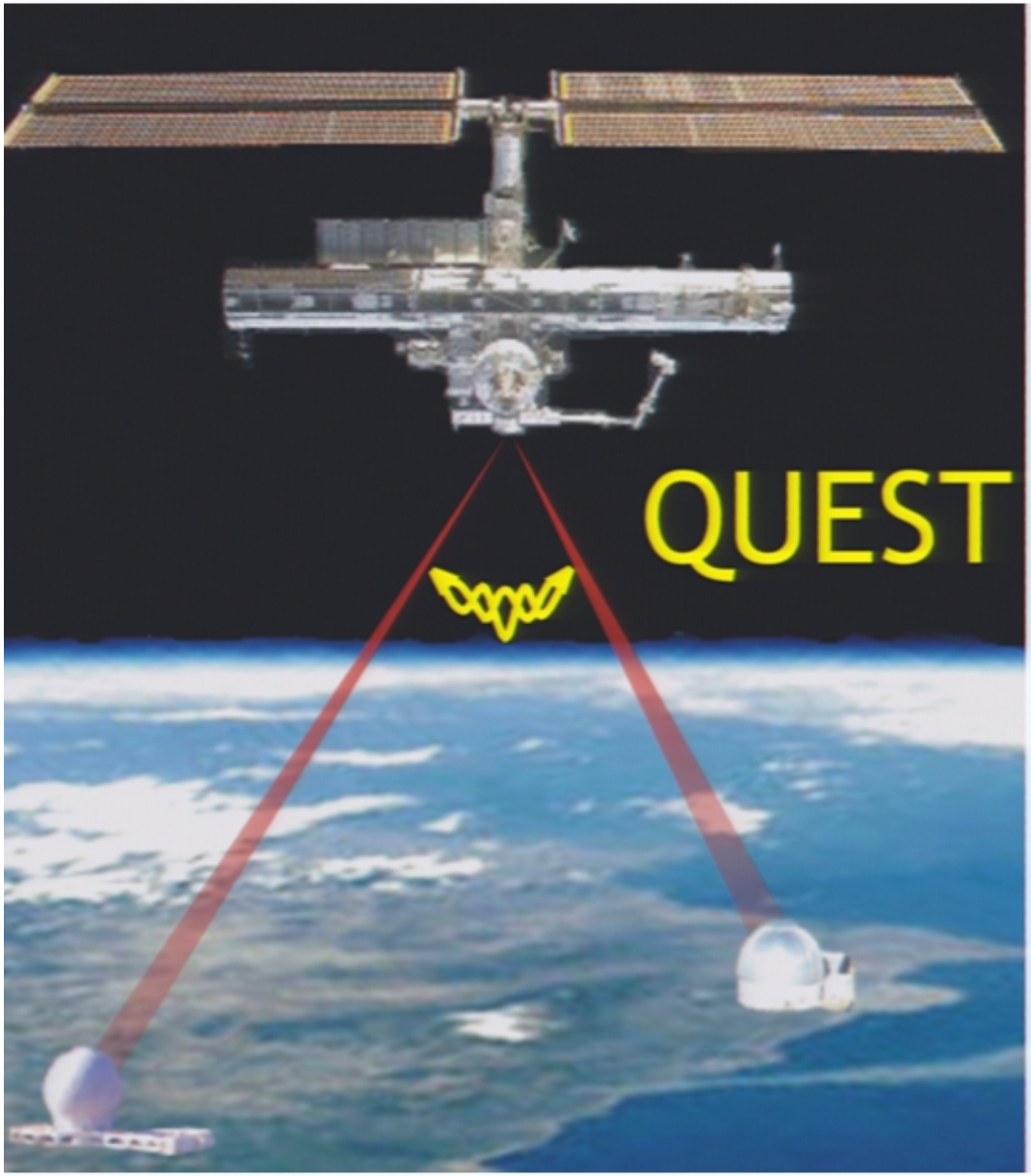
Freespace II

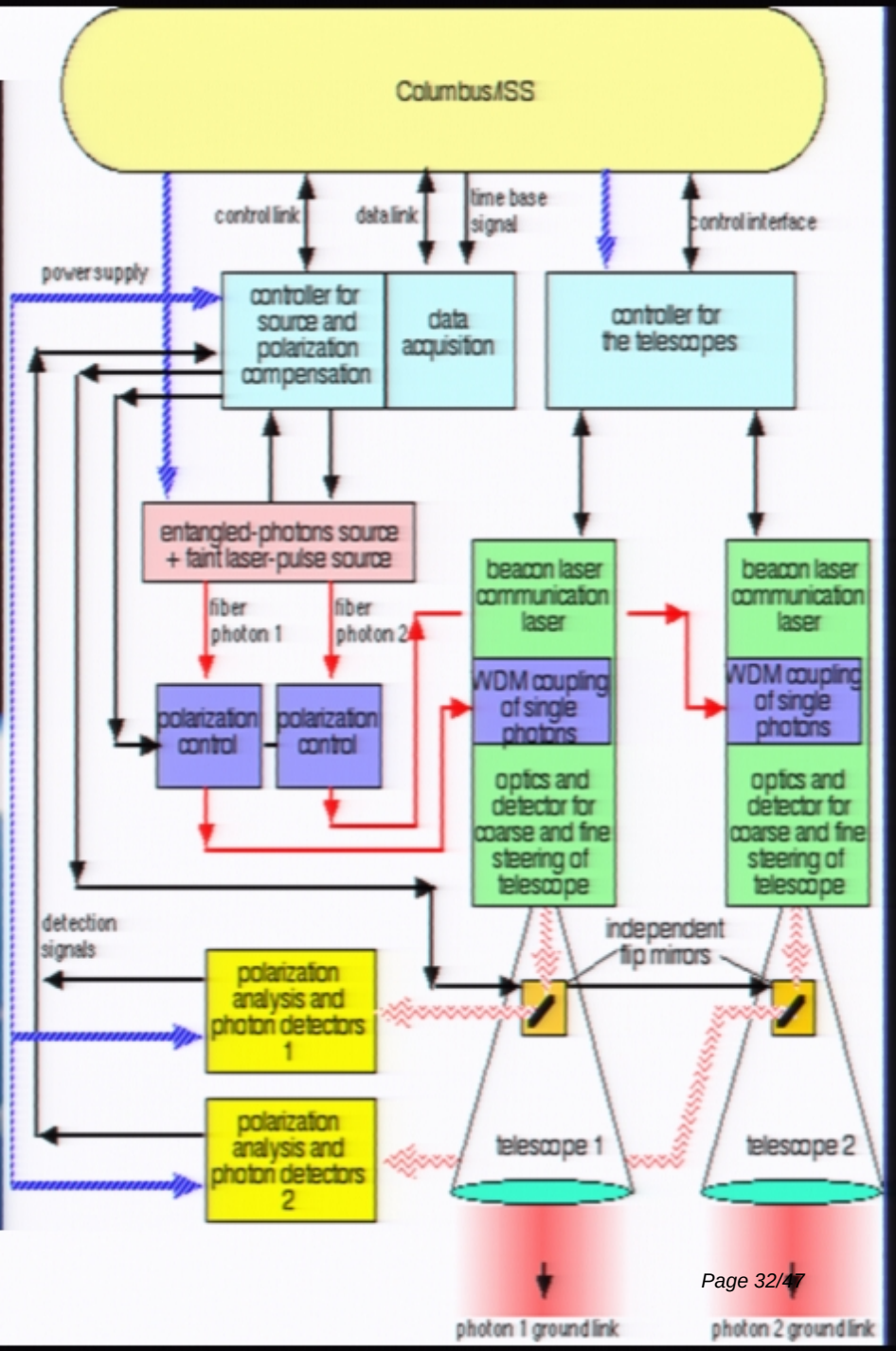
UNIVERSITÄT WIEN

Freespace II

UNIVERSITÄT WIEN



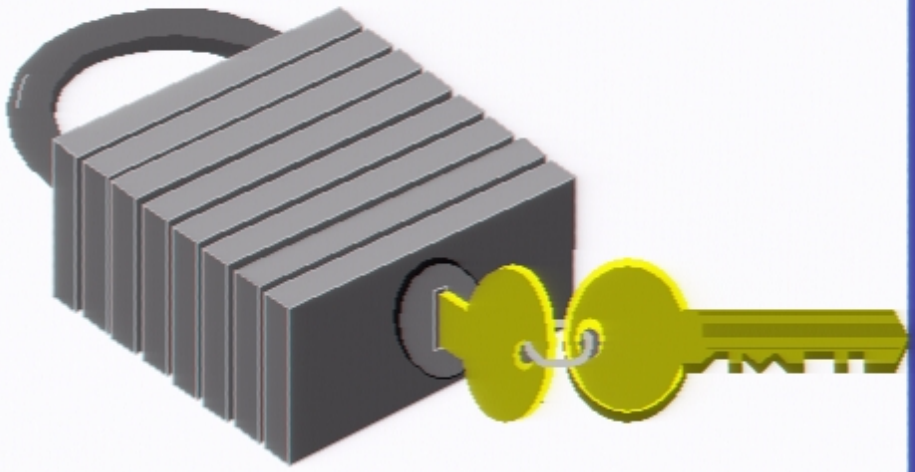

QUEST


Columbus/ISS
control link
data link
time base signal
control interface
power supply
controller for source and polarization compensation
data acquisition
controller for the telescopes
entangled-photons source + faint laser-pulse source
fiber photon 1
fiber photon 2
beacon laser communication laser
WDM coupling of single photons
optics and detector for coarse and fine steering of telescope
polarization control
polarization control
detection signals
independent flip mirrors
polarization analysis and photon detectors 1
polarization analysis and photon detectors 2
telescope 1
telescope 2
photon 1 ground link
photon 2 ground link

Quantum Cryptography

UNIVERSITÄT WIEN

Transmission of a Secret Message



Security:

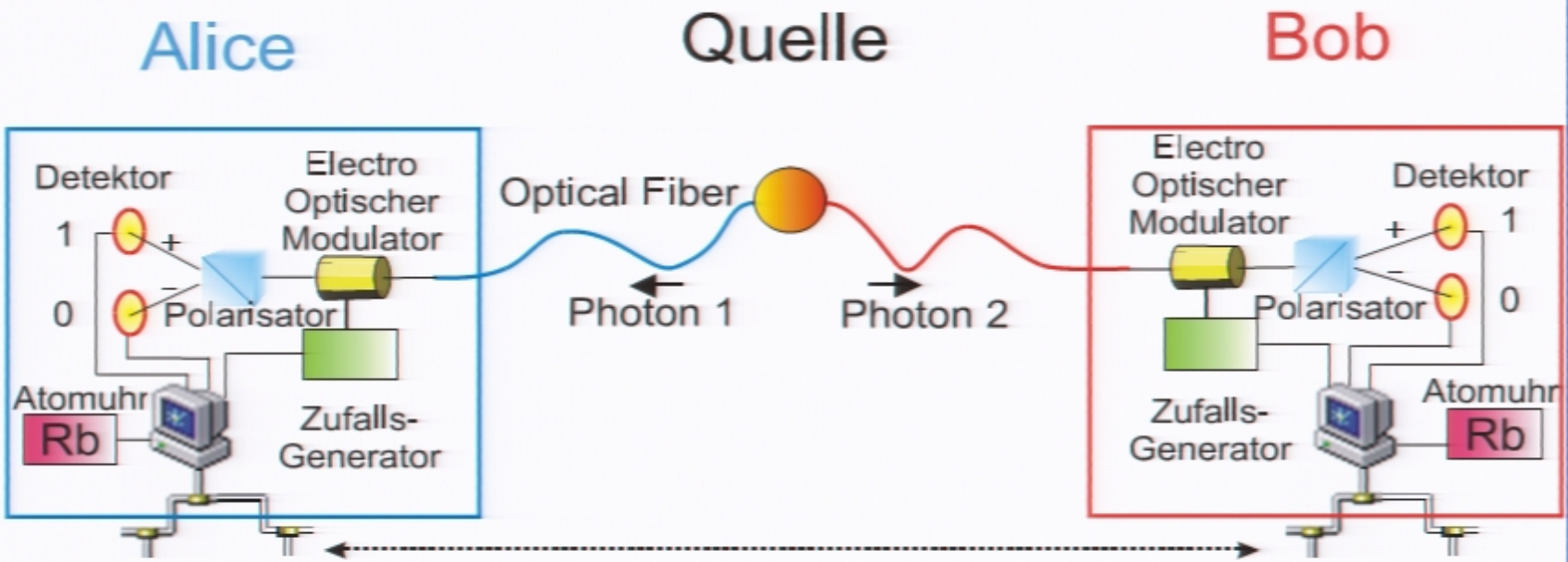
Quanta are extremely sensitive

Security guaranteed by Quantum Physics

UNIVERSITÄT WIEN

Quantum Cryptography

Ekert PRL 1990



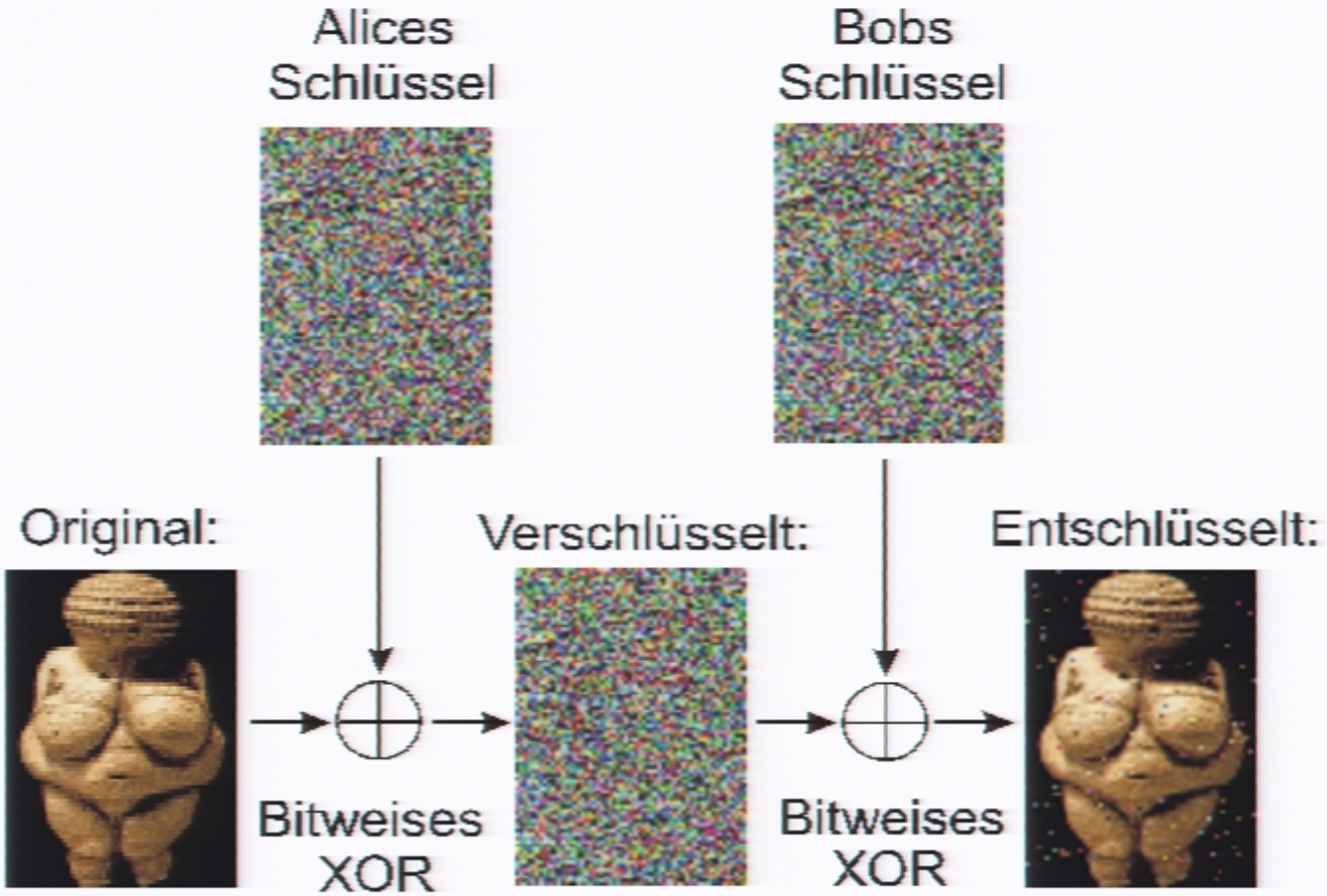
T. Jennewein et al. PRL 84 (2000) 4279

Gregor Weihs, Univ Waterloo

UNIVERSITÄT WIEN

Quantum Cryptography

The experimental confirmation



Schlüssel: 51840 Bit, Bit Fehlter Wahrsch. 0.4 %

Quantum Cryptography

21 April 2004:

A World Premiere

Vienna City Hall

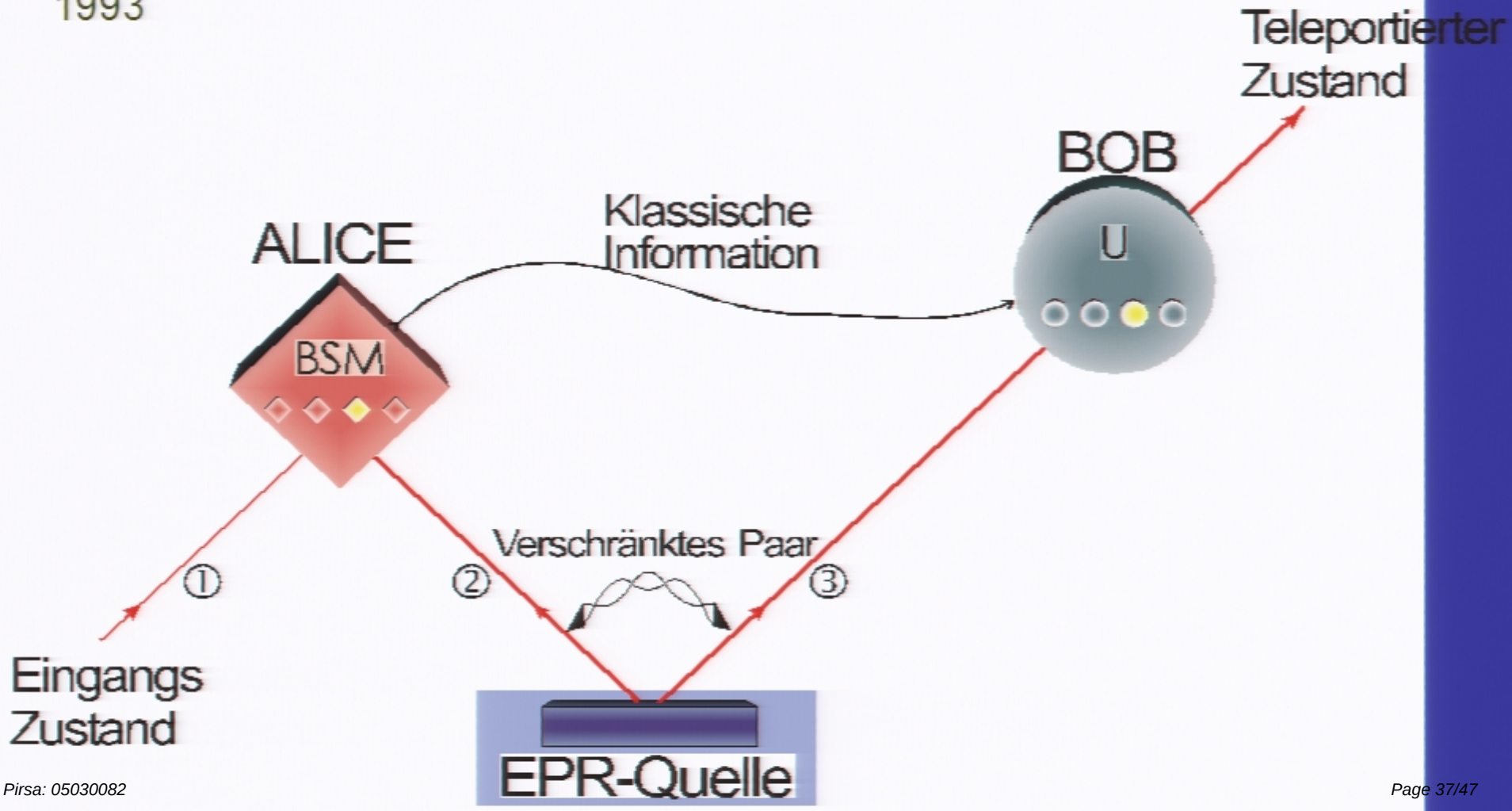
to

Bank Austria

UNIVERSITÄT WIEN

Quantum Teleportation

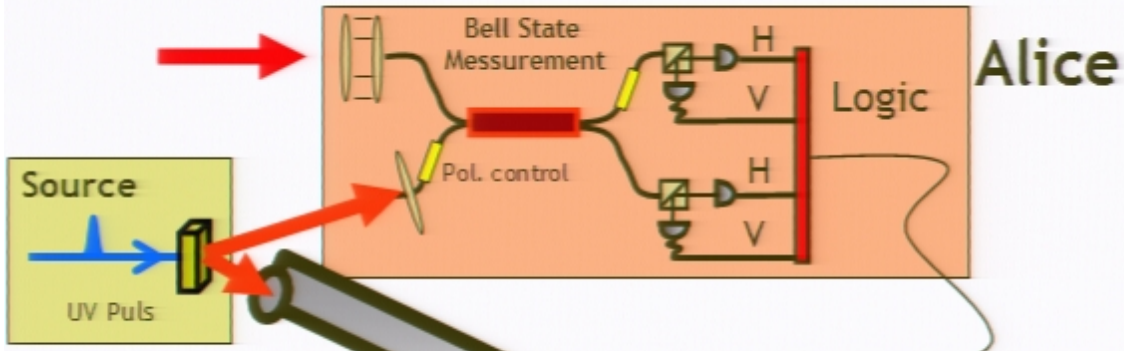
Bennett, Brassard, Crepeau, Josza, Peres, Wooters
1993

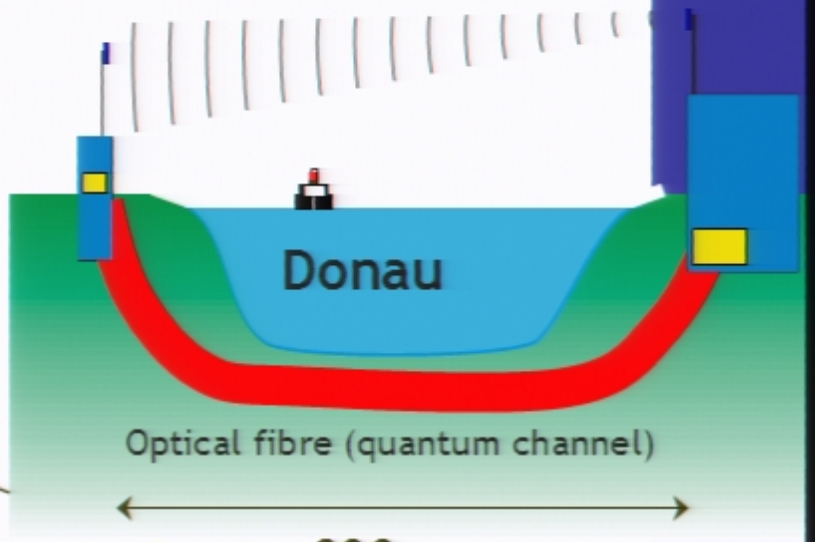


Long Distance Teleportation: The Third-Man Experiment

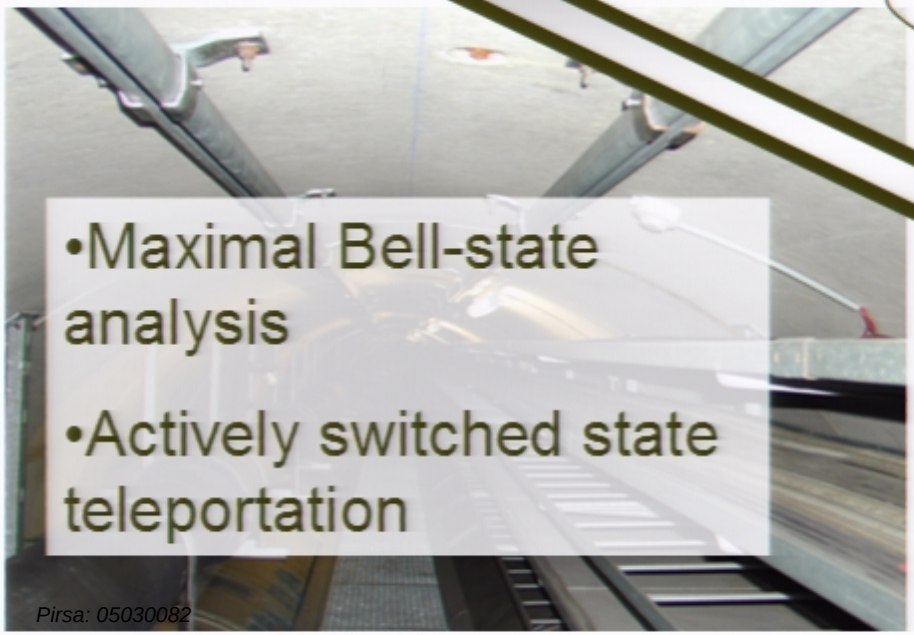
UNIVERSITÄT WIEN

R. Ursin



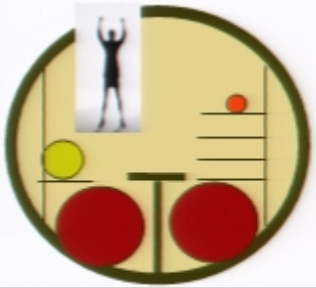


Classical Information

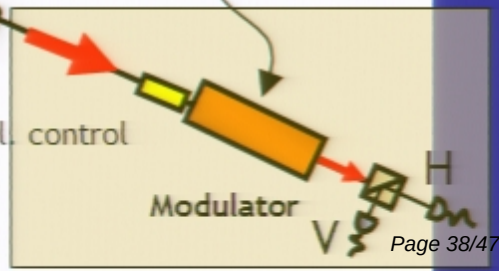


- Maximal Bell-state analysis
- Actively switched state teleportation

Quantum Information

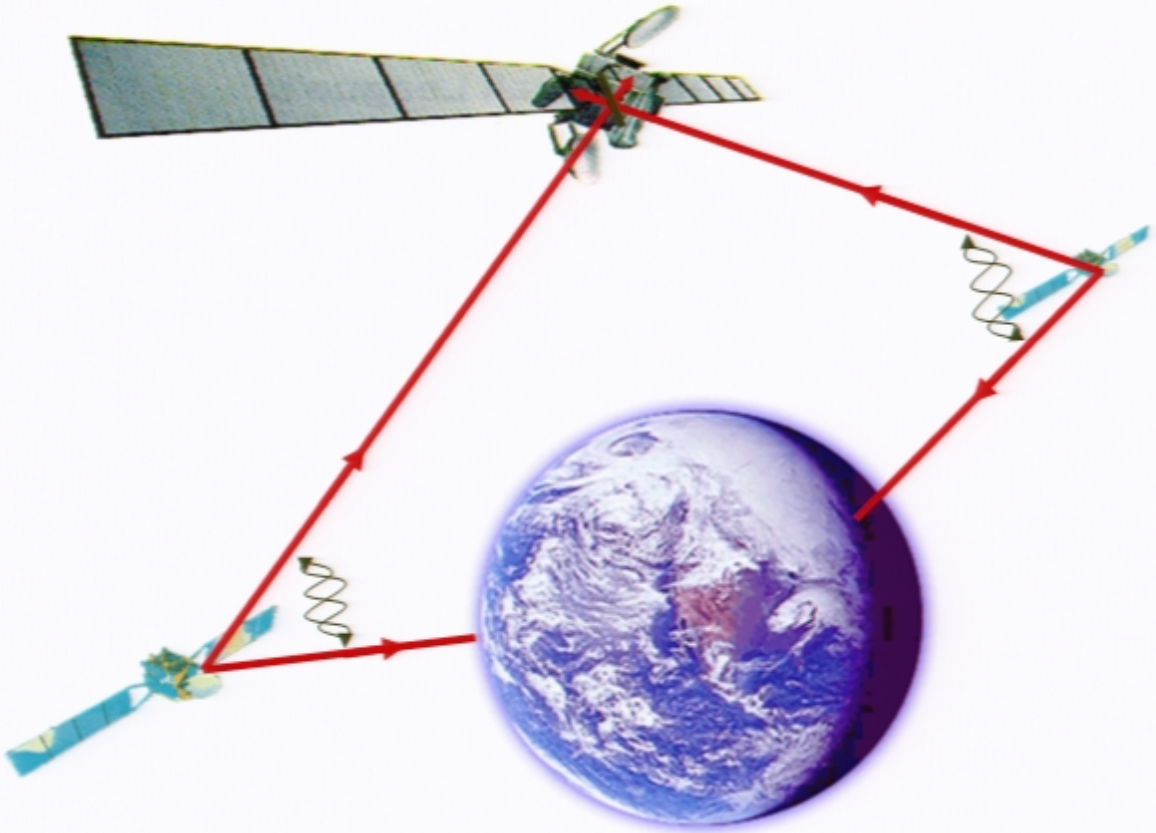


Bob



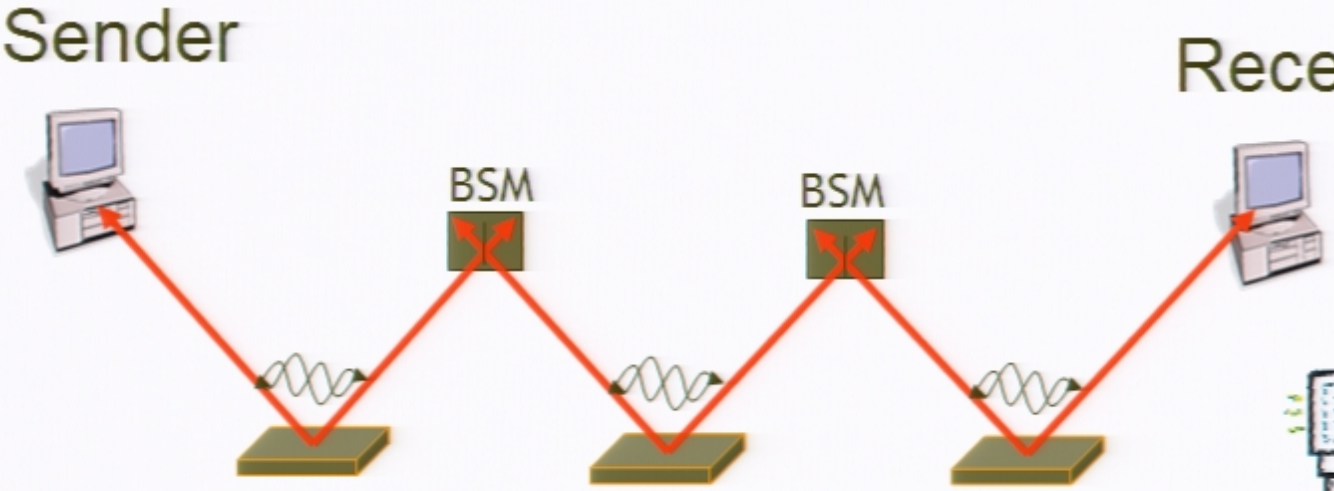
UNIVERSITÄT WIEN

World Wide Quantum Communication



Another Vision!

UNIVERSITÄT WIEN



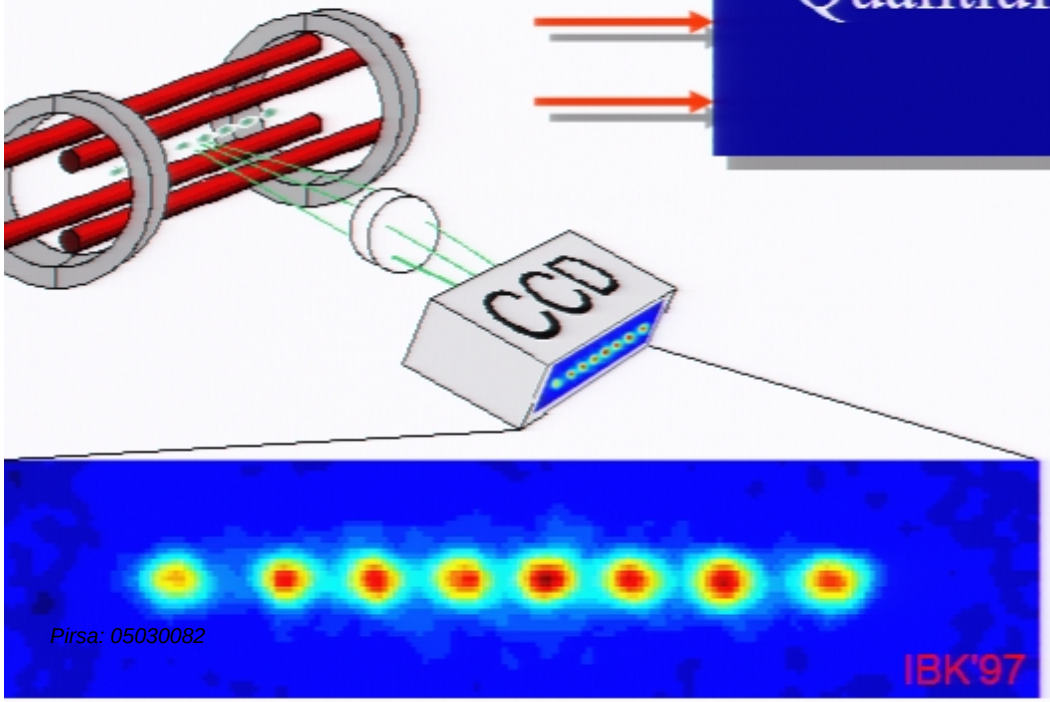
Vision:

Quantum network
and Teleportation

The Quantum Computer

UNIVERSITÄT WIEN

Superposition
Randomness
Entanglement



NMR:

LaFlamme Univ Waterloo

Ions: Cirac-Zoller

Blatt et al

UNIVERSITÄT WIEN

Predicting the Future

"Where a calculator on the Eniac is equipped with 18.000 vacuum tubes and weighs 30 tons, computers in the future may have only 1000 tubes and weigh only 1½ tons "

Popular Mechanics, March 1949

UNIVERSITÄT WIEN

Predicting the Future

"Where a calculator on the Eniac is equipped with 18.000 vacuum tubes and weighs 30 tons, computers in the future may have only 1000 tubes and weigh only 1½ tons "

Popular Mechanics, March 1949

UNIVERSITÄT WIEN

Predicting the Future

"Where a calculator on the Eniac is equipped with 18.000 vacuum tubes and weighs 30 tons, computers in the future may have only 1000 tubes and weigh only 1½ tons "

Popular Mechanics, March 1949

UNIVERSITÄT WIEN

In the Beginning was the Bit

Information is the irreducible kernel from which everything else flows

UNIVERSITÄT WIEN

»I want to know how God created this World. I am not interested in this or that phenomenon .... I want to know His thoughts, all the rest are just details.«

Albert Einstein