DEPARTMENT OF
NETWORKED SYSTEMS
AND SERVICES

Introduction, motivation

Quantum Computing and its Applications
BMEVIHIAD00, Spring 2025

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MŰEGYETEM 1782

QUANTUM FLAGSHIP

Discover About Newsroom

Stay tuned

The future is Quantum.

The Second Quantum Revolution is unfolding now, exploiting the enormous advancements in our ability to detect and manipulate single quantum objects. The Quantum Flagship is driving this revolution in Europe.

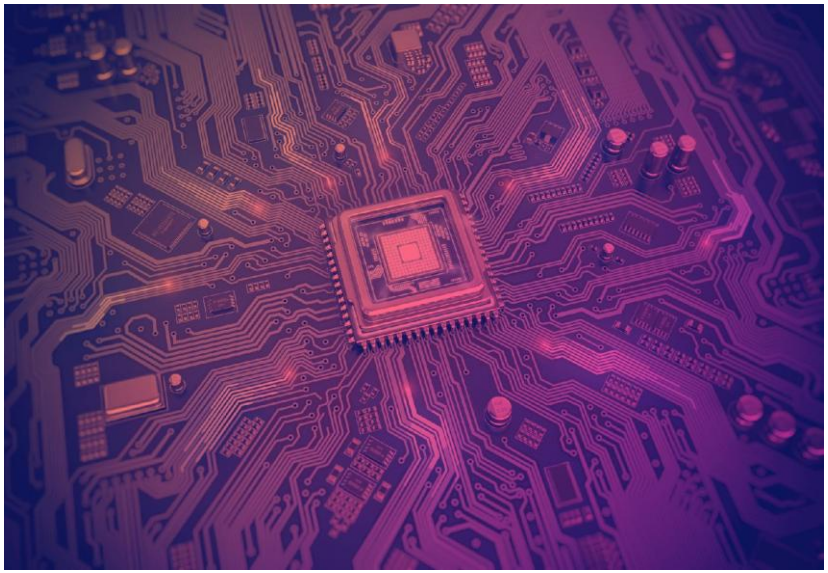
LEARN MORE

100 YEARS OF QUANTUM IS JUST THE BEGINNING

The 2025 International Year of Quantum Science and Technology (IYQ) recognizes 100 years since the initial development of quantum mechanics. Join us in engaging with quantum science and technology and celebrating throughout the year!

Search All Events →

WHAT DOES IT MEAN TO BE QUANTUM?



A system is quantum if it behaves according to the laws of quantum mechanics.

Quantum systems display peculiar features

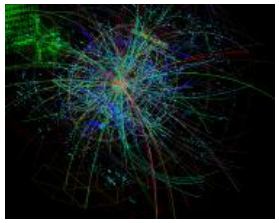
- quantization
- wave-particle duality
- tunneling effects
- superposition
- quantum interference
- …

Quantum systems are typically microscopic

but

the laws of quantum mechanics are the basis of many macroscopic systems.

SYSTEMS OPERATING ON THE BASIS OF QUANTUM MECHANICS

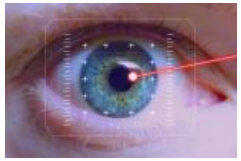


Collisions at CERN

Photosynthesis

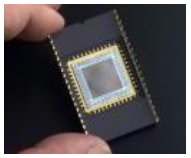
Solar panels

Nuclear power plants



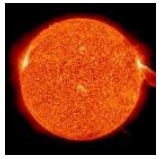
Lasers

Integrated circuits



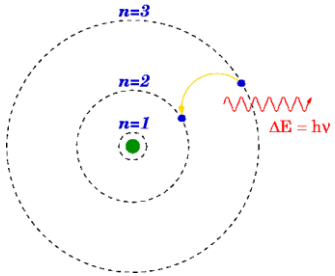
CCDs

LEDs

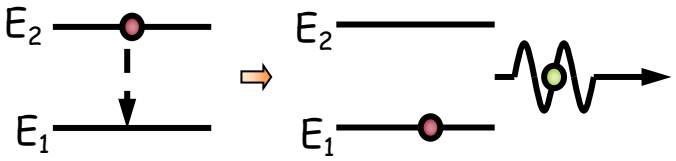


Nuclear fusion

QUANTIZATION
LIGHT ABSORPTION AND EMISSION

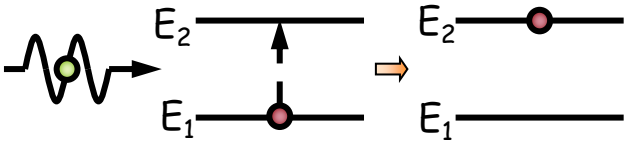


Bohr's atomic model



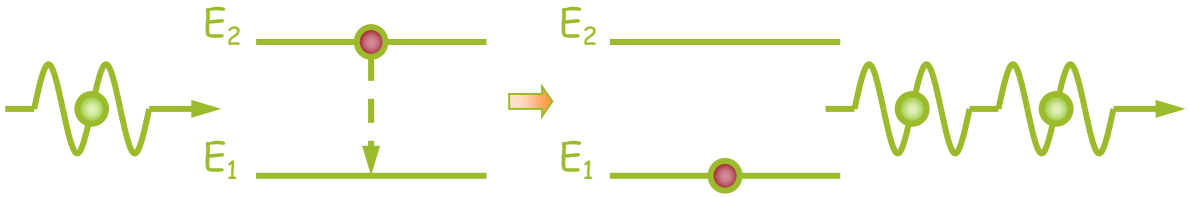
Spontaneous emission

Absorption

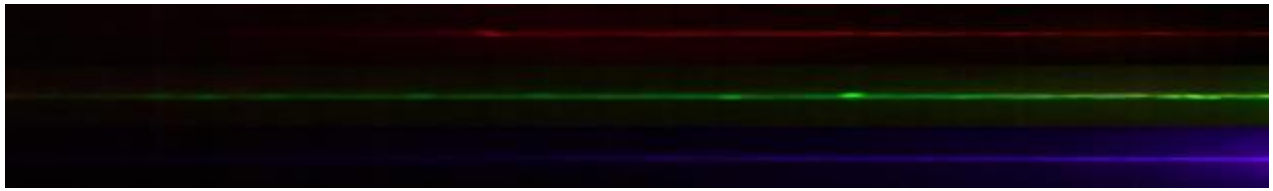


Conversion of light to electrochemical energy

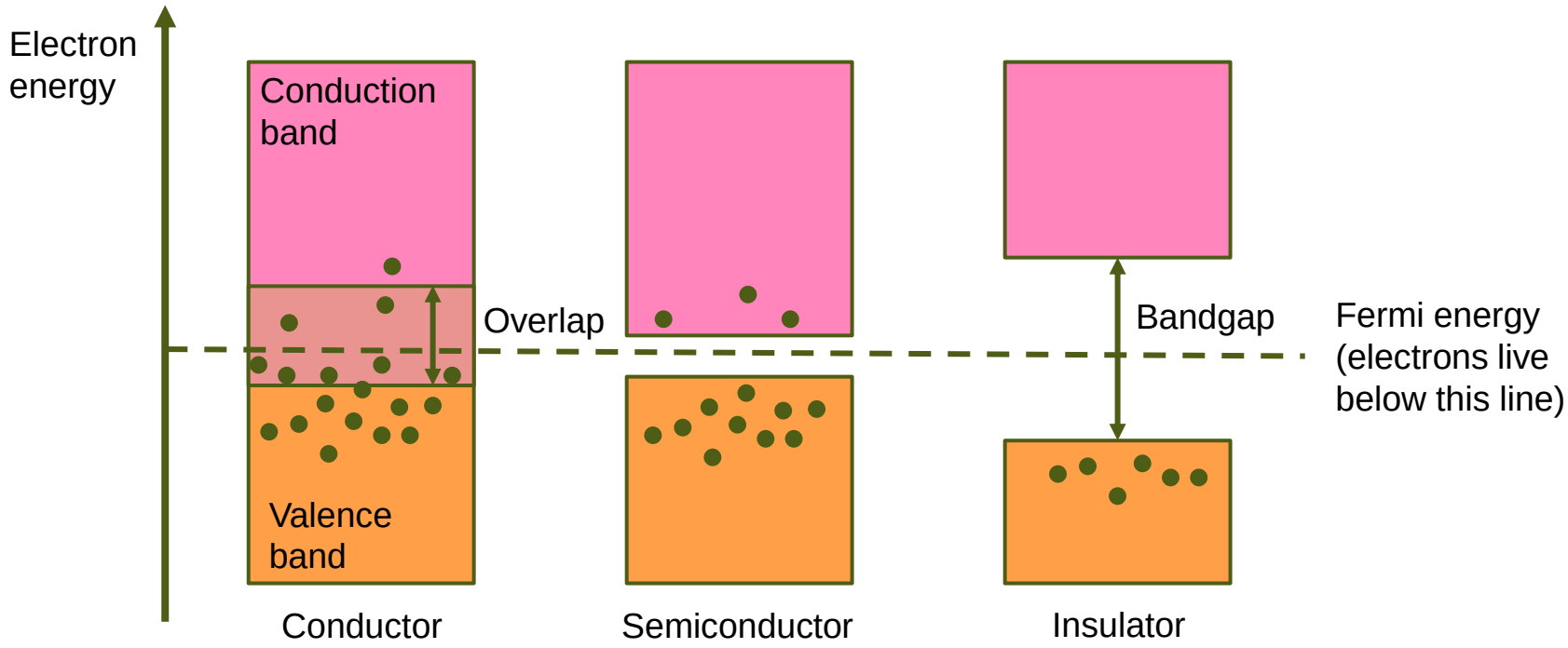
QUANTIZATION
STIMULATED EMISSION – LASERS



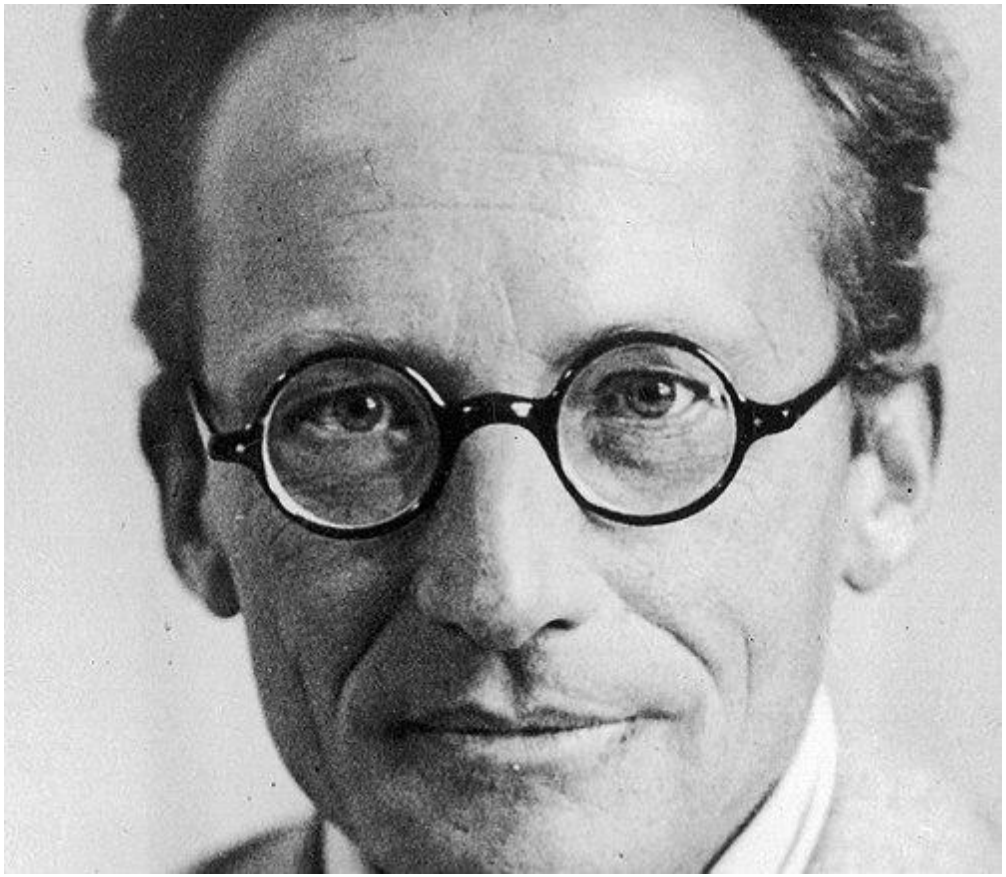
Laser = **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation



QUANTIZATION SEMICONDUCTORS



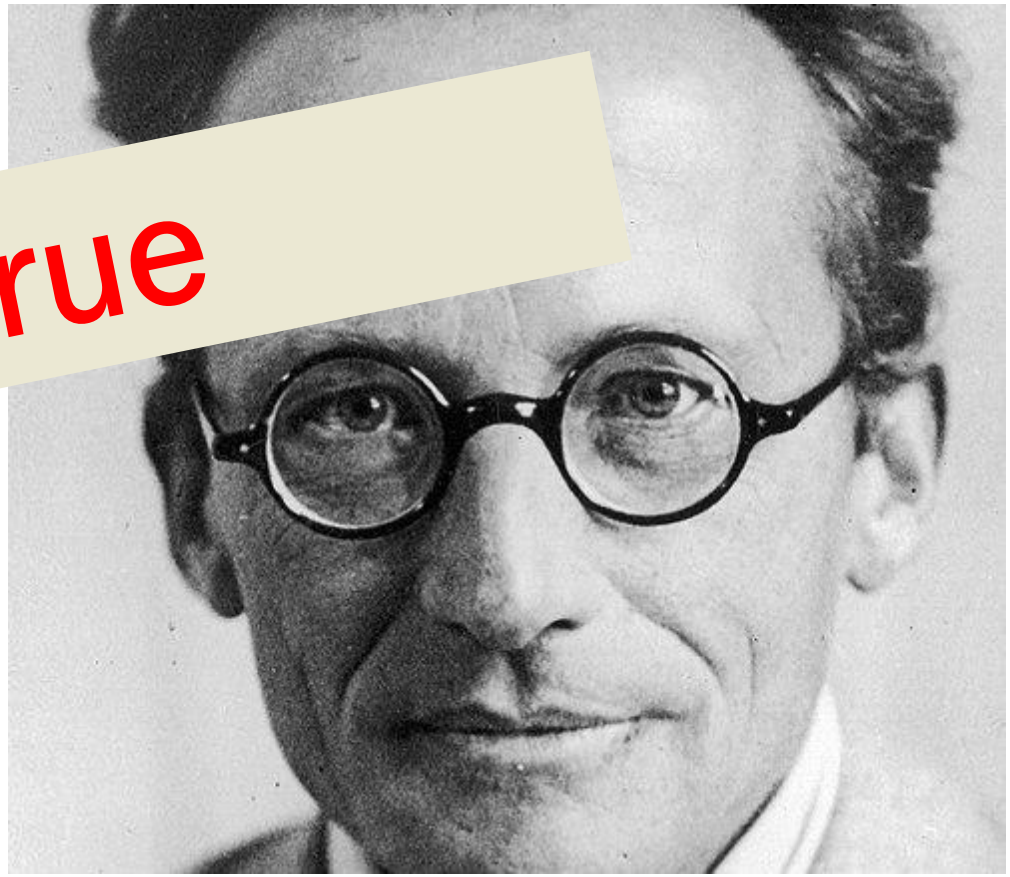
*„**We never experiment with just one electron or atom** or (small) molecule. In thought-experiments we sometimes assume that we do; this invariably entails ridiculous consequences... **we are not experimenting with single particles**, any more than we can raise Ichthyosauria in the zoo"*



Erwin Schrödinger [*Brit. J. Phil. Sci.* 3, 233 (1952)]

*„**We never experiment with just one electron or atom** or (small) molecu*
In thoug
consequences...
***we are not experimenting with single particles**, any more than we can raise Ichthyosauria in the zoo"*

Not true

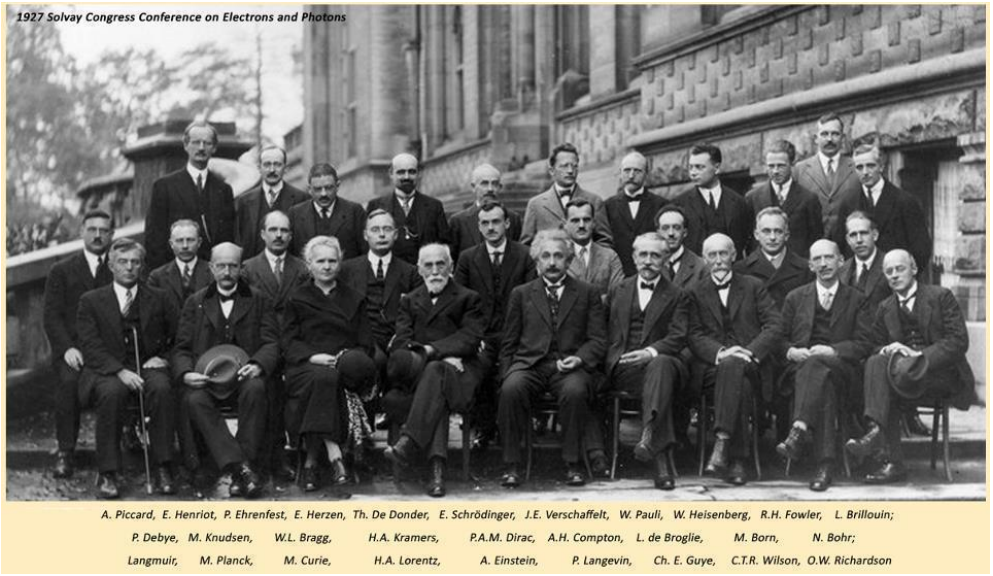


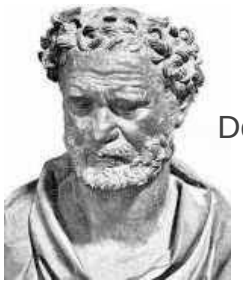
Erwin Schrödinger [*Brit. J. Phil. Sci.* 3, 233 (1952)]

We are living in the age of the second quantum technological revolution

CLASSICAL IS NOT ENOUGH

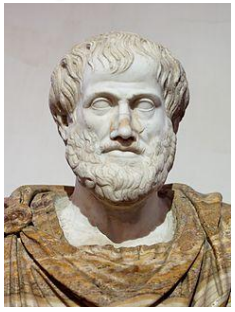
Solvay conference
1927
17 Nobel laureates

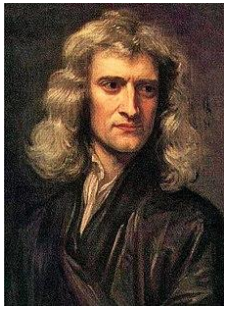




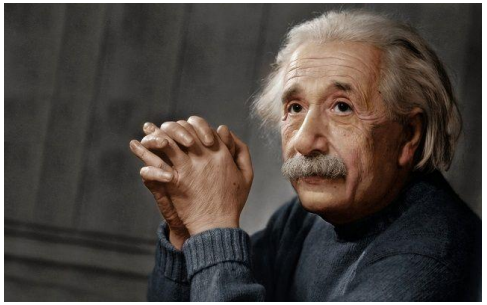
Democrítus of Abdera
(B.C. 460-370) i

Arisztotle
(B.C. 384-322)





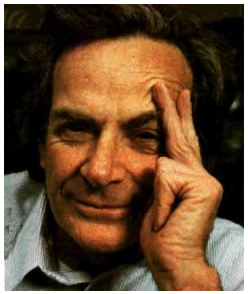
1 Nobel laureate



QUANTUM HISTORY

Solvay conf. 1927

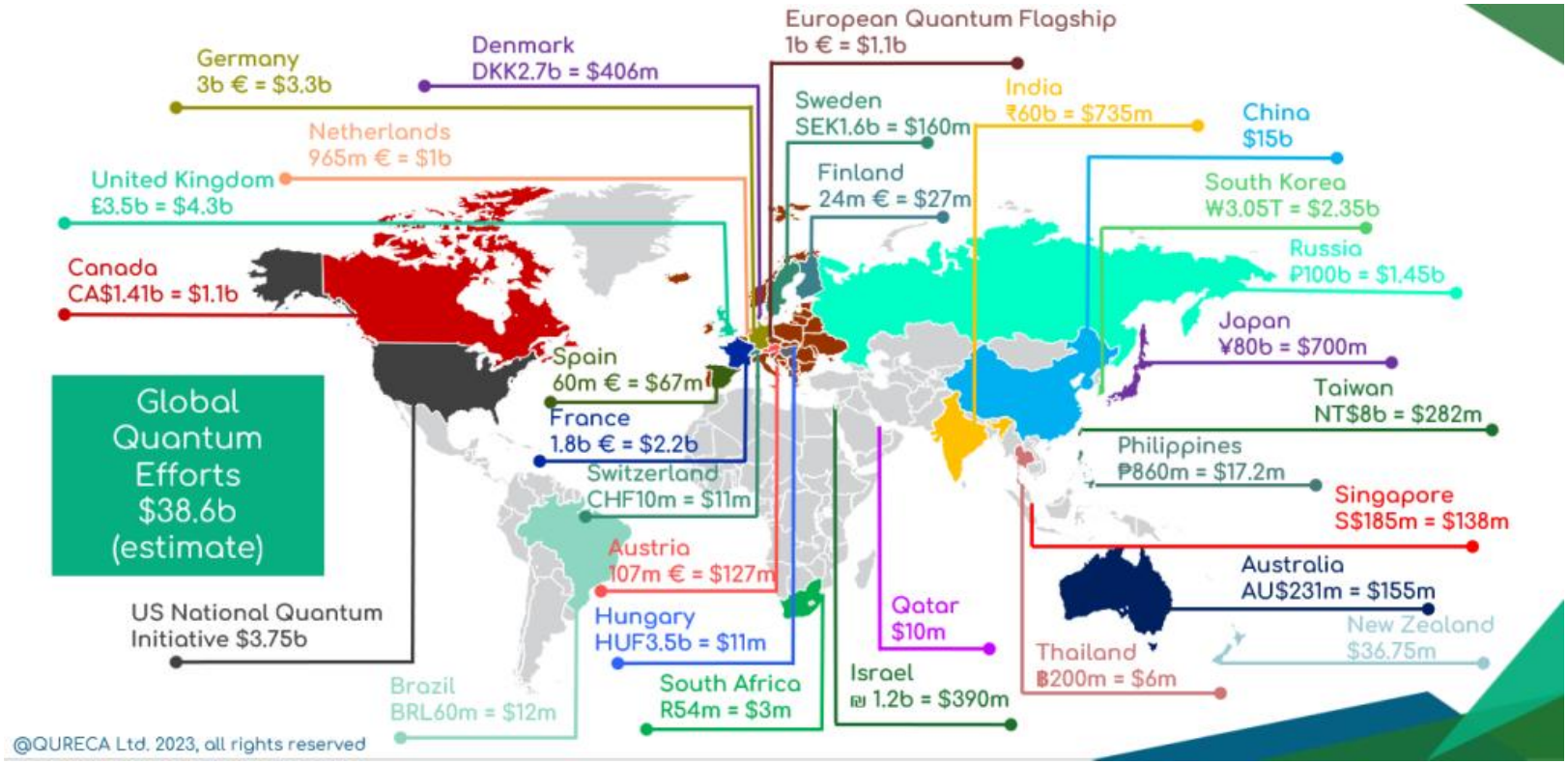
R. P. Feynmann
1985



2018

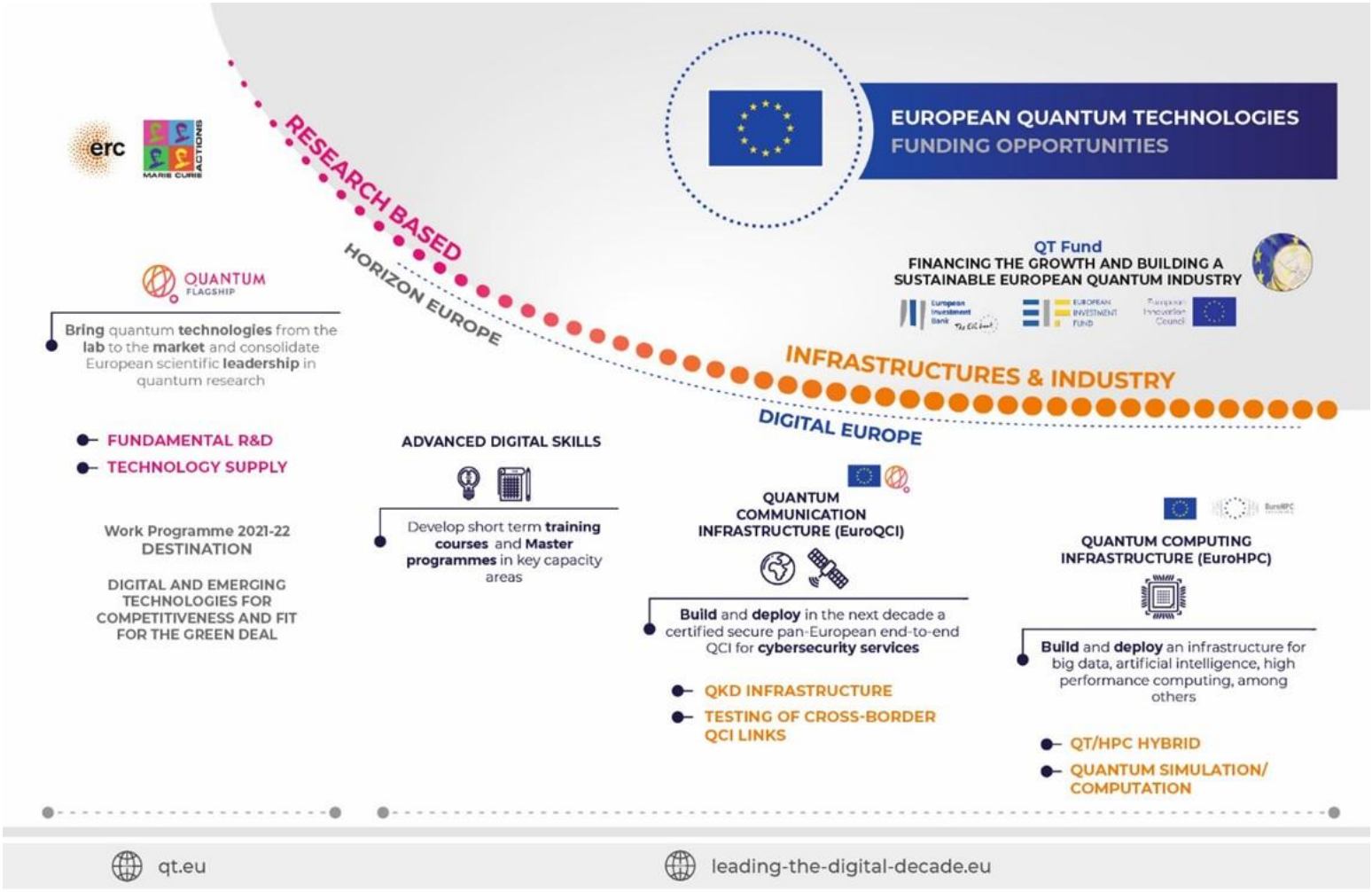
2030

QUANTUM PROJECTS ALL OVER THE WORLD



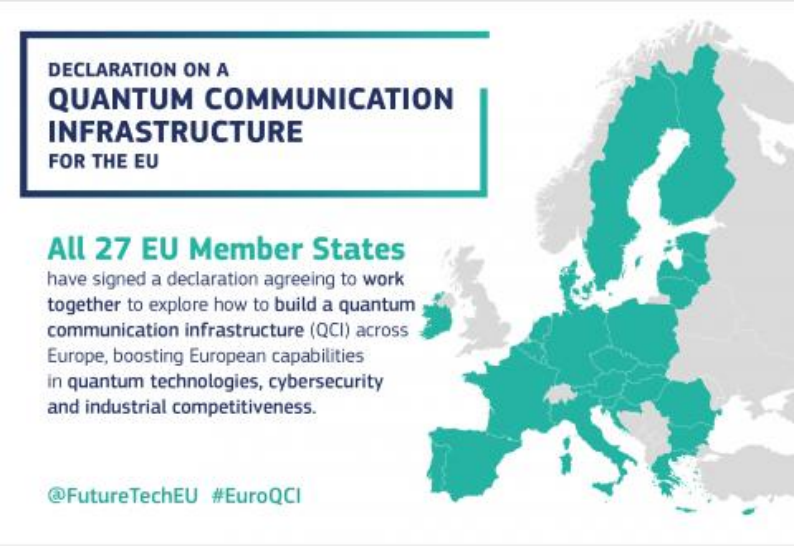
Maninder Kaur, "Overview of Quantum Initiatives Worldwide 2023", Qureca Ltd., July 19, 2023, https://qureca.com/overview-of-quantum-initiatives-worldwide-2023/

IN EUROPE: ROLLING PLAN OF THE EUROPEAN COMMISSION



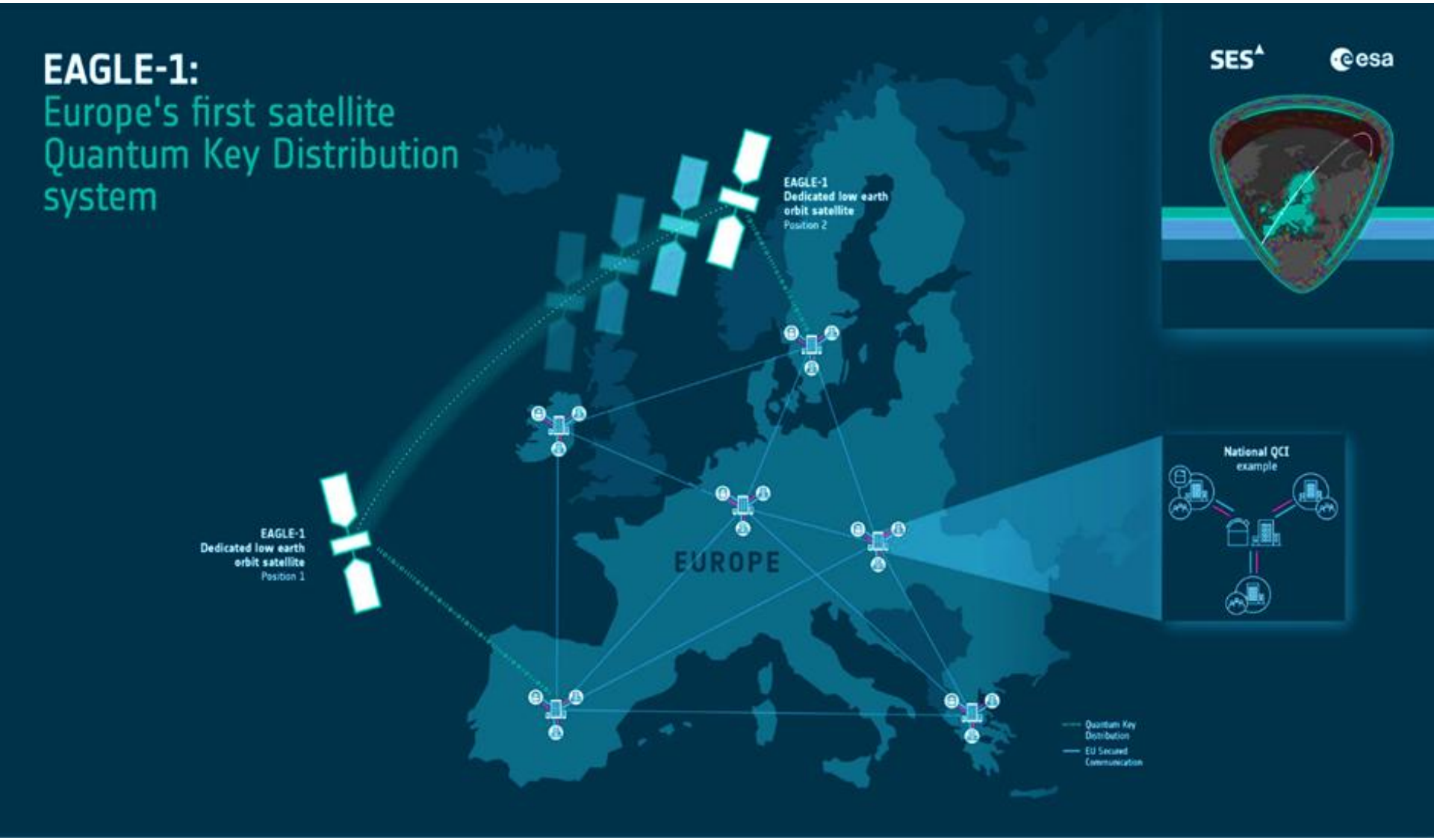
https://joinup.ec.europa.eu/collection/rolling-plan-ict-standardisation/quantum-technologies-rp2024

EUROPEAN QUANTUM COMMUNICATION INFRASTRUCTURE (EUROQCI)



EuroQCI

„In 2023-2025, the Digital Europe programme will fund support for:
•the development of European QKD devices and systems
•the development and deployment of national quantum communication networks
•a testing and certification infrastructure for QKD devices, technologies and systems that will ultimately be used in the EuroQCI.
In 2024-2026, the Connecting Europe Facility will fund support for cross-border links between national quantum communication networks, along with links between the EuroQCI's earth and space segments."


EAGLE-1:
Europe's first satellite
Quantum Key Distribution
system
SES
esa
EAGLE-1
Dedicated low earth
orbit satellite
Position 2
EAGLE-1
Dedicated low earth
orbit satellite
Position 1
EUROPE
National QCI
example
Quantum Key
Distribution
EU Secured
Communication

HUNGARIAN LANDSCAPE: NATIONAL QUANTUM PROJECTS

2017-2021:

HUNQUTECH

2020-2025:

Quantum Information National Laboratory HUNGARY

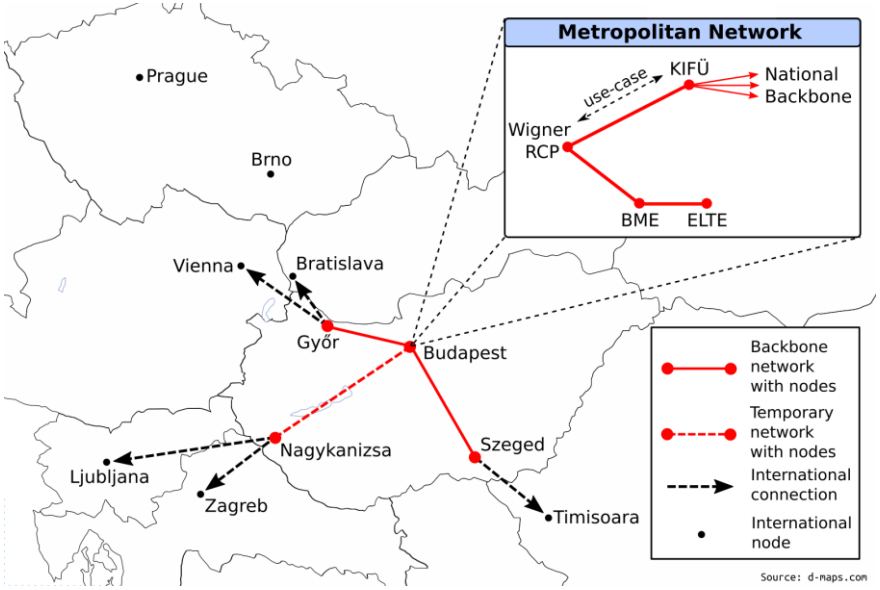
2023-2026:

QCIHungary

OBJECTIVES OF THE HUNGARIAN QCI PROJECT

- Deployment of a **functioning national quantum communication backbone**
- **Test, and validate continuous, high security communication between two governmental data centres**
- Further **development of experimental QKD systems**.
- **Preparation for satellite-based quantum communication**.
- Launch programs to **train experts to be able to operate and use the future quantum communication infrastructure**
- Develop a **software stack for the abstraction layer** for further application development.
- **International cooperation**

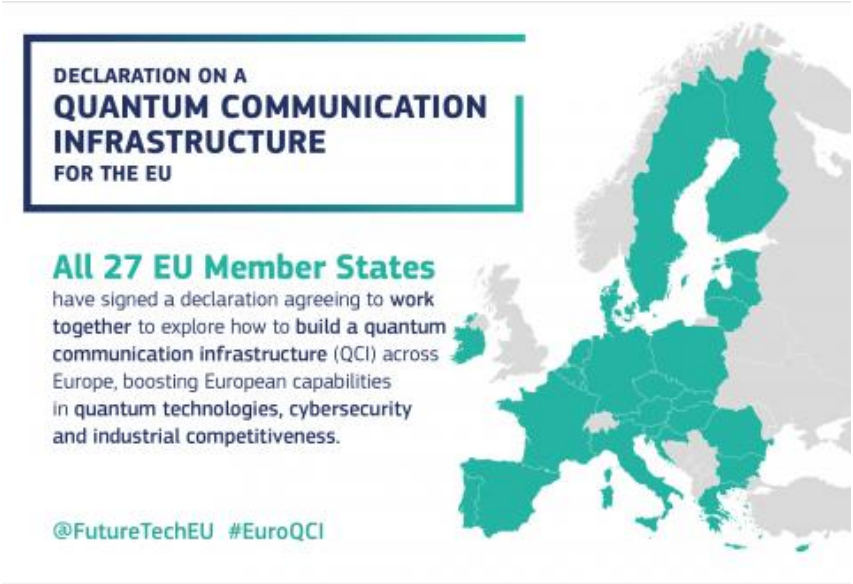
Topology Map



QCIHungary

WE ARE PART OF EUROQCI

EuroQCI



Development activities

- Develop a QKD system using entangled photon pairs sent over a free-space optical telescope link.
- Install an optical ground station for satellite-based QKD systems.
- Realize a QKD system based on entangled photon pairs sent over an optical fiber link.
- Complete the development of a continuous variable QKD system.

QCIHungary

OUR QUANTUM COMMUNICATIONS RESEARCH GROUP

OUR MAIN ACTIVITIES AT THE MOBILE COMMUNICATION AND QUANTUM TECHNOLOGIES LABORATORY

Space&5G/6G

Quantum

IoT

Classical optical comm. (including RoF)

MCL
Mobile Communications & Quantum Technologies Lab.

Our university is funding member of the 5G Coalition of Hungary and active member of its 6G working group

5G Koalíció

OUR AREA OF INTEREST IN THE QUANTUM DOMAIN

Quantum computing and quantum communications offer a wide range of solutions in a variety of areas

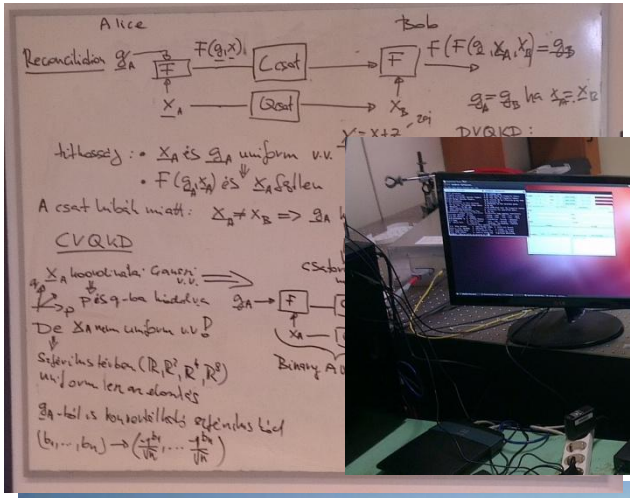
- quantum computers
- quantum cryptography
- quantum random numbers
- quantum key distribution

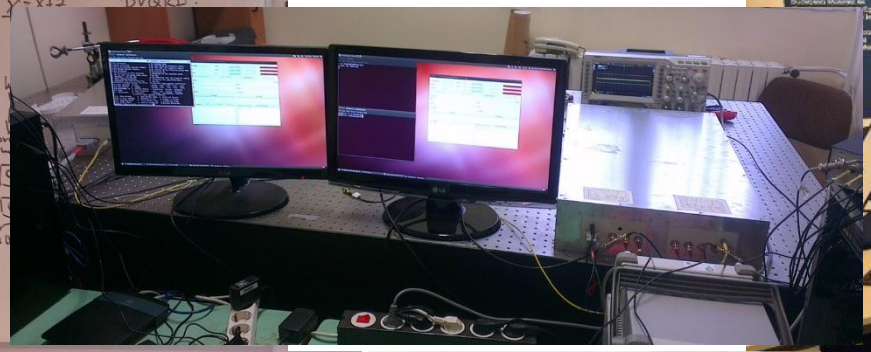
MCL
Mobile Communications & Quantum Technologies Lab.

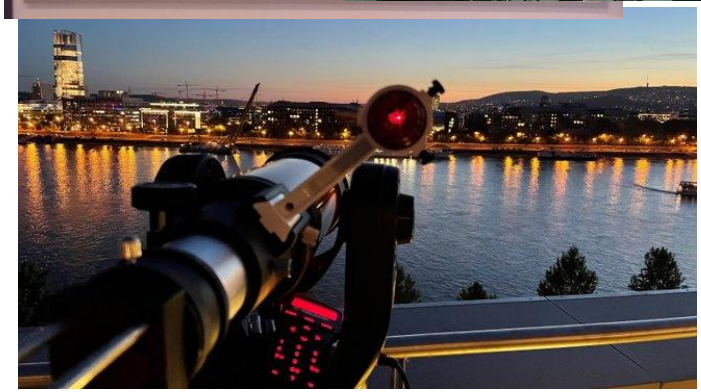
One of the main issues: how quantum communication solutions can be applied in engineering (e.g. telecommunications) systems to increase the current level of security

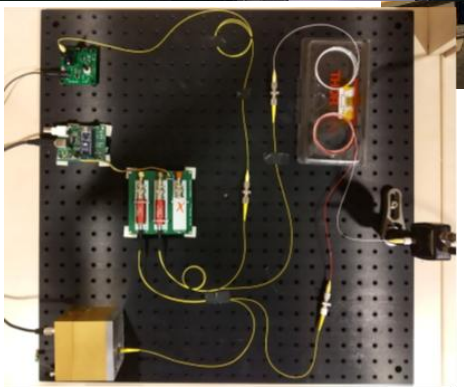
We are involved in several research projects and teach several courses related to quantum informatics and quantum communication

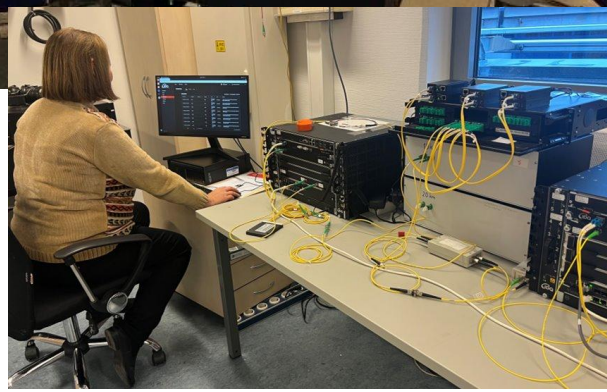
THEORY, DESIGN, DEVELOPMENT, MEASUREMENT, PRACTICAL APPLICATIONS











OUR ACTIVITIES (1)

Competences and actual projects – fiber

- Own developed Optical Quantum Random Number Generator
- BB84 QKD demonstration with own developed system *(in cooperation with Ericsson Hungary)*
- CV QKD long distance demonstration with own developed system as part of the national QKD network *(in cooperation with Hungarian Telekom and HUN-REN Wigner Research Centre for Physics)*
- Developing an entanglement-based QKD system (fiber-based, using SNSPD detectors)
- OpenQKD OpenCall: QuantumGigalink - Extension of high-speed leased line service with QKD encryption function *(in cooperation with Magyar Telekom)*
- Participation in the national project of the European Quantum Communication Infrastructure (EuroQCI)
- Modeling, analysis, planning, implementation and operational support of QKD networks *(in cooperation with NETvisor Zrt.)*

EuroQCI QCIHungary Quantum Information National Laboratory HUNGARY ERICSSON ADVANET Magyarország Rendszerintegrációs Kft. Magyar Telekom Netvisor

OUR ACTIVITIES (2)

Competences and actual projects – free-space and space

- Development of an entanglement-based free-space QKD over River Danube *(in cooperation with One Magyarország Zrt.)*
  - in-house entangled photon source at 810nm, in-house optical clock synchronization
- Participating in different ESA projects
  - QuStation - Quantum Communications Capable Optical Ground Stations in Hungary *(in cooperation with ATL Zrt.)*
  - Certain - Complex electronic hardware for free-space entanglement-based quantum key distribution system *(in cooperation with Relcom Kft.)*
  - DeQOS - Development of Quantum and Optical Communication for Satellite Systems Course *(in cooperation with ATL Zrt., C3S Ltd., E-Group Zrt.)*
- Deploying quantum-capable optical ground station
- Investigating the possibilities for cubesat-based QKD
- Theoretical work on future's satellite based QKD systems

OUR ACTIVITIES (3)

Research directions – quantum internet

- Developing and analyzing entanglement-based quantum communication protocols over the quantum internet (quantum wifi, superactivation of quantum channels)
- Analyzing different aspects of satellite-based quantum networks (architecture, configurations, routing)
- Investigation of application possibilities of different quantum memories (both in fiber-based and satellite-based networks)

Research directions – quantum computers

- Analyzing different quantum algorithms on different quantum computers
- Developing new algorithms for quantum computers

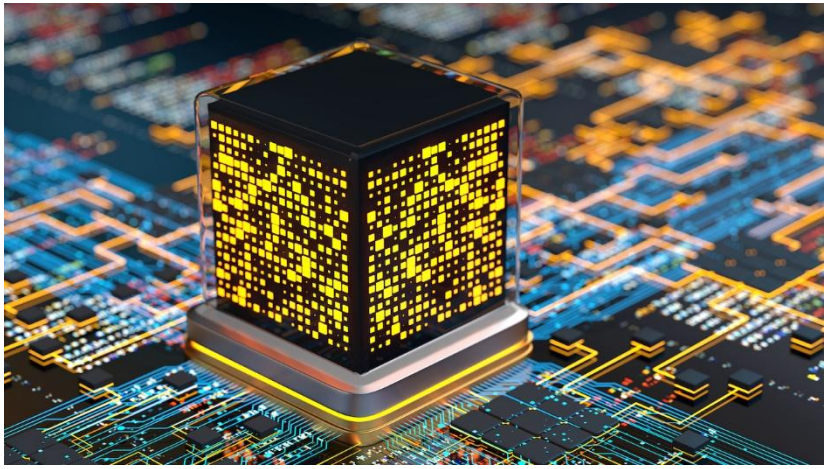
Educational activities (BSc, MSc, PhD)

- 20+ years experience

EuroQCI QCIHungary QNL Quantum Information National Laboratory HUNGARY

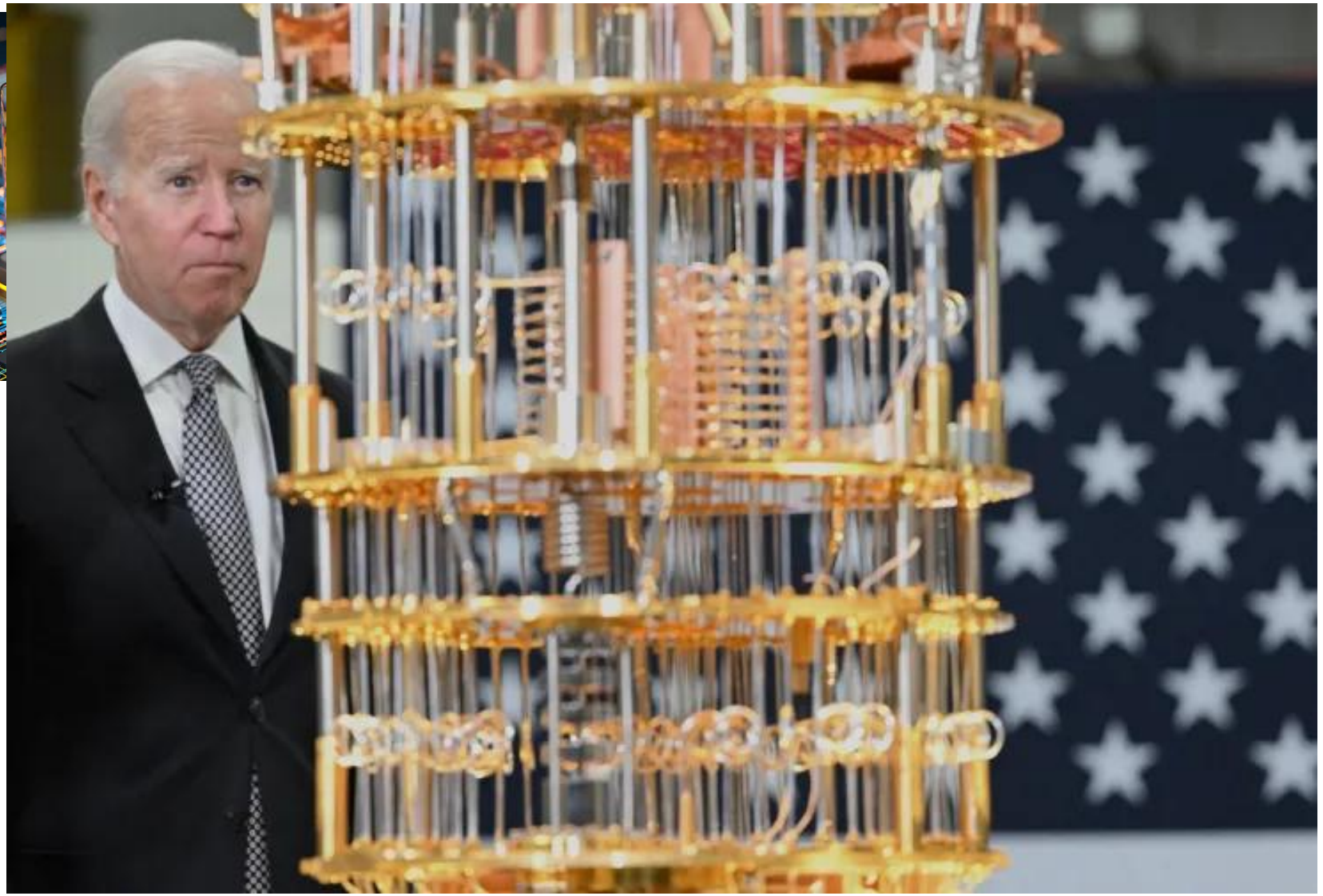
Why is it interesting?

CONTEXT

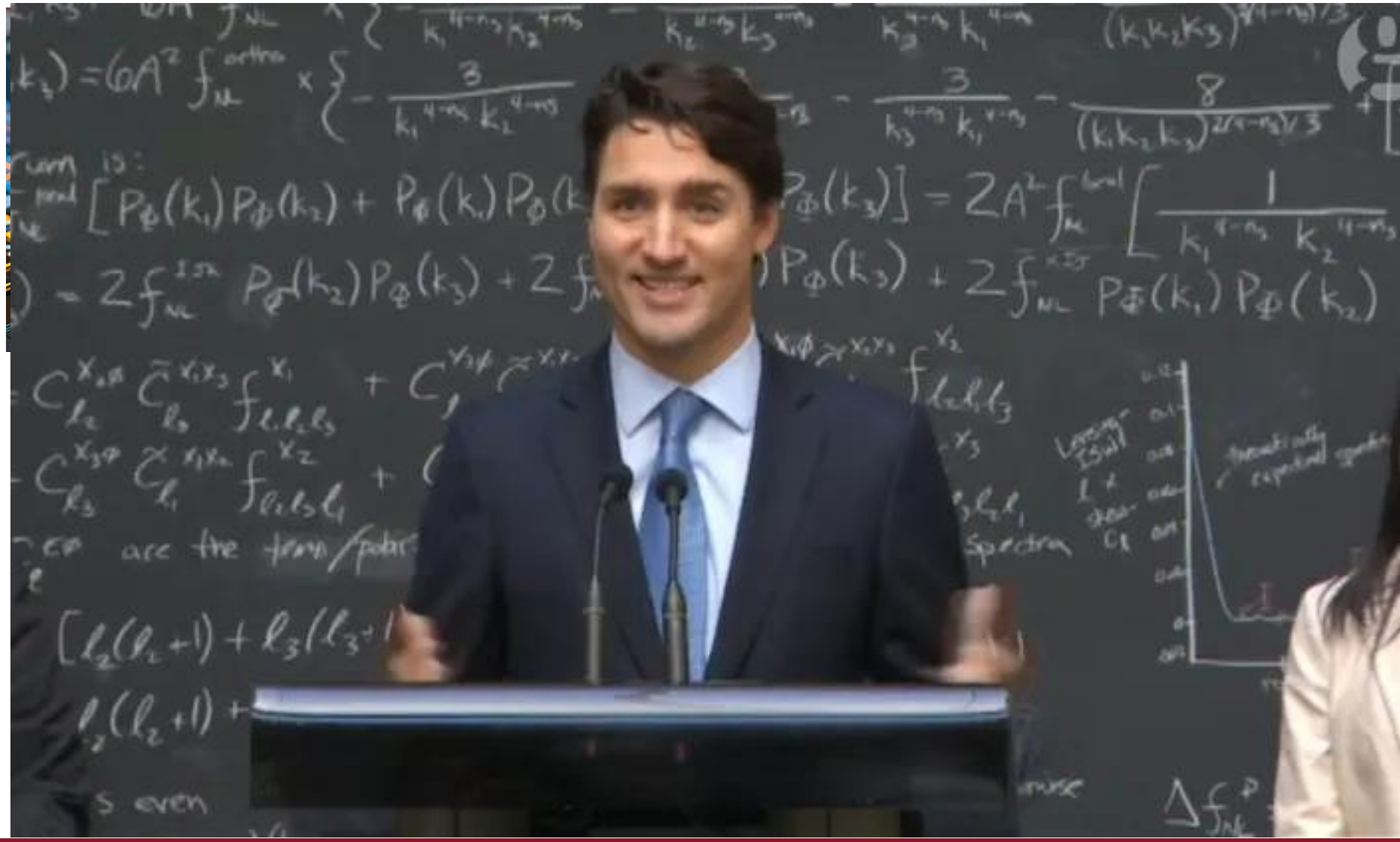



IQM
VTT

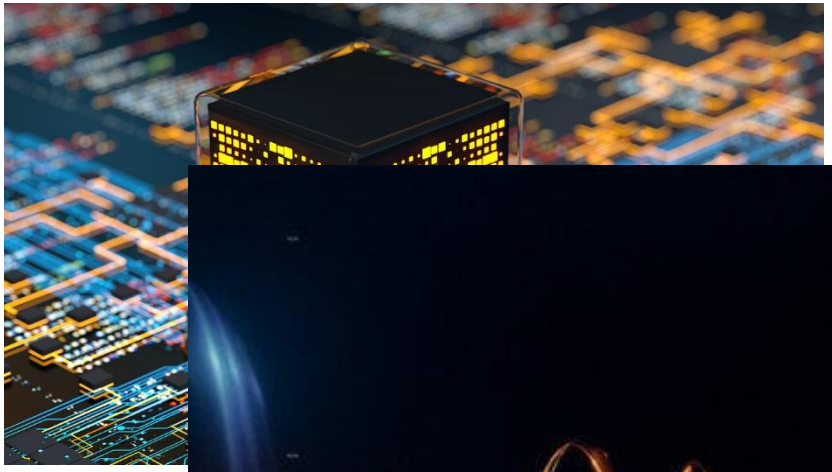
CONTEXT



CONTEXT



CONTEXT



The Nobel Prize in Physics 2022

Ill. Niklas Elmehed © Nobel Prize Outreach

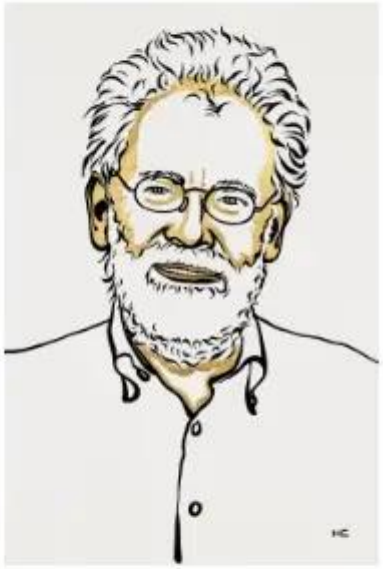
Alain Aspect

Prize share: 1/3

Ill. Niklas Elmehed © Nobel Prize Outreach

John F. Clauser

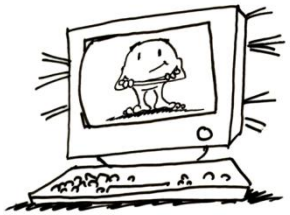
Prize share: 1/3



Ill. Niklas Elmehed © Nobel Prize Outreach

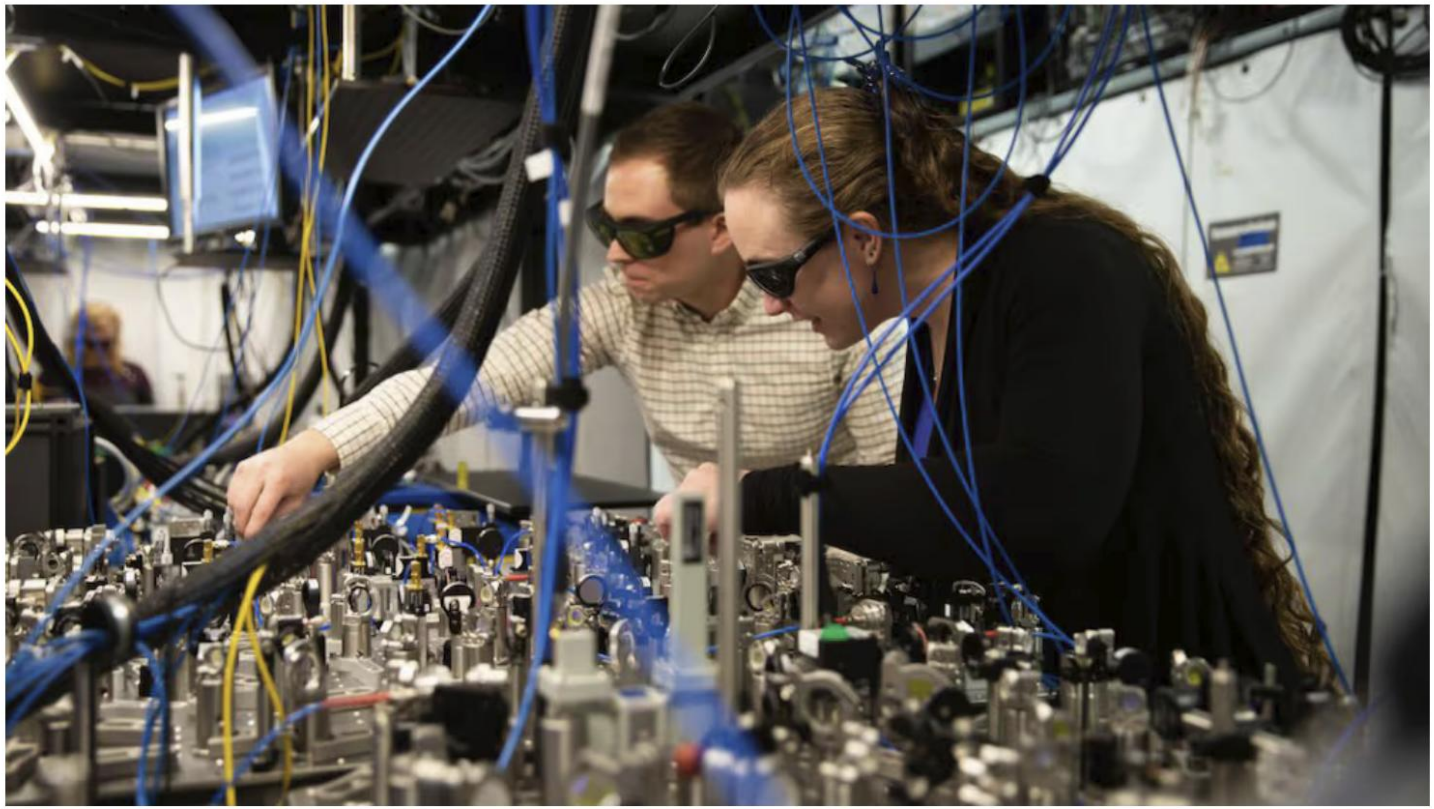
Anton Zeilinger

Prize share: 1/3



Microsoft's latest breakthrough in quantum computing: What it means

▶ New technology will boost the reliability of quantum computing, which is driving discoveries in fields such as health care, energy, AI and financial modelling



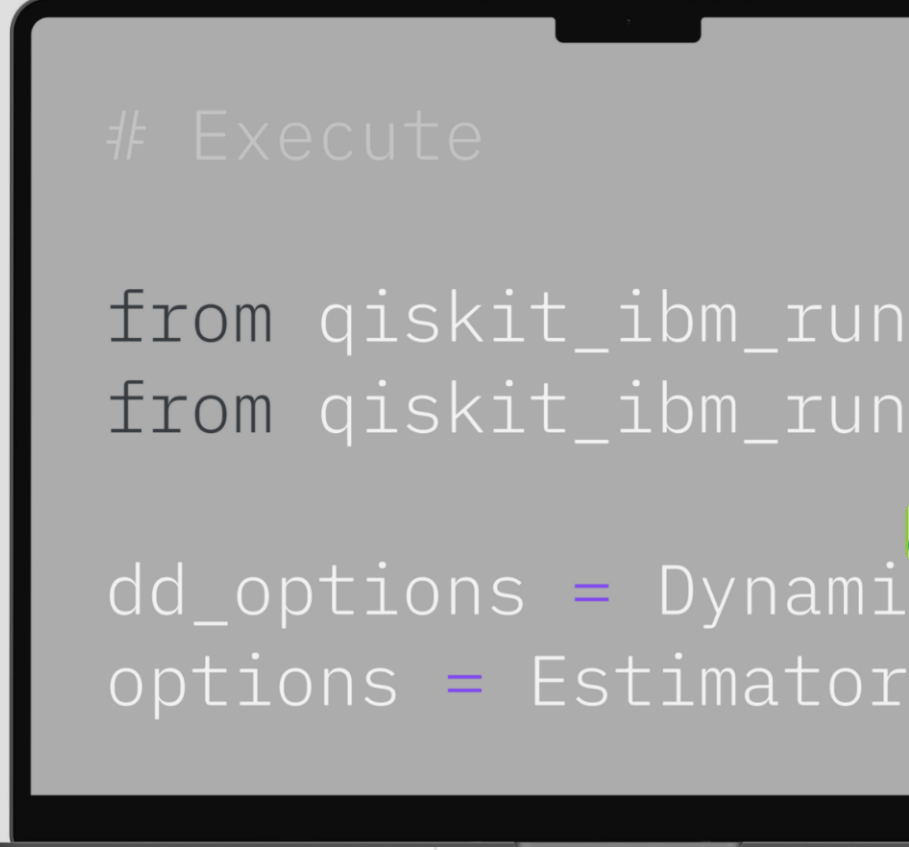
Developers performed more than 14,000 experiments with the new technology without a single error, Microsoft and Quantinuum said. Photo: Quantinuum

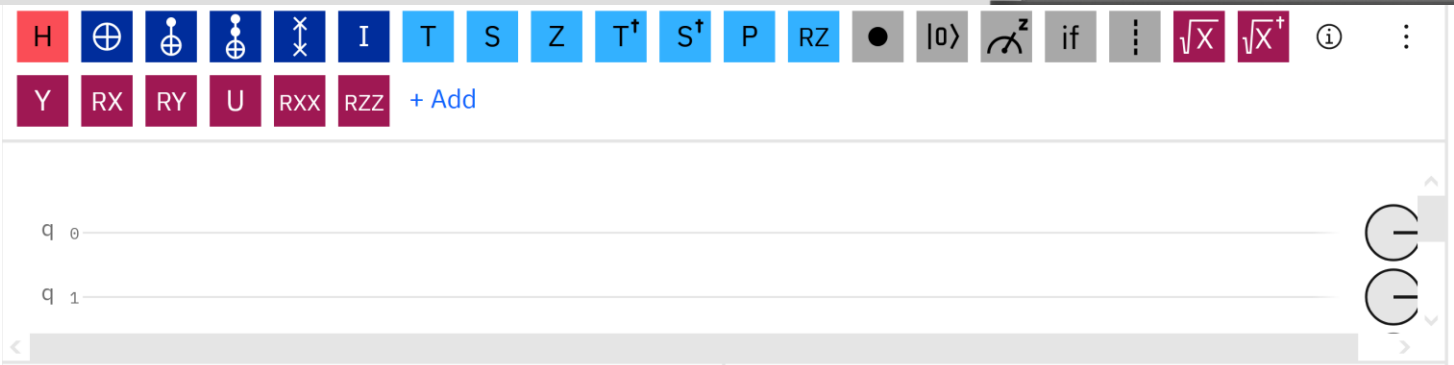
Alkesh Sharma
Apr 03, 2024

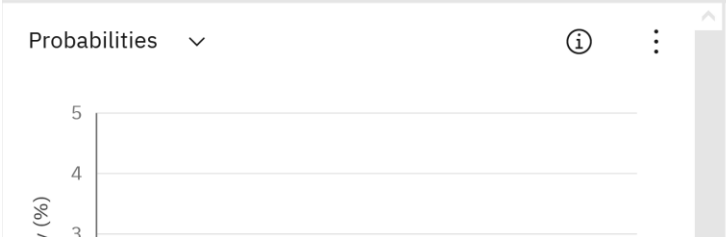
The most popular quantum software, now even more powerful

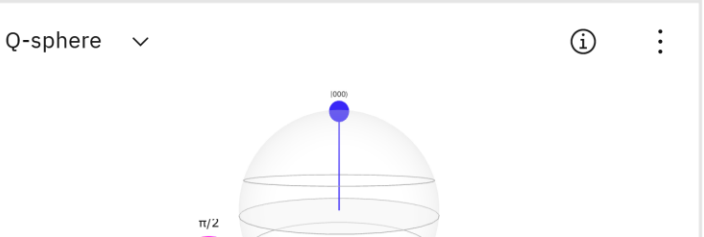
Read the Qiskit SDK v1.0 announcement →

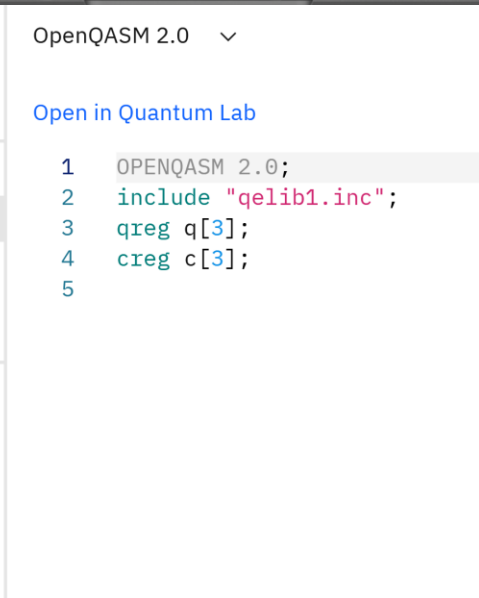
Watch the video











News

Researchers create entangled quantum magnets with protected quantum excitations

Published: 29.8.2024

Researchers created a new entangled quantum state of matter by building an artificial quantum material atom-by-atom. The state, dubbed a higher-order topological quantum magnet, may be a way to address key problems in quantum technology, such as decoherence in qubits.

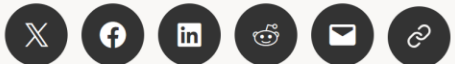
EAGLE-1: Advancing Europe's Leadership in Quantum Communications

Newsroom | 22 Apr 2024

The EAGLE-1 system is a major technology breakthrough that paves the way for secure communications in the EU. Comprising a low-earth-orbit satellite and an extensive ground network, the space-based Quantum Key Distribution (QKD) system will jointly provide valuable mission data for a sovereign European end-to-end solution for secure QKD services.

German cubesat to test quantum key distribution

Debra Werner August 19, 2024



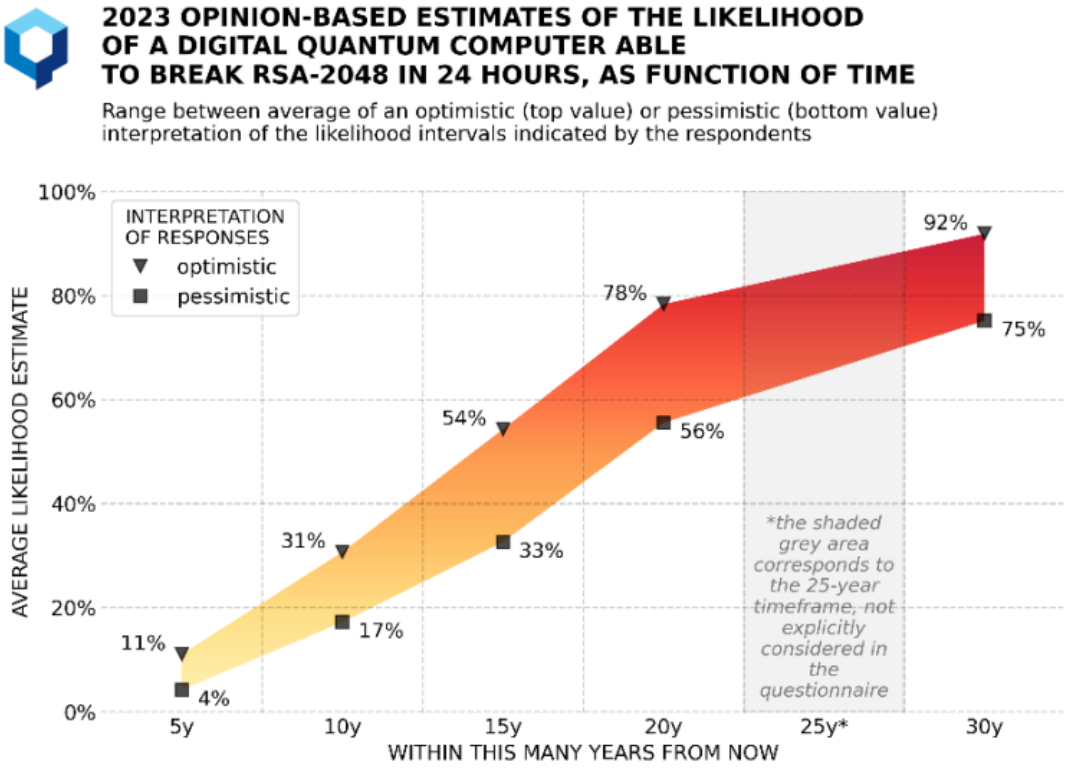
SPACE IMPULSE

News Insights Advisory About Us | Newsletter

QUBE Set To Test Quantum Key Distribution In Space, Points Toward Growing Links Between Quantum And Space Industries

RESEARCH SPACE BUSINESS Matt Swayne • August 20, 2024

WHY NOW?



Forrás: Global Risk Institute 2023

Mosca inequality

The subject and its teachers

LECTURERS IN THIS SEMESTER









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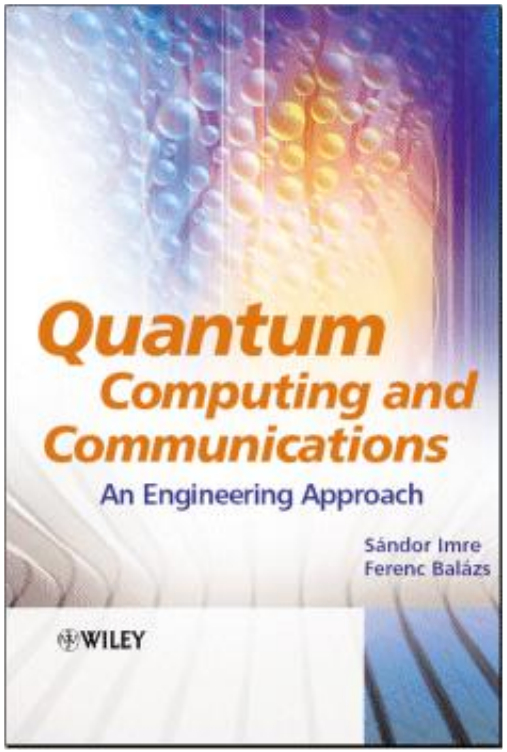
HANDOUTS, BOOKS

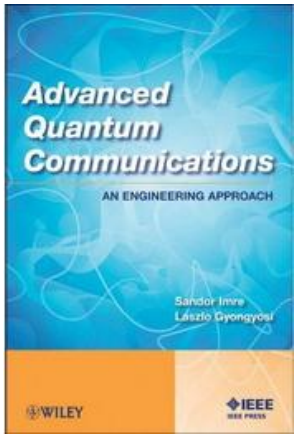
- Slides of lectures will be available in Microsoft Teams

  „If you don't watch the video, the slides are not enough to catch up"

- Books:

  „the recommended books are great, slides can be used to recap the lecture"





COURSE MATERIALS

- It will be added to the Teams group of the course

OFFICIAL SCHEDULE OF THE SEMESTER

Lecture: Monday: 10.15-11.45

Practice: Wednesday: 10:15-11:45

Any changes will be communicated via Neptun or Microsoft Teams!

ACTUAL SCHEDULE OF THE SEMESTER

- To help our students, we will offer this course as a hybrid course
- Monday lectures will be recorded and shared with students. NO lectures will be held on Monday, BUT in person consultations and mid terms will be held on Monday
- Wednesday practical exercises will be in person practical exercises

SCHEDULE OF THE SEMESTER (1)

Topics of the semester on Monday

Date	Topics
2025.02.10	Introduction and motivation
2025.02.17	Postulates
2025.02.24	Entanglement
2025.03.03	Measurement
2025.03.10	Quantum interferometer. No Cloning Theorem
2025.03.17	In person consultation before mid-term
2025.03.24	Mid term. Quantum key distribution
2025.03.31	Teleportation
2025.04.07	Quantum parallelism
2025.04.14	In person consultation before mid-term
2025.04.21	Spring break
2025.04.28	Breaking the RSA: Shor's algoritm
2025.05.05	Mid term. Searching in an unsorted database: Grover's algorithm
2025.05.12	Space-based quantum communication
2025.05.19	Mid term.

SCHEDULE OF THE SEMESTER (2)

Topics of the practical exercises (Wednesday)

Date	Topics
2025.02.12	Operations with quantum bits and quantum registers
2025.02.19	Operations on the Bloch sphere
2025.02.26	Design of quantum information circuits
2025.03.05	Quantum random number generation
2025.03.12	Programming of quantum computers
2025.03.19	Programming of quantum computers
2025.03.26	Programming of quantum computers
2025.04.02	Programming of quantum computers
2025.04.09	Programming of quantum computers
2025.04.16	Programming of quantum computers
2025.04.23	Spring break
2025.04.30	Quantum key distribution in practice 1: technological implementation of fiber-based quantum key distribution
2025.05.07	Quantum key distribution in practice 2: technological implementation of free-space quantum key distribution
2025.05.14	In person consultation before mid-term
2025.05.21	An informal meeting in the lab

ASSESSMENT

- 3 small mid-term
- 1 homework (project work)

ASSESSMENT

Small mid term

- 3-5 questions, 30 minutes, in person, during the Monday lecture
- Date:
  - March 24
  - May 5
  - May 19
- In the retake week, you can retake any (or all) of the small mid term
- On average, the material for the small mid term will be 4 weeks of material, regardless of the date of the mid term. Details will be communicated by Teams before the exam

Home work (project work)

ASSESSMENT

Home work (project work)

- Can be done individually or in a team
- There are both engineering and programming tasks
- Submission format: document, PPT or video
- Detailed list and instructions: week #2
- Two deadlines:
  - March 20 (No stakes, you can submit the first half of the assignment, we will review it and help you get maximum points for the final version)
  - May 4 (final deadline)

MID-YEAR MARK

You must achieve at least 40% for every of the three small mid terms (each of them) **AND** at least 40% of the homework score must be achieved.

Final grade for the subject:

- 3x20% of the mid term
- 40% of the homework result

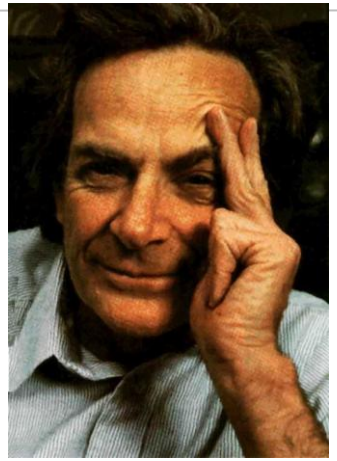
Grading:

- below 40%: insufficient / Unfulfilled (1)
- 40%-54%: satisfactory (2)
- 55%-69%: average (3)
- 70%-84%: good (4)
- 85%-: excellent (5)

WHAT TO KNOW, EVEN DURING THE NIGHT WHEN YOU ARE SLEEPY

- Postulates and important basics information
  - Postulates from engineering point of view
  - Effects of Hadamard gate
  - Etc…

- Connections
  - e.g., Grover database search can be applied in cracking RSA
- Logics of operations
  - e.g., the measurement is similar how the male *Gasterosteus aculeatus* rivalize with each other



"… it seems that the laws of physics present no barrier to reducing the size of computers until bits are the size of atoms, and quantum behavior holds sway."

Richard P. Feynman (1985)

Stop living "classically"! Superposition is essential for a well-rounded life.

Prof. Sándor Imre, 2010

DISCLAIMER

This presentation was presented as part of the Quantum Computing and its Application course @ Budapest University of Technology and Economics, Budapest, Hungary.
The course is offered by the Department of Networked Systems and Services (http://www.hit.bme.hu).

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