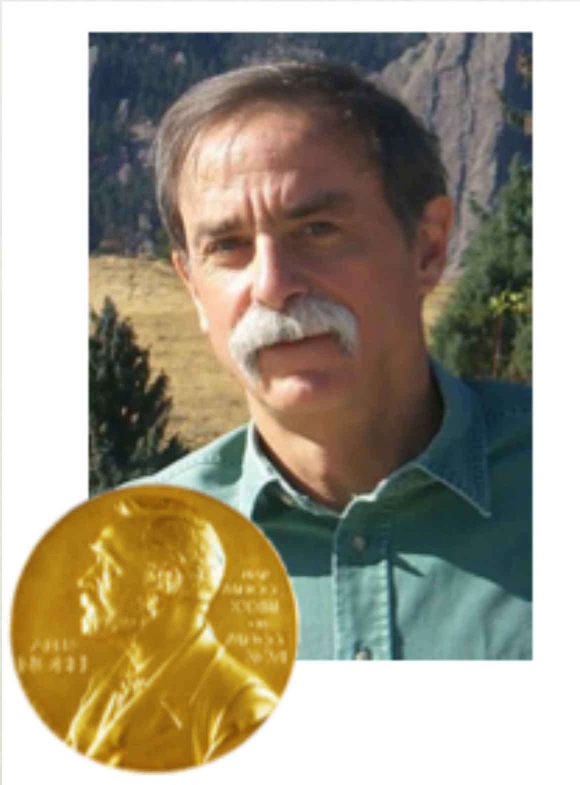
“Nikoli ne opravljamo poizkusov z enim samim elektronom ali atomom ali (majhno) molekulo. V miselnih eksperimentih včasih predpostavimo prav to, pa zato vedno znova pridemo do trapastih zaključkov. (…) Zato je treba priznati, da ne moremo eksperimentirati s posameznimi delci nič bolj, kot lahko vzgajamo ihtiozavre v živalskih vrtovih.”

E. Schrödinger (1952)



David J. Wineland in Serge Haroche

Nobelova nagrada za fiziko 2012

“za prelomne eksperimentalne metode, ki omogočajo merjenje in nadzor nad posameznimi kvantnimi sistemi, pri čemer se ohranijo njihove kvantne lastnosti, kar se je predhodno smatralo kot **nemogoče**”

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

Erwin Schrödinger (1926)

SUPERPOZICIJA STANJ

$$\psi(x,t)=\alpha\,\psi_1(x,t)+\beta\,\psi_2(x,t)$$

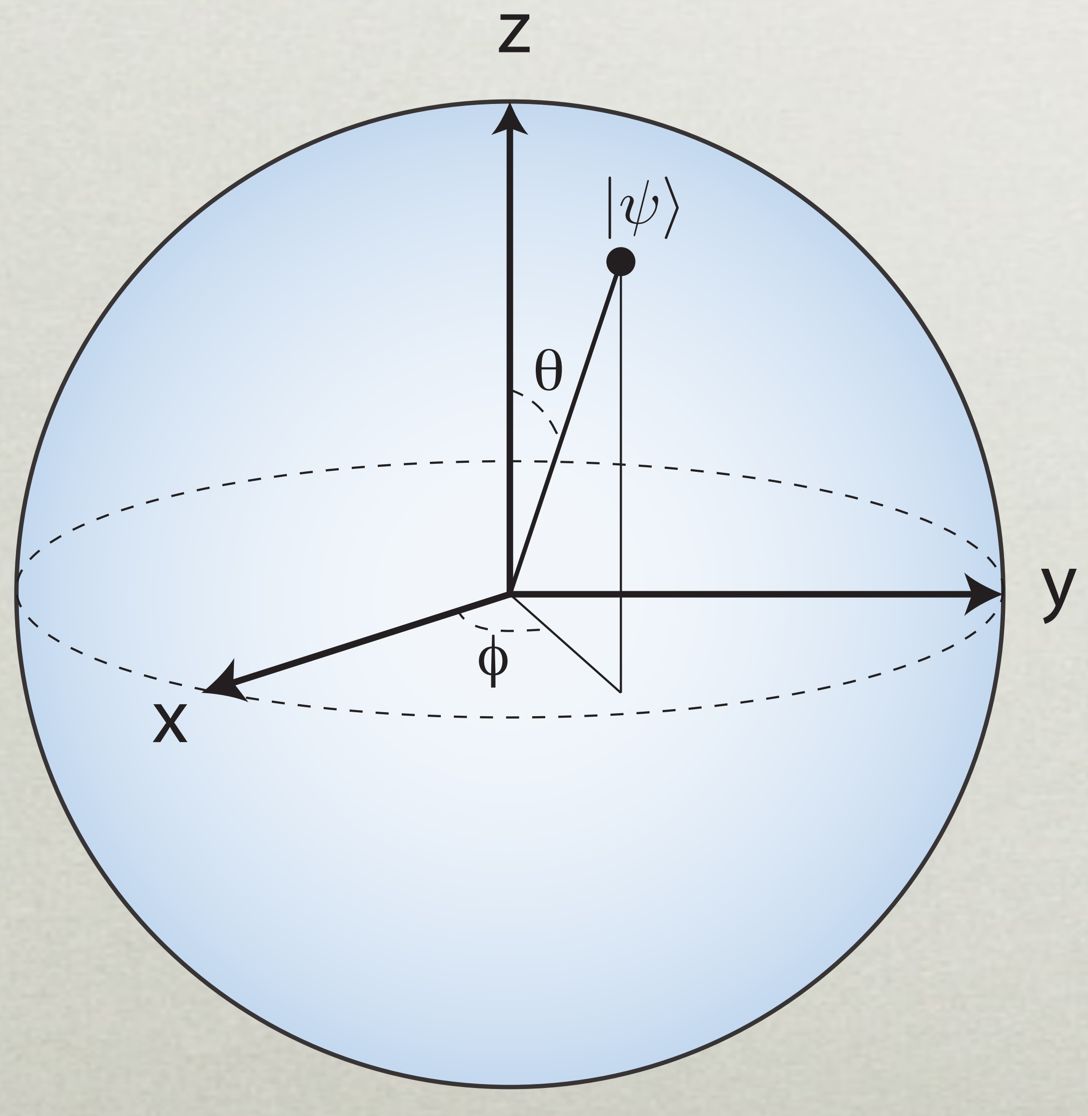
Vir slike: Wikipedia (javna last)

KUBIT

Informacija je neločljivo povezana s svojim fizičnim zapisom.

Rolf Landauer (1996)

računska baza: $|0\rangle, |1\rangle$



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

verjetnostni amplitudi

$$\alpha = \cos\frac{\theta}{2} \qquad \beta = e^{i\phi}\sin\frac{\theta}{2}$$

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.

OCTOBER 15, 1935 PHYSICAL REVIEW VOLUME **47**

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

N. BOHR, *Institute for Theoretical Physics, University, Copenhagen*

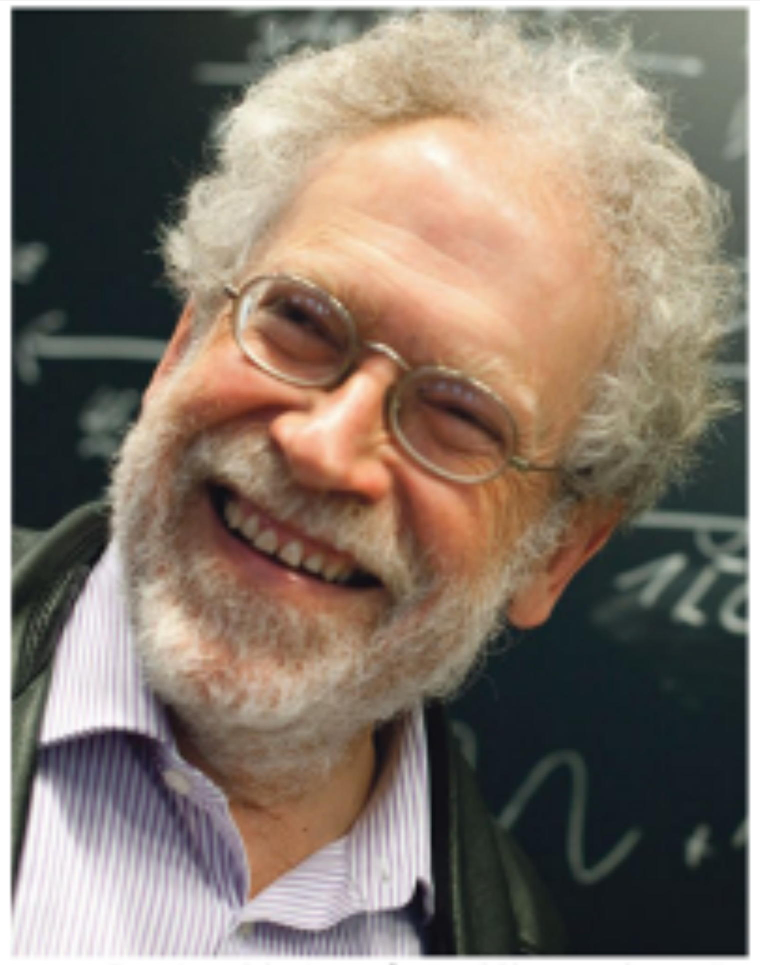
(Received July 13, 1935)

It is shown that a certain "criterion of physical reality" formulated in a recent article with the above title by A. Einstein, B. Podolsky and N. Rosen contains an essential ambiguity when it is applied to quantum phenomena. In this connection a viewpoint termed "complementarity" is explained from which quantum-mechanical description of physical phenomena would seem to fulfill, within its scope, all rational demands of completeness.

The Nobel Prize in Physics 2022

Alain Aspect je Clauserjeve ugotovitve uporabil v svojih eksperimentih in še dodatno potrdil kvantno prepletenost. FOTO WIKIPEDIA

John Clauser je na podlagi Bellovih neenakosti potrdil pravilnost teorije kvantne mehanike. FOTO PETER LYONS/WIKIMEDIA

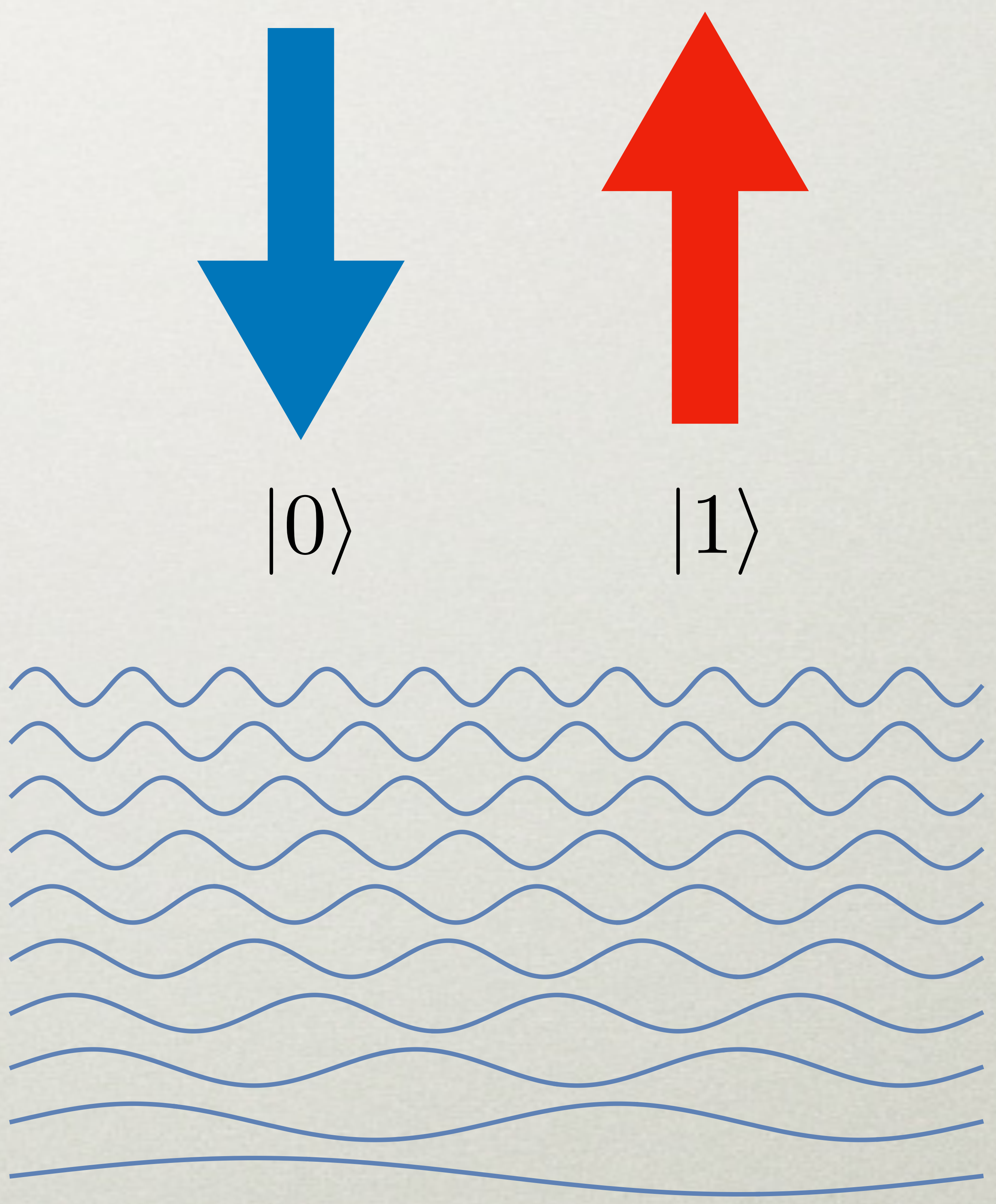


Anton Zeilinger je med drugim uspešno izvedel kvantno teleportacijo. FOTO BARBARA SAX/AFP

KVANTNE NAPRAVE

- **danes**:
  atomske ure
  generatorji naključnih števil
  kvantna distribucija ključev za šifriranje
  manjši kvantni računalniki

- **prihodnost**:
  inercijska navigacija
  natančna gravimetrija
  simulacije kvantnih sistemov (molekul)
  globalni kvantni internet
  kvantni računalniki z veliko kubiti



https://qt.eu http://www.qutes.si

Date

16 Nov 2021

Authors

Jerry Chow

Oliver Dial

Jay Gambetta

Tags

Quantum Hardware

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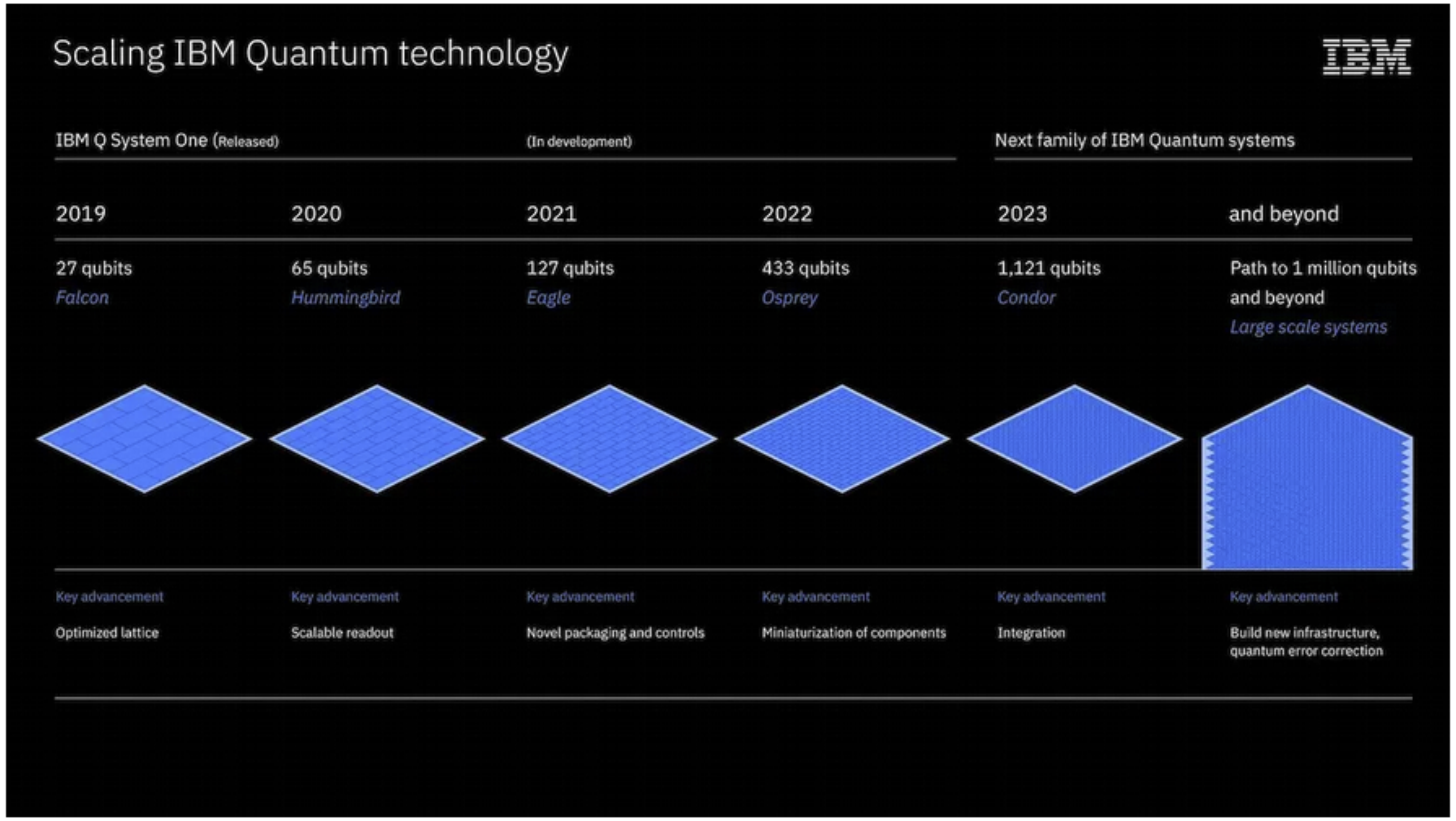
Today, IBM Quantum unveiled Eagle, a 127-qubit quantum processor. Eagle is leading quantum computers into a new era — we've launched a quantum processor that has pushed us beyond the 100-qubit barrier. We anticipate that, with Eagle, our users will be able to explore uncharted computational territory — and experience a key milestone on the path towards practical quantum computation.

> In addition to unveiling Eagle, our 127-qubit quantum processor, and previewing the design for IBM Quantum System Two, our next-generation system that will house future quantum processors, we also introduced, Quantum Serverless, a new programming model for leveraging quantum and classical resources. Read more.

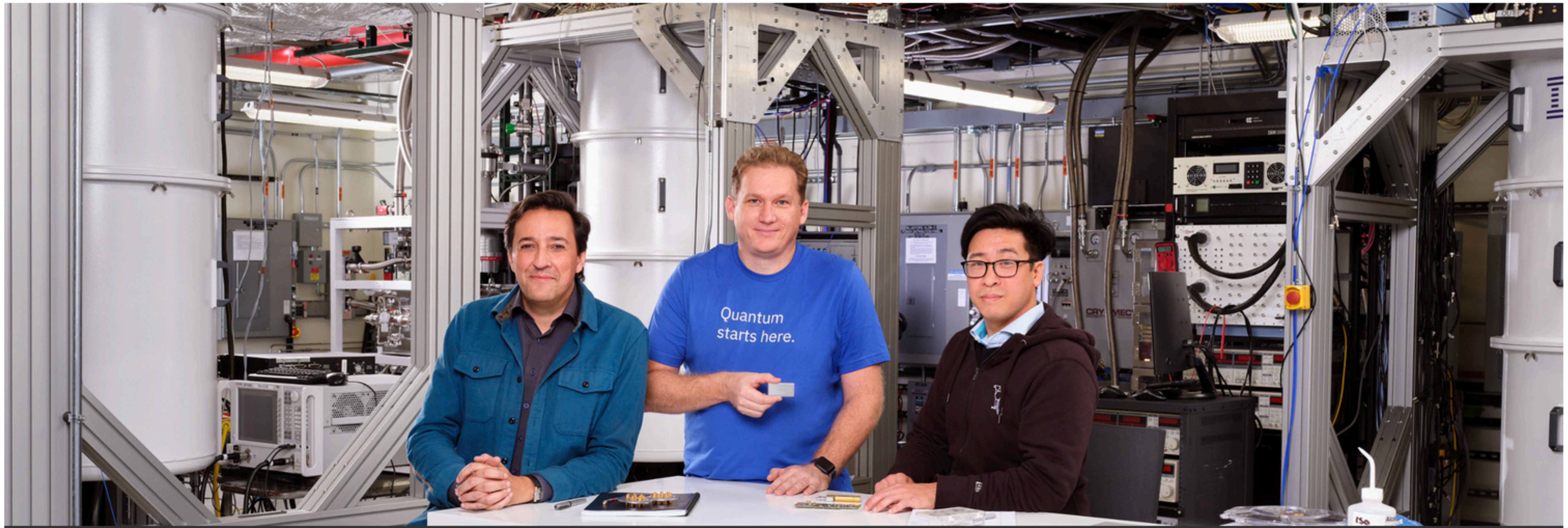
We view Eagle as a step in a technological revolution in the history of computation. As quantum processors scale up, each additional qubit doubles the amount of space complexity — the amount of memory space required to execute algorithms — for a classical computer to reliably simulate quantum circuits. We hope to see quantum computers bring real-world benefits across fields as this



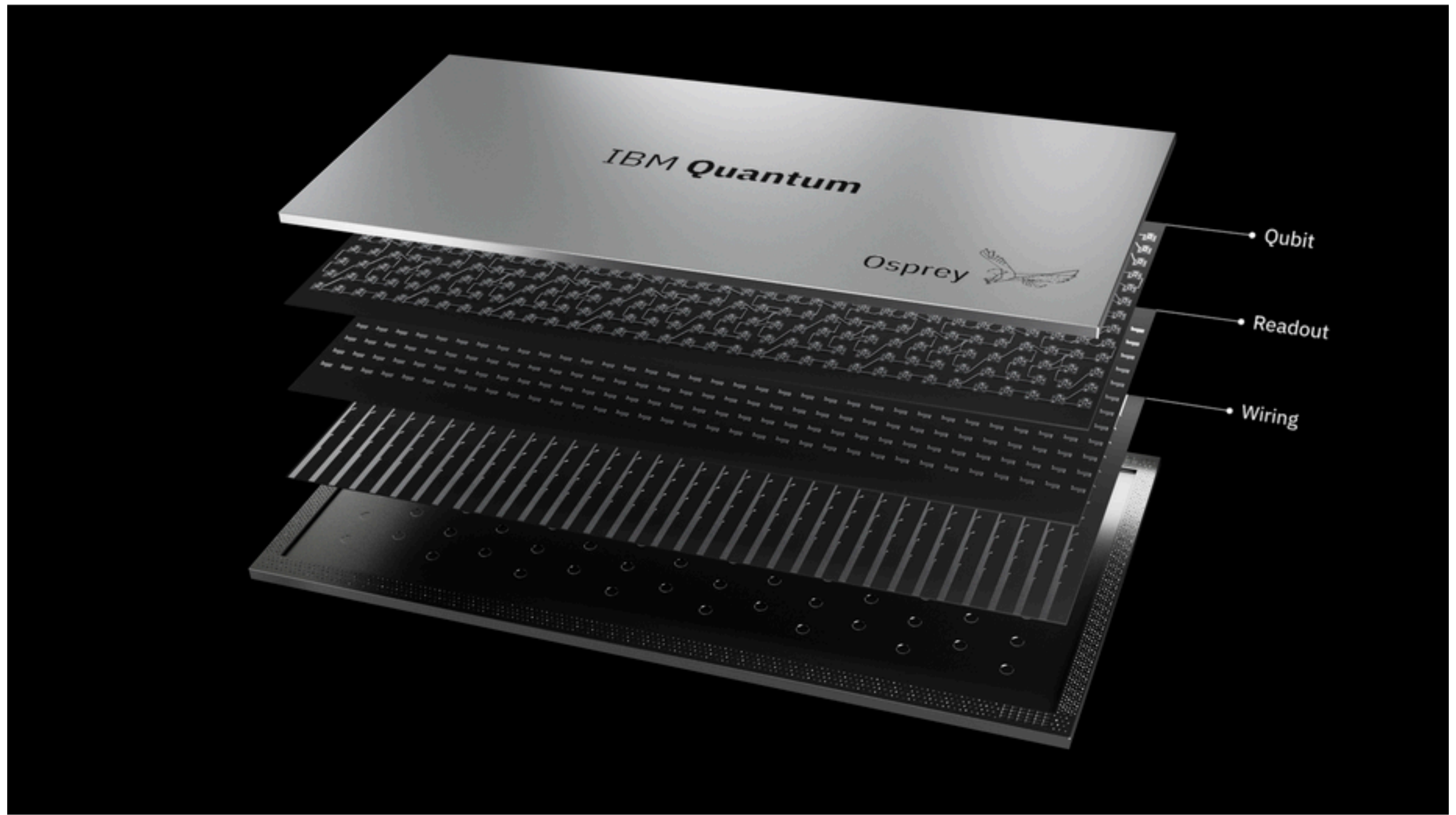
IBM Unveils 400 Qubit-Plus Quantum Processor and Next-Generation IBM Quantum System Two

Company Outlines Path Towards Quantum-Centric Supercomputing with New Hardware, Software, and System Breakthrough

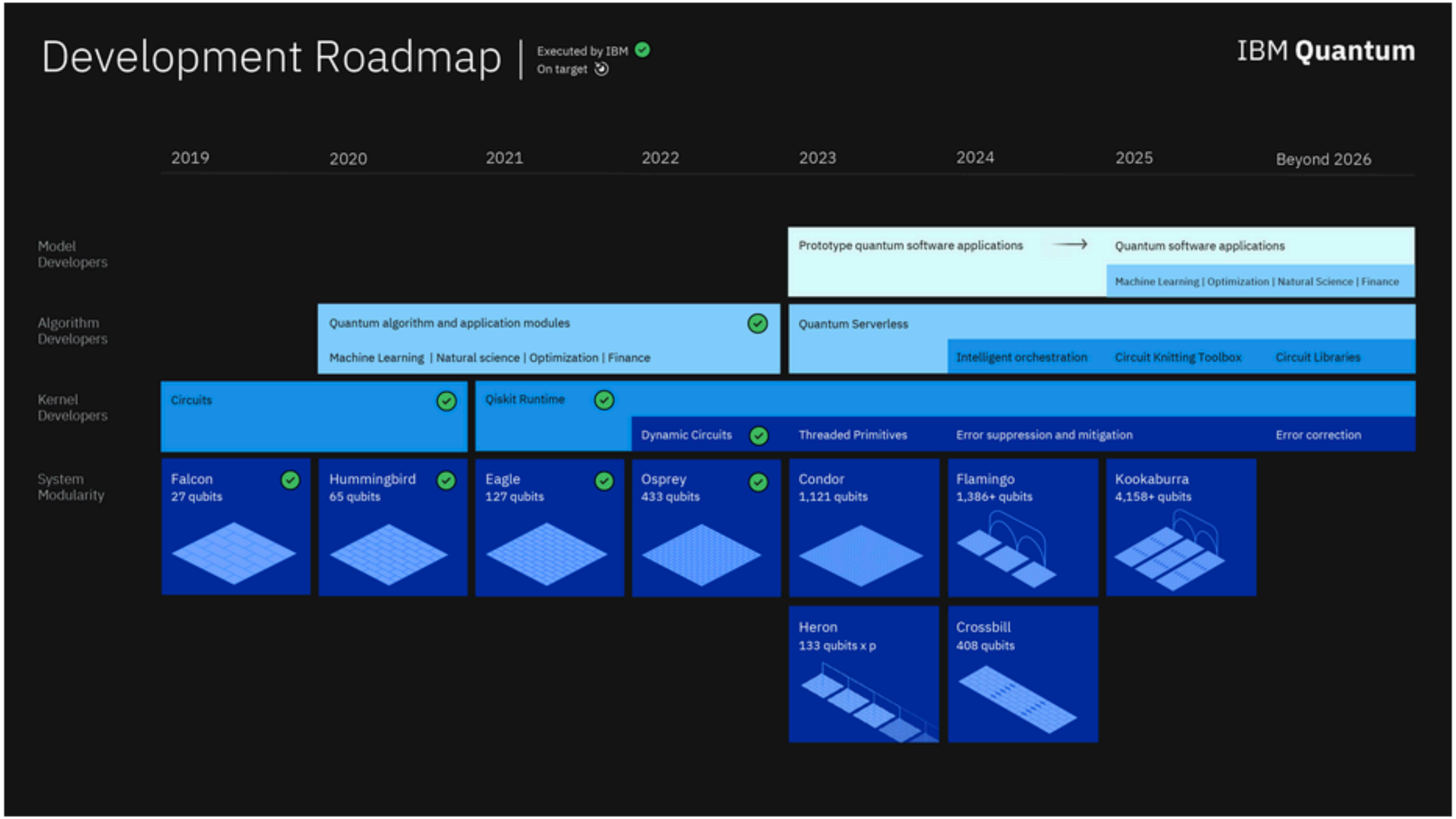
Nov 9, 2022



Dario Gil, Jay Gambetta and Jerry Chow holding the new 433 qubit 'IBM Osprey' processor



https://newsroom.ibm.com/2022-11-09-IBM-Unveils-400-Qubit-Plus-Quantum-Processor-and-Next-Generation-IBM-Quantum-System-Two


Development Roadmap
Executed by IBM
On target
IBM Quantum
2019
2020
2021
2022
2023
2024
2025
Beyond 2026
Model Developers
Prototype quantum software applications
Quantum software applications
Machine Learning | Optimization | Natural Science | Finance
Algorithm Developers
Quantum algorithm and application modules
Machine Learning | Natural science | Optimization | Finance
Quantum Serverless
Intelligent orchestration
Circuit Knitting Toolbox
Circuit Libraries
Kernel Developers
Circuits
Qiskit Runtime
Dynamic Circuits
Threaded Primitives
Error suppression and mitigation
Error correction
System Modularity
Falcon 27 qubits
Hummingbird 65 qubits
Eagle 127 qubits
Osprey 433 qubits
Condor 1,121 qubits
Flamingo 1,386+ qubits
Kookaburra 4,158+ qubits
Heron 133 qubits x p
Crossbill 408 qubits

Date
08 Sep 2022

Authors

Pat Gumann

Jerry Chow

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4 minute read

IBM scientists cool down the world's largest quantum-ready cryogenic concept system

Project Goldeneye pushes the limits of low-temperature refrigeration while laying the groundwork for the quantum industry's ability to scale to larger experiments.

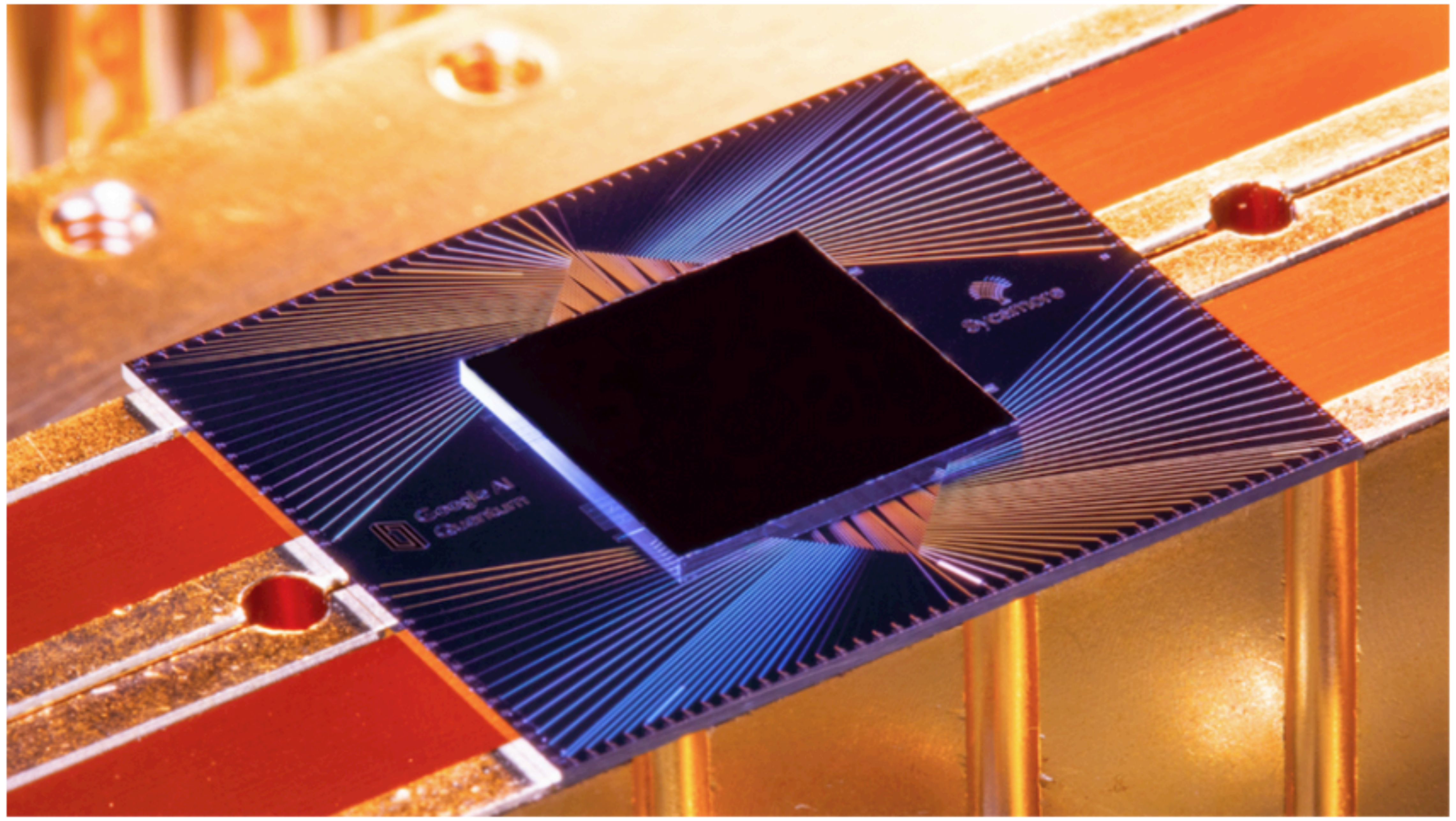
Welcome to the Quantum AI campus

Santa Barbara is home to the Quantum AI Campus and Google's first quantum data center.

Google Claims Quantum Computing Achievement, IBM Says Not So Fast

Google's quantum computer performed a computation in 200 seconds that would have taken the world's fastest supercomputer 10,000 years to calculate. But IBM is dismissing Google's claim that it achieved quantum supremacy.

By Michael Kan October 23, 2019



Sycamore processor

9 languages

Article Talk

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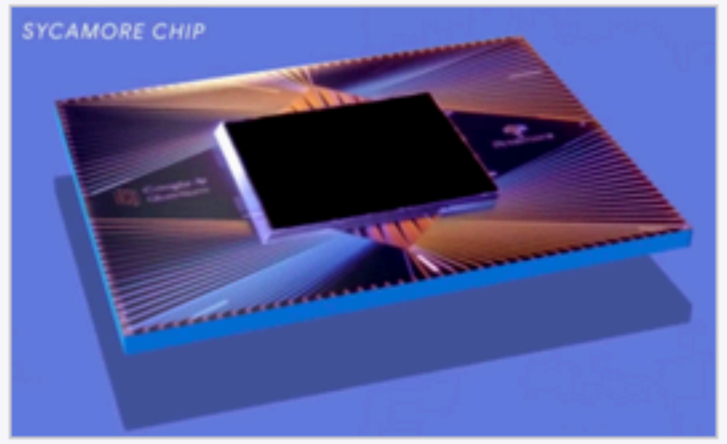
From Wikipedia, the free encyclopedia

Sycamore is a quantum processor created by Google's Artificial Intelligence division.[1] It has 53 qubits.



The Sycamore processor

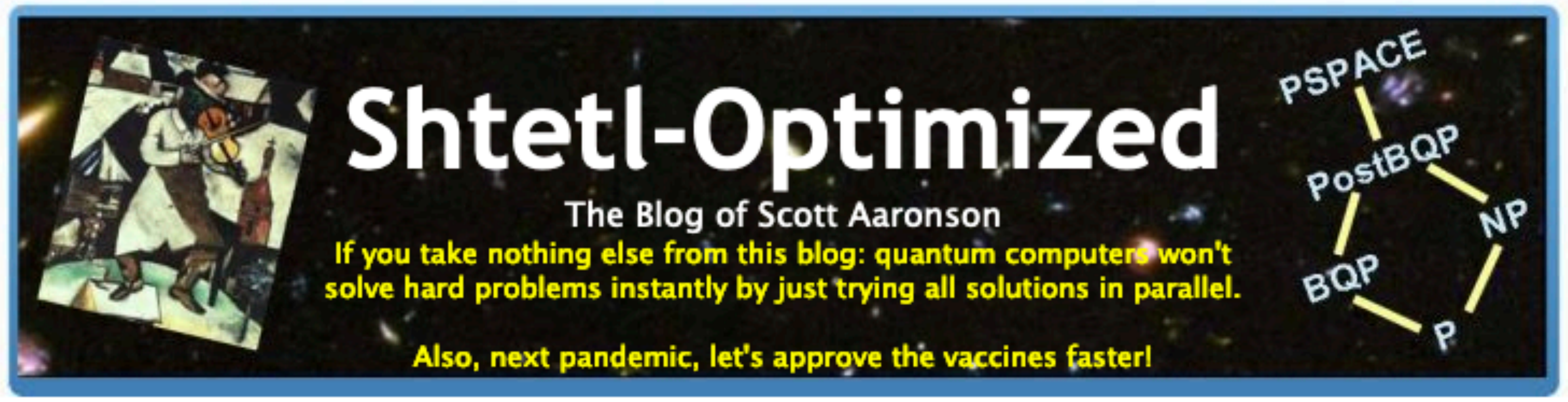
In 2019, Sycamore completed a task in 200 seconds that Google claimed, in a *Nature* paper, would take a state-of-the-art supercomputer 10,000 years to finish. Thus, Google claimed to have achieved quantum supremacy. To estimate the time that would be taken by a classical supercomputer, Google ran portions of the quantum circuit simulation on the Summit, the most powerful classical computer in the world.[2][3][4][5] Later, IBM made a counter-argument, claiming that the task would only take 2.5 days on a classical system like Summit.[6][7] If Google's claims are upheld, then it would represent an exponential leap in computing power.[8][9][10][11]

In August 2020, quantum engineers working for Google reported the largest chemical simulation on a quantum computer – a Hartree–Fock approximation with Sycamore paired with a classical computer that analyzed results to provide new parameters for the 12-qubit system.[12][13][14]

In April 2021, researchers working with Sycamore reported that they were able to realize the ground state of the toric code, a topologically ordered state, with 31 qubits. They showed long-range entanglement properties of the state by measuring non-zero topological entropy, simulating anyon interferometry and their braiding statistics, and preparing a topological quantum error correcting code with one logical qubit.[15]

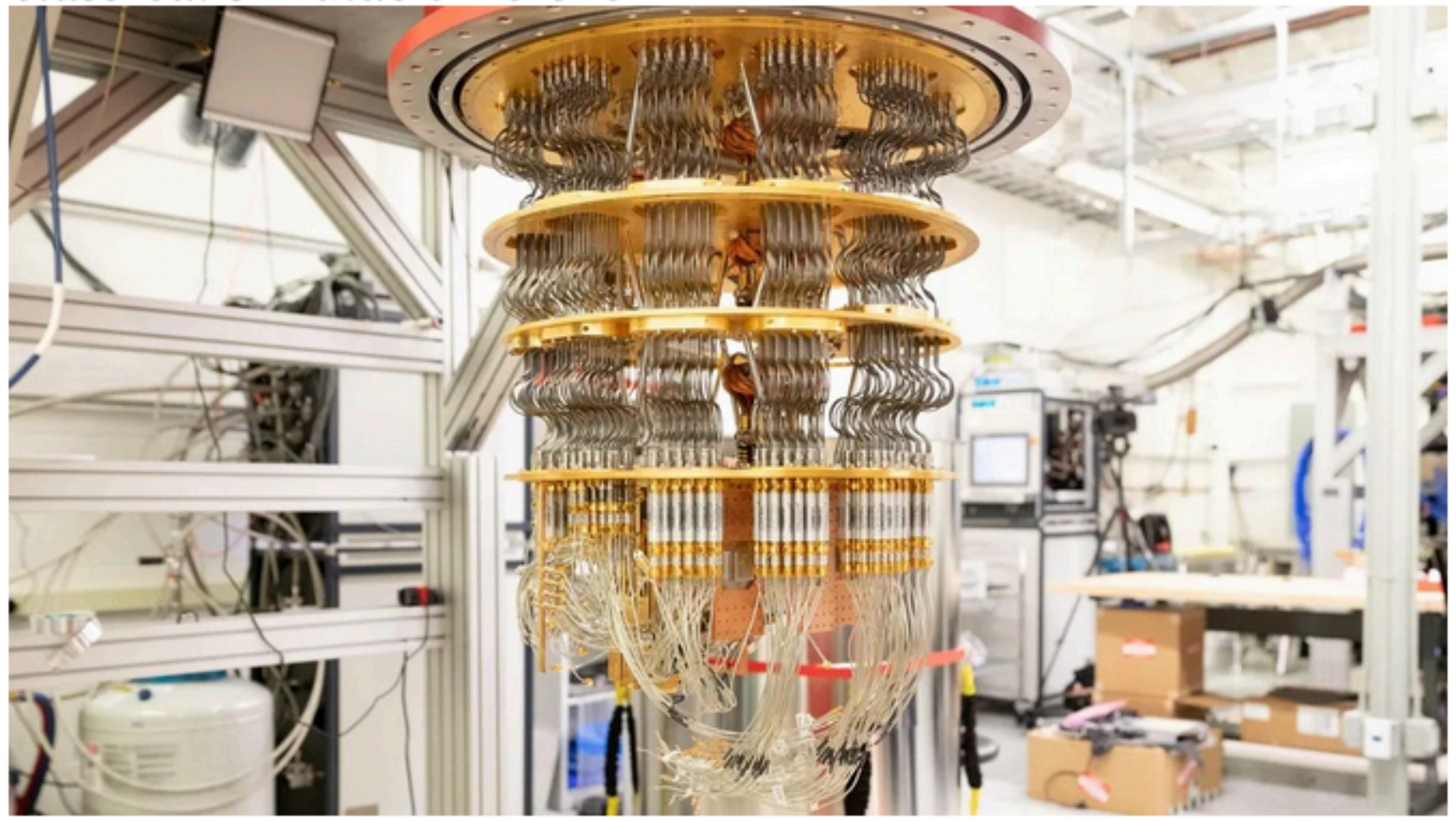
In July 2021, a collaboration consisting of Google and multiple universities reported the observation of a discrete time crystal on the Sycamore processor. The chip of 20 qubits was used to obtain a many-body localization configuration of up and down spins. The configuration was stimulated with a laser to achieve a periodically driven "Floquet" system where all up spins are flipped for down and vice versa in periodic cycles which are multiples of the laser's cycles. No energy was absorbed from the laser so the system remained in a protected eigenstate order.[16][17]

In 2022, the Sycamore processor was used to simulate traversable wormhole dynamics.[18]



« My AI Safety Lecture for UT Effective Altruism   Short letter to my 11-year-old self »

Google's Sycamore chip: no wormholes, no superfast classical simulation either



Science

Microsoft's quantum computing dreams shattered by dodgy Majorana particle research

Written by
Chandraveer Mathur

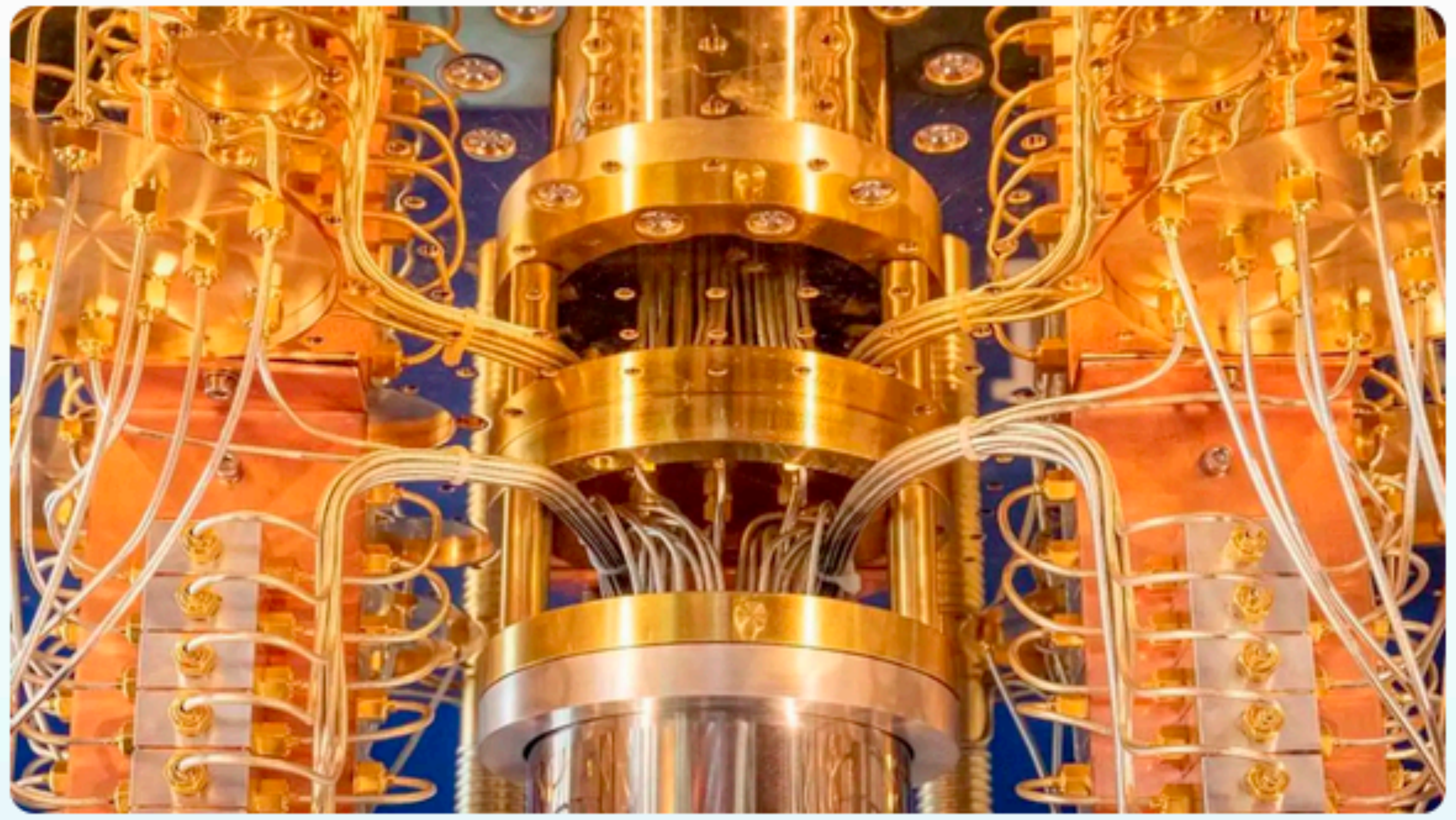
Last updated on Feb 14, 2021, 09:24 pm

In 2018, Microsoft employee and physicist Leo Kouwenhoven **published a paper** claiming to have observed a particle called the Majorana fermion. The breakthrough could've benefited Microsoft's quantum computing technology greatly.

But in January this year, Kouwenhoven's researchers released **another paper** including more experimental data. It concludes the particle was not found at all. The authors will redact the 2018 paper from the prestigious journal *Nature*.

Fruitless endeavor

Microsoft's Majorana-based quantum computing quest could come to an end



This development could be the end of Microsoft's quest to commercialize Majorana particles. The Silicon Valley giants, including Google, IBM, and Intel, have demonstrated prototype quantum computers with up to 50 qubits using existing solutions.

Microsoft's investment in Majoranas over the last nine years hasn't yet materialized into a single workable qubit.

Frolov says Kouwenhoven's group should release raw research data for external scrutiny.

TOM SIMONITE BUSINESS 02.12.2021 07:00 AM

Microsoft's Big Win in Quantum Computing Was an 'Error' After All

In a 2018 paper, researchers said they found evidence of an elusive theorized particle. A closer look now suggests otherwise.

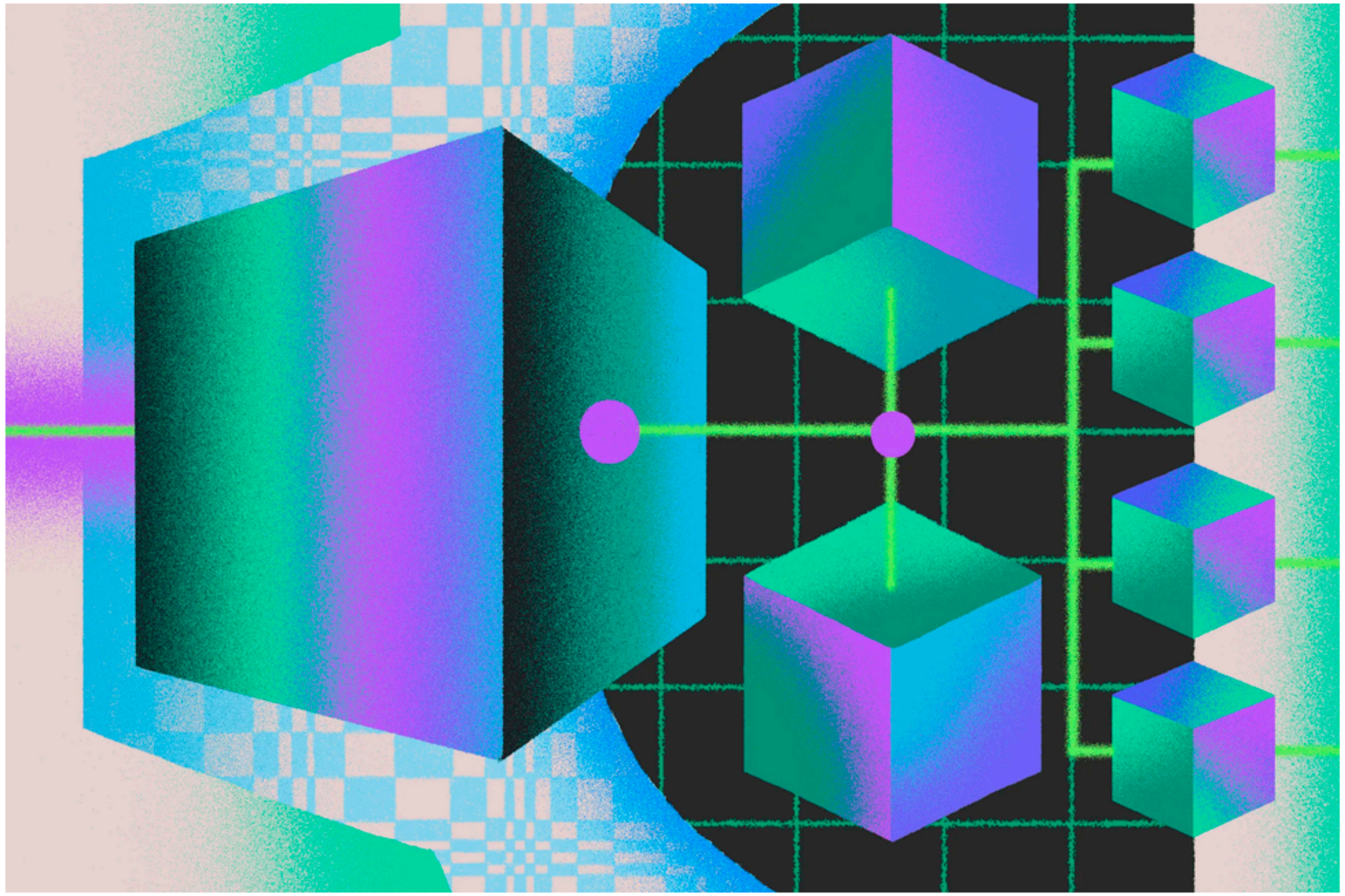
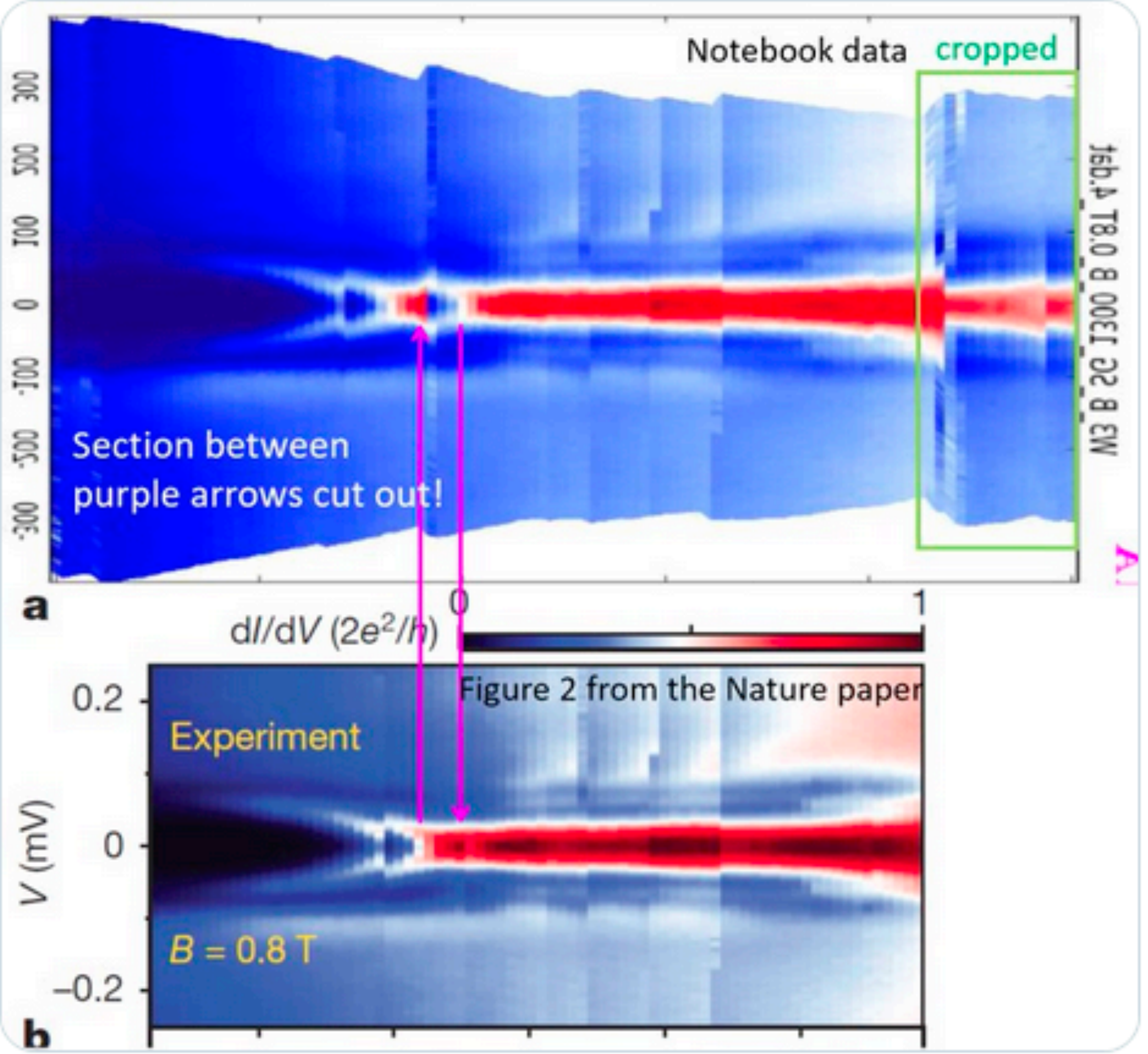


ILLUSTRATION: ARIEL DAVIS

Sergey Frolov @spinespresso · Feb 4, 2021

Replying to @spinespresso

Then @VincentMourik stared at it for a long time and realized: it was the same data! But... four vertical lines (current-voltage characteristics) were missing from the middle. At first we could not believe it, made 15 slides just studying the noise patterns in the two images...



NEWS AND VIEWS | 19 January 2022

Silicon qubits move a step closer to achieving error correction

A silicon-based quantum-computing platform has met key standards for reducing error – setting the stage for quantum devices that could benefit from established semiconductor microchip technologies.

Ada Warren & Sophia E. Economou

Quantum bits (qubits) that use the quantum properties of electrons in silicon devices offer enormous potential for developing compact and robust quantum computers that take advantage of the existing silicon-microchip industry. But quantum operations are subject to error, and getting error rates low enough to make quantum silicon devices feasible remains a challenge. Three papers in this issue, by Xue *et al.*[1], Noiri *et al.*[2] and Mądzik *et al.*[3], report demonstrations of qubit operations in silicon devices with fidelities above the threshold of one of the most popular quantum error-correcting codes. The results suggest that these devices could be a competitive platform for scalable quantum-information processing.

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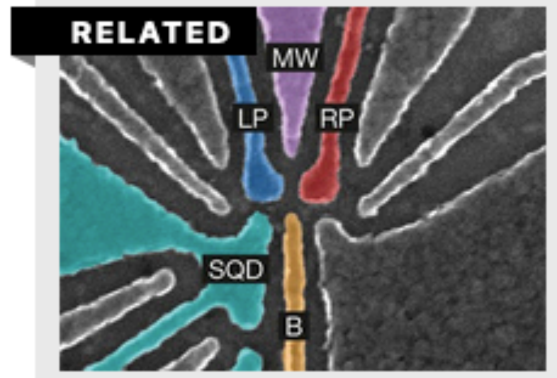

Read the paper: Quantum logic with spin qubits crossing the surface code threshold

The basic idea behind any quantum computer is that the quantum nature of qubits enables them to be in a state that is not simply '1' or '0', but some combination known as a superposition. This means that two qubits can be in a superposition of '01', '10', '11' and '00', which leads to even more possibilities. This ability can be used to speed up certain computations that are too complicated for a classical computer to perform in a reasonable amount of time. These include Shor's algorithm, a strategy for factorizing large numbers, which could compromise existing encryption schemes for internet security, and other algorithms that could be used in materials science and drug design.

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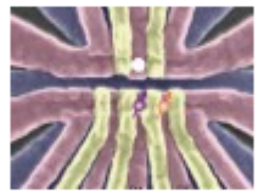
Read the paper: Fast universal quantum gate above the fault-tolerance threshold in silicon



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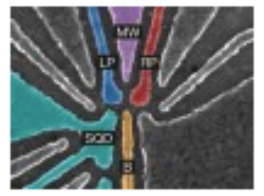
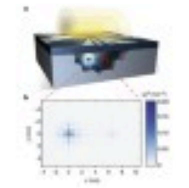
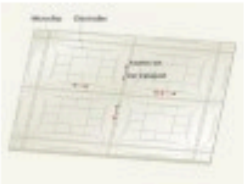


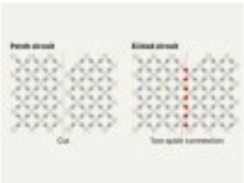
Read the paper: Precision tomography of a three-qubit donor quantum processor in silicon



Quantum computer based on shuttling trapped ions



Quantum computing takes flight



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Quantum information   Quantum physics

future tense

What if Quantum Computing Is a Bust?

BY CHRIS JAY HOOFNAGLE AND SIMSON GARFINKEL JAN 26, 2022 • 9:00 AM

Quantum winter is coming? Maybe. Robert Haverly/Unsplash

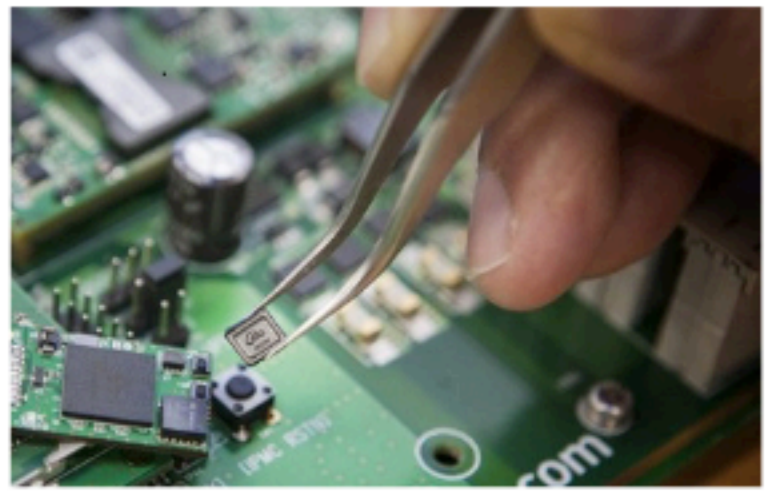
Redefining Randomness

Quantis QRNG Chip

The source of full entropy for automotive, computing, critical infrastructure, IoT, mobile & security applications

ID Quantique introduces its true Quantum Random Number Generator (QRNG) Chip, which offers the highest attainable security and robustness for the generation of random bits. It is ideal for use in the automotive, computing, critical infrastructure, IoT, mobile and security applications where compact size and resistance to external environmental perturbations are critical.

Based on a technology concept and patent from IDQ, the Quantis QRNG Chip harnesses true quantum randomness from the shot noise of a light source captured by a CMOS image sensor.



- Intrinsically and provably random
- Robust and controlled entropy source
- Instant full entropy from the first bit

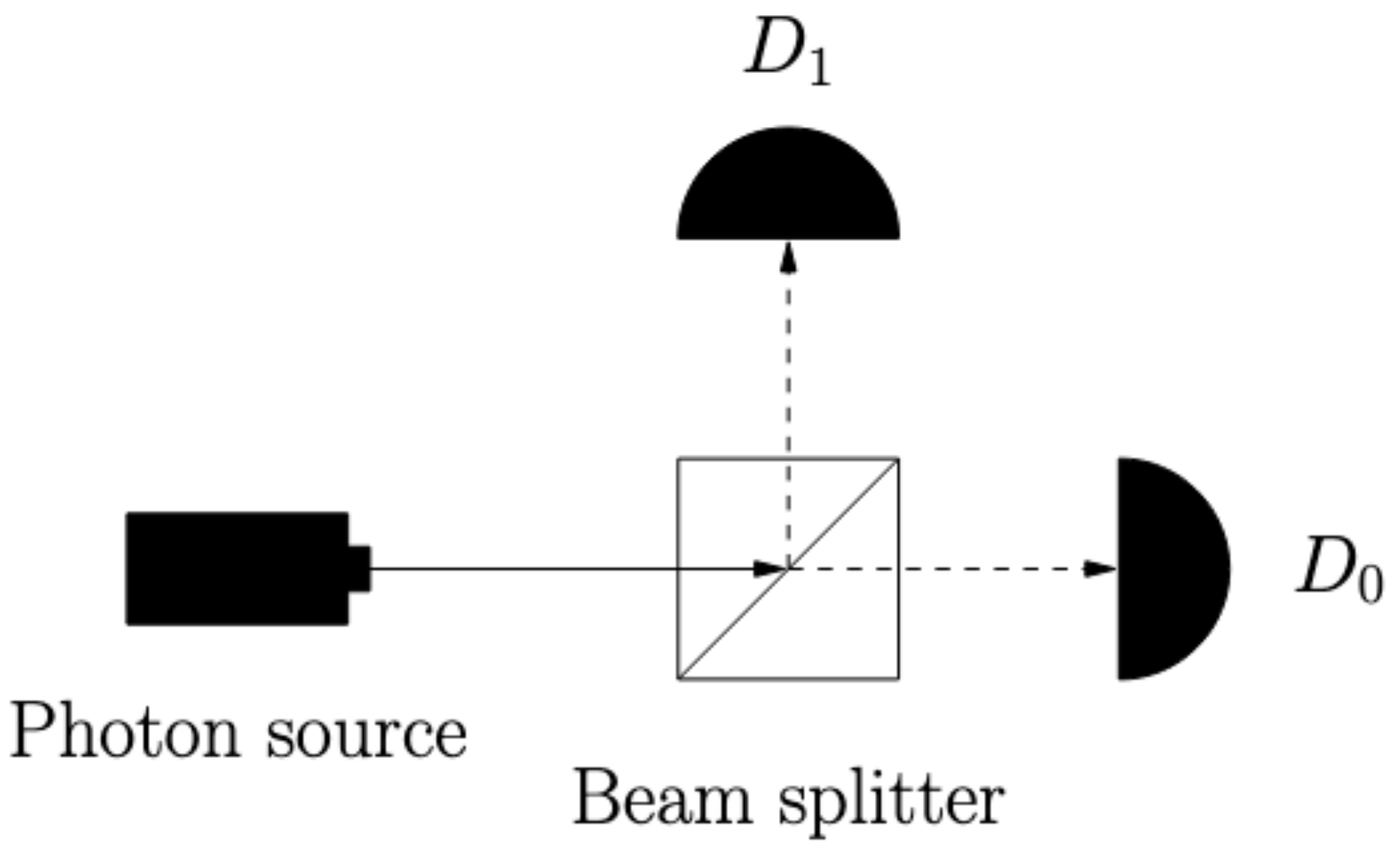
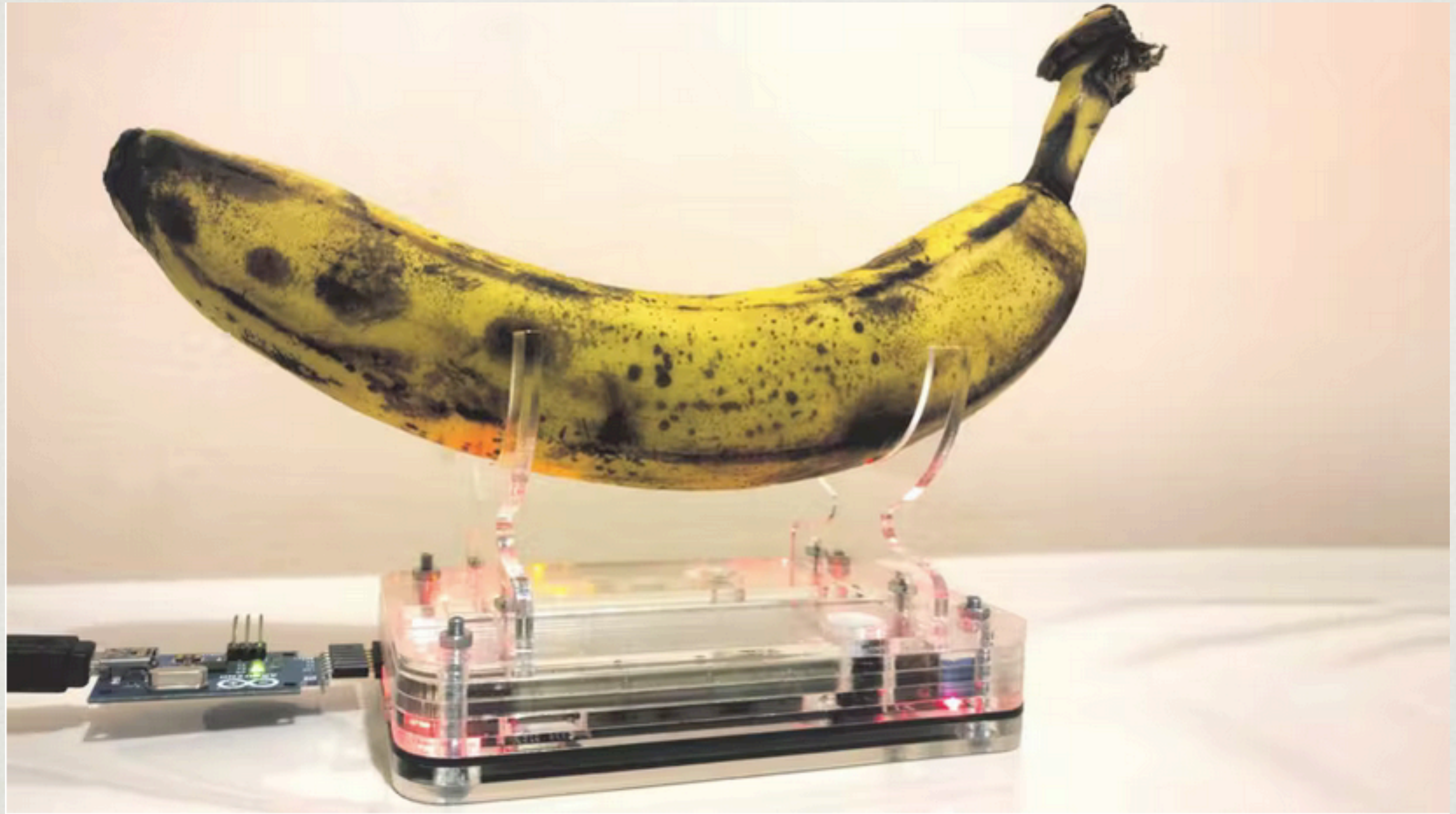


FIG. 6 A weak light source sends a state with one photon to a balanced beam splitter. The path the photon takes at the output is random and there will be a detection with the same probability at each detector. We can consider that a click on detector D_0 is recorded as a 0 bit and a detection in D_1 is a 1.

PRIMER: BANANA RNG



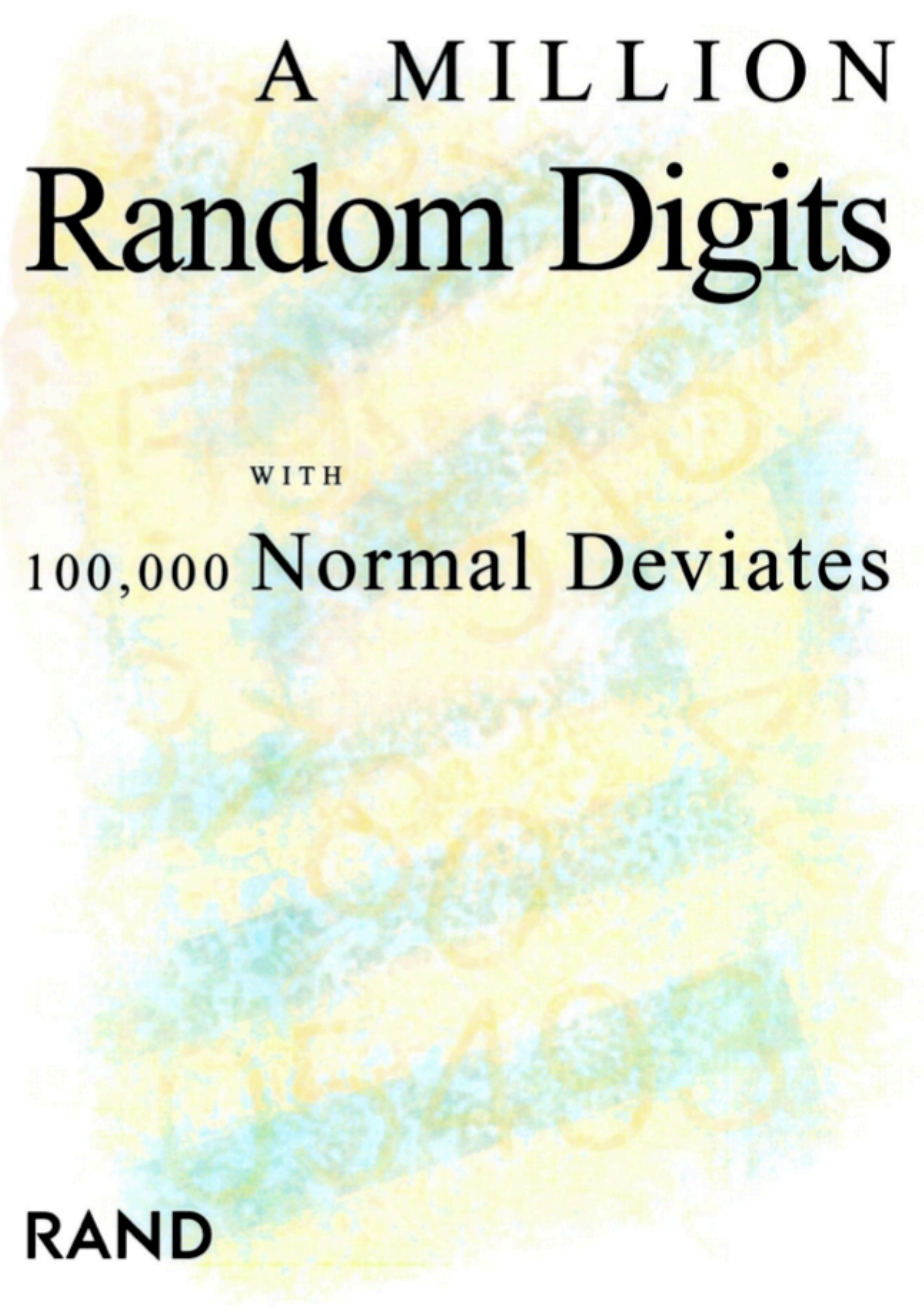
zaznavanje jedrskih razpadov atomov ^{40}K

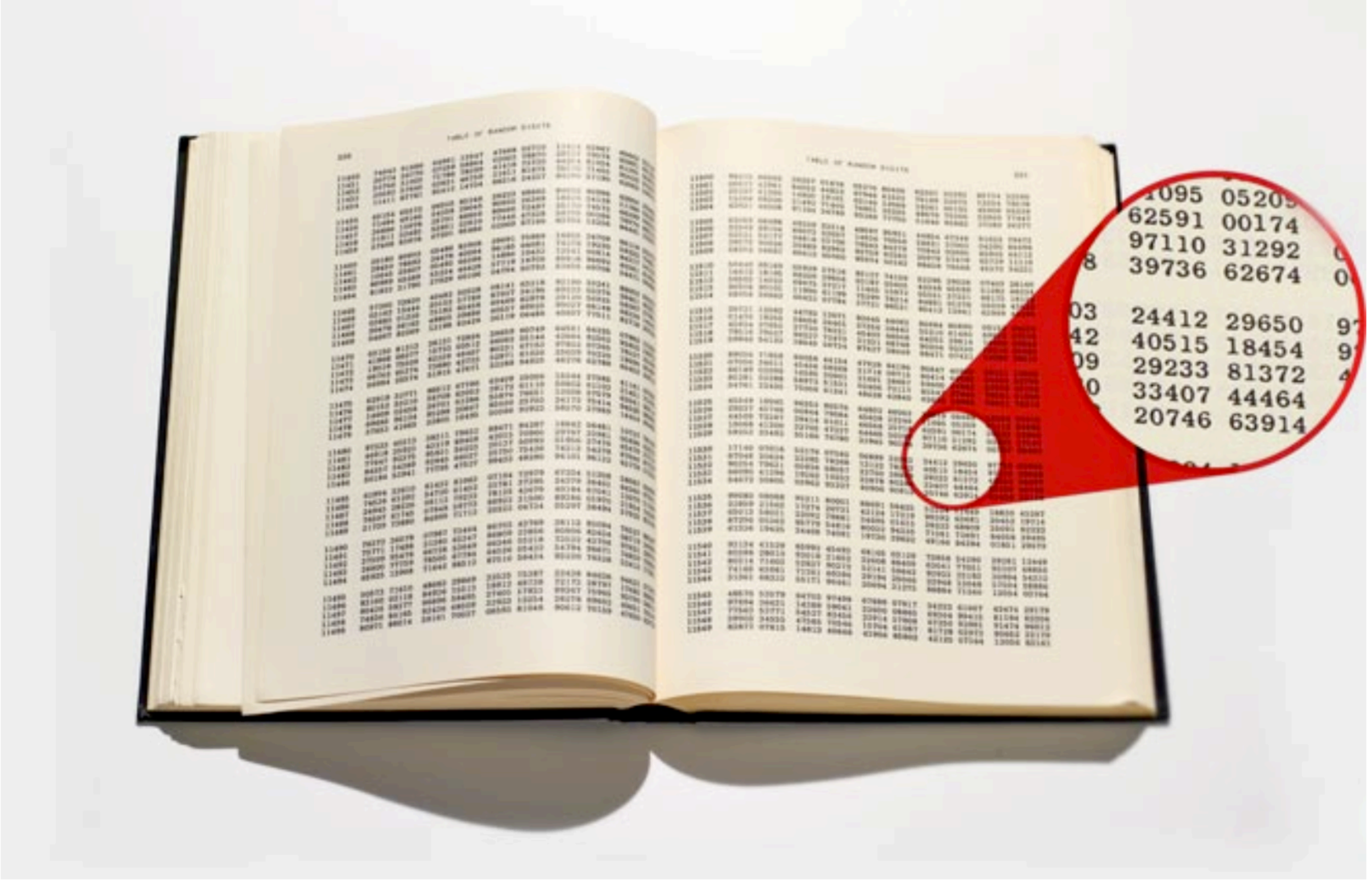
https://www.valerionappi.it/brng-en/

1955: The million-digit book

Book with 50 rows of 50 digits per page for 400 pages.
Reissued in paperback in 2001. Available at Amazon.

This book has maximum suspense: when reading digits in succession, at any step, one has no clue of what comes after!!!





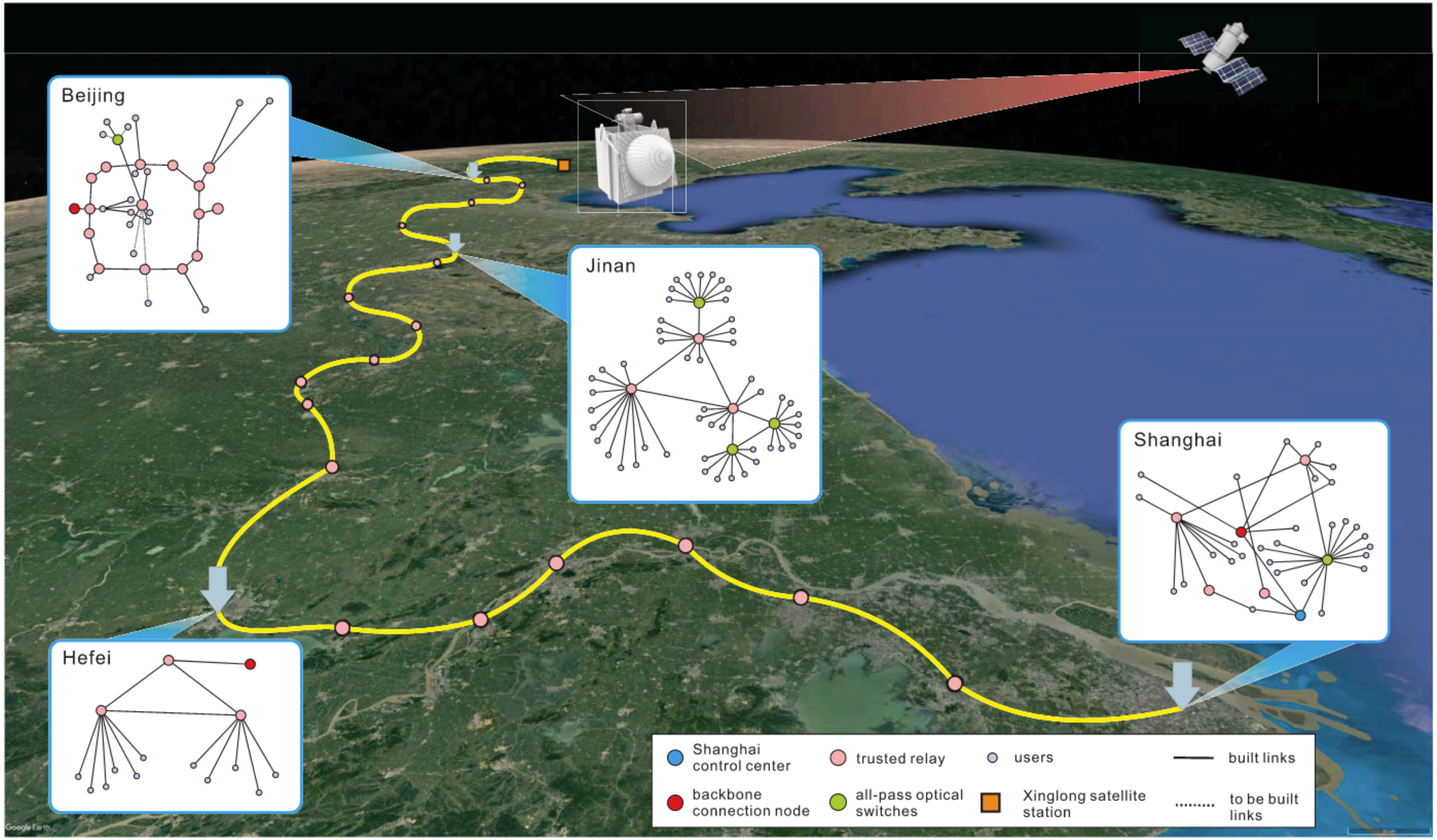


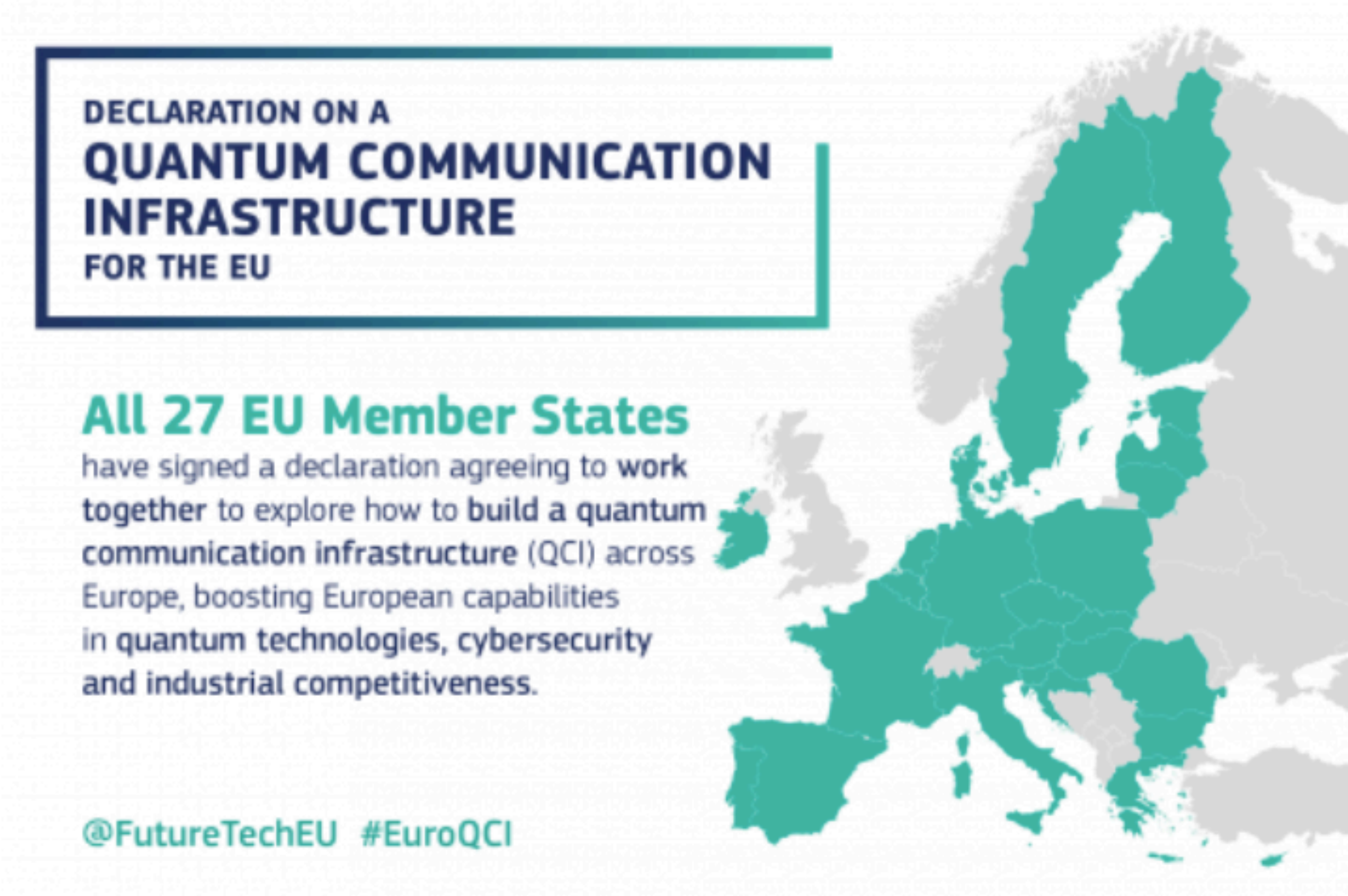
FIG. 2. Schematic diagram of the space-ground integrated quantum network in China (Chen *et al.*, 2020), consisting of four quantum metropolitan area networks in the cities of Beijing, Jinan, Shanghai, and Heifei, a backbone network extending over 2000 km, and ground-satellite links. There are three types of nodes in the network: user nodes, all-pass optical switches, and trusted relays. The backbone network is connected by trusted intermediate relays. The satellite is connected to a ground-satellite station near Beijing, which can provide ultra-long-distance communications (Liao *et al.*, 2018).

The European Quantum Communication Infrastructure (EuroQCI) Initiative

The EuroQCI initiative aims to build a secure quantum communication infrastructure that will span the whole EU, including its overseas territories.

Since June 2019, all 27 EU Member States have signed the European Quantum Communication Infrastructure (EuroQCI) Declaration, signalling their commitment to the EuroQCI initiative.

The participating countries are working with the European Commission and the European Space Agency (ESA) to design, develop and deploy the EuroQCI. The aim is for it to be fully operational by 2027.



Quantum communication infrastructure: Questions and answers >

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Follow the Commission's work on tech and digital @DigitalEU

POLITIQUE • SCIENCES

Emmanuel Macron veut mettre la France dans le trio de tête mondial des technologies quantiques

Le président de la République a présenté jeudi un plan d'investissement national de 1,8 milliard d'euros dans le quantique, appelé à transformer l'informatique et l'industrie.

Le Monde avec AFP

Publié le 21 janvier 2021 à 06h37 - Mis à jour le 21 janvier 2021 à 17h14 • Lecture 2 min.

Emmanuel Macron au Centre de nanosciences et de nanotechnologies de l'université Paris-Saclay (Essonne), le 21 janvier 2021.
JEAN-CLAUDE COUTAUSSE POUR " LE MONDE"

Le président de la République, Emmanuel Macron, a présenté, jeudi 21 janvier sur le plateau de Saclay, en Essonne, un plan d'investissement national de 1,8 milliard d'euros dans le domaine quantique, qui doit mettre la France dans *« les trois premiers mondiaux »* de ces technologies appelées à transformer

Les plus lus

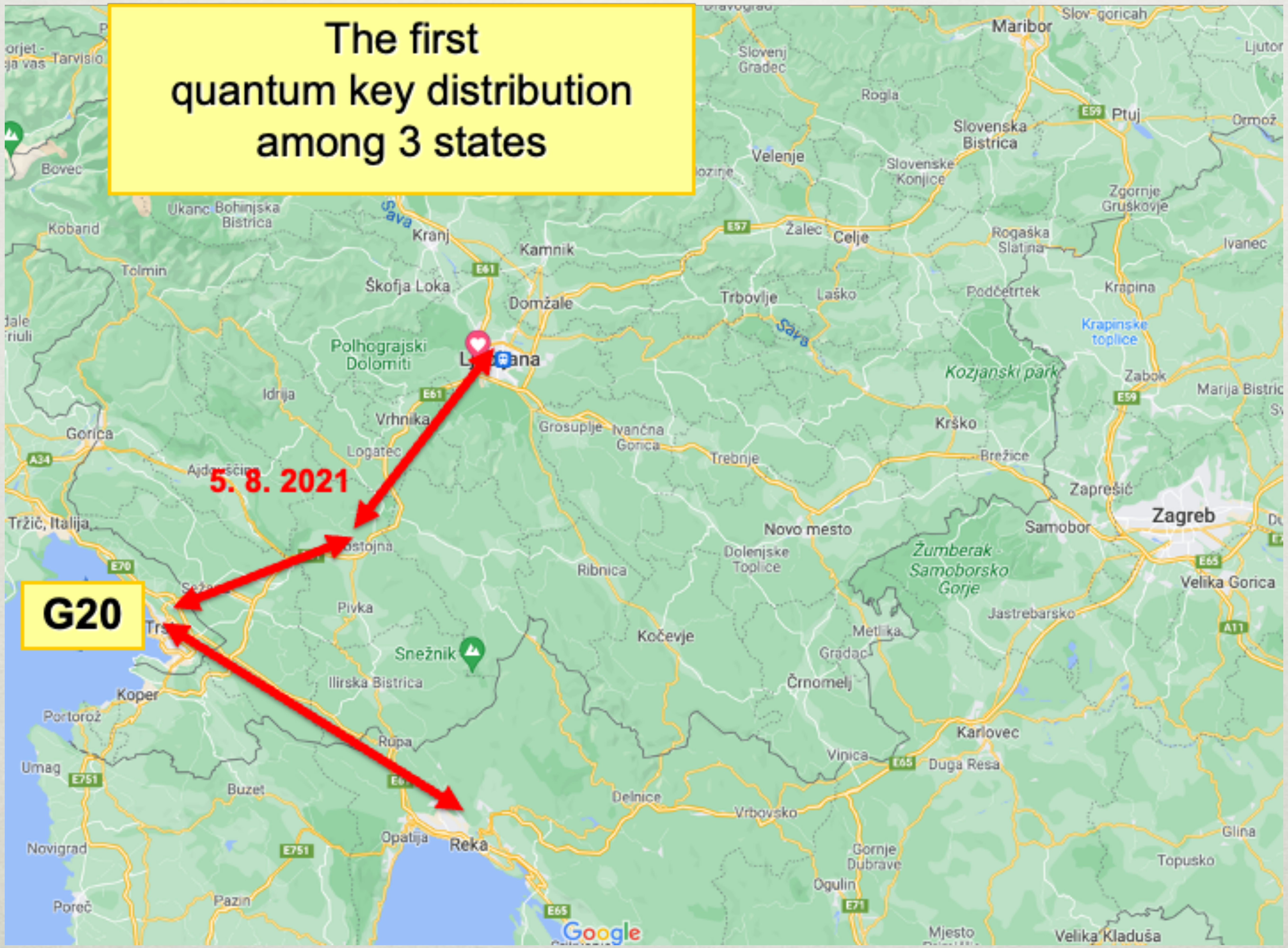
1 Après celui de Dax, l'hôpital de Villefranche paralysé par un rançongiciel

2 « Viser l'objectif zéro Covid constitue un moyen clair de traverser la pandémie en minimisant les dégâts »

3 Covid-19 : comment l'Australie et la Nouvelle-Zélande réussissent à éradiquer le virus sur leur territoire

Srečanje ministrov za digitalno politiko skupine G20
Trst, 5. 8. 2021

demonstracija kvantno šifriranega prenosa podatkov med tremi državami (Italija-Slovenija-Hrvaška)


The first
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among 3 states
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Trbovlje
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Polhograjski Dolomiti
Idrija
Vrhnika
Logatec
Grosuplje
Ivančna Gorica
Trebnje
Krško
Brežice
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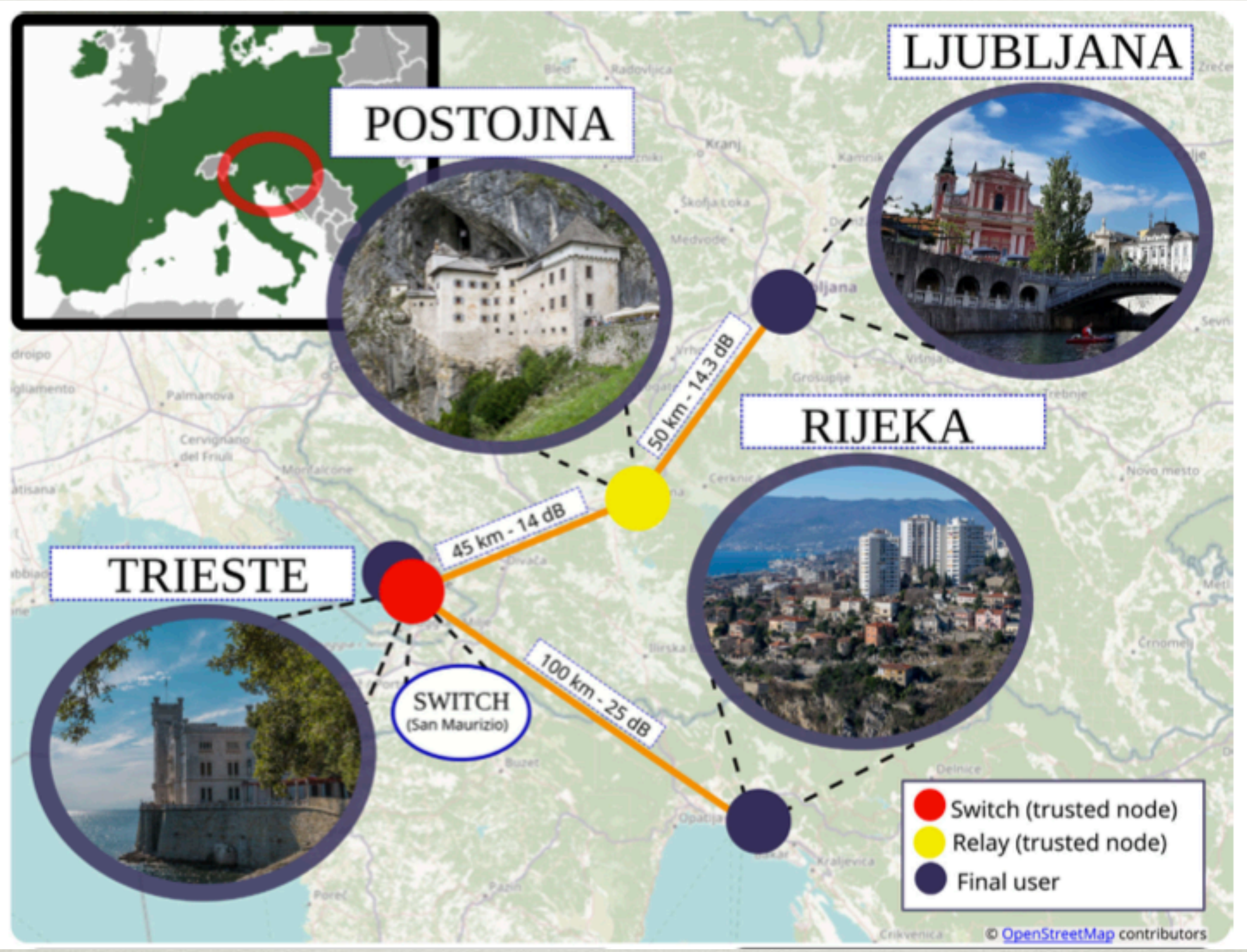

D. Ribezzo et al., Adv. Quant. Tech. 2200061 (2022)

Telekom povezava
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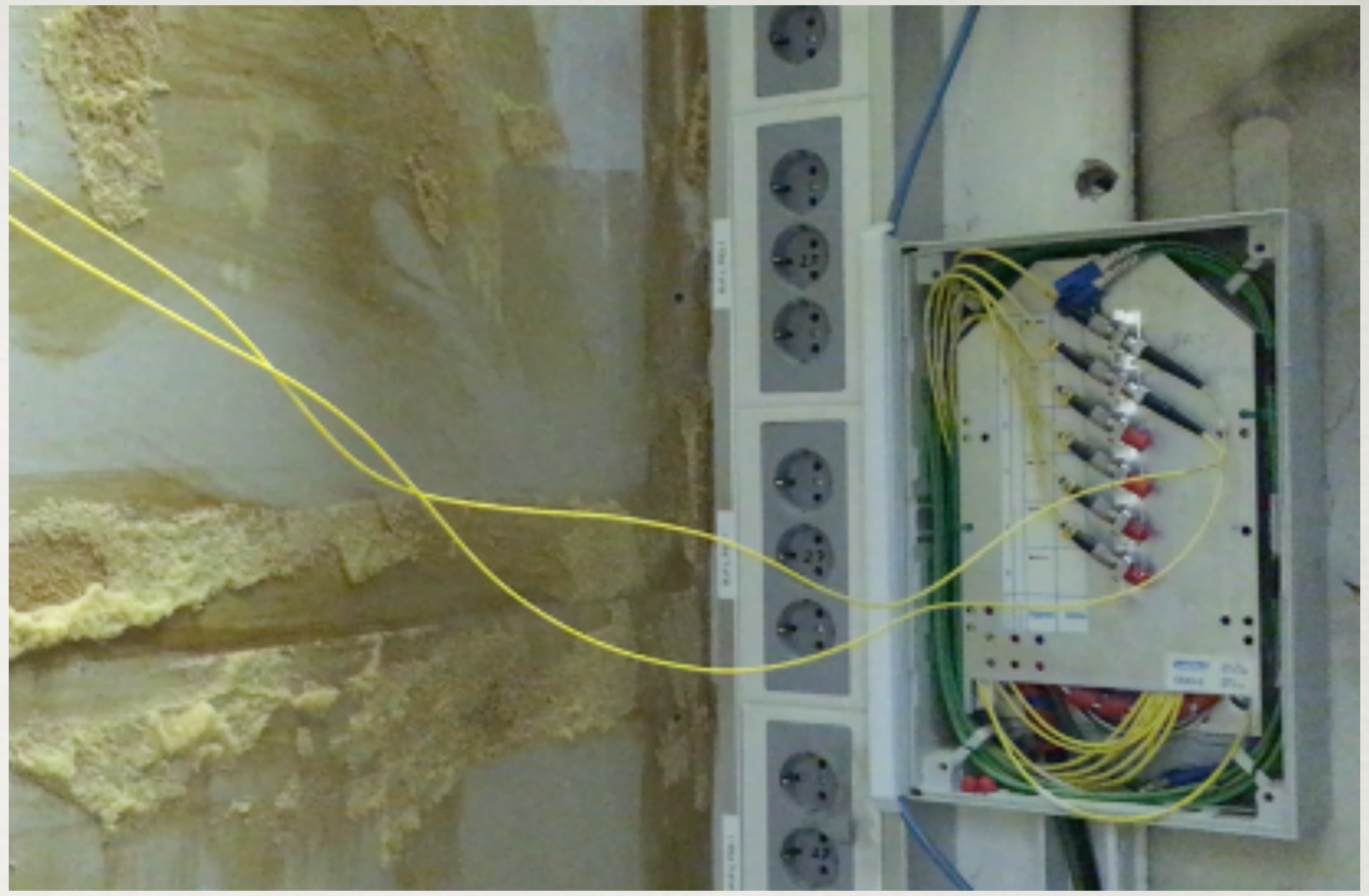
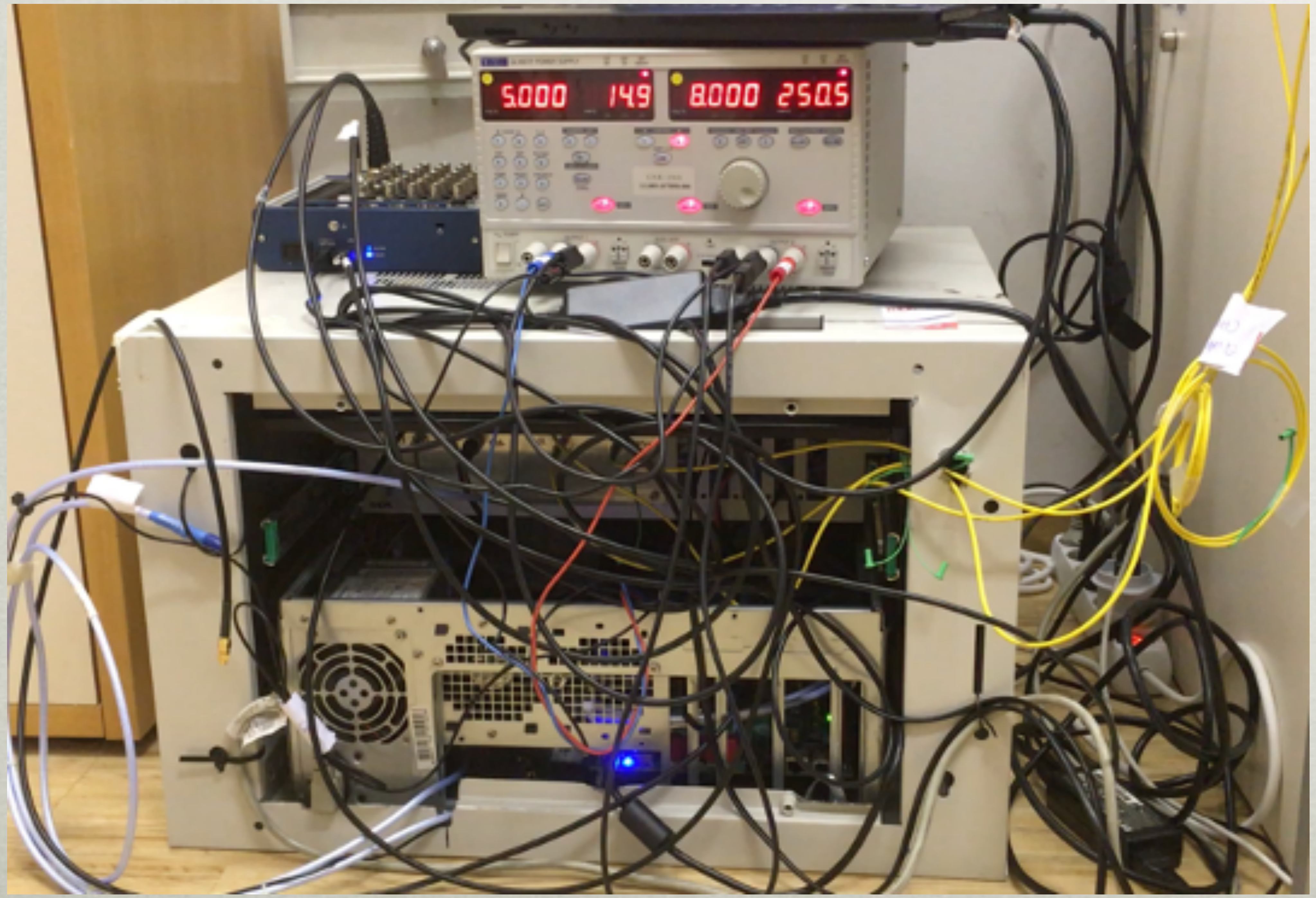
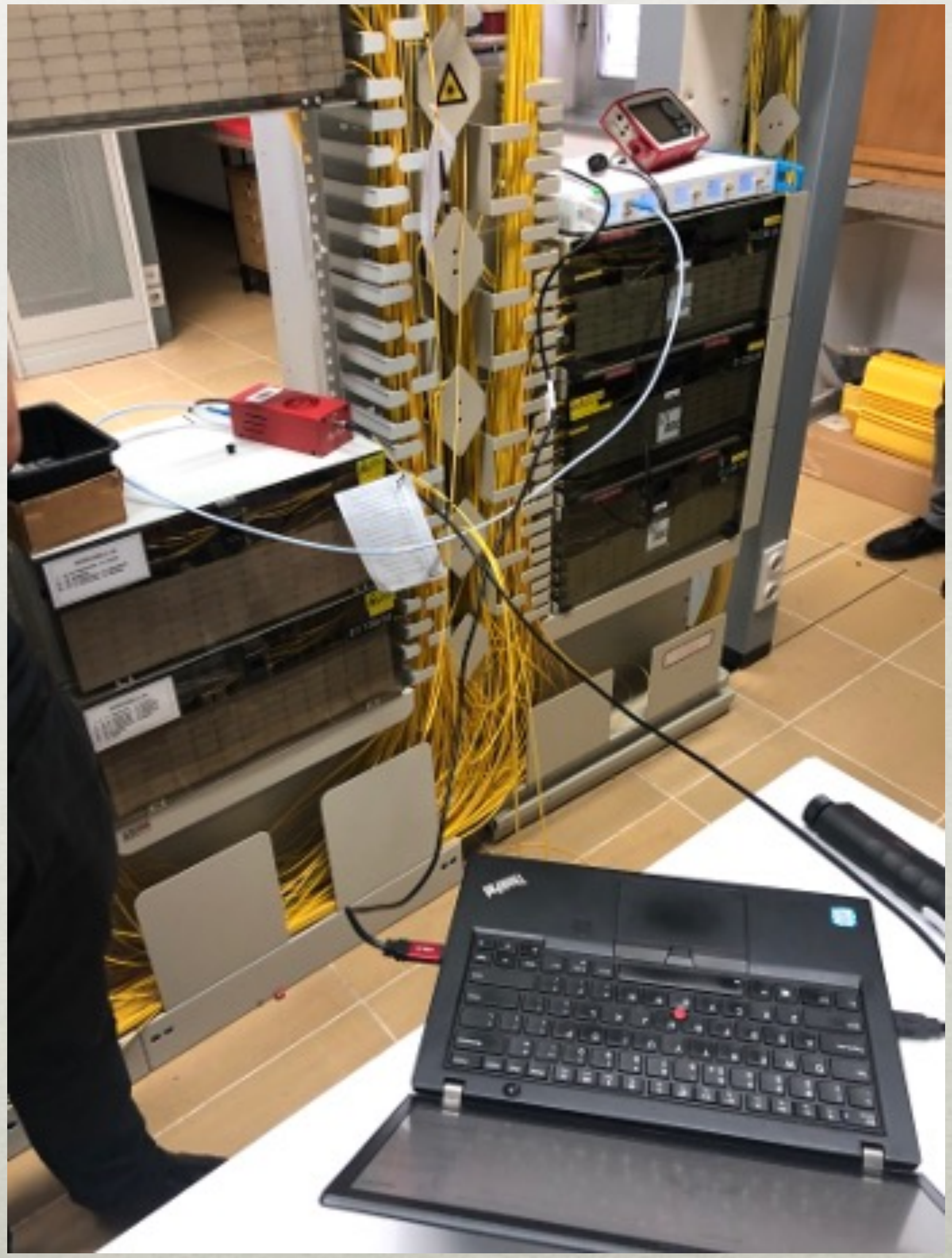


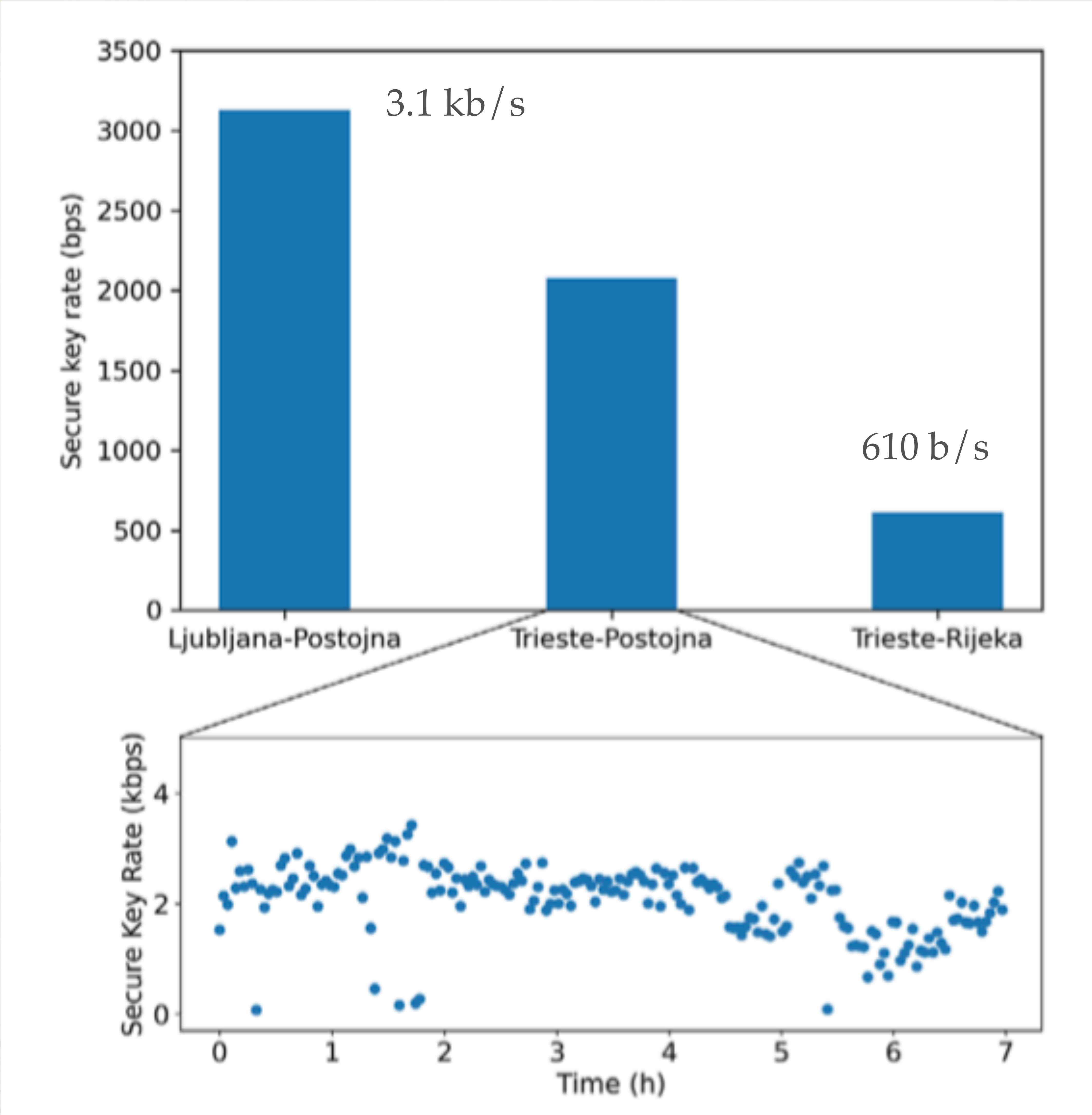


QKD enota na FMF

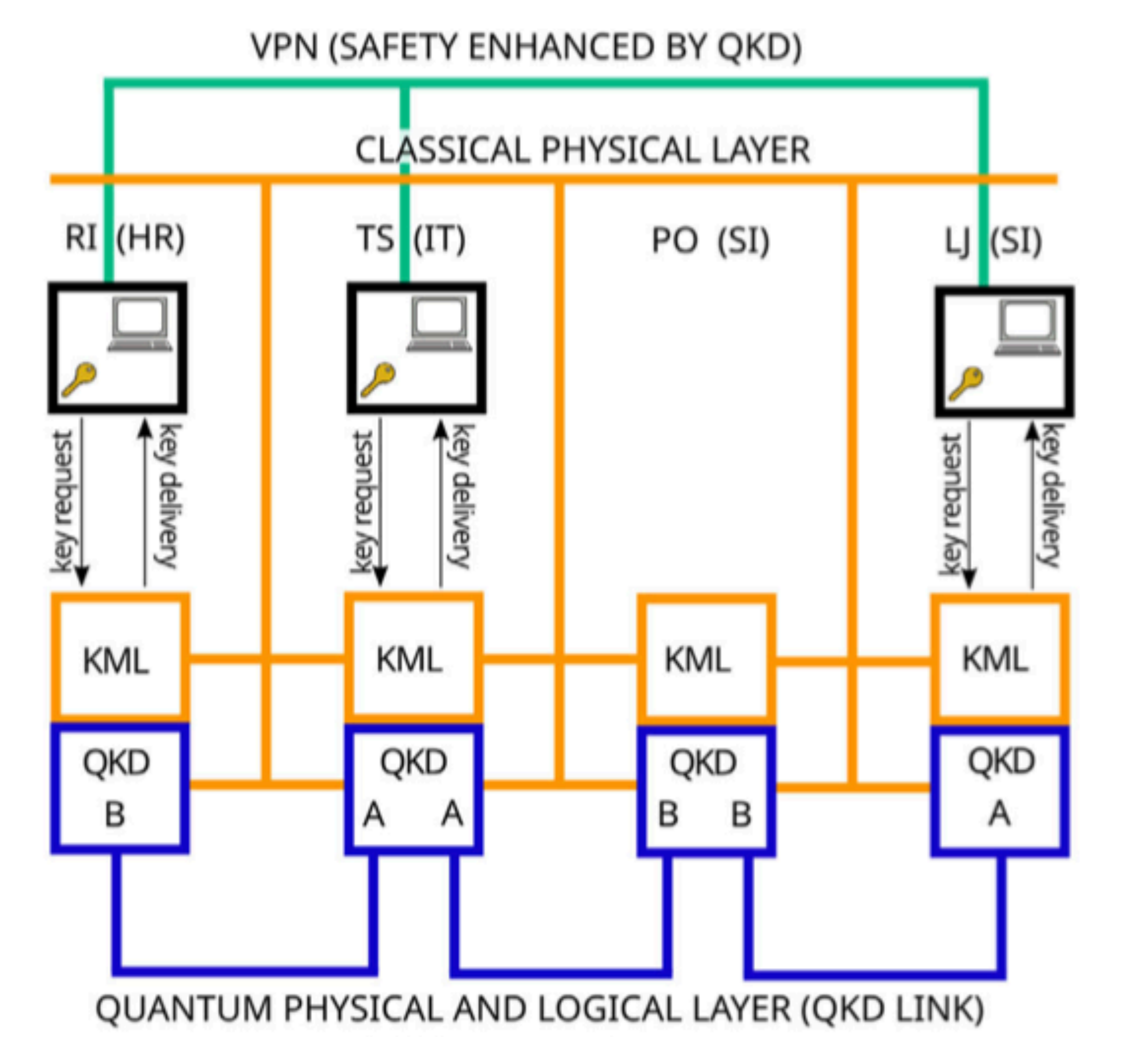
Varno vozlišče v Postojni



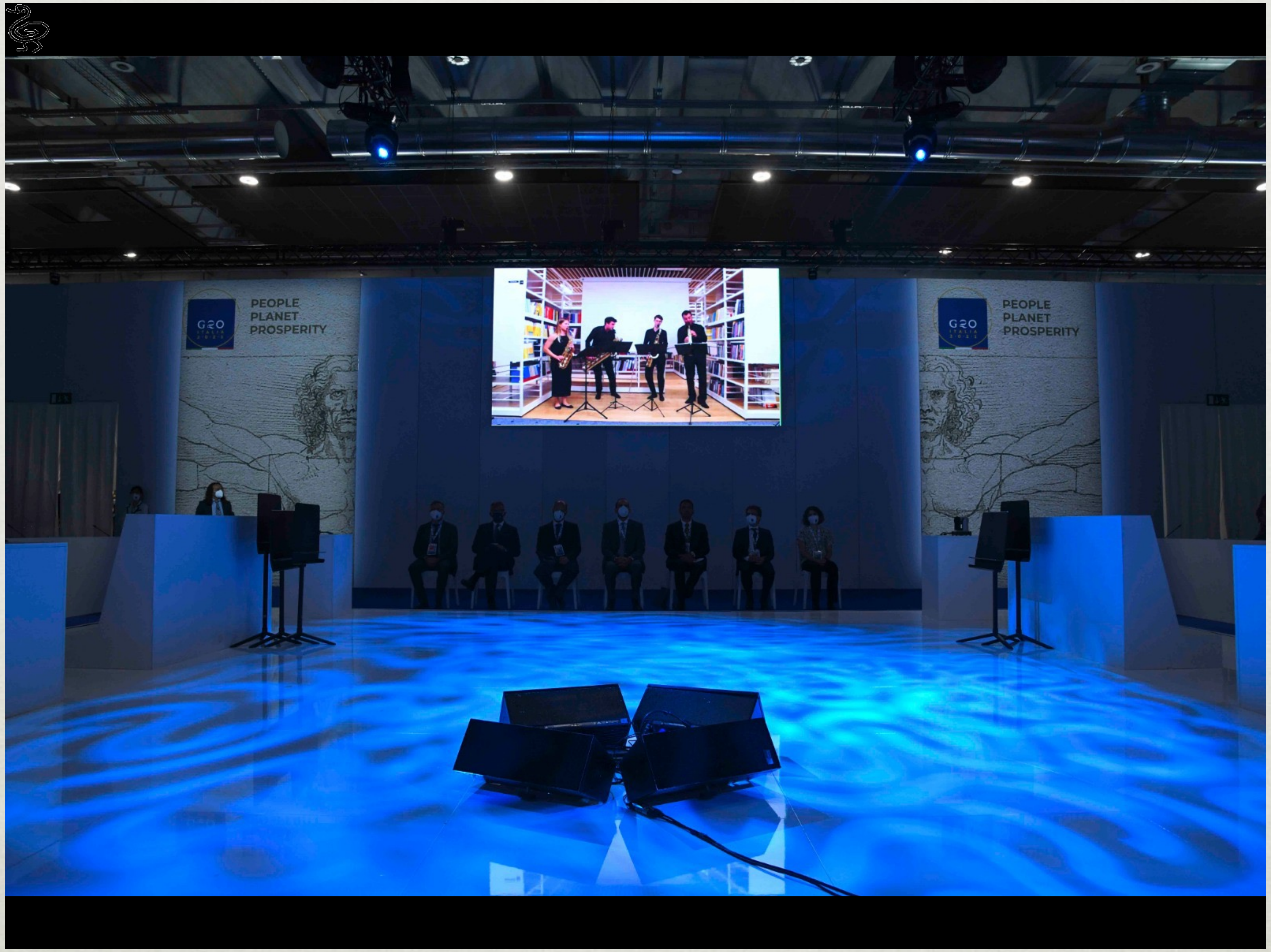

QTI
QUANTUM
TELECOMMUNICATIONS
ITALY
232



D. Ribezzo et al., Adv. Quant. Tech. 2200061 (2022)

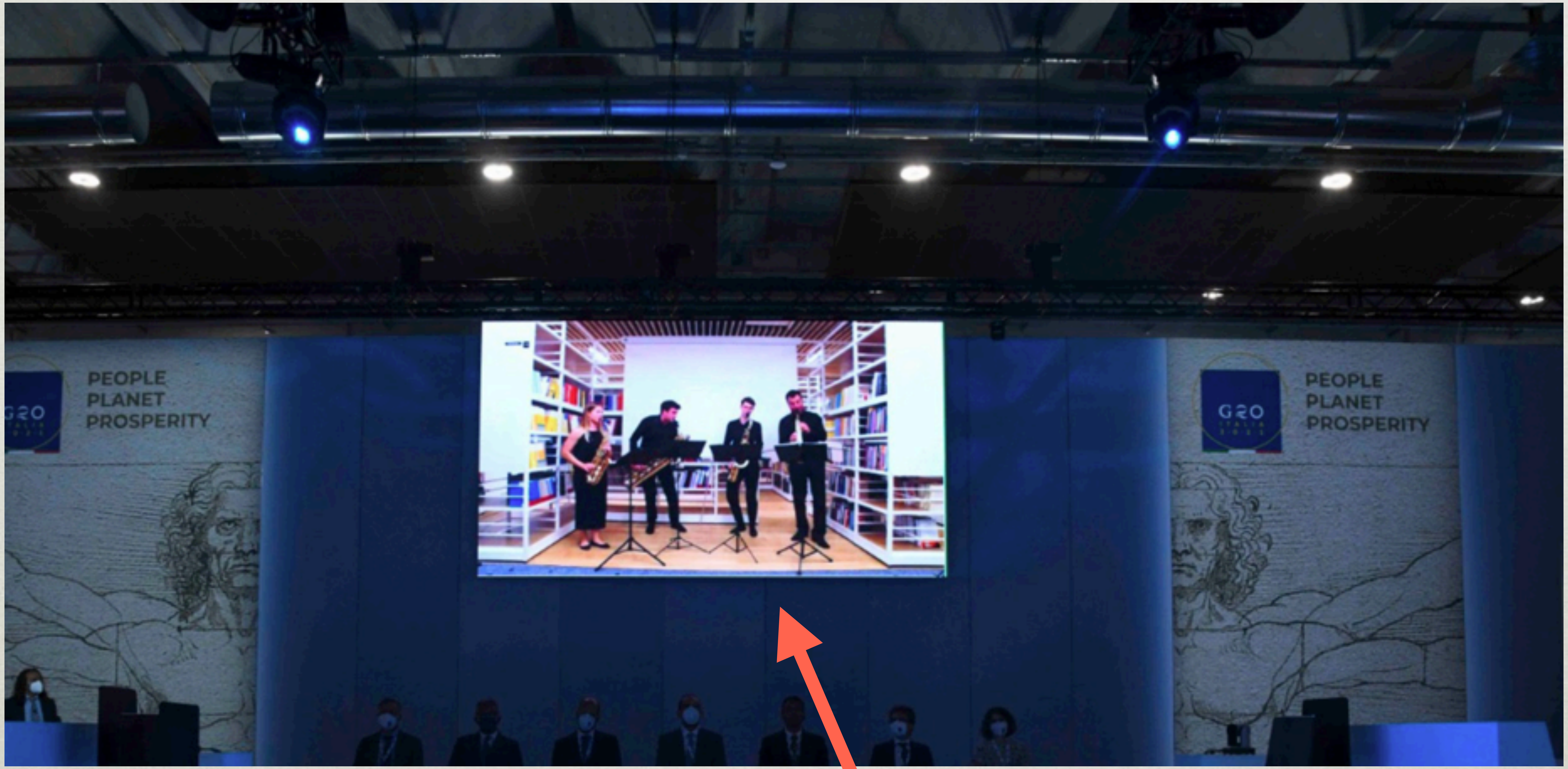

VPN (SAFETY ENHANCED BY QKD)
CLASSICAL PHYSICAL LAYER
RI (HR)
TS (IT)
PO (SI)
LJ (SI)
key request
key delivery
key request
key delivery
key request
key delivery
KML
KML
KML
KML
QKD B
QKD A A
QKD B B
QKD A
QUANTUM PHYSICAL AND LOGICAL LAYER (QKD LINK)

Koncert preko navideznega zasebnega omrežja (VPN)



Akademija za glasbo UL, Akademija za glasbo UZ, konservatorij "Giuseppe Tartini" iz Trsta

Z uporabo videokonferenčnega sistema **OpenMeetings**

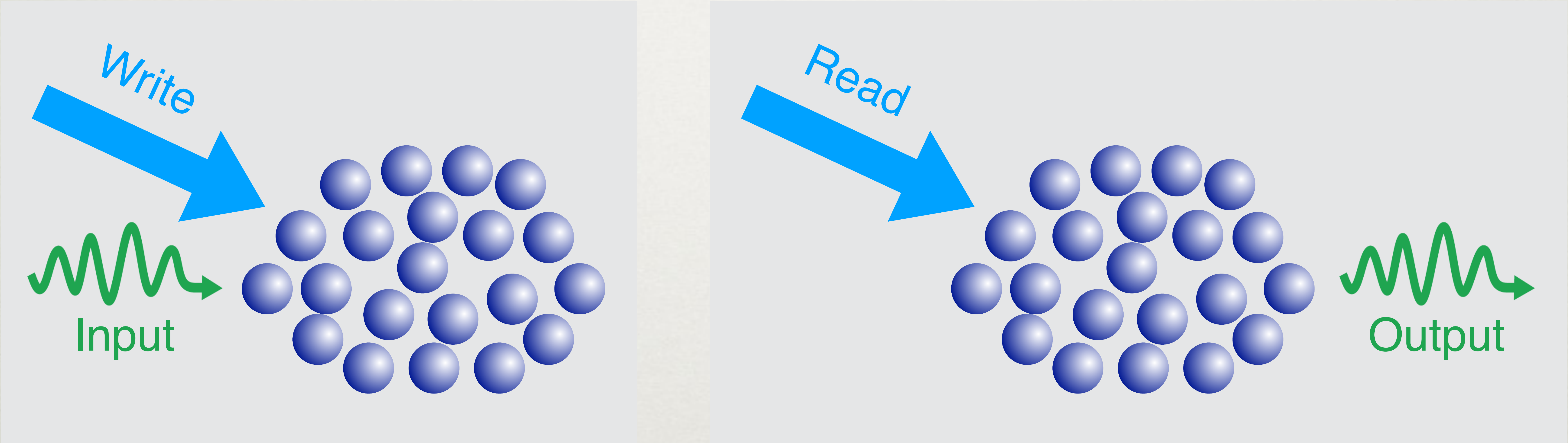


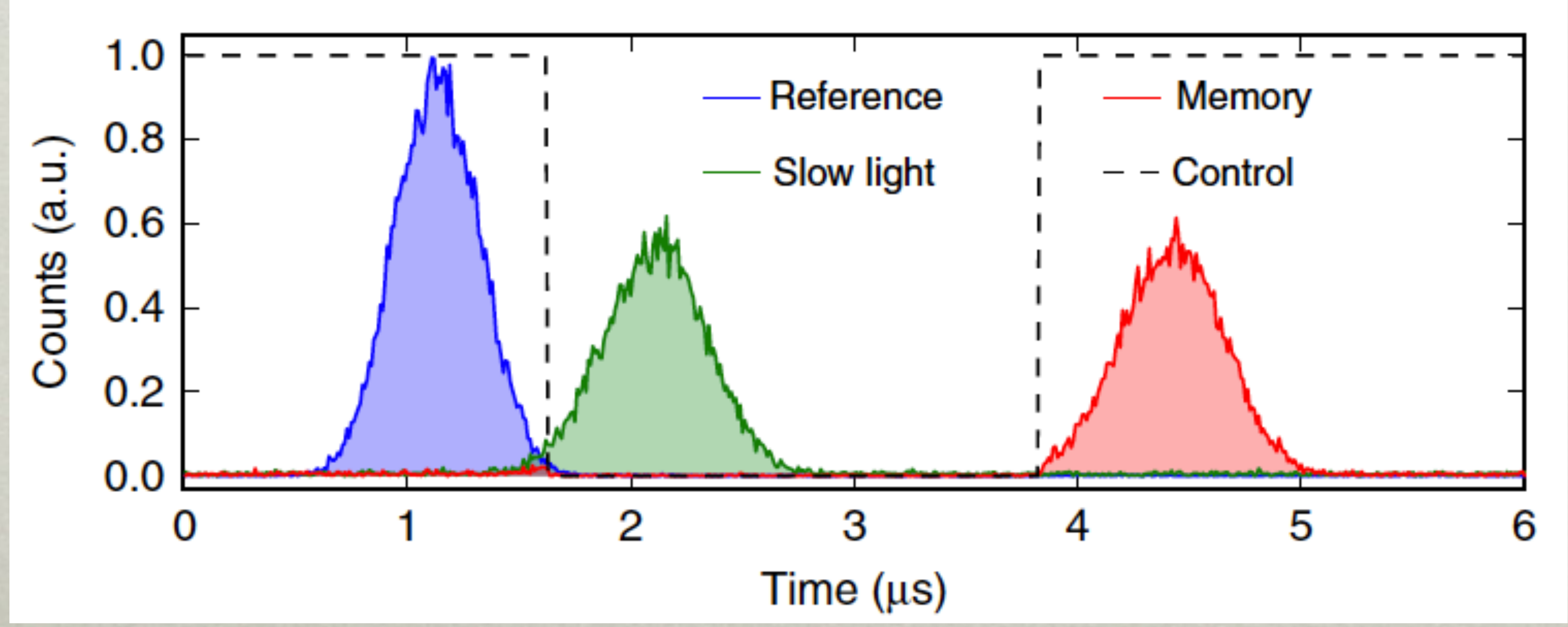
knjižnica FMF

Siquid

- Konzorcij: UL FMF (koordinator), IJS, Beyond Semiconductor, Urad vlade RS za varovanje tajnih podatkov (UVTP), Urad vlade RS za informacijsko varnost (URSIV)
- Cilji:
  - pilotska povezava med IJS in UL FMF
  - povezava državnih organov (7 lokacij v Ljubljani)
  - povezave do državnih meja
  - v drugi fazi: optična zemeljska postaja

Kvantni spomin z atomi





Eugene Polzik, *Kopenhagen*
Nicolas Gisin, *Ženeva*
Julien Laurat, *Sorbonne*

Laboratorij za fiziko hladnih atomov, IJS

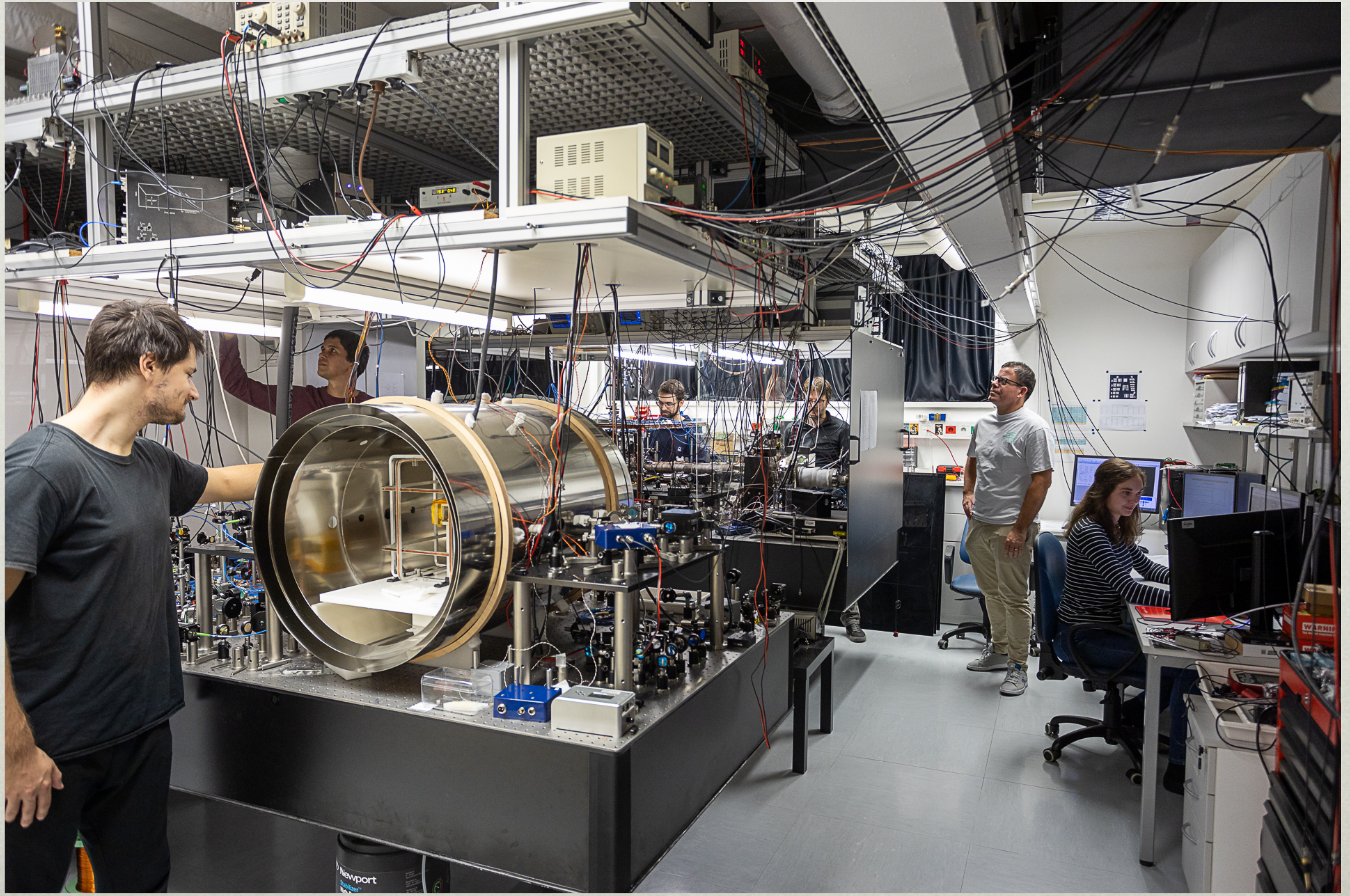
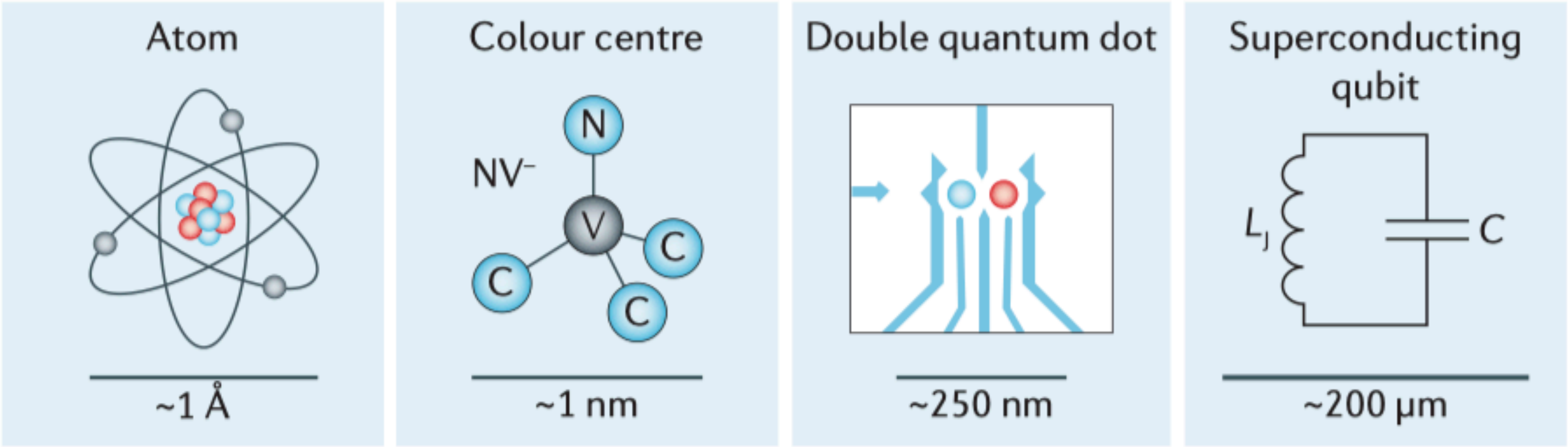


Foto: Marjan Verč



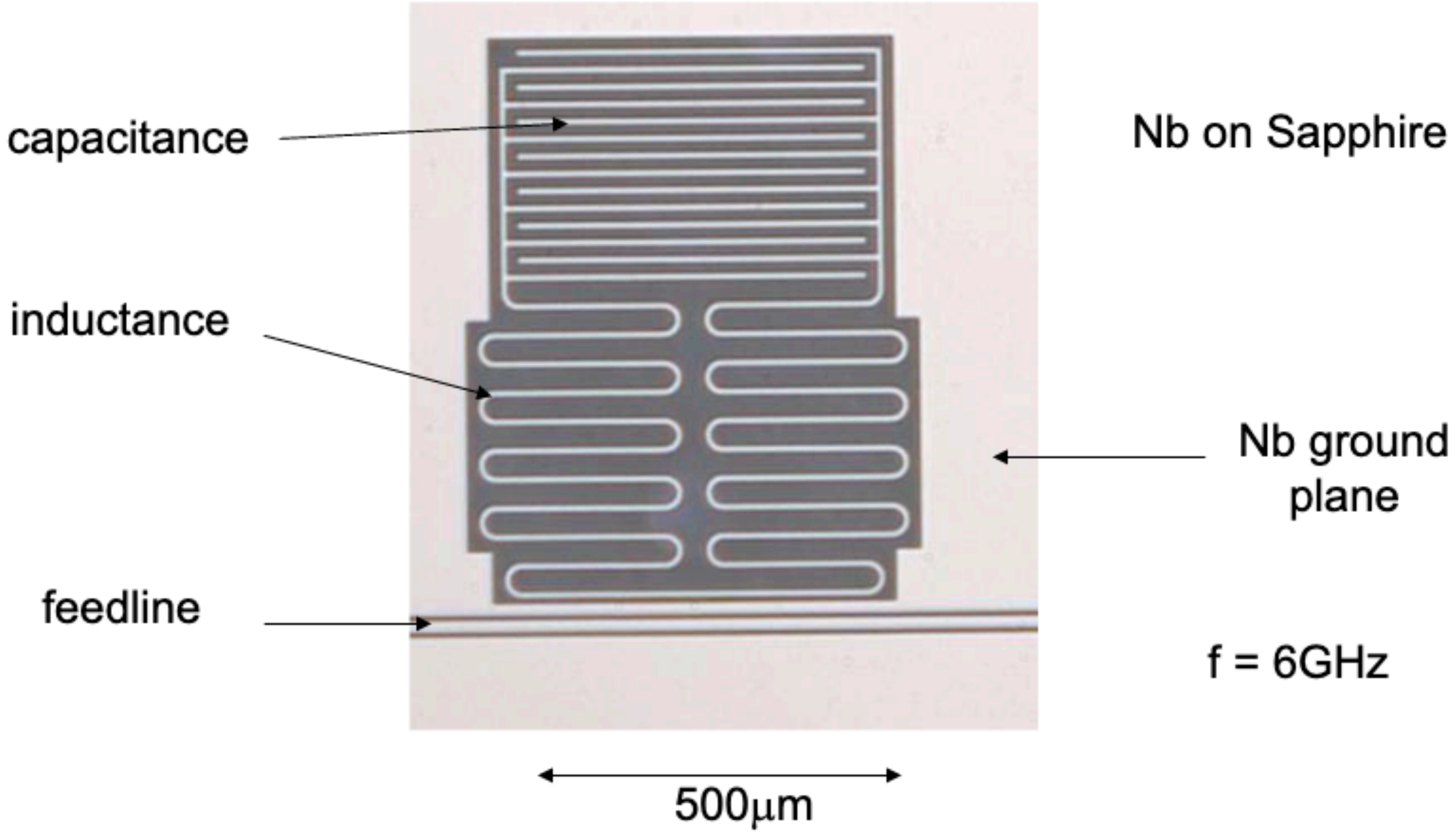
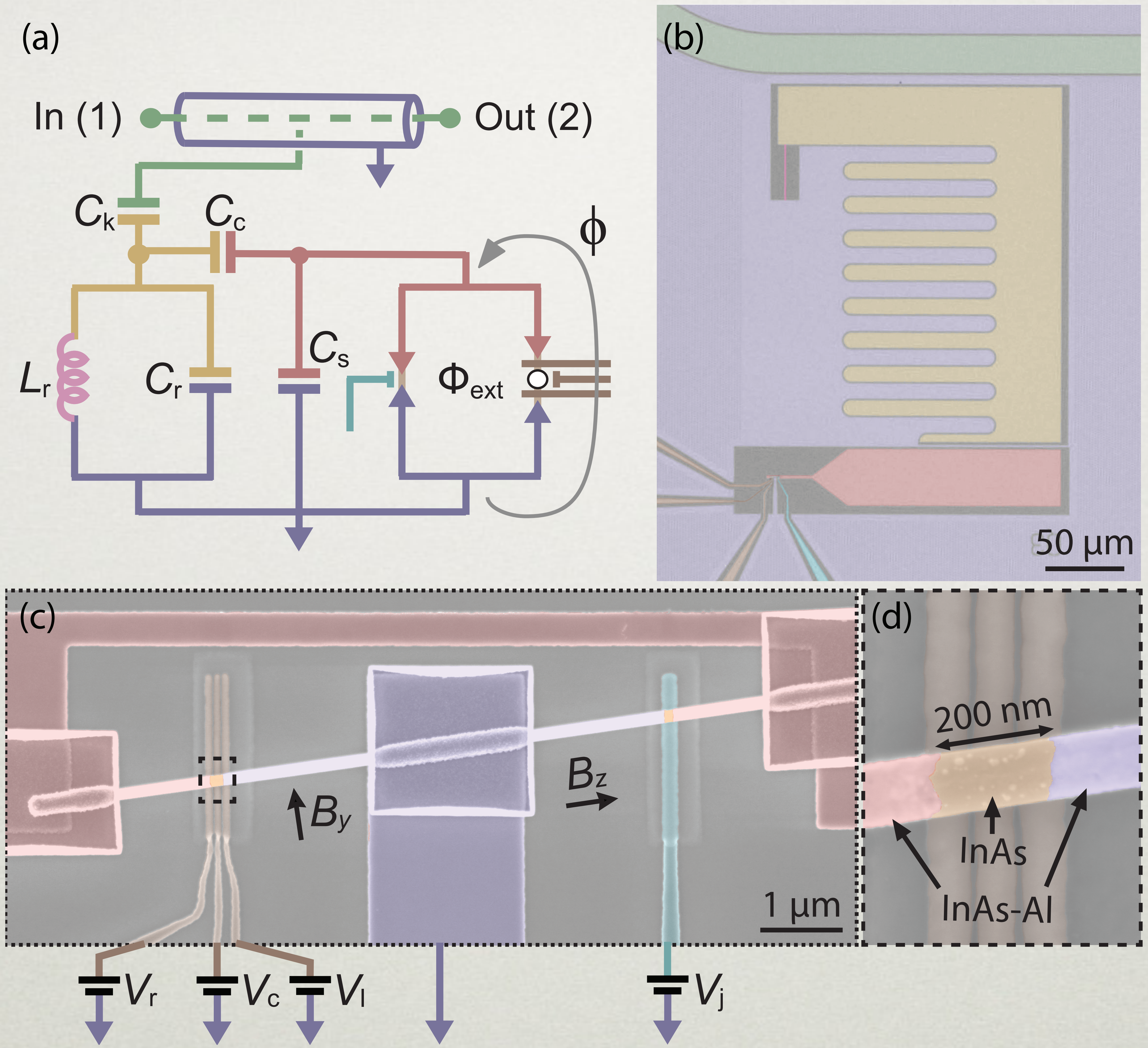


Figure source: Burkard et al. (2020)

Figure source: Devoret lectures

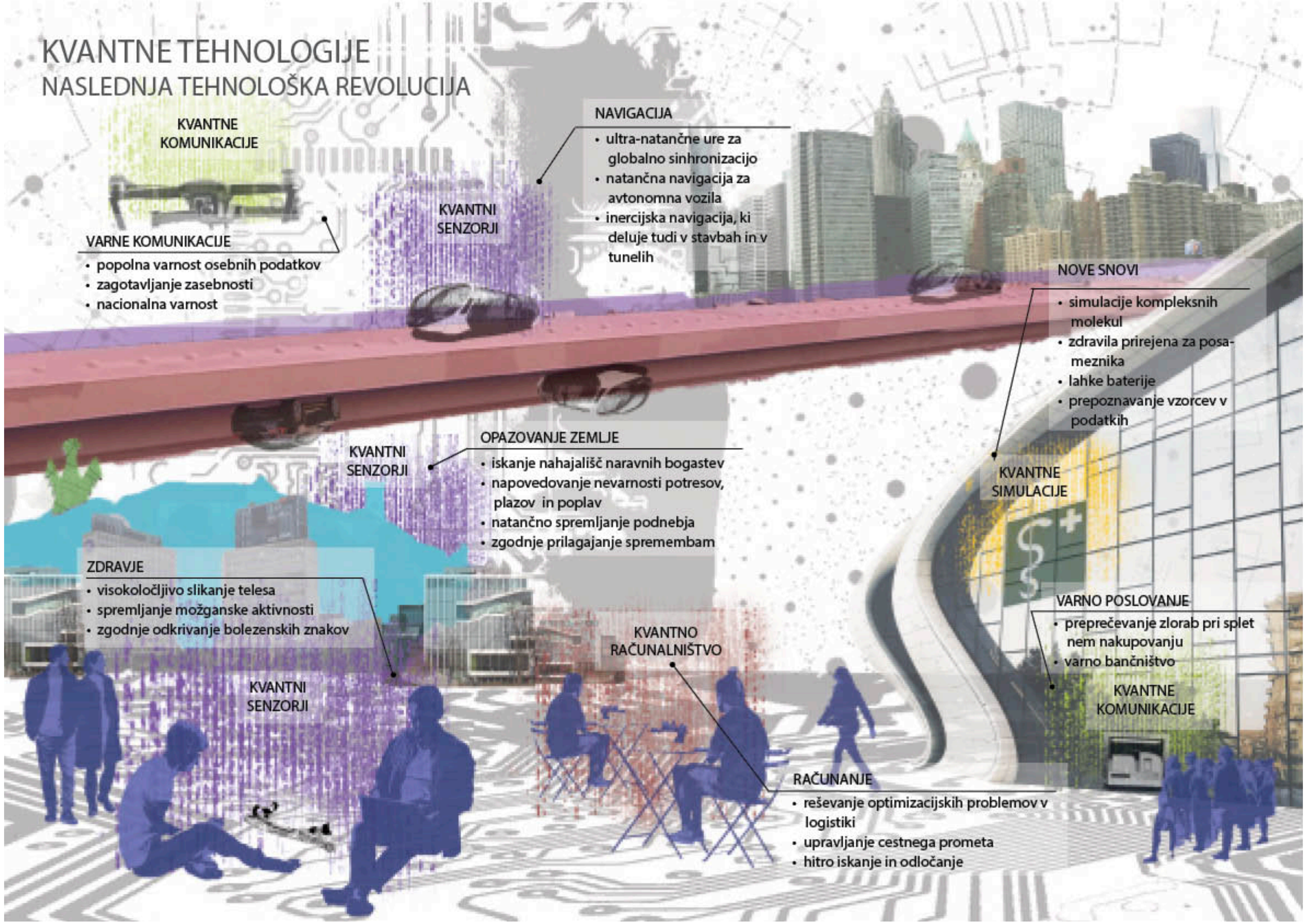
QUANTUM DOTS IN TRANSMONS



dispersive measurements of the qubit state

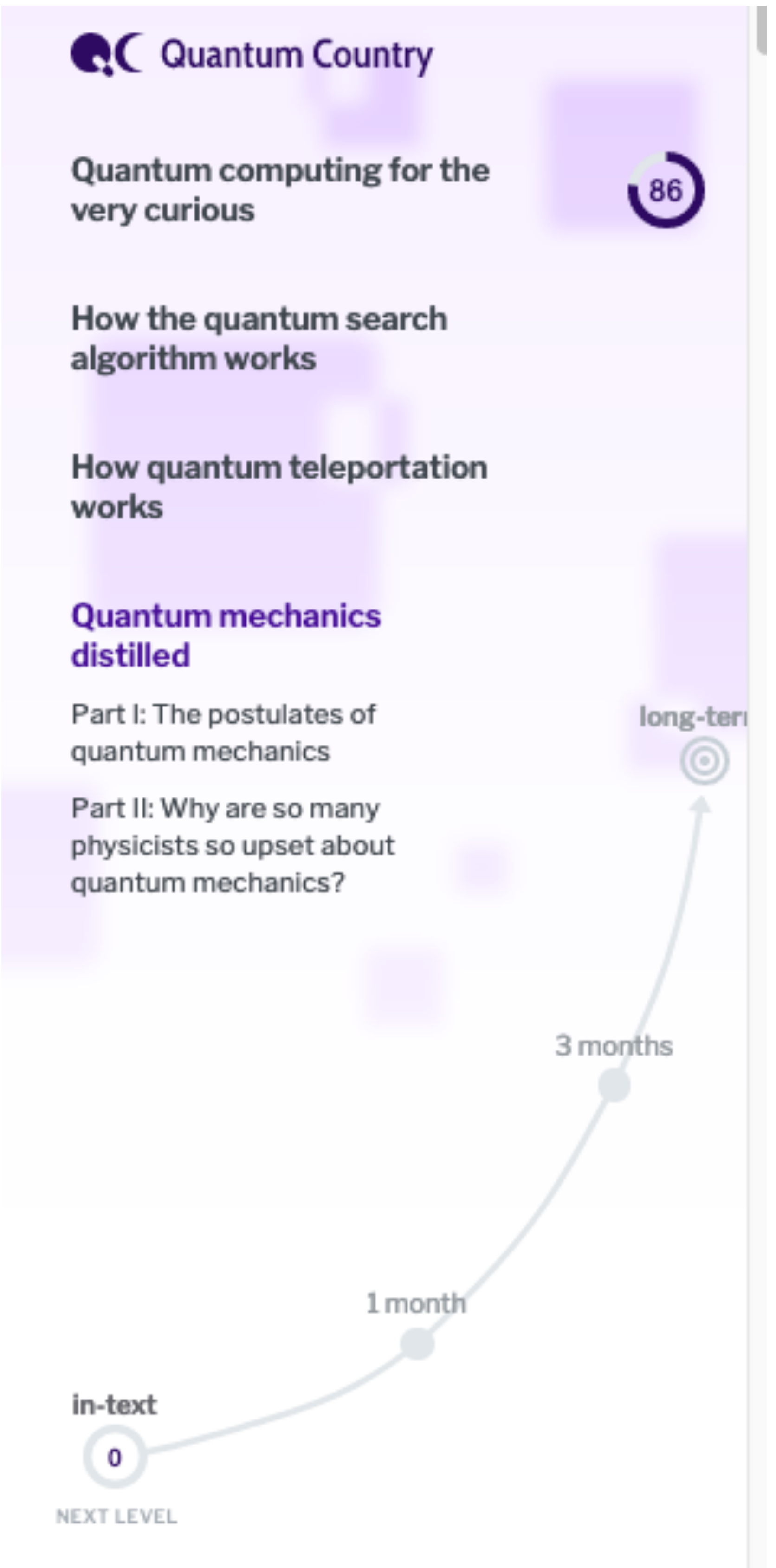
QuTech and Kavli Institute of Nanoscience, Delft University of Technology (TU Delft)

Bargerbos, Pita-Vidal, Žitko, Ávila, Splitthoff, Grünhaupt, Wesdorp, Andersen, Liu, Kouwenhoven, Aguado, Kou, van Heck, PRX Quantum (2022)



KVANTNE TEHNOLOGIJE
NASLEDNJA TEHNOLOŠKA REVOLUCIJA
KVANTNE KOMUNIKACIJE
VARNE KOMUNIKACIJE
• popolna varnost osebnih podatkov
• zagotavljanje zasebnosti
• nacionalna varnost
KVANTNI SENZORJI
NAVIGACIJA
• ultra-natančne ure za globalno sinhronizacijo
• natančna navigacija za avtonomna vozila
• inercijska navigacija, ki deluje tudi v stavbah in v tunelih
NOVE SNOVI
• simulacije kompleksnih molekul
• zdravila prirejena za posameznika
• lahke baterije
• prepoznavanje vzorcev v podatkih
KVANTNI SENZORJI
OPAZOVANJE ZEMLJE
• iskanje nahajališč naravnih bogastev
• napovedovanje nevarnosti potresov, plazov in poplav
• natančno spremljanje podnebja
• zgodnje prilagajanje spremembam
KVANTNE SIMULACIJE
ZDRAVJE
• visokoločljivo slikanje telesa
• spremljanje možganske aktivnosti
• zgodnje odkrivanje bolezenskih znakov
KVANTNO RAČUNALNIŠTVO
VARNO POSLOVANJE
• preprečevanje zlorab pri spletnem nakupovanju
• varno bančništvo
KVANTNI SENZORJI
KVANTNE KOMUNIKACIJE
RAČUNANJE
• reševanje optimizacijskih problemov v logistiki
• upravljanje cestnega prometa
• hitro iskanje in odločanje

https://quantum.country/qcvc



Learning this material is challenging. Quantum computing and quantum mechanics are famously "hard" subjects, often presented as mysterious and forbidding. If this were a conventional essay, chances are that you'd rapidly forget the material. But the essay is also an experiment in the essay form. As I'll explain in detail below *the essay incorporates new user interface ideas to help you remember what you read*. That may sound surprising, but uses a well-validated idea from cognitive science known as spaced-repetition testing. More detail on how it works below. The upshot is that anyone who is curious and determined can understand quantum computing deeply and for the long term.

> For more than a century, cognitive scientists have studied human memory. And they've figured out some simple strategies that ensure you'll remember something permanently. The single most important idea is to *re-test you on your knowledge, with expanding time intervals between tests.*

You may find the essay particularly helpful if you're taking an introductory class on quantum computing. If that's your situation, I advise you to read the entire essay immediately at the beginning of semester (or even before), answering all the questions as you go. Then continue to follow the procedure described just above, taking a few minutes to complete each review session, prompted by the reminders you'll be sent. This will make it far easier to understand the rest of the course you're taking, and help you get much more out of it.

It may seem tempting to try to avoid this mathematics. If you look around the web, there are many flashy introductions to quantum computing that avoid mathematics. There are, for instance, many rather slick videos on YouTube. They can be fun to watch, and the better ones give you some analogies to help make sense of quantum computing. But there's a hollowness to them. Bluntly, if they don't explain the actual underlying mathematical model, then you could spend years watching and rewatching such videos, and you'd never really get it. It's like hanging out with a group of basketball players and listening to them talk about basketball. You might enjoy it, and feel as though you're learning about basketball. But unless you actually spend a lot of time playing, you're never going to learn to play basketball. To understand quantum computing, you absolutely must become fluent in the mathematical model.

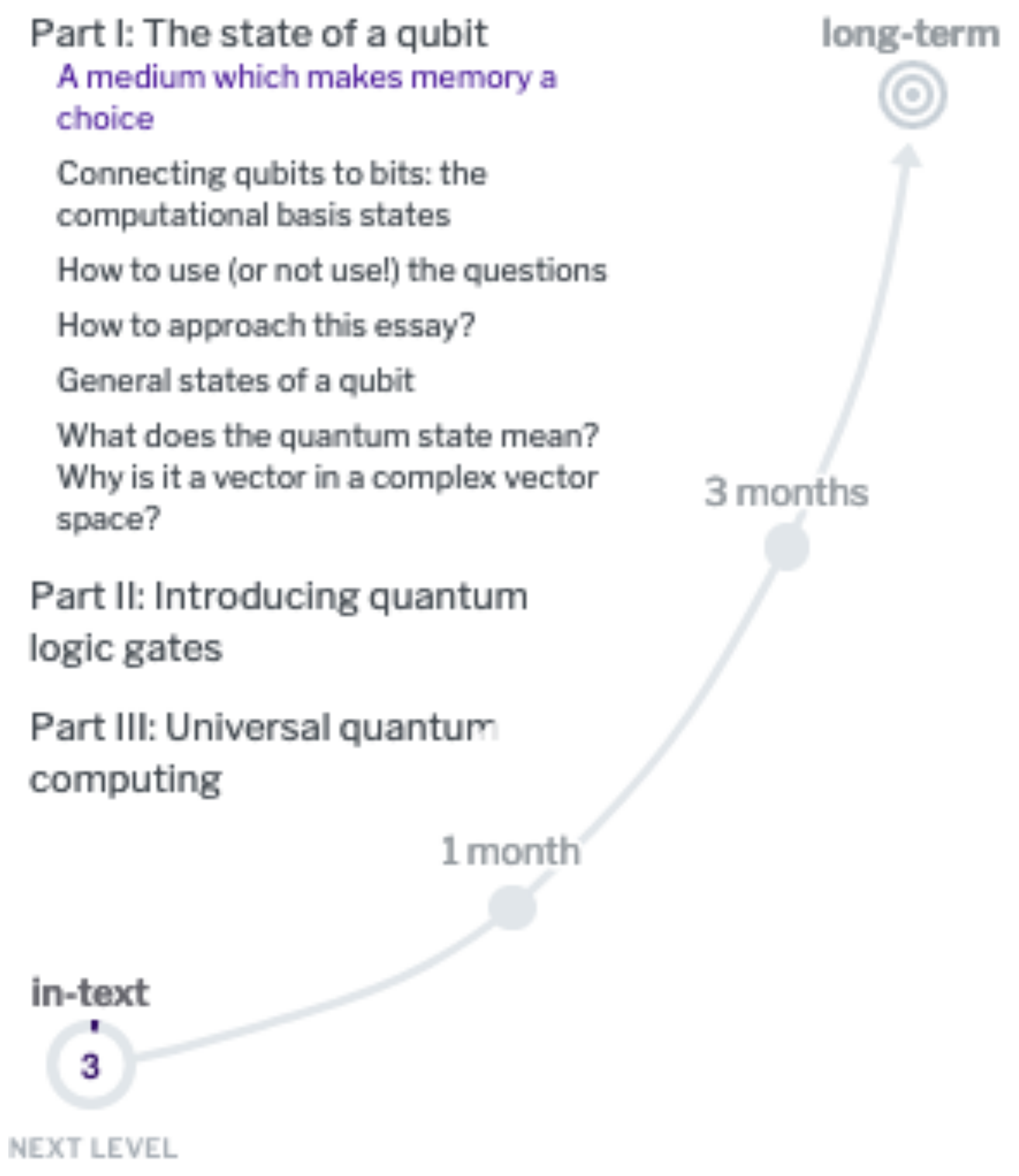
Part I: The state of a qubit, 1h
Part II: Introducing quantum logic gates, 1h30

Alright, let's review what we've learnt. Please indulge me by answering the questions just below. It'll only take a few seconds – for each question, think about what you believe the answer to be, click to reveal the actual answer, and then mark whether you remembered or not. If you can recall, that's great. If not, that's also fine, just note the correct answer, and continue.

How many dimensions does the state space of a qubit have?

Click anywhere to reveal

Didn't remember | Remembered



RT 2021: Domače naloge

Rok Žitko

1 Valovni paket

Napiši program za seštevanje ravnih valov $y(x) = \sum_{i=1}^{n} A_i \sin(k_i x)$. Kako za dan n izbrati amplitude A_i in valovna števila k_i, da dobimo čim bolj lokaliziran valovni paket? Povprečno valovno število $1/n \sum_{i=1}^{n} k_i$ naj bo fiksirano na 1. Fiksirana naj bo tudi normalizacija na intervalu $[0 : 2\pi]$, denimo $\int_0^{2\pi} y^2(x)dx = 1$.

2 Simulacija nehomogene verige sklopljenih nihal

Imejmo sistem $N = 1000$ z vzmetmi povezanih nihal, ki jih opišemo z enačbami (razdelek 1.10)

$$-K(\psi_n - \psi_{n-1}) - K(\psi_n - \psi_{n+1}) = m_n \ddot{\psi}_n, \tag{1}$$

za $n = 1, \ldots, N$, dodatno pa velja še $\psi_{N+1} = 0$ in $\psi_0 = A \sin(\omega t)$. Mase nihal m_n so lahko različne. Na začetku vsa nihala mirujejo, $\psi_n(t = 0) = \dot{\psi}_n(t = 0) = 0$ za $n = 1, \ldots, N$.

a) Reši program, ki bo računal časovno dinamiko sistema nihal z metodo končnih korakov (razdelek 1.1). Preizkusi ga za primer enakih mas, $m_n \equiv m$. Kaj se zgodi z valovanje, ko pride do desnega roba? Za lažje računanje izberi $K = m = 1$, primerni vrednosti za ω in A pa poišči sam!

b) Kaj se zgodi, če obravnavamo isti problem, a se mase nihal razlikujejo? Zapiši $m_n = 1 + \delta m_n$, kjer dodatne mase δm_n naključno izžrebaš v nekem izbranem intervalu $[-a : a]$. Kaj se zgodi s povečevanjem širine intervala $2a$?

3 Kvantni Zenov paradoks

Imejmo spin, ki kaže ob času 0 vzdolž smeri osi x, torej $|\psi(0)\rangle = \frac{1}{\sqrt{2}}(|\uparrow\rangle + |\downarrow\rangle)$. Imejmo polje vzdolž osi z, tako da je stanje po času T enako (razdelek 3.21)

$$|\psi(T)\rangle = \frac{1}{\sqrt{2}} \left(e^{-i\omega_0 t/2} |\uparrow\rangle + e^{i\omega_0 t/2} |\downarrow\rangle \right). \tag{2}$$

V tem trenutku opravimo meritev komponente spina vzdolž osi x. Rezultat določa Bornovo pravilo (razdelek 3.14), ob meritvi pa pride do kolapsa valovne funkcije (razdelek 3.17), pri čemer je treba upoštevati, da obstajata dva možna rezultata meritve. Nato postopek večkrat ponovimo: počakamo T in pomerimo ponovno, etc. Cilj te naloge je napisati program, ki bo simuliral rezultate zaporednih meritev. Naj bo $\omega_0 = 2\pi$.

a) Napiši program, ki določi verjetnosti za oba možna izzida meritve komponente spina vzdolž smeri x. Izžrebaj meritev skladno s tema verjetnostima in napiši rutino, ki določa novo valovno funkcijo (po kolapsu na lastno stanje operatorja spina v smeri x). Program naj izpisuje zaporedje rezultatov za izbrano vrednost T.

b) Prouči, kako se rezultati obnašajo za različne T. Zanimivi izbiri sta denimo $T = 0.5$ (polovica periode) in $T = 0.25$ (četrt periode).

c) Kaj pa se dogaja, če je T čedalje manjši? Pojav se imenuje kvantni Zenov paradoks.

4 Schmidtov razcep in entropija prepletenosti

Schmidtov razcep ja operacija, pri kateri vektor iz produktnega prostora zapišemo kot linearno kombinacijo vektorjev iz posameznih prostorov:

$$|\psi\rangle = \sum_{i=1}^{n} \alpha_i |u_i\rangle \otimes |v_i\rangle, \tag{3}$$

kjer je n dimenzija posameznega prostora ($n = 2$ za kubite), $|u_i\rangle$ in $|v_i\rangle$ pa vektorja iz posameznih prostorov. Če je od nič različna le ena vrednosti α_1, potem je stanje separabilno, sicer pa je vsaj delno prepleteno. V splošnem jakost kvantne prepletenosti kvantificiramo z entropijo prepletenosti:

$$S = -\sum_{i=1}^{n} |\alpha_i|^2 \log(|\alpha_i|^2). \tag{4}$$

Napiši program, ki naključno generira pare kubitov $\psi = c_{00}|00\rangle + c_{01}|01\rangle + c_{10}|10\rangle + c_{11}|11\rangle$ z amplitudami c_{ij}, ki so enakomerno naključno porazdeljene v intervalu $[0 : 1]$, vektorje normira, izračuna koeficiente α_i in nato še entropijo S. Določi histogram vrednosti S za 10000 realizacij.

5 Meritev naključnih kubitov

Napiši program, ki naključno generira točke na sferi. Izračunaj povprečne vrednosti spremenljivk x, y, z, x^2, y^2 in z^2 (recimo za 10000 naključnih točk). Napiši še program, ki naključno generira stanja na Blochovi sferi. Izračunaj povprečne vrednosti opazljivk X, Y, Z, X^2, Y^2 in Z^2.

Kako se rezultati razlikujejo, če točke niso generirane z enakomerno porazdelitvijo po površini?

6 Preizkuševalec bomb

Napiši program za simulacijo problema preizkuševalca bomb. Imamo 1000 bomb, polovica je delujočih, polovica pokvarjenih. Vsako vstavimo v en krak Mach-Zenderjevega detektorja. Simulirati moramo rezultate kvantnomehanskih meritev. V primeru pokvarjene bombe je meritev ena sama: foton pade na detektor A ali B. V primeru delujoče bombe sta meritvi dve: najprej na bombi (je foton prisoten ali ni?), če ne pride do eksplozije pa še na detektorju (foton na A ali na B?).

a) Koliko delujočih bomb lahko odbereš v povprečju?

b) Premisli, kako bi lahko odbral še večji delež! Sprogramiraj simulator tudi za takšen boljši način.

7 Simulacija spina v časovno odvisnem polju

V razdelku 3.21 učbenika je zapisana splošna rešitev za časovno odvisnost stanja spina v konstantnem (po času) magnetnem polju. Časovno odvisno polje lahko obravnavamo tako, da to rešitev uporabimo za kratke časovne intervale Δt.

a) Na ta način obravnavaj dinamiko spin v časovno spremenljivem polju $B = B_0 \cos(\omega t)$ vzdolž osi z. Oglej si rešitve za različne izbire začetnega kota θ, začetni ϕ pa naj bo 0.

b) Primerjaj primere $\omega < \omega_0$, $\omega = \omega_0$ in $\omega > \omega_0$!

8 Vezano stanje za ozek privlačen potencial

Numerično reši stacionarno Schroedingerjevo enačbo za primer potenciala, ki je povsod enak nič, le v bližini izhodišča je močno privlačen. Potencial lahko opišeš z Gaussovo funkcijo, katere širino zmanjšuješ, globino pa povečuješ, tako da je integral ves čas konstanten. Ugotovi, h kateri funkciji rezultat (valovna funkcija) konvergira z zmanjševanjem širine!

Literatura:

- Rok Žitko: Kvantne in računalniške tehnologije, DMFA, Ljubljana (2017)

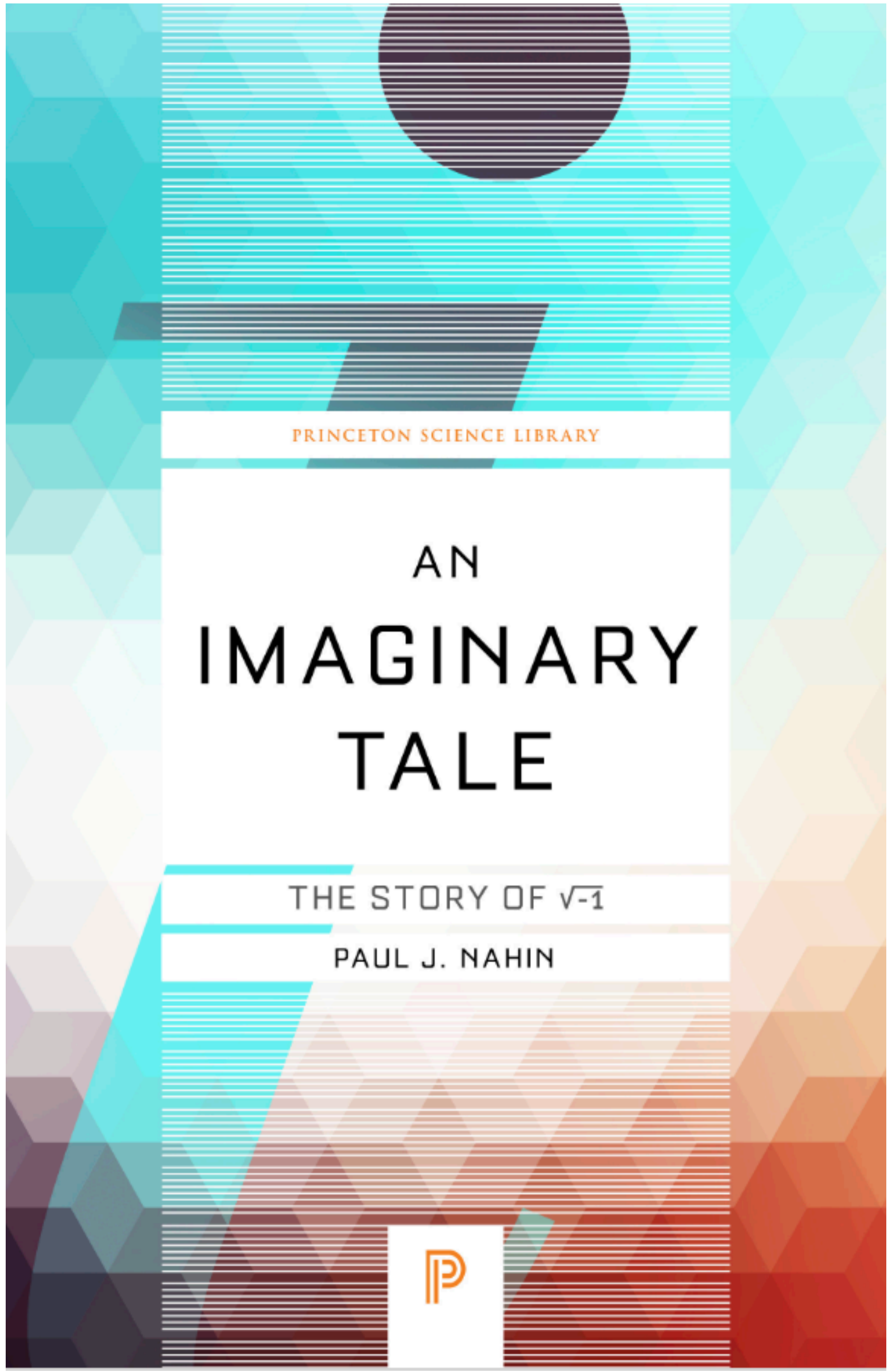
- Nielsen, Chuang: Quantum computation and quantum information. Cambridge University Press (2000). Prvi dve poglavji.

- James Gleick: The Information: A History, a Theory, A Flood (2011). Poljudnoznanstvena knjiga o pojmu informacije.
- J. P. Dowling: Schrödinger's Killer App: Race to build the World's First Quantum Computer, CRC Press (2013). Poljudna knjiga o kvantnih računalnikih.
- J. P. Dowling: Schrödinger's Web: Race to build the Quantum Internet, CRC Press (2021). Poljudna knjiga o kvantnem internetu.

https://en.cppreference.com/w/cpp/numeric/complex

https://docs.python.org/3/library/cmath.html

https://docs.julialang.org/en/v1/manual/complex-and-rational-numbers/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http://www.stat.ucla.edu/~ywu/linear.pdf

THE MATHEMATICS OF QUANTUM MECHANICS

Martin Laforest, PhD

UNIVERSITY OF WATERLOO | IQC Institute for Quantum Computing

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