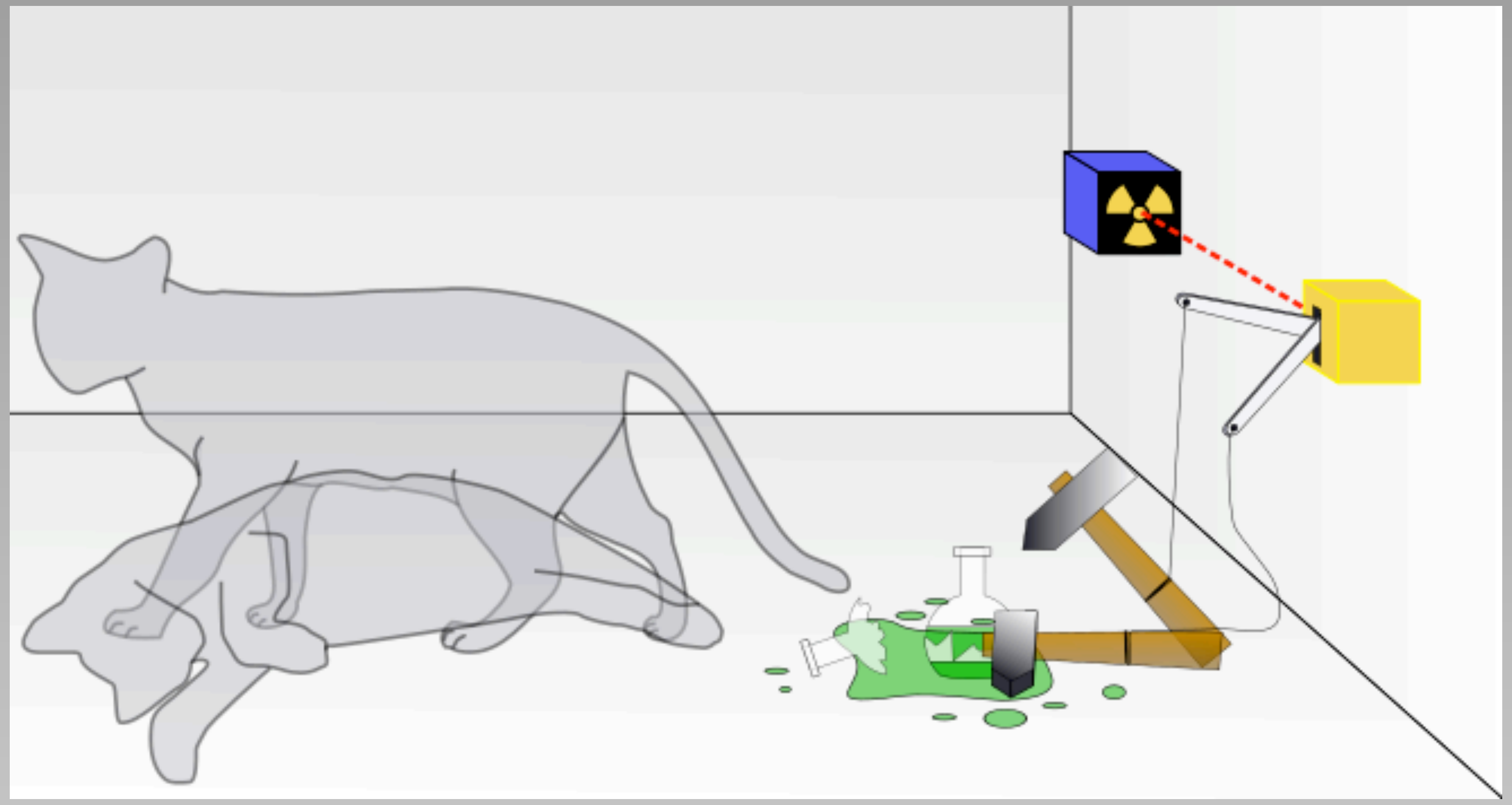
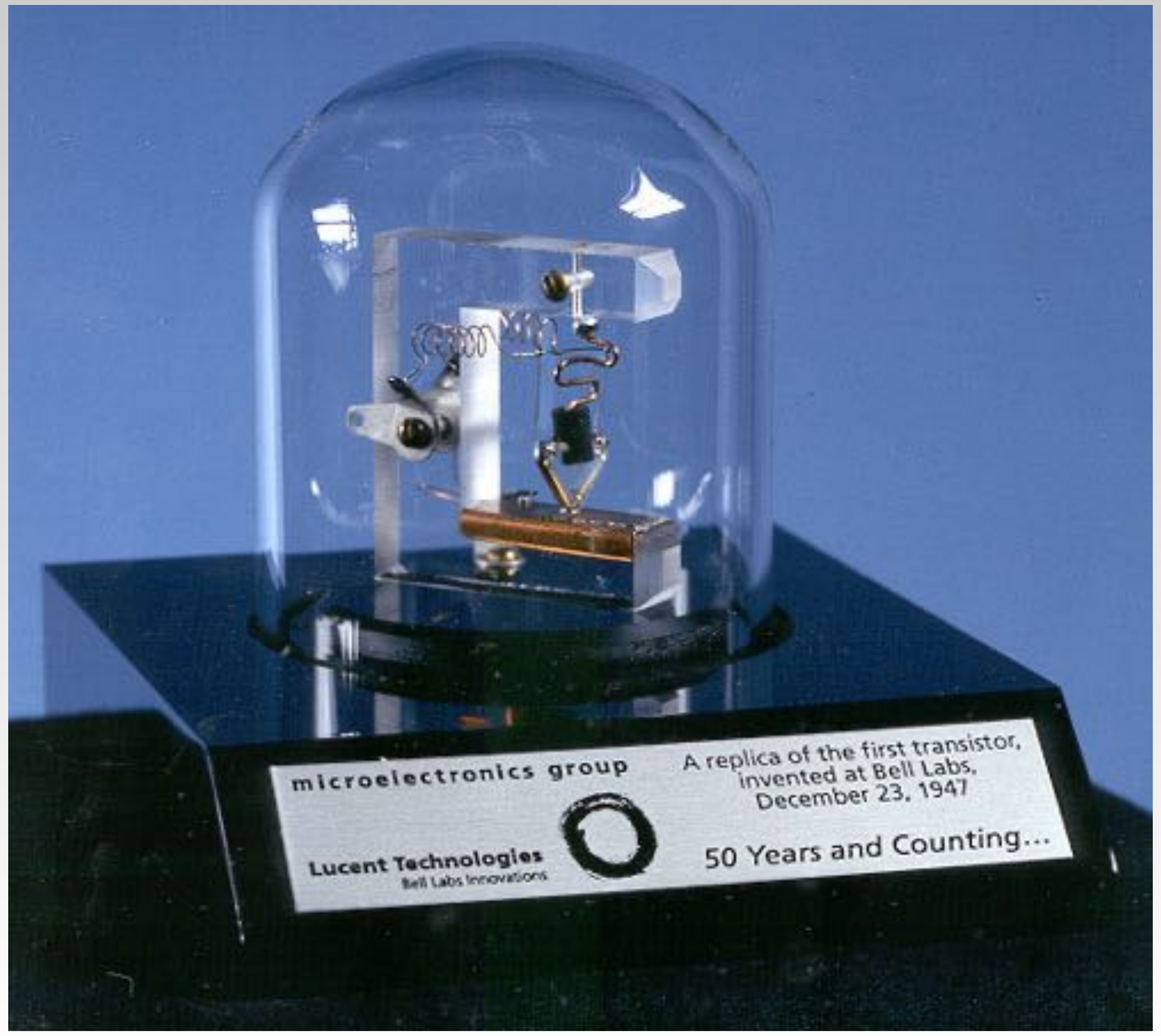
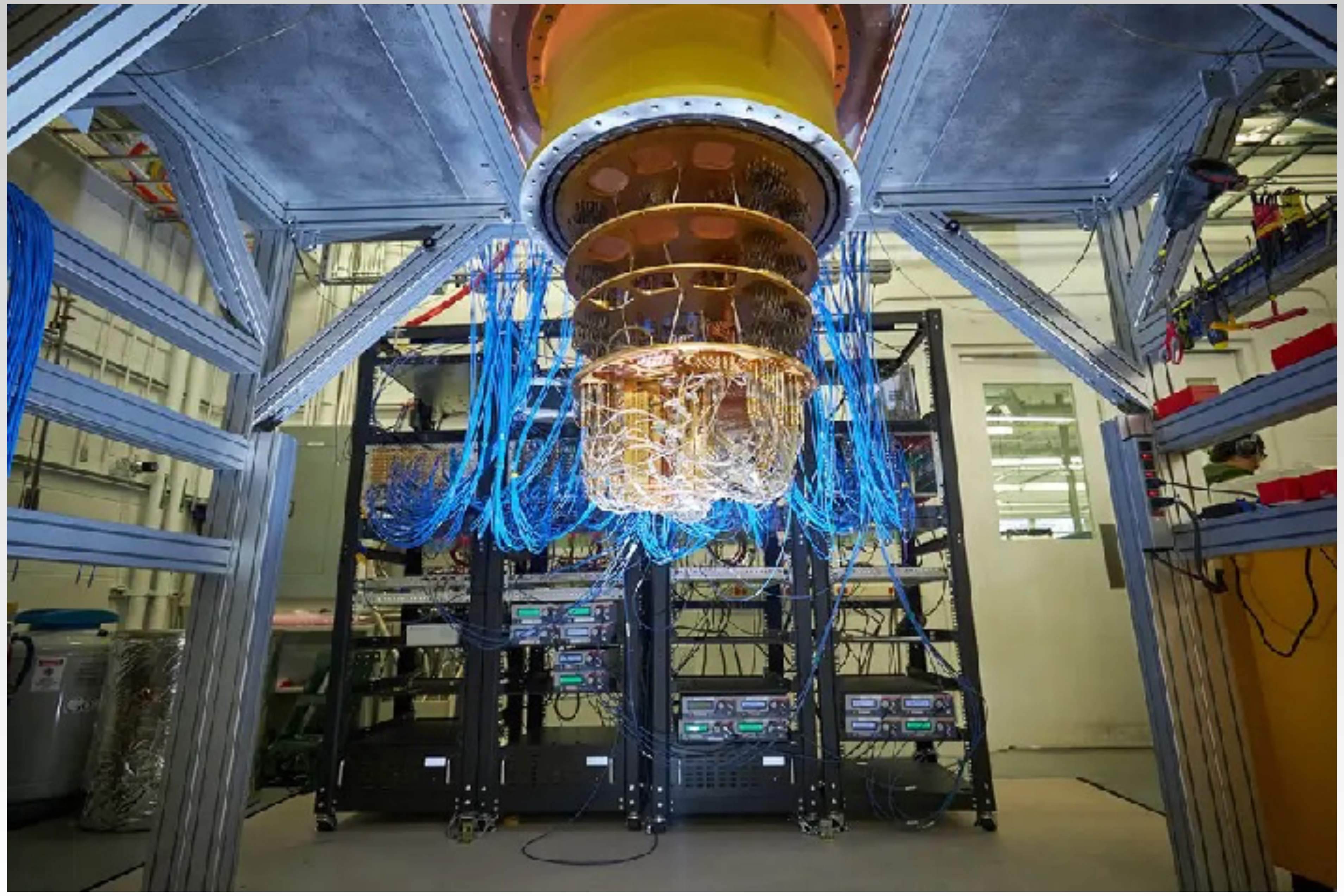
Kvantne in računalniške tehnologije







"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"

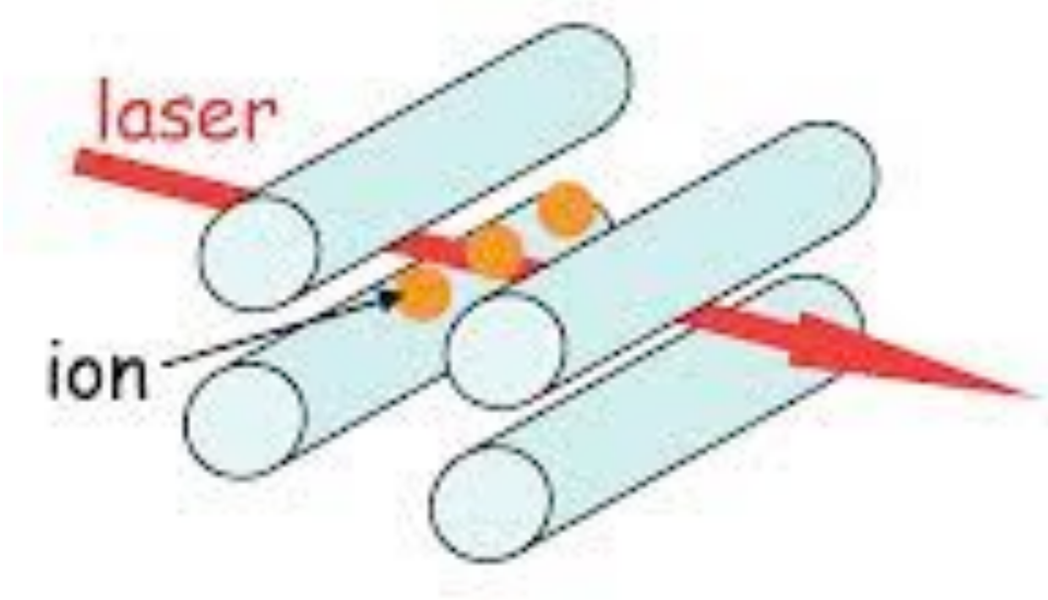
Vzrok: "Počasen" napredek laserskih, računalniških in superprevodnih tehnologij

Nobelova nagrada 2012

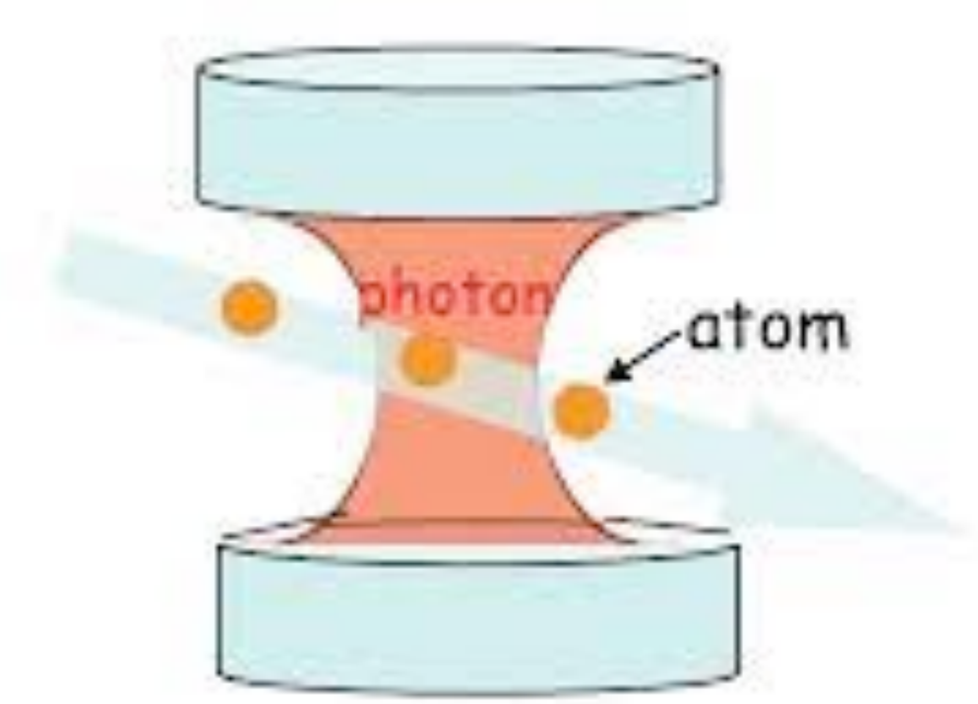
En atom s fotoni [Wineland]

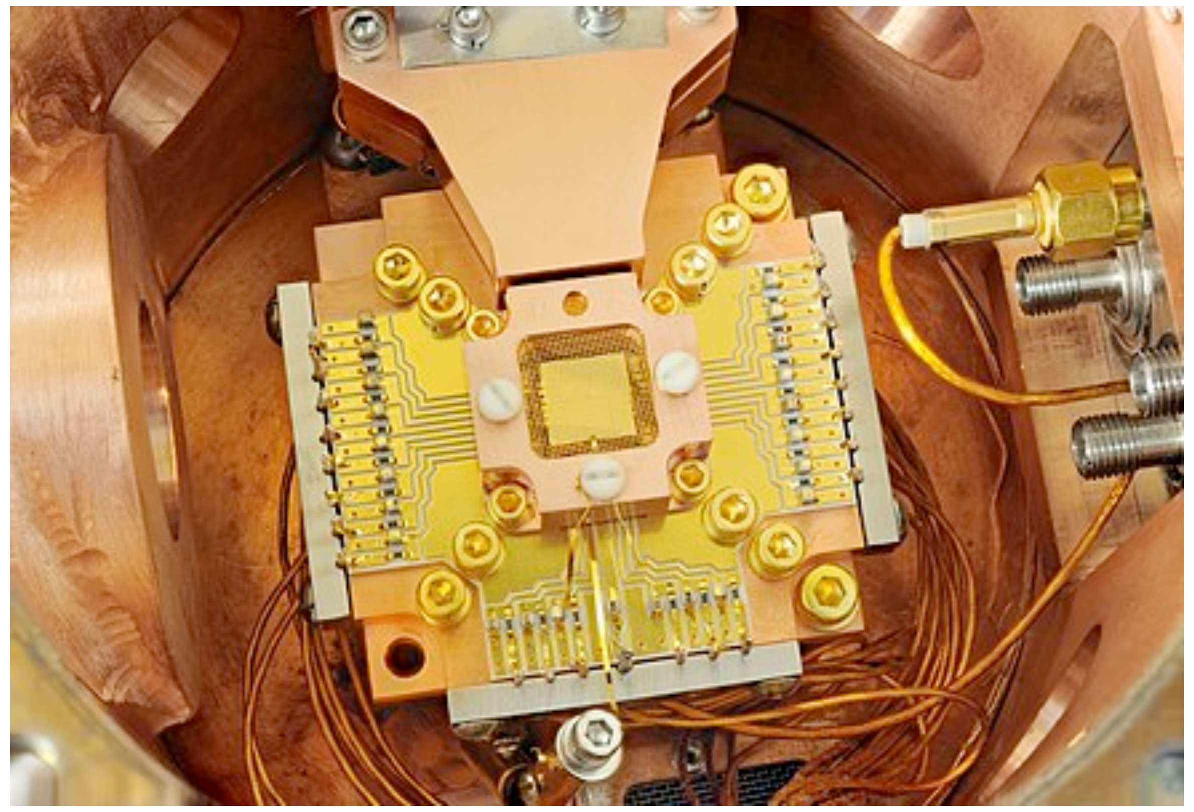
En foton z atomi [Haroche]

Ionska past

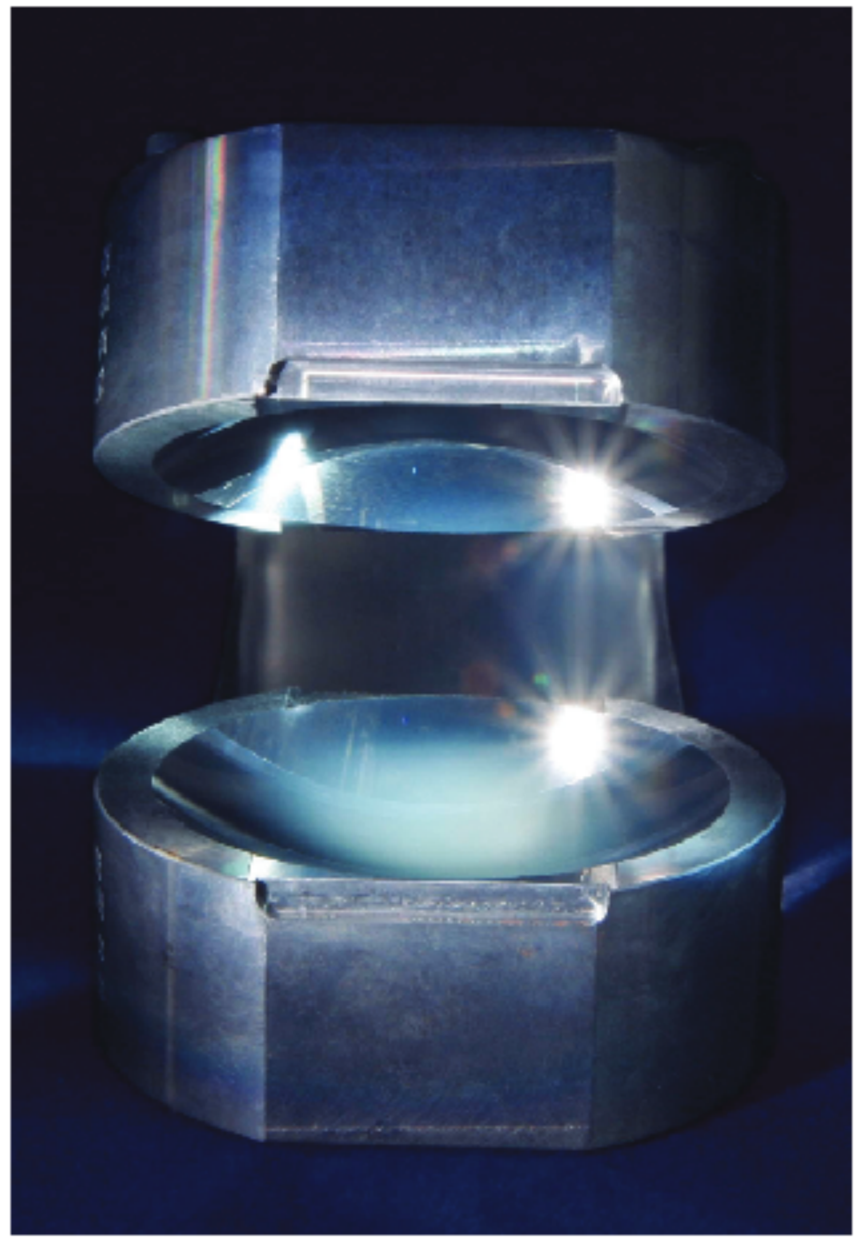


Foton v škatli





Čip iz ionske pasti [NIST]



Fotonska past [ENS]

Valovna enačba

Schroedinger (1926)

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

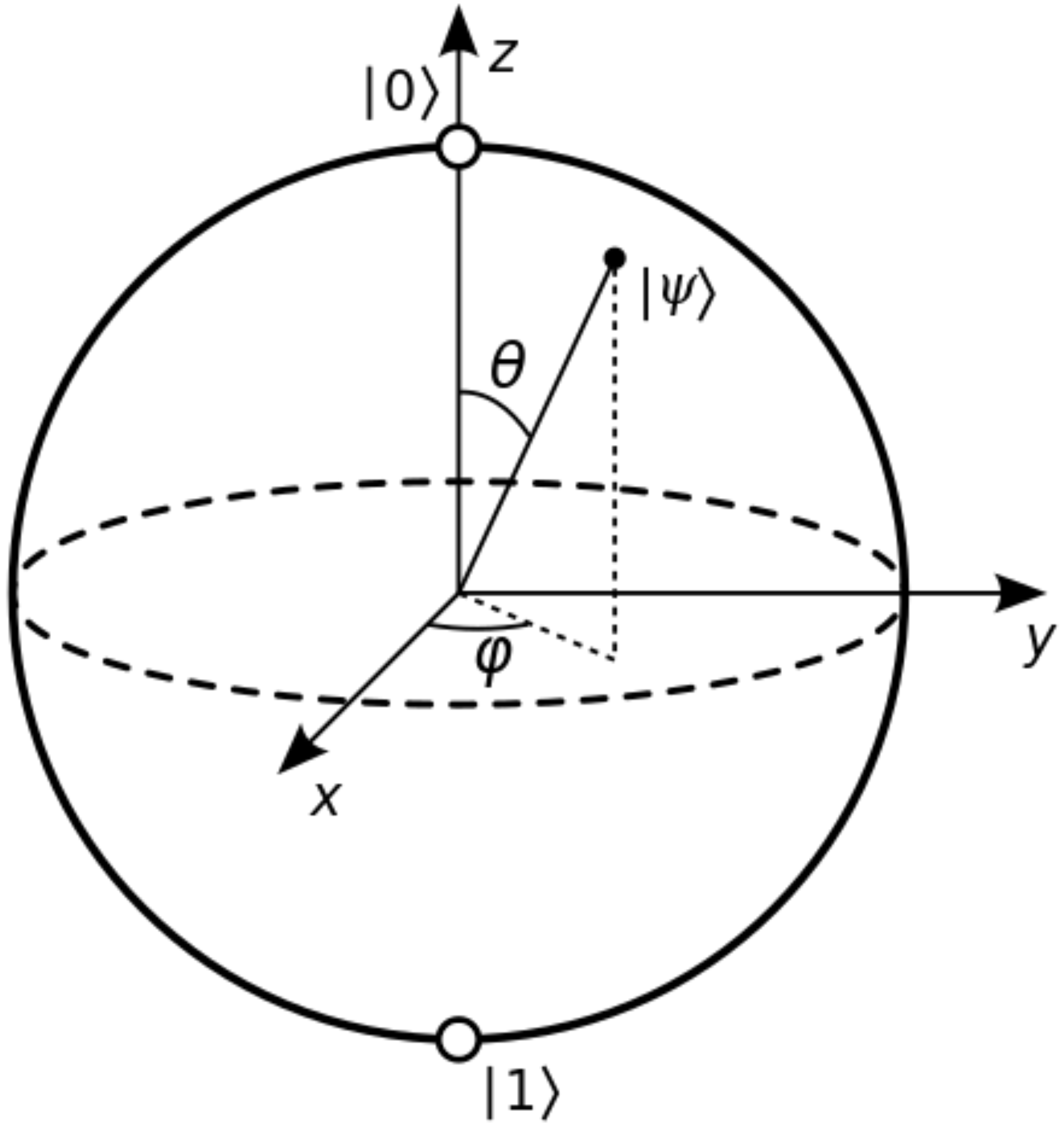
Superpozicija stanj

$$\Psi(x,t) = \alpha\Psi_1(x,t) + \beta\Psi_2(x,t)$$

Kubit

Informacija je neločljivo povezana s svojim fizičnim zapisom (R. Landauer)

Blochova sfera



$$\Psi = \alpha | \uparrow \rangle + \beta | \downarrow \rangle$$

$$\alpha = \cos(\theta/2)$$

$$\beta = e^{i\phi} \sin(\theta/2)$$

Kako pomeni operacija?
Kako sklopimo več kubitov med sabo?

Prepletenost

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 48

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.

… in Bellove neenačbe

Nobelova nagrada za fiziko 2022

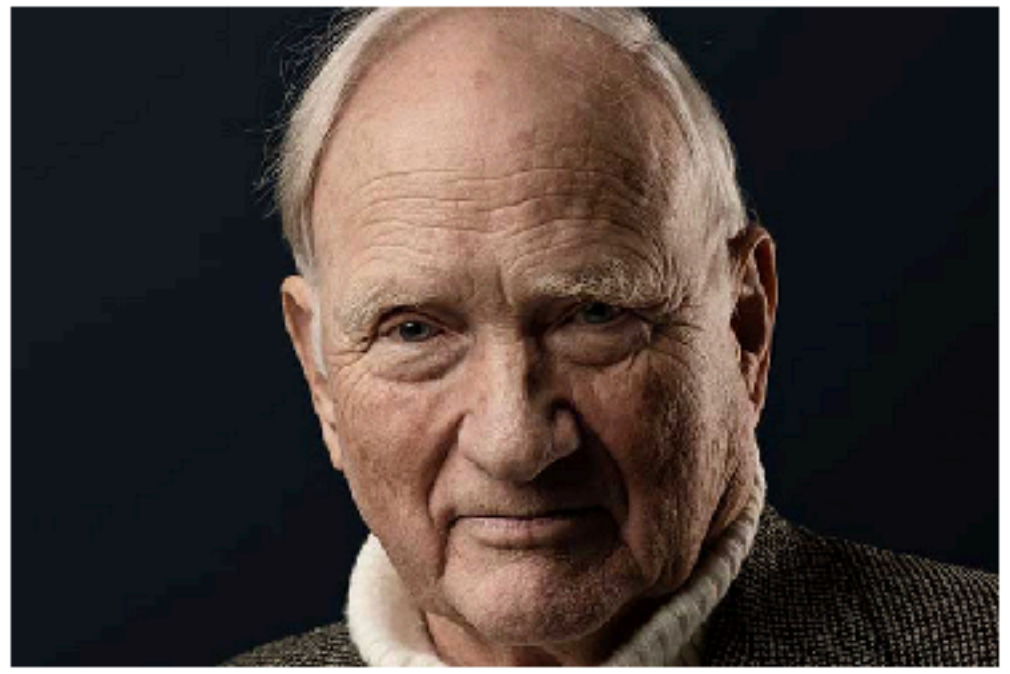
The Nobel Prize in Physics 2022

Alain Aspect

"for experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science"

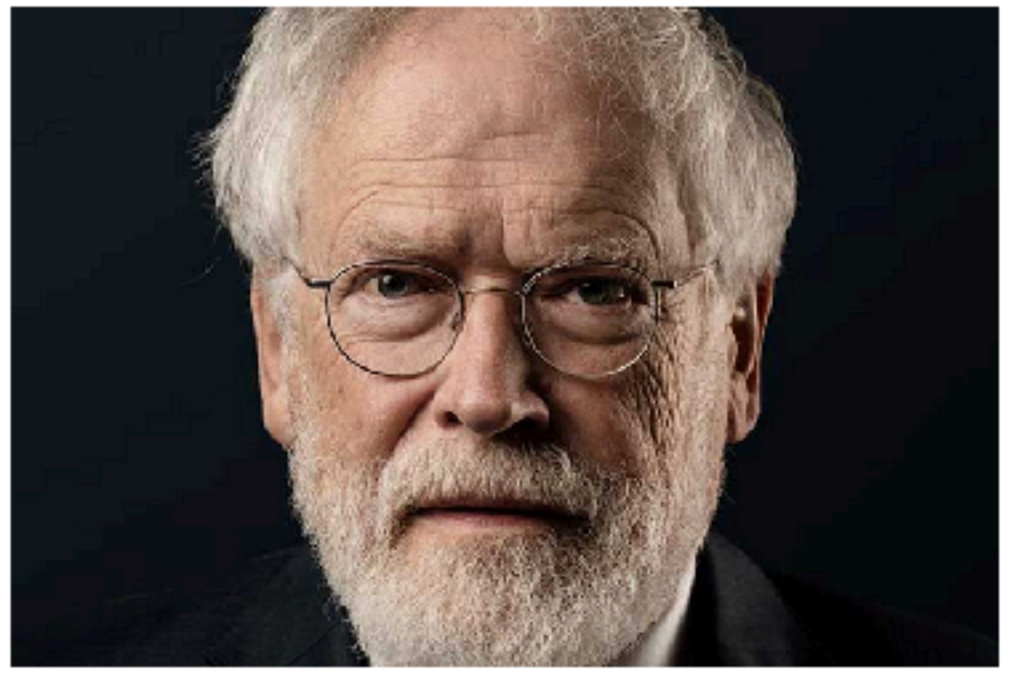
John F. Clauser

"for experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science"



Anton Zeilinger

"for experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science"



Za eksperimente s prepletenimi fotoni, ki so pokazali kršitev Bellovih neenačb in začetek kvantne informatike

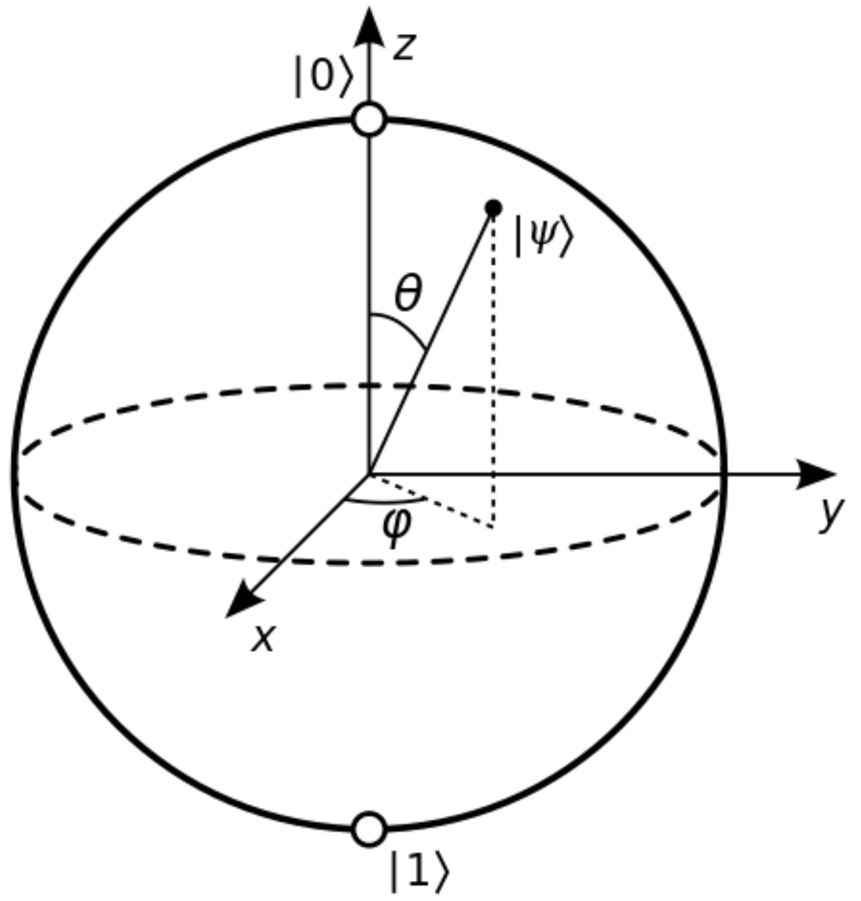
Kvantne naprave = naprave, ki uporabljajo koherenco/prepletenost

Današnji primeri:

- atomske ure
- generator naključnih števil
- Kvantna distribucija ključev za šifriranje
- Manjši kvantni simulatorji/računalniki

Prihodnost:

- Inercijska navigacija
- Simulatorji kvantnih sistemov
- Kvantni internet [globalni]
- Večji kvantni računalniki/



Evropski quantum flagship: https://qt.eu
Slovenski oddelek: http://www.qutes.si/home/

Danes …

IBM eagle [2021]

News 7 minute read

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.

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 increase in space complexity moves us into a realm beyond the abilities of classical computers. While this revolution plays out, we hope to continue sharing our best quantum hardware with the community early and often. This approach allows IBM and our users to work together to understand how best to explore and develop on these systems to achieve quantum advantage as soon as possible.

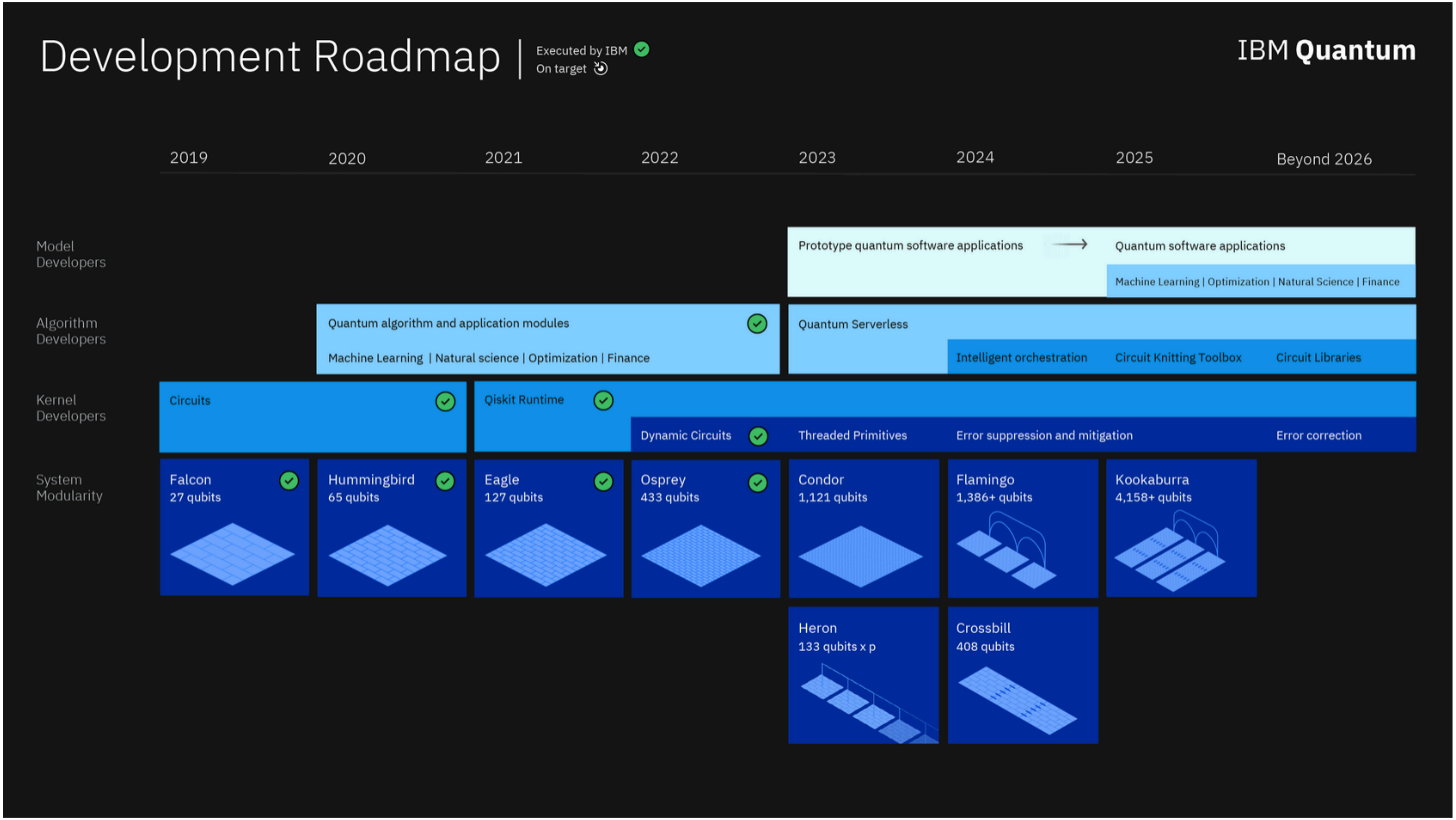
IBM osprey [2022]

NEW YORK, Nov. 9, 2022 /PRNewswire/ -- IBM (NYSE: IBM) today kicked off the IBM Quantum Summit 2022, announcing new breakthrough advancements in quantum hardware and software and outlining its pioneering vision for quantum-centric supercomputing. The annual IBM Quantum Summit showcases the company's broad quantum ecosystem of clients, partners and developers and their continued progress to bring useful quantum computing to the world.

"The new 433 qubit 'Osprey' processor brings us a step closer to the point where quantum computers will be used to tackle previously unsolvable problems," said Dr. Darío Gil, Senior Vice President, IBM and Director of Research. "We are continuously scaling up and advancing our quantum technology across hardware, software and classical integration to meet the biggest challenges of our time, in conjunction with our partners and clients worldwide. This work will prove foundational for the coming era of quantum-centric supercomputing."

IBM heron [2023]

Vir: https://newsroom.ibm.com/



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

Date
08 Sep 2022

Authors

Pat Gumann

Jerry Chow

Topics

Quantum Systems

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News

4 minute read

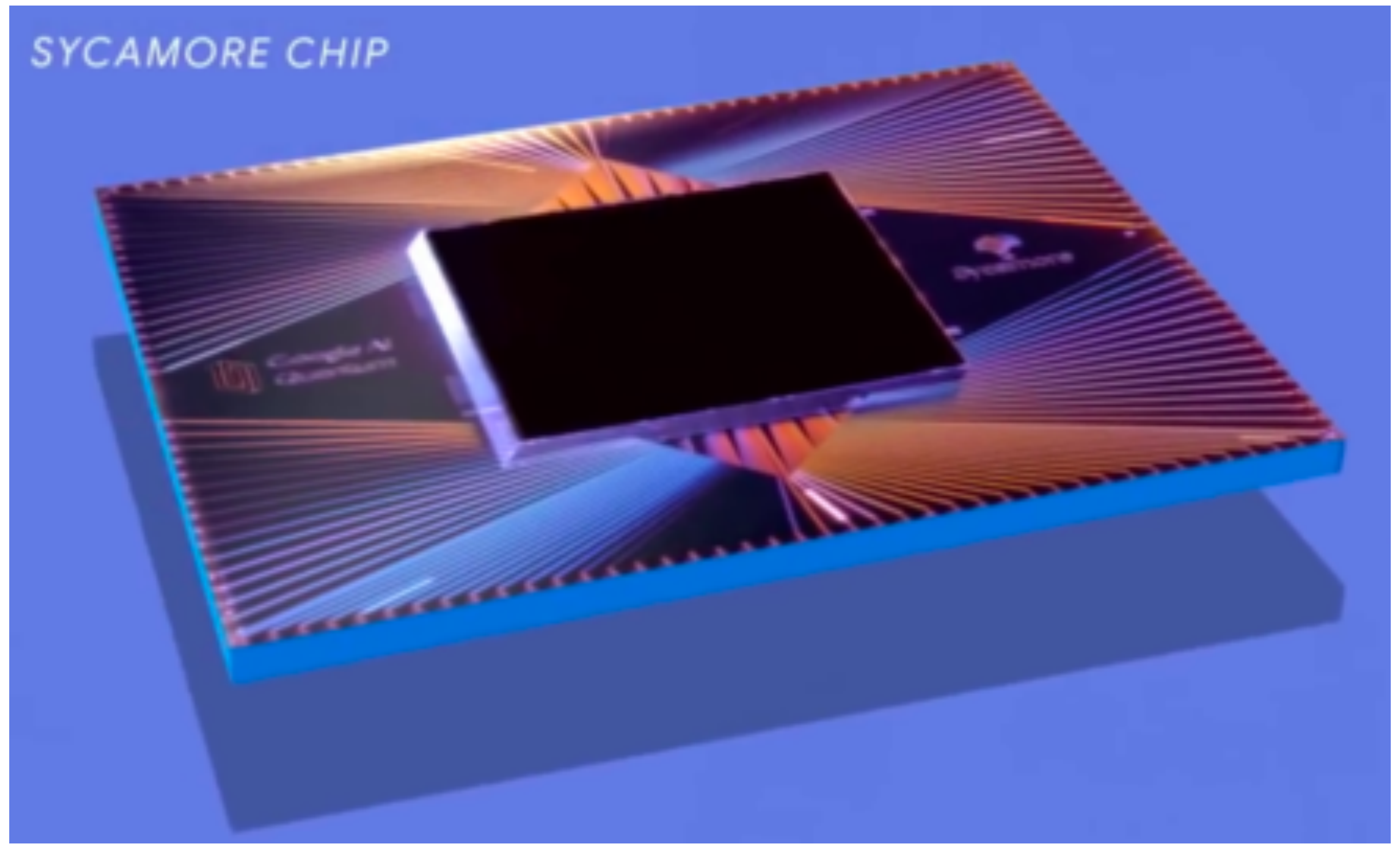
IBM scientists cool down the world’s largest quantum-ready cryogenic concept system

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

https://research.ibm.com/blog/goldeneye-cryogenic-concept-system

Welcome to the Quantum AI campus

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



Quantum Supremacy Using a Programmable Superconducting Processor

WEDNESDAY, OCTOBER 23, 2019

Posted by John Martinis, Chief Scientist Quantum Hardware and Sergio Boixo, Chief Scientist Quantum Computing Theory, Google AI Quantum

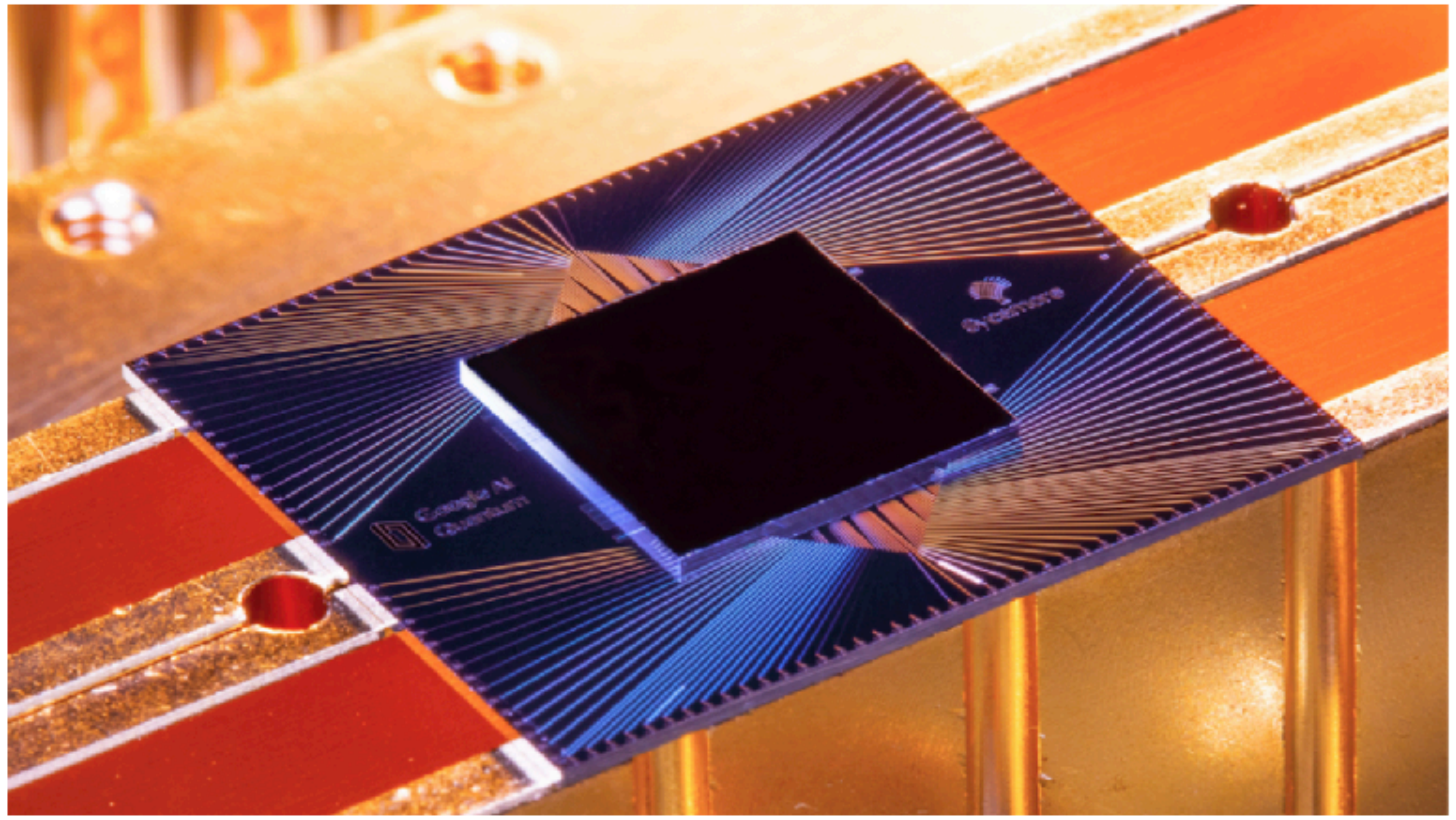
Physicists have been talking about the power of **quantum computing** for over 30 years, but the questions have always been: will it ever do something useful and is it worth investing in? For such large-scale endeavors it is good engineering practice to formulate decisive short-term goals that demonstrate whether the designs are going in the right direction. So, we devised an experiment as an important milestone to help answer these questions. This experiment, referred to as a **quantum supremacy** experiment, provided direction for our team to overcome the many technical challenges inherent in quantum systems engineering to make a computer that is both programmable and powerful. To test the total system performance we selected a sensitive computational benchmark that fails if just a single component of the computer is not good enough.

Today we published the results of this quantum supremacy experiment in the *Nature* article, "**Quantum Supremacy Using a Programmable Superconducting Processor**". We developed a new 54-qubit processor, named "Sycamore", that is comprised of fast, high-fidelity **quantum logic gates**, in order to perform the benchmark testing. Our machine performed the target computation in 200 seconds, and from measurements in our experiment we determined that it would take the world's fastest supercomputer 10,000 years to produce a similar output.

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



Kvantno inspirirani klasični algoritmi (tenzorske mreže)

https://blog.research.google/2019/10/quantum-supremacy-using-programmable.html

https://www.pcmag.com/news/google-claims-quantum-computing-achievement-ibm-says-not-so-fast

Kvantno inspirirani klasični algoritmi

Evidence for the utility of quantum computing before fault tolerance

Youngseok Kim, Andrew Eddins, Sajant Anand, Ken Xuan Wei, Ewout van den Berg, Sami Rosenblatt, Hasan Nayfeh, Yantao Wu, Michael Zaletel, Kristan Temme & Abhinav Kandala

Nature **618**, 500–505 (2023) | Cite this article

Abstract

Quantum computing promises to offer substantial speed-ups over its classical counterpart for certain problems. However, the greatest impediment to realizing its full potential is noise that is inherent to these systems. The widely accepted solution to this challenge is the implementation of fault-tolerant quantum circuits, which is out of reach for current processors. Here we report experiments on a noisy 127-qubit processor and demonstrate the measurement of accurate expectation values for circuit volumes at a scale beyond brute-force classical computation. We argue that this represents evidence for the utility of quantum computing in a pre-fault-tolerant era. These experimental results are enabled by advances in the coherence and calibration of a superconducting processor at this scale and the ability to characterize[1] and controllably manipulate noise across such a large device. We establish the accuracy of the measured expectation values by comparing them with the output of exactly verifiable circuits. In the regime of strong entanglement, the quantum computer provides correct results for which leading classical approximations such as pure-state-based 1D (matrix product states, MPS) and 2D (isometric tensor network states, isoTNS) tensor network methods[2,3] break down. These experiments demonstrate a foundational tool for the realization of near-term quantum applications[4,5].

PRX QUANTUM **5**, 010308 (2024)

Featured in Physics

Efficient Tensor Network Simulation of IBM's Eagle Kicked Ising Experiment

Joseph Tindall,[1,*] Matthew Fishman,[1] E. Miles Stoudenmire,[1] and Dries Sels[1,2]

[1] *Center for Computational Quantum Physics, Flatiron Institute, New York, New York 10010, USA*
[2] *Center for Quantum Phenomena, Department of Physics, New York University, 726 Broadway, New York, New York 10003, USA*

(Received 7 September 2023; accepted 25 November 2023; published 23 January 2024)

We report an accurate and efficient classical simulation of a kicked Ising quantum system on the heavy hexagon lattice. A simulation of this system was recently performed on a 127-qubit quantum processor using noise-mitigation techniques to enhance accuracy [Y. Kim *et al.*, Nature, 618, 500–5 (2023)]. Here we show that, by adopting a tensor network approach that reflects the geometry of the lattice and is approximately contracted using belief propagation, we can perform a classical simulation that is significantly more accurate and precise than the results obtained from the quantum processor and many other classical methods. We quantify the treelike correlations of the wave function in order to explain the accuracy of our belief propagation-based approach. We also show how our method allows us to perform simulations of the system to long times in the thermodynamic limit, corresponding to a quantum computer with an infinite number of qubits. Our tensor network approach has broader applications for simulating the dynamics of quantum systems with treelike correlations.

DOI: 10.1103/PRXQuantum.5.010308

Grover's Algorithm Offers No Quantum Advantage

E.M. Stoudenmire[1] and Xavier Waintal[2]

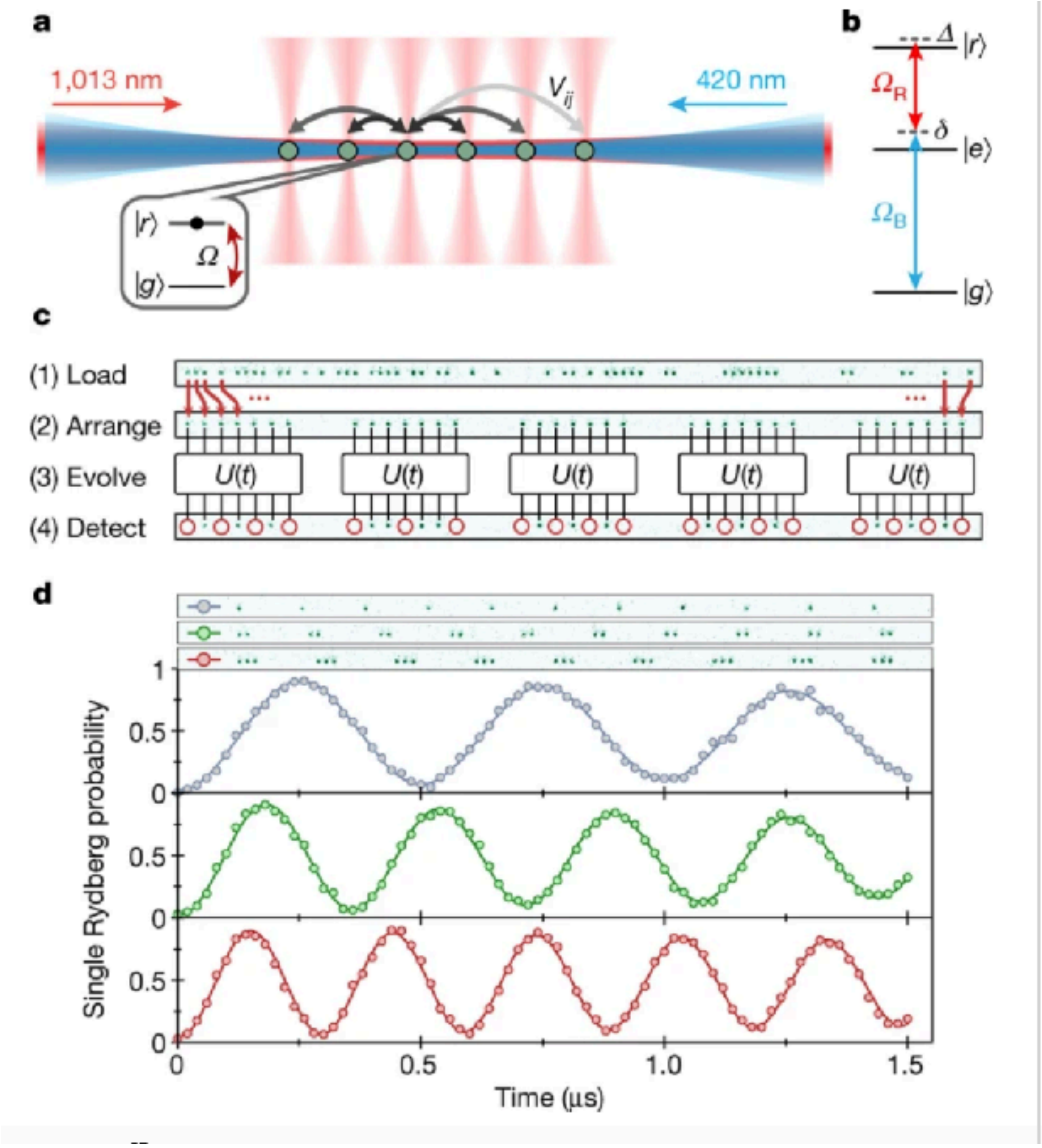
[1] *Center for Computational Quantum Physics, Flatiron Institute, 162 5th Avenue, New York, NY 10010, USA*
[2] *PHELIQS, Université Grenoble Alpes, CEA, Grenoble INP, IRIG, Grenoble 38000, France*

(Dated: March 21, 2023)

Grover's algorithm is one of the primary algorithms offered as evidence that quantum computers can provide an advantage over classical computers. It involves an "oracle" (external quantum subroutine) which must be specified for a given application and whose internal structure is not part of the formal scaling of the quantum speedup guaranteed by the algorithm. Grover's algorithm also requires exponentially many steps to succeed, raising the question of its implementation on near-term, non-error-corrected hardware and indeed even on error-corrected quantum computers. In this work, we construct a quantum inspired algorithm, executable on a classical computer, that performs Grovers' task in a *linear* number of call to the oracle — an exponentially smaller number than Grover's algorithm — and demonstrate this algorithm explicitly for boolean satisfiability problems (3-SAT). Our finding implies that there is no *a priori* theoretical quantum speed-up associated with Grover's algorithm. We critically examine the possibility of a practical speed-up, a possibility that depends on the nature of the quantum circuit associated with the oracle. We argue that the unfavorable scaling of the success probability of Grover's algorithm, which in the presence of noise decays as the exponential of the exponential of the number of qubits, makes a practical speedup unrealistic even under extremely optimistic assumptions on both hardware quality and availability.

Kvantni simulatorji

Rydbergovi atomi



D-wave

Quadratic unconstrained binary optimization (QUBO)

$$f_Q(x) = x^\top Q x = \sum_{i=1}^{n} \sum_{j=i}^{n} Q_{ij} x_i x_j$$

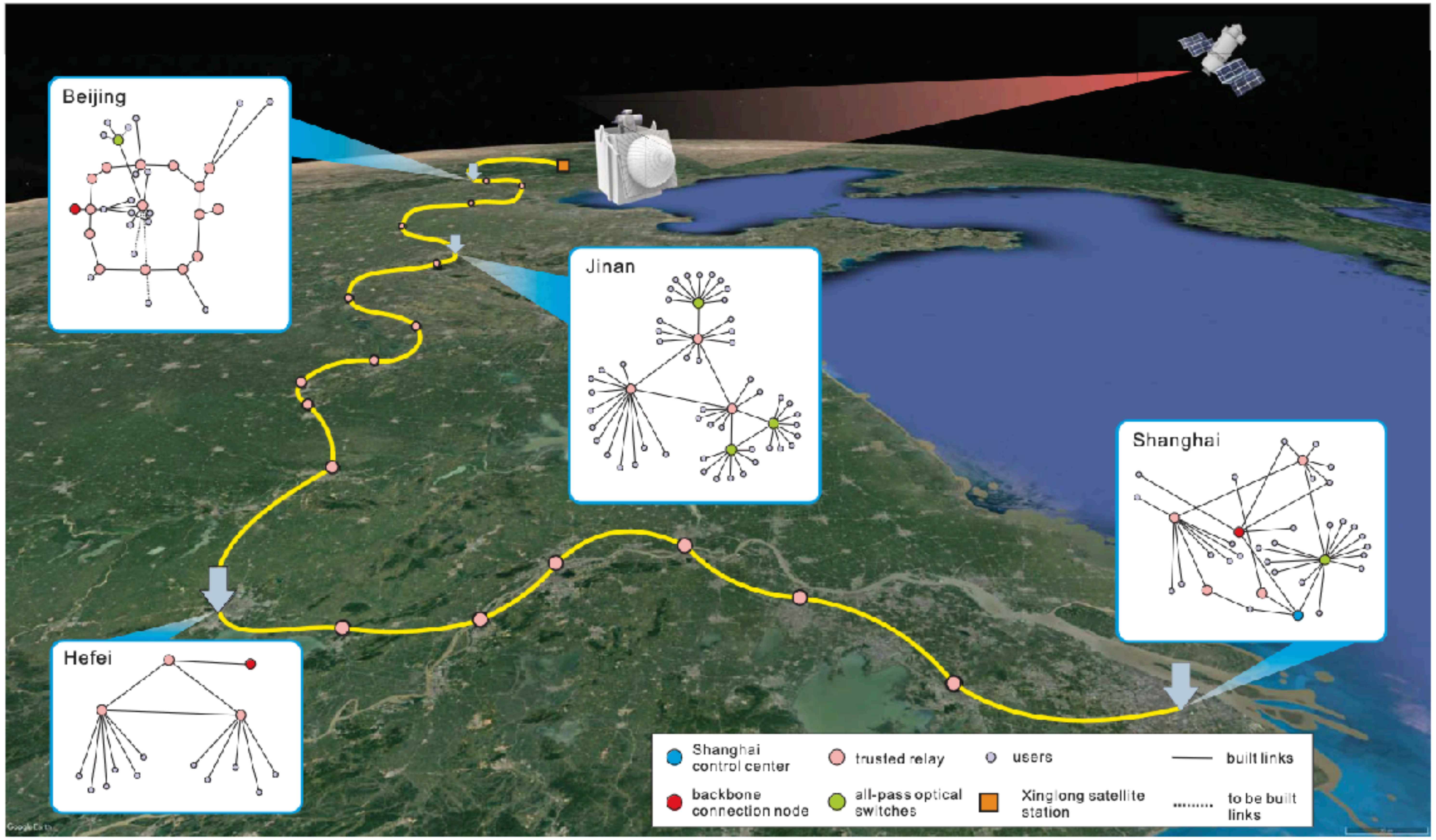


FIG. 2 (Color online) Schematic diagram of the space-ground integrated quantum network in China (Chen *et al.*, 2020), consisting of four quantum metropolitan area networks in the cities of Beijing, Jinan, Shanghai, and Heifei, a backbone network over 2000 km, and ground-satellite links. There are three 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 ultralong distance communications (Liao *et al.*, 2018).

https://arxiv.org/pdf/1903.09051.pdf

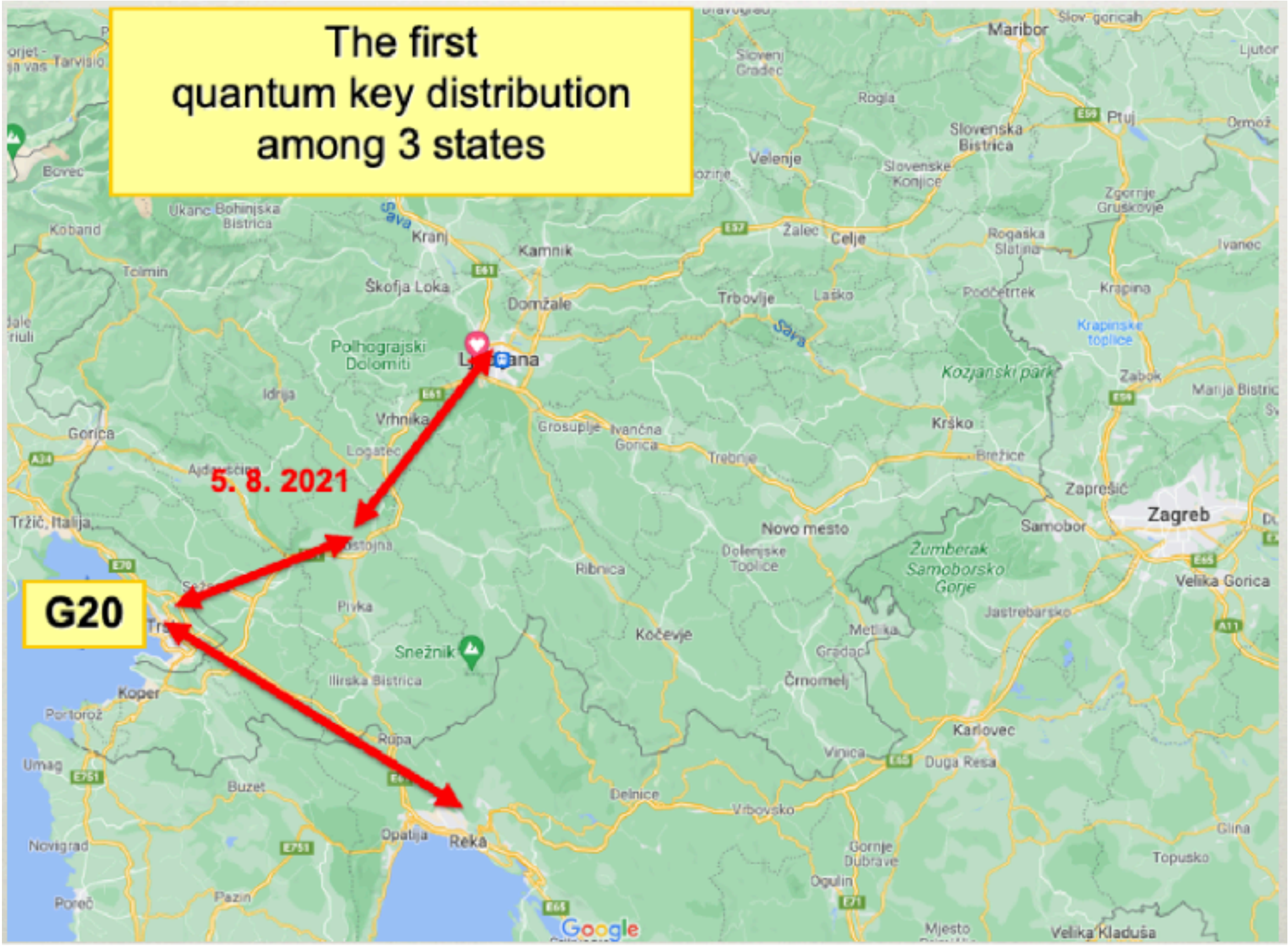
Quantum Communication Infrastructure

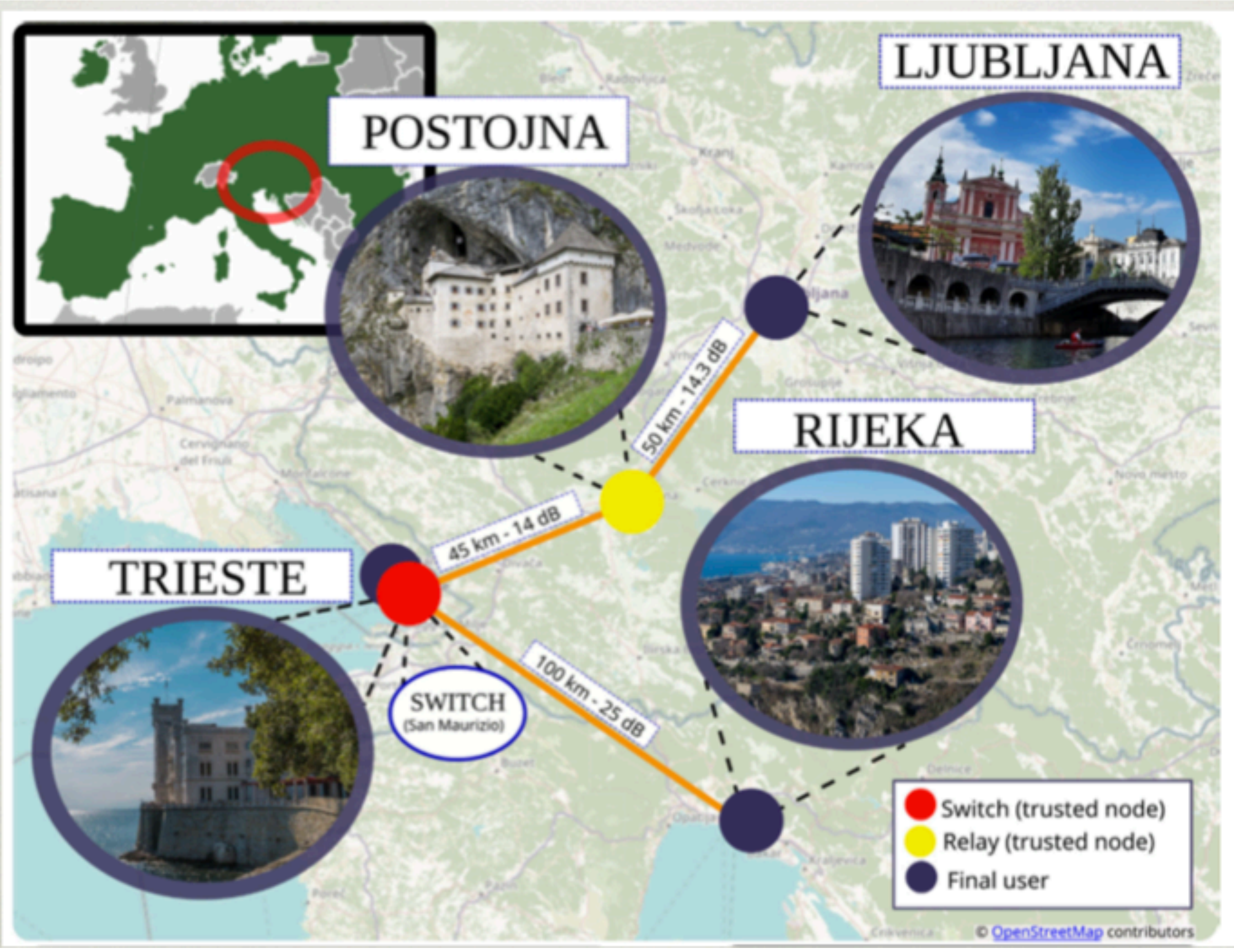
Europe's Quantum Communication Infrastructure initiative - EuroQCI

https://petrus-euroqci.eu/

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

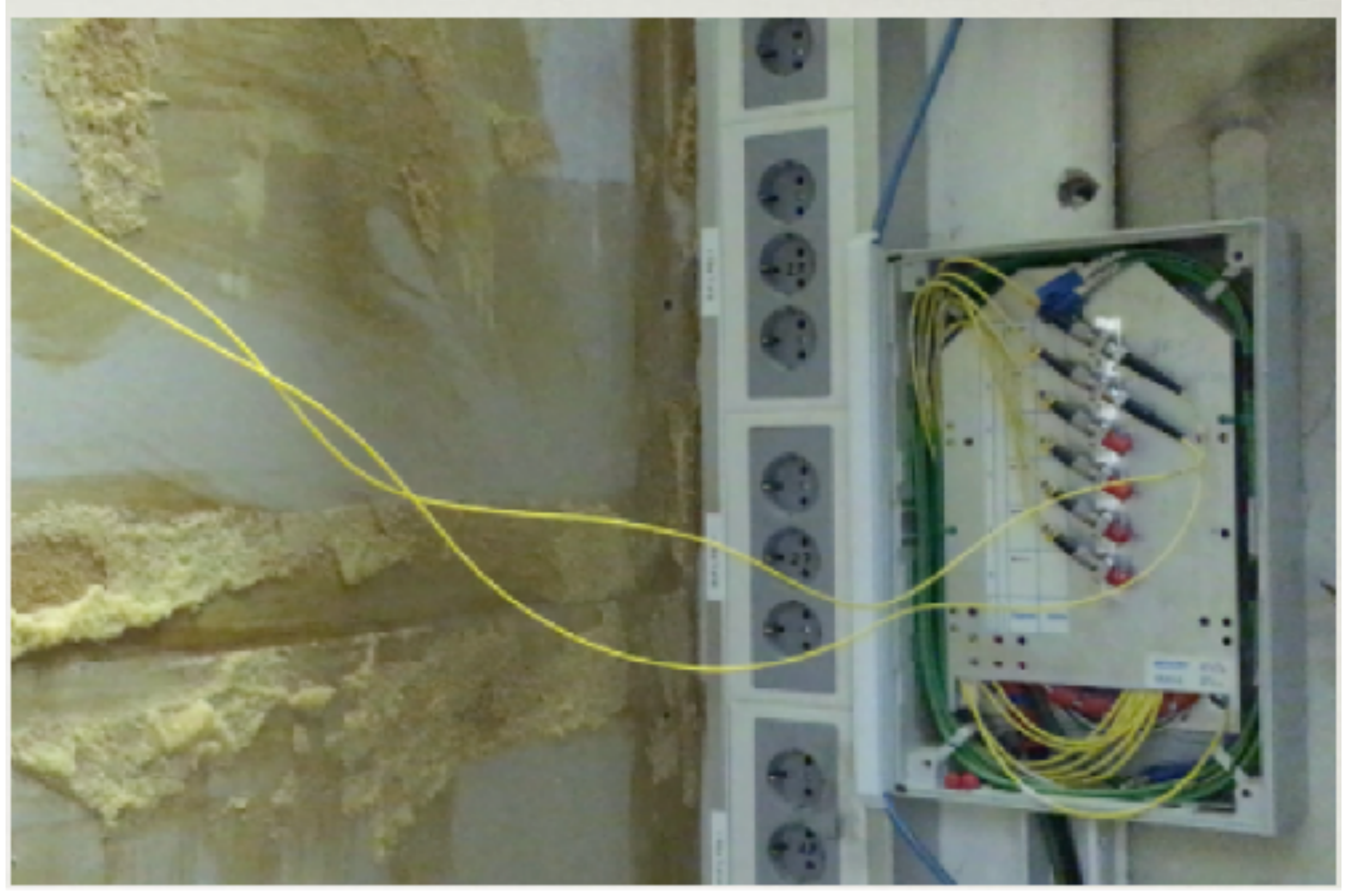
demonstracija kvantno šifriranega prenosa podatkov med tremi državami (Italija-Slovenija-Hrvaška)

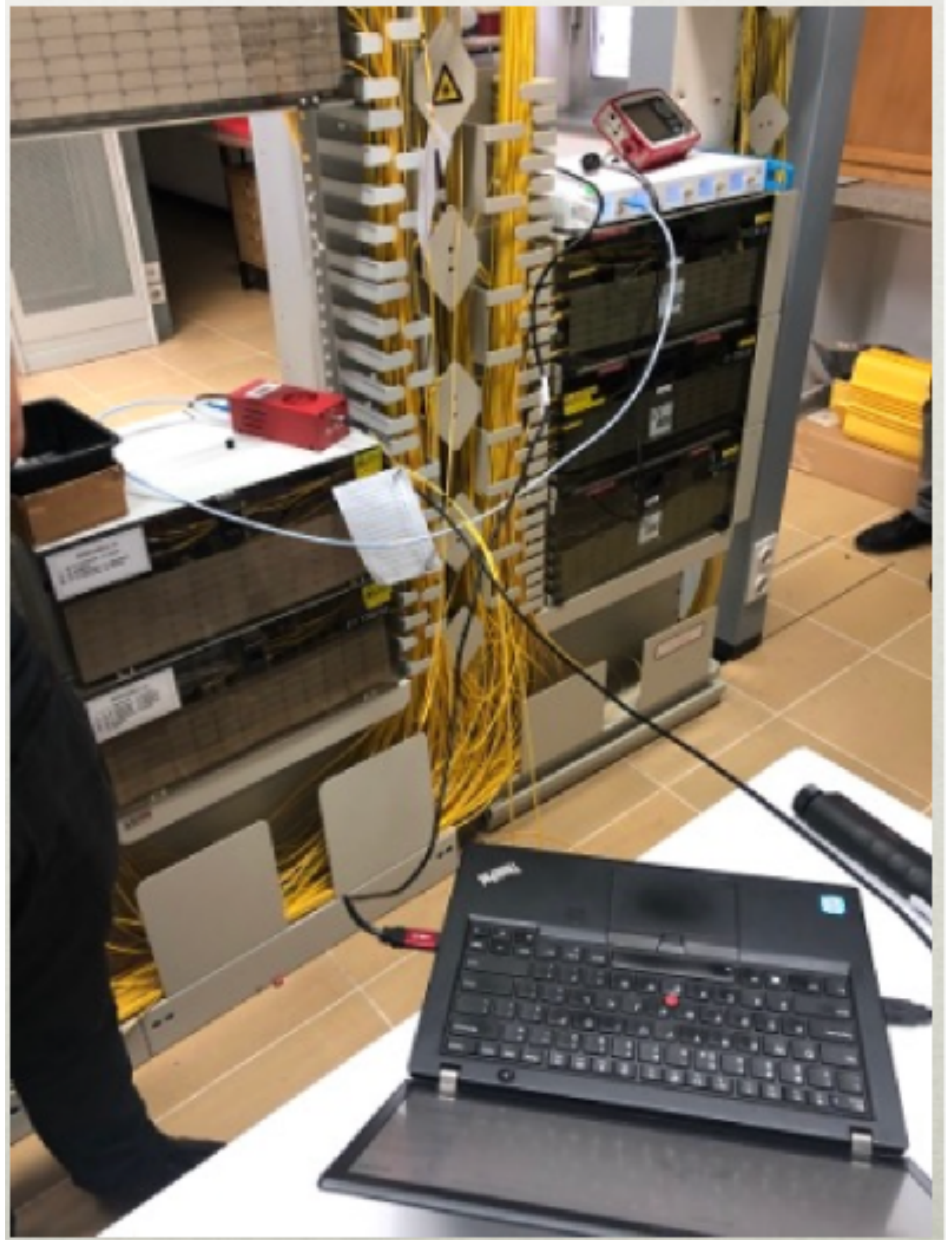




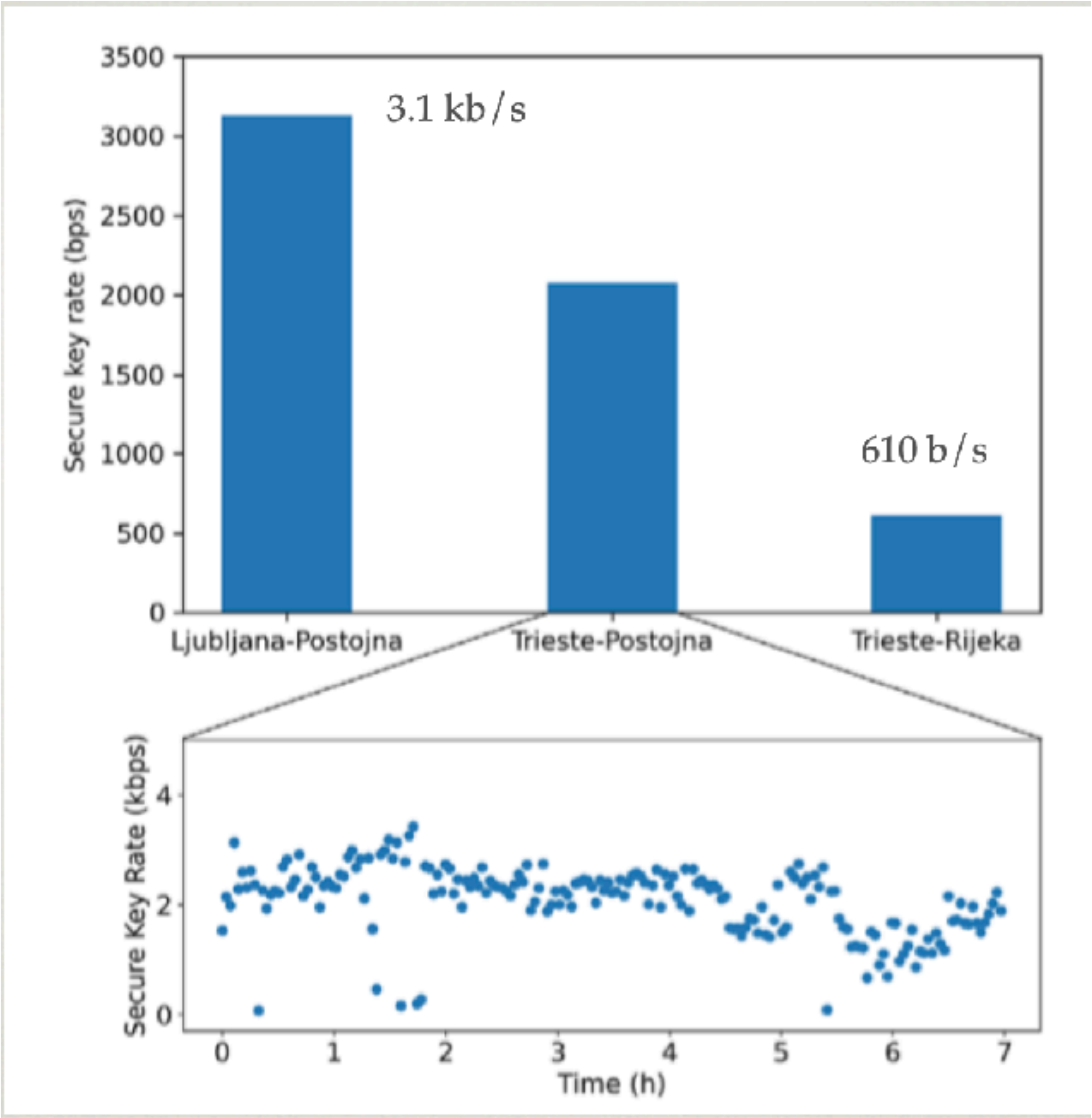
D. Ribezzo et al., Adv. Quant. Tech. 2200061 (2022)

Varno vozlišče v Postojni



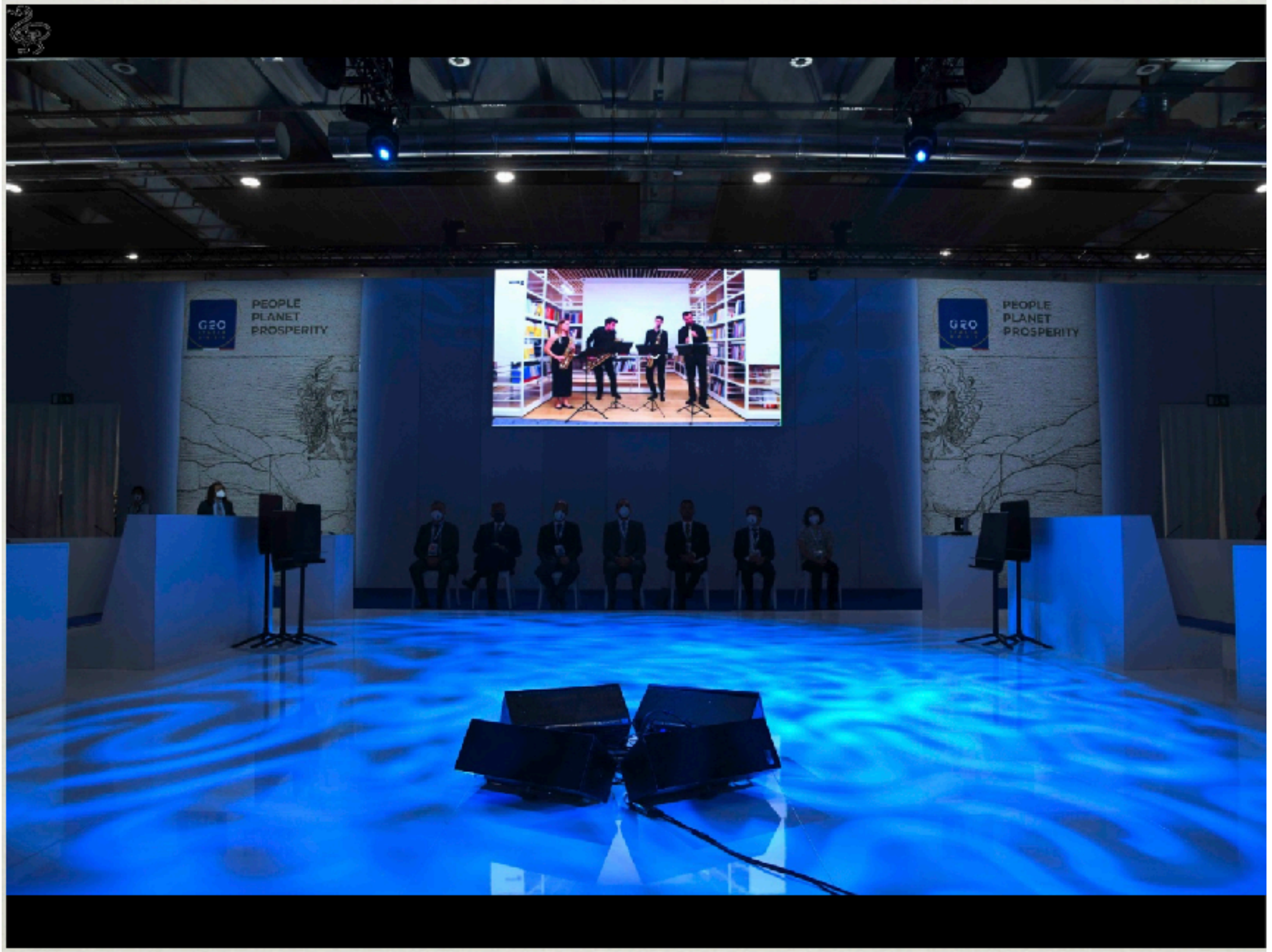


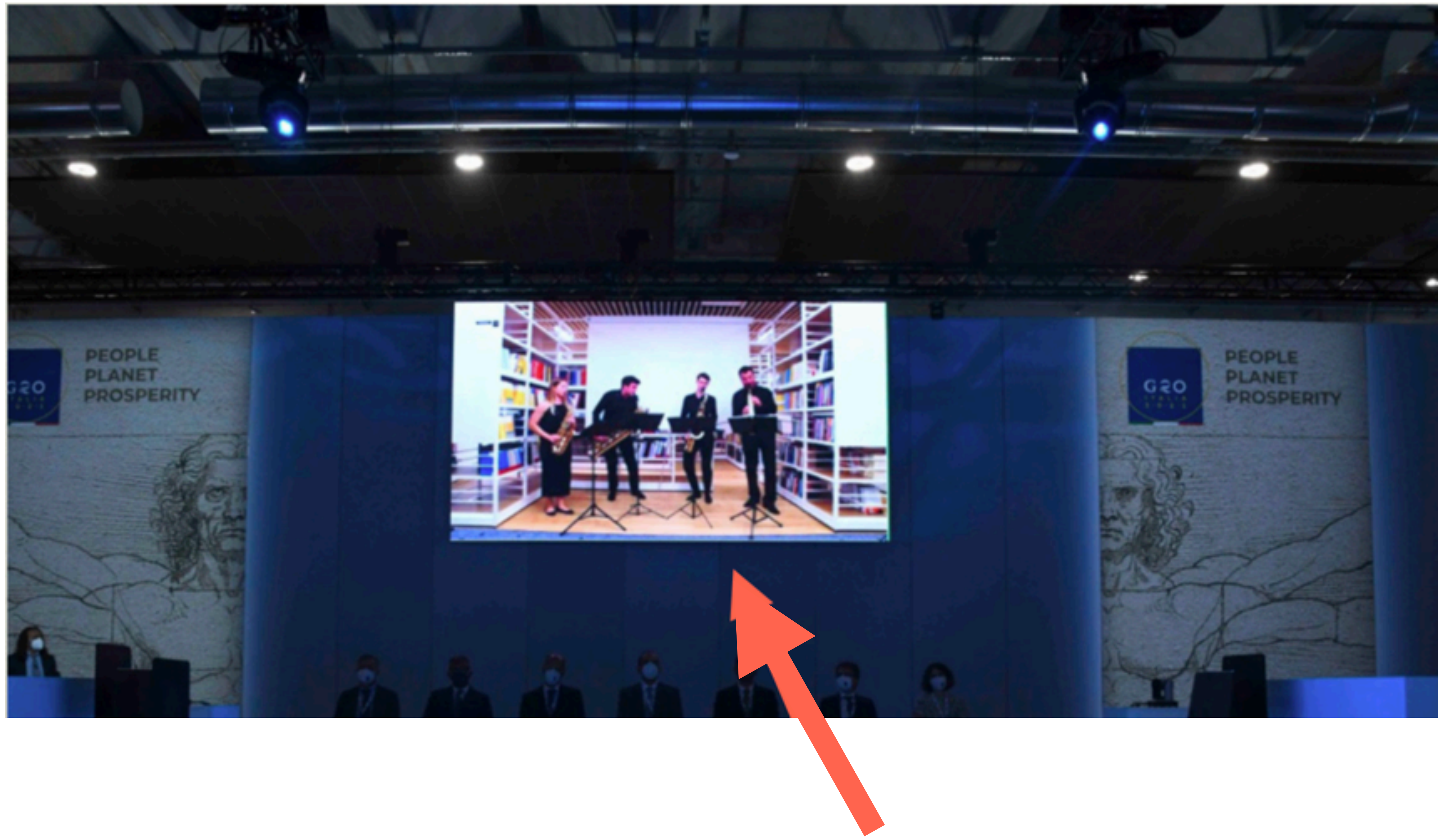
Delovanje



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

Koncert preko navideznega zasebnega omrežja (VPN)





Knjižnica FMF

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

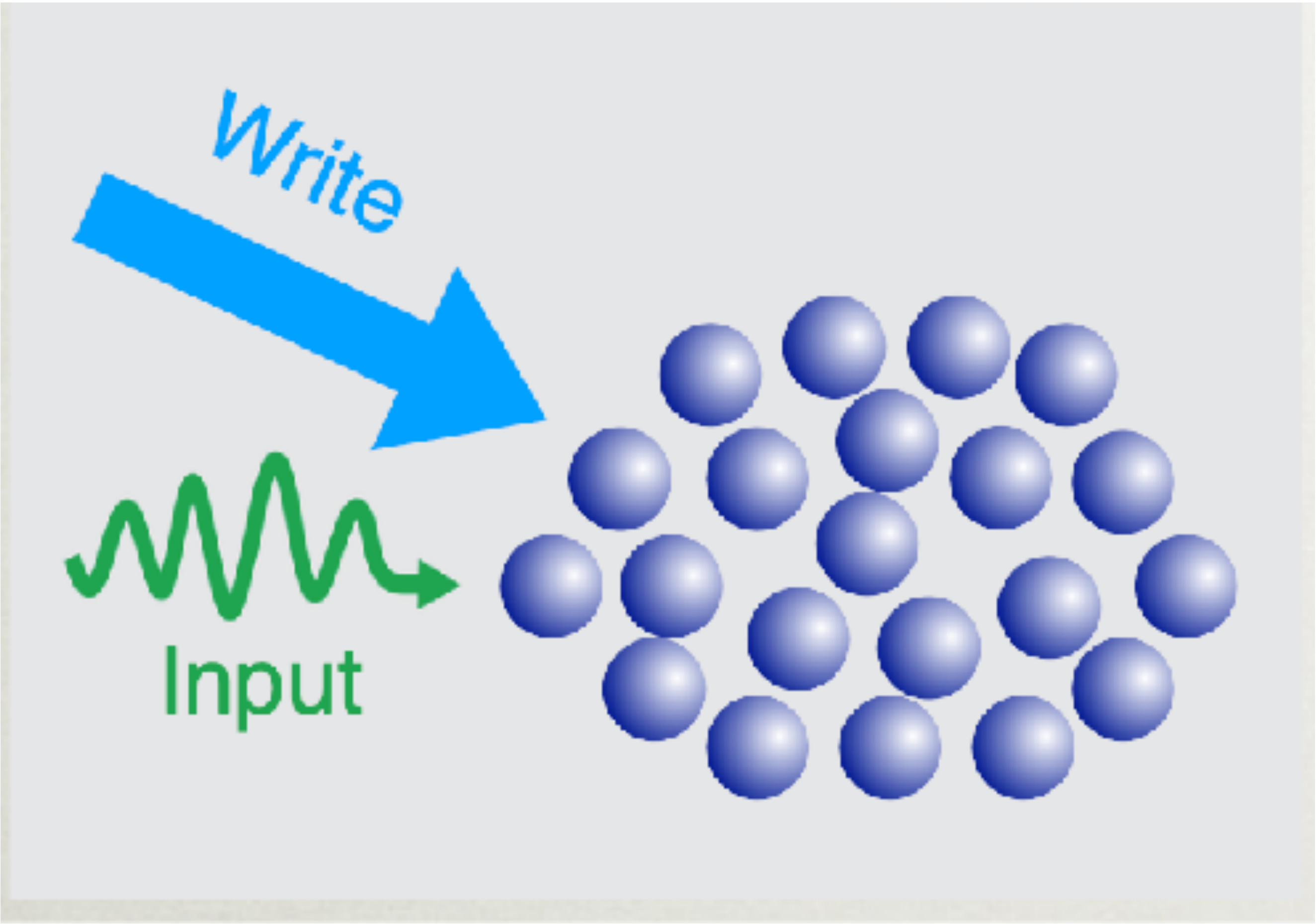
SIQUID

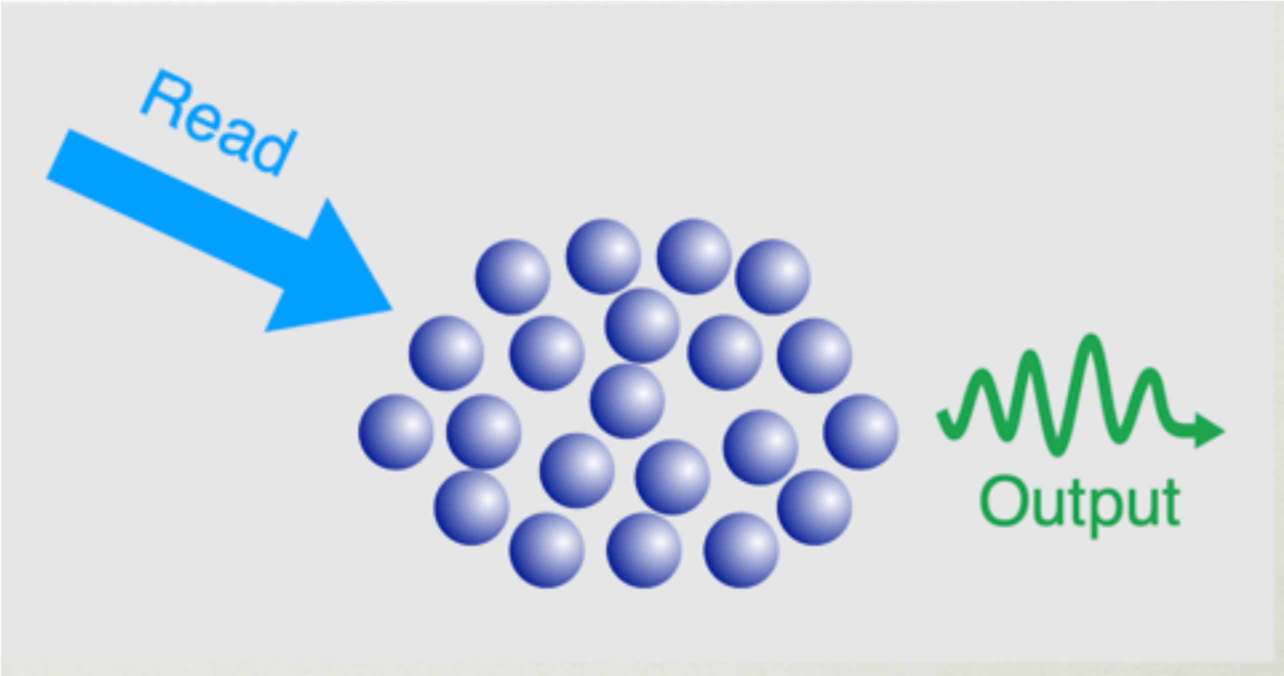
Konzorcij: UL FMF (koordinator), IJS,
Beyond Semiconductor, Urad vlade RS za varovanje tajnih podatkov (UVTP),
Urad vlade RS za informacijsko varnost (URSIV)

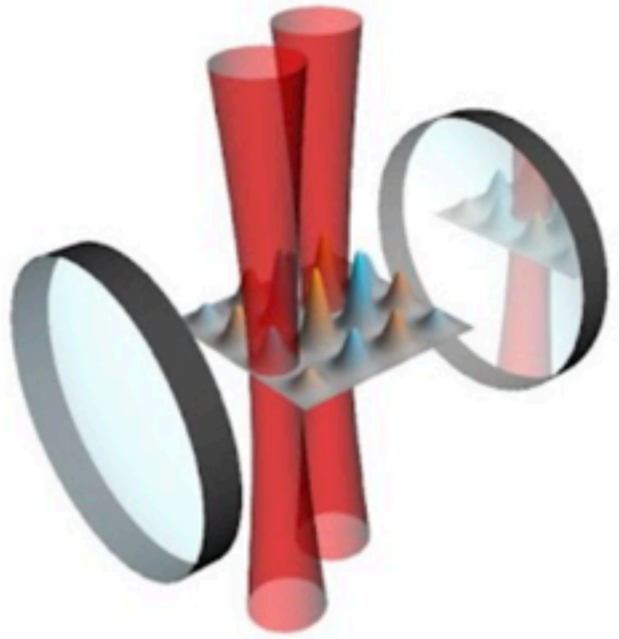
Cilji:

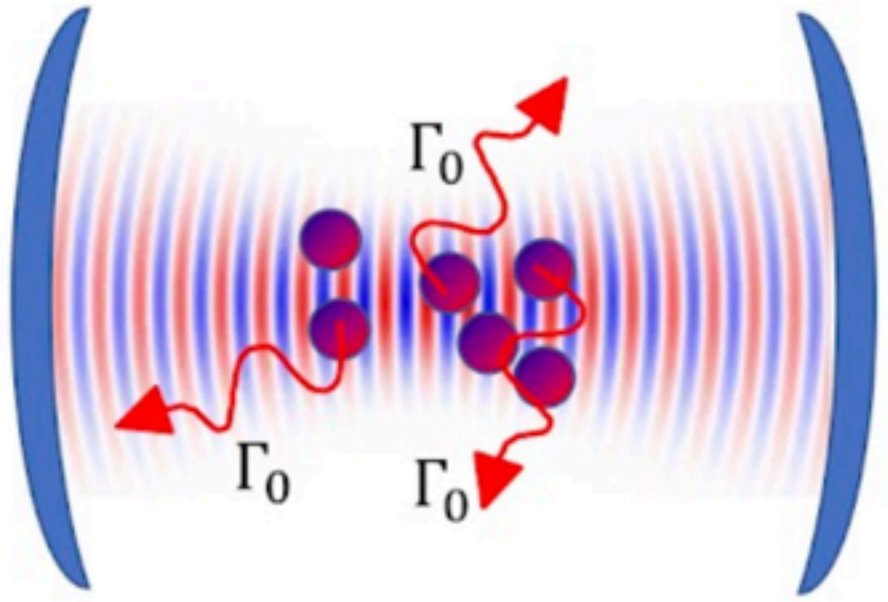
- pilotska povezava med IJS in FMF
- Povezava državnih uradov
- Povezava do državnih meja
- 2. Stadij: optična zemeljska postaja

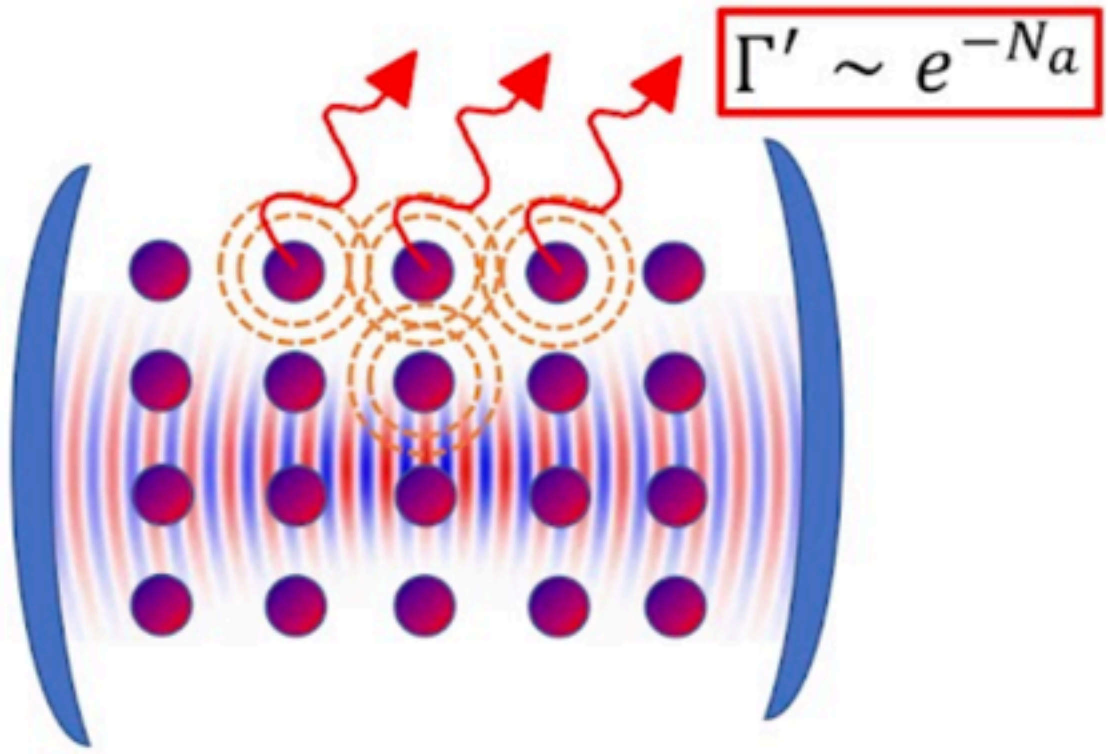
Kvantni spomin z atomi









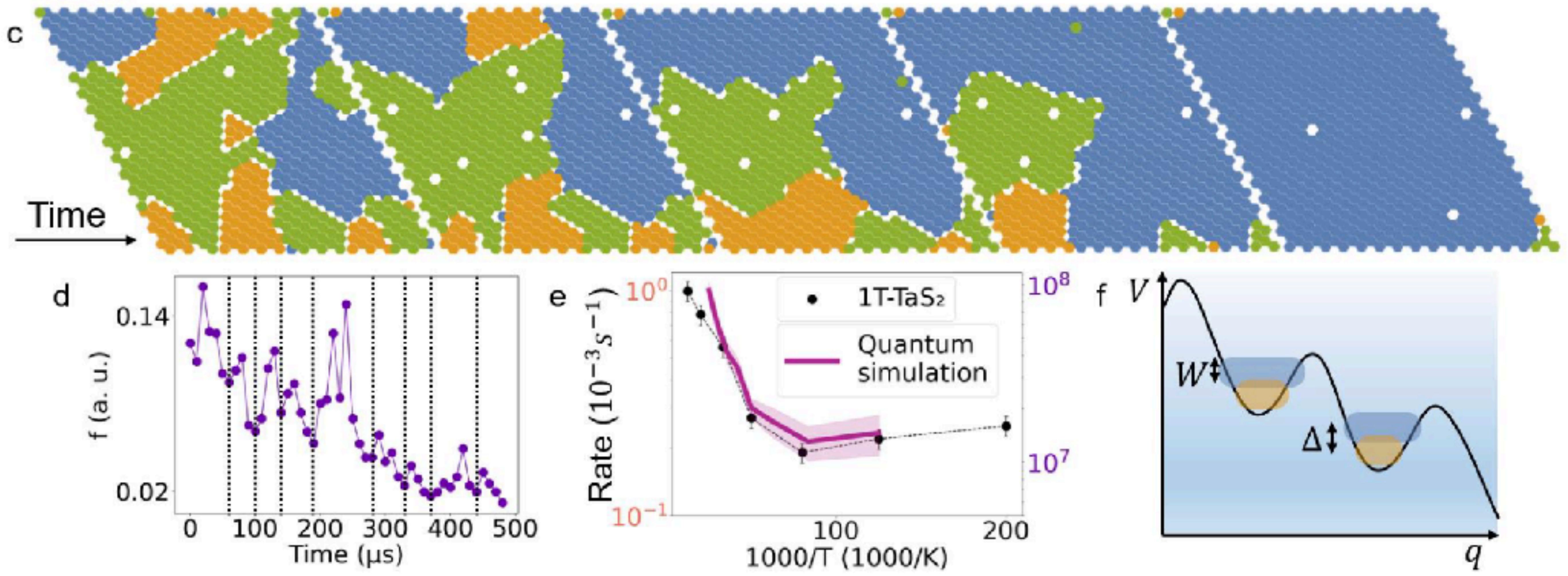


QuantEra konzorcij: QuSiED - Quantum simulation with engineered dissipation

D-wave kvantni simulator

QUBO: $$\min_{q_i=0,1} \left(\sum_i a_i q_i + \sum_{i<j} b_{ij} q_i q_j \right)$$

Simulacije dinamike materialov



Jaka Vodeb, et al., arXiv:2103.07343

Laboratorij za fiziko hladnih atomov

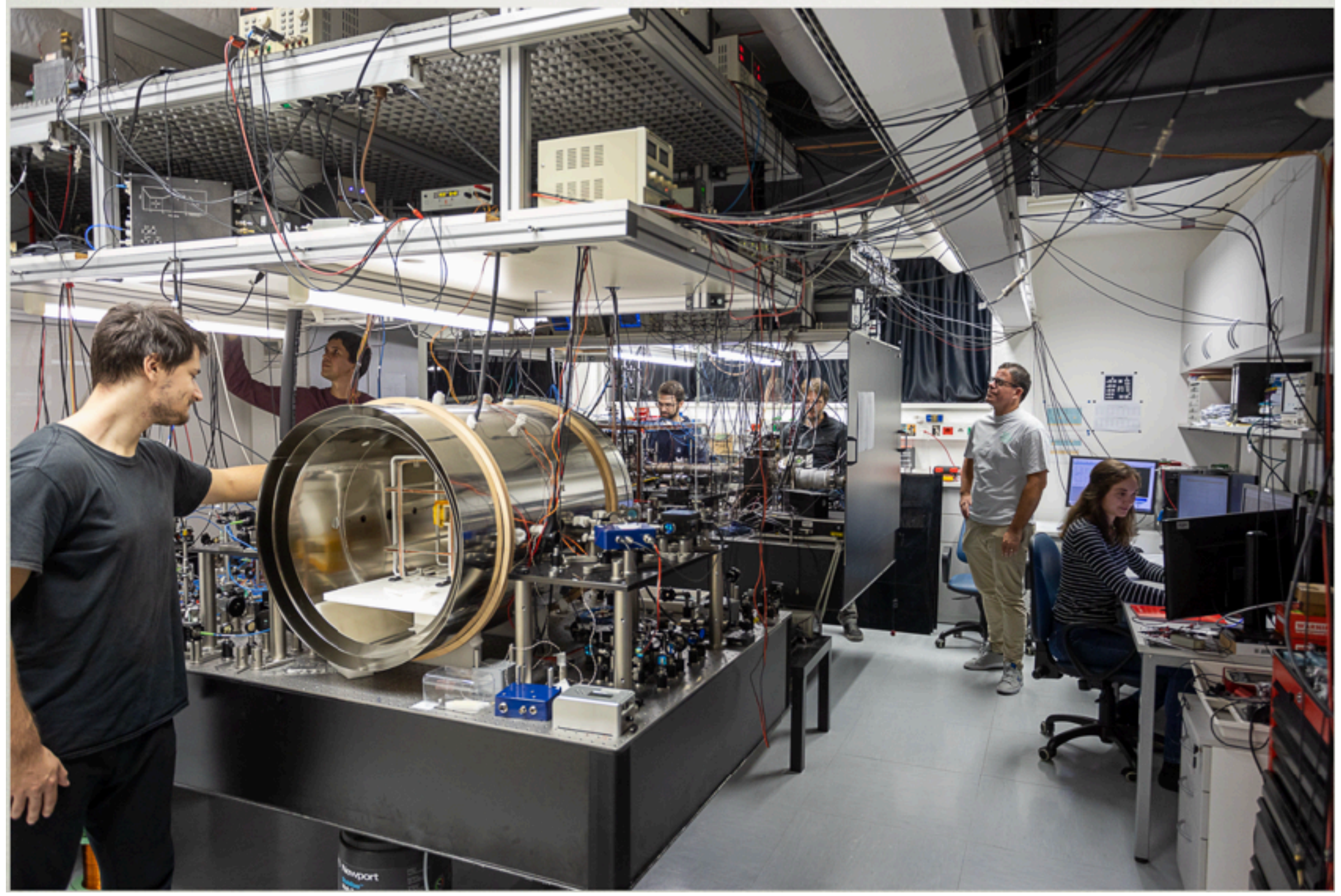


Foto: Marjan Verč

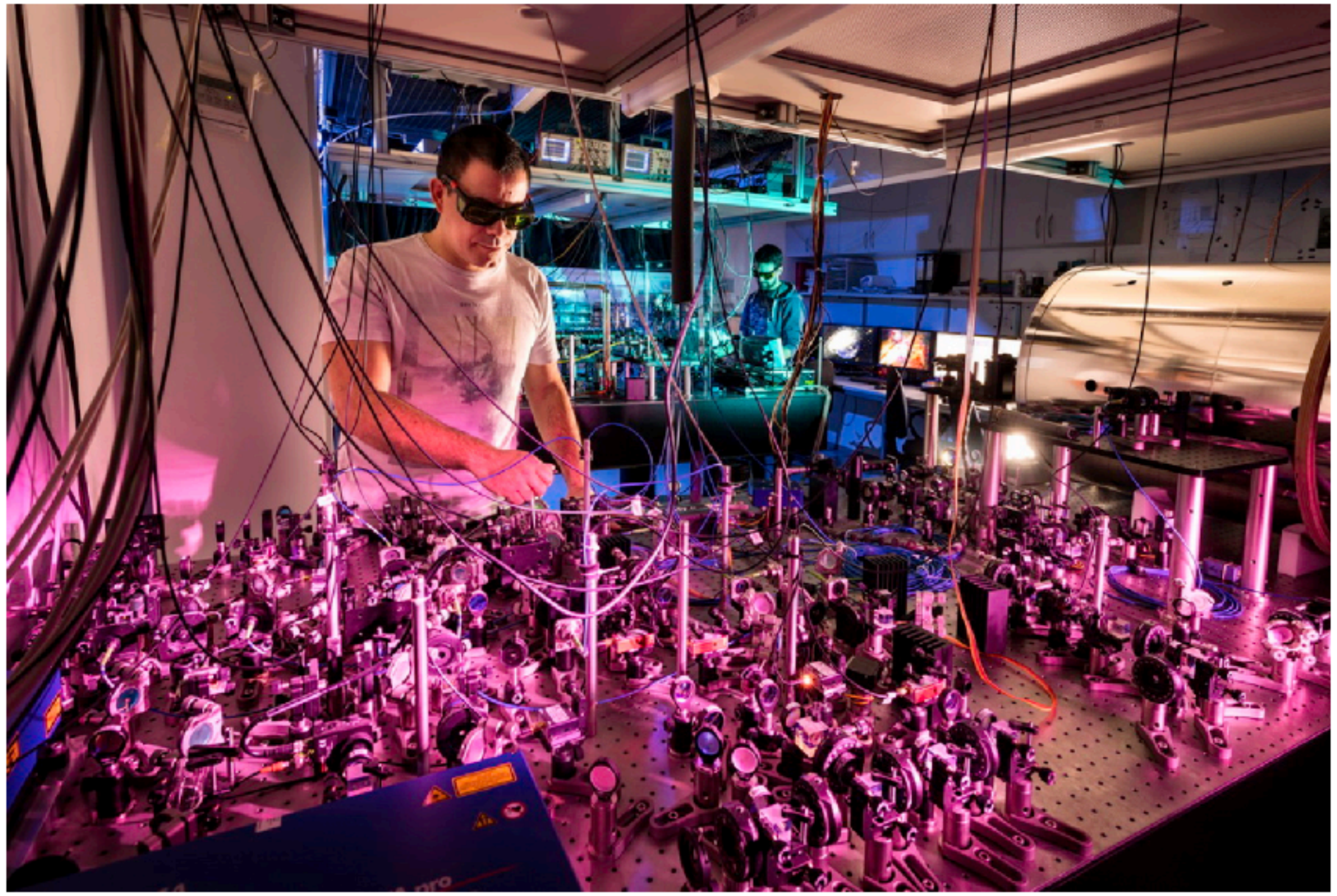
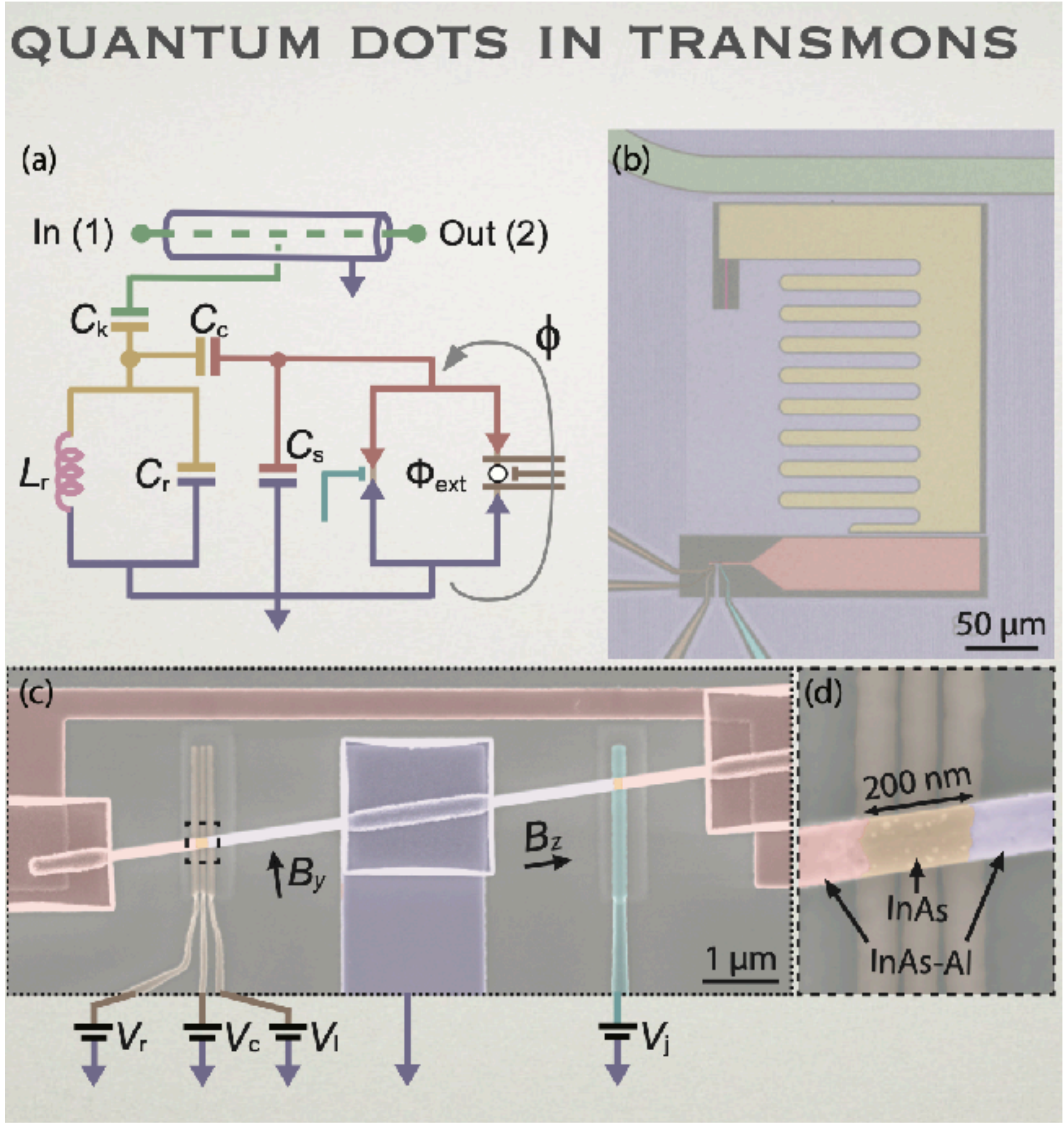


Foto: Arne Hodalič and Katja Bidovec

https://ultracool.ijs.si/

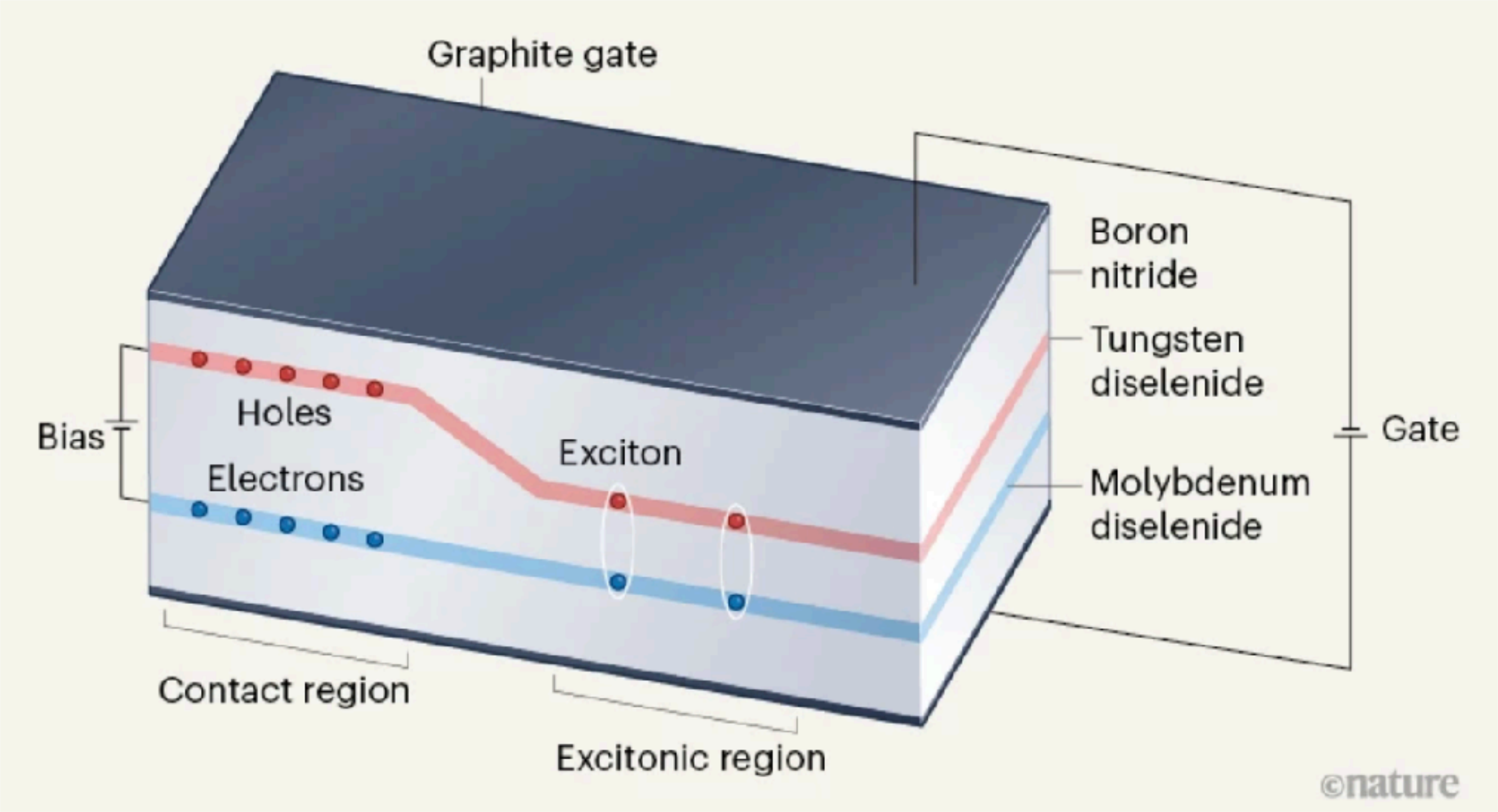
Kvantne pike in kubit



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)

Nove kvantne platforme



Denis Golež, Z. Sun, Nature **598**, 571-572 (2021) and
Ma, L. *et al. Nature* **598**, 585–589 (2021).

Quantum computing for the very curious

by Andy Matuschak and Michael Nielsen

Presented in a new mnemonic medium which makes it almost effortless to remember what you read.

https://quantum.country/qcvc

RT 2023: Domače naloge

Denis Golež

1. **Numerično reševanje harmonskega in anharmonskega nihala**
   Napiši program za numerično reševanje enačbe gibanja $\ddot{\theta}+a\theta = 0$ s končnimi časovnimi koraki δt. Uporabi Eulerjevo in Runge-Kutta metodo in razumi kako je frekvenca nihanja odvisna od parametra a. Ugotovi, kako upada amplituda nihanja s časom zaradi numeričnih napak pri končnem δt pri obeh metodah (namig: katera krivulja opisuje ovojnico?). Pokaži, da natančnost integracije primerno skalira s korakom za obe metodi. Je numerična rešitev za periodo nihanja odvisna od δt? Napiši še program za numerično reševanje enačbe gibanja $\ddot{\theta} + a\sin(\theta) = 0$. Kako je perioda odvisna od amplitude nihanja ?

2. **Problem plenilcev in plena**
   Preprost opis dinamike populacije plenilcev in plena predstavljajo Lotka-Voltera enačbe

$$\frac{dx}{dt} = \alpha x + \beta xy \qquad \frac{dy}{dt} = \gamma y + \beta xy,$$

   kjer je x populacija plena in y populacija plenilcev. Uporabi Eulerjevo in Runge-Kutta metodo in razumi kakšen je pomen parametrov α, β, γ? Kaj se zgodi, če nastaviš $\beta = 0$ in kaj če je le-ta majhen? Kakšna je dinamika v nasprotnem primeru, kjer je β največji parameter?

3. **Simulacija nehomogene verige sklopljenih nihal** Opiši sistem $N = 1000$ z vzmetmi povezanih nihal, ki jih opišemo z enačbami (razdelek 1.10) Imejmo sistem $N = 1000$ z vzmetmi povezanih nihal, ki jih opišemo z enačbami (razdelek 1.10)