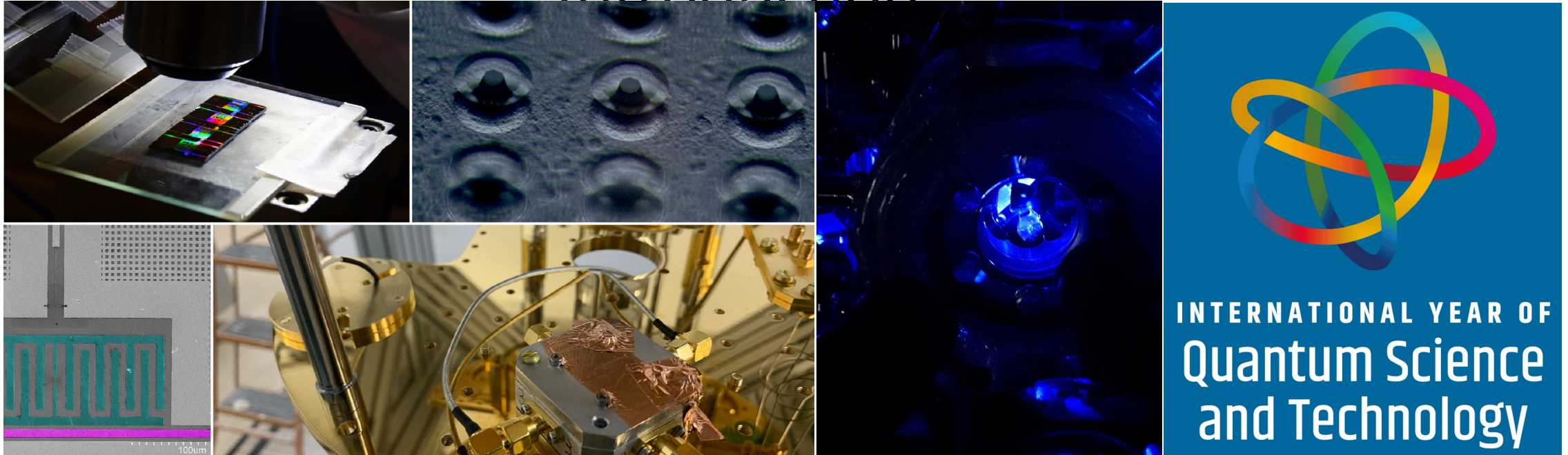




Quantum Technologies – A Brief Introduction



Selection of Quantum devices from São Paulo State researchers

Gustavo Wiederhecker¹ and Stephan Reitzenstein²

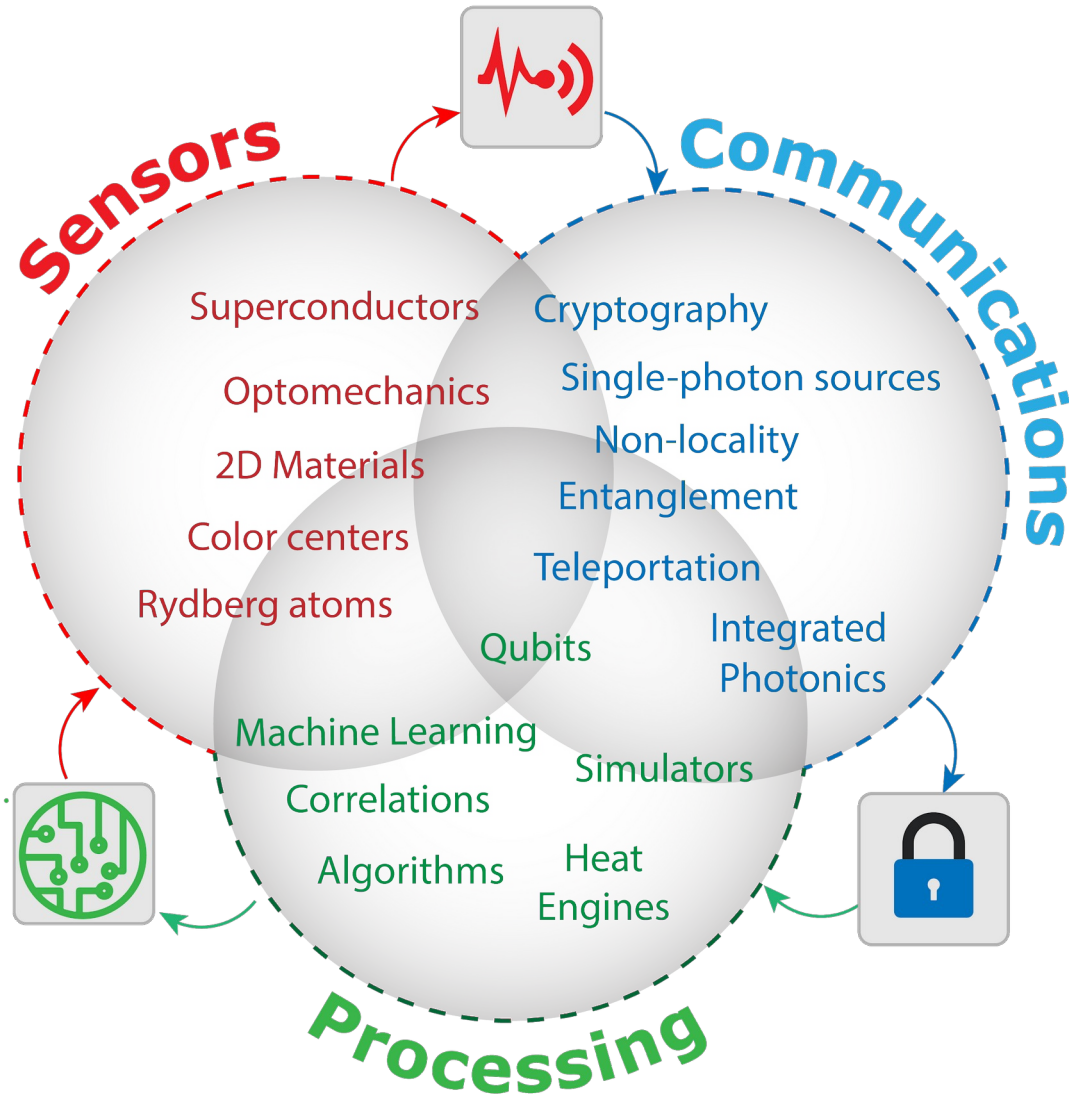
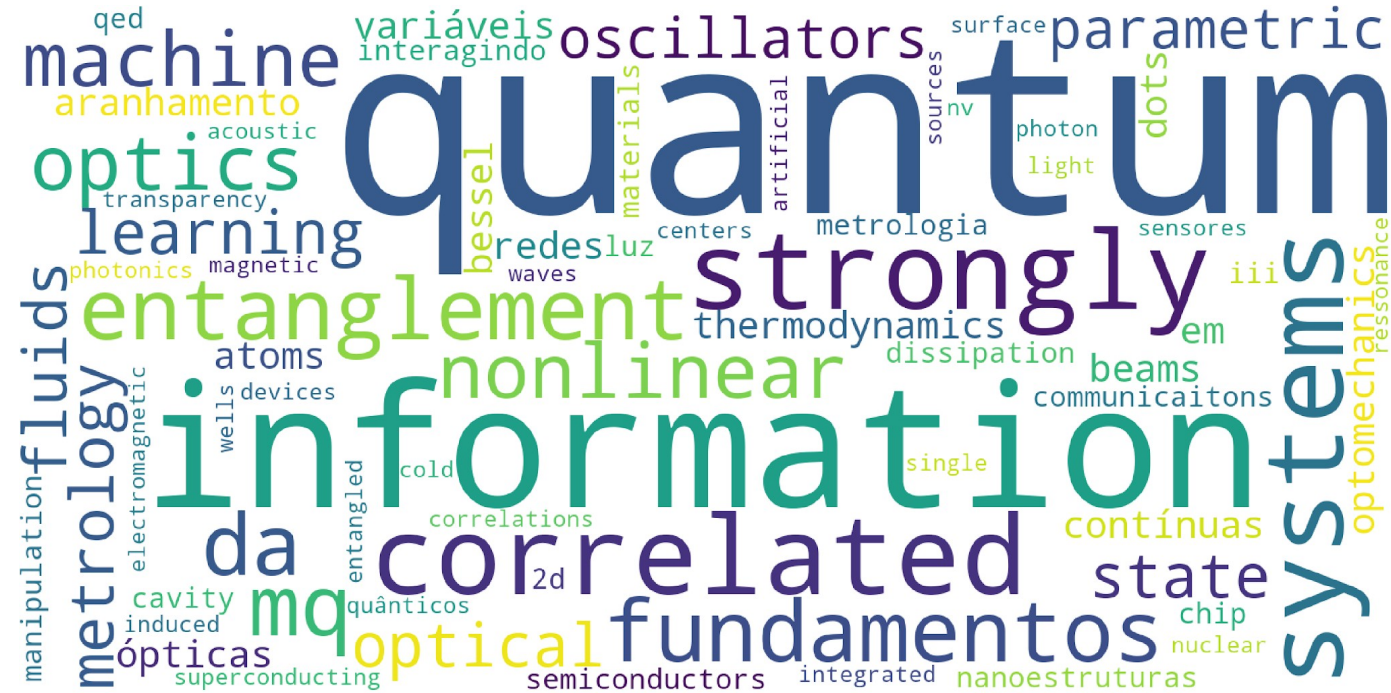
¹Physics Institute, State University of Campinas (UNICAMP), Brasil

²Institut für Festkörperphysik, Technische Universität Berlin,





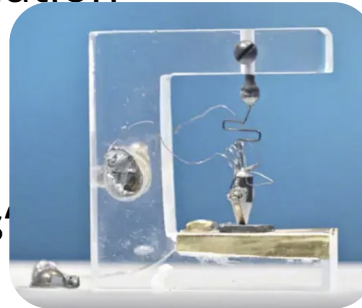
Quantum Technologies – What is this about?





The First Quantum Revolution – First Generation Quantum Technologies

- The *First Quantum Revolution* started at the beginning of the 20th century
- Primary goal: *understand* nature at the atomic scale
 - Experiments on blackbody radiation
 - Periodic table of elements
 - Photo-electric effect
 - Wave-particle duality
- First Generation “Quantum Devices”
 - Transistor (1958)
 - Lasers (1960)

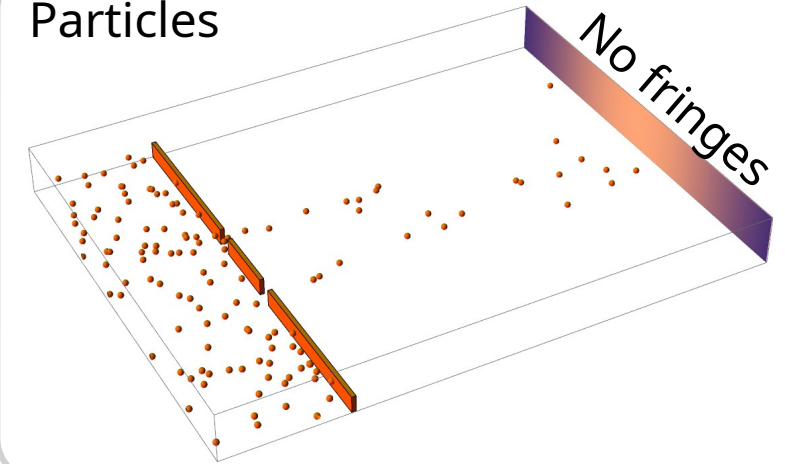


First transistor at Bell Labs, 1958



Ted Maiman and the first laser, 1960

Particles



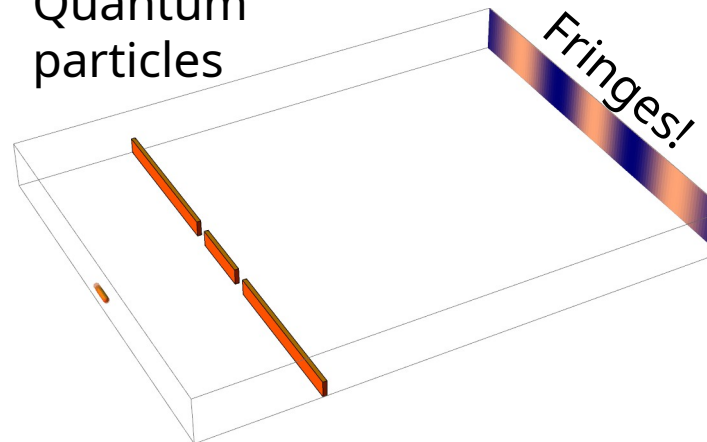
<https://www.joerg-enderlein.de/wave-or-particle>



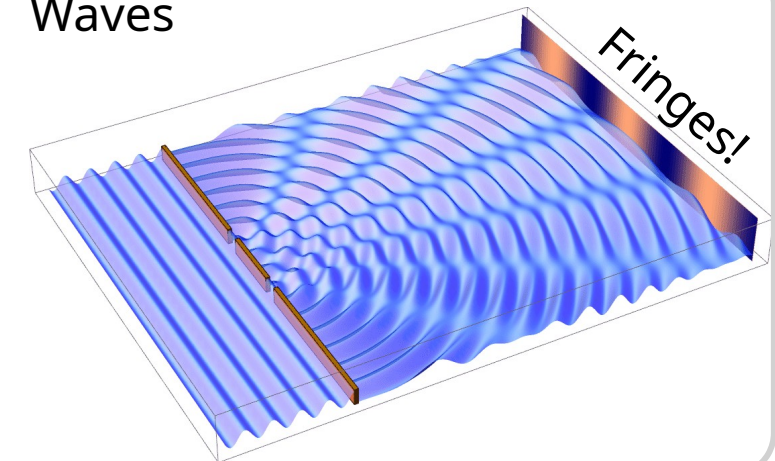
Alain
Aspect,
Physics
Nobel 2023

“The main ingredient of the first quantum Revolution, wave-particle duality, has led to inventions such as the transistor and the laser that are at the root of the information Society.”

Quantum
particles

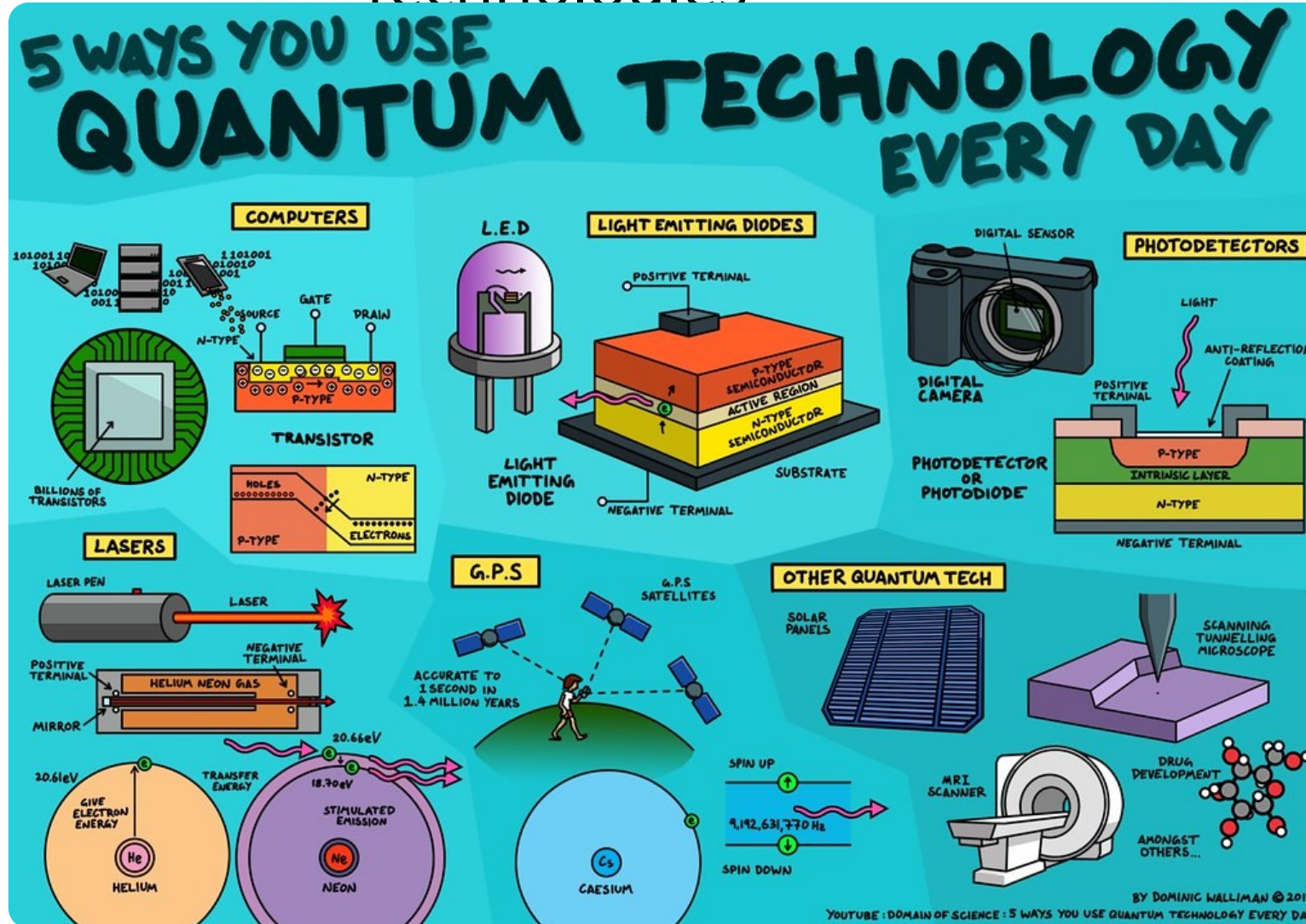
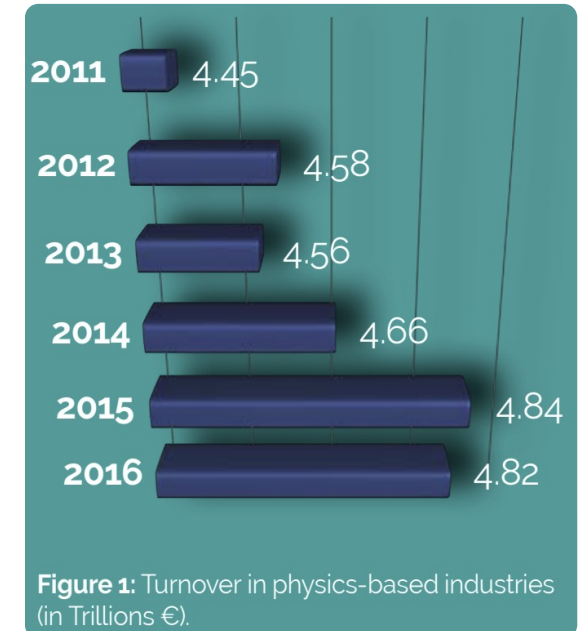


Waves





The First Quantum Revolution – First Generation Quantum Technologies



- 4.4 trillion EUR/year
- Gross-value added 1.4 trillion EUR
 - Manufacturing, Information, Communication
- 17 million people employed in 2014

The Importance of Physics to the Economies of Europe. European Physical



The Second Quantum Revolution – Second Generation Quantum Technologies

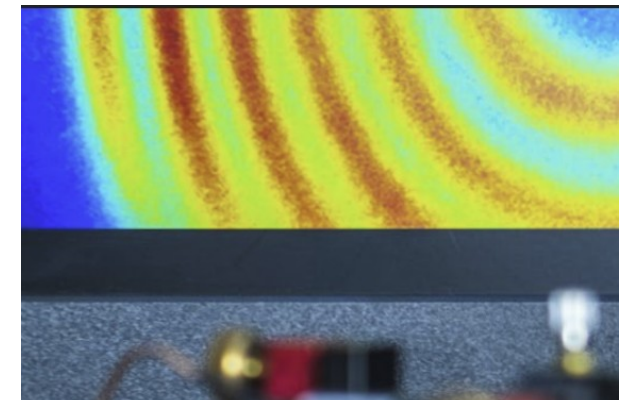
- The *Second Quantum Revolution* started in the 1980s
- Primary goal: *actively employ* quantum mechanics and *utilize quantum effects* on the single particle / single photon level
 - **Uncertainty principle:** the uncertain quantum state of system is revealed upon a measurements $\Rightarrow$ **Basis for secure quantum communication**
 - **Quantum Superposition:** if an event can be realized in two or more indistinguishable ways, the state of the system is a superposition of each way simultaneously $\Rightarrow$ **Basis for quantum computers**
 - **Entanglement:** the superposition principle applied to certain nonlocal correlations $\Rightarrow$ **Basis for information exchange in the quantum internet and enhanced sensors**



photonics.ixblue.com



IBM.com



Fraunhofer's [Quantum imaging project](#) (QUILT)

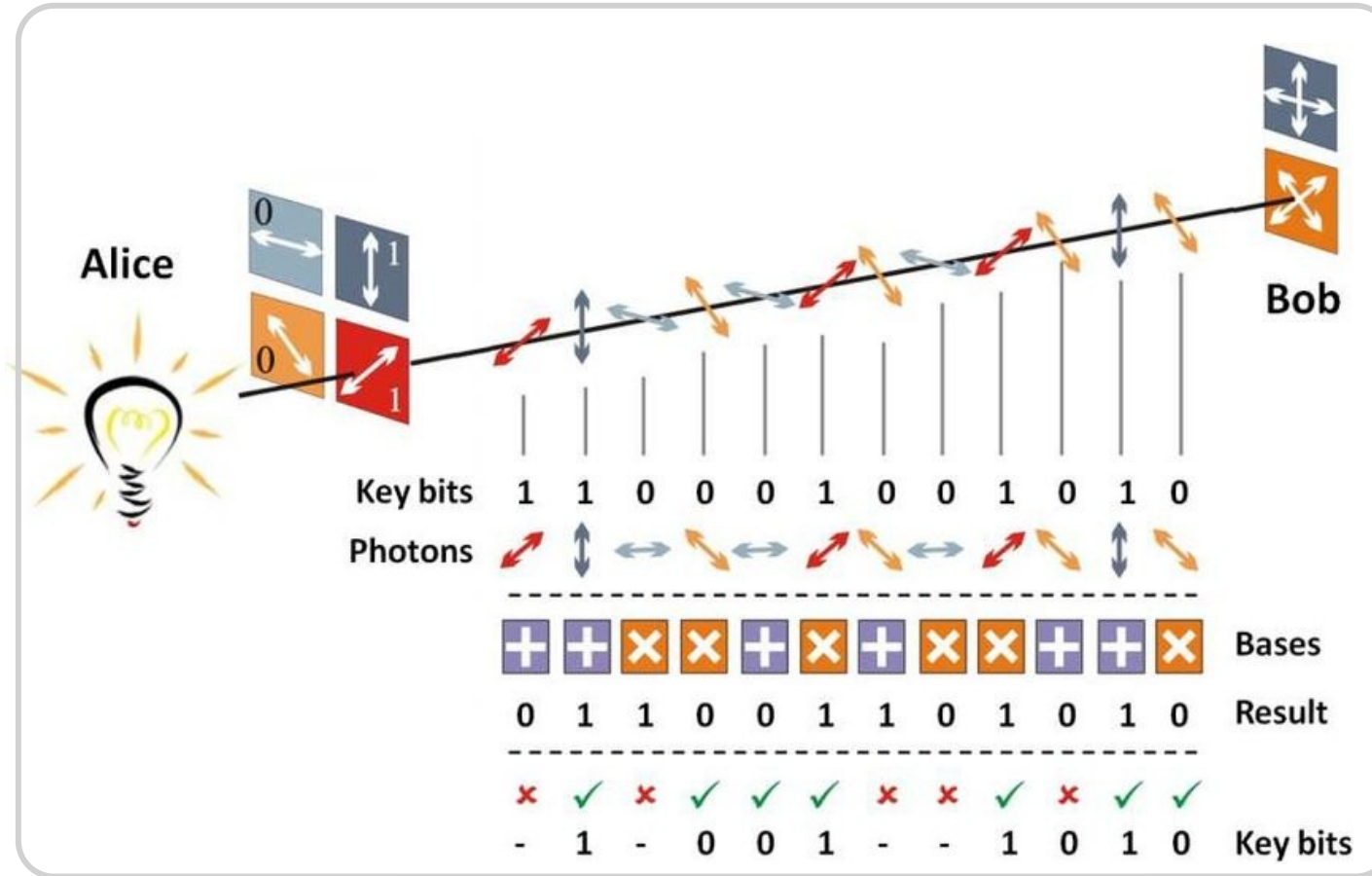
Second Generation Quantum Technologies - Milestones

BB84 Quantum Key Distribution

G. Brassard



C. H. Bennett



"...a communication channel on which it is impossible in principle to eavesdrop without a high probability of disturbing the transmission in such a way as to be detected."



In case of eavesdropping attack by Eve: - 1 - 1 0 1 - - 1 1 1 0 ⇒ 25% error rate

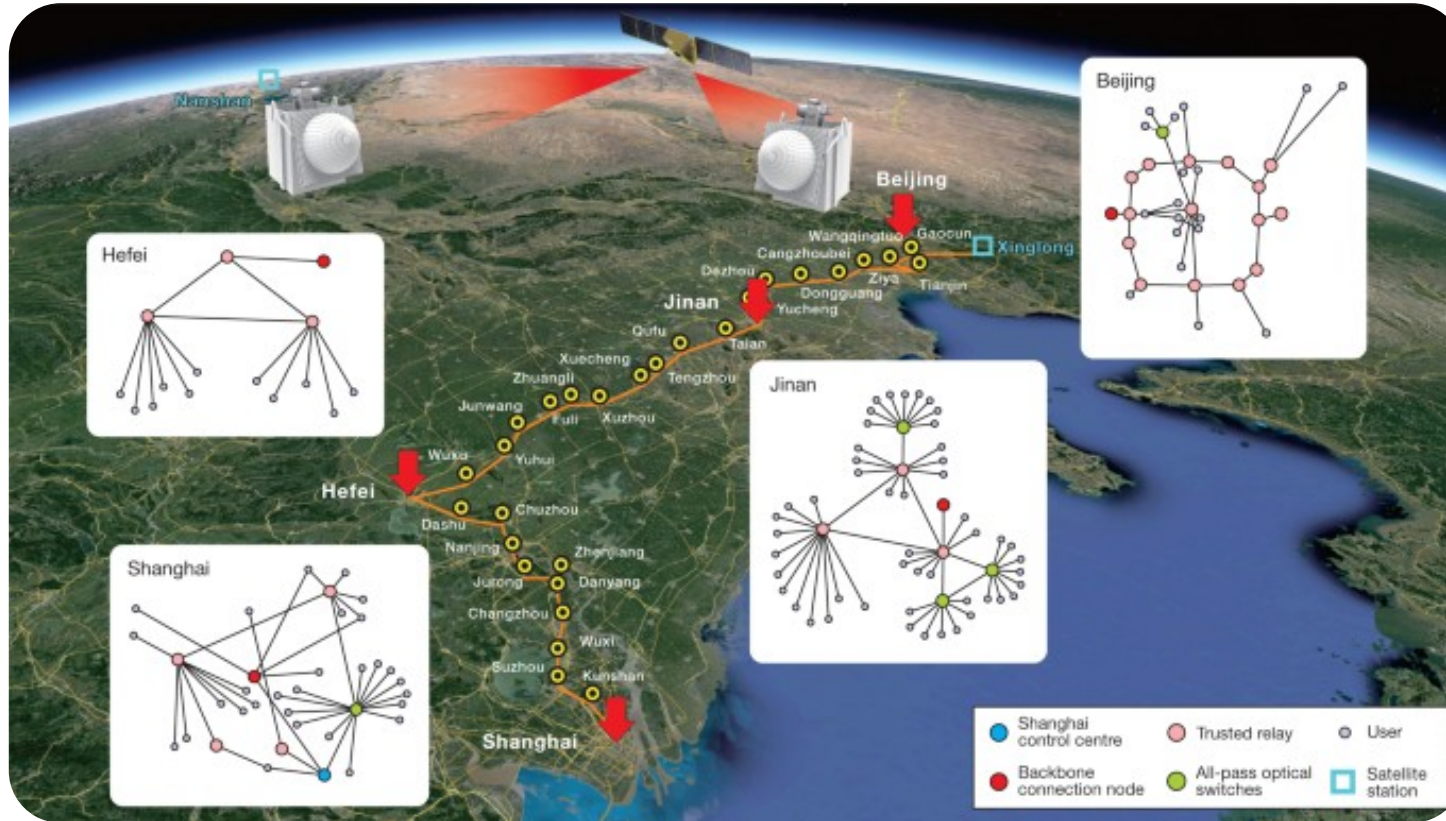
Second Generation Quantum Technologies - Milestones

BB84 Quantum Key Distribution

G. Brassard



C. H. Bennett



An integrated space-to-ground quantum communication network over 4,600 kilometres. *Nature* **589**, 214–219 (2020)

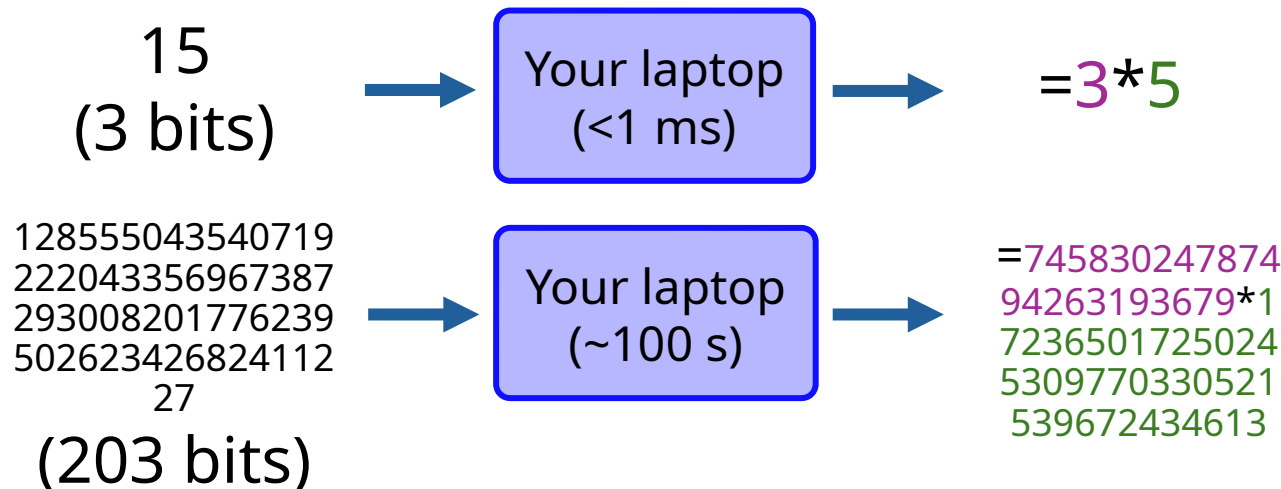
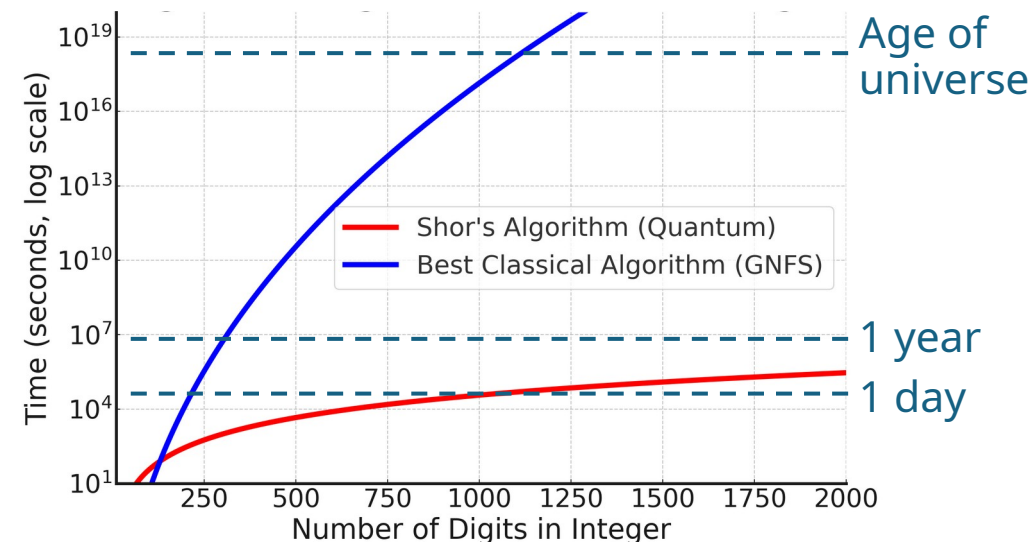
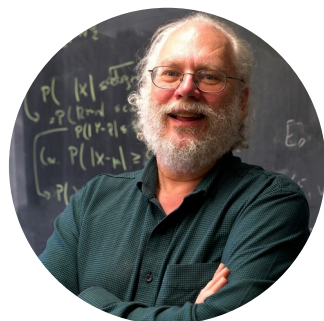


J. W. Pan

Experiment: C. H. Bennett, F. Bessette, G. Brassard, L. Salvail & J. Smolin, *J. Crypt.* 5, 3 (1992)

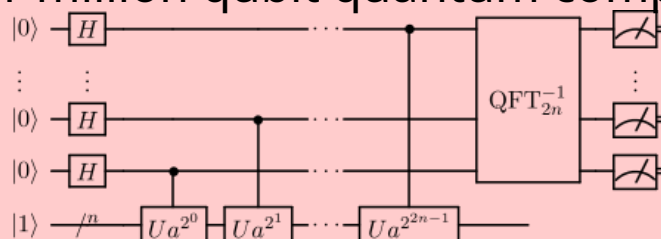
Second Generation Quantum Technologies - Milestones

Shor's Algorithm to achieve exponential speed up in computational power for prime factorization



Thousands
of bits

Your million qubit quantum computer



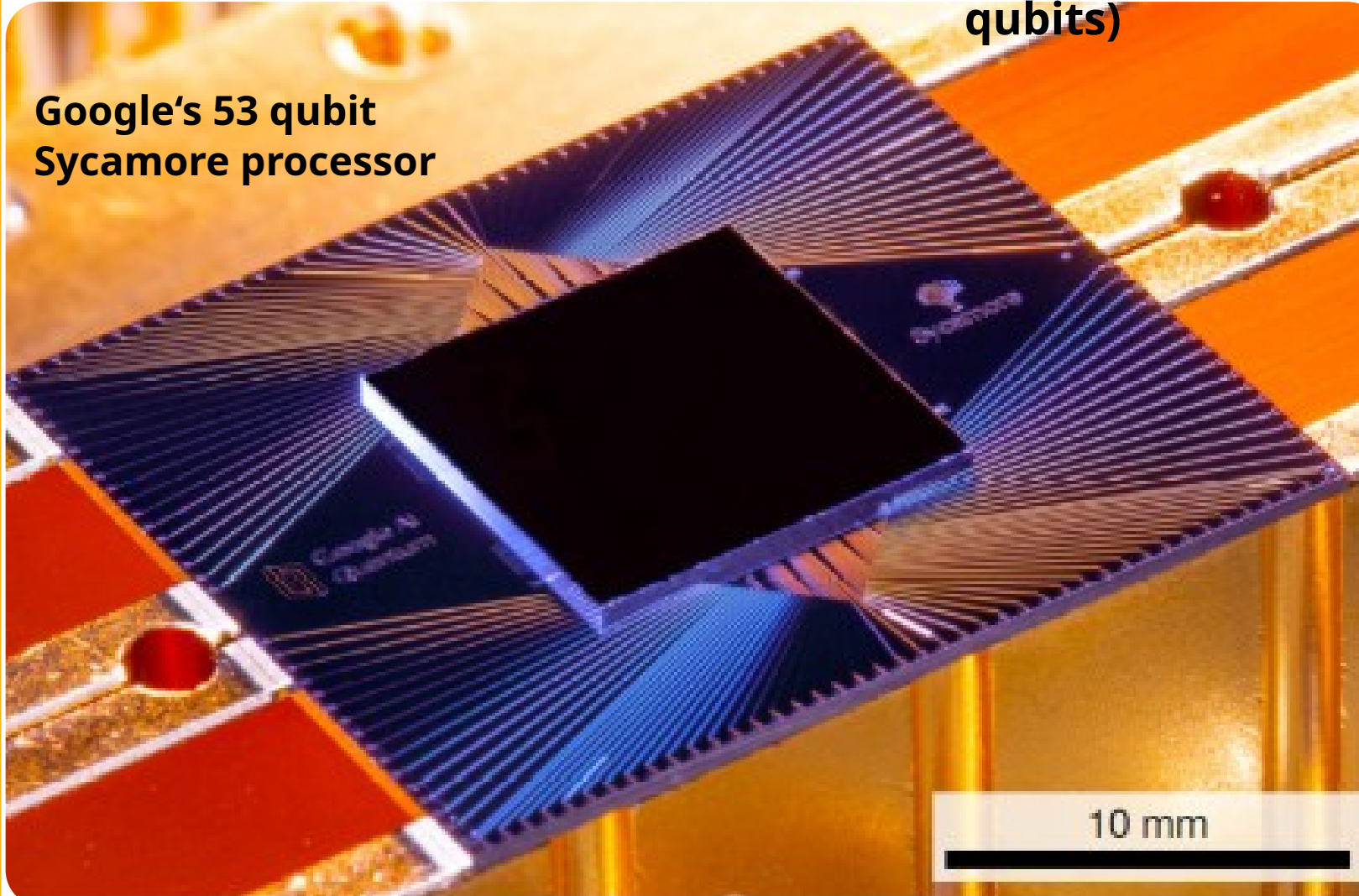
Answer
in a two
weeks!



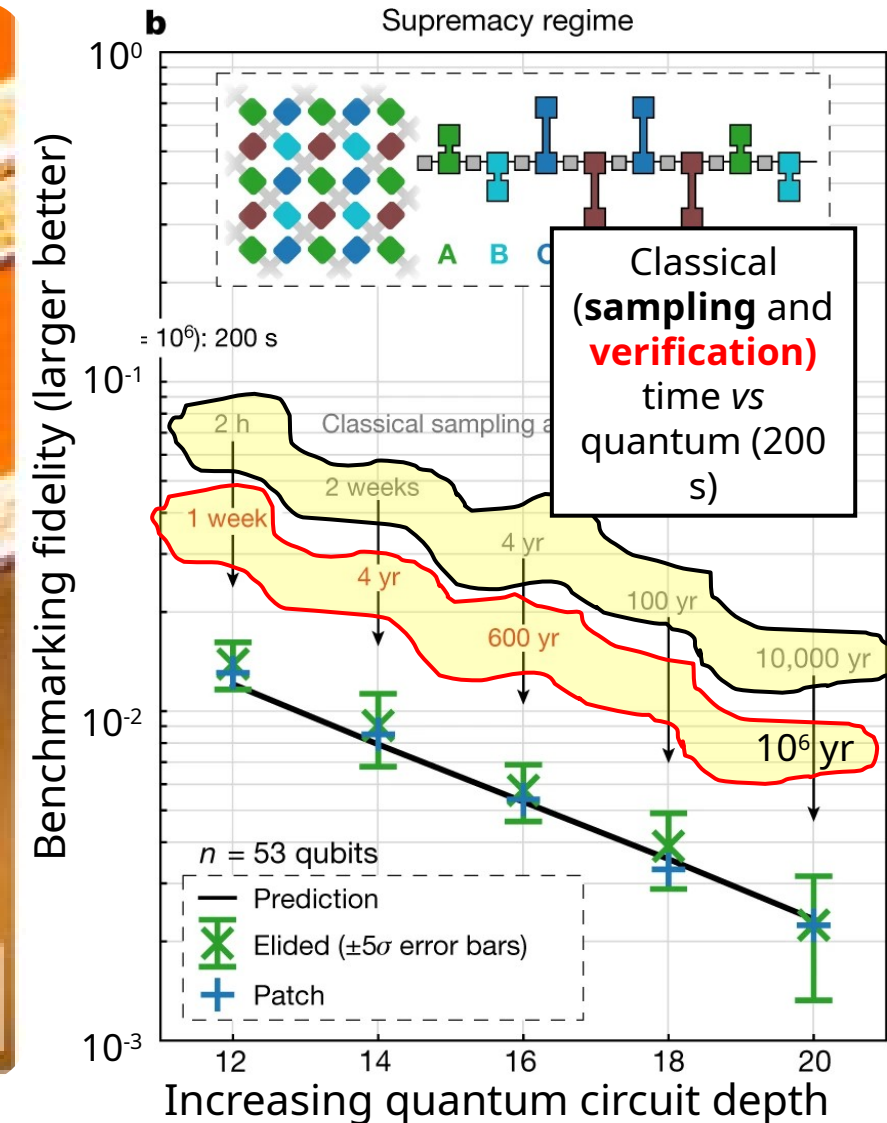
Second Generation Quantum Technologies - Milestones

Reaching Quantum Supremacy (superconducting qubits)

Google's 53 qubit
Sycamore processor

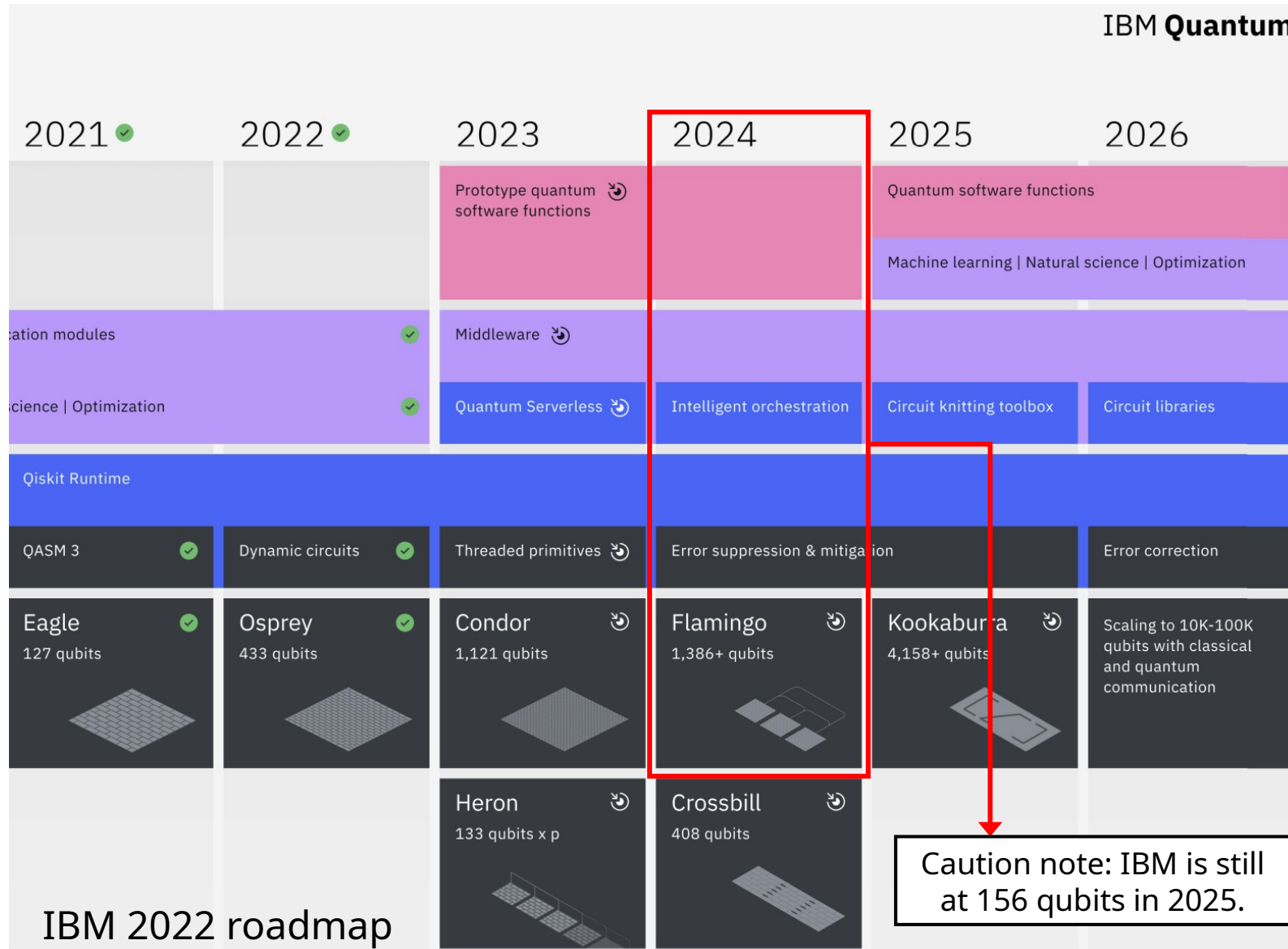


10 mm





Second Generation Quantum Technologies - Milestones



Dall-E

Quantum grain of salt

- Quantum computers are babies
- Increase in qubit number and circuit depth
- Noise may cause quantum computing to fail*
- Quantum hype may hinder development

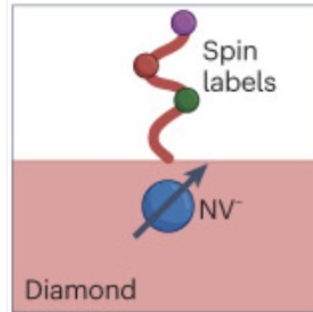
*<https://gilkalai.wordpress.com/quantum/roadmap-for-the-debate-on-quantum-computing/>



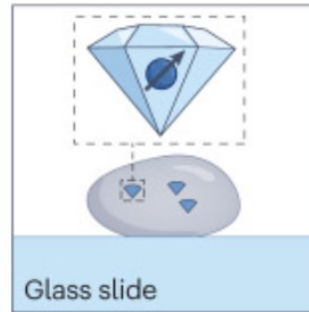
Second Generation Quantum Technologies - Milestones

Quantum sensing (life sciences)

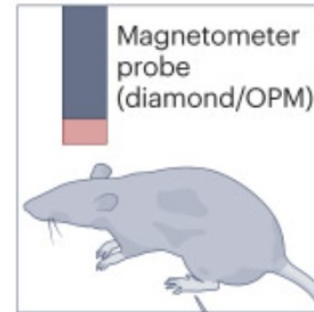
Molecular structure determination



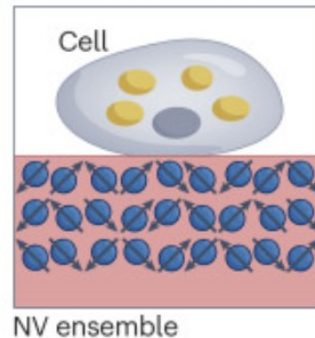
Thermal measurements with nanodiamonds



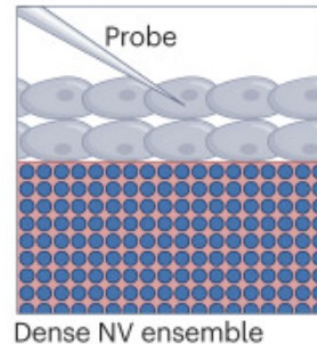
In vivo magnetic activity in animals



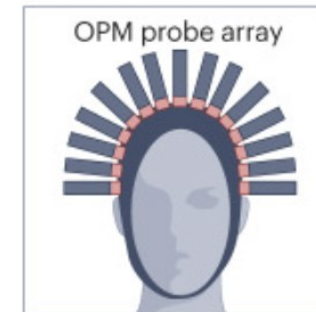
Subcellular organelle metabolic studies



Electrical activity studies in cellular cultures



Clinical diagnostics in humans



Molecular scale

Cellular scale

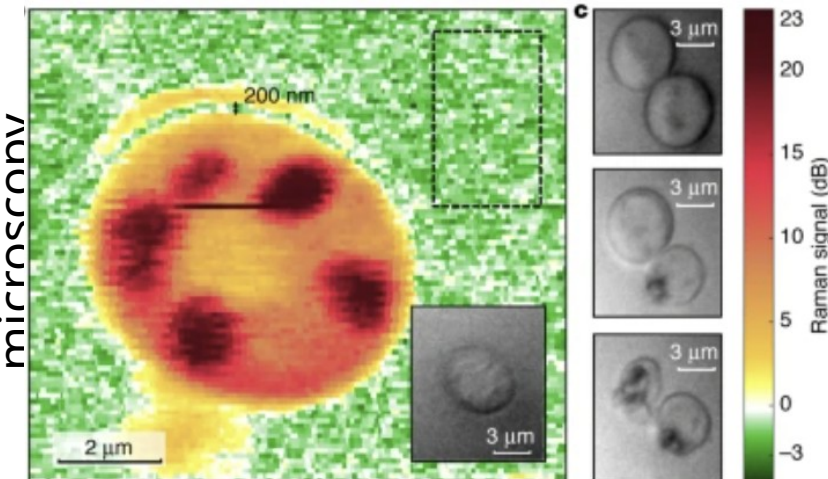
Organism scale

Quantum-Enhanced
Magneto-
encephalogram



Boto, E.. et al. Nature 555, 657–661 (2018).

Quantum-Enhanced
microscopy

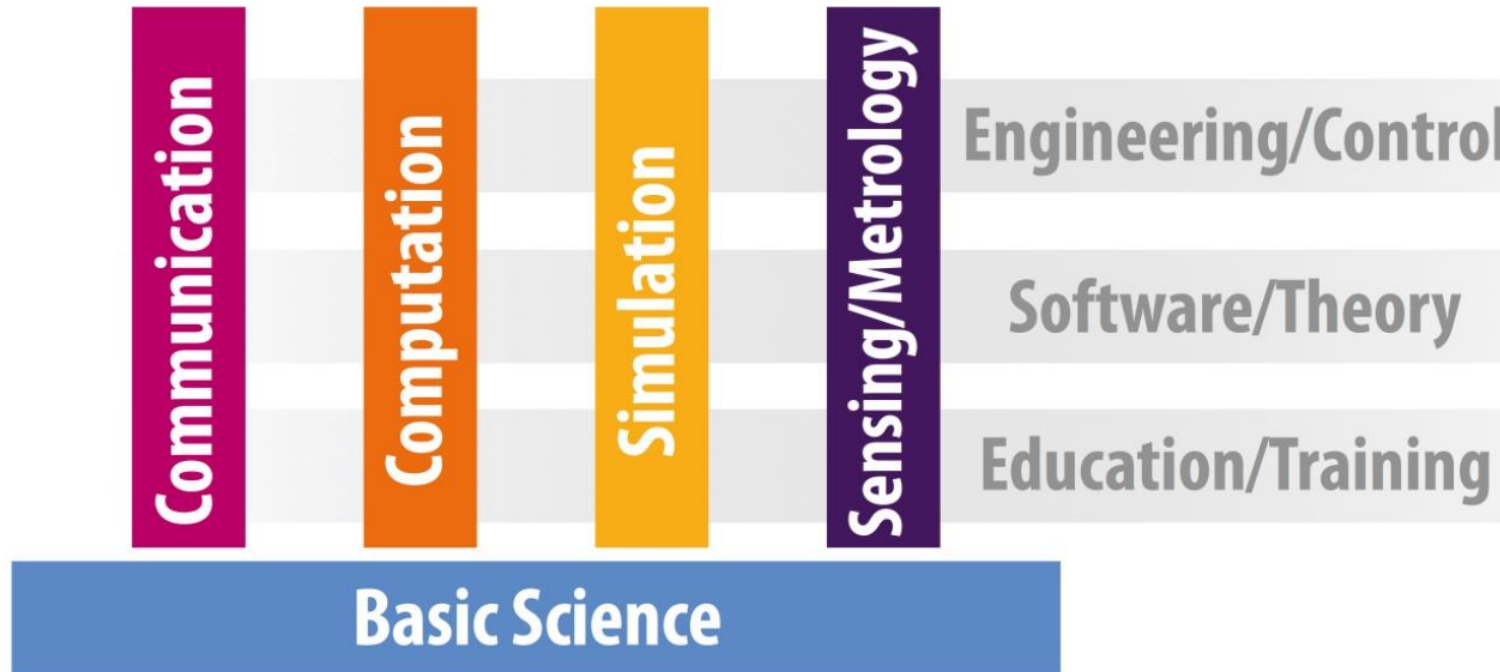


Casacio, C.A. et al. Nature 594, 201–206 (2021).

Aslam N, et al. Nat Rev Phys. 2023
Defienne, et al. Nat. Photon. **18**, 1024–1036 (2024).



The Pillars of the Second-Generation Quantum Technology

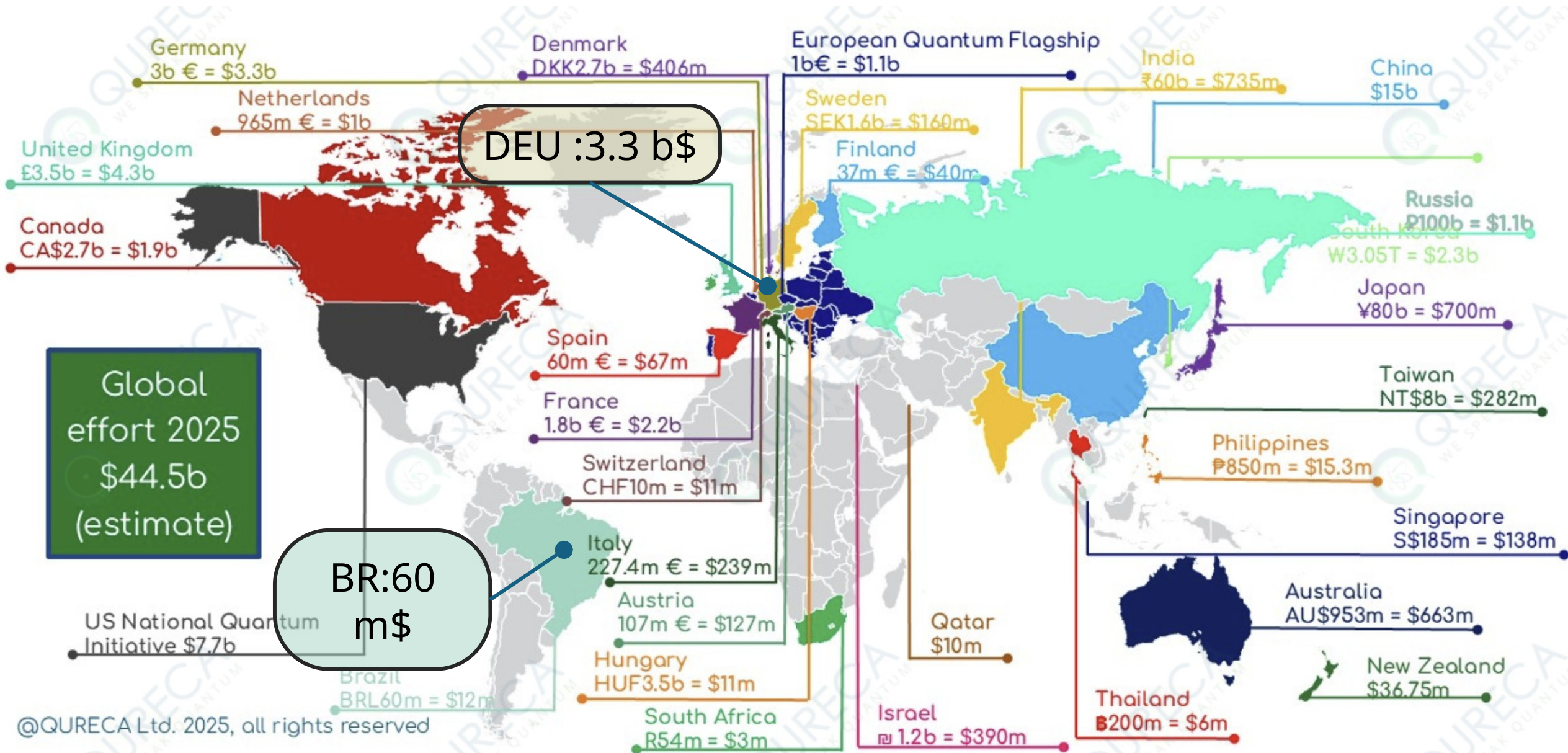


“global markets for various quantum technologies are above USD 1 trillion led by photonics, semiconductors and cyber security” [1]

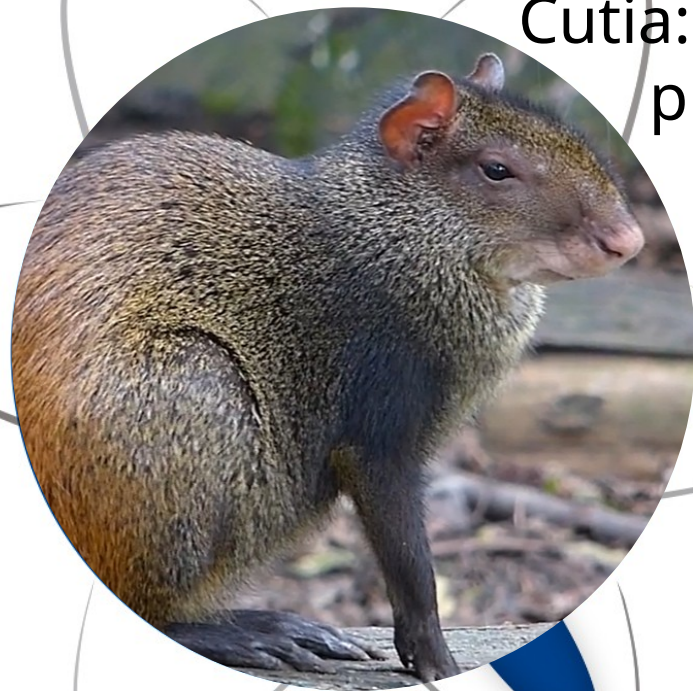


[1] UK Government Office for Science
<https://nqit.ox.ac.uk/content/quantum-age-technological-opportunities.html>

Global Public Funding in Quantum Technologies



Cutia: Dasyprocta
punctata



utia

Quantum Technologies Initiative



Workforce
development



National and International
Collaboration networks



Strategic
Partnerships



Research
Infrastructure



Innovation and
Startups



Diffusion of Knowledge
& Ethics

Initial budget:
30 MUSD (5 Years)



Young Researchers Award – Awardees – 1MUSD startup packages

Ions Traps



Amilson
Fritsch
IFSC

JQI-Maryland

Atomic vapor
magnetometers



Hans Florez
UFABC

U. Nottingham

Quantum
states with
spatial modes



Rafael Barros
IFUSP

Tampere Uni.

Optomechanical
Optics/RF
transducers



Rodrigo
Benevides
IFUSP

ETH Zurich

Single-photon
sources



Saimon
Silva
IFGW

JKU- Linz

Agenda

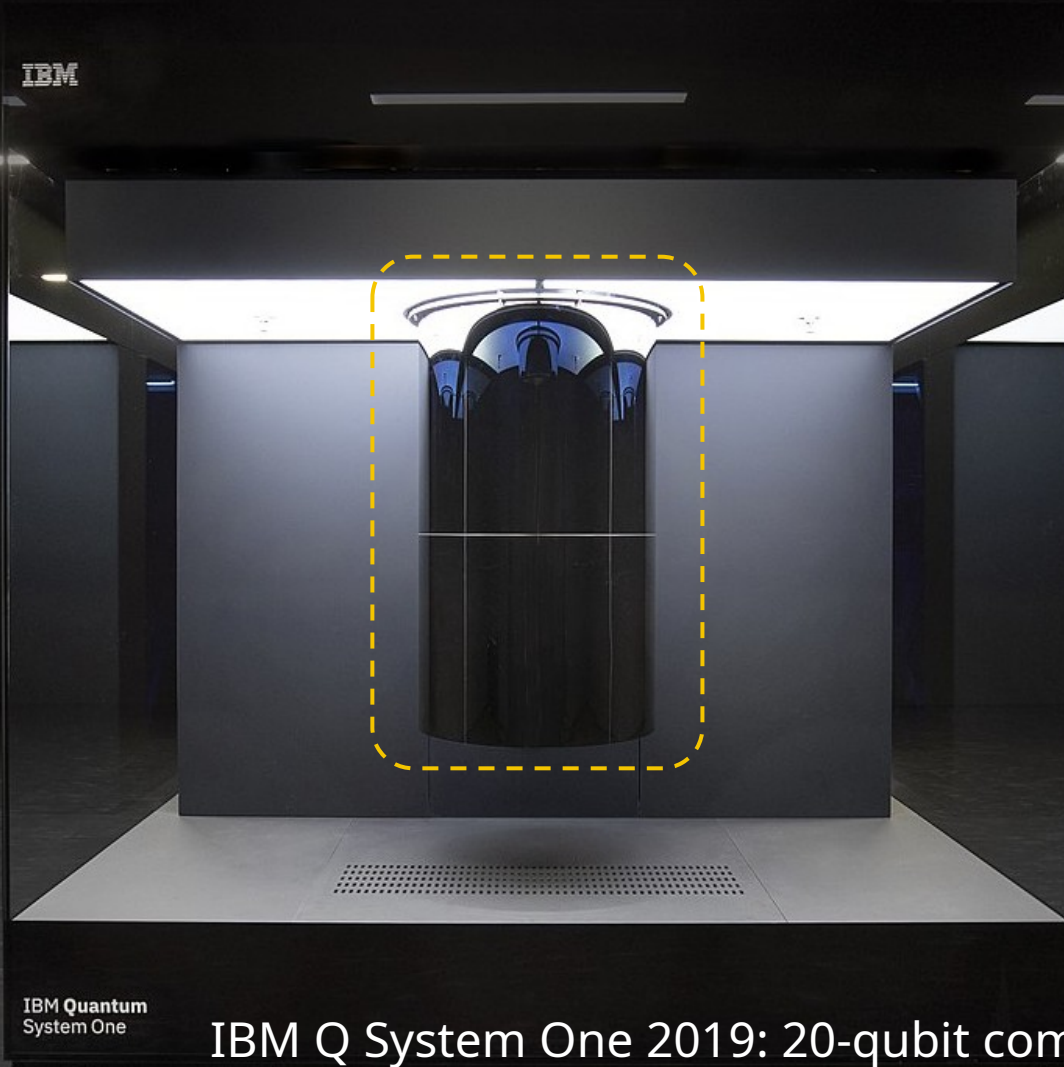
- 9:15 – 9:30: **Patricia Marques Castilho**, São Carlos Physics Institute, University of São Paulo (USP)
- 9:30 – 9:45: **Jens Eisert**, Dahlem Center for Complex Quantum Systems, Freie Universität Berlin
- 9:45 – 10:00: **Felipe Fanchini**, School of Sciences, São Paulo State University (UNESP), Bauru
- 10:00 – 10:15: **Christian Schneider**, TUM School of Computation, Information and Technology,
Munich
- 10:15 – 10:30: **Roberto Alves Gallo Filho** - Kryptus Segurança da Informação S.A
- 10:30 – 10:50: **Q&A/Discussion**



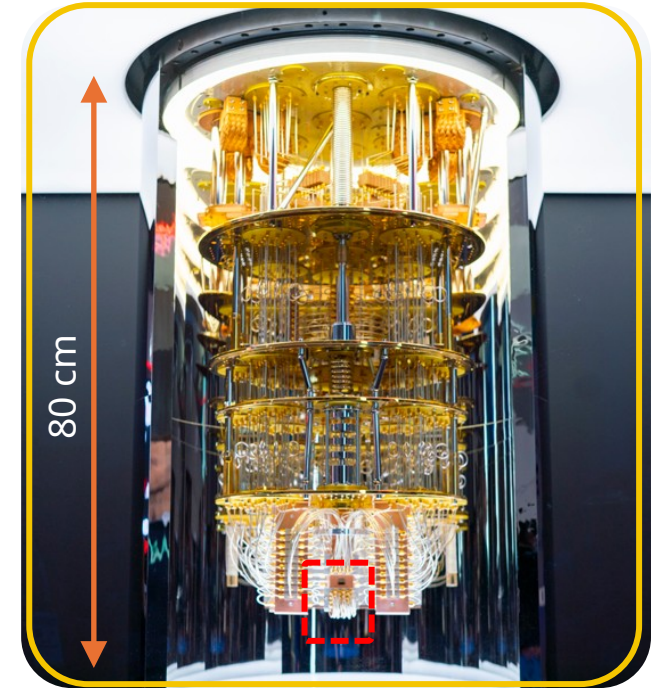


Second Generation Quantum Technologies - Milestones

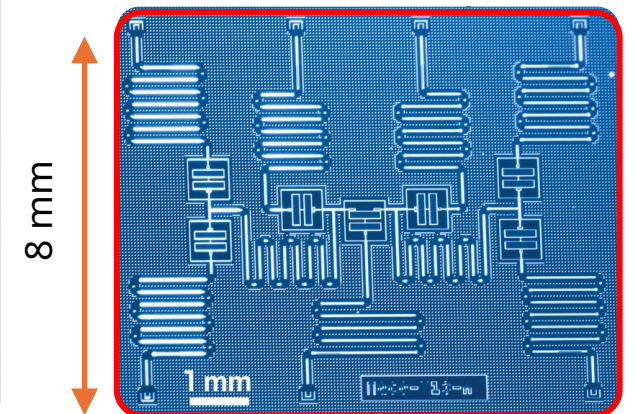
2 meters



IBM Q System One 2019: 20-qubit computer (based on superconducting qubits)



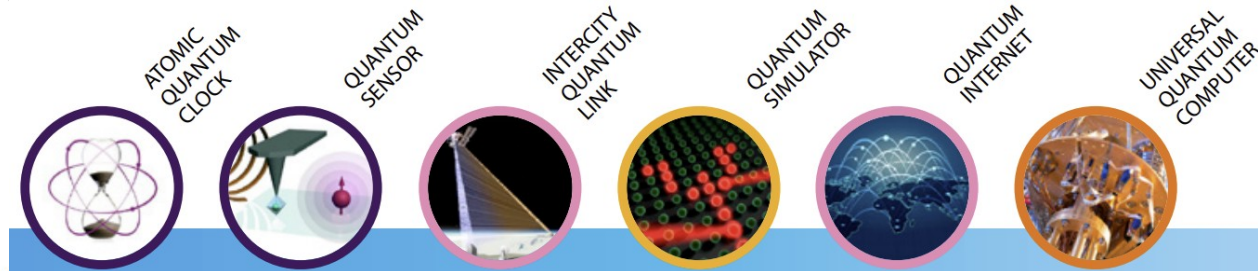
20 mK dilution



Example 7-qubits chip



Second-Generation Quantum Technology - Timeline



2016 Quantum Manifesto: "This manifesto is a call to launch an ambitious European initiative in quantum technologies, needed to ensure Europe's leading role in a technological revolution now under way"

1. Communication

0 – 5 years

- A Core technology of quantum repeaters
- B Secure point-to-point quantum links

5 – 10 years

- C Quantum networks between distant cities
- D Quantum credit cards

2. Simulators

- A Simulator of motion of electrons in materials
- B New algorithms for quantum simulators and networks

- C Development and design of new complex materials
- D Versatile simulator of quantum magnetism and electricity

3. Sensors

- A Quantum sensors for niche applications (incl. gravity and magnetic sensors for health care, geosurvey and security)
- B More precise atomic clocks for synchronisation of future smart networks, incl. energy grids

- C Quantum sensors for larger volume applications including automotive, construction
- D Handheld quantum navigation devices

4. Computers

- A Operation of a logical qubit protected by error correction or topologically
- B New algorithms for quantum computers
- C Small quantum processor executing technologically relevant algorithms

- D Solving chemistry and materials science problems with special purpose quantum computer > 100 physical qubit



Second Generation Quantum Technologies - Milestones

Quantum Teleportation



J. W. Pan



H.
Weinfurter



A. Zeilinger

