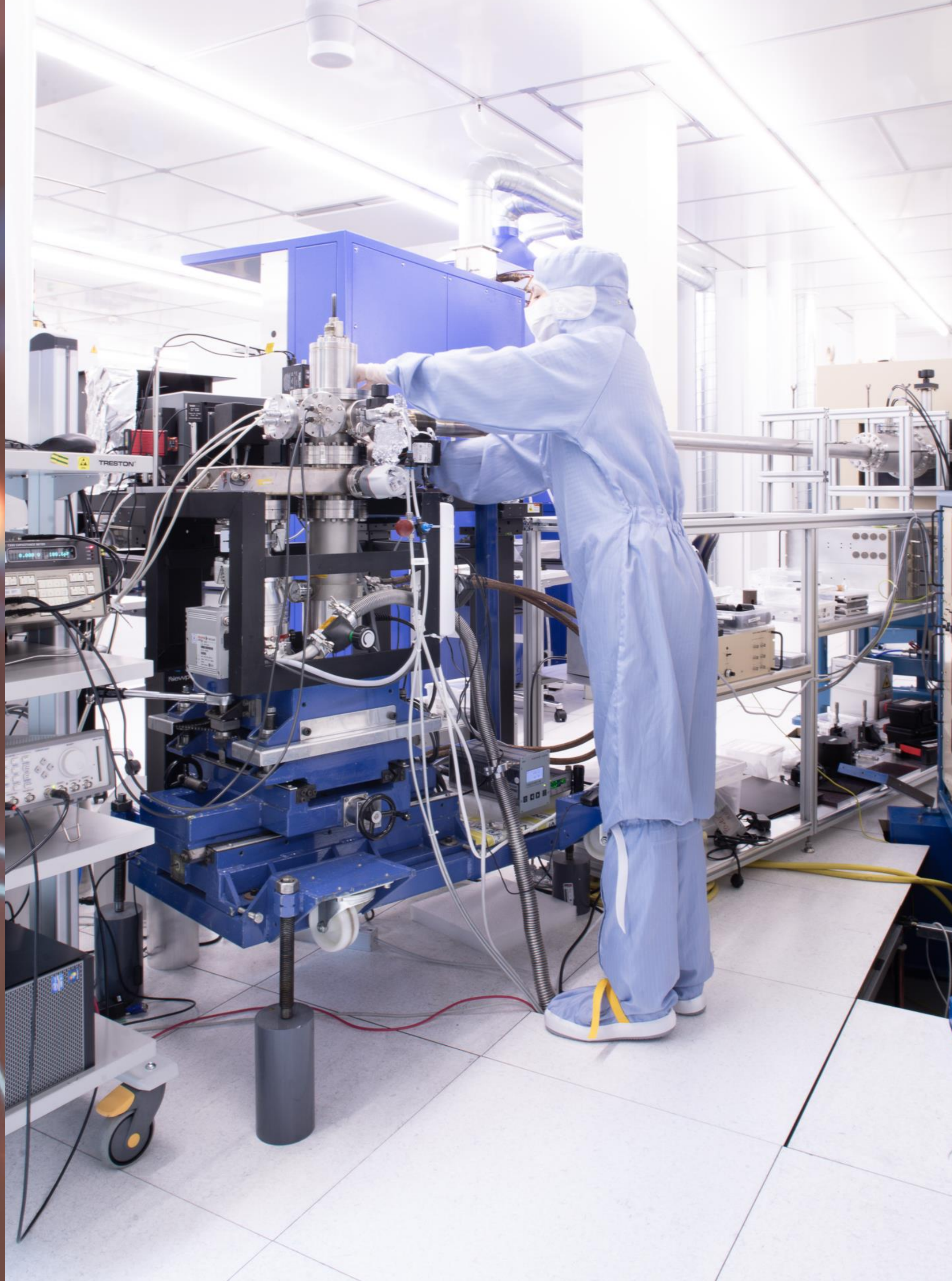
Where are we going?

Quantum technology for future applications



1st and 2nd quantum revolution

Overview of quantum technologies

Status and opportunities

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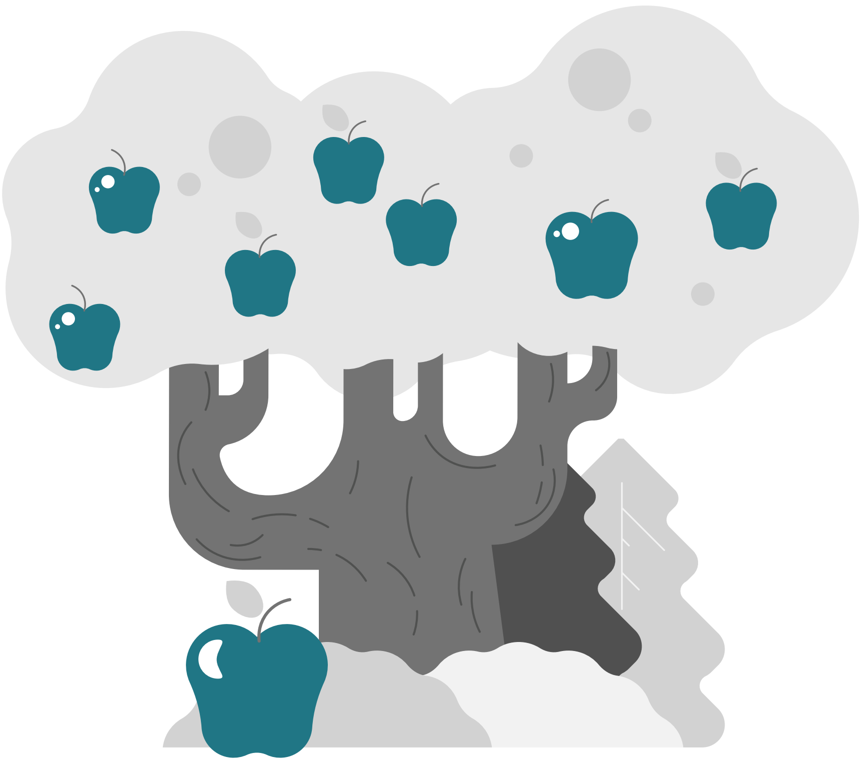
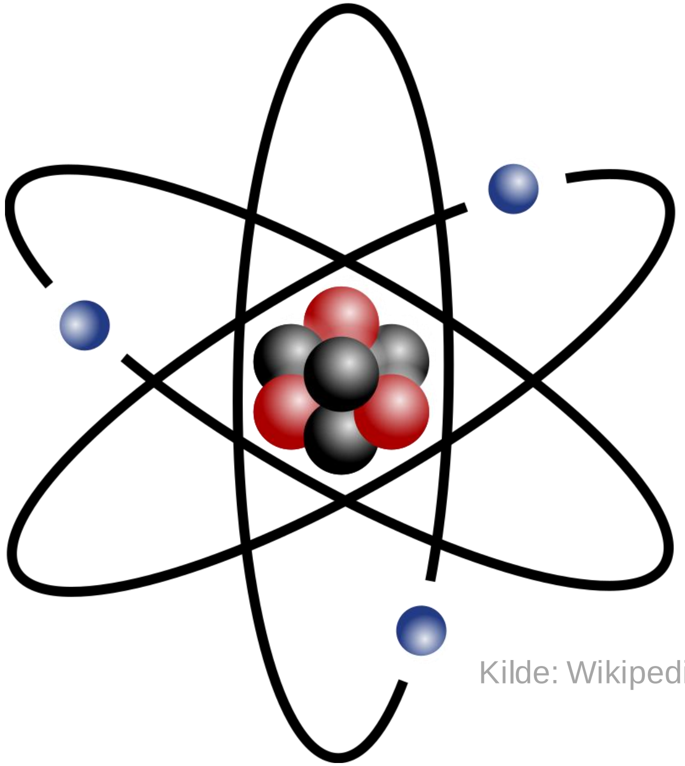
1st and 2nd quantum revolution

Overview of quantum technologies

Status and opportunities

From classical to quantum physics





Kilde: Wikipedia

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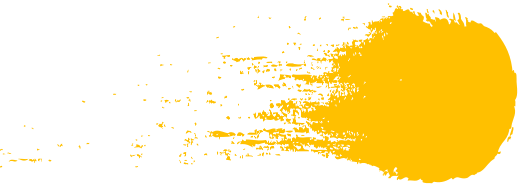
The 1st quantum revolution: Quantum physics experiments

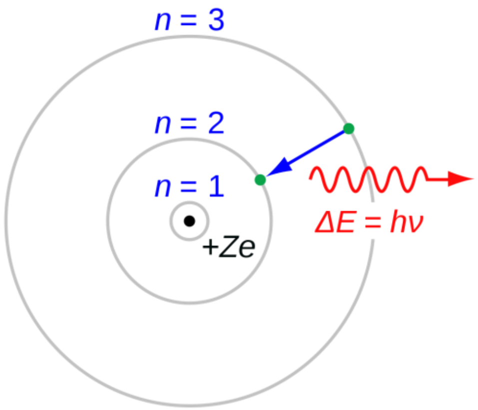
Max Planck, Albert Einstein, Arthur Compton



Light can behave like particles

Photons have momentum

Niels Bohr



Quantum systems have discrete (quantized) energy levels

Louis de Broglie

Particle-wave duality

Particles can exhibit wave-like properties

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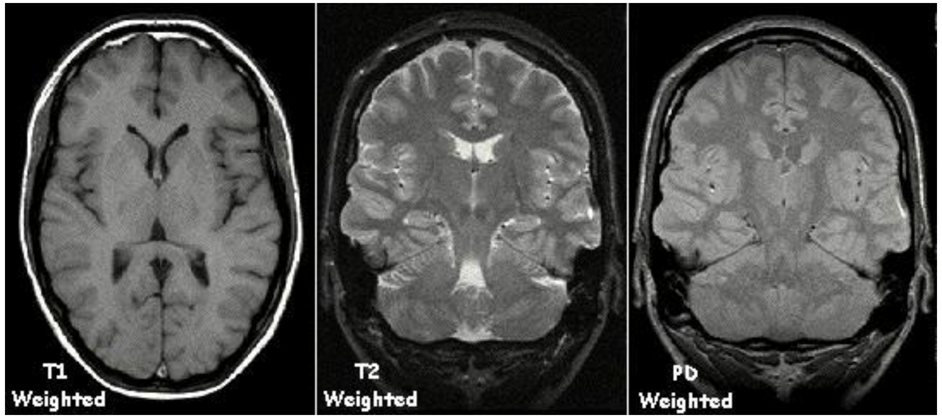
Quantum revolution 1.5: Macroscopic quantum properties



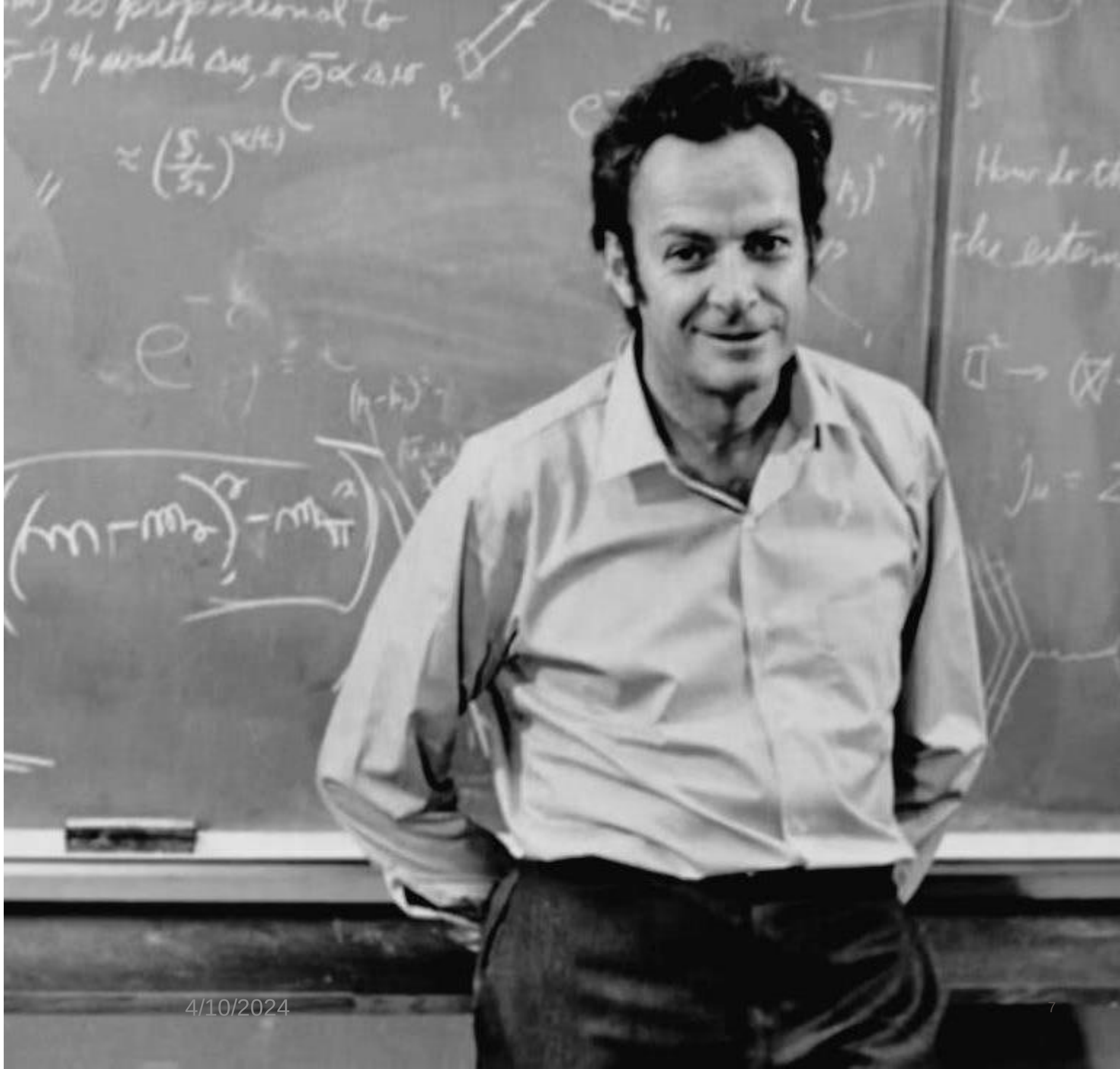
https://en.wikipedia.org/wiki/Magnetoresistive_RAM#/media/File:200mm_1_Mb_MRAM_-_D60_Symposium_-_Defense_Advanced_Research_Projects_Agency_-_DSC05568.jpg
By KieranMaher at English Wikibooks https://commons.wikimedia.org/w/index.php?curid=12766438
https://commons.wikimedia.org/wiki/File:RBG-LED.jpg

“nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical.”

Richard Feynman

Quantum technology exploits the unique and exotic properties of quantum mechanics

- Superposition
- Quantum entanglement
- Tunneling



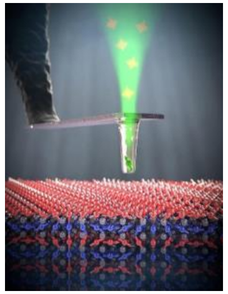
The 2nd quantum revolution: Direct control over quantum systems

1. Computing	2. Sensing	3. Communication
• Information processing • Solve tasks not possible with classical computing	• Nanoscale spatial resolution • Fast response	• Transmit information • Quantum security

Quantum technology promises new opportunities

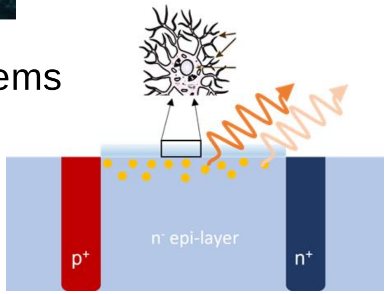
Extreme conditions

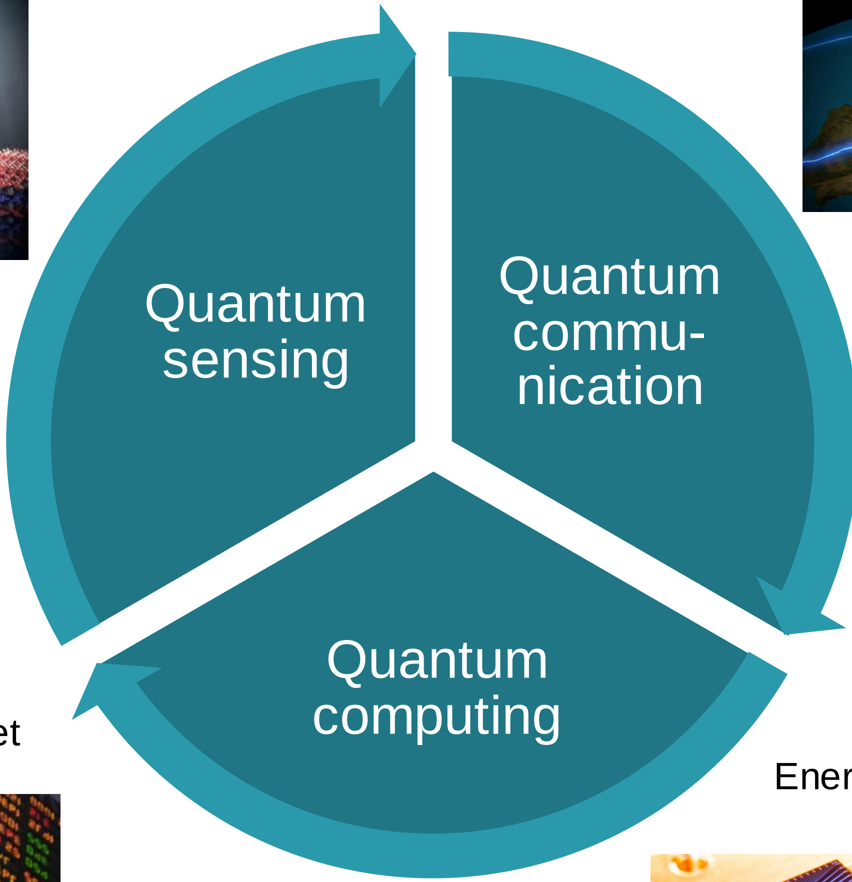
Nanoscale

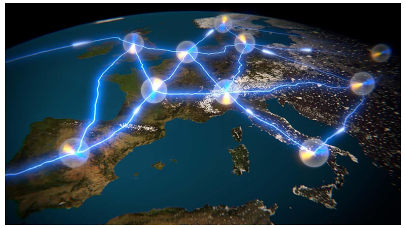


Better control systems

Signals in cells







Quantum internet

Quantum cryptography

Secure communication based on laws of quantum physics

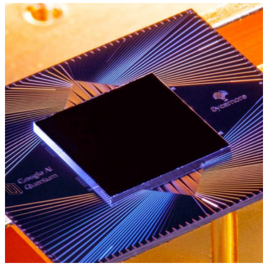
Model weather, climate

Model finance market

Better logistics

Optimized energy consumption

Energy efficient computation



Find new drugs and materials for green transition

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1st and 2nd quantum revolution

Overview of quantum technologies

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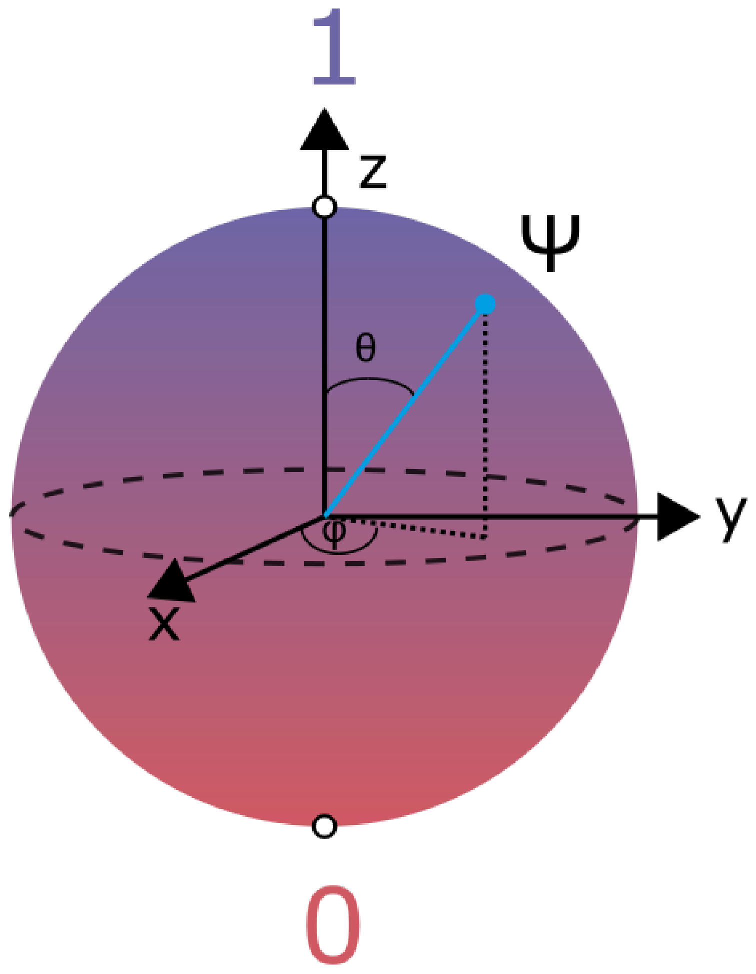
Quantum bits: the building block of quantum technology

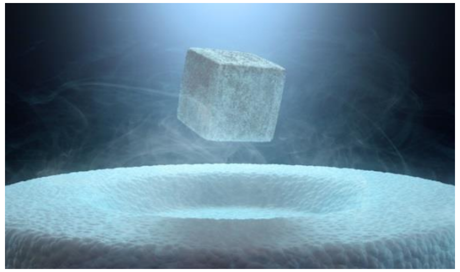
Qubit guidelines:

1. Stable, two-level quantum system
2. Communication path
3. Scalable
4. Energy efficient



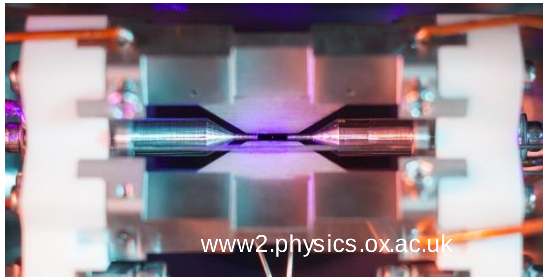
Choice of material platform depends on application

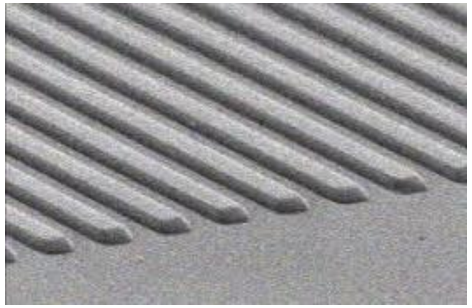
- Superconductors
- Trapped ions
- Optical gratings
- Quantum dots
- Defects in semiconductors
- …



Superconductors

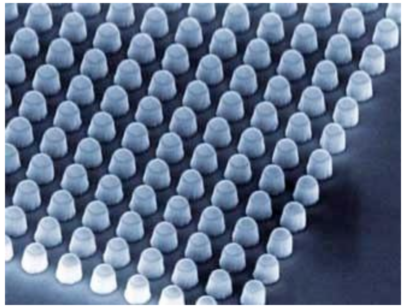
Trapped ions

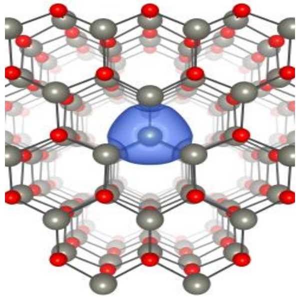




Optical gratings

Quantum dots





Semiconductor
point defects

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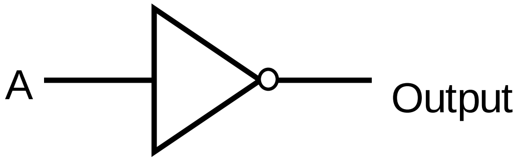
1. Gate model for quantum computing

Logic gates

- Classical circuits based on logic gates
- Gates perform logic operations
  - Rules for answering YES/NO questions
  - Input is 1 and 0 from transistors/bits

Example: NOT (inverter)

A	Output
0	1
1	0



Quantum logic gates

- Most popular architecture for QC
- Inspired by classical logic gates
- Manipulate qubits by gate operations
- Quantum circuits are formed by qubits and quantum gates

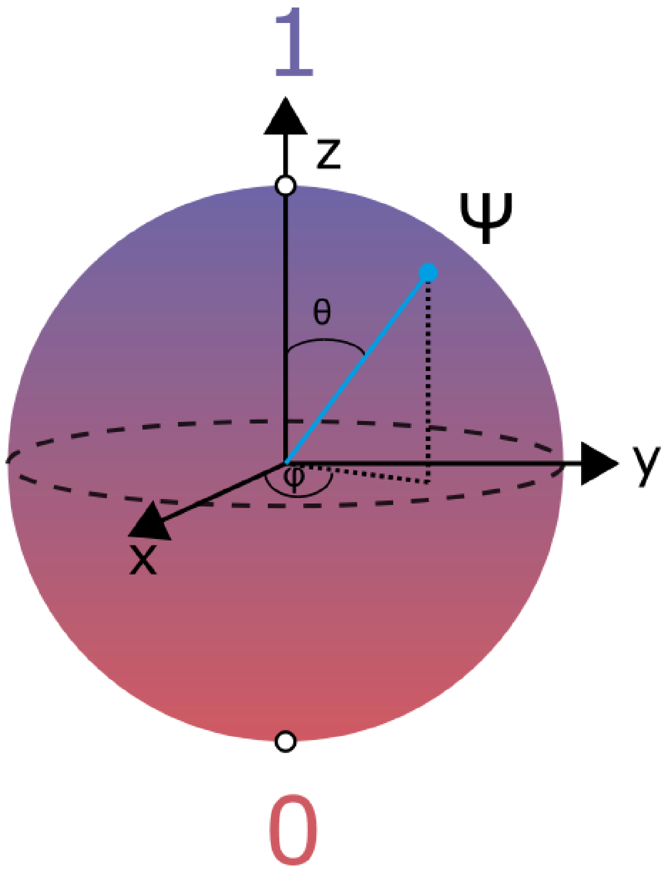
Quantum gate operations

- Quantum gates can operate on one, two or more qubits

- We represent quantum gates by unitary matrices (U*U=I)
  - 1-qubit gates are 2×2 matrices
  - 2-qubit gates have 16 matrix elements, etc.

- In practice; e.g. pulse of electromagnetic field

Represent qubits as a vector along a Bloch-sphere



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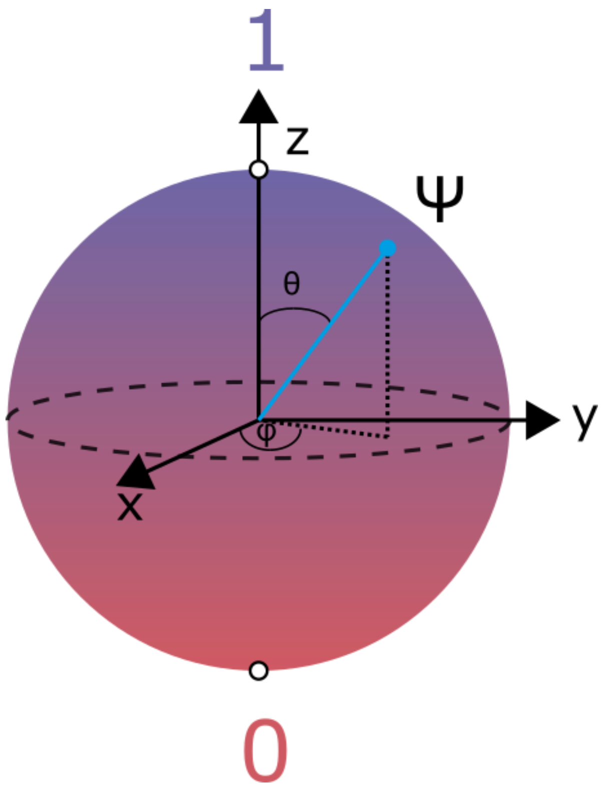
One-qubit quantum gates

X gate

- Quantum NOT
- Performs bit flip (0-to-1 and 1-to-0)

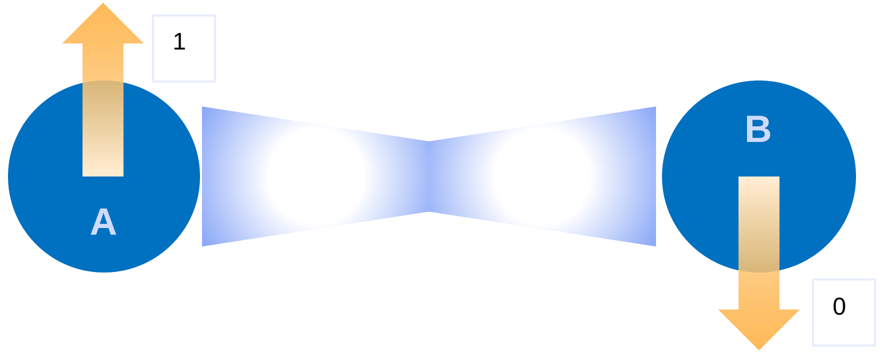
Hadamard gate

- Quantum analog to one-qubit Fourier transform
- Transforms a basis state (0 or 1) to a superposition of states



Controlled NOT (CNOT)

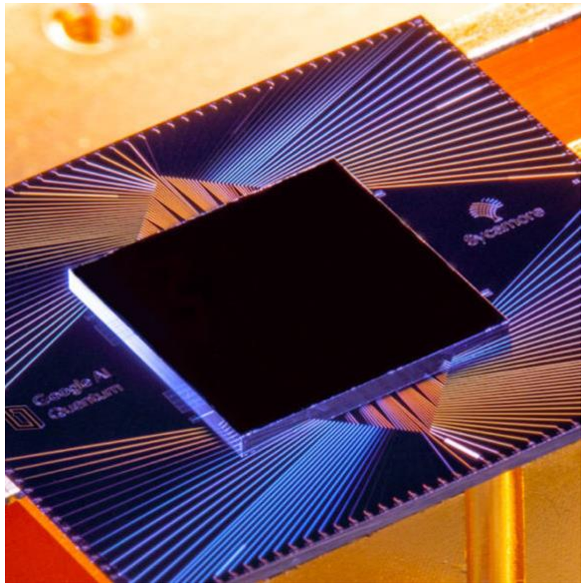
CNOT can generate a maximally entangled state between two qubits



Satus for quantum computing

Where are we now?

- Noisy intermediate-scale quantum (NISQ)
- Superconducting qubits
- Quantum advantage is debatable
- Ideal time to learn!



https://www.nature.com/articles/s41586-019-1666-5

https://www.ibm.com/quantum/roadmap

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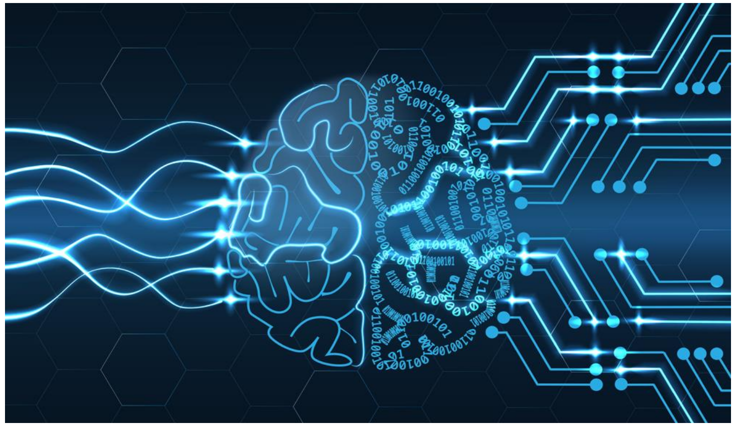
2. Sensors are the foundation of the digital and green shifts

Kilde: Wikipedia

Better control systems

Improved safety



Input to AI

Optimized energy consumption

https://iot.eetimes.com/the-power-and-potential-of-applying-artificial-intelligence-to-sensor-generated-data/

Need for quantum sensors

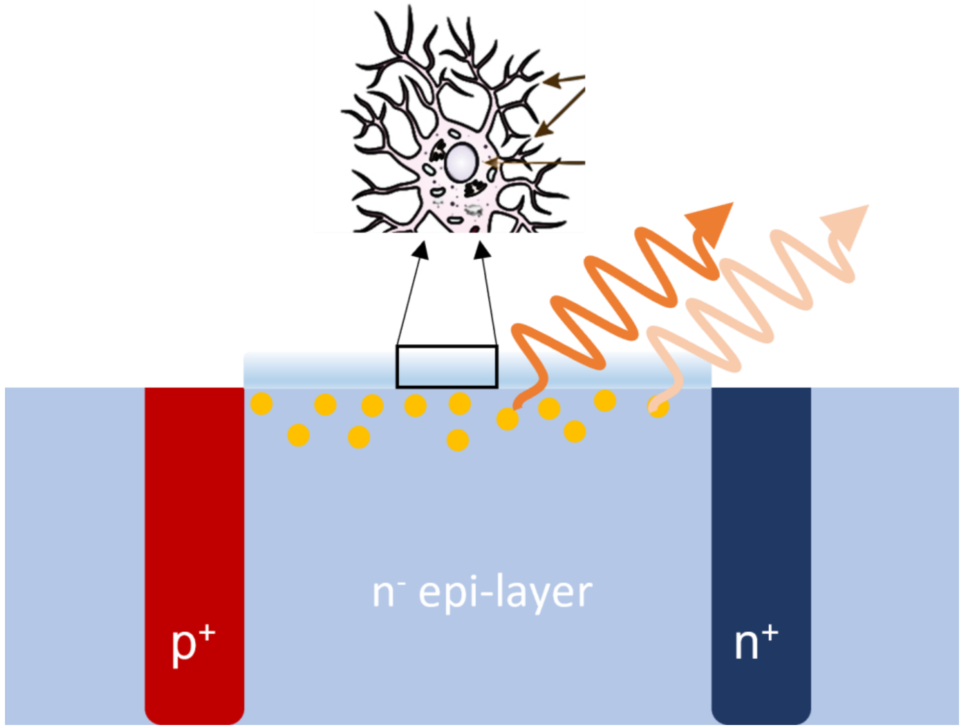
Limitations of today's technology

- Limitation in detection
  - Spatial resolution
  - Sensitivity
  - Extreme conditions

- Limitation in operation
  - Speed
  - Extreme conditions

Next generation: Quantum sensors

- Nanoscale spatial resolution, fast detection and extreme conditions possible
- Sensitivity beyond classical limit



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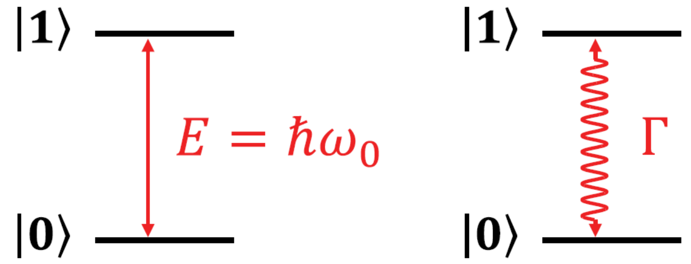
What is quantum sensing ?

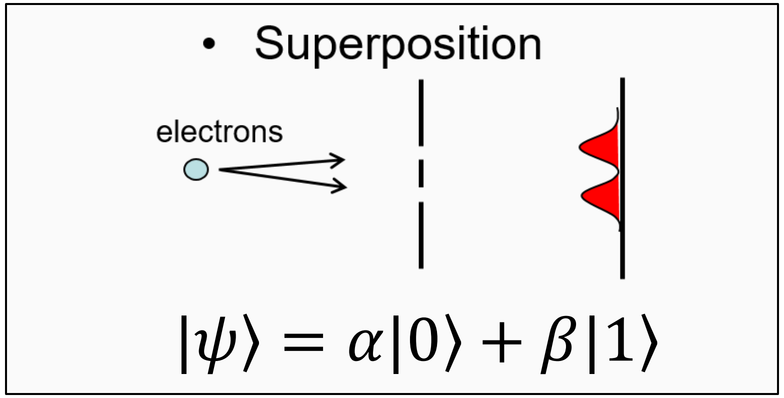
Definitions:

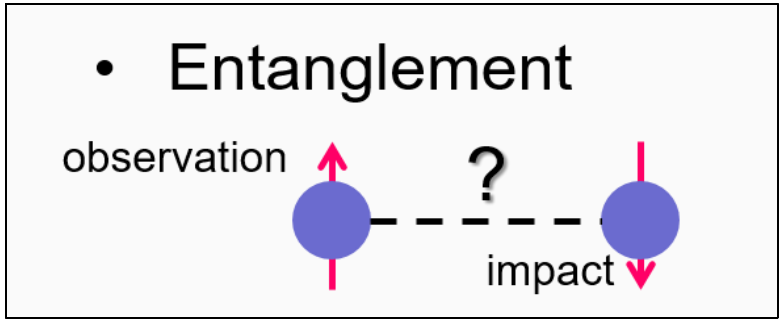
1. Use of quantum system with quantized energy levels to measure a physical quantity

2. Use of quantum coherence (i.e., wavelike spatial or temporal superposition states) to measure a physical quantity.

3. Use of quantum entanglement to improve the sensitivity or precision of a measurement, beyond what is possible classically



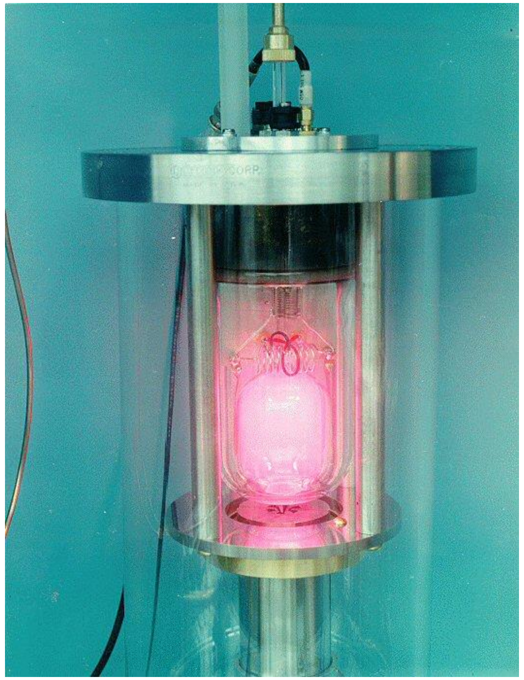




Degen et al., Rev. Mod. Phys., Vol. 89, No. 3, (2017)

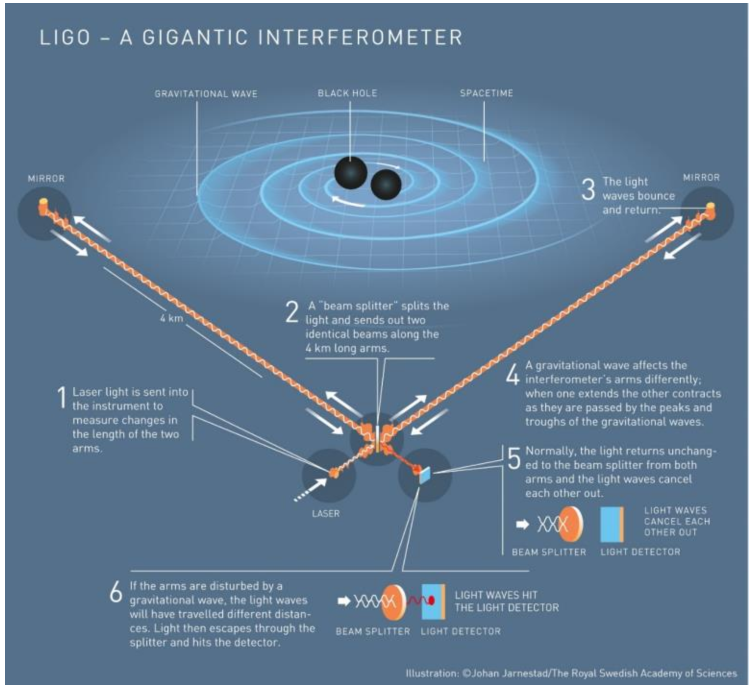
Early examples of quantum sensors

Atomic clock

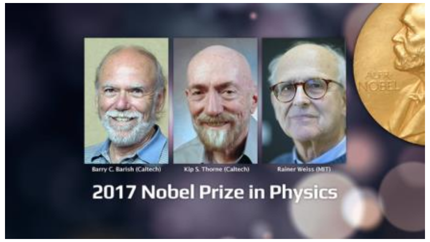


Kilde: Wikipedia

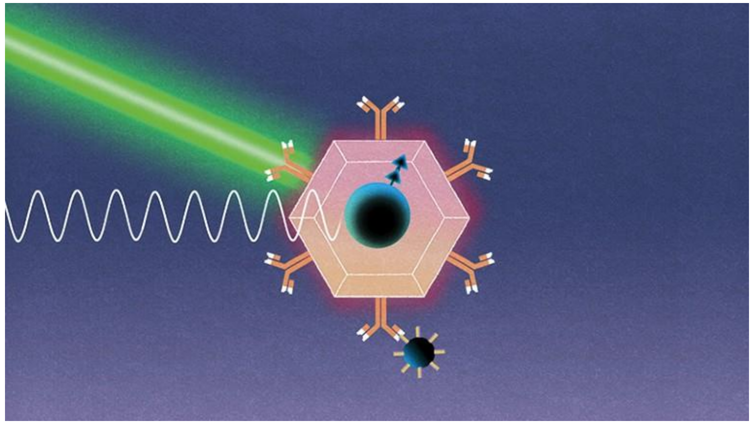
LIGO: Gravitational wafer



LIGO collab.,
Nature Photonics,
7, 613 (2013)



NV-centres in diamond (semiconductor-based) for biological sensing



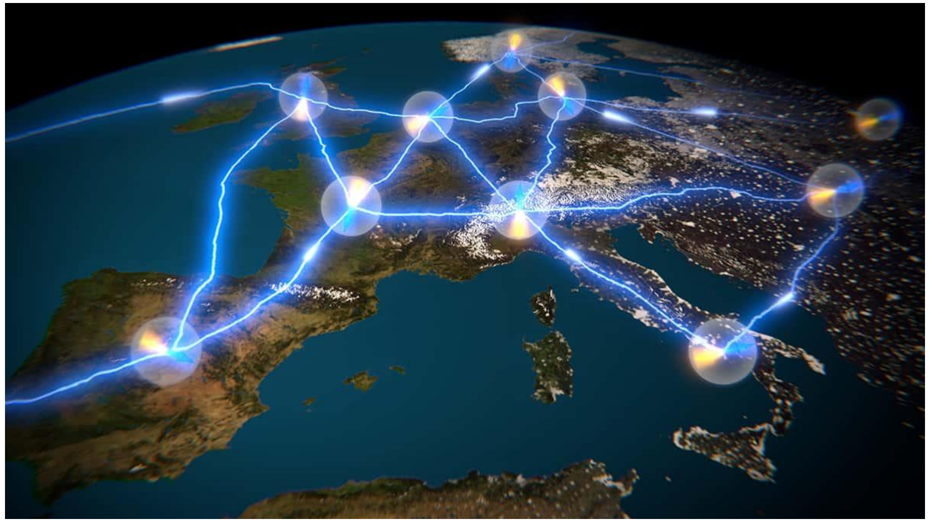
Nature 591, S37 (2021)

3. Quantum communication

Transferring a quantum state from one place to another

Application areas

- Provably secure communication
- Quantum networks
  - Optical fiber network
  - Free space network
  - Part of quantum computers
- Secure quantum internet



https://www.wired.com/sponsored/story/with-quantum-computings-rise-cybersecurity-takes-center-stage/
https://physicsworld.com/a/a-roadmap-for-the-quantum-internet/

Transmitting information
Flying qubits

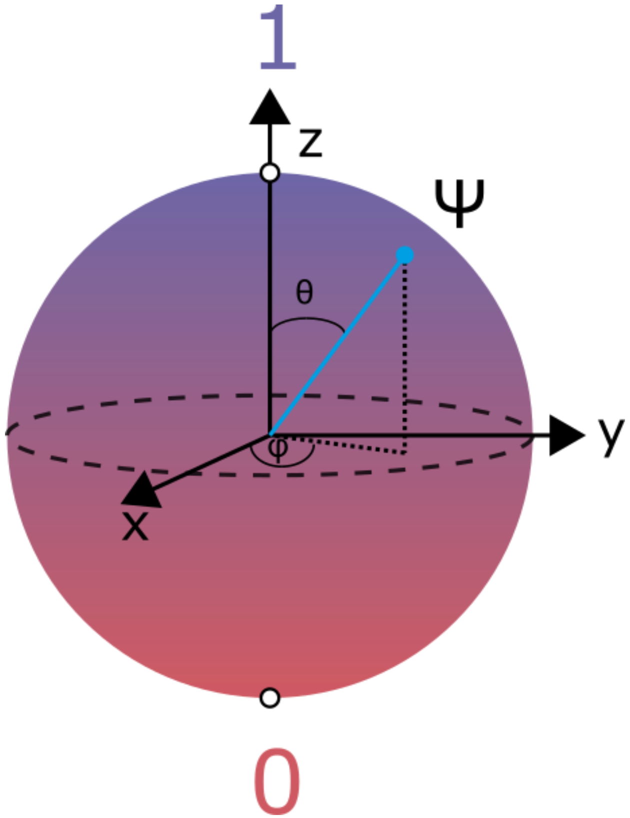
Individual or entangled photons are used to transmit data in a provably secure way

Degree of freedom to encode information in

- Spatially encoded qubits
- Temporal structure
- **State of polarization**

Advantage of photonic polarization qubits

- Easily generated and manipulated
- Photons interact little with the environment



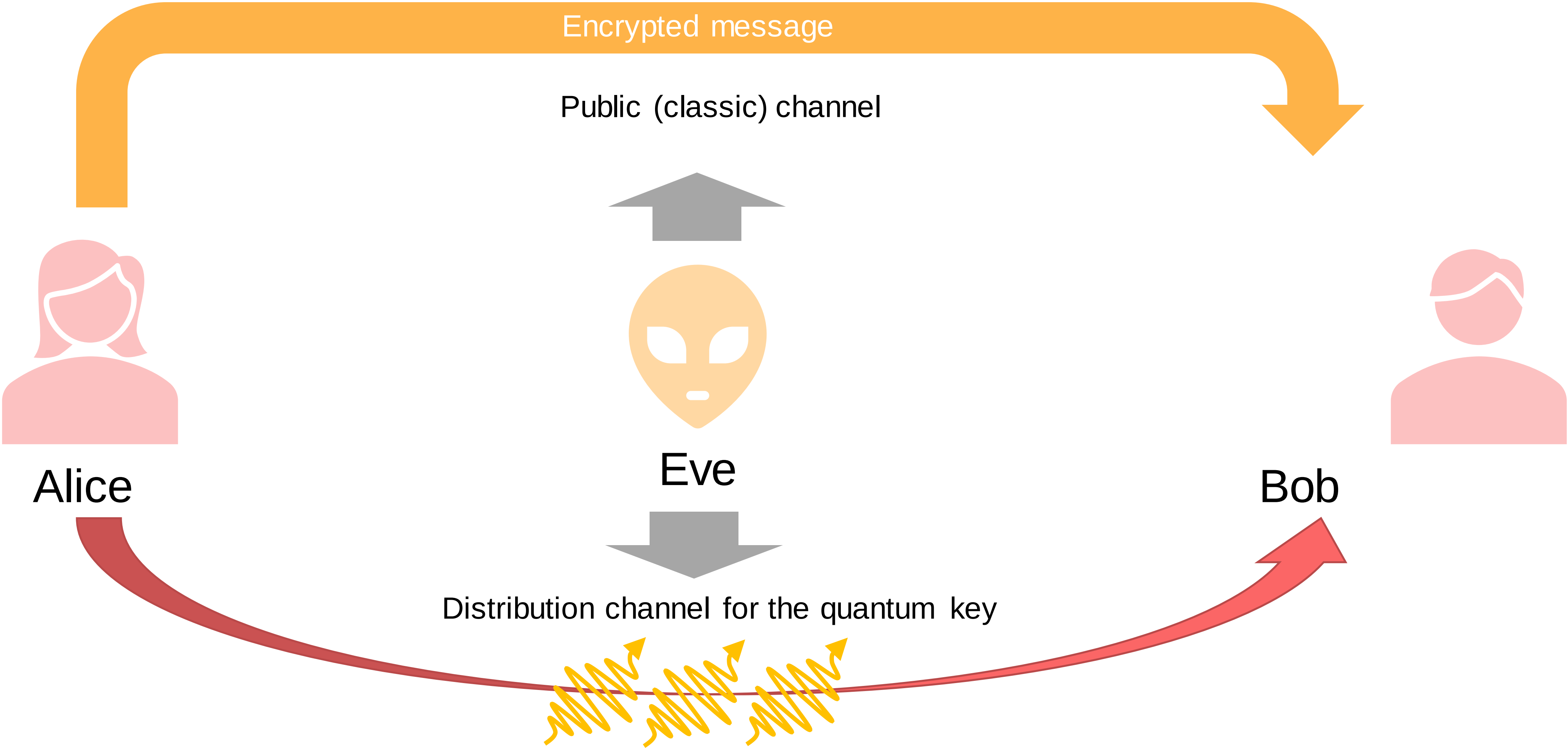
Why quantum communication?

Security in the quantum age

https://www.healthcarecompliancepros.com/blog/usa-leads-the-way-with-the-most-expensive-healthcare-data-breaches

IBM Research, https://www.flickr.com/photos/ibm_research_zurich/51248690716/, CC BY 2.0

Security through quantum mechanics
Quantum key distribution (QKD)



1^{st} and 2^{nd} quantum revolution

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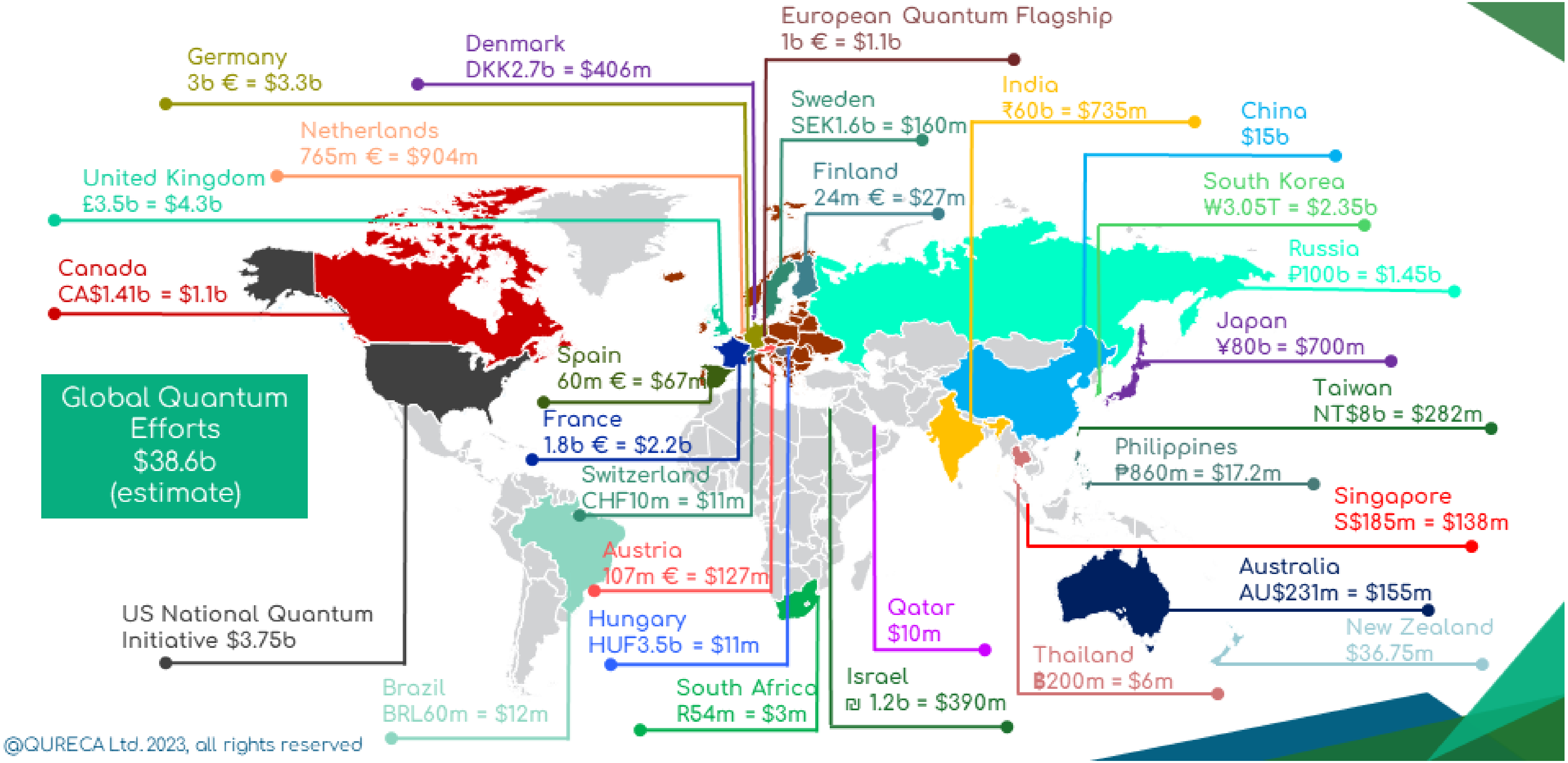
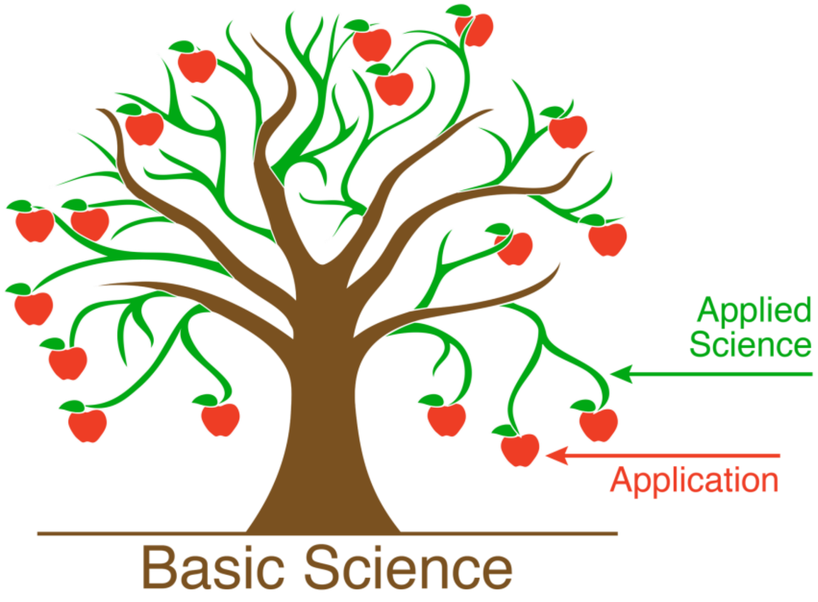
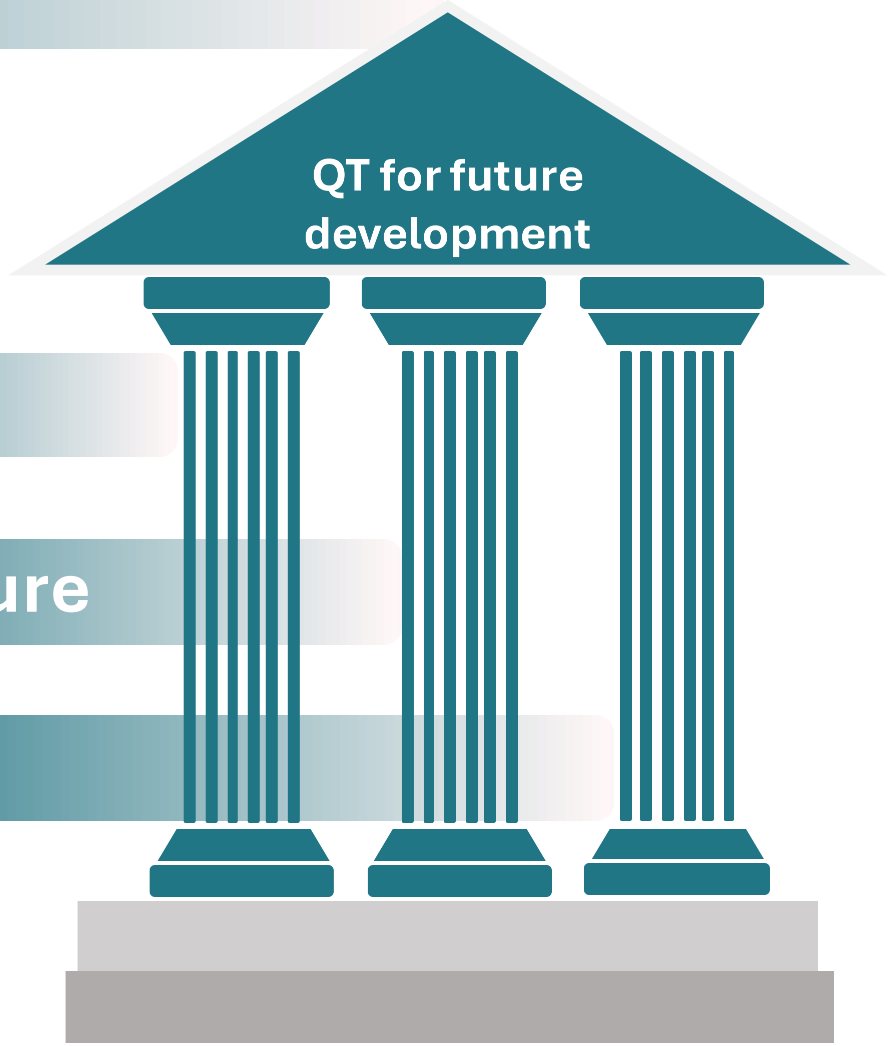
Quantum technology is a major theme in research and technology development



UiO is investnig in QT



- Education
- Infrastructure
- Research



Education

- Ny studieretning i kvanteteknologi (BSc)
  - Starter høsten 2024
  - Gir bred bakgrunn over hele feltet
  - Dette er det første BSc-programmet i Norge, og andre i Norden, med en slik mulighet
- Nye studieretninger på MSc-nivå ved FI
  - Studieretning for kvanteteknologi og maskinlæring innen beregningsorientert vitenskap
  - Studieretning i kvanteteknologi innen fysikk
- PhD (forskerutdanning)

Quantum literate workforce

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Støttet av Forskningsrådet

Infrastructure

- QT is an experimental field
- QT is a main strategic area in NorFab
- Norway needs competence building in practical QT

NorFab and UiO-MiNaLab provide open-access test arena for QT

UiO MiNaLab

Contact

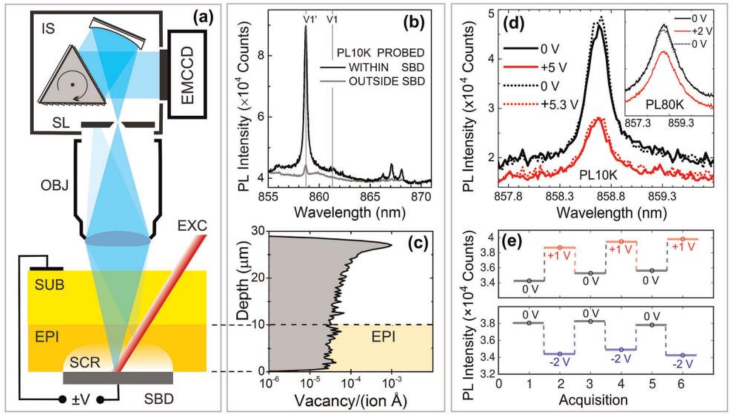
E-mail: norfab-minalab@smn.uio.no

- Vegard Skiftestad Olsen, Lab Manager
- Eirini Zacharaki, Research Infrastructure Coordinator

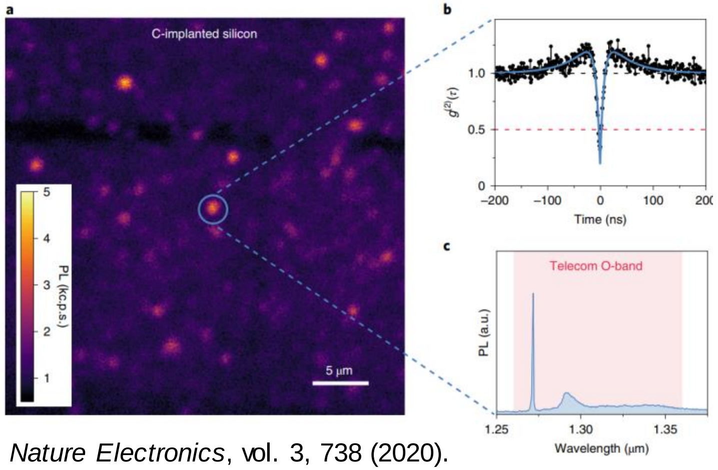
Research

- UiO has extensive theoretical, computational and experimental quantum science and technology
- Semiconductors for sustainable QT
- Quantum sensors will be strategically important for Norway

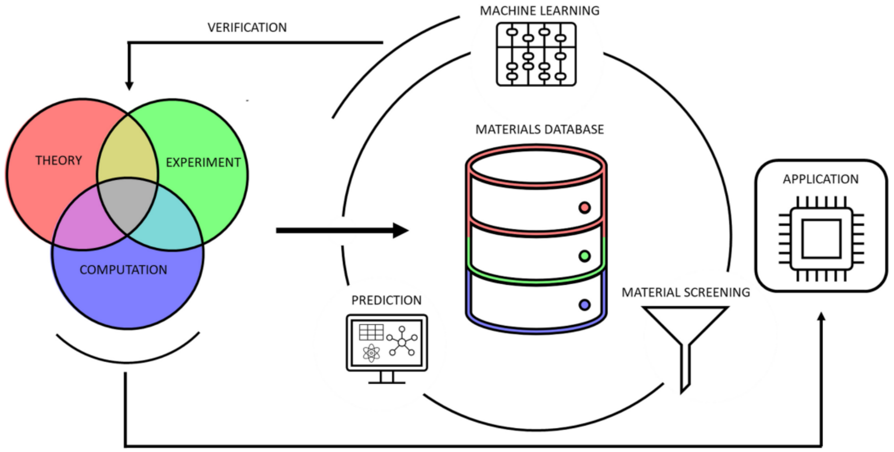
Collaboration between research, start-ups, industry and public sector is needed



npj Quantum Information, vol. 5, 111 (2019).



Nature Electronics, vol. 3, 738 (2020).



npj Comp Mat, vol. 8, 207 (2022).

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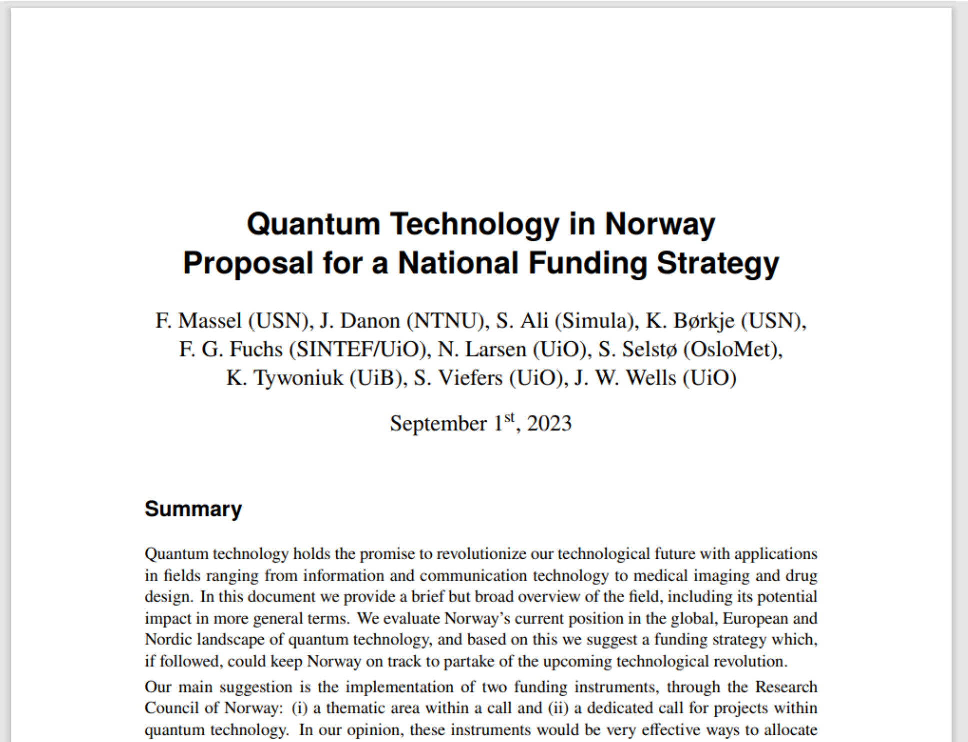
Støttet av Forskningsrådet

White paper:
Quantum Technology in Norway –
Proposal for a National Funding Strategy
Self-published on
https://www.quantumnorway.no/



Quantum Technology in Norway
Proposal for a National Funding Strategy

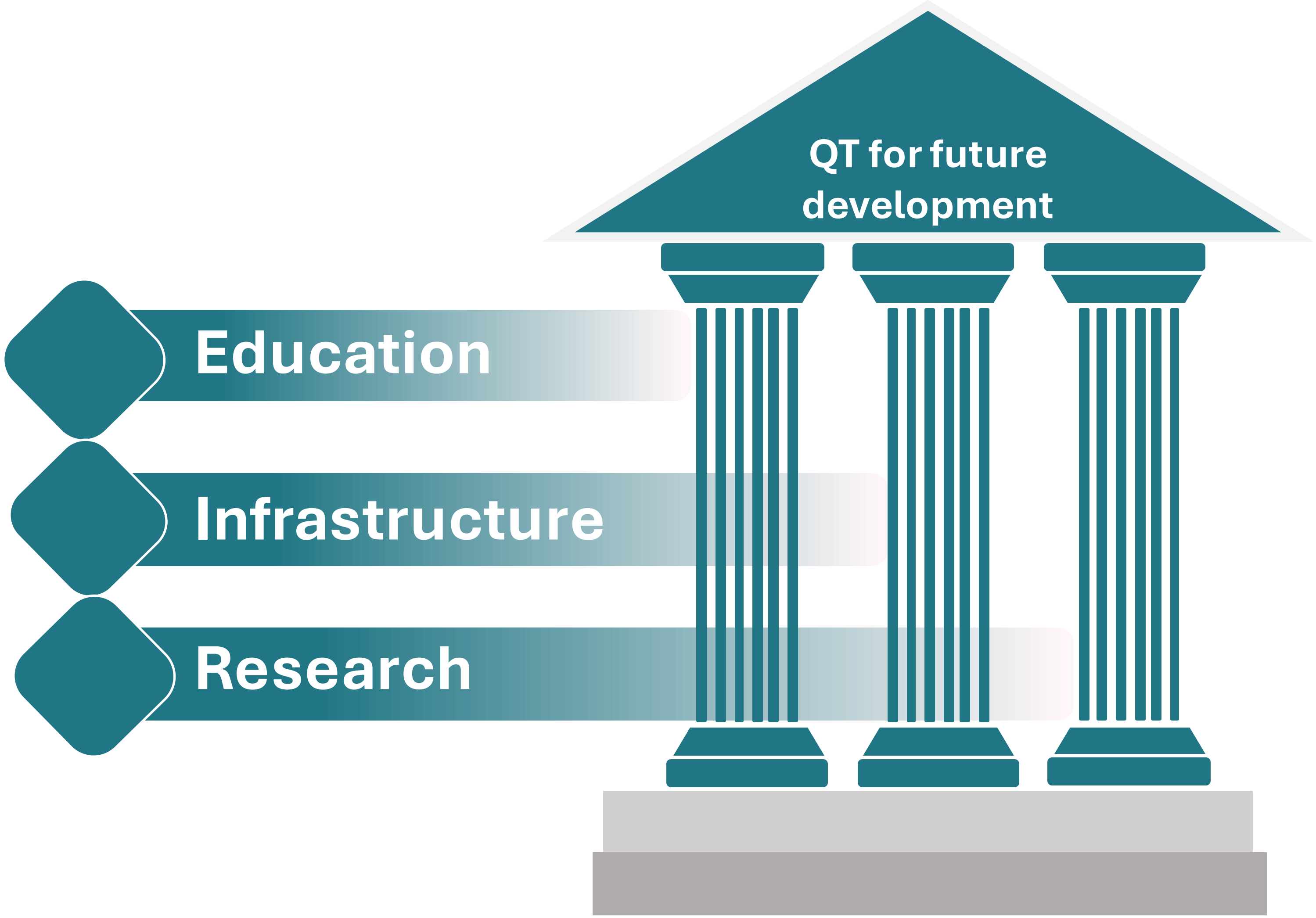
F. Massel (USN), J. Danon (NTNU), S. Ali (Simula), K. Børkje (USN),
F. G. Fuchs (SINTEF/UiO), N. Larsen (UiO), S. Selstø (OsloMet),
K. Tywoniuk (UiB), S. Viefers (UiO), J. W. Wells (UiO)

September 1st, 2023

Summary

Quantum technology holds the promise to revolutionize our technological future with applications in fields ranging from information and communication technology to medical imaging and drug design. In this document we provide a brief but broad overview of the field, including its potential impact in more general terms. We evaluate Norway's current position in the global, European and Nordic landscape of quantum technology, and based on this we suggest a funding strategy which, if followed, could keep Norway on track to partake of the upcoming technological revolution.

Our main suggestion is the implementation of two funding instruments, through the Research Council of Norway: (i) a thematic area within a call and (ii) a dedicated call for projects within quantum technology. In our opinion, these instruments would be very effective ways to allocate



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oslo
science
city