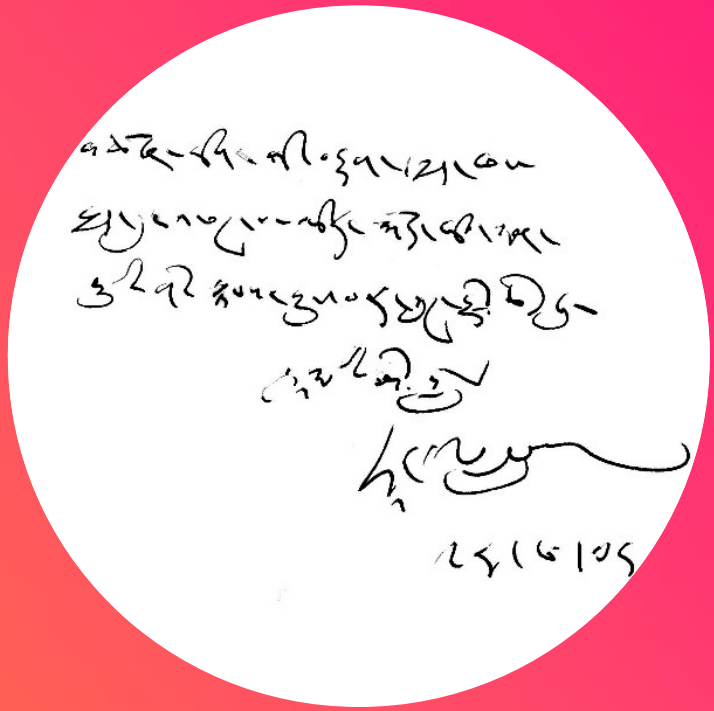
The second quantum revolution

10 APRIL 2019

Tommaso Calarco
Quantum Flagship Community Network

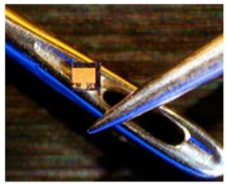


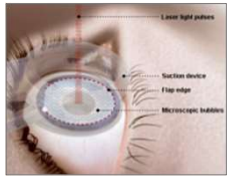
Moore’s law

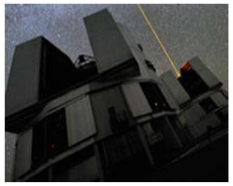
The number of transistors on a chip doubleD about every two years

The first quantum revolution

… shaped the world we live in today

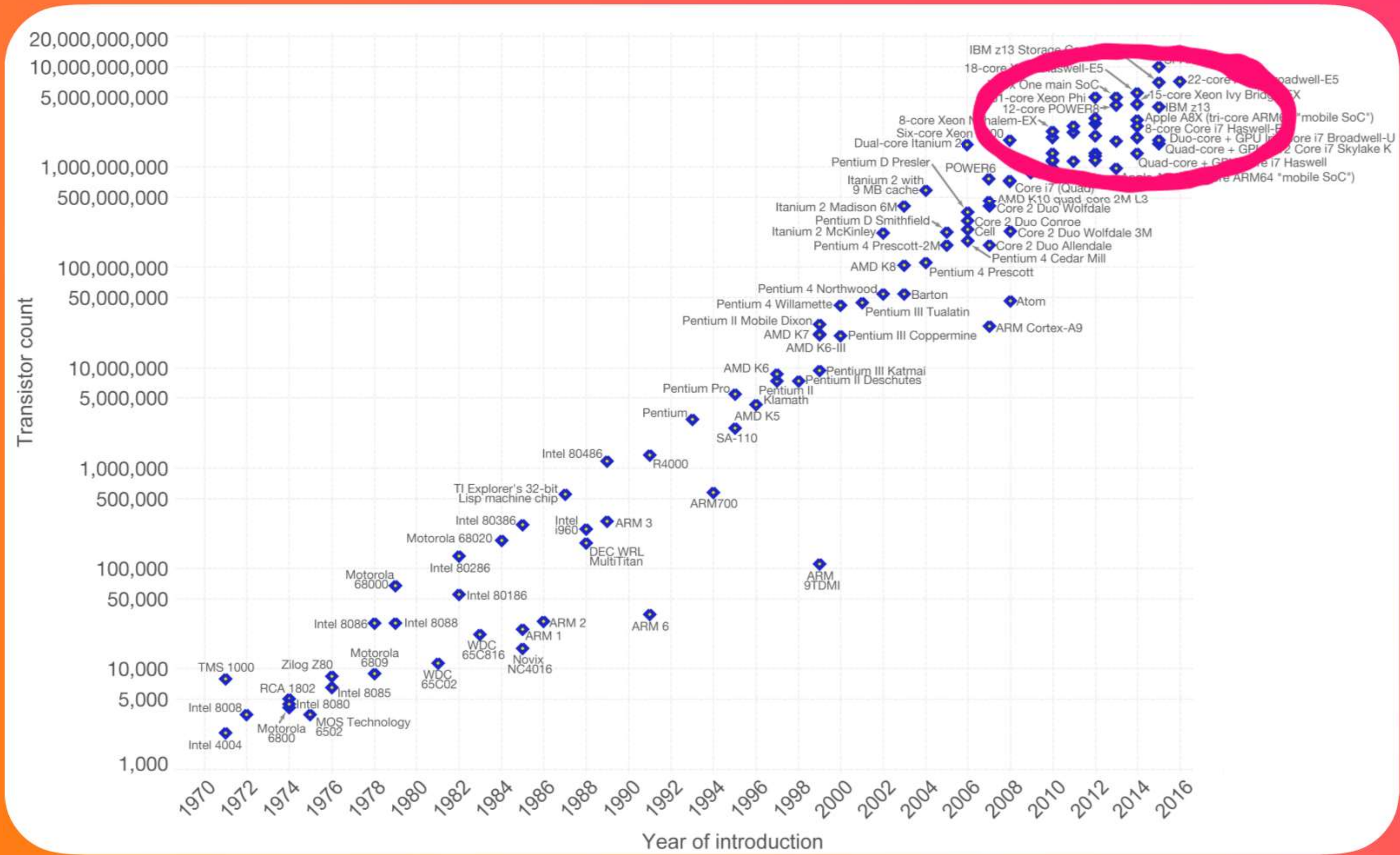






- Fundamental laws of the microscopic world: **quantum mechanics**
- Ground-breaking technologies such as **transistor** and **laser**
- Based on **bulk effects**:
  Many quanta manipulated at once

Moore’s law


Transistor count
Year of introduction
20,000,000,000
10,000,000,000
5,000,000,000
1,000,000,000
500,000,000
100,000,000
50,000,000
10,000,000
5,000,000
1,000,000
500,000
100,000
50,000
10,000
5,000
1,000
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
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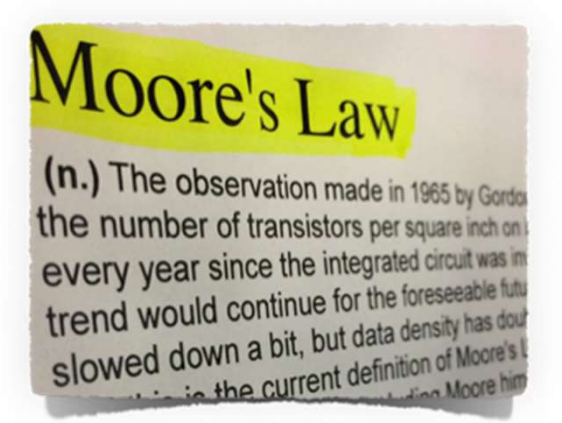
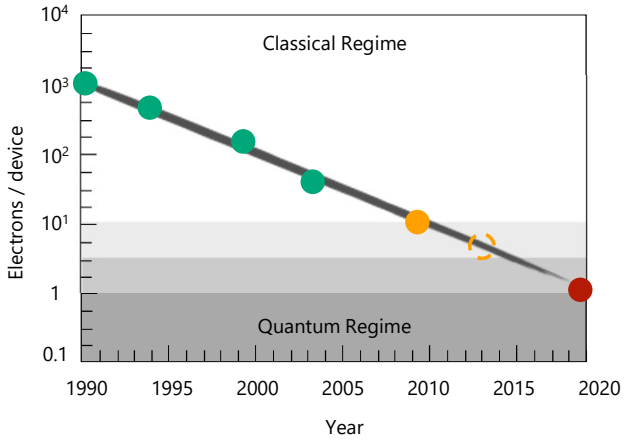
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
Intel 4004
Intel 8008
TMS 1000
RCA 1802
Intel 8080
Motorola 6800
MOS Technology 6502
Zilog Z80
Intel 8085
Motorola 6809
Intel 8086
Intel 8088
Motorola 68000
Intel 80186
Intel 80286
WDC 65C02
WDC 65C816
Motorola 68020
Intel 80386
TI Explorer's 32-bit Lisp machine chip
ARM 1
ARM 2
Novix NC4016
Intel i960
DEC WRL MultiTitan
ARM 3
ARM 6
Intel 80486
R4000
ARM700
ARM 9TDMI
Pentium
SA-110
AMD K5
Pentium Pro
Pentium II Klamath
AMD K6
Pentium II Deschutes
Pentium III Katmai
AMD K6-III
AMD K7
Pentium II Mobile Dixon
Pentium III Coppermine
Pentium 4 Willamette
Pentium 4 Northwood
Pentium III Tualatin
Barton
AMD K8
Pentium 4 Prescott
Pentium 4 Prescott-2M
Itanium 2 McKinley
Pentium D Smithfield
Itanium 2 Madison 6M
Itanium 2 with 9 MB cache
Pentium D Presler
Dual-core Itanium 2
Six-core Xeon
POWER6
Core i7 (Quad)
AMD K10 quad-core 2M L3
Core 2 Duo Wolfdale
Core 2 Duo Conroe
Cell
Core 2 Duo Wolfdale 3M
Core 2 Duo Allendale
Pentium 4 Cedar Mill
Atom
ARM Cortex-A9
IBM z13
Apple A8X (tri-core ARM64 "mobile SoC")
Quad-core + GPU Core i7 Haswell

The future is quantum





Moore's Law:
Number of transistors on an integrated circuit doubles approximately every two years

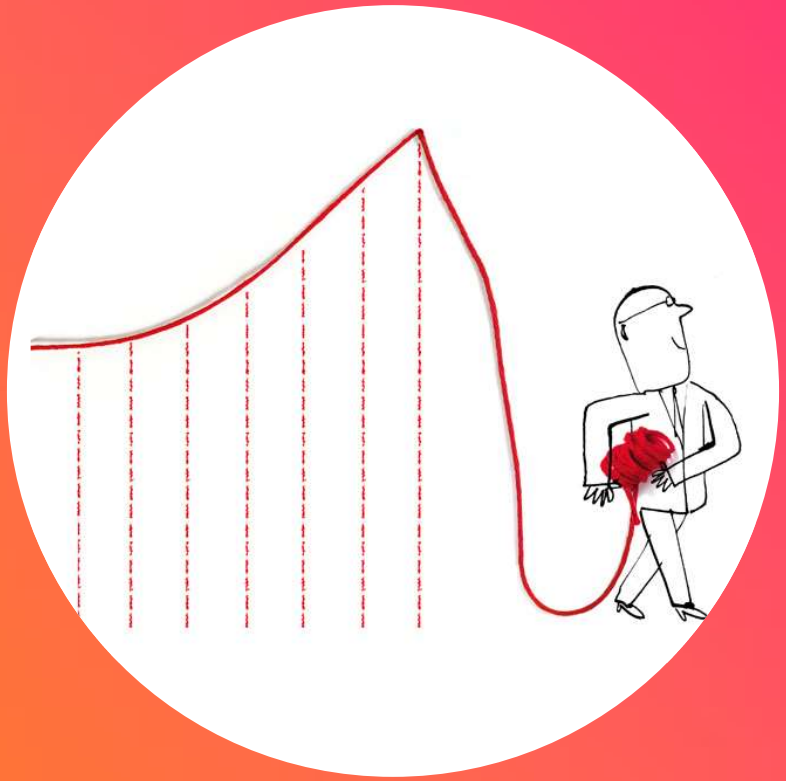
Eventually, a quantum wall will be hit – a question of **when**, not **if**

- Push back the hitting time (more Moore)

and/or

- Change completely the technology (more than Moore)

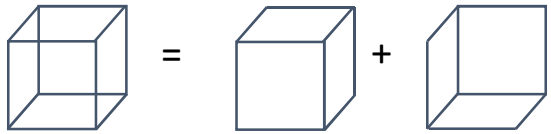
The end of Moore’s law…



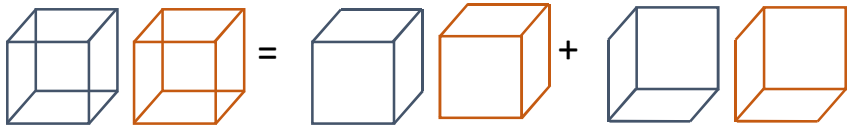
… stimulus for innovation!

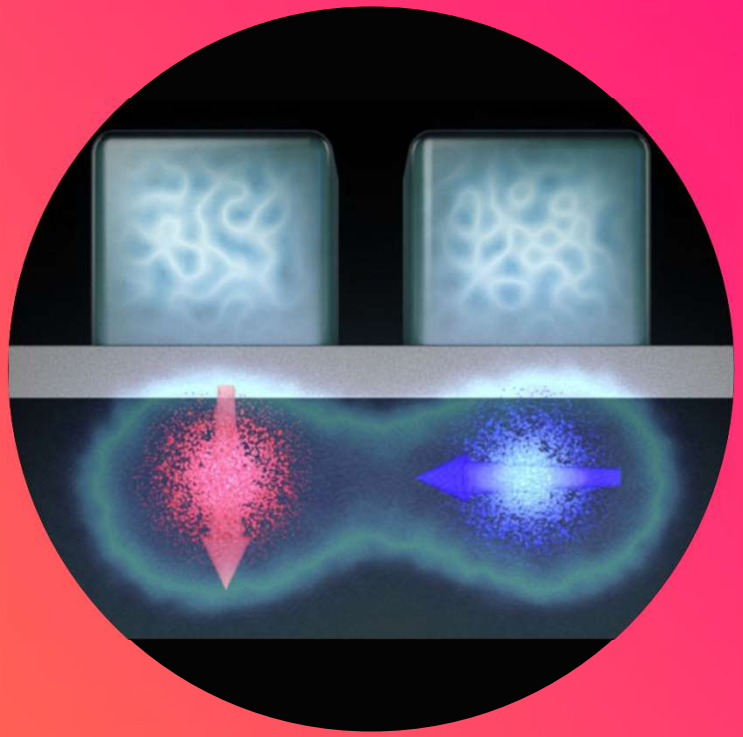
“Spooky” action-at-a-distance

Superposition



Entanglement





Quantum cryptography: security for data, finance, smart grids,…

QUANTUM
Communication

Quantum communication

… will help protect citizens' data

- **Technology**: Transmission of single photons with no eavesdropping possible
- **Vision**: Consumer quantum cryptography (quantum bank card/ATM, quantum door/car key, …) and security for finance, e-commerce, smart grids, …
- **Status**: European scientific community/SMEs leading at world level, commercial products already available
- **Challenges**: Continental-scale quantum communication (quantum repeaters)

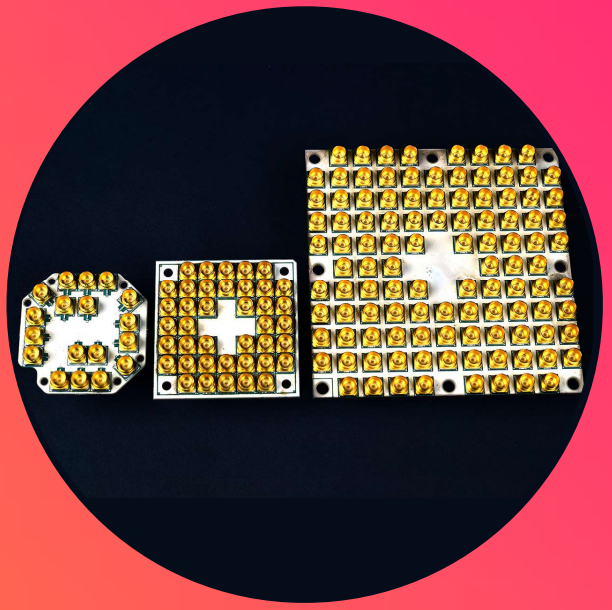
QUANTUM

Quantum communication

… will help protect citizens' data

First quantum-encrypted international video call between President **Chunli Bai** of the Chinese Academy of Sciences in **Beijing** and President **Anton Zeilinger** of the Austria Academy of Sciences in **Vienna** (Sept. 2017)

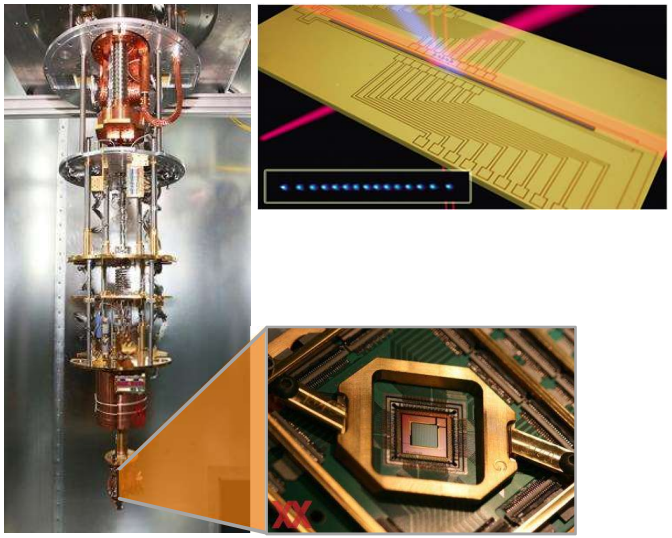
Enormous computing power for optimization (traffic, logistics, energy grids…) and artificla intelligence



QUANTUM
Computing

Quantum computers

… enormous computing power available

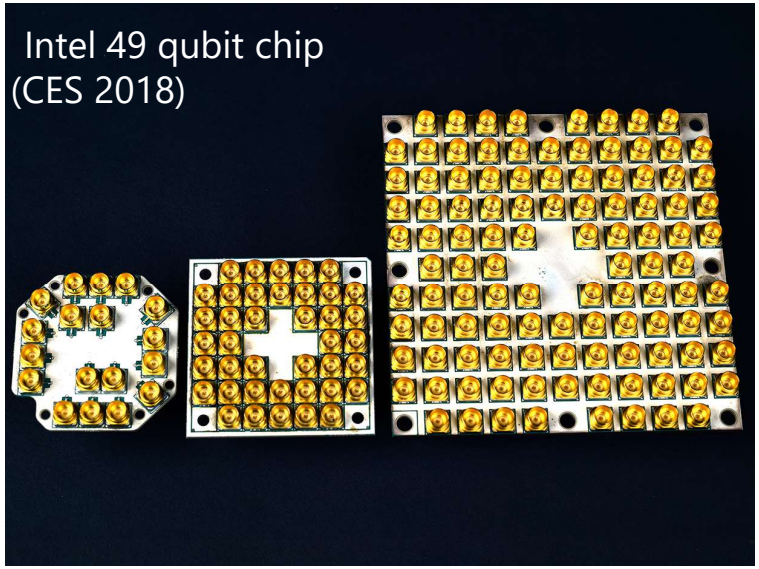


- **Technology**: Exploit “quantum parallelism”
- **Vision**: Enormous computing power for optimization (traffic, production, energy grids, …) and quantum machine learning
- **Status**: Specialized quantum computers will soon outperform classical computers in very specific tasks. High interest by global IT corporations.
- **Challenges**: Error correction to scale up to “universal quantum computers“

QUANTUM

Quantum computers

… enormous computing power available



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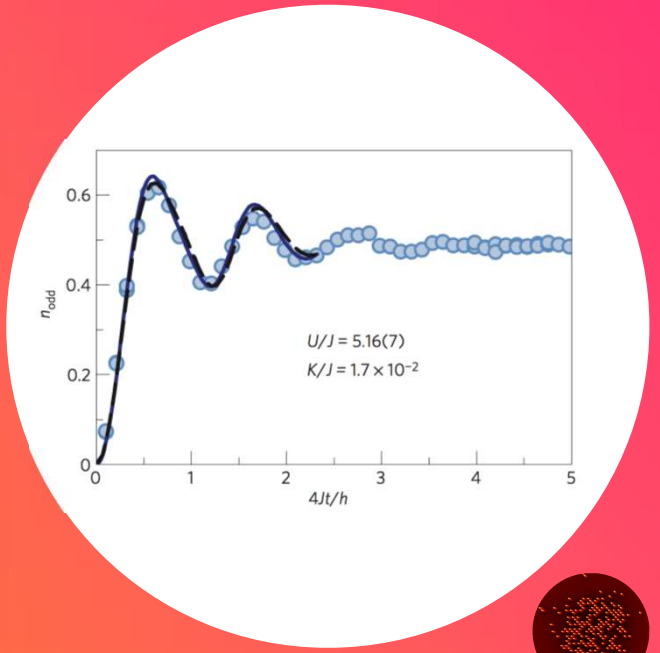
QUANTUM

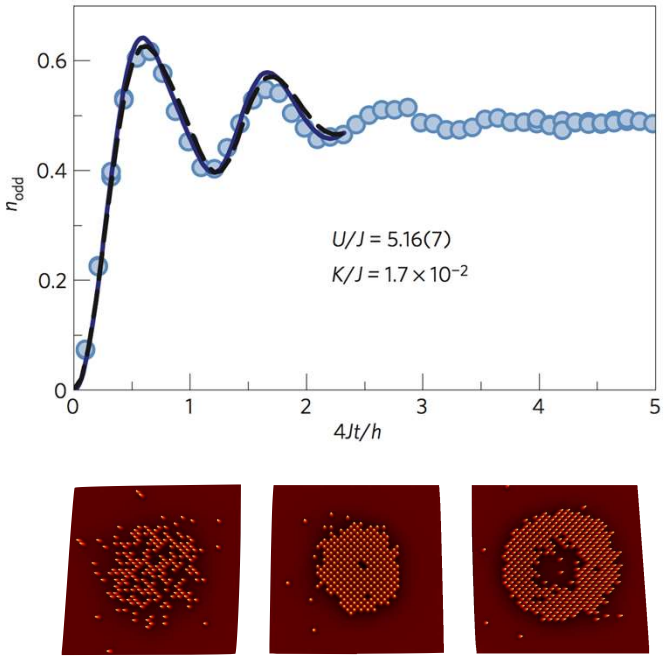
Design of new chemicals (drugs, fertilizers,…) and new materials, such as high-temperature superconductors



QUANTUM
Simulation

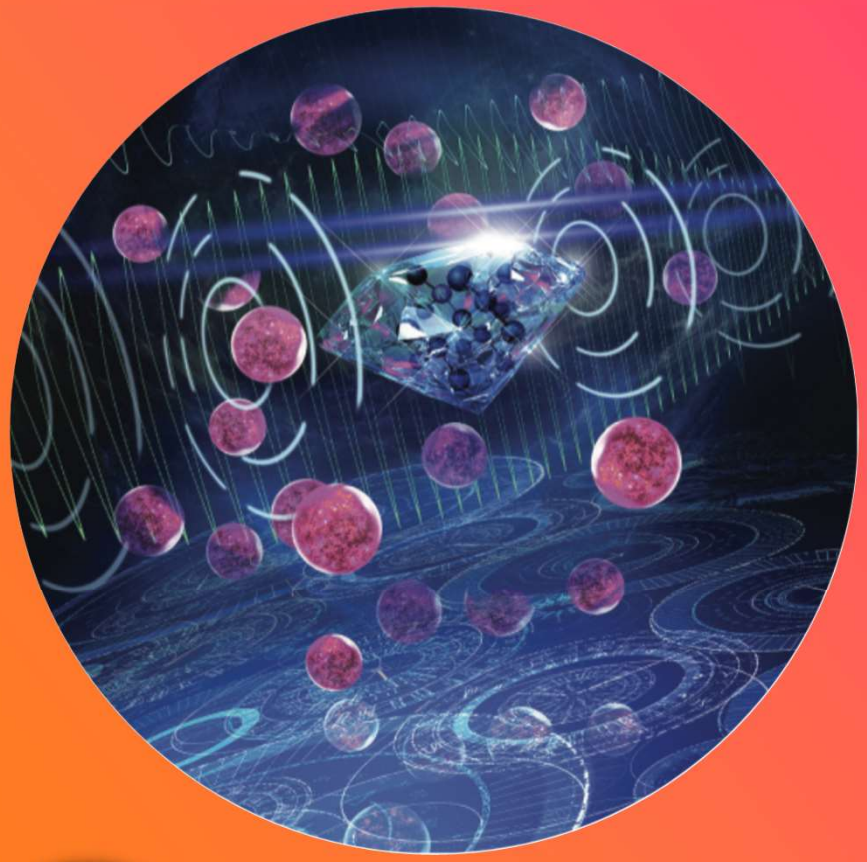
Quantum simulators

… key to new chemicals, drugs and materials



- **Technology**: Use simple model quantum systems to understand more complex systems
- **Vision**: Key to the design of new chemicals, from drugs to fertilisers, and of new materials, such as high-temperature superconductors
- **Status**: First hints of a quantum simulator outperforming a classical supercomputer
- **Challenges**: Mainly engineering to scale up

QUANTUM

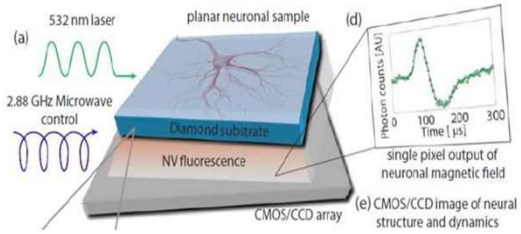


QUANTUM
Sensing & metrology

From medical diagnostics to ultraprecise navigation;
… Internet of Things

Quantum metrology and sensors

… boost measurement performance

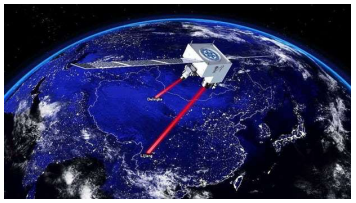


- **Technology**: Based on single quanta, e.g., electrons, the smallest possible charges and magnets
- **Vision**: Boost consumer devices and services, from **medical diagnostics** and **imaging** to **high-precision navigation**, to future applications in the **Internet of Things**
- **Status**: First quantum technologies to have broad impact in many areas
- **Challenges**: Mainly engineering for robustness, size, price, energy consumption

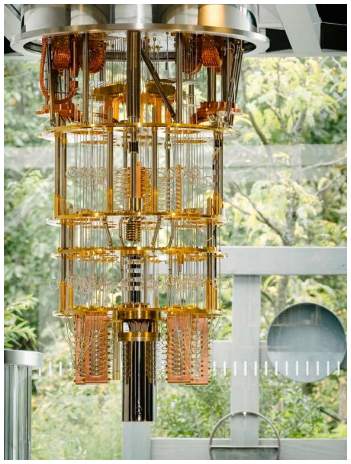
QUANTUM

Strong worldwide activities from governments and companies

e.g., China



e.g., IBM, Google, Microsoft, Intel



2016 — 5 qubits

2017 — 16 qubits

20 qubits

2018 — 50 qubits

QUANTUM

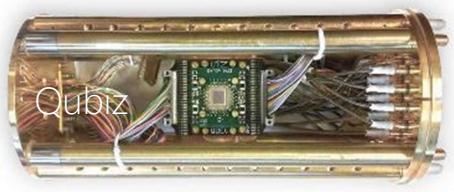
EU world leading experts

I. Bloch group


A. Wallraff group

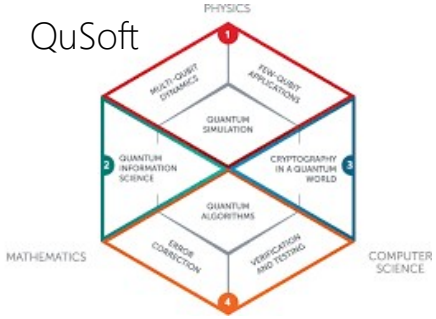

Qutech

R. Blatt group


Qubiz


S. Haroche group

QuSoft



QUANTUM

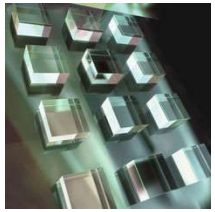
Strong EU supply chain

Attocube

Zurich Instruments

Menlo System

ASML

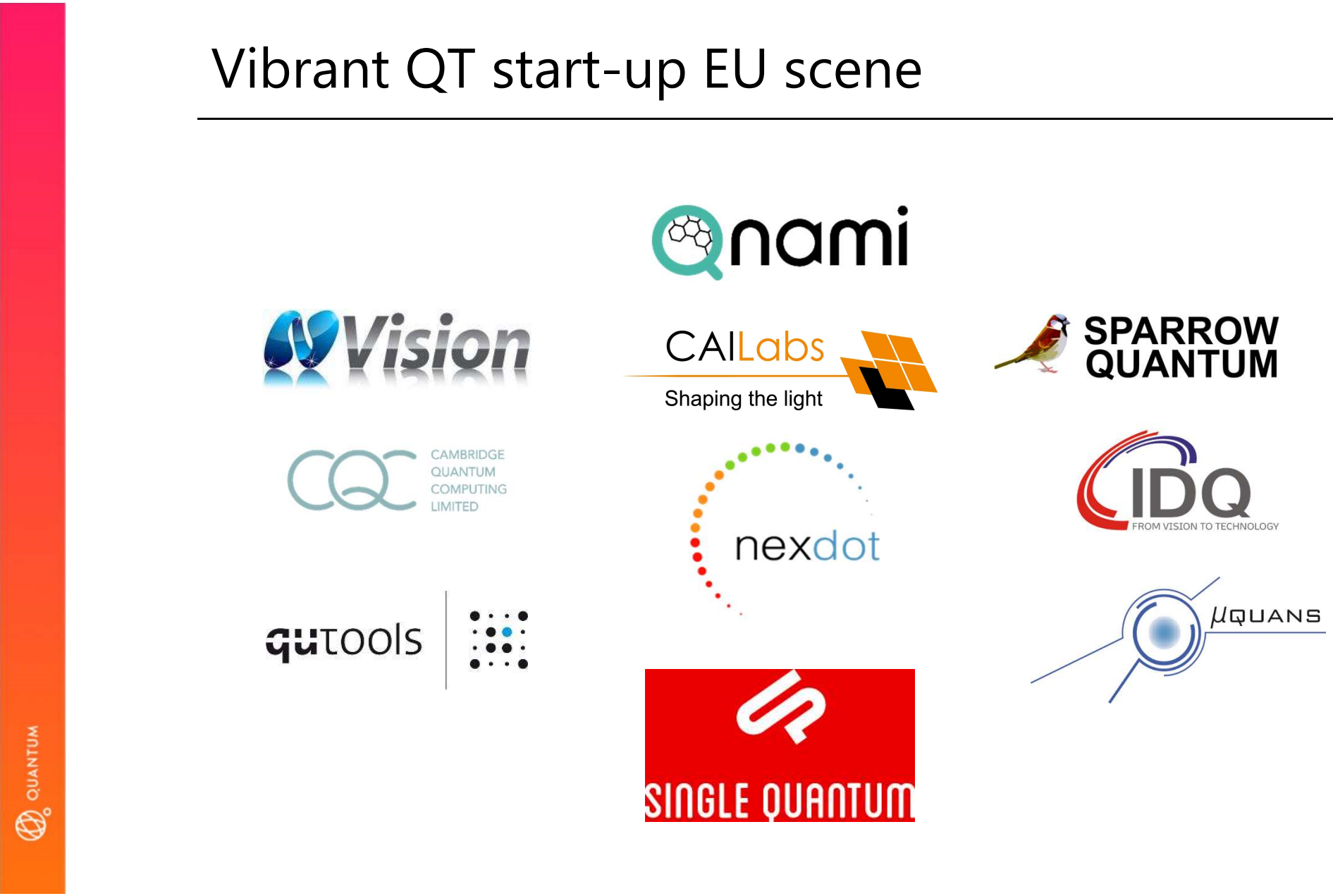


Element Six

Toptica

QUANTUM

Vibrant QT start-up EU scene



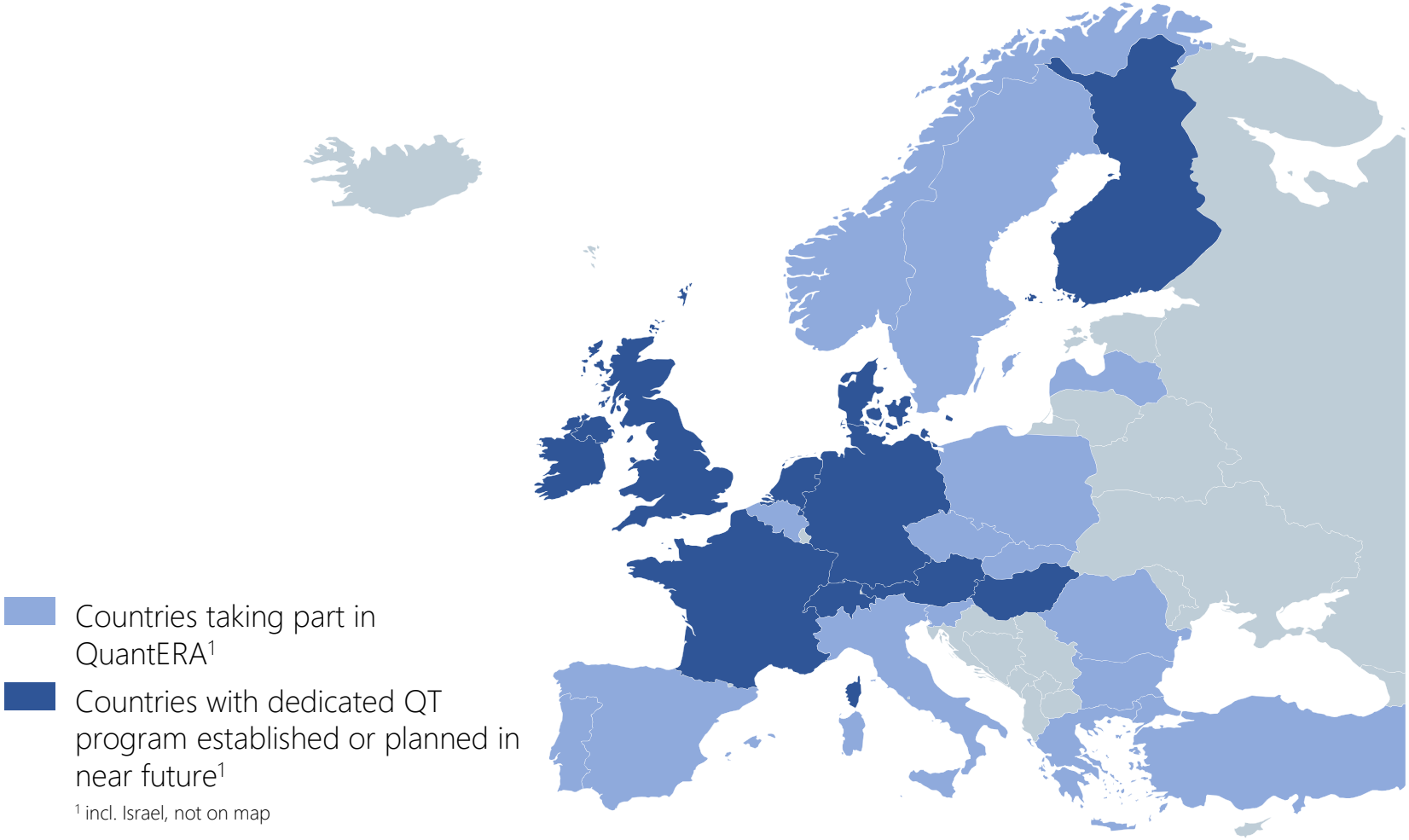
Broad interest from EU industry

Industry members of the Strategic Advisory Board

AIRBUS	Thierry Botter
Ametic	Ulises Arranz Cuellar
creo TECH Instruments S.A.	Grzegorz Kasprowicz
ERICSSON	Fabio Cavaliere
infineon	Christoph Sandner
kpn	Jaya Baloo

QUANTUM

Strong commitment from EU governments



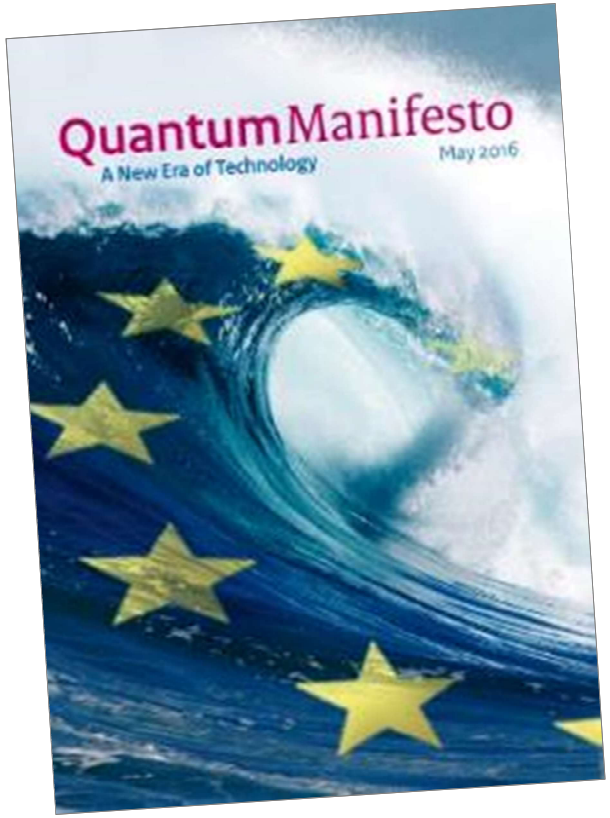
QUANTUM

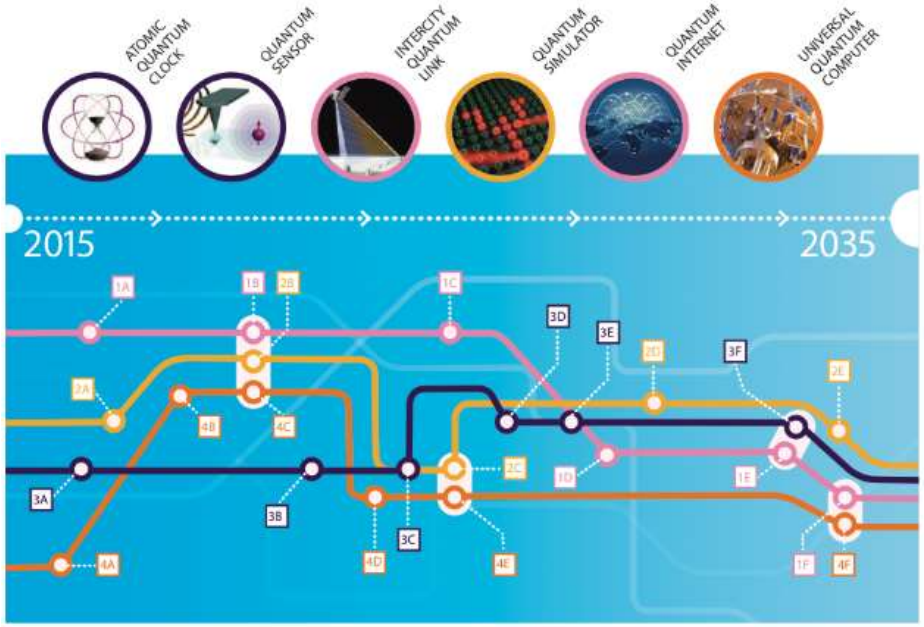
Quantum Flagship: culmination point uniting ***all*** stakeholders

- Common mission
  Provide European citizens with more secure telecommunications and data storage, more reliable healthcare, and more performing computation, by building within 20 years a quantum web: quantum computers connected via quantum networks, using data from quantum sensors.
- Common vision
  - ✓ EU as a dynamic and attractive region for innovative research, business and investments in QT
  - ✓ EU as a leader in the future global industrial landscape, which utilizes QT
  - ✓ EU as global scientific leader in quantum research
- Effects already visible
- Implementation (funding instruments) flexible

QUANTUM

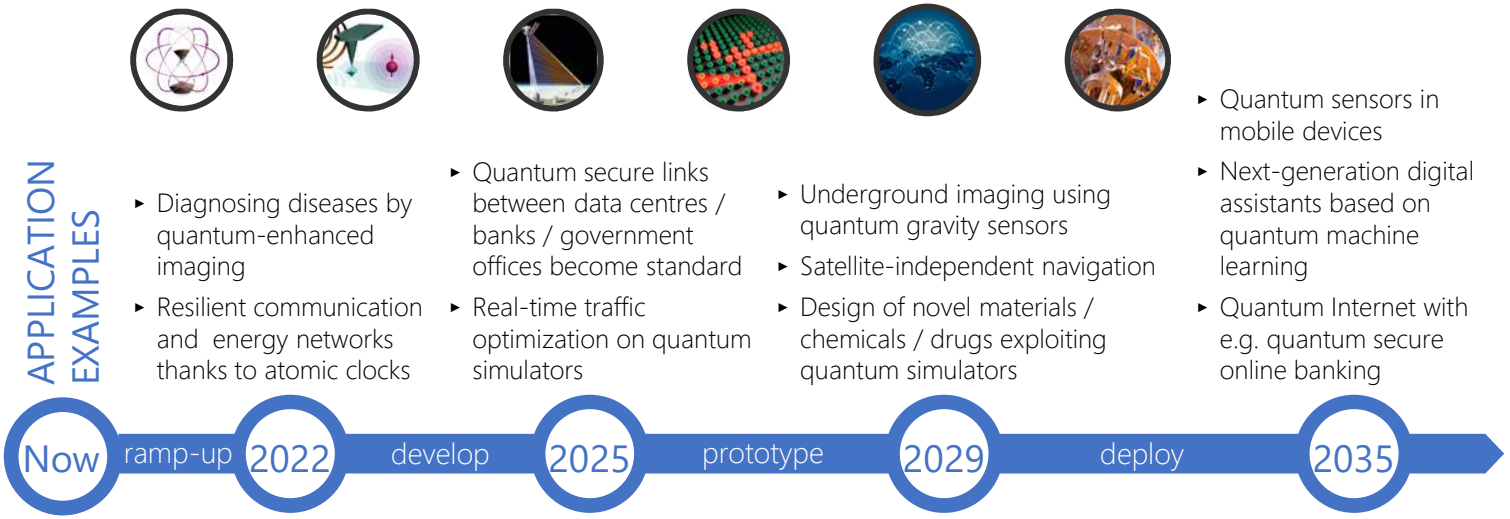
Quantum Manifesto handover to EC: May 2016





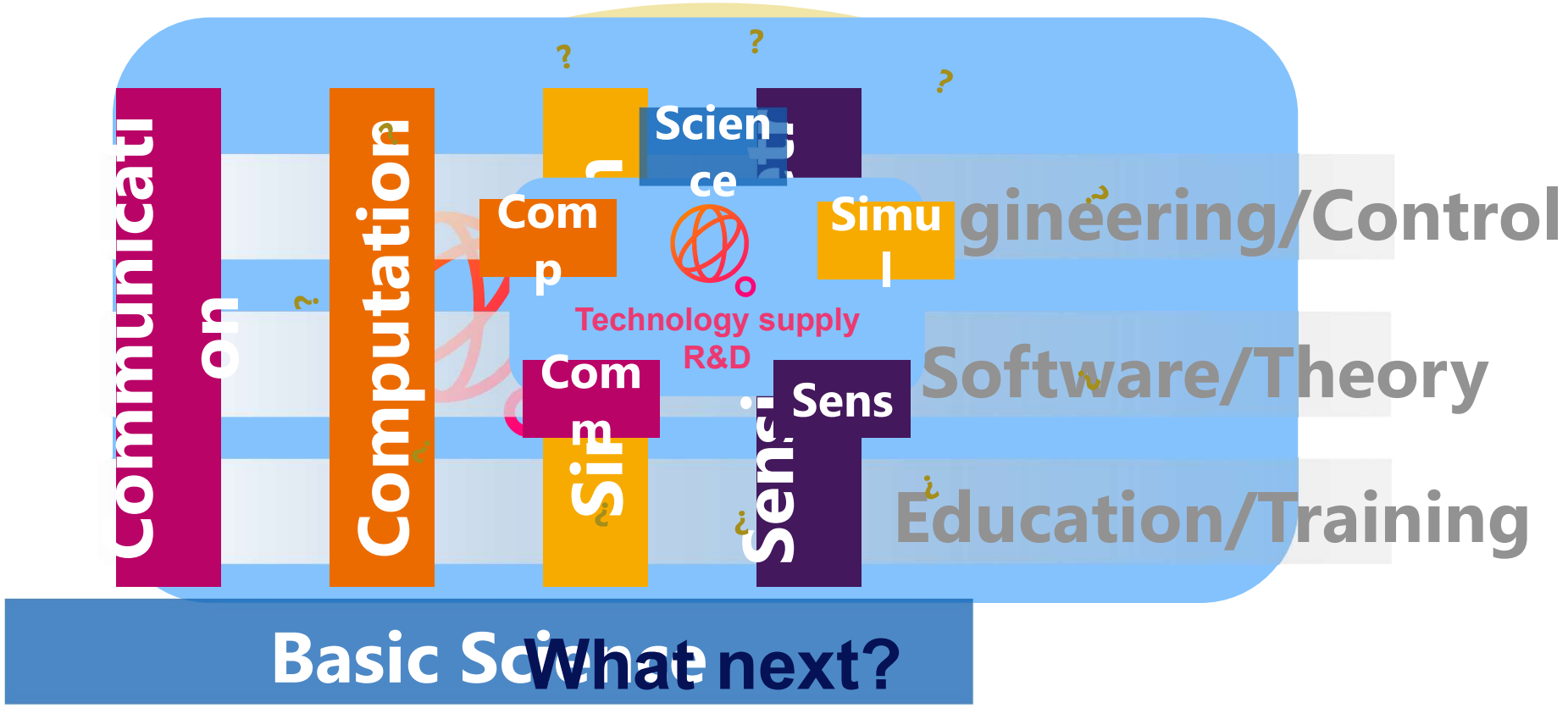
QUANTUM

QT flagship timeline



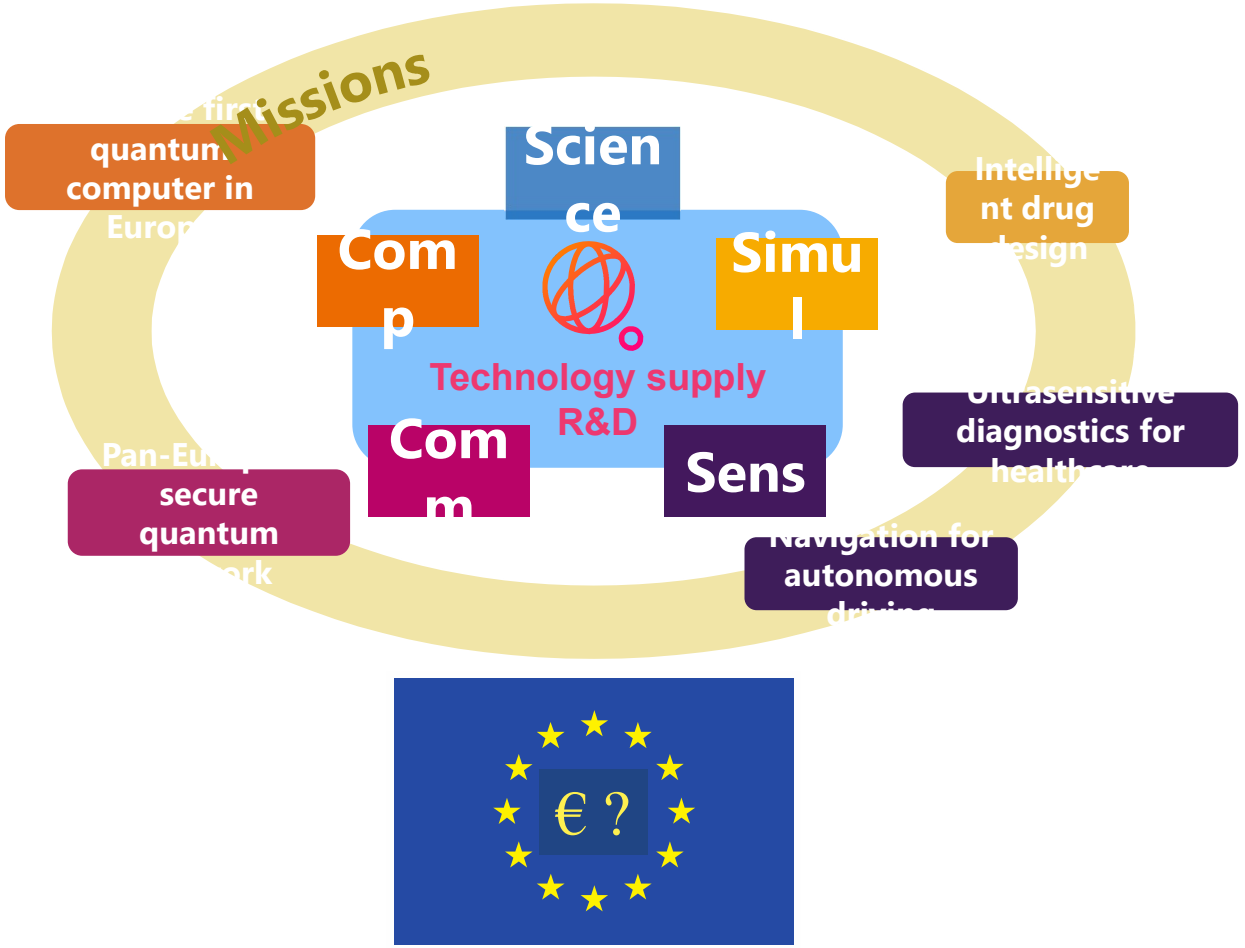
QUANTUM

Flaghip structure/call

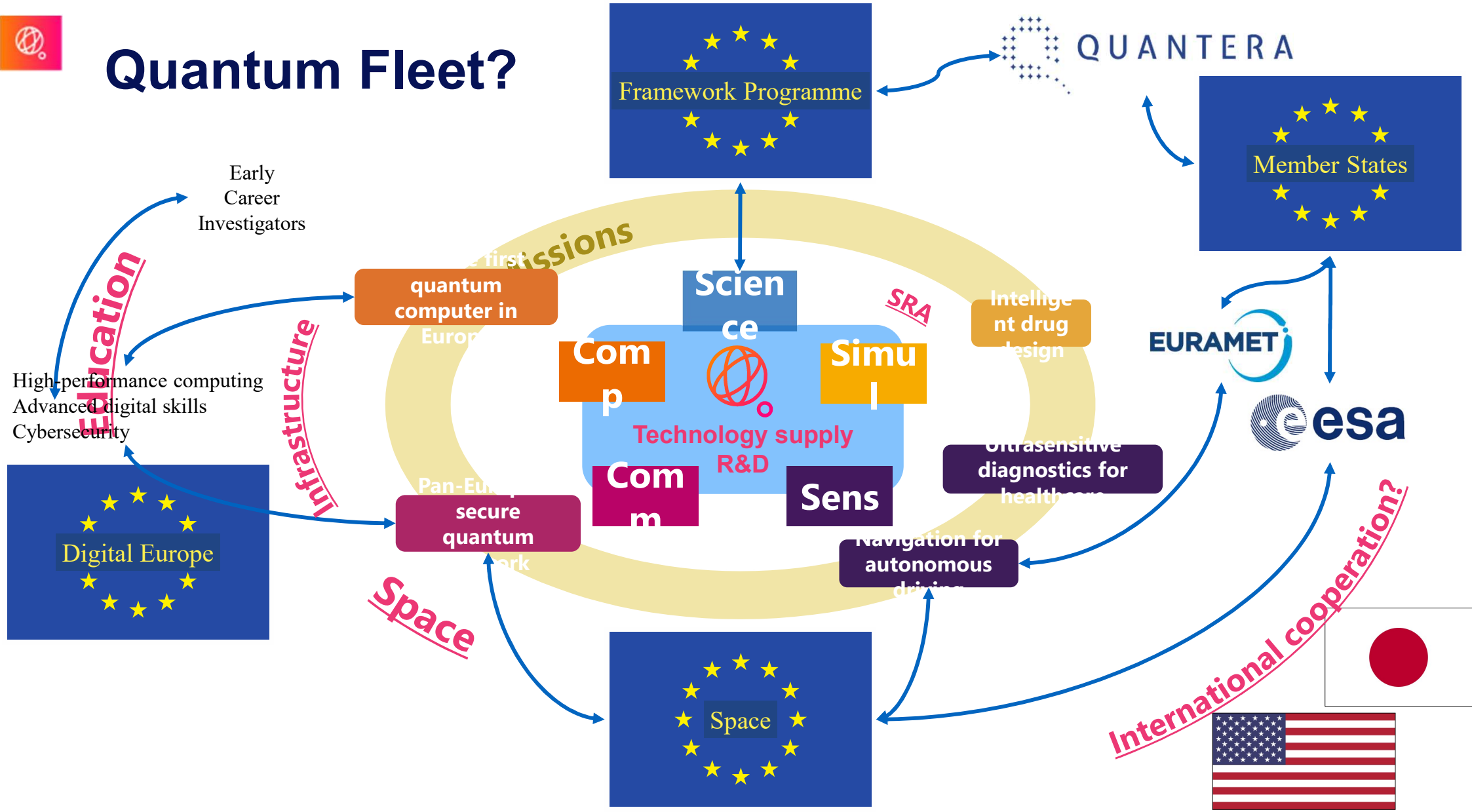


Strategic Research Agenda (SRA)

What next?
Quantum missions?



Quantum Fleet?



QUANTUM FLAGSHIP

01 Launched in October 2018

02 Budget of EUR 1 billion

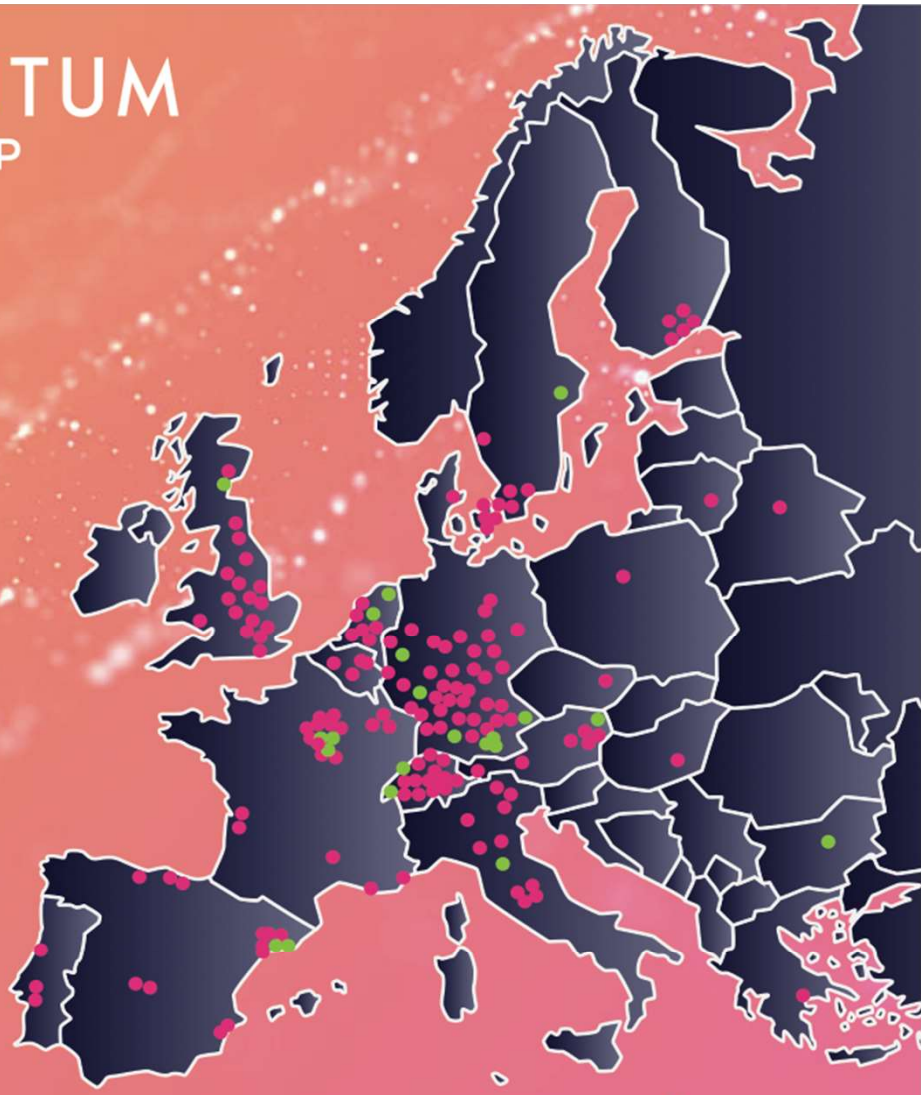
03 10 years

04 One of the largest and most ambitious research initiatives of the European Union

05 5 research domains

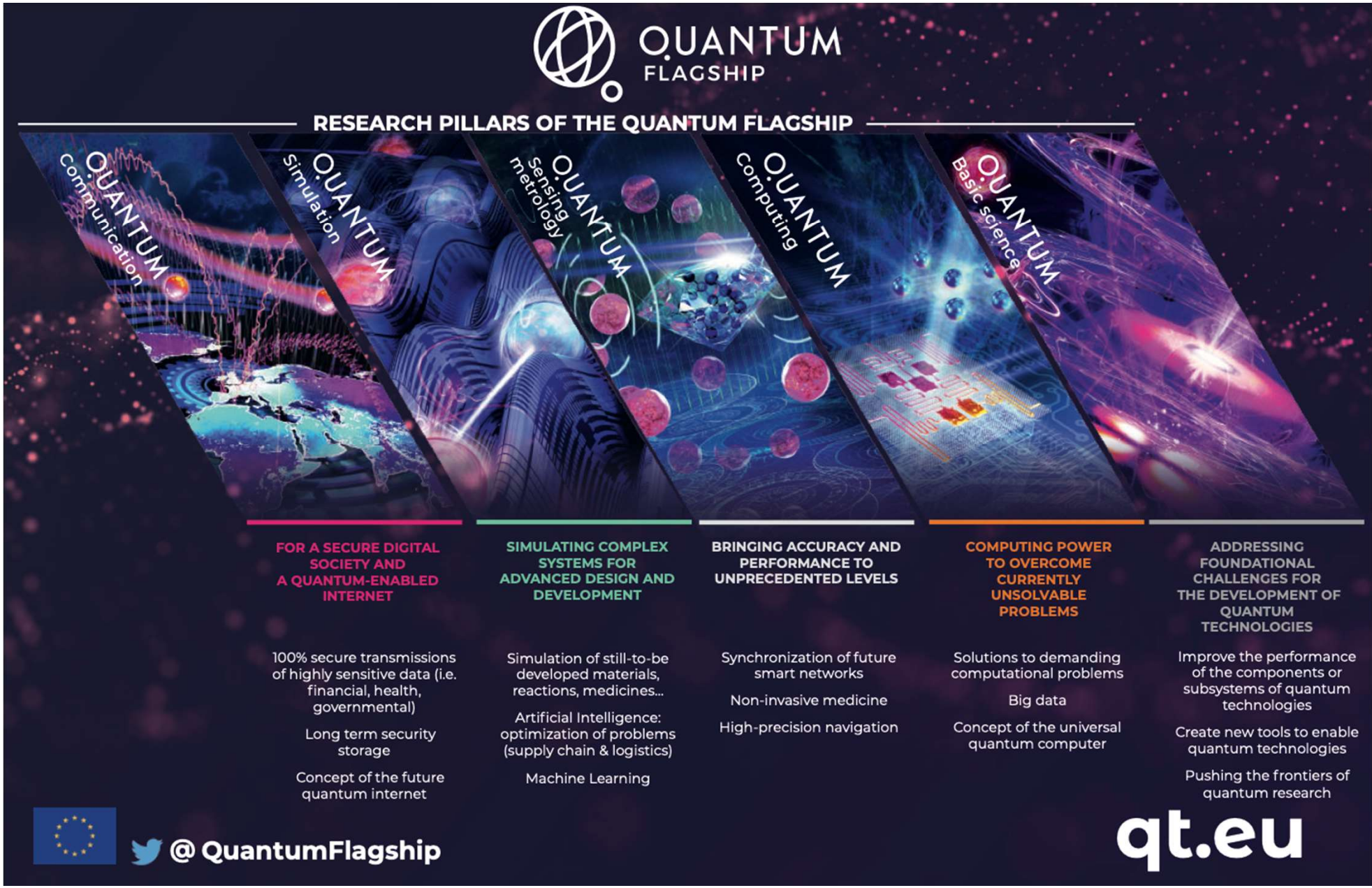
06 20 selected projects for the ramp up phase

07 More than 5000 researchers and industry partners



info@qt.eu

qt.eu


QUANTUM FLAGSHIP
RESEARCH PILLARS OF THE QUANTUM FLAGSHIP
Q.QUANTUM Communication
Q.QUANTUM Simulation
Q.QUANTUM Sensing metrology
Q.QUANTUM Computing
Q.QUANTUM Basic science
FOR A SECURE DIGITAL SOCIETY AND A QUANTUM-ENABLED INTERNET
100% secure transmissions of highly sensitive data (i.e. financial, health, governmental)
Long term security storage
Concept of the future quantum internet
SIMULATING COMPLEX SYSTEMS FOR ADVANCED DESIGN AND DEVELOPMENT
Simulation of still-to-be developed materials, reactions, medicines...
Artificial Intelligence: optimization of problems (supply chain & logistics)
Machine Learning
BRINGING ACCURACY AND PERFORMANCE TO UNPRECEDENTED LEVELS
Synchronization of future smart networks
Non-invasive medicine
High-precision navigation
COMPUTING POWER TO OVERCOME CURRENTLY UNSOLVABLE PROBLEMS
Solutions to demanding computational problems
Big data
Concept of the universal quantum computer
ADDRESSING FOUNDATIONAL CHALLENGES FOR THE DEVELOPMENT OF QUANTUM TECHNOLOGIES
Improve the performance of the components or subsystems of quantum technologies
Create new tools to enable quantum technologies
Pushing the frontiers of quantum research
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