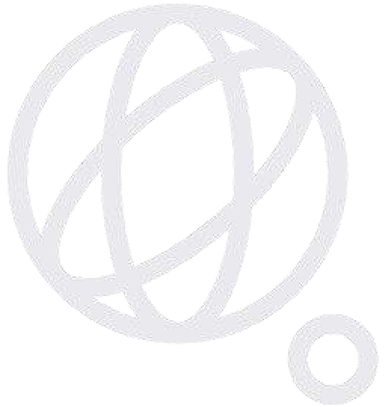
QUANTUM
FLAGSHIP

The Quantum Technologies Flagship

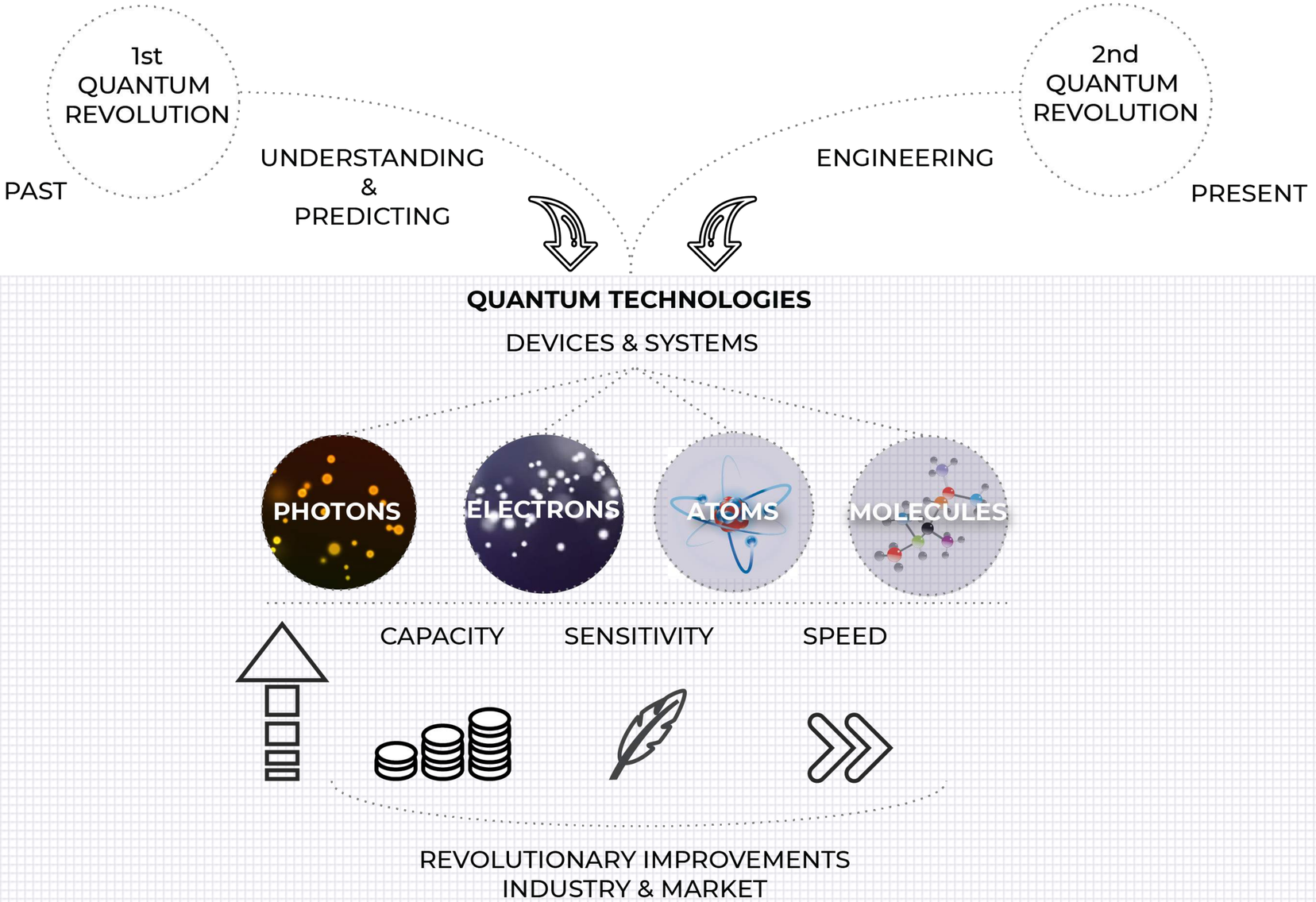


8 NOVEMBER 2019

Tommaso Calarco
Quantum Flagship Community Network

QUANTUM

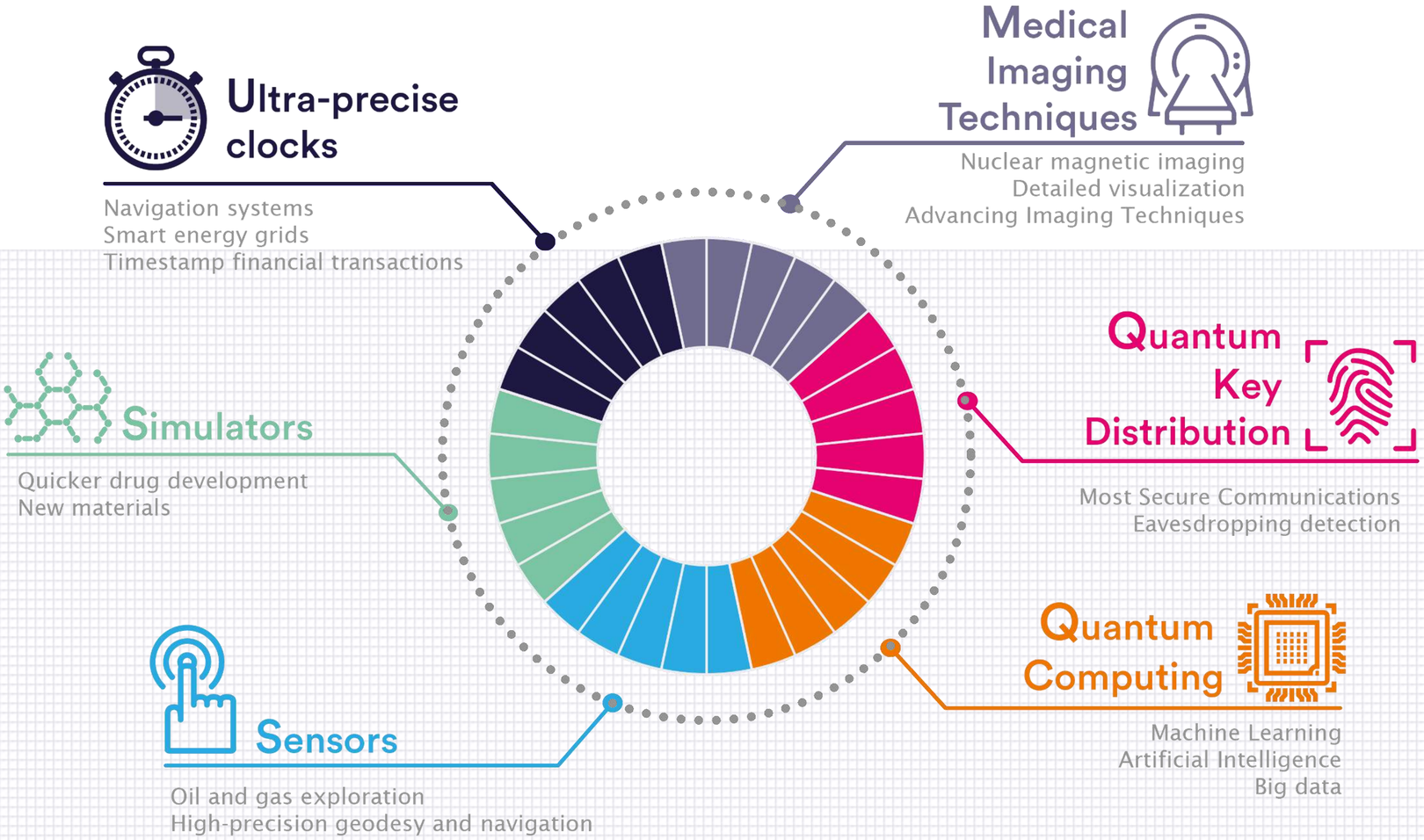
WHAT ARE QUANTUM TECHNOLOGIES?



QUANTUM

Quantum Technology Applications

European Commission



QUANTUM

1 The development of quantum computers started in 1982, but accelerated drastically in the past two years

NOT EXHAUSTIVE

1982
Richard Feynman formulates the vision of a quantum computer
"Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem, because it doesn't look so easy."

1999
EU invests €50-75 M in quantum technologies via FET program over next 7 years

2001
SK Telecom starts R&D on quantum communication

2005
Microsoft starts Station Q at UC Santa Barbara

2011
Lockheed Martin buys D-Wave 1[1] $10M

2012
1Qubit is founded

2016
Australian government investing AUD$ 25 million investment over five years to the development of quantum com-puting hardware

2016
Canadian government commits $ 76 millions to the University of Waterloo for quantum hard-ware and software

2017
- Volkswagen announcing co-development with Google
- Several dozens of startup are founded

2018
EU commission announces a US$ 1.13 billion project for support of a range of quantum technologies

1980 | 2000 | 2005 | 2010 | 2015

1999
D-wave is founded

2003
DARPA launches the first quantum network

2010
Canadian government invests €78 M in quantum technologies over next 7 years

July 2014
IBM invests $3 B in research initiative that includes quantum computing

Sep 2015
Intel invests $50 M in QuTech Delft to develop a quantum computer

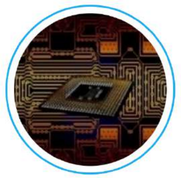
2016
IBM starts making their quantum computers available to the public for the first time with the IBM Q program

2017
1Qubit raises USD 45 mn from Accenture, Allianz and Fujitsu

2018
- DowDuPont announcing co-development with 1 qubit
- IBM and Google start to incubate and consolidate the start-up ecosystems

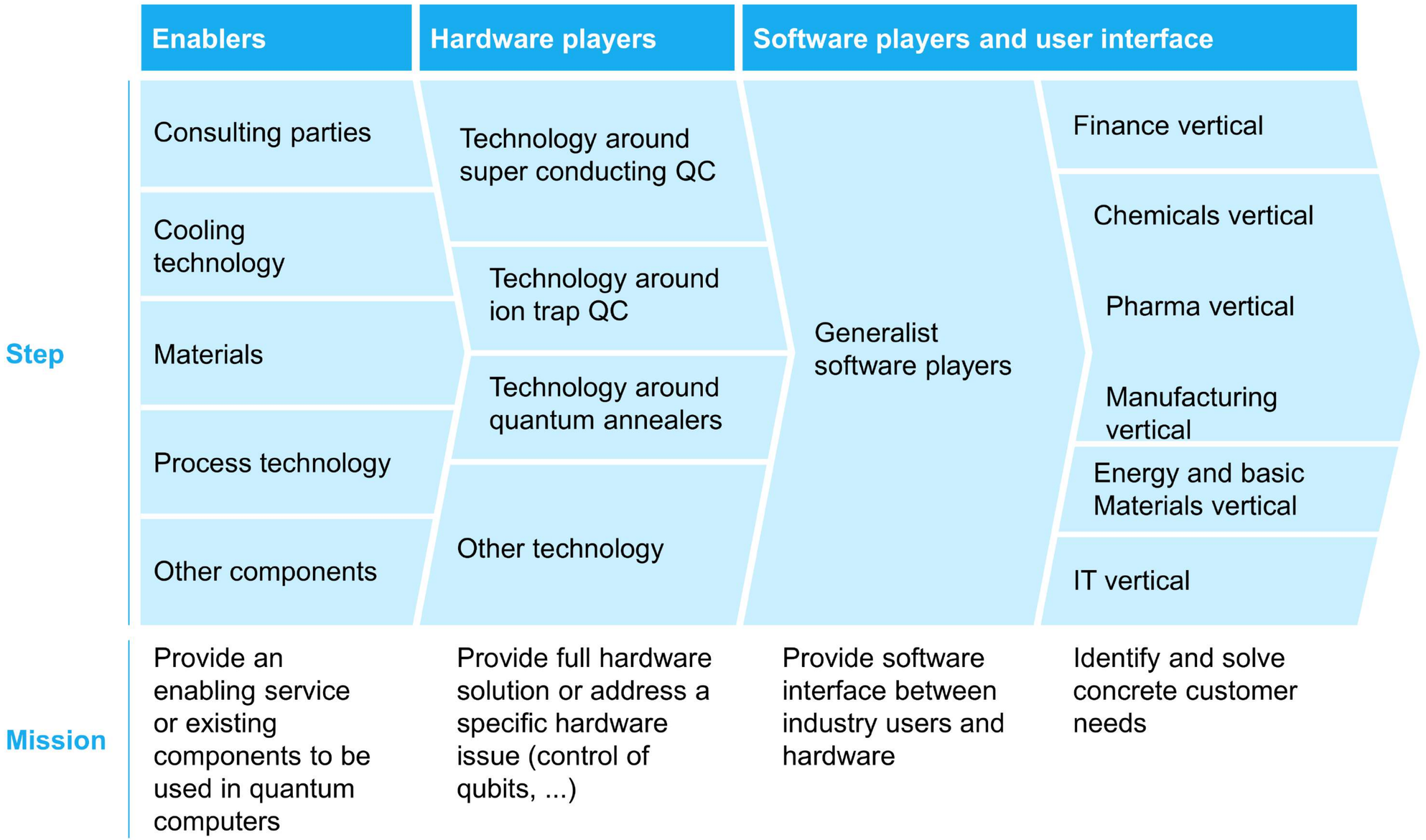
SOURCE: McKinsey analysis, expert interviews, press search

2 Four distinct quantum tools may enable use cases across industries – the capabilities rely on dedicated quantum algorithms

Quantum tool		Example
Quantum simulation for chemicals and materials		▪ **Simulation of quantum systems for R&D on chemicals**, i.e. molecules, solids or polymers ▪ Scope ranging from **small molecules** up to huge **macro-molecules**, e.g., proteins ▪ Use of **variational quantum eigensolver** (VQE) and quantum subspace expansion (QSE) as algorithms
Optimization		▪ Solving of **numeric** optimization **problems** with a **large number** of **variables**, e.g., in **manufacturing** and **finance** ▪ **Optimization** in business **operations** like **supply chain, logistics**
AI and machine learning		▪ Better algorithms for **AI/machine learning** ▪ Potential applications in **manufacturing** or **pharma** (optimizing formulations, identifying APIs)
Prime factorization to crack/create encryption		▪ **Handling of larger prime numbers** (factorization) ▪ **Encryption breaking** to get access to (military) intelligence ▪ Creation of safer communication systems and securing of critical data for finance ▪ Use of **Shor's** algorithm

SOURCE: McKinsey analysis, expert interviews, press search

3 The current value chain in quantum computing



- As of 2019, the value chain is fragmented as the industry has not settled on one hardware concept and on one dominant business model
- Especially startups tend part play in several areas of the value chain, e.g. covering hardware and the ancillary software interface
- Specialization and consolidation is expected once QC becomes more mature

SOURCE: McKinsey analysis

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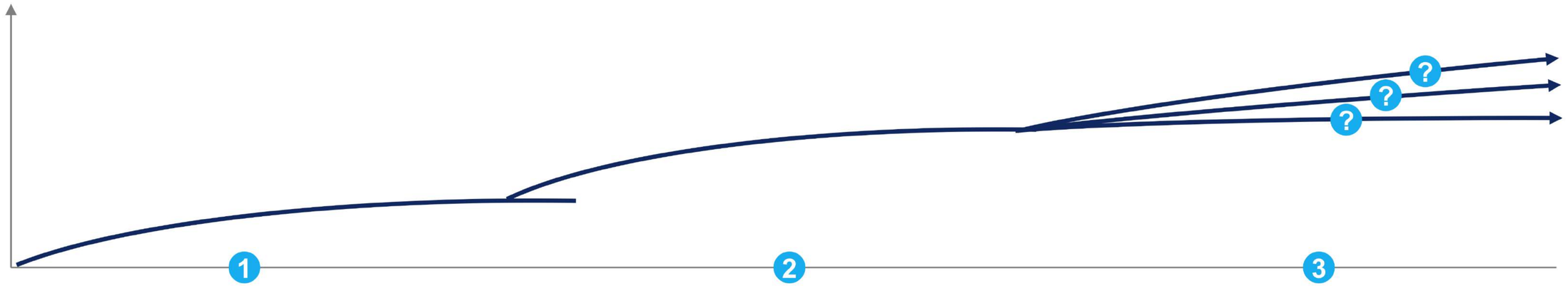
4 The quantum computing market is likely to develop in distinct phases – by the early-to-mid 2020ies, a critical window will be reached

Window	**Early stage: Incubation** (1981 - 2020)	**NISQ[1] era: Midterm market development** (2020-2030)	**Universal quantum computing: Full value creation** (2030 onwards)
Maturity			
Key activities	**Target :** Basic research and echnology development ▪ Academic and 1st commercial R&D activities ▪ Disruptive changes occur	**Target :** Commercialization wherever QC can bring early value ▪ Commercial R&D and business development ▪ Disruptive and incremental changes occur	**Target :** Bring QC to the masses, maximize value and reduce cost ▪ Upscale and rollout to serve late adopters ▪ Incremental changes dominate
Source of funding	**Only governments or pioneers invest**	**QC is financed by corporate R&D budgets, VCs and governments**	**Value-based pricing**

1 noisy intermediate-scale quantum computers, a concept coined by John Preskill

SOURCE: McKinsey analysis

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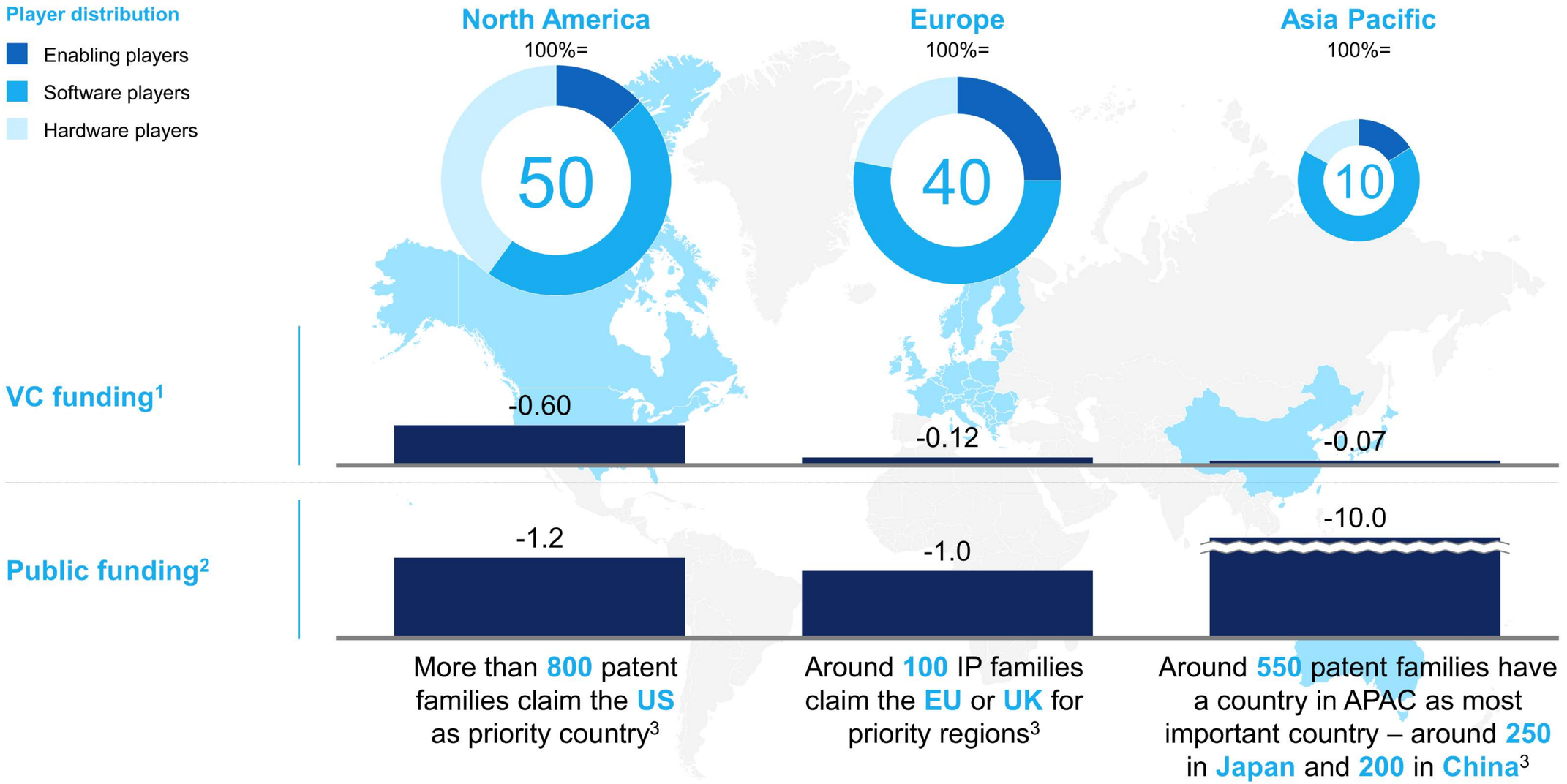
5 The global quantum computing landscape – Europe is currently in a middle position between North America and Asia Pacific

Comparison of the number of QC players, funding and GDP (USD bn) per region in 2019



1 Estimate based on press search; 2 Considering public funding grants, including funded future grants; 3 based on claimed priority of patent families

SOURCE: McKinsey analysis; Patinformatics 2017; press search

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The Quantum Flagship

culmination point uniting ***all*** stakeholders

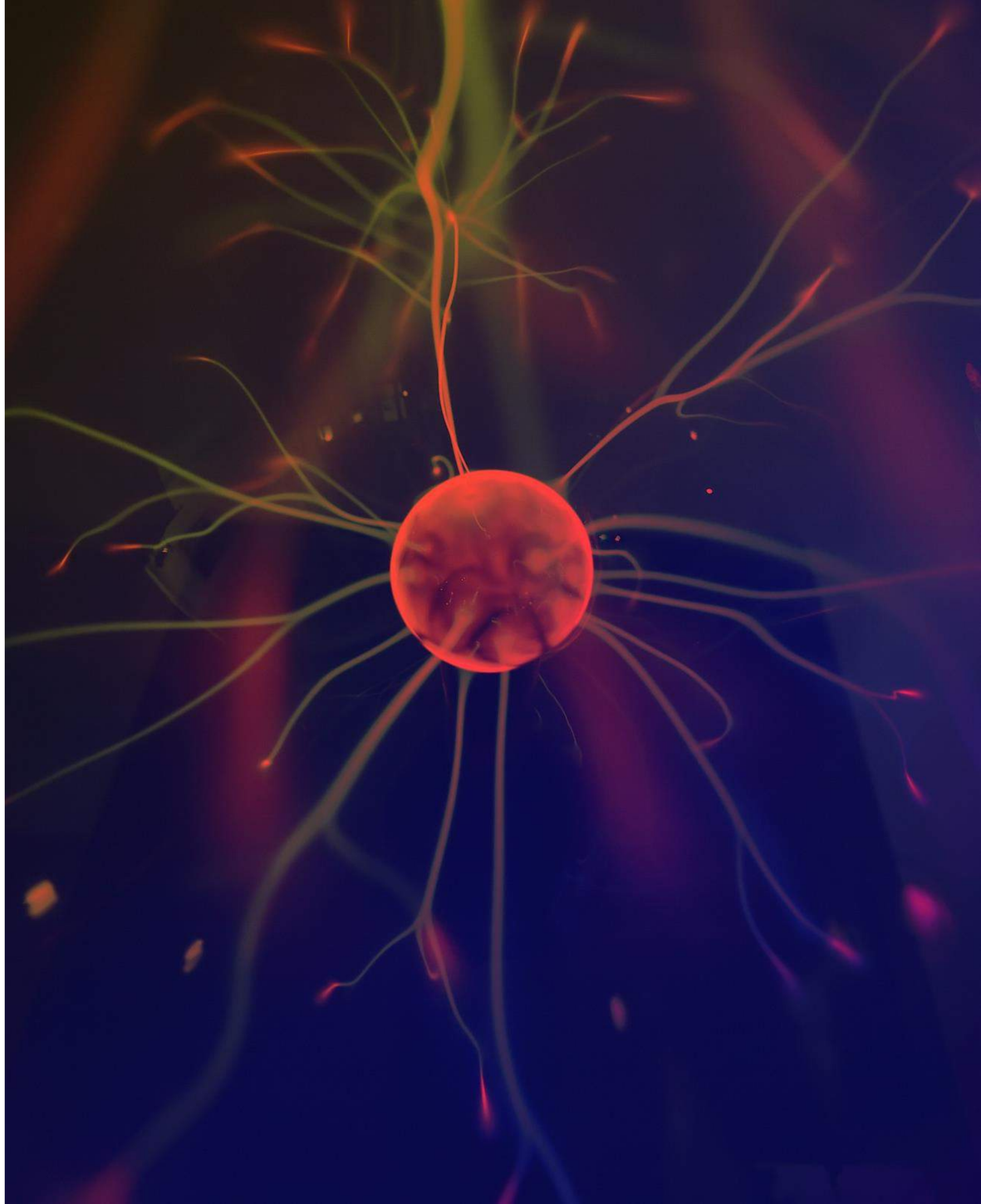
A long-term, large-scale research initiative

Foster world-leading knowledge and skills

Bring quantum technologies from the **lab** to the **market**

Develop technologies and open research facilities for quantum in Europe

Bring together research institutions, academia, industry, enterprises, and policy makers, in a joint and **collaborative initiative** on an unprecedented scale



Goals
Flagship's Vision for Quantum Technologies in Europe

Consolidate and **expand** European **scientific leadership** and **excellence** in quantum research

Kick-start a **competitive** European industry in quantum technologies and position Europe as a **leader** in the future global industrial landscape

Make **Europe** a **dynamic** and **attractive** region for innovative **research, business** and **investments** in quantum technologies

The Quantum Flagship at a Glance

October 2018

2000+ experts

10 years

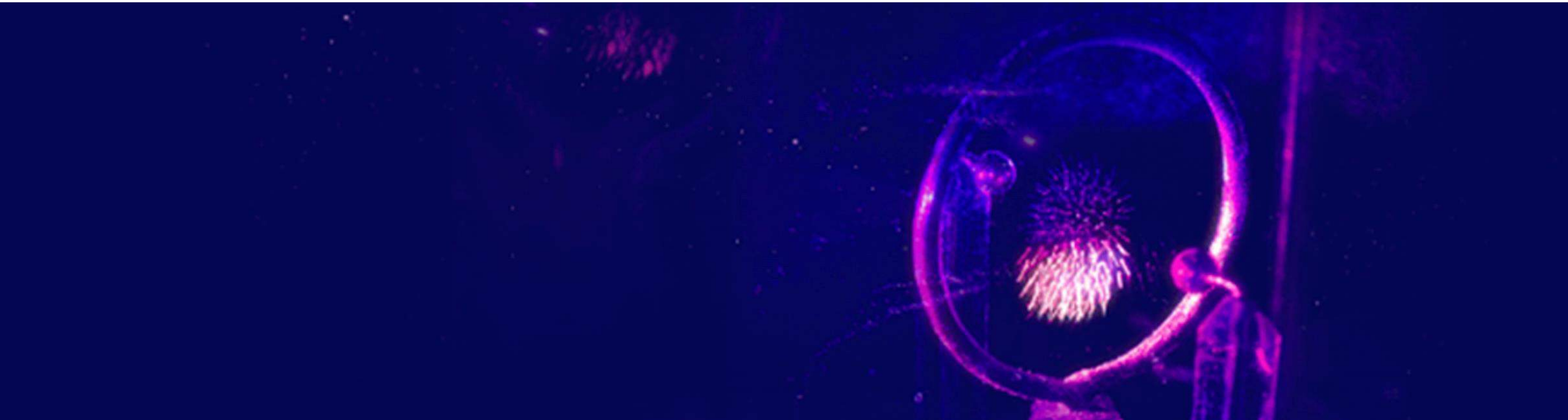
1 billion €

2018-2021
Ramp-up phase

152 million €

141 proposals

20 projects



Application Pillars

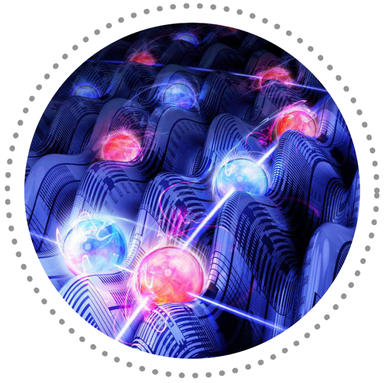
4 projects

QUANTUM Communication

For a Secure Digital Society and a Quantum-enabled Internet

Quantum Internet - secure communication and applications

2 projects

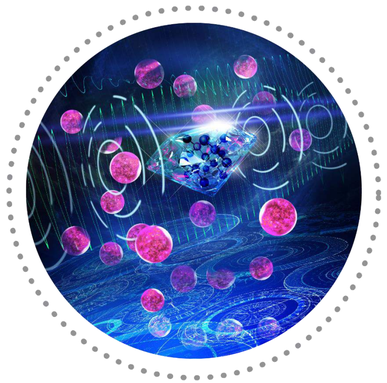


QUANTUM Simulation

Simulating Complex Systems for Advanced Design and Development

By 2021 quantum simulators 20x more precise

4 projects

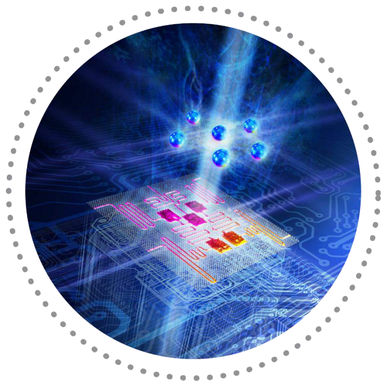


QUANTUM Sensing metrology

Bringing Accuracy And Performance To Unprecedented Levels

By 2021, sensors with resolution 1000x better

2 projects

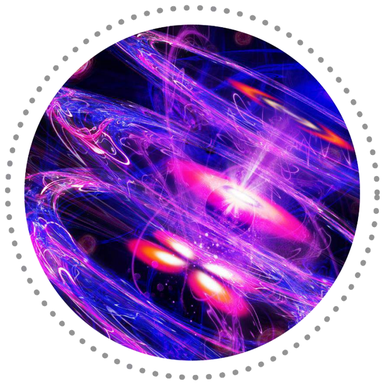


QUANTUM Computing

Computing Power To Overcome Currently Unsolvable Problems

By 2021, quantum computers of 50-100 qubits demonstrating first quantum

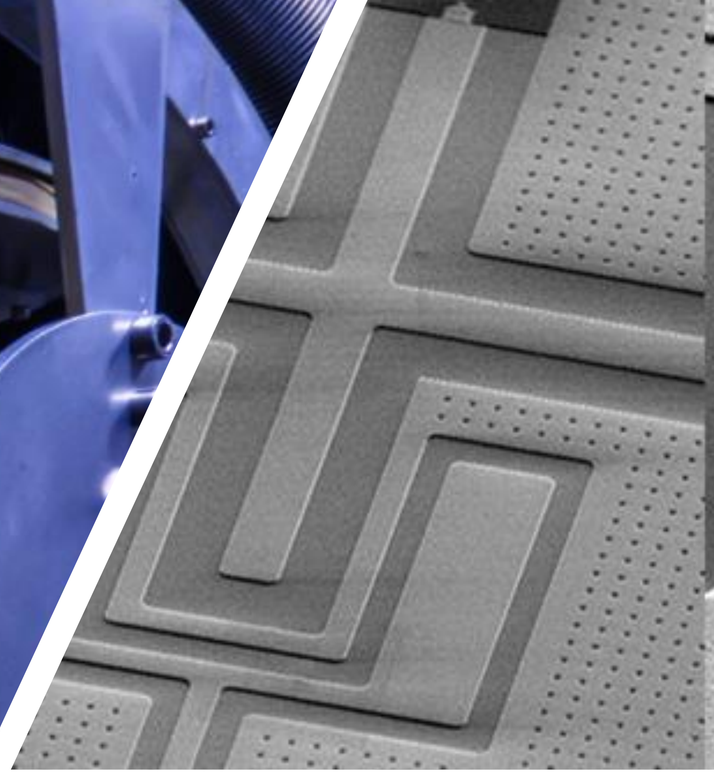
7 projects

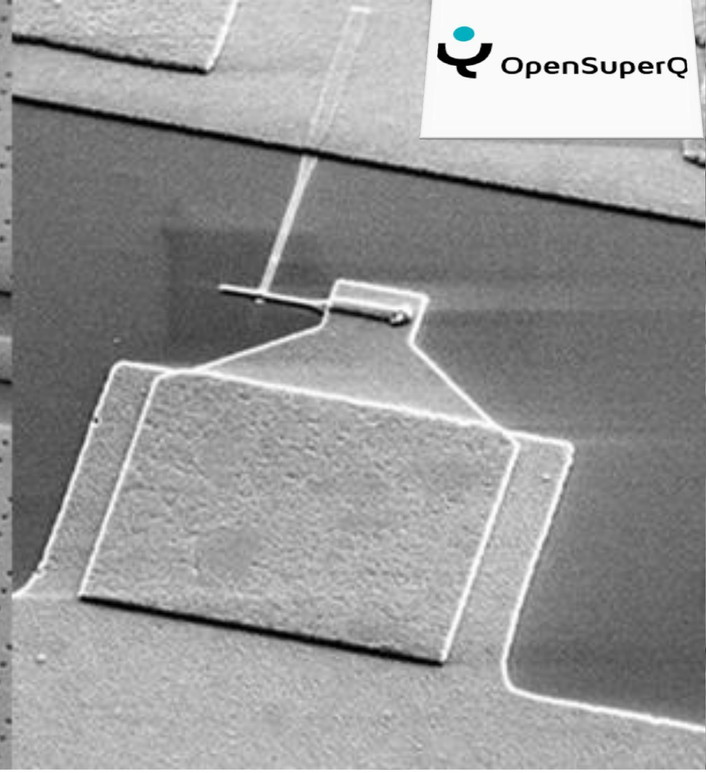


QUANTUM Basic science

Addressing Foundational Challenges For Development Of Quantum Technologies

Discover & understand new fundamental quantum principles





OpenSuperQ

QUANTUM Computing

2 projects

PROJECT: AQTION
(Advanced quantum computing with trapped ions)
Coordinating Institution:
UNIVERSITAET INNSBRUCK
Coordinator: Thomas Monz

PROJECT: OpenSuperQ
(An Open Superconducting Quantum Computer)
Coordinating Institution:
UNIVERSITAT DES SAARLANDES
Coordinator: Frank Wilhelm-Mauch

QUANTUM Communication

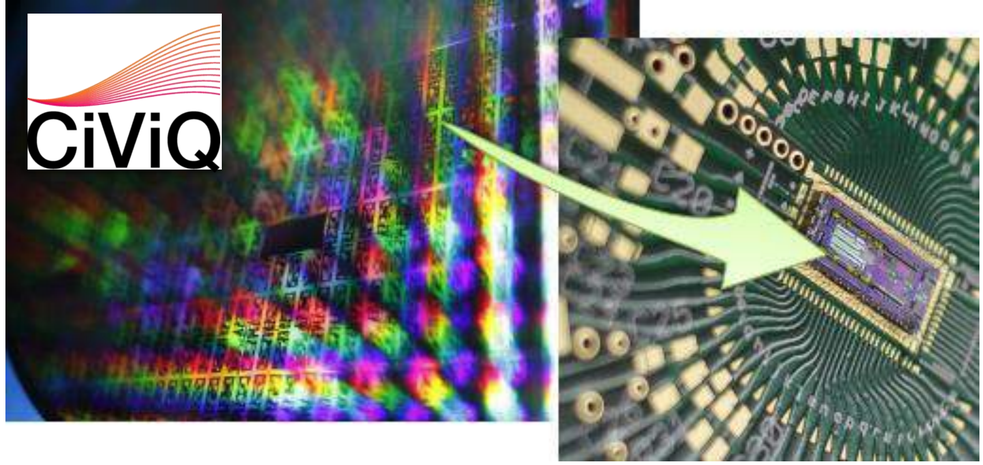
4 projects

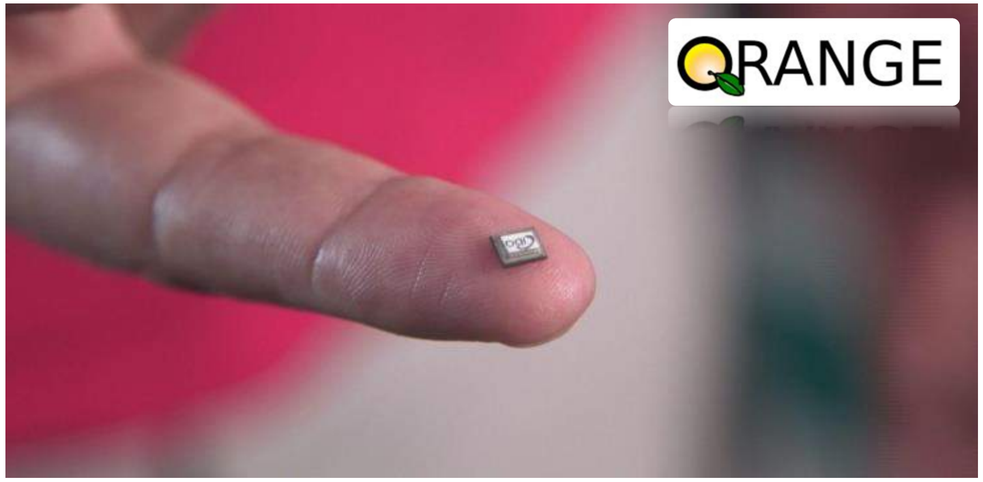
PROJECT: CiViQ
(Continuous Variable Quantum Communications)
Coordinating Institution:
ICFO - THE INSTITUTE OF PHOTONIC SCIENCES
Coordinator: Valerio Pruneri

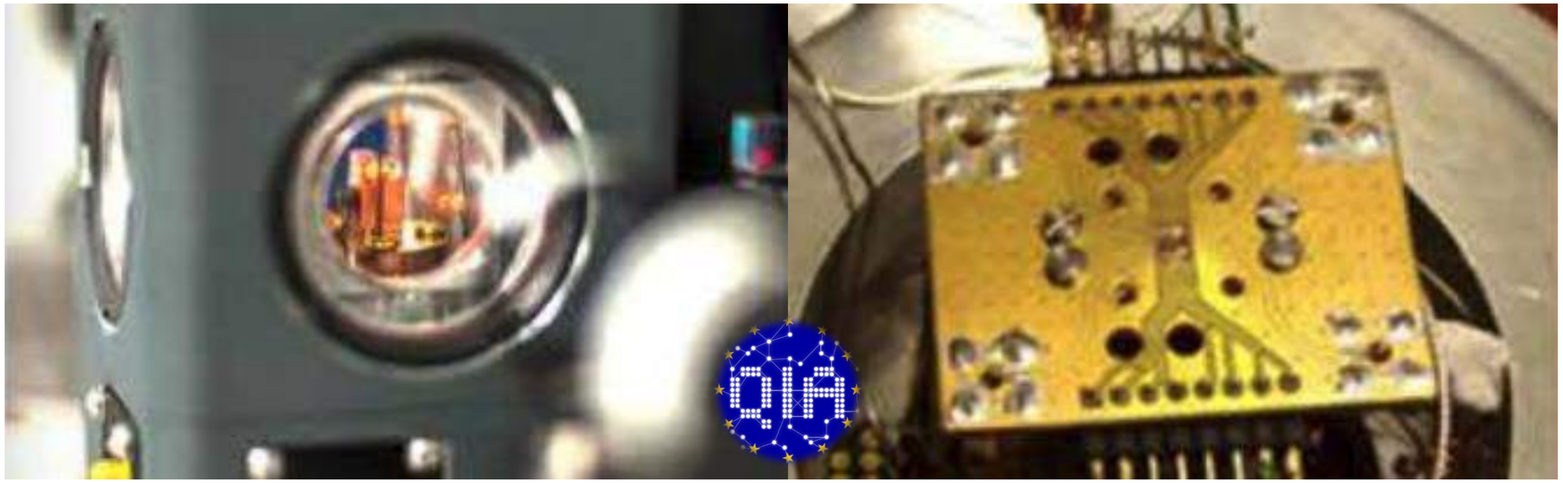
PROJECT: QIA
(Quantum Internet Alliance)
Coordinating Institution:
TECHNISCHE UNIVERSITEIT DELFT
Coordinator: Stephanie Wehner

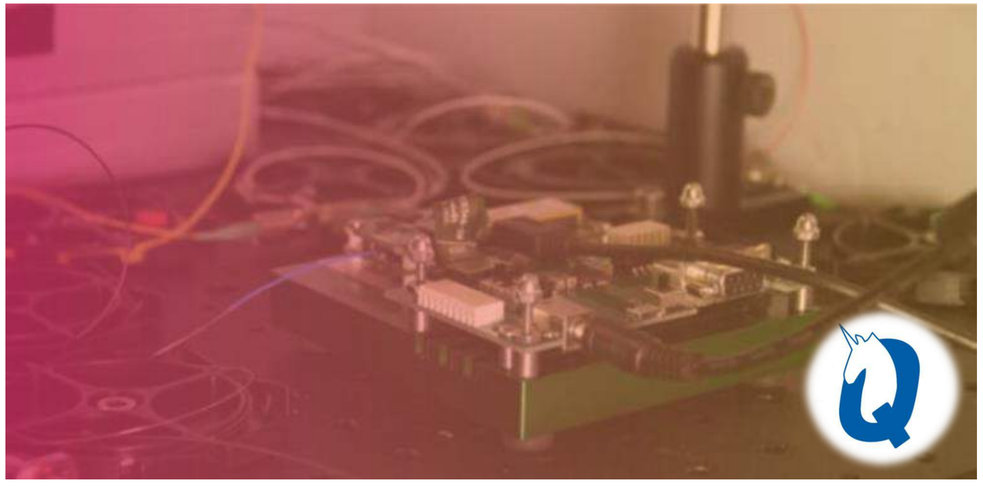
PROJECT: QRANGE
(Quantum Random Number Generators: cheaper, faster and more secure)
Coordinating Institution:
UNIVERSITE DE GENEVE
Coordinator: Hugo Zbinden

PROJECT: UNIQORN
(Affordable Quantum Communication for Everyone: Revolutionizing the Quantum Ecosystem from Fabrication to Application)
Coordinating Institution:
AIT AUSTRIAN INSTITUTE OF TECHNOLOGY GMBH
Coordinator: Hannes Hübel









QUANTUM Simulations

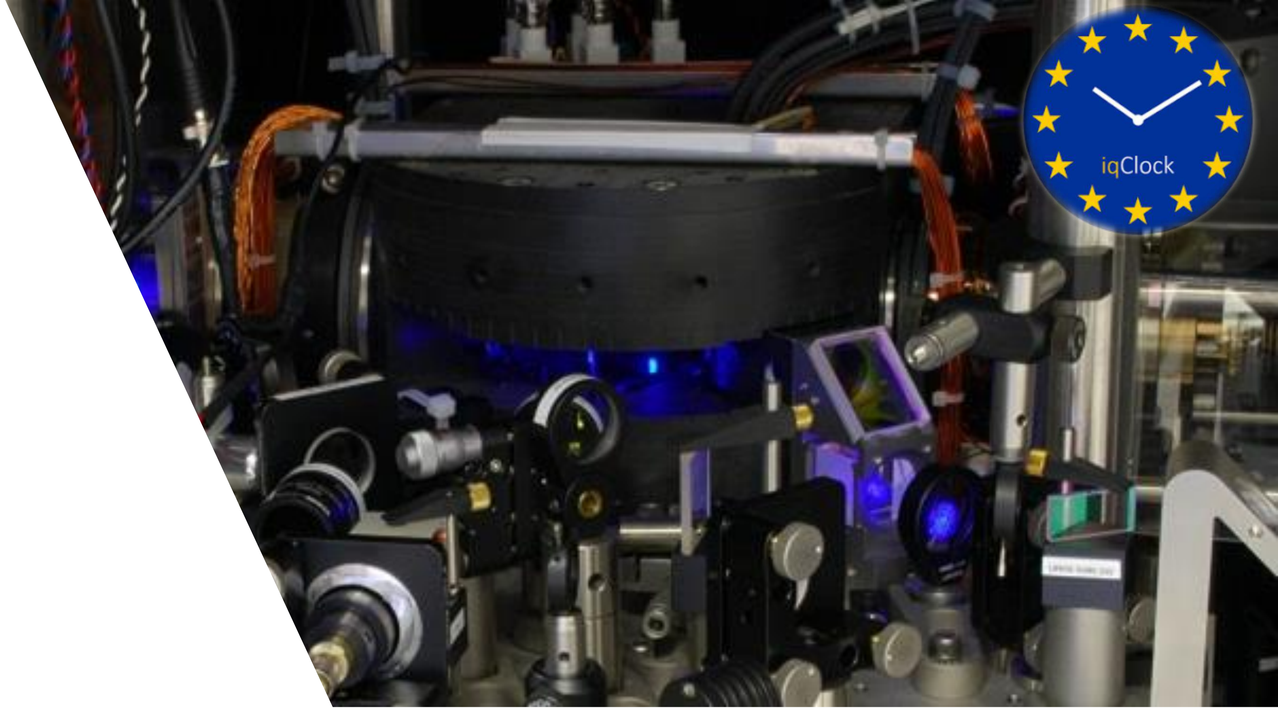
2 projects

PROJECT: PASQuanS
(Programmable Atomic Large-Scale Quantum Simulation)
Coordinating Institution:
MAX-PLANCK-GESELLSCHAFT ZUR FORDERUNG DER WISSENSCHAFTEN EV
Coordinator: Immanuel Bloch

PROJECT: Qombs
(Quantum simulation and entanglement engineering in quantum cascade laser frequency combs)
Coordinating Institution:
CONSIGLIO NAZIONALE DELLE RICERCHE
Coordinator: Augusto Smerzi

4 projects

QUANTUM Sensing and Metrology



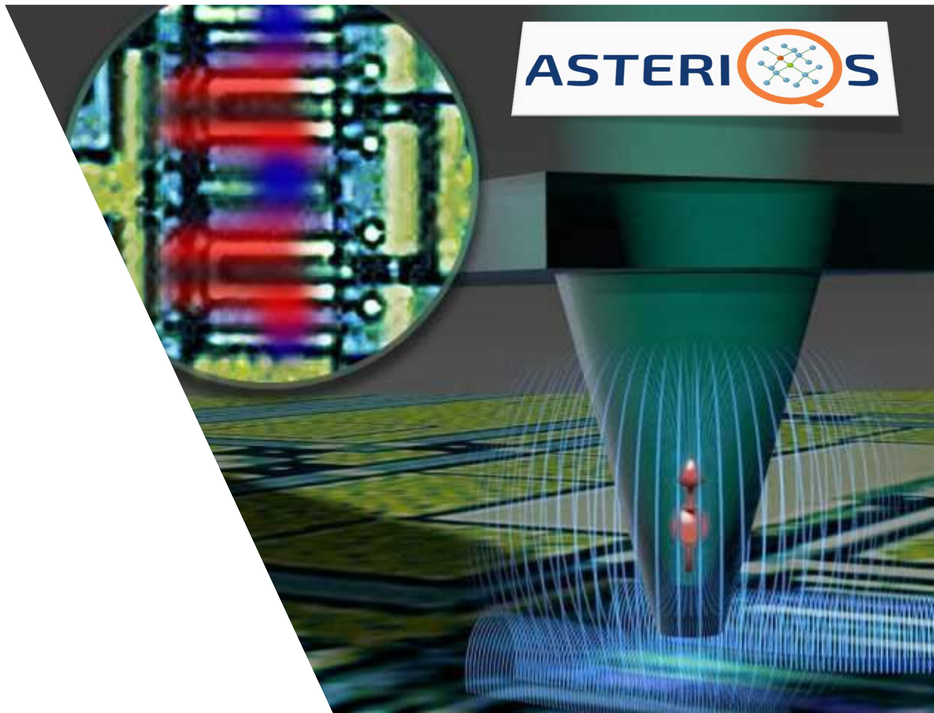
PROJECT: ASTERIQS

(Advancing Science and TEchnology thRough dIamond Quantum Sensing)

Coordinating Institution:

THALES SA

Coordinator: Thierry Debuisschert



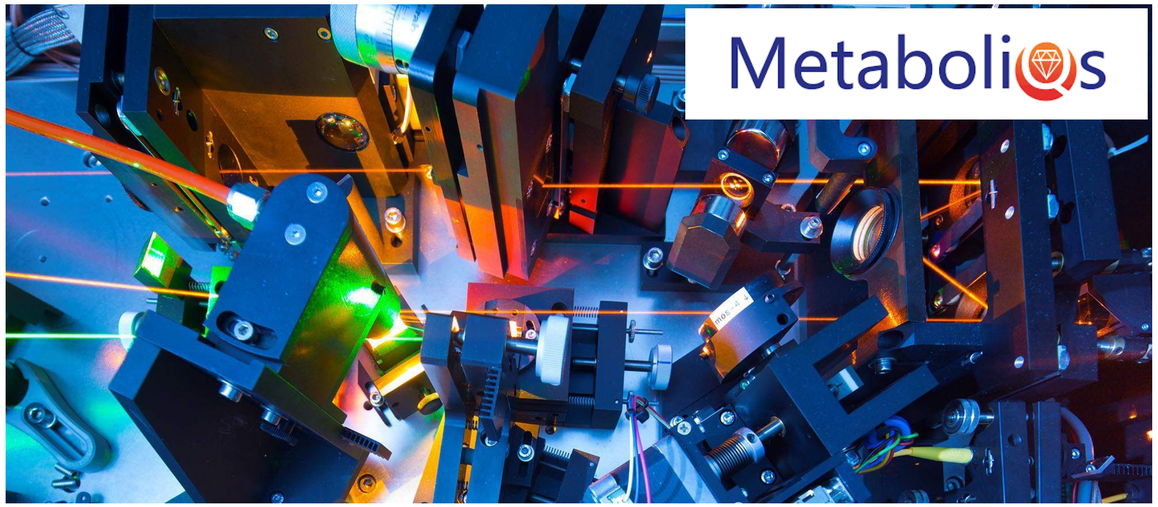
PROJECT: iqClock

(Integrated Quantum Clock)

Coordinating Institution:

UNIVERSITEIT VAN AMSTERDAM

Coordinator: Florian Schreck



4 projects

QUANTUM Sensing and Metrology

PROJECT: MetaboliQs

(Leveraging room temperature diamond quantum dynamics to enable safe, first-of-its-kind, multimodal cardiac imaging)

Coordinating Institution:

FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V.

Coordinator: Christoph Nebel

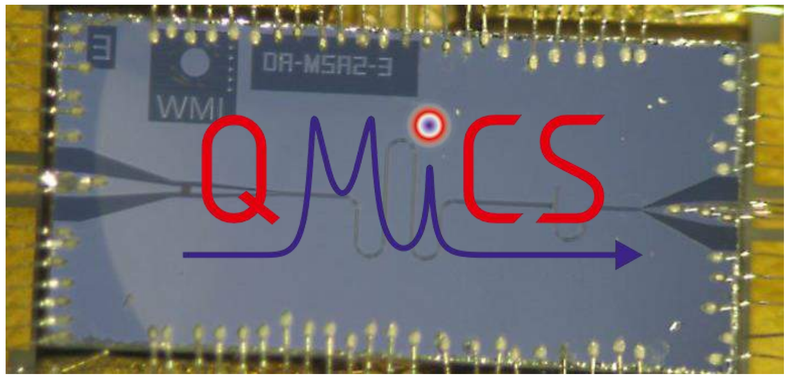
PROJECT: macQsimal

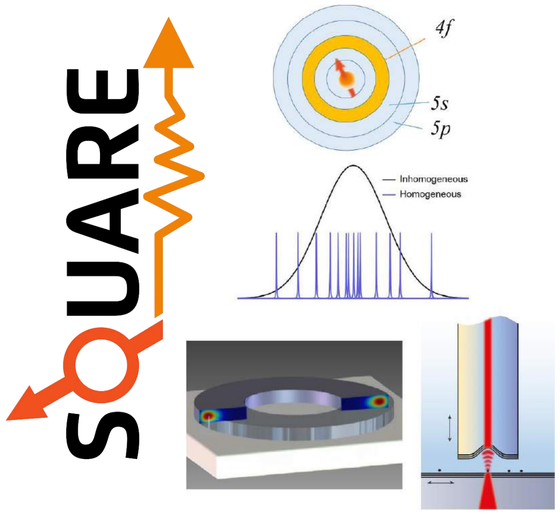
(Miniature Atomic vapor-Cells Quantum devices for SensIng and Metrology AppLications)

Coordinating Institution:

CSEM CENTRE SUISSE D'ELECTRONIQUE ET DE MICROTECHNIQUE SA - RECHERCHE ET DEVELOPPEMENT

Coordinator: Jacques Haesler





QUANTUM Basic Science

7 projects

PROJECT: S2QUIP

(Scalable Two-Dimensional Quantum Integrated Photonics)

Coordinating Institution:

KUNGLIGA TEKNISKA HOEGSKOLAN

Coordinator: Klaus Jöns

PROJECT: 2D-SIPC

(Two-dimensional quantum materials and devices for scalable integrated photonic circuits)

Coordinating Institution:

ICFO - THE INSTITUTE OF PHOTONIC SCIENCES

Coordinator: Dmitri Efetov

PROJECT: QMiCS

(Quantum Microwave Communcation and Sensing)

Coordinating Institution:

BAYERISCHE AKADEMIE DER WISSENSCHAFTEN

Coordinator: Frank Deppe

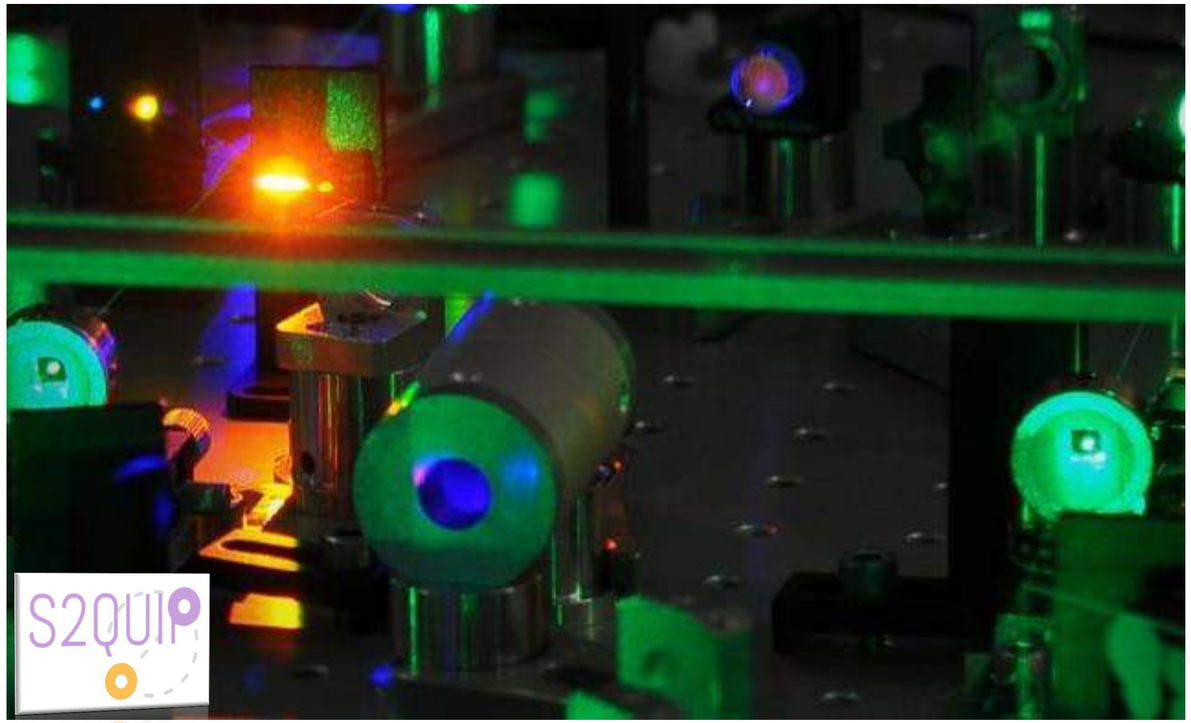
PROJECT: SQUARE

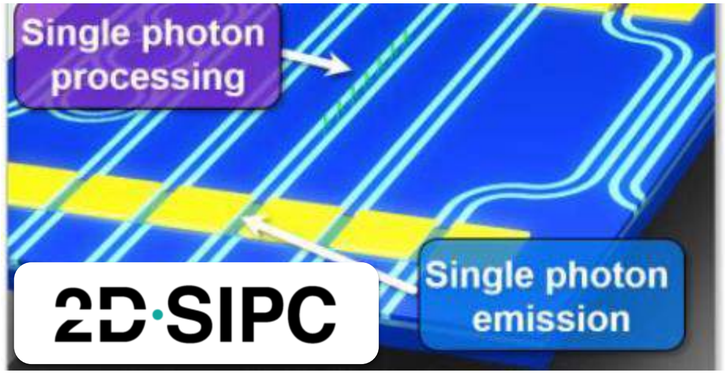
(Scalable Rare Earth Ion Quantum Computing Nodes)

Coordinating Institution:

KARLSRUHER INSTITUT FUER TECHNOLOGIE

Coordinator: David Hunger





QUANTUM Basic Science

7 projects

PROJECT: PhoG

(Sub-Poissonian Photon Gun by Coherent Diffusive Photonics)

Coordinating Institution:

THE UNIVERSITY COURT OF THE UNIVERSITY OF ST ANDREWS

Coordinator: Natalia Korolkova

PROJECT: PhoQuS

(Photons for Quantum Simulation)

Coordinating Institution:

SORBONNE UNIVERSITE

Coordinator: Alberto Bramati

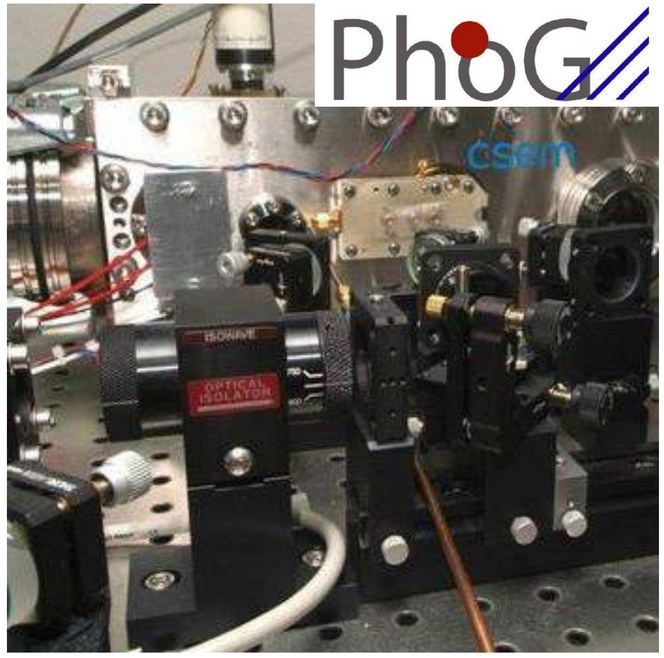
PROJECT: MicroQC

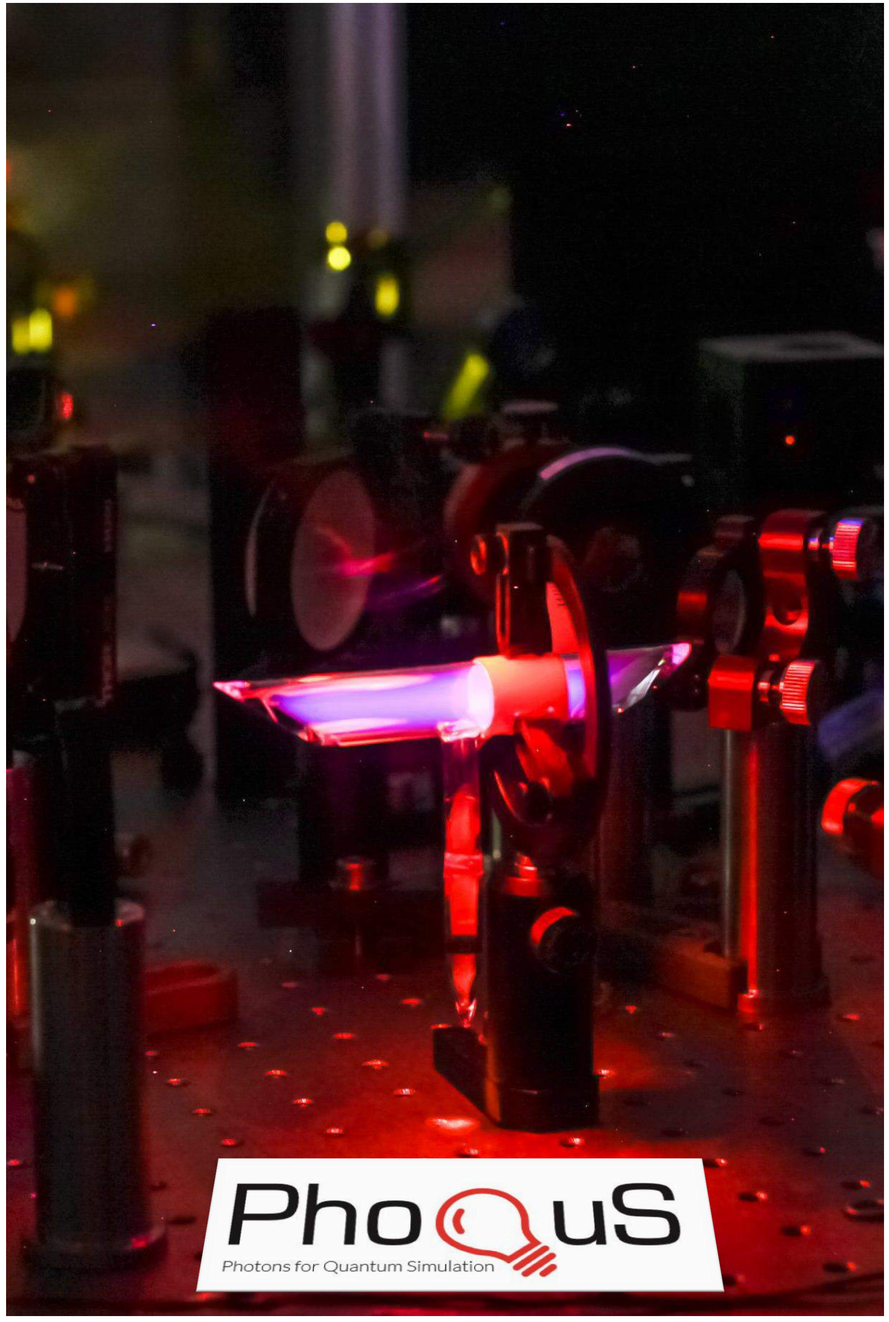
(Microwave driven ion trap quantum computing)

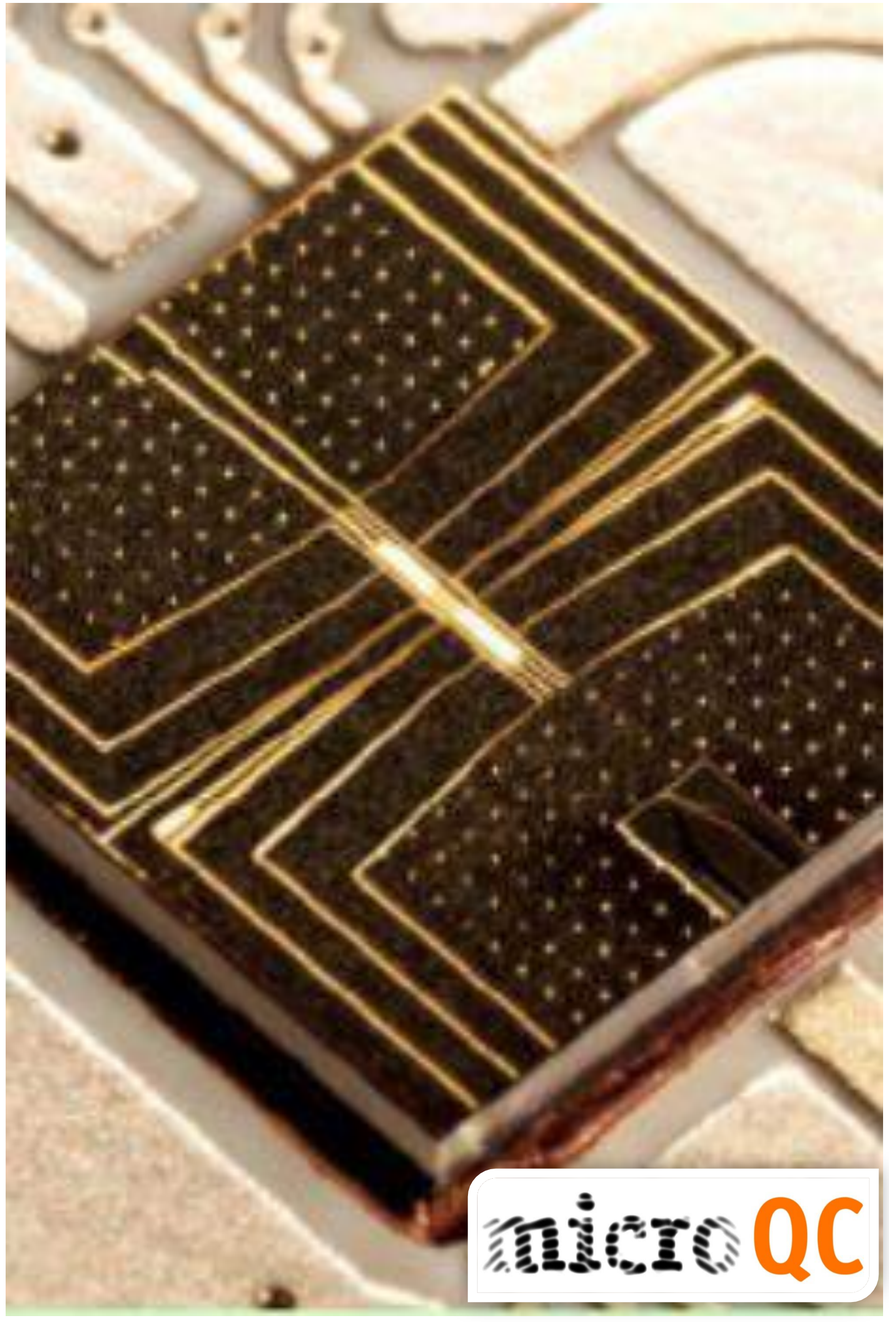
Coordinating Institution:

FOUNDATION FOR THEORETICAL AND COMPUTATIONAL PHYSICS AND ASTROPHYSICS

Coordinator: Nikolay Vitanov







QUANTERA

November 2016

QuantERA ERA-NET cofund initiative
→ ERA-NET aims to increase Member States funding to challenge driven research and innovation agendas

€67 million budget from European Commission and national funding agencies

26 European countries

National and regional research funding programmes

Complementary to the Quantum Flagship's activities

FROM VISION TO REALITY – THE EU'S COMMITMENT

Built with the support of the Commission's proposed Horizon Europe and Digital Europe programmes

HORIZON EUROPE

QUANTERA

QUANTERA

Give **funding support** to **international research projects** in the field of Quantum Technologies

QUANTUM FLAGSHIP

QUANTUM FLAGSHIP

Bring quantum technologies from the **lab** to the **market** and **consolidate** European **scientific leadership** in quantum research

DIGITAL EUROPE

QUANTUM COMMUNICATION INFRASTRUCTURE (QCI)

Build and **deploy** in the next decade a certified secure pan-European end-to-end QCI for **cybersecurity** services

QUANTUM COMPUTING INFRASTRUCTURE

Build and **deploy** an infrastructure for big data, artificial intelligence, high performance computing, among others

Quantum Communication Infrastructure

Integrate quantum cryptography into critical communication systems

Combine terrestrial and satellite components for wide coverage

Protection of data networks, clock synchronization, e-voting,…

Backbone infrastructure for the quantum internet

Quantum Computation & Simulation Infrastructure

Classical quantum simulation hardware in HPC

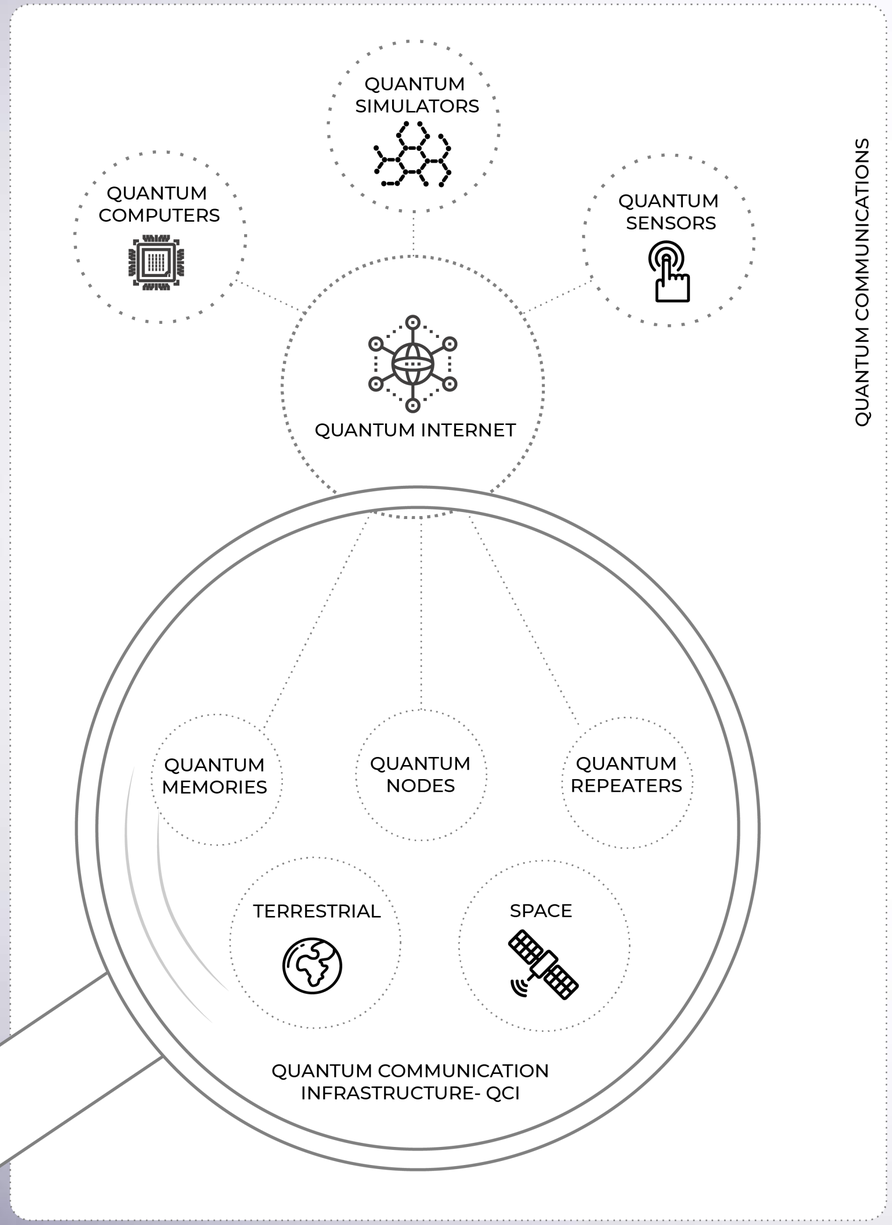
Quantum computation and simulation hardware (ion traps, super-/semi-conducting qubits, spin qubits, phtonic circuits, neutral atoms)

Quantum testbed facilities for hardware developers

Quantum application database (verification/validation, algorithms, apps)

European Commission

Quantum Internet: the ultimate goal



→ Distributed quantum computers, and quantum sensors interconnected via quantum communication networks