OCTOBER 29TH, 2018

QUANTUM Simulation

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QUANTUM

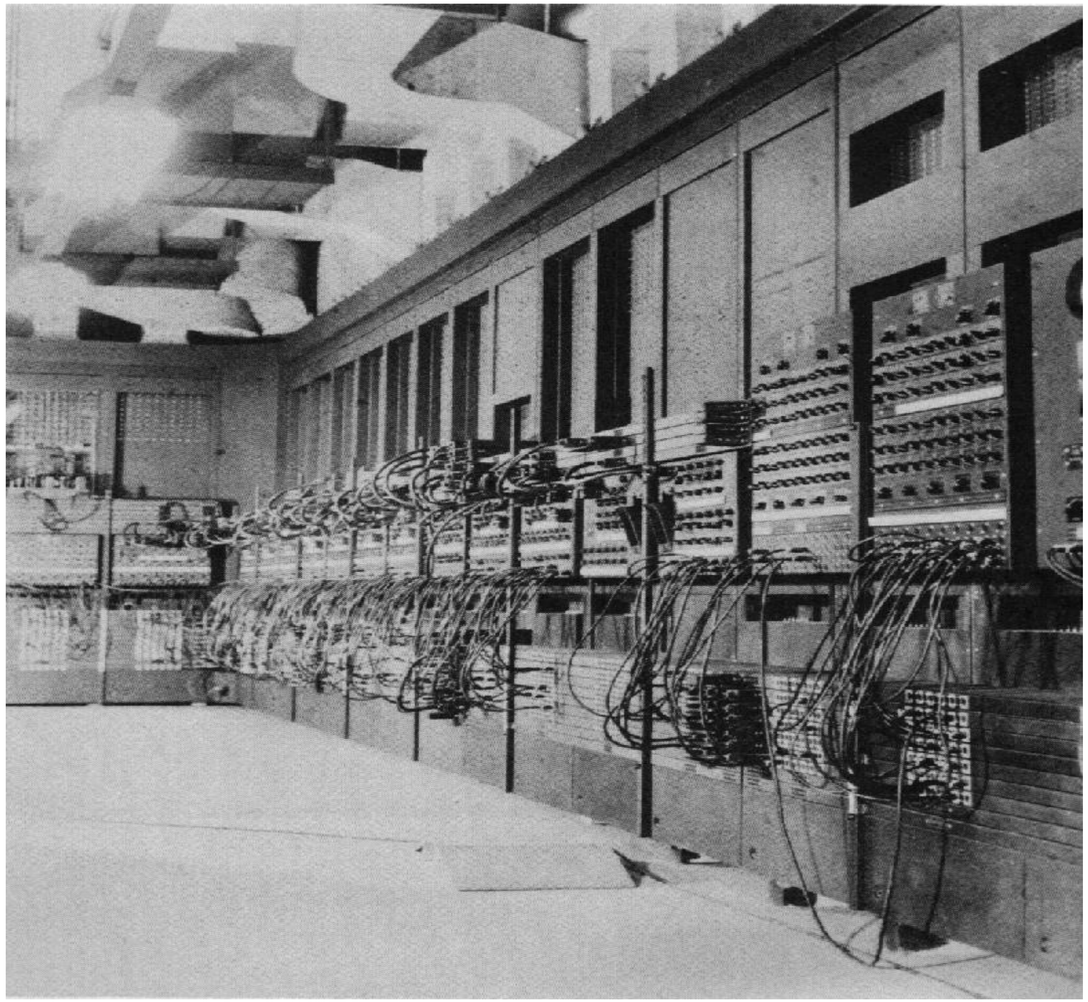
QUANTUM Simulation

Why a pillar on quantum simulation?

Quantum systems do not live in our physical space but in a huge (Hilbert) space

PROBLEM:
Quantum Mechanical systems cannot be studied, in general, with classical computers.
The storing memory and number of operations grow exponentially with the size of the quantum system.

Even big computers cannot be big enough



ENIAC
(1946)

Why a pillar on quantum simulation?

Quantum systems do not live in our physical space but in a huge (Hilbert) space

PROBLEM: Quantum Mechanical systems cannot be studied, in general, with classical computers.
The storing memory and number of operations grow exponentially with the size of the system.

IDEA: "Let the computer itself be built of quantum mechanical elements which obey quantum mechanical laws." (RPF, '82)

Why it is a good idea? The quantum device can contain a large amount of information without using an exponentially large amount of physical resources.

VISION: **Quantum simulators**
Tune and tailor controllable quantum systems to simulate other complex quantum systems.

IMPACT: **Quantum supremacy**

Quantum simulators can be constructed to study:

materials, chemical reactions, phase transitions, high-Tc superconductivity, high-energy physics, …

Main **advantage** over all-purpose quantum computers: **Simpler to build.** Quantum simulators are *task-oriented*.
Main **disadvantage**: no quantum error-correction protocols.

Quantum supremacy: the point where we can solve problems and understand the world not only with a radically new tool but also with a radically new way of reasoning.

Projects in the Quantum Simulation Pillar

- **PASQUANS** — Coordinators: Immanuel Bloch (MPQ, DE), Antoine Browaeys (IO, FR) — www.pasquans.eu *(under construction)*
- **Qombs** — Coordinator: Augusto Smerzi (CNR-INO, IT) — www.qombs.eu *(under construction)*

Basic science associated projects

- **PhoG** — Coordinator: Natalia Korolkova (Univ. St. Andrews, UK) — http://www.st-andrews.ac.uk/~phog *(under construction)*
- **PhoQus** — Coordinator: Alberto Bramati (LKB, Sorbonne Univ., FR) — www.phoqus-project.eu *(under construction)*

PASQuanS

Consortium

Universities and Research Institutes

1&2 — Max Planck Gesellschaft (DE) & Institut d'Optique (FR)

3 — Univ. Heidelberg (DE)

4 — CNRS – Collège de France (FR)

5 — Öster. Akademie. Wissensch. (AT)

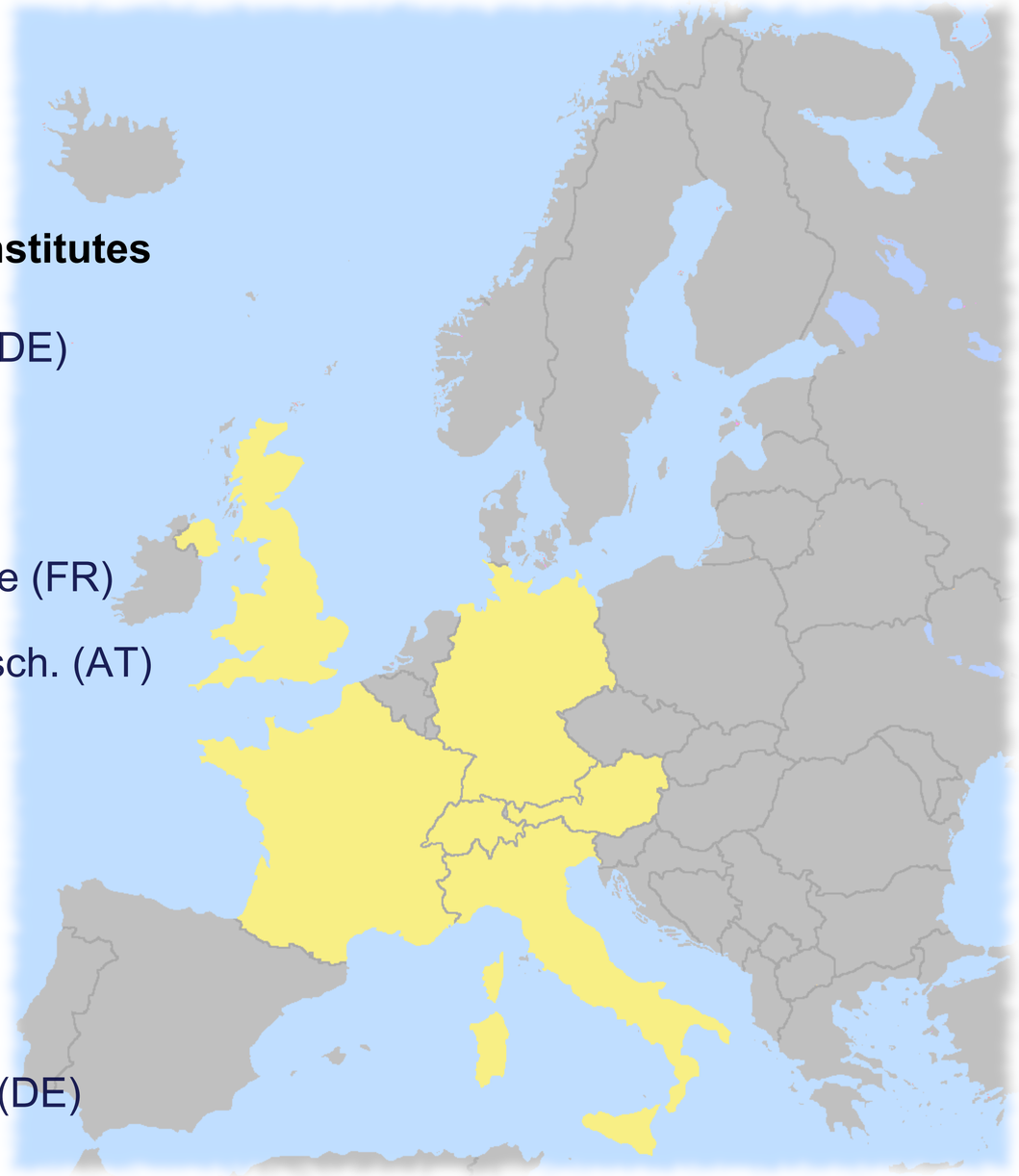
6 — Univ. Padova (IT)

7 — Univ. Strathclyde (UK)

8 — Freie Uni. Berlin (DE)

9 — ETH (CH)

10 — ForschungZentrum Jülich (DE)



Companies

11 — ATOS-Bull (FR)

12 — MuQuanS (FR)

13 — MyCryoFirm (FR)

14 — Toptica (DE)

15 — Azur Light System (FR)

Associated End-Users

Total, Bosch, Airbus, EdF, Siemens

PASQuanS

Programmable Atomic Large-Scale Quantum Simulation

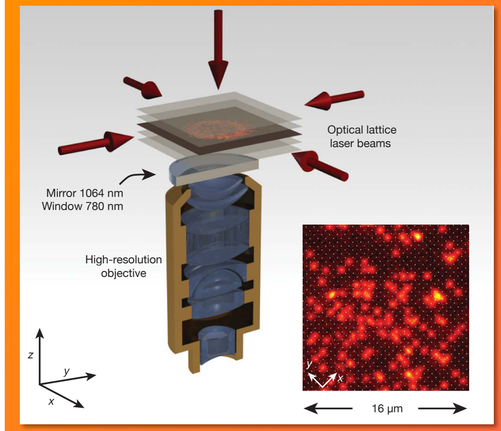
- Build on the **most advanced platforms** based on atoms and ions to **develop the next generation** of **fully programmable** quantum simulators

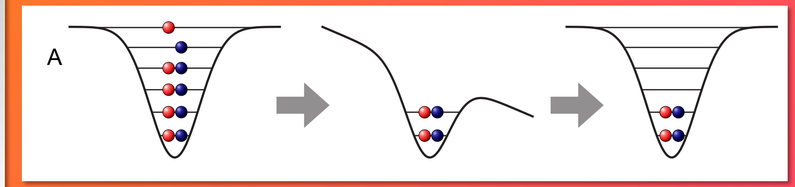
(N > 500 atoms, enhanced control)

- Benchmark/**certify quantum simulation** platforms for answering scientific and industrial questions.
- Build a base of **end users** to identify industry-relevant problems.
- Applications in: **material science, quantum chemistry, high-energy physics, optimization problems**

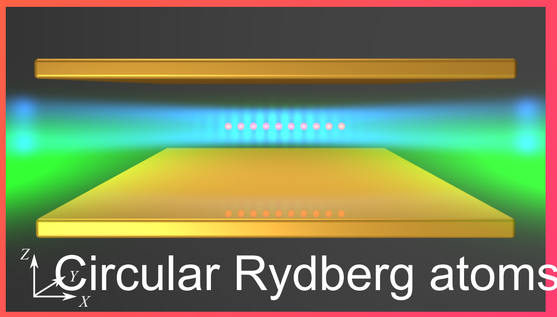
Quantum Flagship, 2018

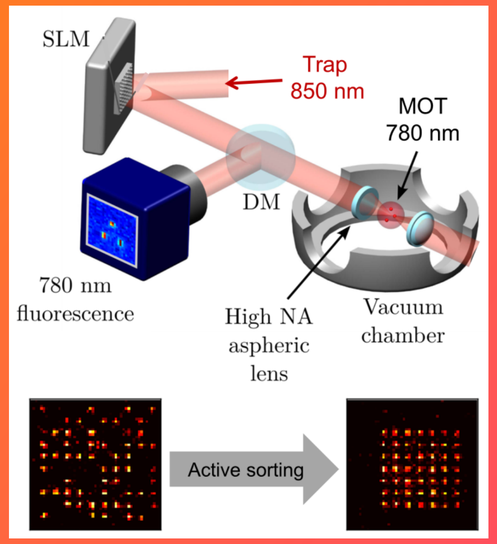
5 State-of-the-art experimental platforms



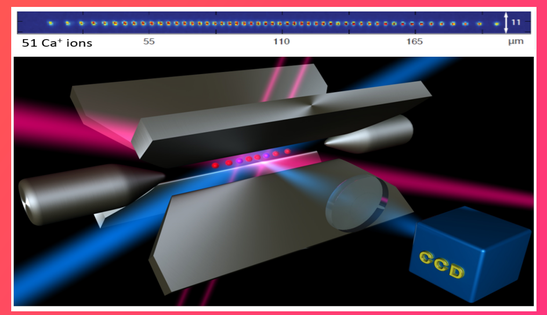


Trapped atoms





Rydberg atoms



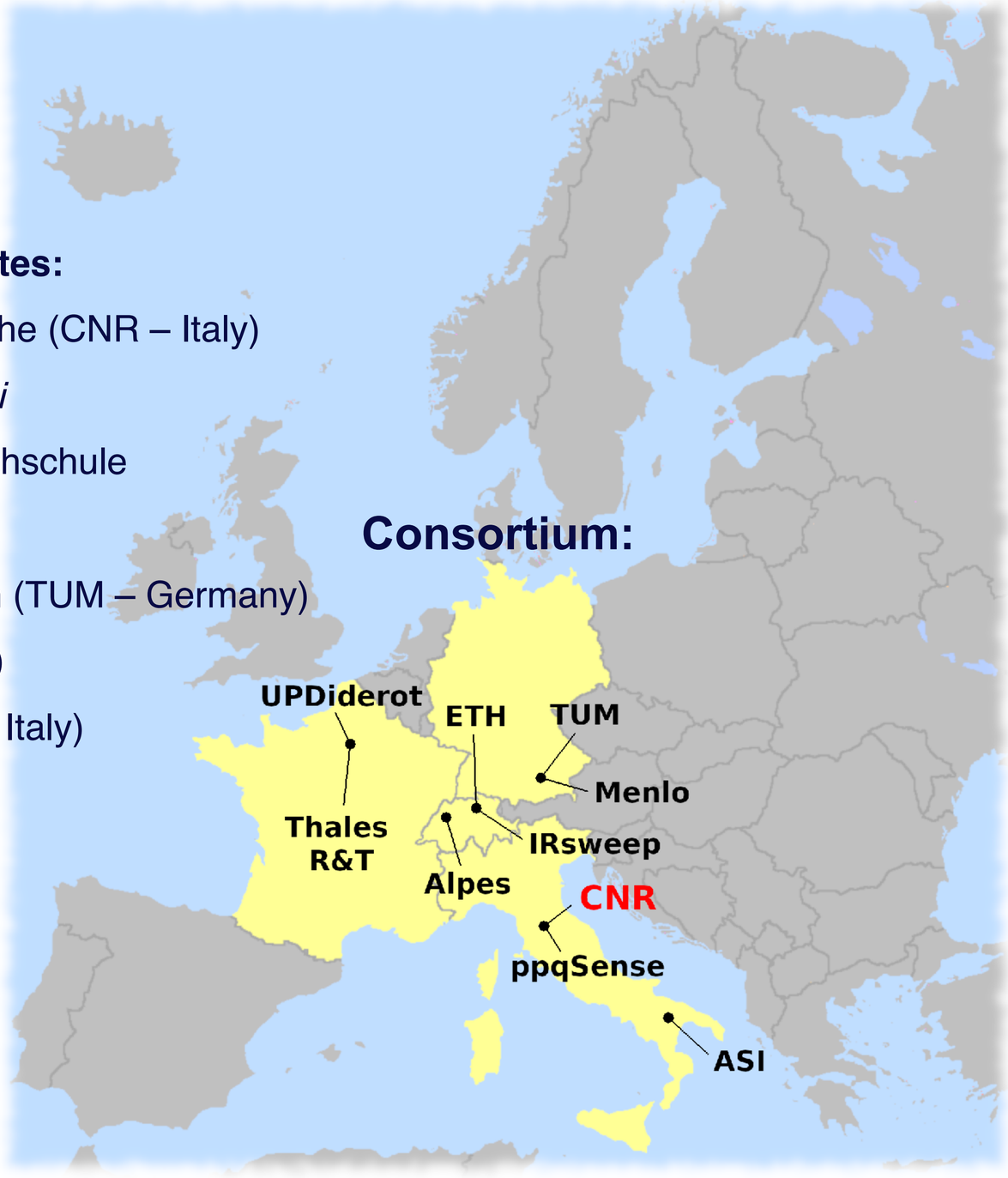
Trapped ions

+ 5 Theory groups with complementary expertise

Universities and Research Institutes:

- Consiglio Nazionale delle Ricerche (CNR – Italy)

  Coordinator: Augusto Smerzi
- Eidgenössische Technische Hochschule Zürich (ETH – Switzerland)
- Technische Universität München (TUM – Germany)
- Université Paris Diderot (France)
- Agenzia Spaziale Italiana (ASI – Italy)



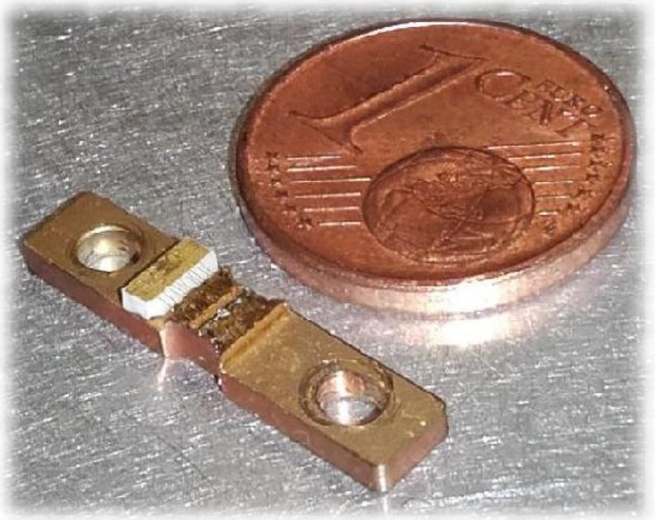
Companies:

- Alpes Lasers (Switzerland)
- IRsweep (Switzerland)
- ppqSense (Italy)
- Menlo Systems (Germany)
- Thales Research & Technology (France)

Qombs

- **Objectives and Addressed challenges**

The goal is to realize a **quantum simulator platform able to simulate** a **quantum cascade laser frequency comb (QCL-comb).**

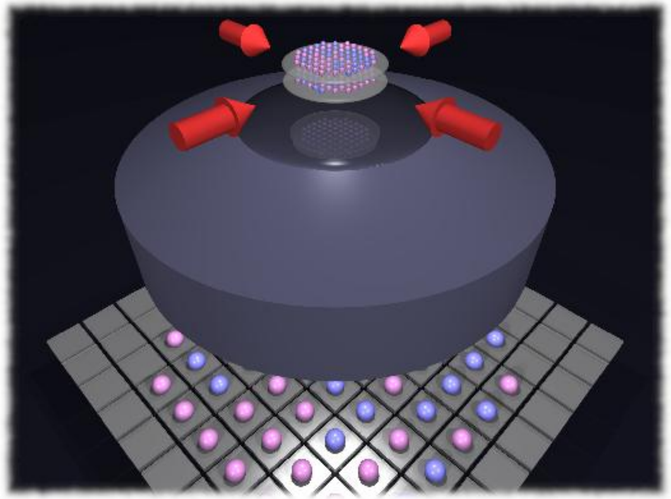


- **The platform**

The quantum simulator will be based on **ultracold fermions and bosons trapped in optical lattices**.

- **Expected deliverable**

A **new generation of QCLs and QCL-combs,** produced in collaboration with the European companies leader in their fabrication, which will be able to operate in a quantum regime, emitting squeezed light with entanglement among the modes.



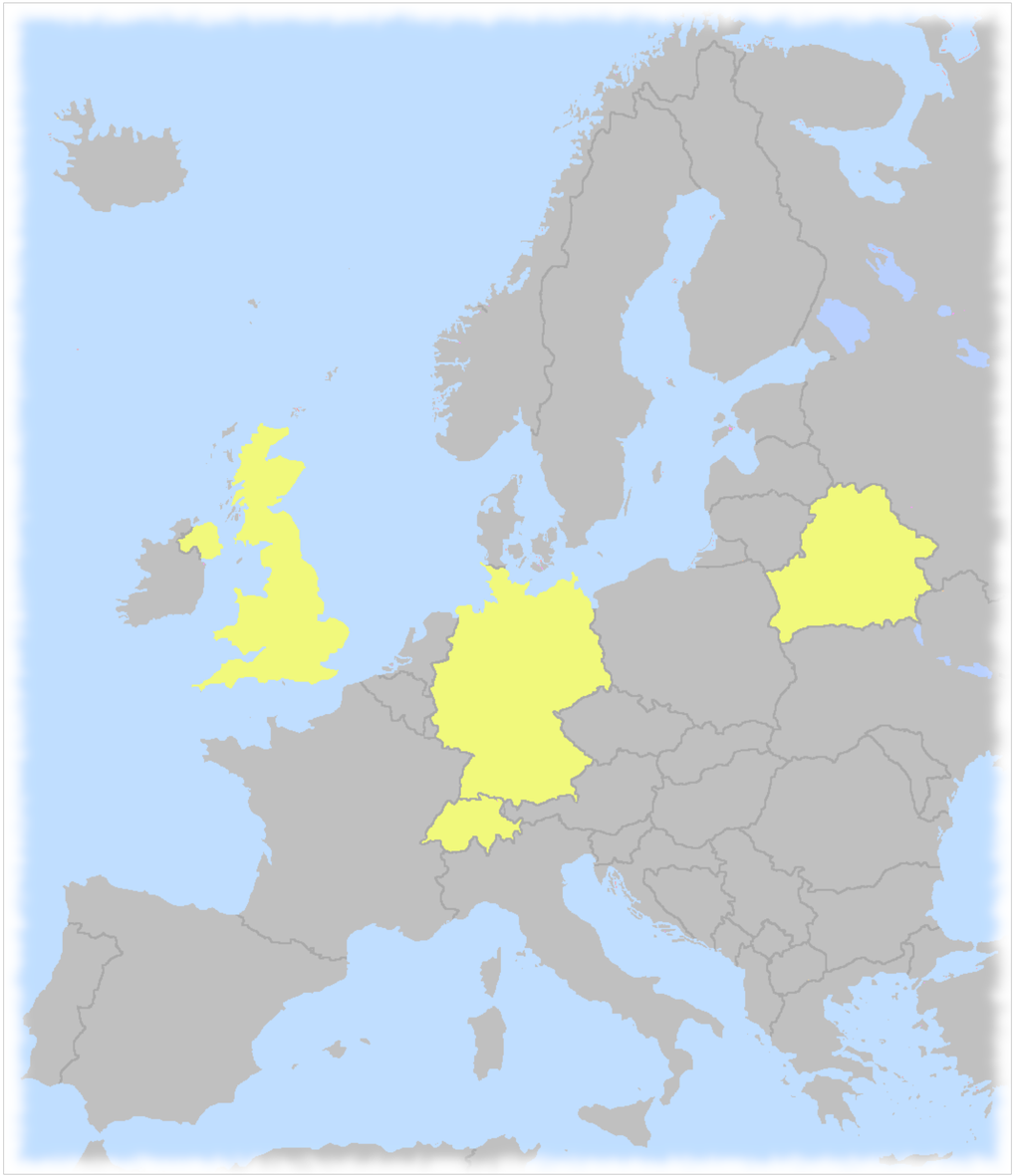
- **Applications**

advanced (secure) free-space communication, high-sensitivity detection of pollutants and health monitoring.

PhoG Project 820365

Consortium

1. Natalia Korolkova, University of St. Andrews, Coordinator
2. Robert Thomson, Heriot Watt University, Edinburgh, UK
3. Dmitri Mogilevtsev, Institute of Physics, Belarus Academy of Sciences, Minsk (IPNASB)
4. Christine Silberhorn, University of Paderborn, Germany
5. Dmitri Boiko, Centre Suisse d'Electronique et Microtechnique (CSEM),Switzerland



PhoG Project 820365

Sub-Poissonian Photon Gun by Coherent Diffusive Photonics

Objective: deliver deterministic and compact sources of highly non-classical states with **sub-Poissoninan statistics + multi-partite entanglement**

How: coherent diffusive photonics operating with **dissipatively coupled waveguide networks** in linear and non-linear glass materials

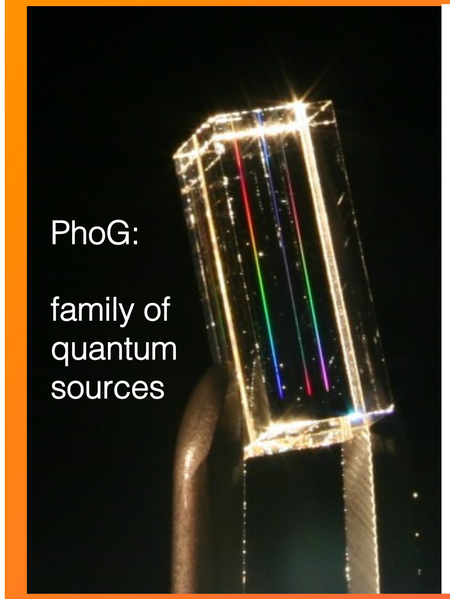
Expected deliverables:

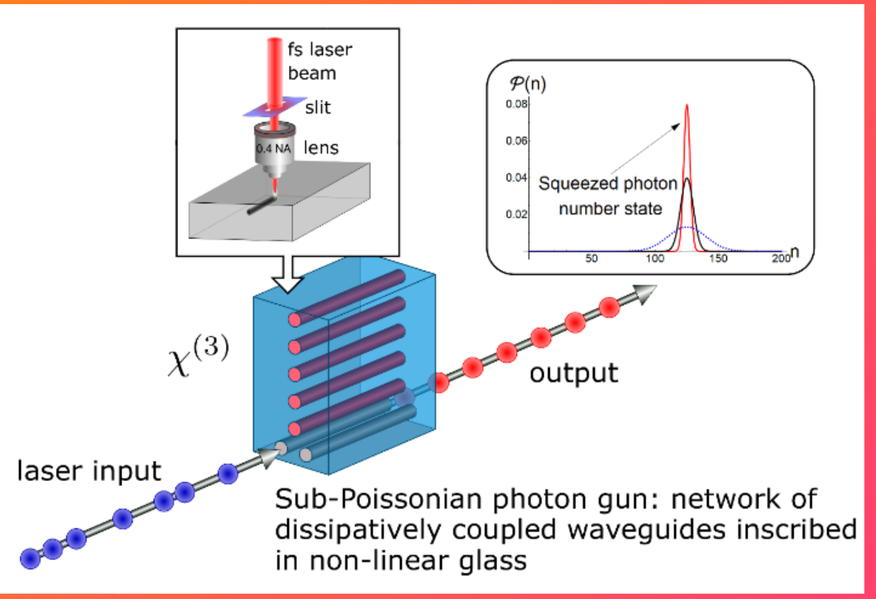
-) quantum networks based on management of correlation flow in waveguide arrays

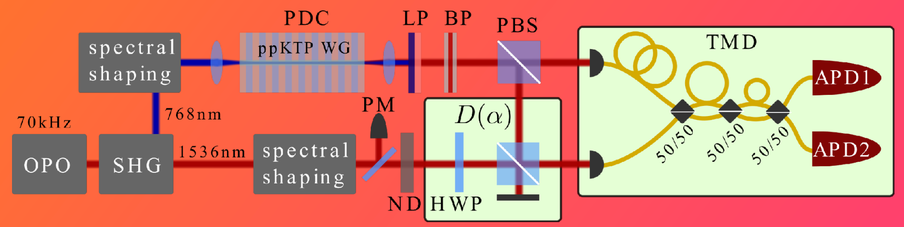
-) entanglement-enhanced imaging with improved resolution

-) atomic clocks with entanglement-enhanced frequency stability

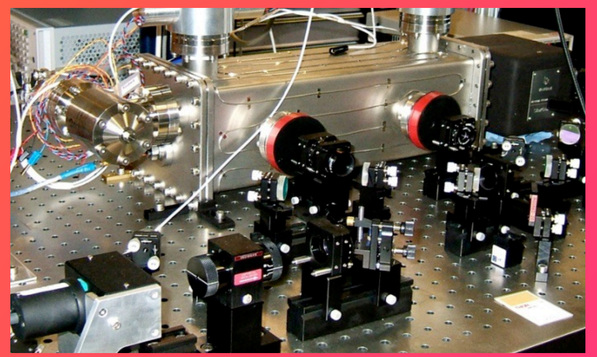
-) assessment of technology benefits & roadmap for **metrology applications.**







Quantum state characterization; Time-multiplex detection; Nonlinear waveguides χ (2)



Optically-pumped space Cesium clock at CSEM:

PhoG applications in metrology

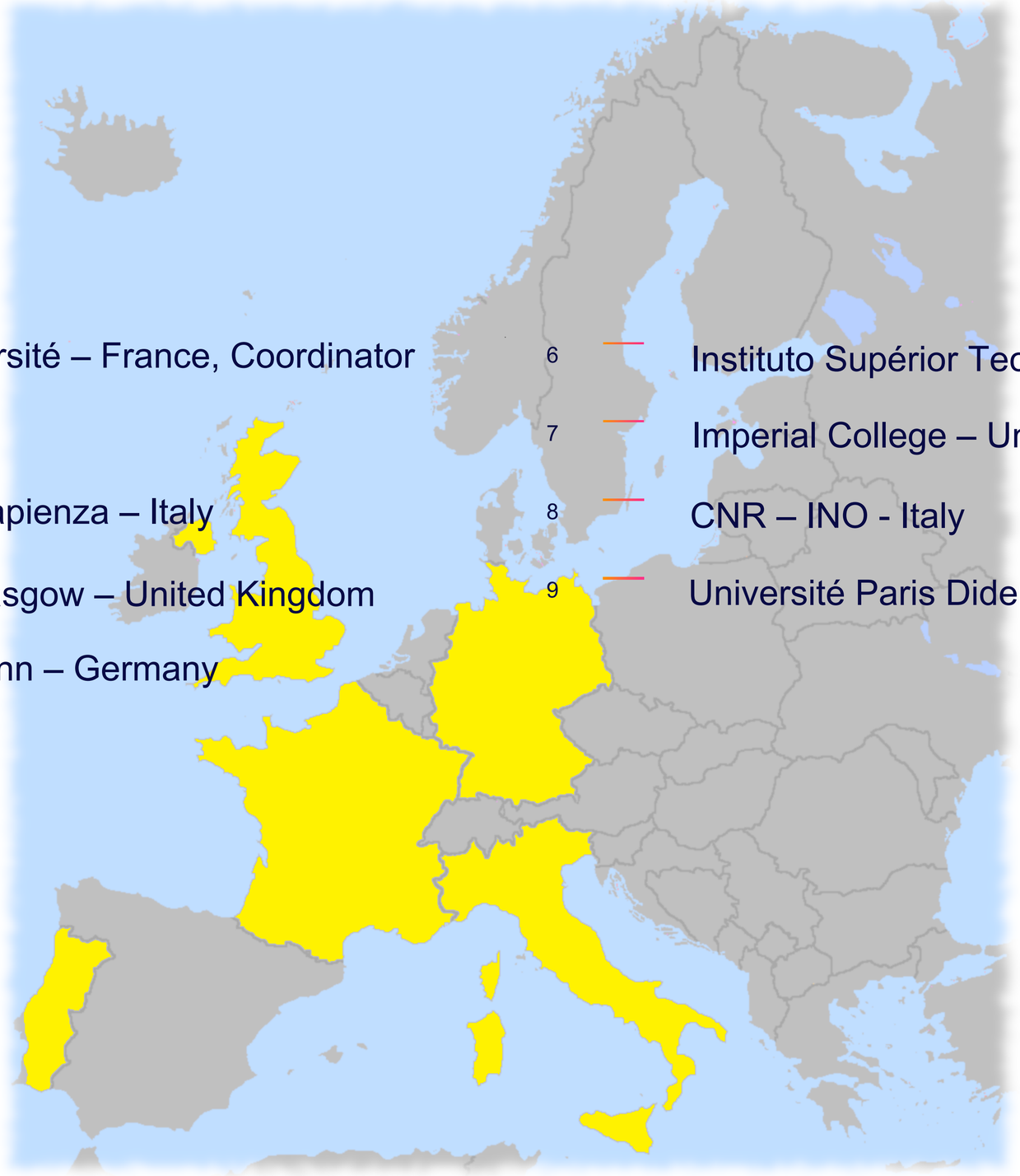
Basic science

PhoQuS

Photons for Quantum Simulation

Consortium

1. Sorbonne Université – France, Coordinator
2. CNRS – France
3. Università La Sapienza – Italy
4. University of Glasgow – United Kingdom
5. University of Bonn – Germany
6. Instituto Supérior Tecnico – Portugal
7. Imperial College – United Kingdom
8. CNR – INO - Italy
9. Université Paris Diderot – France



PhoQuS
Photons for Quantum Simulation

Photons for Quantum Simulation

Novel platform for quantum simulation, based on photonic quantum fluids.

The density, phase and velocity of the generated quantum fluid can be fully controlled and their evolution detected in real time with high spatial resolution.

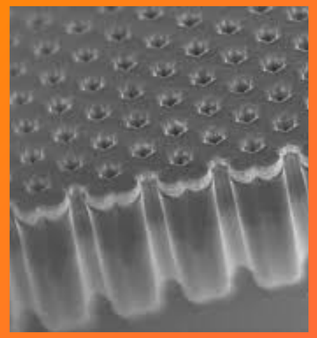
Objectives

- Full understanding of the **superfluid** and **quantum turbulent regimes** for quantum fluids of light.
- **Simulation** of systems of very different nature, ranging from **condensed matter** to **astrophysics**, as **Black Holes and Hawking radiation** and the simulation of **localization** phenomena and of **strongly correlated systems**

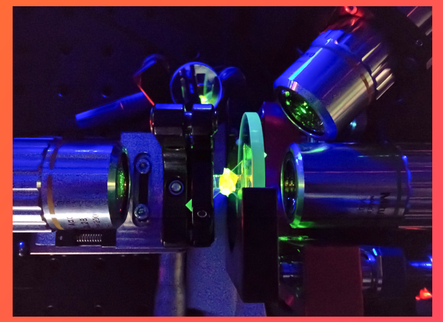
Impact

The project will have impact on fundamental science and quantum technologies (quantum simulations e.g. in solid state physics and cosmology).

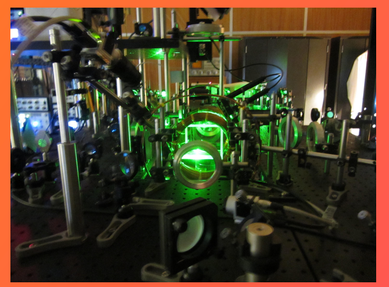
6 state of the art experimental photonic platforms



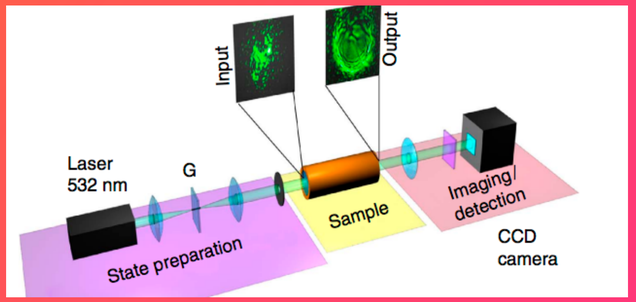
Photons fluids in microcavity polaritons



Photon BEC



Photon Bubbles in atomic BEC



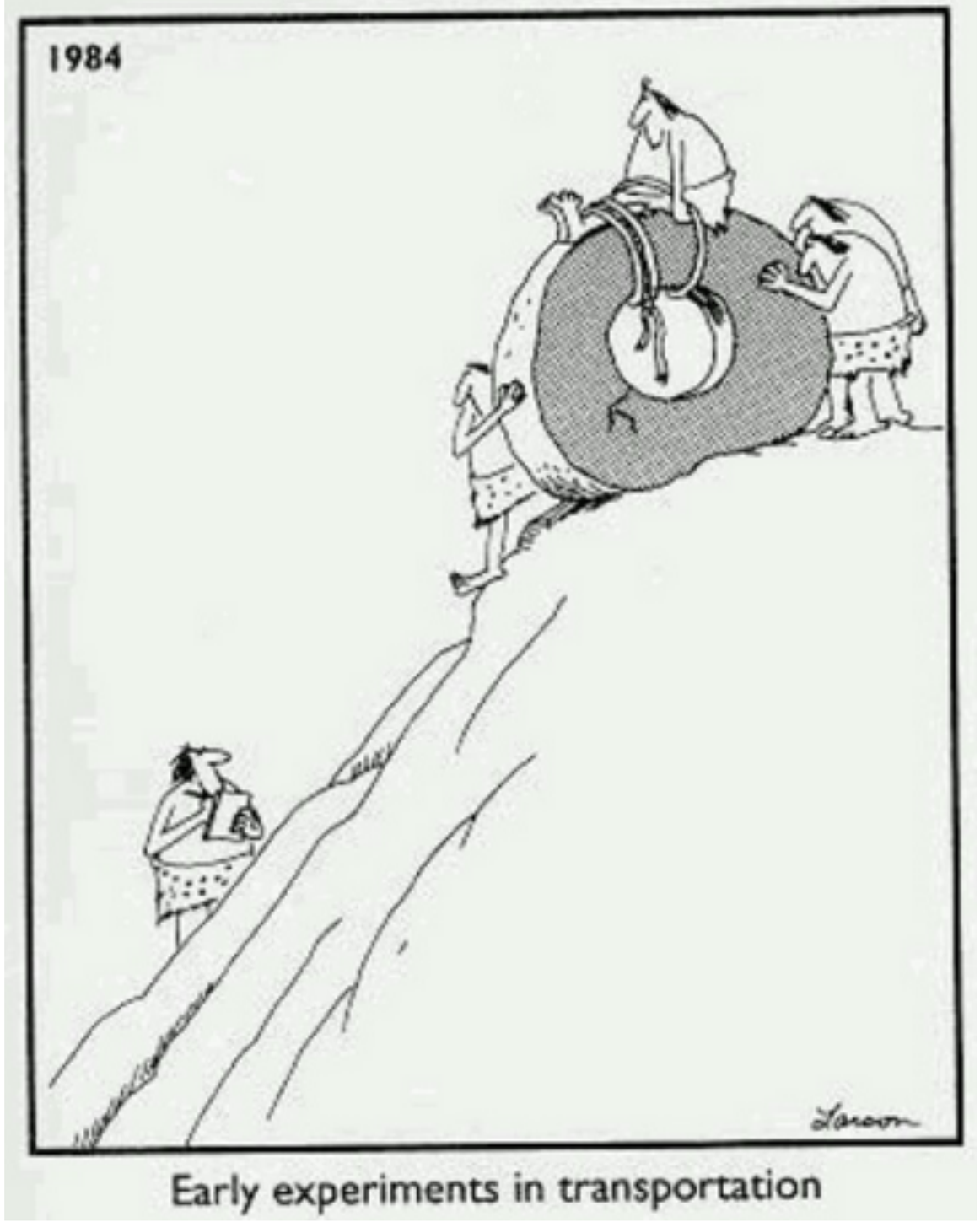
Photon fluids in propagating geometry (Rb vapors, photorefractive crystals, thermo-optic liquids)

3 theory groups with worldwide recognized expertise in photonic quantum fluids

QUANTUM
Simulation

Conclusion

We are a long way ahead of the first pioneering investigations done in the early '80.
Time to build: thank you for the opportunity and thank you for the attention.



Early experiments in transportation