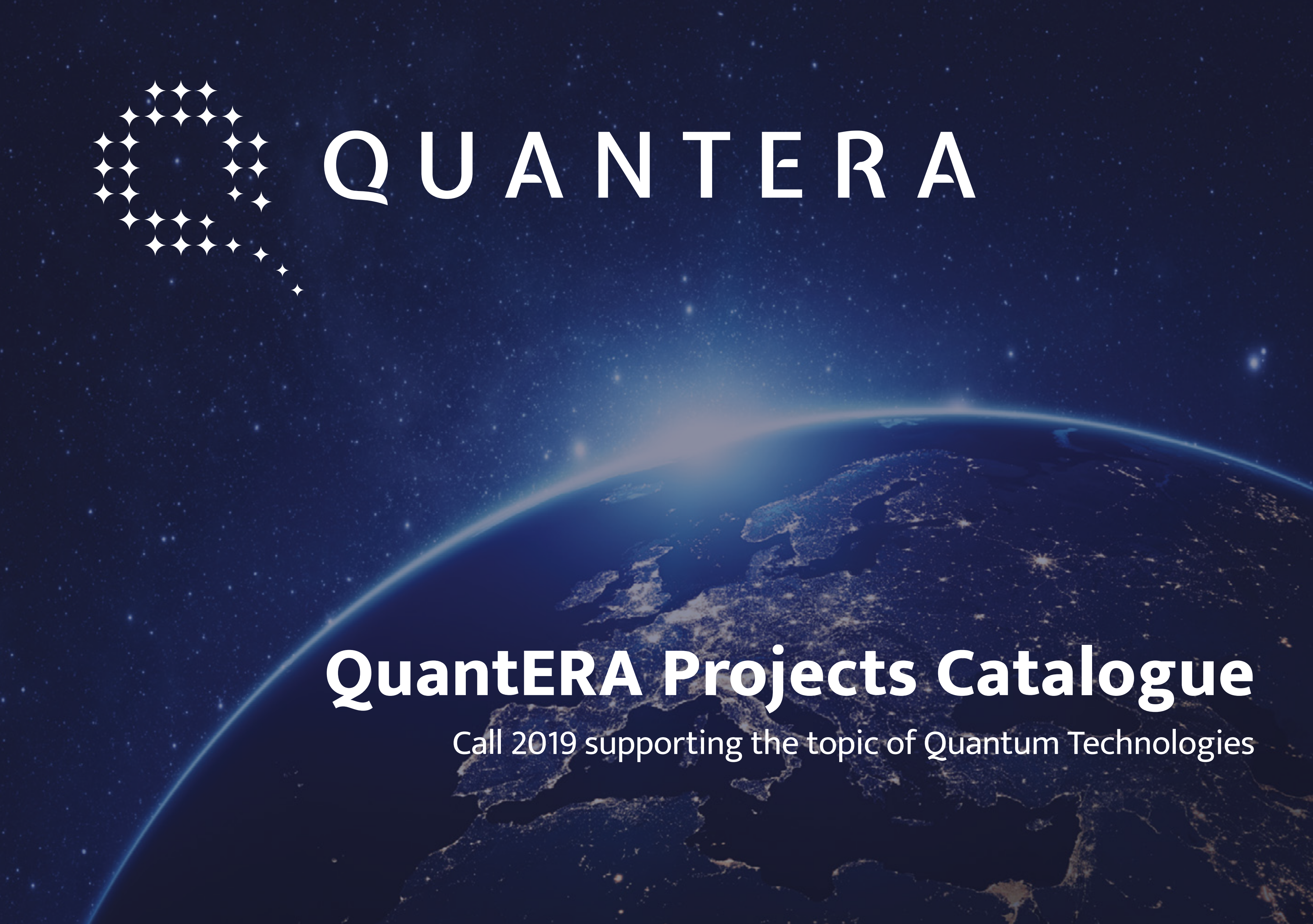

QUANTERA

QuantERA Projects Catalogue

Call 2019 supporting the topic of Quantum Technologies

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QuantERA ERA-Net Cofund in Quantum Technologies

QuantERA is a consortium of 32 organisations from 27 countries, coordinated by the National Science Centre, Poland. It is a European Research Area Network (ERA-NET) in the field of quantum technologies (QT) established as an answer to the growing need for collaborative endeavours and a common funding scheme in this field of research.

QuantERA Calls

The main goal of QuantERA is to launch transnational calls for proposals in the field of quantum technologies. This goal has been successfully accomplished with two calls implemented in 2017 and 2019.

The first QuantERA Call, launched in 2017, attracted unexpectedly high attention of the research community. Thanks to the joint funding provided by the European Commission and QuantERA member organisations, QuantERA funded a total of 26 projects worth over EUR 32M (the Call 2017 projects catalogue is available at www.quantera.eu). Promising research ideas involved 128 research teams and aimed, in particular, to develop novel physical platforms for quantum communication, sensing, and computing, to advance architectures and algorithms for future quantum information processing systems, and to push for hardware scalability.

Building on the initial success, QuantERA Consortium decided to launch a second call for proposals with a broader geographical coverage and a budget of over EUR 20M (this time without the co-funding from the European Commission).

The QuantERA Call 2019, launched by 29 funding organisations from 25 countries, attracted 85 international research consortia applying for over EUR 85 M, out of which 12 were recommended for funding. The projects involve 65 research teams from 19 countries.

Providing the platform for dialogue and cooperation QuantERA contributes to further integration of European research in quantum technologies. QuantERA has been a significant element in the discussions about the future of quantum research in Europe and paved the way for the FET Flagship on Quantum Technology. The results of the QuantERA-funded projects are expected to address a number of societal challenges, including cybersecurity and advanced healthcare.

QuantERA Call 2019 Projects Catalogue

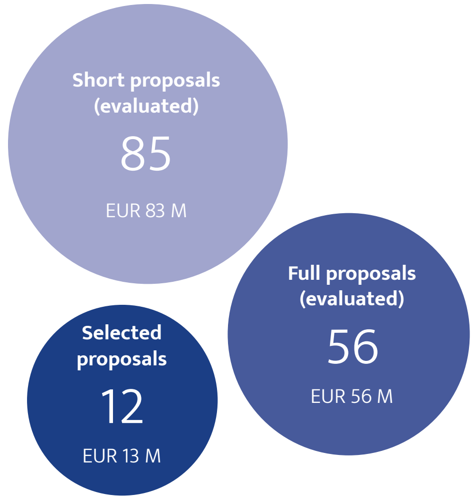
We are pleased to share with you the second catalogue of the QuantERA-funded projects that provides an overview of the 12 excellent proposals recommended for funding within the QuantERA Call 2019.

Topics Addressed

Thematic scope of the QuantERA Call 2019 encompassed the following areas:

- **Quantum communication**
- **Quantum simulation**
- **Quantum computation**
- **Quantum information sciences**
- **Quantum metrology sensing and imaging**

Funding Requested and Granted



Topics Distribution (%)

Call Topics	Short proposals	Full proposals	Selected proposals
Q-communication	25%	27%	42%
Q-computation	31%	30%	25%
Q-information sciences	39%	36%	25%
Q-metrology sensing and imaging	25%	29%	25%
Q-simulation	18%	18%	17%

QuantERA Calls 2017 & 2019

QuantERA Call 2017

Pre-proposals: **221**

Full proposals: **91**

Selected projects: **26**

QuantERA Call 2019

Pre-proposals: **85**

Full proposals: **56**

Selected projects: **12**

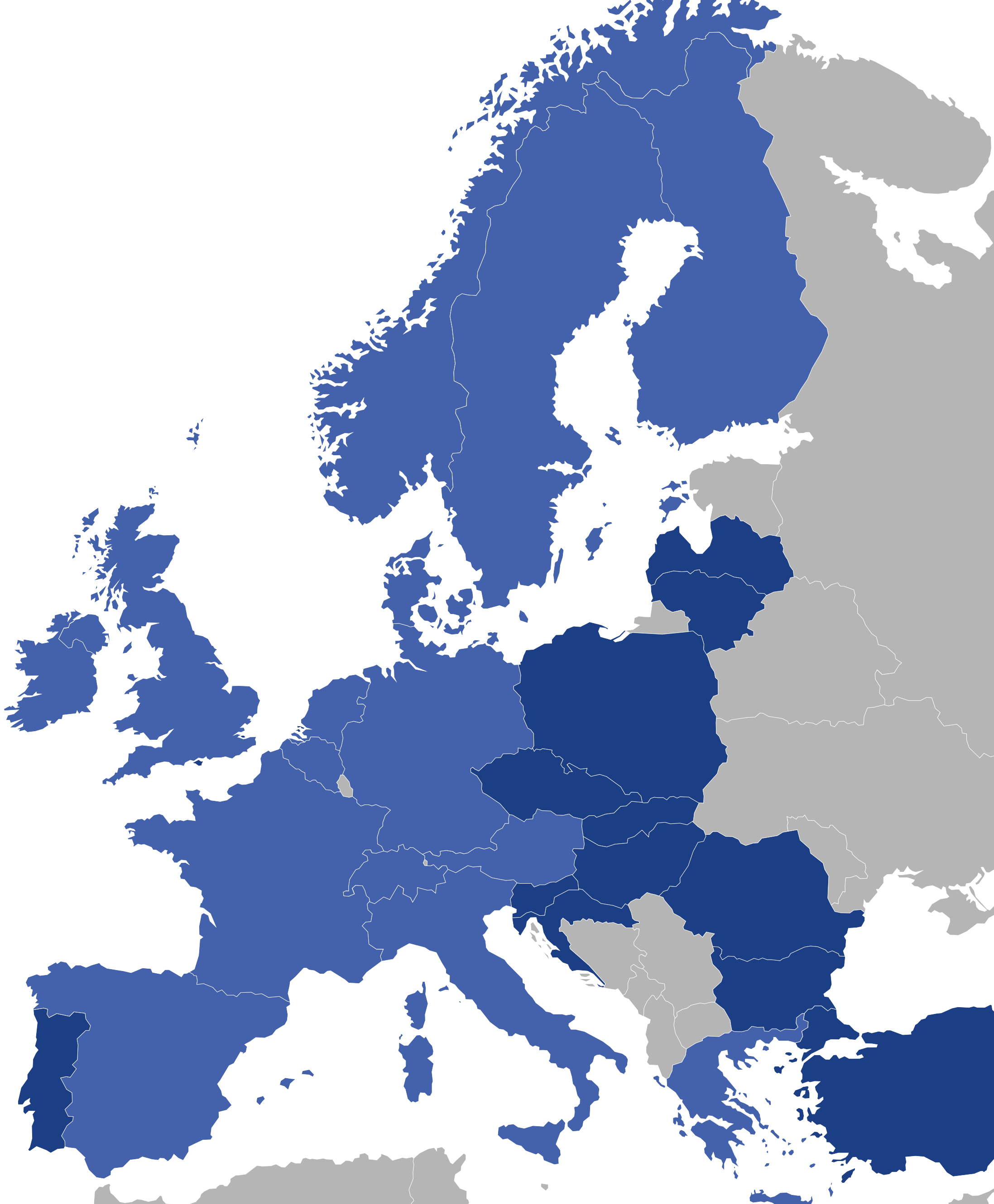
EUR 45 M
total budget

38
transnational research projects

193
research teams from 25 countries

Spreading Excellence

With an aim to spread excellence across the European Research Area, QuantERA network introduces successful mechanisms supporting inclusiveness and greater participation of the less represented countries in the framework programmes. Both of the QuantERA calls encouraged geographically balanced consortia embracing the diversity of scientific communities across Europe and beyond. As a result, research teams from so-called "widening countries" are involved in almost 70% of the funded projects (18 out of 26 in the first call, 8 out of 12 in the second call).



QuantERA Call 2019
Funded Projects

ApresSF

Application-ready superresolution in space and frequency

The wave-particle duality of light introduces two fundamental problems to imaging: the diffraction limit and photon shot noise. With quantum information theory one can tackle both of them with a single holistic formalism: model the light as a quantum object, consider any quantum measurement, and pick the one that gives the best statistics. While Helstrom pioneered the theory and first applied it to incoherent imaging back in the 1970s, it was not until recently that the approach offered genuine surprises on the age-old topic by predicting a new class of superior imaging methods.

For the resolution of two sub-Rayleigh sources, such as stars or microscopic fluorophores, novel methods have very recently been theoretically and experimentally shown to outperform direct imaging, reaching the true quantum limits. Further efforts to generalize the theory for arbitrary sources suggest that, despite the existence of harsh quantum limits, the quantum-inspired methods can still offer significant improvements over direct imaging, potentially rendering more applications in astronomy, as well as in fluorescence microscopy. Such protocols for quantum-enhanced parameter estimation can also be applied to measure time or frequency with very high accuracy.

Given the know-how of the partners, in the proposed project we plan to design, systematically study and implement engineered coherent measurements in order to push the metrological resolution in space, time and frequency to its limits, at the same time making it available for technological and industrial applications.

CONSORTIUM

Coordinator:
ŁUKASZ RUDNICKI
(UNIVERSITY OF GDAŃSK, PL)

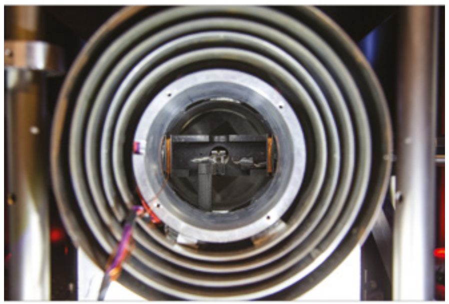
- Christine Silberhorn (University of Paderborn, DE)
- Zdeněk Hradil (Palacky University, CZ)
- Luis Lorenzo Sanchez-Soto (Universidad Complutense, ES)
- Nicolas Treps (Sorbonne Université, FR)
- Jean-François Morizur (Cailabs, FR)

C'MON-QSENS!

Continuously Monitored Quantum Sensors: Smart Tools and Applications

Acquiring and interpreting data about physical processes is vital for science and technology. C'MON-QSENS!'s targeted breakthrough is to develop tools to interpret data acquired from quantum sensors. Indeed, quantum-enhanced ultra-precise sensors are among the most disruptive quantum technologies with near-term applications in several disciplines, but with a limited reach so far.

Most efforts are devoted to the measurement of static properties by singleshot or repeated measurement schemes, while many real-world applications are concerned with dynamical signals. Extracting information from time-series of data needs sensors operating in the continuously monitored regime, and here is where the interdisciplinary approach of C'MON-QSENS! emerges. We aim to develop continuously monitored hot atomic ensembles and optomechanical devices, and we pursue their application in a collaboration with leading experimentalists and theory researchers in quantum information theory, statistical inference and classical signal processing. We will create a unique synergy to close the interdisciplinary gap, so modern methods of (classical) signal processing and data inference can be incorporated within the context of quantum metrology.



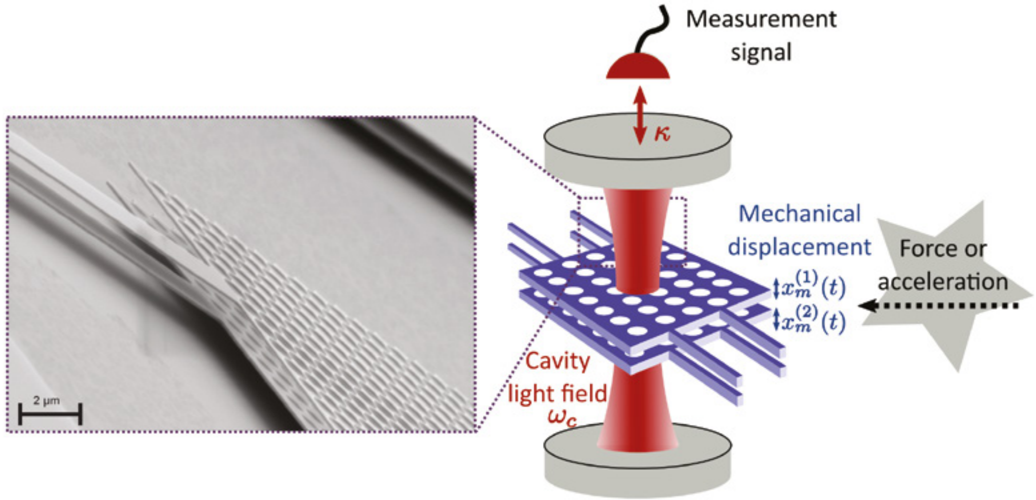
The result will allow advanced sensing tasks to be explicitly demonstrated in experiments. We will both gain a deeper understanding of quantum information processing in the real-time regime, and develop practical approaches to quantum sensing and interpretation of real-time signals. C'MONQSENS! will advance the current frontiers of fundamental and applied knowledge on continuously monitored quantum systems by: A. Constructing advanced dynamical models to allow for an

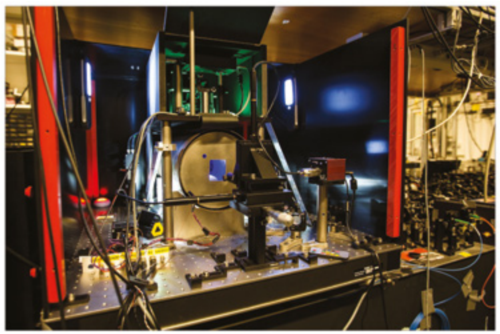
CONSORTIUM

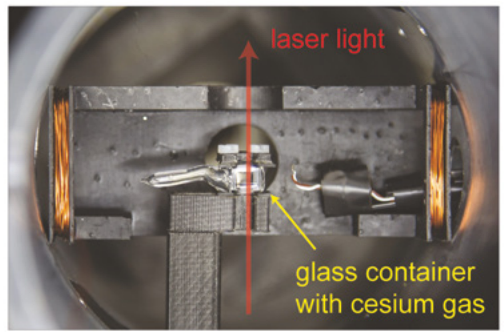
Coordinator:
JOHN CALSAMIGLIA (UNIVERSITAT AUTÒNOMA DE BARCELONA, ES)

- Jan Kołodyński (University of Warsaw, PL)
- Klaus Mølmer (Aarhus University, DK)
- Yonina Eldar (Weizmann Institute of Science, IL)
- Witlef Wieczorek (Chalmers University of Technology, SE)
- Kasper Jensen (University of Nottingham, UK)

accurate description of real-time quantum sensors, including relevant decoherence mechanisms, non-linearities, sources of stochastic noise, and quantum back-action resulting from continuous-time measurements. B. Developing (i) signal processing and statistical inference techniques (Bayesian filtering, compressed sensing, sequential analysis) for highly controlled scenarios when the quantum sensor and signal dynamics can be accurately modelled, and (ii) model-free machine learning methods for real-world complex scenarios. This will advance fundamental theory on continuously monitored quantum systems and provide ultimate bounds on the performance for the relevant sensing tasks. C. Building quantum sensors based on continuously monitored atomic vapours and optomechanical systems. We will apply the dynamical models and inference techniques to optimize the sensors' operating regimes to allow tracking of real-life signals (e.g. neuron, brain, heart, and acceleration) and validate advanced sensing tasks such as wave-form estimation, model selection and change-point/anomaly detection.







eDICT✦

Experimentally-oriented Device Independent CrypTography

Current state-of-the art quantum-assisted cryptography provides safety beyond what can be achieved with current classical technologies. Yet still, its safety is at question when we consider possibilities of quantum hacking or malicious producers of necessary quantum resources.

This project aims at overcoming these main limitations by radically shifting current paradigms—by using device independent cryptographic (DIC) architecture. This is on one hand more demanding on experimental resources and theoretical understanding but on the other hand provides qualitative improvement in safety. DIC devices would then be not only safe against exploiting deviations of a real life from theoretical model but they would also have possibility of verification whether using such a device is secure. The success of the project stands both on firm theoretical foundations of various backgrounds and high-quality experimental realisation. This can be achieved only with the composition of partners with high interdisciplinary reach. Our consortium contains excellent groups covering all necessary parts within the project with their expertise both on theoretical as well as experimental sides. With synergic effort we will devise new more efficient Bell inequalities with improved critical detection efficiency bounds, derive new tools for device independent and iid analysis, and design new DIC key distribution protocols. On experimental side our aim is to provide a testbed for researched Bell inequalities. Namely we will perform practical tests of the possible state production.

CONSORTIUM

Coordinator:
JAN BOUDA
(MASARYK UNIVERSITY, CZ)

- Rupert Ursin (Österreichische Akademie der Wissenschaften, AT)
- Marcin Pawłowski (Uniwersytet Gdański, PL)
- Renato Renner (Eidgenössische Technische Hochschule, CH)
- Tamás Vértesi (Magyar Tudományos Akadémia Atommagkutató Intézete, HU)

✦ Please note that this project has been recommended for funding by the QuantERA Call Steering Committee but the final confirmation of the availability of funds is still pending.

MAQS

Magnetic-Atom Quantum Simulator

We propose to realize a novel quantum simulator made of magnetic atoms in periodic potentials, which will enable the investigation of quantum-many body problems associated with long-range dipole-dipole interactions.

Our proposal is based on a series of key new developments. We will develop new tools to increase the strength of dipole-dipole interactions (shorter-period UV lattices, magneto-association of magnetic atoms into molecules with a stronger magnetic moment), and to control and measure their interaction at the nano-scale (using super-resolution techniques and narrow spectroscopic lines). We will develop new probes to certify the presence of quantum correlations, which are expected to be particularly strong in these many-body long-range interacting systems. We will either probe correlations in real space (microscope, double-well lattices), in momentum space (Doppler spectroscopy), or in the spin sector. These probes will be developed in a joint theory-experiment endeavor, to find the best ways to define and quantify entanglement.

The breakthrough realization of quantum simulators based on lattice-trapped magnetic atoms will allow us to explore for the first time two families of problems. First, we will probe low energy quantum phases stabilized by dipolar interactions; and second, out-of-equilibrium dynamics and quantum thermalization dominated by long-range interactions. A number of exotic phases will be within experimental reach, such as the checkerboard or stripe phases, or peculiar phases of spin systems with long-range interactions. We will aim at protocols to certify the nature of the quantum correlations within these systems. Such correlations can be explored in four different complementary setups: 1) an Er lattice gas within a Dy bath (Innsbruck); strongly dipolar lattice gases made of either 2) Dy atoms in UV lattices (Stuttgart) or 3) Dy2 molecules in standard lattices (Pisa/Florence), and 4) Cr atoms realizing lattice spin models (Paris).

CONSORTIUM

Coordinator:
BRUNO LABURTHE-TOLRA (CNRS, FR)

- Tommaso Roscilde (ENS of Lyon, FR)
- Francesca Ferlaino (Institut für Quantenoptik und Quanten-information, AT)
- Tilman Pfau (Universität Stuttgart, DE)
- Giovanni Modugno (Istituto Nazionale di Ottica, IT)
- Maciej Lewenstein (Institute of Photonic Sciences, ES)
- Mariusz Gajda (Instytut Fizyki Polskiej Akademii Nauk, PL)

PACE-IN✦

Photon-Atom Cooperative Effects at Interfaces

Functional devices for quantum information processing and communication must make use of appropriate matter-light interfaces. Their key role in bringing quantum devices towards practical applications is essential. Hence, building the conceptual and technological base for such interfaces will pave the way for the scalable quantum computation and quantum Internet. The overall objective of this proposal is to meet the critical challenge of studying, implementing and optimizing ground-breaking, dynamically-controlled interfaces between matter and light.

Photons can efficiently and durably transmit quantum information over large distances; cold, trapped ions can be manipulated to enable high-fidelity quantum information processing, while atomic ensembles are particularly suited for long-lived quantum memories, as well as nonlinear generation of non-classical correlations between optical beams. The aim of PACE-IN project is the development of reliable quantum interfaces between atomic systems and photons. We shall develop and demonstrate massive parallel processing, storage and transmission of quantum information by hitherto unexploited collective, multimode quantum states or atomic ensembles and ionic crystals, and design methods to characterize the entanglement and non-classicality of quantum states transferred from atoms and ions to photons.

Efficient interfacing mechanisms between "stationary" atomic qubits or ensembles and "flying" (photonic) quantum variables, whether discrete or continuous, must be robust and dynamically controllable to allow the best possible exploitation of their respective functionalities while maintaining the highest possible overall fidelity/coherence and speed. The scientific and technological challenge that will be addressed in this project is the conceptually and experimentally optimized quantum information processing and manipulation at interfaces for the successful implementation of scalable quantum technologies in combination with long distance quantum communication.

CONSORTIUM

Coordinator:
ROBIN KAISER (CNRS, FR)

- Helmut Ritsch (Universitaet Innsbruck, DE)
- David Petrosyan (FORTH, GR)
- Gershon Kurizki (Weizmann Institute Science, IL)
- Paolo Facchi (INFN, IT)
- Lukáš Slodička (Palacký University Olomouc, CZ)

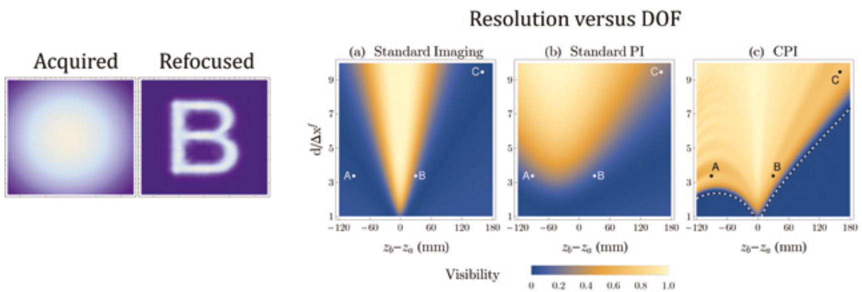
✦ Please note that this project has been recommended for funding by the QuantERA Call Steering Committee but the final confirmation of the availability of funds is still pending.

Qu3D

Quantum 3D Imaging at high speed and high resolution

Qu3D aims at designing and implementing quantum plenoptic cameras: radically novel 3D imaging devices exploiting both momentum-position entanglement and photon-number correlations to enable the typical refocusing and ultra-fast, scanning-free, 3D imaging capabilities of plenoptic devices, but with dramatically enhanced performances:

- diffraction-limited resolution, unattainable in standard plenoptic cameras;
- an unprecedented large depth of focus (DOF), even 10 times larger than in standard imaging at the given resolution;
- ultra-low noise, aiming at sub-shot noise performances.

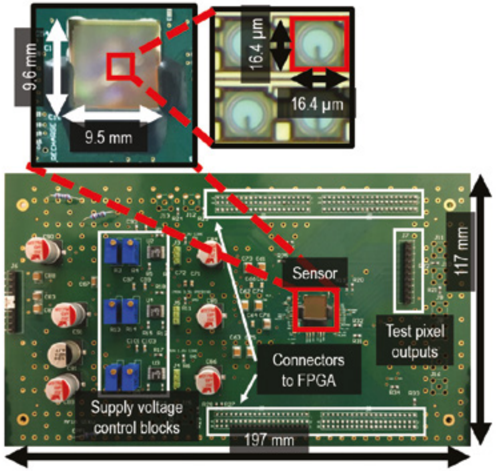


Qu3D merges scientific research and engineering for optimizing the performances of the developed devices in terms of resolution, DOF, noise, and, most challenging, acquisition and elaboration speed. Key elements are world-class single-photon sensor arrays, as well as methods and algorithms for data acquisition, elaboration and analysis inspired by machine learning, compressive sensing, and quantum tomography, combined with

CONSORTIUM

Coordinator:
MILENA D'ANGELO (ISTITUTO NAZIONALE DI FISICA NUCLEARE, IT)

- Bohumil Stoklasa (Palacky University Olomouc, CZ)
- Maria Ieronymaki (Planetek Hellas E.P.E., GR)
- Claudio Bruschini (Ecole polytechnique fédérale de Lausanne, CH)



Copyright: A. C. Ulku et al., "A 512 × 512 SPAD Image Sensor With Integrated Gating for Widefield FLIM," in IEEE Journal of Selected Topics in Quantum Electronics, vol. 25, no. 1, pp. 1–12, Jan.–Feb. 2019, Art no. 6801212.

high-performance low-level programming of fast computing platforms. Based on the enormous scientific, industrial and societal potential of high-speed 3D imaging at high resolution and low noise, the results of Qu3D are expected to generate novel imaging and diagnostic tools, in many branches of science: quantum plenoptic microscopes and endoscopes for biophotonics and biomedical imaging, quantum space imaging devices, quantum 3D cameras for both security and industrial inspection applications. The research is thus expected to open new scientific and technological possibilities, and to play a transformational role in technology and society.

QuantHEP

Quantum Computing Solutions for High-Energy Physics

The key goal of project QuantHEP – Quantum Computing Solutions for High-Energy Physics is to develop quantum algorithms as a solution to the increasingly challenging, and soon intractable, problem of analysing and simulating events from large particle-physics experiments.

The acronym QuantHEP comes from the merging of the names of the sections of the arXiv used by the two communities involved in this project: Quantum Physics (quant-ph), and High-Energy Physics (hep-ex, hep-lat, hep-ph, hep-th). QuantHEP will develop quantum algorithms for event selection and event reconstruction, and will use them to perform proof-of-principle analysis of real data from CERN, exploiting a combination of classical and freely-available quantum processors, and benchmarking the potential advantage of this novel quantum-enhanced processing.

Furthermore, we will develop software libraries to simulate particle physics' objects (elementary particles, composite particles, jets), and will use them as building blocks to develop the quantum simulation of scattering processes. A proof-of-principle scattering quantum simulation will be performed combining classical and freely-available quantum processors, and will be benchmarked against CERN classical simulations to characterize a quantum advantage threshold for HEP processes.

To tackle these challenges, project QuantHEP brings together an interdisciplinary and experienced team whose expertise spans quantum information theory, quantum algorithms, quantum computational complexity, quantum analog and digital computing, quantum simulation, theoretical high-energy physics, experimental (data analysis) high-energy physics, including the corresponding state-of-the-art classical algorithms and neural network methods. Project QuantHEP has also a foundational character, putting forward an original comprehensive approach to investigate and measure the potential of quantum computation for experimental particle physics challenges.

CONSORTIUM

Coordinator:
YASSER OMAR (INSTITUTO DE TELECOMUNICAÇÕES, PT)

- Simone Montangero (INFN, IT)
- Andris Ambainis (Latvijas Universitāte, LV)

QuCoS

Quantum Computation with Schrödinger cat states

This project seeks to establish a radically new, alternative approach to realizing the fundamental building blocks of quantum computers with superconducting qubits. In the next 3 years, we plan to employ only a handful of realistic components to realize robust error-corrected logical quantum bits.

We aim to demonstrate the same level of protection provided by a few hundreds of qubits (with properties beyond the state of the art) in today's mainstream approach of the so-called surface code architecture. Our alternative approach is known as cat codes, because it employs multiple interconnected high coherence cavity modes with non-linear dissipation, to encode a qubit in superpositions of Schrödinger cat states. Our project combines realizing the quantum processor architecture as well as the control system and the protocols that drive it, building towards a full-stack error-corrected quantum computer.

The partners in our collaboration form a strong synergetic group that has the full range of expertise needed to design and realize these systems, and to obtain these challenging goals. Furthermore, all partners of our project, including both industry and academia, have worked together and published works in the fields of quantum computing and quantum information processing. We aim to implement error protected qubits, fault tolerant operations, and demonstrate the scalability of this approach by realizing a repetition code. Our project will enable quantum experiments towards the ambitious and well-defined goal of constructing a logical qubit, on which we can perform gates, and most importantly, quantum error-correctio (QEC). All algorithms with theoretically proven quantum speedup require QEC, therefore, with this project we are realizing an essential building block of a European error corrected quantum processor.

CONSORTIUM

Coordinator:
GERHARD KIRCHMAIR
(UNIVERSITY OF INNSBRUCK, AT)

- Benjamin Huard (Ecole Normale Superieure de Lyon, FR)
- Zaki Leghtas (Ecole Normale Superieure de Paris, FR)
- Ioan Pop (Karlsruher Institut fur Technologie, DE)
- Yonatan Cohen (Quantum Machines, IL)
- Luiza Buimaga-Iarinca (National Institut for Research and Development of Isotopic and Molecular Technologies, RO)

QuICHE

Quantum information and communication with high-dimensional encoding

High-dimensional (HD) photonic quantum information (QI) promises considerable advantages compared to the two-dimensional qubit paradigm, from increased quantum communication rates to increased robustness for entanglement distribution. This project aims to unlock the potential of HD QI by encoding information in the spectral-temporal (ST) degrees of freedom of light.

Every light beam has a large capacity for information coding in its ST degrees of freedom, which, through broadband optical fiber communications, underpins the massive capacity of the internet. Quantum light beams inherit this capacity, which has been as-of-yet underexplored and underutilized. What is needed is a unified theoretical approach to HD quantum states that is relevant to real experimental devices, accounting for real-world imperfections in order to unlock the full potential of ST-encoded HD QI processing. This project will deliver such a joint effort to bridge this gap. We will carry out connected theoretical and experimental research to achieve secure communication in bipartite and multipartite scenarios, enhance the performance of quantum networks, and develop efficient methods for dimension witnesses, entanglement certification, estimation of properties of quantum states and channels, and quantum metrology. Moreover, we will introduce and develop the new concept of HD quantum temporal imaging. Experimental implementation will be based on novel HD encodings in time and frequency based on ultrafast quantum optical approaches in nonlinear waveguide and electro-optic devices. Key to experimentally accessing the HD potential of the ST encoding will be the noiseless manipulation of time scales using the concepts of quantum temporal imaging. Combined experimental and theoretical efforts will yield a unified platform for HD, integrated optical QI processing, communication, and sensing.

CONSORTIUM

Coordinator:
CHIARA MACCHIAVELLO (INFN, IT)

- Dagmar Bruß (University of Düsseldorf, DE)
- Ian Walmsley (Imperial College London, UK)
- Mikhail Kolobov (CNRS, FR)
- Michał Karpiński (University of Warsaw, PL)
- Christine Silberhorn (University of Paderborn, DE)

SECRET

SECuRe quantum communication based on Energy-Time/time-bin entanglement

Entanglement is a crucial resource in quantum communications. It allows a higher level of security in quantum key distribution, as well as being a requirement in many communication protocols supporting the quantum internet. Therefore it is very important to ensure that entanglement can be certified, and a very popular way to do it is through a Bell inequality violation.

A particularly important type of photonic entanglement is called energy-time (ET). It has been very popular over the last 25 years or so, since it is very robust against disturbances that affect other types of entanglement over optical fibers. The downside has been that most experimental implementations employ the famous "Franson's configuration", which has an inherent flaw called the post-selection loophole that invalidates a Bell inequality violation, unless extra assumptions are present. All members of this consortium have been responsible for proposing and carrying out the first, and so far only performed, QC experiments based on ET (and its pulsed version called time-bin) entanglement that do not present the post-selection flaw, and thus can be used to perform experiments based on "genuine" ET/time-bin entanglement.

This project now aims to carry out the first generation of genuine energy-time/time-bin experiments aimed at final, practical applications. We intend to perform, based on this type of entanglement the first: (i) QKD experiments and (ii) entanglement swapping/teleportation experiments. Furthermore, our project will also perform the first implementations of QKD with genuine energy-time/time-bin entanglement on integrated photonic circuits, as well as strong theoretical analysis on the post-selection loophole in these new experiments. The results proposed will form an important experimental and theoretical framework to support the future development of the quantum internet based on the telecommunication optical fibre network.

CONSORTIUM

Coordinator:
GUILHERME B. XAVIER
(LINKÖPING UNIVERSITY, SE)

- Giuseppe Vallone (INFN, IT)
- Adán Cabello (Universidad de Sevilla, ES)

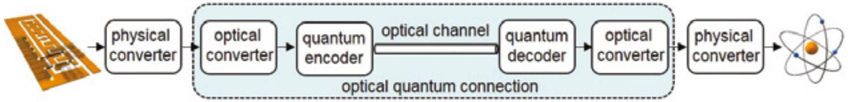
ShoQC

Short-range optical Quantum Connections

The project is concerned with the possibility of connecting heterogeneous quantum devices in a room, a building, or between buildings on a campus or in a limited neighbourhood. The challenge is to develop optical quantum connections versatile enough to connect different physical quantum platforms and faithfully carry a broad range of quantum states including discrete and continuous-variable Gaussian or non-Gaussian states.

In contrast to distances of 1000km or more, as usually envisaged with quantum repeaters, the channel lengths considered are as short as a few meters and no longer than 10km. However, fidelities for directly transmitting fragile highly non-classical states may be far from unity even at such short distances. Especially, errors that do not originate from transmission loss, such as instabilities through thermal noise or mechanical vibrations in a building, will become important. Reliably and efficiently connecting quantum computers through a future broadband local area network will require a high level of fault tolerance. Thus, optical quantum connections based on advanced quantum technology, including quantum error detection and correction, will become crucial in the deployment of future quantum data centers and their interconnects.

First, we will explore the fundamental limits and performance of direct quantum connections independent of active quantum error correction, only depending on the quantum optical engineering of modes, states, and channels. In a further approach, we will incorporate channel-adapted quantum error correction codes to suppress errors that occur in a realistic short-range quantum link. The project will compare these approaches and determine the best combination of theoretical optimality and experimental feasibility.



CONSORTIUM

Coordinator:
PETER VAN LOOCK
(UNIVERSITÄT MAINZ, DE)

- Christoph Marquardt (Max Planck Institute for the Science of Light, DE)
- Nicolas Cerf (Université libre de Bruxelles, BE)
- Jonas Neergaard-Nielsen (Technical University of Denmark, DK)
- Julien Laurat (Sorbonne Université, FR)
- Marco Bellini (CNR, IT)
- Radim Filip (Univerzita Palackeho v Olomouci, CZ)

SiUCs

Superinductor-based Quantum Technologies with Ultrastrong Couplings

Superconducting quantum circuits form one of the most promising solid state platforms for quantum computing. This success builds on the naturally large interaction between light, represented by microwave signals, and matter, embodied by superconducting qubits.

Microwave photons are used at every stage of quantum information protocols: qubit manipulation, qubit readout and qubit-qubit coupling. To describe this rich and ubiquitous light-matter interaction, the community has relied so far on the conceptual tools inherited from quantum optics. However, atoms and photons interact weakly, perfectly justifying the use of the rotating wave approximation (RWA), which states that non-resonant processes can be safely neglected. The situation with superconducting circuits is quite different since qubits can literally be wired to transmission lines carrying microwave photons. And limitations of the RWA have already been pointed out for qubit readout or driven-dissipative protocols.

SiUCs will follow a radically new approach: we will harness the potentiality of very large light-matter coupling -often referred to as ultra-strong coupling- instead of fighting it. In order to address this challenging approach in a controlled way, we will develop an architecture based on superinductors. Resonators and transmission lines built from such components display impedances close to the quantum of resistance (RQ~6.5 kOhms) at gigahertz frequencies, with very low losses, allowing a boost in light-matter interaction. SiUCS will more specifically focus on improving the efficiency of qubit operations involving light-matter interactions. In addition, superinductors will be used to engineer a missing device of the superconducting quantum circuit toolbox: the microwave single photon detector. Finally, unique many-body physics associated to ultrastrong couplings will be investigated thanks to purposely designed quantum simulators.

CONSORTIUM

Coordinator:
POL FORN-DÍAZ (IFAE, ES)

- Ioan Pop (Karlsruhe Institute of Technology, DE)
- Milena Grifoni (Regensburg University, DE)
- Miroslav Grajcar (Slovak Academy of Science, SK)
- Nicolas Roch (University Grenoble Alpes, CNRS, FR)
- Elisabetta Paladino (CNR, IT)

QUANTERA

Call Secretariat

FRENCH NATIONAL RESEARCH AGENCY

Dr. Sergueï Fedortchenko
International Scientific Project Officer
serguei.fedortchenko@anr.fr

www.quantera.eu

Coordinator

NATIONAL SCIENCE CENTRE, POLAND

prof. Konrad Banaszek
Scientific Coordinator
konrad.banaszek@ncn.gov.pl

Sylwia Kostka
Programme Coordinator
sylwia.kostka@ncn.gov.pl

Marlena Wosiak
Coordination Office
marlena.wosiak@ncn.gov.pl

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