

DELIVERABLE 4.4

List of opportunities for future space missions with quantum technologies

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INTRODUCTION

The European Space Agency and several national agencies in Europe and worldwide have initiated and are supporting activities in quantum technologies, with internal studies as well as space missions.

This kind of information is part of the official documentation made available by the space agencies. Here we report on the activities organized by QTSpace in order to create **new opportunities** for space developments of quantum technologies.

There are two relevant outcomes:

- The “Strategic Report for ESA and the National Space Agencies”, prepared in 2017
- The “Policy White Paper on Quantum Technologies for Space”, prepared in 2019

These two documents are currently used by the policy makers, in particular the European Commission, to decide the priorities for the implementation of QT in Space.

IMPLEMENTATION

On **9th June 2017** a meeting was held in **Munich**, with Tommaso Calarco representing the QT Flagship and a selected group of people from Academia, Industry and ESA, to discuss activities regarding QT and Space. The meeting was organized by Angelo Bassi and Mauro Paternostro (as QTSpace Chair and Deputy-Chair, respectively).

It was decided to prepare a strategic report for ESA on QT in Space, to be delivered at the November 2019 ESTEC meeting. The report would have been open to the scientific community for suggestions for improvement. Based on that, a final report was prepared.

In the subsequent months, QTSpace organized an international scientific committee with the aim of preparing the strategic paper. The following members of the scientific and academic community agreed to work on the document:

Secure Communication

Paolo Villoresi - coordinator - University of Padua (IT)
Eleni Diamanti - CNRS, Univ. Pierre and Marie Curie (FR)
Bruno Huettner - ID Quantique (CH)
John Rarity - University of Bristol (UK)
Rupert Ursin - IQOQI (AT)

Time and Frequency Services

Stephan Schiller - coordinator - Heinrich-Heine-Universität (DE)
Davide Calonico - INRIM (IT)
Helen Margolis - NPL (UK)
Ivan Prochazka - Czech Technical University (CZ)
Christophe Salomon - LKB ENS (FR)
Wolfgang Schäfer - TimeTech GmbH (DE)
Harald Schnatz - MenloSystems GmbH (DE)
Lorenzo Simone - Thales Alenia Space (IT)

Earth Sensing and Observation

Philippe Bouyer - coordinator - Institut d'Optique (FR)
Alberto Anselmi - Thales Alenia Space (IT)
Kai Bongs - University of Birmingham (UK)
Trevor Cross - Teledyne e2v (UK)
Guglielmo Tino - University of Florence (IT)
Wolf von Klitzing - FORTH (GR)

Fundamental Physics

Hendrik Ulbricht - coordinator - University of Southampton (UK)
Rainer Kaltenbaek - Universität Wien (AT)
Ernst Rasel - Leibniz Universität Hannover (DE)
Albert Roura – Universität Ulm (DE)
Andre Stefanov – Universität Bern (CH)

Research & Development

Christoph Marquardt - coordinator - M. Planck I. for the Science of Light (DE)
Paolo Bianco - Airbus Defence & Space (UK)
David Vitali - University of Camerino (IT)
Harald Weinfurter - LMU Munich (DE)

The output was the document “**Strategic Report for ESA and the National Space Agencies**” (appendix A), which identifies the state of the art and future strategies for the technological development of quantum devices for space applications. Four pillars were identified:

- Secure Communications
- Time and Frequency Services
- Earth Sensing and Observation
- Fundamental Physics

A fourth horizontal domain “Research and Development” was common to all pillars.

The report was presented in its intermediate form. It was then open to the wider community for feedback, based on which a final report was prepared.

On **15th November 2017**, during the [ESTEC 2nd Workshop on Quantum Technology](#), Angelo Bassi, Chair of QTSpace, handed a strategic report on “Quantum Technologies in Space” over to ESA, represented by Franco Ongaro (Director of Technology, Engineering and Quality and Head of ESTEC) and Jean-François Buggenhout (Deputy Head of Unit, DG CONNECT, European Commission). (Press release in Annex B).

Subsequently, during the **European Quantum Technology Community (EQTC) meeting** held on **18th and 19th April 2018** at ZEISS Forum in **Oberkochen** (Germany), a session *Quantum Technologies in Space* of the EQTC meeting was coordinated and chaired by Angelo Bassi. The discussion focused in two topics: 1) *Quantum Science in Space* and 2) *Quantum Technologies for Space Applications*.

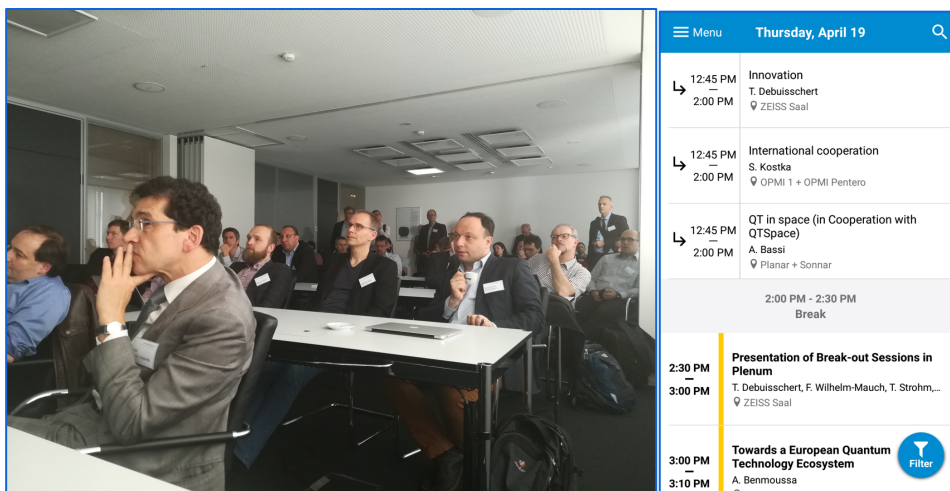


Figure 1: Right Panel: part of the *Quantum Technology in Space* session auditorium. Left panel: Screenshot of the ZEISS app with part of the EQTC meeting program.

After the QTSpace session, a summary of the discussion was presented to the EQTC, that counted more than 250 participants. The presentation was given by the Chair of the Action and it summarized the QTSpace session, which was one of the 6 parallel session of EQTC meeting.



Figure 2: Part of the EQTC auditorium at the QTSpace summary.

In the following months, QTSapce was asked to support the writing of the Space section of the document “[Supporting Quantum Technologies beyond H2020](#)”, which was later handed over to the European Commission, as an input to the discussion on HE.

During **2019**, QTSpace launched **The Quantum Spaceship**, a new coordinated action to promote QT in Space aimed at the engagement with stakeholders in Europe. In particular, the initiative has the goal to open a collaborative channel with the relevant departments at the European Commission and European Space Agency.

Quantum Space Network

Distinguished scientists and representatives of industrial actors operating in some of the ESA member countries have agreed to collaborate with QTSpace towards the achievement of the goals of this initiative. They will form the “Quantum Space Network”(QSN), which will have the mandate to liaise with national stakeholders, policy makers, funding bodies, and ESA delegates. QSN will work in synergy with the Quantum Community Network established within the context of the EU Quantum Flagship initiative.

Members of the Quantum space Network are:

Chair: Angelo Bassi

Deputy Chair: Mauro Paternostro

Country	QSN Member - Academia
Austria	Rupert Ursin, IQOQI Vienna
France	Philippe Bouyer, Institut d'Optique Eleni Diamanti, CNRS, Sorbonne University (deputy)
Germany	Christoph Marquardt, Max Planck Institute for the science of Light Ernst Rasel, University of Hannover (deputy)
Greece	Wolf von Klitzing, Institute of Electronic Structure and Laser, Foundation for Research and Technology - Hellas
Hungary	Laszlo Bacsardi, University of Sopron
Italy	Angelo Bassi, University of Trieste Paolo Villorosi, University of Padua (deputy)
Portugal	Yasser Omar, Universidade de Lisboa Manfred Niehus, ISEL - Instituto Politécnico de Lisboa (deputy)
Spain	Antonio Acin, The Institute of Photonic Sciences Valerio Pruneri, The Institute of Photonic Sciences (deputy)
Switzerland	Hugo Zbinden, Université de Genève
United Kingdom	Mauro Paternostro, Queen's University Belfast Hendrik Ulbricht, University of Southampton (deputy)
Company	QSN Member - Industry
Airbus Defence and Space Ltd	Paolo Bianco
OHB-System AG	Bernhard Sang Stephan Seidel Norbert Lemke
Thales Alenia Space	Mathias van den Bossche

Quantum Space Advisory Board

It consists of leading European scientists have agreed to be part of an Advisory Board (AB) with the task of providing advice to QSN on strategic initiatives.

Prof. Roberto Battiston - University of Trento (IT)
Prof. Wolfgang Ertmer - Leibniz Universität Hannover (DE)
Prof. Elisabeth Giacobino - Sorbonne Université (FR)
Prof. Nicolas Gisin - Université de Genève (CH)
Prof. Sir. Peter Knight - Imperial College London (UK)
Prof. Itzik Ben Israel - Israeli Space Agency, President (IL)

The committee met in Munich on 6th May 2019 to prepare the **Policy White Paper on Quantum Technologies for Space** (Annex A). From the Executive Summary:

This white paper aims at summarising the state of the art in the development of quantum technologies which have impact the field of space applications, and to also delineate a roadmap for the consideration of major actors in this area, i.e. from the European Commission – as responsible in the definition of the EU space strategy – to ESA, national space agencies and industries. The goal is to outline a complete framework for the design, development, implementation, and exploitation of such space QT. Moreover, the paper embodies an opportunity to identify and to implement the necessary steps towards the definition of a realistic avenue for achieving the goals of the European Commission in the development of a mid- and long-term strategic vision of QT in space more prosperous and reliable for Europe.

Following the QT Flagship, the long-term vision that should be pursued is to integrate the terrestrial quantum web with a space one, where quantum computers, simulators and sensors are interconnected via quantum communication networks.

The document was made publicly available for the community and the policy makers.

Parallel to this document also the industrial community prepared a **European Industry White Paper** (Annex A).

CONCLUSIONS

QTSpace successfully coordinated the European academic and industrial community with the goal of presenting and describing the opportunities offered by quantum technologies for Space applications.

The listed output documents were influential in assisting the policy makers, in particular, the European Commission, when deciding and defining the priorities and policies for future Space activities.

ANNEX A

Policy White Papers on Quantum Technologies for Space

QTSpace and European Industries prepared three policy White Papers on quantum technologies for space applications. They are addressed to European policy makers, as well as the scientific and industrial community, with the aim of identifying the most relevant quantum technologies and of shaping the future directions for research and technological development.

[Strategic Report for ESA and the National Space Agencies](#) - November 2017

The Strategic Report on Quantum Technologies in Space aims at coordinating the research and technological activities at the European level, as well as shaping the policies for the next years. The Scientific Committee in charge of the development of the Report has identified the topical areas that will have to be addressed by any realistic attempt at producing working prototypes of quantum technologies for space applications.

The Intermediate Report was handed over to ESA and the Commission during the 2nd Quantum Technology - Implementations for Space Workshop on 15th November 2017 at ESTEC.

[Policy White Paper on Quantum Technologies for Space](#) - August 2019

This White Paper summarises the state of the art in the development of quantum technologies, with clear potential for space applications, and delineates a clear roadmap for the consideration of major actors in this area, from EC to ESA, the national space agencies and industries. The goal is the drawing of a full framework for the design, development, implementation, and exploitation of quantum technologies for space.

[European Industry White Paper](#) - Fall 2019

The European industry has prepared a White Paper to support the development of the Quantum Communication Infrastructure (QCI) that would in a first stage secure government and critical infrastructure communication across the European Union, and in a second stage prepare the connection of quantum computers and sensors in a full Quantum Information Network.

ANNEX B

On 15th November 2017, during the ESA 2nd Workshop on Quantum Technology, Angelo Bassi, Chair of QTSpace, handed a strategic report on “Quantum Technologies in Space” over to ESA, represented by Franco Ongaro (Director of Technology, Engineering and Quality and Head of ESTEC) and Jean-François Buggenhout (Deputy Head of Unit, DG CONNECT, European Commission). The strategic report, prepared a scientific committee of 28 academic and industrial partners, identifies the state of the art and future strategies for the technological development of quantum devices for space applications. The report was presented in its intermediate form. It will be open to the wider community for feedback, based on which a final report will be prepared, whose delivery is scheduled for 2018.

What follows is the joint ESA and QTSpace Press Release.

QTSpace hands over a Strategic Report on Quantum Technologies for Space to ESA and the EU: The goal is to bring Quantum Physics to Space



Figure 1. From left to right: Jean-François Buggenhout, José Gavira Izquierdo, Angelo Bassi, and Franco Ongaro. Photo credit: James Bateman

The European Space Agency (ESA) has been developing quantum technologies (QT) for space science and applications for a number of years, both through its technology development programmes—the Technology Research Programme (TRP)¹ and the General Support Technology Programme (GSTP)²—, but also using its domain specific technology development programmes—such as, the Earth Observation Envelope Programme (EOEP)³, the Science Core Technology Programme (CTP)⁴ and the Advanced Research in Telecommunications Systems (ARTES)⁵. More

¹http://www.esa.int/Our_Activities/Space_Engineering_Technology/Shaping_the_Future/About_the_Technology_Research_Programme_TRP

²http://www.esa.int/Our_Activities/Space_Engineering_Technology/Shaping_the_Future/About_the_General_Support_Technology_Programme_GSTP

³http://www.esa.int/Our_Activities/Space_Engineering_Technology/Science_Core_Technology_Programme_CTP

⁴http://www.esa.int/Our_Activities/Space_Engineering_Technology/About_the_Earth_Observation_Envelope_Programme_EOEP

⁵http://www.esa.int/Our_Activities/Telecommunications_Integrated_Applications/ARTES/ARTES_programme_overview

recently, the Secure and Laser communication technology (ScyLight)⁶, part of ARTES, was specifically set up to focus on optical and quantum encryption technologies. In addition, a new QKD Sat public-private partnership is presently being developed.

ESA sees great potential for the use of quantum technologies in areas such as: Earth and planetary remote sensing, secure communications, fundamental physics, microgravity research and navigation, amongst others. Furthermore, Interest in QT for space is increasing as technologies are becoming mature for ground applications and the space segment is believed to be an essential component of the global commercialisation effort.

For the second year in a row, the Quantum Technology – Implementations for Space Workshop⁷ was held at ESTEC, ESA's Space Research and Technology Centre, in Noordwijk, The Netherlands. The workshop gathered academia, industry, European institutions and other stakeholders in this field.

An important addition to this year's edition was the inclusion of QTSpace in the workshop's Scientific Programme Committee, following calls to increase collaboration with this body during last year's workshop.

QTSpace⁸ is a newly established European network on Quantum Technologies in Space, funded by the EU COST (European Cooperation in Science and Technologies). QTSpace is the first network to bring together quantum physics and space research, arguably the two most important achievements of mankind in science and technology over the last century.

The ambitions of QTSpace are twofold: 1) lift our current understanding of nature to a higher level, which necessitate performing quantum experiments in outer space; 2) use the new generation of quantum devices for improving space-related technology.

In the past few months, QTSpace was engaged in the preparation of a Strategic Report on Quantum Technologies for Space. A team of 28 academic and industrial actors have shaped the priorities and strategies for the forthcoming years by identifying four pillars for scientific and technological development: secure communication, time and frequency

⁶http://www.esa.int/Our_Activities/Telecommunications_Integrated_Applications/ScyLight

⁷<http://old.esaconferencebureau.com/2017-events/17c16>

⁸ www.qtspace.eu

services, earth sensing and observation, and fundamental physics. All such themes will be boosted by the emerging second generation of quantum technologies.

On 15th November 2017, the second day of the [ESA workshop](#), Angelo Bassi, Chair of QTSpace, handed a strategic report on “Quantum Technologies in Space” over to ESA, represented by Franco Ongaro–Director of Technology, Engineering and Quality and Head of ESTEC, and to the EU represented by Jean-François Buggenhout–Deputy Head of Unit, DG CONNECT, European Commission.

The Report can be accessed from the [QTSpace website](#) and is now open to the scientific community for comments and suggestions, which will help preparing a final version of the document.

The Report embodies an important step forward towards enhanced coordination and synergy among the current space-related research activities within Europe. It will help Europe to better stand the fierce competition of USA and China.

Photo credit: James Bateman