European Innovation Council

PATHFINDER CHALLENGE
Alternative Quantum Information Processing, Communication and Sensing

CHALLENGE GUIDE
Version 14/06/2022
EIC Work Programme reference: HORIZON-EIC-2022-PATHFINDERCHALLENGES-01-06
Call deadline date: 19/10/2022 17.00 CET
EIC Programme Manager: Samira NIK
Challenge page: https://eic.ec.europa.eu/eic-funding-opportunities/calls-proposals/eic-pathfinder-challenge-alternative-approaches-quantum-information-processing-communication-and_en

The EIC will hold an online Info Session on this Pathfinder Challenge call on 05/07/2022. Participation in the meeting, although encouraged, is optional and is not required for the submission of an application. Information about how to access the Info Session and on additional dissemination events can be found at EIC Pathfinder Challenges Applicants' Day (europa.eu) **and** EIC Pathfinder (europa.eu)**.**

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1. About this document

The Challenge Guide serves as guidance and background for the common understanding, participation rules and obligations for the EIC beneficiaries that are involved in the Challenge Portfolio. Contractual Obligations are further detailed in the EIC Work Programme (https://eic.ec.europa.eu/eic-work-programme-2022_en) and collected in the Pathfinder Challenge guidance on contractual issues, available on the Challenge page.

The Challenge Guide is a guidance document accompanying a Pathfinder Challenge call for proposals to provide applicants with additional technical information to underpin the objectives and to provide further information about how portfolio considerations will be taken into account in the evaluation of proposals.

The Challenge Guide is prepared by and under the responsibility of the relevant EIC Programme Manager (information about the EIC Programme Managers is available on the EIC Website https://eic.ec.europa.eu/eic-communities/eic-programme-managers_en). It further details the call by complementing notably the Scope, Specific Objectives and/or Specific Conditions set out in the EIC Work Programme. In no case does the Challenge Guide contradict or supplant the Work Programme text.

2. Background concerning the scope and objectives of the Challenge

This section provides additional information on the relevant scientific and technological domains pertaining to scope and objectives of the Challenges that applicants may wish to take into account. This section should be read as background to the Challenge call in the EIC Work Programme text (attached as Annex). Proposals to this Challenge are expected to explain how they relate to and intend to go beyond the state of the art, and how they interpret and contribute to the objectives of the Challenge.

Overview

This Pathfinder Challenge and the associated portfolio have the objective to build upon alternative implementations/platforms and so far, unexploited quantum principles that could become key elements in future quantum systems. The Challenge portfolio activities will stimulate the collaboration of the funded projects as well as the networking with the innovation ecosystem to enhance the development of the EU technological sovereignty in this field. The call aims to fund a portfolio of breakthrough research and technological developments projects on new quantum implementations and principles, which could lead to breakthrough innovations and enable new players to offer unique solutions for the architecture and critical building blocks of new quantum systems.

Within the last two decades, quantum technologies (QT) have made tremendous progress, moving from fundamental blue-sky research into a cross-disciplinary field of applied research, technological development, and commercialization. Governments and companies worldwide are investing extensively to utilize the quantum technologies potential. As a result, they entered into the quantum race to be leaders in areas such as computing, communications, sensing, imaging, and simulation [1], [2].

Quantum computing takes on board quantum effects to dramatically speed up certain calculations, such as number factoring, which could eventually lead to major improvements in biochemistry, materials science, drug discovery, and machine learning [2], [3]. Quantum communication involves generation and use of quantum states and resources for communication protocols. Its main applications are in provably secure communication, long-term secure storage, cloud computing and other cryptography-related tasks, as well as a secure 'quantum web' in future [2]. In quantum sensing the high sensitivity of coherent quantum systems to external perturbations is exploited to enhance the performance of measurements of physical quantities and has a broad variety of potential applications, such as precision measurements of time, acceleration, and electric, magnetic, and gravitational fields. The idea of quantum simulation goes back to Richard Feynman, who suggested that interacting quantum systems could be efficiently simulated employing other precisely controllable quantum properties [4]. Realistic programmable quantum simulators and quantum annealers could give rise to quantum devices that are able to solve routing and scheduling problems with polynomial speedups over classical computers. Quantum simulation for scientific research holds enormous promise and could have a major economic impact [5], [6].

In order to consolidate and expand European scientific leadership and excellence in this research area and to kick-start a competitive European industry in Quantum Technologies, the European Commission launched its EUR 1 billion Quantum Technology Flagship in October 2018 on a 10-year timescale. QT Flagship aims to make Europe a dynamic and attractive region for innovative research, business, and investments in this field. The long-term horizon is a "Quantum Web": Quantum computers, simulators and sensors interconnected via quantum networks distributing information and quantum resources, utilizing unique quantum phenomena such as coherence and entanglement [1], [7].

However, the Quantum Flagship is currently focused on mainstream quantum technologies, in qubit implementation, sensors and other areas and there is room for exploiting alternative implementations/platforms and (controllable) quantum principles that could become key elements in future quantum systems. Such new implementations and principles could lead to breakthrough innovations and enable new players to offer unique solutions for the architecture and critical building blocks of new quantum systems. This could represent a significant opportunity for European researchers, innovators, and companies in this competitive field [7], [8].

Quantum computerization and quantum circuits create high investment costs both in time and financial terms. However, performance of current quantum devices is far from optimum and hence new theoretical or hardware approaches that can improve the performance of current quantum devices or attempt a totally new path are critical for further progress in implementation of quantum devices. The scope of this Challenge is to develop innovative approaches to encoding, manipulating, or storing information in quantum objects, or to exploiting quantum phenomena for information processing, communication, and sensing in a way that differs from the mainstream approaches currently being pursued in quantum research. Proposals should clearly identify the limits of the current quantum information processing paradigms they are trying to improve upon and propose relevant metrics to track progress and demonstrate success or a superior paradigm compared with conventional quantum information processing approaches [8].

We consider the following to be mainstream approaches, without being exhaustive:

- Quantum key distribution
- Quantum cryptography
- Quantum clocks
- Diamond NV qubits
- Quantum cascade laser
- Quantum Random Number Generators
- Quantum communication on the ground

To further clarify we emphasize that this Challenge does not seek for proposals that focus on further exploring topics mentioned above, but rather look for new approaches and novel ideas.

In the following, some examples of such new implementations and principles are presented, without being exclusive, which could lead to breakthrough innovations and enable new players to offer unique solutions for the architecture and critical building blocks of new quantum systems.

Data Encoding Patterns for Quantum Algorithms

Quantum computers are based on the laws of quantum mechanics, which make them capable of solving certain problems faster than their classical counterparts. However, programming these quantum devices is challenging as the current quantum computers (first generation) still have severe limitations because their noisy qubits are only stable for a limited period of time. Moreover, the quantum nature of these devices must be taken into account as a key difference with respect to classical computing. Current quantum computers do not have access to a database or a quantum version of random-access memory (RAM). Hence, in order to use data in a quantum computer the data must be loaded by encoding it into the state of the qubits. There are various data encodings that define how the data can represented by qubits. However, often the theoretical algorithms assume that data can be loaded efficiently, whereas the runtime complexity of the loading routine depends on (i) the data encoding that defines how the data is represented and (ii) the data itself. In some cases, loading the data requires at least exponential time which destroys a potential speed-up. Especially for the first generation of devices that are currently available, the resources (qubits and operations) needed to encode the data are limited. Therefore, understanding the consequences of a particular data encoding is crucial [9], [10].

To tackle this challenge, scientists have recently introduced four new patterns for quantum (QRAM) encoding: Schmidt Decomposition can be used to prepare an arbitrary state while a hardware implementation for a QRAM is still missing. Matrix Encoding and Quantum Phase Estimation are patterns for algorithms that require a matrix as an input. Post-Selective Measurement can be used to proceed with the branch where the solution is encoded. Moreover, they demonstrated the usage of several of the patterns within an algorithm and concluded that encodings are a key ingredient for understanding quantum algorithms—and why certain input data can prevent an exponential speed-up.

Quantum Simulations for Materials Science, Chemistry and Pharma

One of the earliest and most compelling applications for quantum computers is Richard Feynman's idea of simulating quantum systems with many degrees of freedom. Such systems are found across chemistry, physics, and materials science [11].
By manipulating quantum states of matter and taking advantage of their unique features such as superposition and entanglement, quantum computers promise to efficiently deliver accurate results for many important problems in quantum chemistry, such as the electronic structure of molecules [12].

Identifying and developing small molecules and macromolecules that might help cure illnesses and diseases is the core activity of pharmaceutical companies. These companies have long been looking for ways to speed up the discovery and development of new drugs, while lowering error rates and reducing the cost of the whole process. Quantum computing could be the solution pharma companies have been dreaming of. Today, pharmaceutical companies use computers to understand and predict the behaviour of molecules that could form a new drug, a process called computer-assisted drug discovery (CADD). This method has been around for quite a long time, but it still takes an average of 13-17 years to come up with new treatments, which is far too slow for today's digital age. Quantum computing is expected to be able to predict and simulate the structure, properties, and behaviour or reactivity of molecules more effectively than conventional computing can, and it is ideally suited for drug discovery, because the molecules used in drugs are themselves quantum systems. This would revolutionise drug discovery, making radical new treatments for various diseases like Cancer and Alzheimer's, amongst others, a real possibility [13].

Although quantum computing has not yet reached the necessary maturity, experts agree that it will not take long. McKinsey & Company predicts that value creation for quantum computing in the pharmaceuticals industry will begin by 2030, and recommends that pharma companies already establish partnerships with pure-play quantum companies and assess their quantum readiness now to lay the groundwork, where scientists will use cloud, AI, and quantum computing to advance discoveries in genomics, single cell transcriptomic, population health, clinical applications, and chemical and drug discovery [13]. Moreover, with the current rate of quantum hardware development, we can look forward to a new wave of developments in quantum algorithms, and the emergence of new computational disciplines dedicated to study of chemistry, materials science, and physics on quantum computers [11].

Improving Quantum Sensing by Variational Quantum Circuits

Recent progress in quantum technology of sensors has provided us with the most precise measurement devices available in physical sciences. Examples include the development of optical clocks, atom and light interferometers, and magnetic field sensing.
Using so-called variational quantum circuits to optimize the sensitivity of an atomic sensor based on entangled atoms is a promising way to push the limits of quantum sensing. A research team have employed so-called variational quantum circuits to optimize the sensitivity of an atomic sensor based on entangled atoms. The result is a sensor that, with surprisingly modest quantum resources, should outperform those based on standard Ramsey interferometry.

An important aspect of this work lies in the fact that it brings the quantum sensing community and the variational quantum algorithm community together. While variational quantum algorithms are getting major attention for quantum computing applications, it is rare for them to appear in an atomic experimental setting or in a sensing setting. The exquisite observation that variational algorithms could work in a realistic sensing application should inspire many experimentalists to think about optimizing their setups with variational quantum circuits, regardless of whether they involve atoms, light, spins, or superconductors. This work gives an inspiring model for how cross fertilization between quantum experimentalists and quantum computer scientists can be brought about [14], [15].

Generating High-Quality Quantum Light with Modular Waveguide Device

Although there are several ways to create a quantum computer, light-based approaches are promising because the information processor can operate at room temperature and the computing scale can be easily expanded. In April 2022, for the first time, a group of researchers have successfully generated strongly non-classical light using a modular waveguide-based light source [17]. The achievement represents a crucial step toward creating faster and more practical optical quantum computers. This waveguide Optical Parametric Amplifier

(OPA) module combined with a specially designed photon detector allowed them to generate a state of light known as Schrödinger cat, which is a superposition of coherent states. This method can be used to increase the computing power of quantum computers and to make the information processer more compact.

OPAs use nonlinear optical crystals to generate squeezed light, but conventional OPAs don't generate the quantum light with the properties necessary for faster quantum computing. To overcome this challenge, researchers developed an OPA based on a waveguide-type device that achieves high efficiency by confining light to a narrow crystal. By carefully designing the waveguide and manufacturing it with precision processing, they were able to create an OPA device with much smaller propagation loss than conventional devices. It can also be modularized for use in various experiments with quantum technologies.

The OPA device was designed to create squeezed light at telecommunications wavelengths, a wavelength region that tends to exhibit low losses. To complete the system, researchers needed a high-performance photon detector that worked at telecom wavelengths. However, standard photon detectors based on semiconductors do not meet the performance requirements for this application. Thus, the researchers developed a detector designed specifically for quantum optics. The new superconducting nano-strip photon detector (SNSPD) uses superconductivity technology to detect photons.
The new waveguide OP combined with this photon detector generates a highly non-classical -- or quantum - state of light called Schrödinger cat, which is difficult with conventional, low-efficiency waveguide OPAs and opens the possibility of using this device for a wide range of quantum experiments [16].

3 Portfolio considerations for the evaluation of applications to the Challenge

This section describes how portfolio considerations will be taken into account in the second stage of the evaluation of applications. In the first stage, all applications will be evaluated individually by external experts and scored against the evaluation criteria set out in the Work Programme. All applications that pass the defined thresholds against the criteria will be included in the second stage of the evaluation. At the second stage, all above threshold applications will be considered collectively by an evaluation committee chaired by a relevant Programme Manager. At this stage, the Evaluation Committee will consider which applications to recommend for funding in terms of a coherent portfolio of projects that can interact, reinforce each other, or compete to increase the overall impact.

In the second evaluation step, the evaluation committee, aims to build a consistent Challenge portfolio to advance Quantum information processing, Quantum communication, and Quantum sensing with the utilization of novel, non-mainstream implementation platforms, based on quantum phenomena. The proposals selected in the portfolio should be based on diverse novel approaches to data encoding and areas of deployment and application.

Categories

In order to build the portfolio, the evaluation committee will map the proposals against a set of categories:

I. **Implementation quantum platform/system (e.g., Superconducting qubits, Single photon sources, Trapped ions, Ultra-cold atoms in optical lattices, Topological nanowires, Nuclear magnetic resonance, etc.)**
The quantum platforms are the comprehensive hardware and software systems for performing complex quantum algorithms, experiments and advancing the world of quantum computing and simulation, sensing, and communication.

II. **Quantum data encoding approach (Basic encoding, Angle encoding, QRAM encoding, Amplitude encoding, etc.)**
Quantum computer expects data in quantum state for processing and the first step in quantum computing is to load classical data by encoding it into the state of the qubits. This process, also known as quantum data encoding or embedding, is an important step in pre-processing the data, deciding number of qubits, designing quantum circuits and efficient execution of quantum algorithm. Moreover, encoding patterns facilitate the development of quantum applications for software developers. However, not one encoding model would serve all scenarios; rather, a careful design decision has to be made. Proposals are expected to address issues such as considerations for data encoding patterns, new data encoding patterns, number of qubits suitable for each pattern, etc.

III. **Applications of Quantum computing, Quantum simulations and Quantum sensing**
Quantum computing has been attracting increasing interest in many areas as it would be very advantageous for a vast array of problems in physics, chemistry, and biology. For instance, quantum computing could make current Computer Assisted Drug Development tools more effective by helping to predict molecular properties with high accuracy. That can affect the development process in several ways, such as modelling how proteins fold and how drug candidates interact with biologically relevant proteins. In the longer term, quantum computing may improve generation and validation of hypotheses by using machine-learning algorithms to uncover new structure-property relationships, which can lead to creation of new chemical compounds, drugs and materials. Proposals are expected to offer new approaches in quantum computing for applied sciences such as chemistry, materials science and pharmaceuticals.

Quantum sensing is expected to provide new opportunities - especially with regard to high sensitivity and precision in applied physics, healthcare, engineering and information technology while leading to innovative applications in fields as diverse as metrological standards, defence, security, oil and gas aerospace or biological imaging. Quantum sensing proposals will be categorized per application area.

The evaluation committee will seek for clear demonstration of how information processing, communications principles and architectures, or quantum sensing would be developed, controlled, programmed, and measured. They will also explore the quantifiable advantage with respect to classical approaches and mainstream quantum technology alternatives, meaning the proposed techniques should be applicable to a class of relevant problems or applications, exhibiting similar advantages to the mainstream quantum technology approaches, in terms of sensitivity, accuracy, energy efficiency.

Portfolio considerations

For building the portfolio of projects to be funded, the evaluation committee will apply the following portfolio considerations:

- The proposals selected in the portfolio should display diversity in the implementation quantum platform/ system.
- The proposals in the portfolio should cover a variety of different data encoding or embedding approaches, and a variety of different applications in quantum computing, quantum simulation and quantum sensors, in order to assess the relative advantages of the approaches for different applications. Preference will be given to non-mainstream applications.

The evaluation committee will examine the proposals following these considerations in order to ensure that the final set of funded proposals covers the objectives of the call without major gaps.

4 Implementation of the Challenge portfolio

Grant negotiations

Applicants may be requested to make amendments to their proposed project in order to take into account the portfolio objectives and enhance the portfolio. Such changes may include: an additional work package to undertake common/ joint activities (workshops, data exchanges, joint research, etc) with other projects in the portfolio; adjustments to the timings of some activities and deliverables in order to synchronise better with the implementation timings of other projects; specific target changes to improve complementarity/ comparability with activities and results from other projects. All such changes will be discussed during the grant preparation stage with the aim of reaching a consensus between all projects on the adjustments needed.

Challenge portfolio roadmap

Following the selection of proposals to be funded under the Challenge, the Programme Manager will work together with the selected projects to develop a common roadmap for the Challenge. This roadmap will integrate the activities and milestones of the individual projects into a shared set of objectives and cross-project activities. The roadmap serves as a common basis for implementing the projects - including possible adjustments, reorientations or additional support to projects - and can be updated in light of emerging results or difficulties during the implementation. The objectives can be revised, for instance based on projects' unexpected achievements, new technology trends, external inputs (other projects, new calls…).

In particular, the Challenge roadmap will include activities on the transition to innovation and commercialisation, and to stimulate business opportunities. These activities may be supported and reinforced during the implementation with additional funding and expertise through pro-active management.

Tools for proactive management of projects

Projects in the portfolio may be offered additional support, either individually or collectively, in order to reinforce portfolio activities or explore the transition to innovation. Such additional support includes:

- Booster grants of up to €50k (see Annex 6 of the EIC Work Programme)
- Access to additional EIC Business Acceleration Services (see https://eic.ec.europa.eu/eic-funding-opportunities/business-acceleration-services_en)
- Access to the Fast Track to the EIC Accelerator, the decision for which would follow a project review (see Annex 4 of the EIC Work Programme)
- Access to the EIC Market Place, once operational, to connect with innovators, investors and other selected partners
- Interactions with relevant projects and initiatives outside the portfolio, including other EU funding initiatives as well as those supported by national, regional, or other international bodies.

ANNEX Extract of EIC work programme

II.2.6 EIC Pathfinder Challenge: Alternative approaches to Quantum Information Processing, Communication, and Sensing

Introduction and scope

The Quantum Flagship is currently focused on mainstream quantum technologies, in qubit implementation, sensors and other areas. Nevertheless, alternative implementations/platforms and so far, unexploited (controllable) quantum principles exist and could become key elements in future quantum systems. Such new implementations and principles could lead to breakthrough innovations and enable new players to offer unique solutions for the architecture and critical building blocks of new quantum systems. This could represent a significant opportunity for European researchers and companies in this competitive field.
The scope of this call is to develop innovative approaches to encoding, manipulating, or storing information in quantum objects, or to exploiting quantum phenomena for information processing, communication, and sensing in a way that differs from the mainstream approaches currently being pursued in quantum research. Proposals should clearly identify the limits of the current quantum information processing paradigms they are trying to improve upon and propose relevant metrics to track progress and demonstrate success or a superior paradigm compared with conventional quantum information processing approaches.

Specific objectives

The proposals under this EIC Pathfinder Challenge:

- are expected to contribute to the development of information processing, communication or sensing components, for terrestrial or space applications, exhibiting similar advantages to the mainstream quantum technology approaches, in terms of sensitivity, accuracy, energy efficiency, etc;
- should describe how their proposed information processing or communication system would be controlled and could lead to the development of an information processing or communication device using a non-classical information theory approach;
- should aim to show how information processing or communications principles and architectures would be developed that demonstrate a clear and quantifiable advantage with respect to classical approaches and mainstream quantum technology alternatives. This should be applicable to a class of relevant problems or applications;
- should show how the foundations for novel approaches to encoding, manipulating, and storing information that could lead to practical applications
- would be established. Such novel approaches could find their roots in, for example, new phases of matter, exotic physical systems, biological systems, or other approaches;

- should describe how the proposed information processing or communication system would be controlled, programmed, and measured and should address relevant interfacing aspects.

Expected outcomes and impacts

This EIC Pathfinder Challenge aims at the following:

- technology breakthroughs that form the basis for future information processing, communication, and sensing technologies on ground and in space;
- synergetic collaboration with existing European platforms, infrastructures, and innovation eco-systems in quantum technology;
- increased diversity of information processing technologies platforms exploiting non-classical information theory approaches.

The activity must clearly achieve the proof of principle and validate the scientific basis of the breakthrough technology (TRL starting at 2 and reaching 3-4). Proposals are expected to demonstrate collaboration in order to create a critical mass of cooperation between EU research, industry and other relevant actors in the emerging area of quantum information processing. The overall goals are to enable new players to offer unique solutions as building blocks for new information processing or communication systems, and to foster the interdisciplinary communities and innovation eco-systems that are driving this forward.

Bibliography

[1] Jenet, A., Trefzger, C., Lewis, A.M., Taucer, F., Van Den Berghe, L., Tüchler, A., Loeffler, M. and Nik, S., Standards4Quantum: Making Quantum Technology Ready for Industry: Putting Science into Standards, EUR 30196 EN, Publications Office of the European Union, Luxembourg, (2020), ISBN 978-92-76-18452-2, doi:10.2760/882029, JRC118197

[2] Acín, A., Bloch, I., Buhrman, H., Calarco, T. Eichler, Ch., Eisert, J., Esteve, D., Gisin, N., Glaser, SJ., Jelezko F., Kuhr, S., Lewenstein, M., Riedel M., Schmidt, P., Thew R., Wallraff, A., Walmsley, I., and
Wilhelm, F., The quantum technologies roadmap: a European community view, New J. Phys. 20 (2018) 080201

[3] Palmer, J., Here, There and Everywhere: Quantum Technology Is Beginning to Come into Its Own, The Economist, (2017)

[4] Feynman, R.P. Simulating physics with computers. Int J Theor Phys 21, 467–488 (1982). https://doi.org/10.1007/BF02650179

[5] H. Bernien, S. Schwartz, A. Keesling, H. Levine, A. Omran, H. Pichler, S. Choi, A. S. Zibrov, M. Endres, M. Greiner, V. Vuletić, M. D. Lukin, Probing many-body dynamics on a 51-atom quantum simulatorNature 551, 579 (2017)

[6] Neukart, F., Von Dollen, D., Compostella, G., Seidel, Ch., Yarkoni, Sh., and Parney, B., Traffic flow optimization using a quantum annealer, (2017), https://arxiv.org/abs/1708.01625

[7] Quantum Flagship website https://qt.eu/

[8] EIC Work Programme 2022, https://eic.ec.europa.eu/eic-work-programme-2022_en

[9] Weigold, M., Barzen, J., Leymann, F., and Salm, M., Expanding Data Encoding Patterns For Quantum Algorithms, (2021) IEEE 18, International Conference on Software Architecture Companion (ICSA-C)

[10] IonQ, Algorithmic Qubits: A Better Single-Number Metric (2022) https://ionq.com/posts/february-23-2022-algorithmic-qubits

[11] Bauer, B., Bravyi, S., Motta, M., and Chan, G. Quantum algorithms for quantum chemistry and quantum materials science, (2020), arXiv:2001.03685v2 [quant-ph] 11 Jul 2020

[12] Cao, Y., Romero, J., Olson, J.P., Degroote, M., Johnson, P.D., Kieferová, M., Kivlichan, I.D., Menke, T., Peropadre, B., Sawaya, N., Sim, S., Veis, L., and Aspuru-Guzik, A., Quantum Chemistry in the Age of Quantum Computing, (2019), Chem. Rev. 2019, 119, 19, 10856–10915

[13] Evers, M., Heid, A., and Ostojic, I., Pharma's digital Rx: Quantum computing in drug research and development, (2021), McKinsey and Company, https://www.mckinsey.com/industries/life-sciences/our-insights/pharmas-digital-rx-quantum-computing-in-drug-research-and-development

[14] Kaubruegger, R., Vasilyev, D. V., Schulte, M., Hammerer, K., and Zoller, P., Quantum Variational Optimization of Ramsey Interferometry and Atomic Clocks, (2021), Phys. Rev. X 11, 041045

[15] Coles, P., Pushing the Limits of Quantum Sensing with Variational Quantum Circuits, (2021), Physics 14, 172

[16] Takase, K., Kawasaki, A., Jeong B. K., Endo, M., Kashiwazaki, T., Kazama, T., Enbutsu, K., Watanabe, K., Umeki, T., Miki, Sh., Terai, H., Yabuno, M., China, F., Asavanant, W., Yoshikawa, J-I., Furusawa, A., Generation of Schrödinger cat states with Wigner negativity using a continuous-wave low-loss waveguide optical parametric amplifier, (2022), Optics Express, 2022; 30 (9): 14161 DOI: 10.1364/OE.454123