SFC Alliances for Research Challenges

Quantum Technologies for the Future of Scotland

Relevant contact details (in alphabetical order):

Management Team:
Lucia Caspani[2], Margherita Mazzera[3], Hamid Ohadi[4], Elton Santos[5], Luca Sapienza[1,*]

*Advanced Research Centre, University of Glasgow
11 Chapel Lane, Glasgow G11 6EW, United Kingdom
e-mail: luca.sapienza@glasgow.ac.uk
group website: www.sites.google.com/view/integrated-quantum

Academic Advisory Team:
Gerald Buller[3], Brian Gerardot[3], Andrew Huxley[5], Philip King[4], Stefan Kuhr[2], Brendon Lovett[4], Alan Miller[6], Caroline Muellenbroich[1], Patrik Öhberg[3], Daniel Oi[2], Miles Padgett[1], Douglas Paul[1], Erling Riis[2], Sheila Rowan[1], Peter Wahl[4]

Industrial Advisory Team:
Coherent, M Squared Lasers, Vector Photonics, III-V Epi, IDQ, Chromacity, Thales, Horiba, Toshiba, Andor, Single Quantum, Helia Photonics, Fraunhofer UK Research, Clydespace, Alter Technologies, British Telecom

Interested partner universities/organisations:
[1]University of Glasgow, [2]University of Strathclyde, [3]Heriot-Watt University, [4]University of St Andrews, [5]University of Edinburgh, [6] Scottish Universities Physics Alliance, James Watt Nanofabrication Centre, Heriot-Watt Nanofabrication Facility, the Scottish Microelectronics Centre at the University of Edinburgh, the Quantum Hubs, Centre for Quantum Technology at the University of Glasgow, Fraunhofer UK Research

Disciplines that would be included:
Engineering, Physics, Mathematics, Chemistry, Biology, Healthcare, Space Science, Computer Science, Economy, Social Sciences

Quantum Technologies for the Future of Scotland

The UK National Quantum Technologies Programme was the first of its kind to be announced worldwide, is acknowledge globally as one of the strongest quantum programmes, and Scotland has played a major role in its success. Though quantum computing has been the most publicly prominent quantum technology, many other quantum technologies have enormous potential to drive societal, cultural, and economic growth.
Examples of questions that one can ask are: "How can/will quantum technologies impact society? What are the big challenges in net-zero, healthcare, security, and space science that quantum technologies can solve? Is it full-body imaging at the cellular level? Is it GPS-free navigational capability and optical-resolution radar imaging? Is it future quantum sensors for intelligent homes that assess/assist health, frailty, multimorbidity, or remote heart/brain health tracking?".
This ARC will create the needed - yet currently missing - connection between industry, the research communities, end-users and disciplines outside quantum mainstream research, therefore supporting Scotland's role as a high-tech powerhouse, enabling cultural, societal, and technological transformation.

Advances in materials growth and manufacturing technology have allowed the miniaturisation of devices to dimensions where their properties are described by quantum mechanics. In this realm, a completely new range of effects takes place and devices with novel functionalities can be devised, exploiting quantum phenomena such as entanglement and superposition: *the quantum technology revolution is within reach*.
Its impact is expected to be pervasive: from speed-of-light communication with unbreakable cryptographic security, to faster computation schemes allowing new advanced simulation capabilities that could, for instance, be used to design new drugs; from ultra-small and ultra-sensitive sensing and imaging devices for healthcare, to more energy efficient devices for net-zero goals, as highlighted by the Quantum technologies: Blackett review.
Ultimately, discovering and understanding the fundamental behaviour of quantum materials will pave the way to new technologies that will allow to cross boundaries between disciplines and develop applications based on quantum-enhanced devices for photonics, space sciences, life sciences, healthcare and net-zero.

Quantum and Photonics Technologies are identified by BEIS in the UK Innovation Strategy as one of the seven technology families that will drive the transformation of deep tech in the UK. In 2014, the UK led the world in establishing a Quantum Technology Programme to translate its world leading research to the benefit of UK-based industry. This quantum focus has now received an investment of the order of £1Bn in both academic and industrial projects and a new five-year strategy is currently being written by BEIS, covering a further round of investment from 2024.
Scotland is central to the UK's mission, leading one of the UK's four quantum technology hubs (QuantIC) and is a key contributor to the other three. Scotland also hosts the only UK Fraunhofer Centre and the James Watt Nanofabrication Centre, both of which are key ingredients to the UK programme.
From an industrial perspective, as highlighted in the Photonics Scotland report, Scotland is home to over 200 photonic and quantum companies, employing over 6500 people, with an output for the sector of over £1Bn, a significant component of which relates to exports. These companies range from system integrators (Thales and Leonardo), key supply chain companies (Sivers, Helia, Alter,...) to high growth SMEs (M Squared Lasers) and a thriving cluster of new start up and spin out companies (Chromacity and Vector Photonics).
Moving forward, this proposal seeks to **cement Scotland as the place for Quantum Technology**, capitalising on the Scottish strengths throughout the supply chain, to maximise the return on investment and on the human and industrial capital, built up through many years of investment.
It seeks to do this by further strengthening the links between our world-class academic base and our industrial and user sector, with particular emphasis on extending the traditional markets in transport and defence/security into healthcare and the green economy.
This ARC project would seek to do this by focusing on:
- sector workshops around external funding calls for co-created R&D projects (e.g. the next incarnation of the industrial strategy challenge fund, as part of the phase III of the UK Quantum Programme)
- two-way secondments scheme where both industrial and academic practitioners are supported to work on technical or market appraisal projects.

- *Brief description of the proposed challenge area:*

Our ARC proposal will create a hub that will connect academic institutions, industries, young researchers, and the public, with the goal of integrating quantum technologies into the Scottish economy. It will create bridges between the established research and technological excellence in Scotland and the future generation of quantum players (researchers, end-users, entrepreneurs, educators, students) yet to come.

Quantum Technologies for the Future of Scotland

We propose to establish a **network in quantum technologies**, with a central aim to position Scotland as a leading voice in this rapidly emerging industry sector.
Scotland's world class universities are already leading **cutting-edge research** that surpasses the boundaries between different disciplines and research areas. The Scottish excellence has been recently highlighted by the results of the REF that found 85% of Scotland's research to be world-leading (4*) and internationally excellent (3*), the two highest categories of performance. There is a clear need for the formation of a structured network to bridge the **connections between quantum researchers, industrial partners and end-users** across Scotland, providing a platform for knowledge transfer and quantum skills development.
This network will support the development of new ideas and exchanges between academia and industry, and it will also put particular emphasis on the **training of the next generation of researchers**. This will ensure that the skills needed for the development and commercialisation of existent and future quantum technologies are present in Scotland, thus supporting the **further progress of the Scottish economy**.
Quantum technologies are one of the main strengths in Scotland, mutually benefitting from a well-developed industrial presence in quantum and quantum-related areas (including photonics, space science, healthcare, computing). For instance, **Photonics** alone in Scotland has a £1.2Bn contribution and close to 7000 employees. This is a sector that is growing at 12% per year (photonicsuk.org) and rivals that of the pharmaceuticals sector that contributes £1.8Bn. **Space Science technology** is present with over 130 companies, with a turnover of £254M, putting Scotland as a world-leader in space technology. Scottish **Life Sciences** companies are steadily growing (turnover from £4.5Bn in 2014 to £6.6Bn in 2018), with the employment in the sector steadily increasing to 40.000 people. Quantum technologies have demonstrated, for instance, key sensing technology required for more practical, and far cheaper, brain imaging systems for patients, enabling **healthcare** research (for diagnosing and developing successful treatments for dementia, Alzheimer, Parkinson, strokes, and other diseases), as well as environmental monitoring to reduce greenhouse gas emissions, for instance of methane, essential for achieving the goal of **net-zero emissions**.
For Scotland to maintain its leading role in the quantum technology sector, we need to leverage our national excellence in academic quantum research, to collaborate with industry on challenge-led initiatives and, in particular, support the training of world-class researchers that will be at the heart of the **quantum transition in the technology sector**. Such training is critical for the development and commercialisation of future quantum technologies, driving the **integration of quantum technology into the Scottish economy**.
We will strengthen interactions with industry and interdisciplinary connections, by organising exchanges of researchers, scientific meetings, and workshops, at the basis also for the training of researchers.
These activities will allow making sure that the right degree of expertise is available to industries for the applications of quantum technologies in their research development and production.
We will take advantage of, and connect to, the existing networks, such as the Scottish Universities Physics Alliance (SUPA), alongside other **research pools** relevant to this ARC, such as SRPe, SULSA and SINAPSE, that have played a key role in bringing together research communities across Scotland. Indeed, SUPA represents the physics community, with a network of 1200+ researchers that collaborate on technology development, international collaboration, and student training. Moving forward, SUPA and the ARC will work together so as to ensure an effective bridge between the different disciplines within SUPA, e.g. materials science and photonics, quantum technologies, training and industry engagement. SUPA also brings strong relations with the other Scottish research pools, Innovation Scotland/Photonics Scotland, Scottish Enterprise etc, and has had joint initiatives with many of these that will therefore provide a strong platform from which to launch this ARC initiative. We will leverage the existing links to **international activities and exchanges**, like the International Max Planck Partnership and the Lower Saxony-Scotland Partnership, as well as the recent EPSRC international networks in quantum technology, of which 3 out of 8 are led by Scottish Universities - all evidence of international engagement and Scottish leadership in the field relevant to this ARC proposal.

o How it aligns with Scottish Government priorities:

This ARC proposal aims at maintaining Scotland as a global leader on the quantum technology map (academic research and industry) and at further developing its potential, in order to deliver the objectives of the Scottish government. In particular, we will support **future prosperity** through inclusive growth, creating **new jobs** at all levels in support of quantum technology, ensuring the presence of an **inclusive, skilled and diverse workforce** through specific training, further developing the already strong **industry**, taking advantage of the existing resources to branch into the quantum technology areas.

Exploitation and leadership of this emerging market will require planning of the correct skills training, combined with research and translation focused on key technologies. The proposed ARC aims at **bringing together the Scottish community in this space across universities, industry, and Government stakeholders**, to enable Scotland to be successful in this emerging market.

Scotland's National Strategy for Economic Transformation (March 2022) outlines the opportunity for enabling and emerging technologies such as **photonics and quantum technologies**. The Photonics Leadership Group 2021 report states that Scotland's photonic company output was £1.18Bn in 2020, with £98k gross value added (GVA)/employee, and photonics is now shifting to new markets including healthcare, communications, transport, environmental monitoring and resilient defence and security markets. Photonics-based quantum technologies are predicted to revolutionise **position, navigation and timing** (PNT) especially for connected and autonomous vehicles. The Connected Places Catapult predicts UK companies could be responsible for manufacturing £6.4Bn PNT systems pa for transport (6.4% of the global market) by 2035 resulting in an additional 23,400 direct and 14,600 indirect jobs across the UK in quantum and photonics manufacture. The "Satellite-derived Time and Position: A Study of Critical Dependencies" UK Government Office for Science review in 2018 highlights the importance of PNT devices for critical national infrastructure, including energy supply and distribution, emergency services, telecoms, transport, logistics, national security and businesses with the potential for £5.2Bn loss if Global Navigation Satellite Systems (GNSS) were denied for 5 days. This report highlights resilience requirements of 72-hour holdover for all critical national infrastructure, but present systems are too expensive. Scottish universities (Edinburgh, Glasgow, Heriot-Watt and Strathclyde) are leading key parts of the UK Quantum Technology (QT) programme to build miniature PNT systems, key for a **resilience economy and connected and autonomous vehicles**, aligning to the Scottish Government's National Performance Framework. The location of the UK QT Hub for Quantum Enhanced Imaging (QuantIC) in Glasgow and the strong Scottish university work with Scottish photonics companies provides a real opportunity for the Scottish economy to benefit from quantum technologies. This ARC proposal aims to underpin and enhance the opportunity for Scotland through networking, skills training, strategic road mapping, outreach to attract the next generation, and **working with Scottish Government to build the policies required for success**.

Key national security and defence objectives that quantum technologies – and this ARC - align to:

- alternative position, navigation and timing devices (atomic clocks, gyroscopes, accelerometers, gravimeters, magnetometers)
- operation in global navigation satellite system (GNSS)-denied environments
- future sensing (especially range finding, lidar, electro-optics, covert imaging, imaging through obscurants and asymmetric imaging technologies)
- secure communication (through fibre, free-space, satellite-to-satellite, satellite-to-earth)

o *The nature of the multidisciplinary response required and how areas of evidenced Scottish sector research excellence and quality would be required to be involved:*

Quantum science is a pervasive area that, given its fundamental foundations, is **expected to revolutionise current technology** by providing, for instance, faster computation schemes and hardware, secure communication (on earth, earth to space, satellite to satellite), improved drug development and healthcare (for instance allowing more complex simulations, providing enhanced imaging, miniaturising devices).

A **multidisciplinary approach** is therefore at the heart of quantum technologies, and, with this proposal, we aim at creating bridges between different research areas: quantum technologies development requires **collaborations** across mathematics, computer science, theoretical physics, experimental physics, and engineering, not to mention application-specific expertise, such a chemistry, biology, materials science, health, defence, and **between academia, industry and end-users**. We aim at including all flavours of quantum technologies, from photonics to electronics, theory and software. We will also involve science communicators, social scientists, and economists to support the **development of quantum knowledge in the public through responsible innovation and to ensure a sustainable economic growth of this sector**.

Scottish research excellence in quantum technology is demonstrated by an active research community, represented also by the research supported by the Imaging Quantum Hub (QuantIC), led by the University of Glasgow, as well as the involvement in all the four **Quantum Technology Hubs**, for instance of the University of Strathclyde and Glasgow, the only two universities in the UK to be part of all the hubs. The Universities of St Andrews, Heriot-Watt and Edinburgh are also involved in the four Quantum Technology Hubs and have strong research activities in quantum technologies. **Underpinning industries** are present, in particular, in the areas of photonics, computing, imaging, sensing and healthcare.

o *Justification of the balance the challenge strikes between breadth and specificity:*

This proposal aims at creating a **highly collaborative, wide breath network** that will support the exchange of researchers and the training of interdisciplinary skills, by bringing together researchers from different areas and with different background (from academia and industry, from hard to soft sciences and economy). While the focus is on quantum technologies, we are not limiting our attention to one specific area, but rather **encourage and strengthen the development of research in photonics, space science, life science and healthcare**, by creating new links and taking advantage of the existing very active playground for classical and quantum technology in Scotland. To ensure the wide breath of impact, we will encourage discipline hopping, for instance by providing opportunities for student exchanges and **secondments with industry**, as a way to create new ideas and concepts through the dialogue between different research areas and with industry, to make sure that the **economical and societal impacts are maximised**.

- *Suggested future or current defined funding opportunity(ies) which an ARC focused on this challenge would be well-placed to target:*

Quantum technologies have been the focus of substantial funding from UKRI, in particular through the establishment of 4 Quantum Hubs and, more recently, of the National Centre of Quantum Computing, all strongly represented by the research institutions linked together by this proposal. In the same way, Quantum Technologies is a theme in EPSRC, and Innovate UK has had several quantum device-focused calls in the last few years. Quantum technology has also been specifically targeted by dedicated European funding (for instance the QuantERA programme and the Quantum Flagship).

By bringing together leading institutions in Scotland, we will be able to further strengthen and give visibility to a **Scottish interconnected critical mass in quantum technologies** and provide proof-of-principle results that will be the basis for larger funding bids (like Programme Grants, phase 3 UK QT Programme funding, European consortia). Furthermore, we will leverage our connections for the submission of proposals for Centre of Doctoral Trainings in quantum technology in Scotland (currently missing).

- *A brief description of the prospective or potential coalition of universities and others involved which could deliver an ARC in this area. This should indicate who would lead:*

The University of Glasgow will lead this coalition of universities that will bring together cutting-edge research in various quantum technology areas. The partners of the network include the University of Strathclyde, Heriot-Watt University, University of St Andrews, and the University of Edinburgh. We will be open to add other universities and research institutes, with the goal of being as inclusive as possible. Partnerships and collaborations will also be encouraged with Research & Technology Organisations such as Fraunhofer UK (whose central offices are based in Glasgow), the Catapults, etc. Bringing together the major academic and industrial players in the Scottish quantum community ensures our ability to deliver, supported also by the interaction with existing research pools and the quantum technology hubs. The ARC will be managed by a team of leading early career researchers from across all the partners, supported by senior advisors to develop the future leaders and advocates for quantum technology in Scotland.

- *The added benefit that would be brought by SFC funding:*

The SFC funding will allow the creation of a network in quantum technologies and the establishment of new connections between universities, between disciplines, and between industries and academia.

The project would be supported by a **project officer**, who would split their time between the different universities, with a background in industrial liaison, with expertise in the co-creation of development projects, ideally with specific knowledge of the quantum sector. The principal objective for this post would be to further strengthen the links between the excellent research base within our universities and the significant, and rapidly growing, industrial/end user community. This post holder would be supported by our boards, comprising leading academic and key industrial figures from the Scottish quantum ecosystem.

Industrial/end user-academic secondment and pairing scheme: the ARC principal delivery mechanism would be the creation of industrial/end user-academic secondment and pairing schemes. These would support joint working on the scoping, de-risking or market analysis for quantum technologies, applied to industrial and society priorities. Priority would be given to those opportunities which either generate immediate benefit or that would pump-prime a significant co-created development opportunity that could be supported by existing UK Government mechanisms, corporate level investments or inward investment opportunities. Award of such a pairing would be made based on a simple joint application form, appropriately endorsed by both host organisations, and any single application would be limited to a maximum of £20k in value, for a period of no less than three months.